INTERNATIONAL WORKSHOP ON RENEWABLE ENERGY AND HYDROGEN EXPORT

Global perspectives & Norwegian opportunities

HEXAGON COMPOSITES

Storage and transport of compressed hydrogen

Trondheim March 23th 2015, Per S. Heggem, Director, Hexagon Global Hydrogen Team

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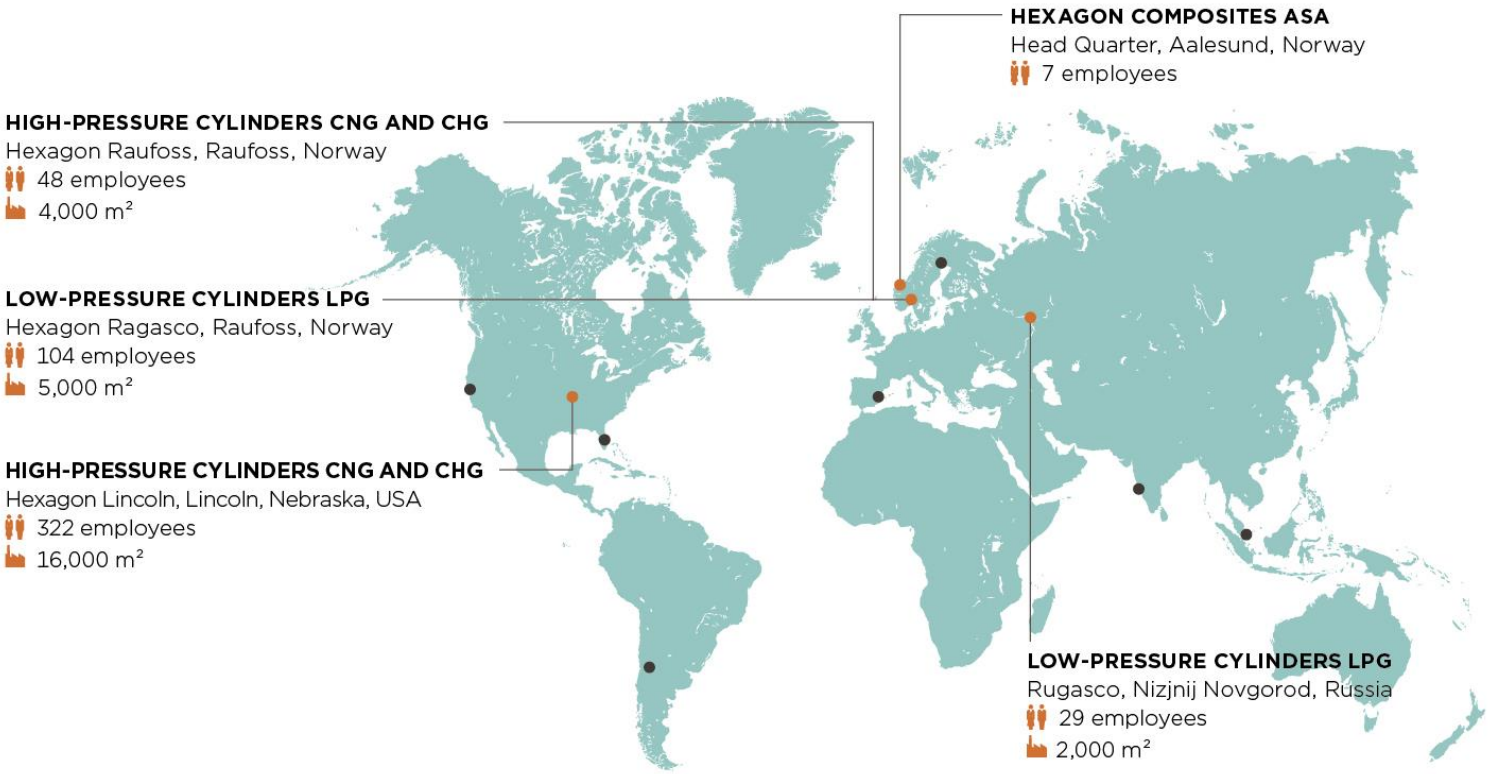
HEXAGON COMPOSITES IN BRIEF

- Headquartered in Ålesund, Norway
- Global market leader in lightweight composite pressure cylinders (Type 4) for Compressed Natural Gas (CNG), Compressed Hydrogen Gas (CHG) and Liquefied Petroleum Gas (LPG)
- Manufacturing facilities in Norway, the United States and Russia (JV)
- Listed on the Oslo Stock Exchange under ticker: HEX

HEXAGON COMPOSITE GROUP



HIGH-PRESSURE CYLINDERS

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Hexagon Lincoln, Lincoln, NE and Hexagon Raufoss, Raufoss, Norway

- 50 years fabricating advanced filament-wound composites, 20 years building Type 4 cylinders
- Global leader in the industry with Type 4 tanks that are the best combination of safety, efficiency and durability available

Composite high-pressure cylinders for passenger and commercial vehicles, buses and bulk transportation

HEXAGON LINCOLN

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2010-2015

- Largest capacity of composite manufacturing in the world
- Largest direct purchaser of high strength carbon fiber in the world.
- 2015 expansion project underway to support continued growth

2015-

NORWAY AND THE EXCESS OF RENEWABLE ENERGY

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One of many business cases that can take benefit from storing and transport of high pressure compressed hydrogen

- Wind generated energy at remote location
  - Weak grid with high cost for expansion of local grids
- Convert the energy to Hydrogen.
  - Accumulate hydrogen in ground storages and/or transportable cylinders
  - Use high pressure equipment and utilize local renewable energy to compress hydrogen (added value to the Hydrogen owner)
- Direct fill of local FC-vehicles (high pressure means less cost for transfer of hydrogen to FC-vehicles)
- Transport high pressure hydrogen to urban locations with hydrogen refueling stations (high pressure will reduce both CAPEX and OPEX for hydrogen refueling stations).

Make a mobile high pressure hydrogen pipeline

MOBILE HIGH PRESSURE PIPELINE

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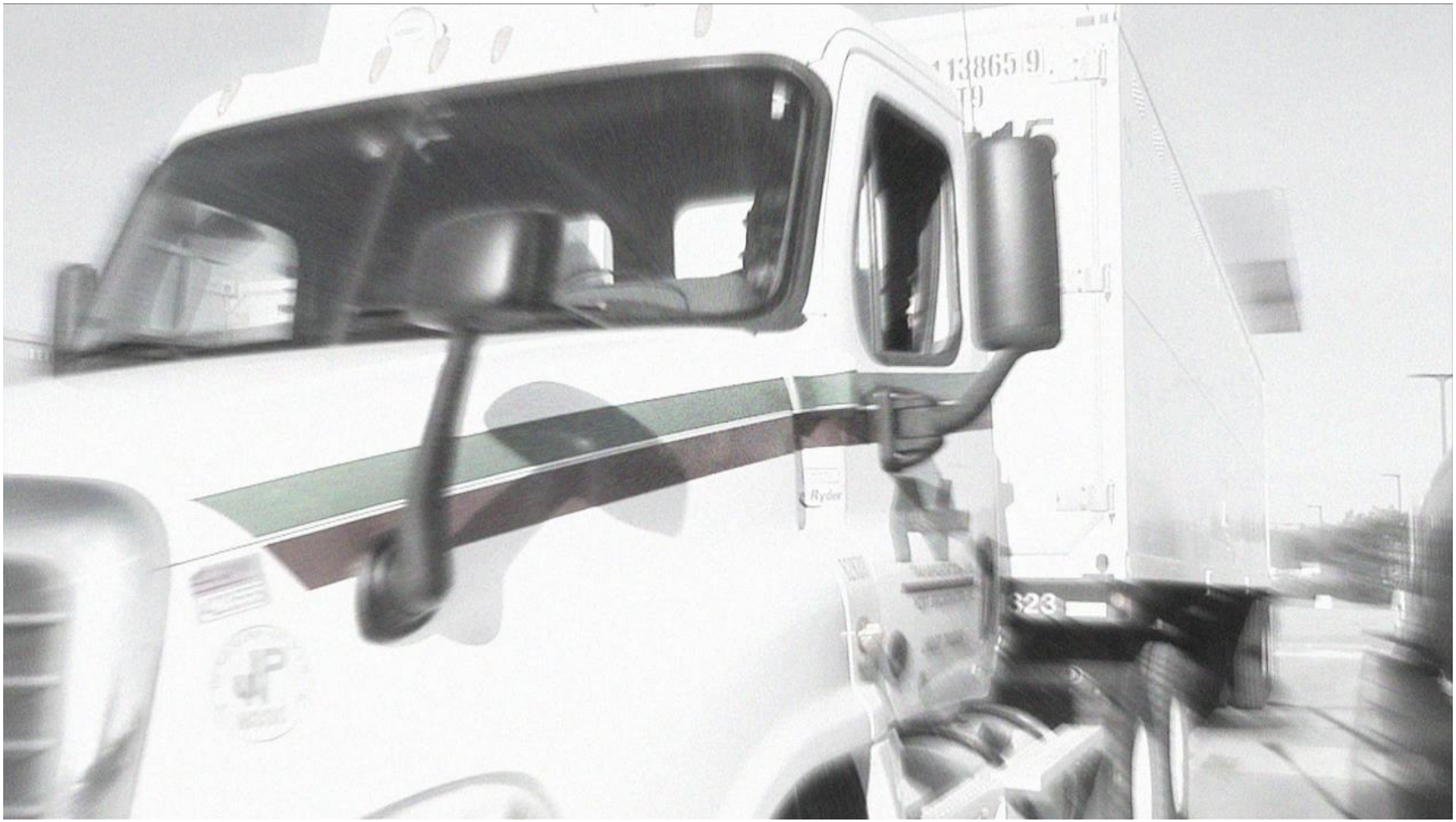

STEEL TO COMPOSITE – THE EVOLUTION

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Weight of storage per scf NG

Steel bottle trailer
140,000 scf

Steel tube trailer
190,000 scf

TITAN4™
364,000 scf

TITAN™ T5M
473,000 scf

TITAN™ XL
521,000 scf

Portable volume in scf NG

TITAN4™

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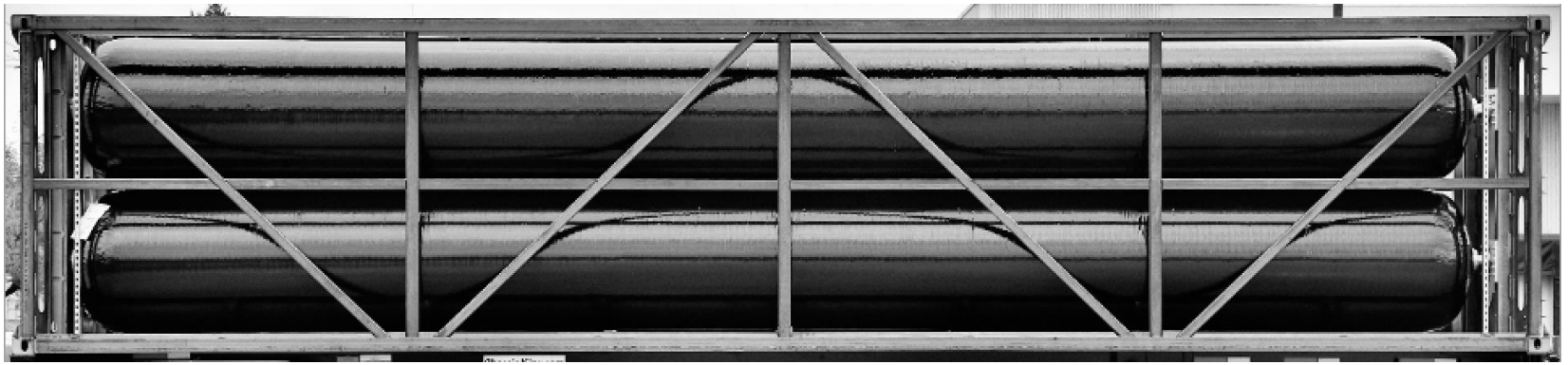
- **364,000 scf of CNG**
- **617 kg of H_2 [CHG]**
- **34,000 liter volume**
- 4 large composite tanks
- Intermodal ISO 40´container
- GVW
  - <80,000 lbs with CNG
  - ~65,000 lbs with CHG
- DE-FG36-08GO18062
- **US DOT approval in 2012**



TITAN™ T5 MAGNUM TRAILERS

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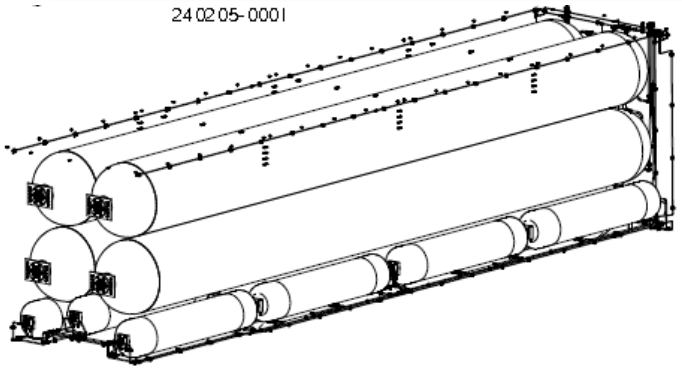
- **473,000 scf of CNG**
- **802 kg of H_2 [CHG]**
- **44,000 liter volume**
- 5 TITAN tanks + 9 Tuffshell tanks
- Integrated trailer chassis
- GVW
  - ~92,000 lbs with CNG
  - <70,000 lbs with CHG
- **Used in tandem operation in Mexico**
  - **[T3-S2-R4 configuration]**



BULK HAULING OF COMPRESSED GASES

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Several hundreds TITAN modules on the roads worldwide for distribution of CNG.
First TITAN Hydrogen under final testing

HEXAGON LINCOLN TYPE 4 CYLINDERS IN SWAP BODY MODULES

- 450L/250bar cylinders approved for use in Europe (CNG).
- 450 – 650L/525-700 bar cylinders under development for hydrogen. (Available 2015)
- Hexagon Lincoln has concepts ready for bulk hauling modules for 1.3 Mt compressed hydrogen base on Type 4 cylinders.

CHANGING THE LANDSCAPE

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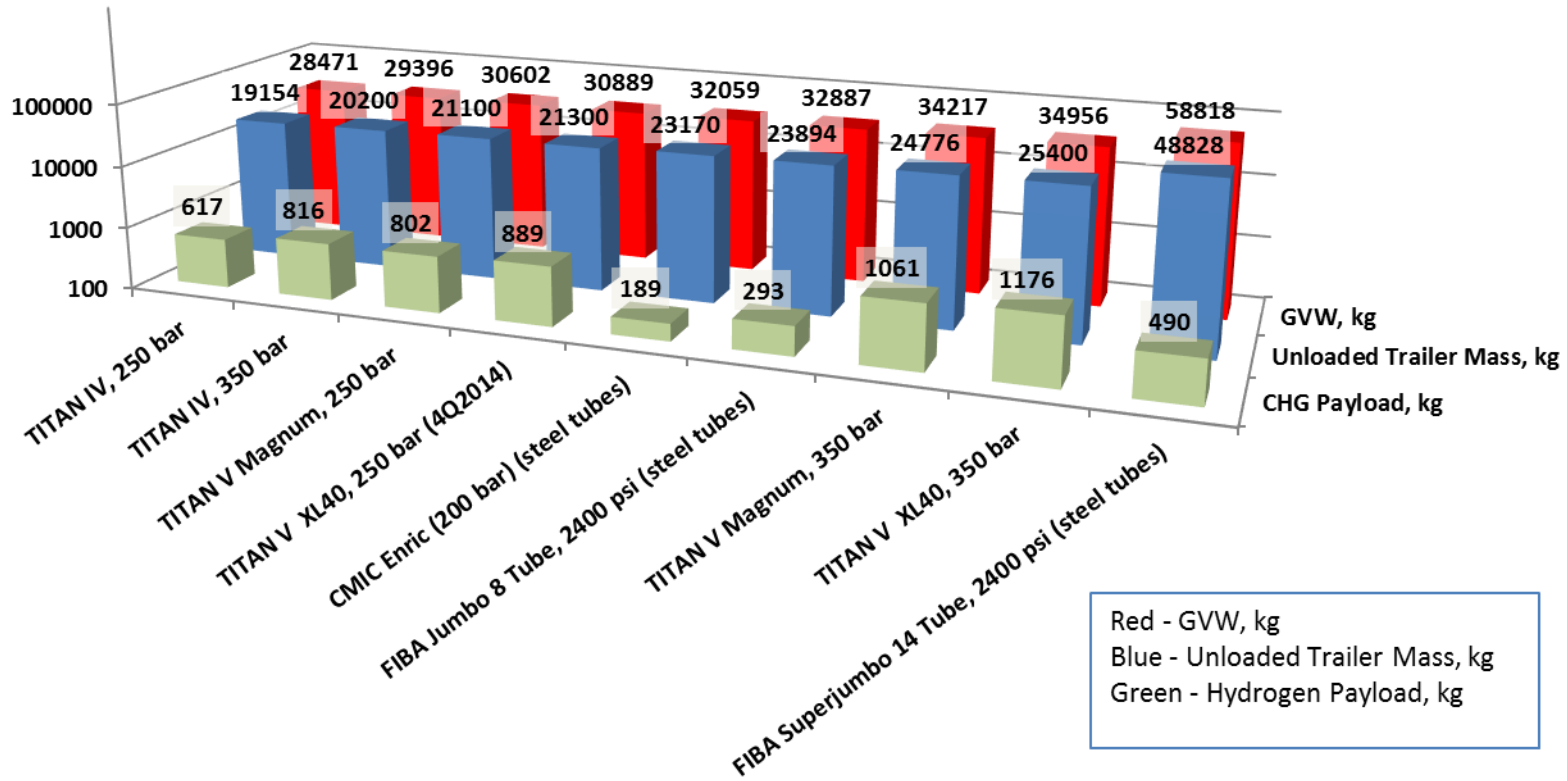

Next generation 40’ trailer module at 700bar is targeting 1300 kg hydrogen payload.

SAFETY RELATED TO USE OF COMPOSITE CYLINDERS

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- Trailers with Composite Cylinders has been in several incidents
  - Roll overs
  - Off road
  - Fire
  - Grenade attack

No loss of gas or safety issues related to the composite cylinders

COLOMBIA- NOVEMBER 2014

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EXTERNAL HYDROGEN R&D ACTIVITIES AT HEXAGON

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- **European based (FCH-JU and Enova)**
  - General understanding on how Composite behave (**HyComp**)
  - Optimization of Hydrogen transport (**DeliverHy**)
  - Effect of Impact on Composite performance (**HyPactor**)
  - Effect of Fire on Composite performance (**FireComp**)
  - Transfer of Hydrogen from one to another receptacle -temperature effects (**HyTransfer**)
  - Electrochemical compressors and optimization of Hydrogen Refueling Stations (**Phaedrus**)
  - Prototype and testing of high pressure hydrogen trailer in Norway (**HyTrans**)
  - Development of cost effective and reliable hydrogen refueling station components and systems for fuel cell vehicles (**H2Ref**)

- **US-based (DOE):**
  - Several projects related to cost optimization of composite structures and liner material/production technology.

TYPE 4 – IMPACT TOLERANCE

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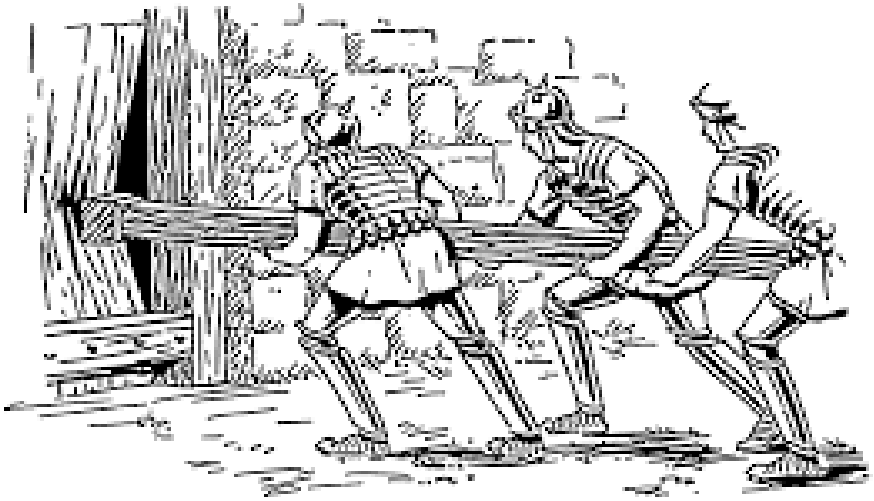
REGULATION, CODES AND STANDARDS FOR TRANSPORT OG COMPRESSED GAS



- Technology is ready
- Lack of relevant Regulation, Codes and Standard is an hinder
- The industry need a break through on RCS topics related to Composite Cylinders

Hexagon Raufoss has taken initiative through Standard Norway for developing an adequate ISO standards for transport of larger quantity of Hydrogen (ISO 17519). This Committee is today convened by Hexagon Raufoss.

DEVELOPMENT STATUS – ISO/DIS 17519

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Gas cylinders — Refillable permanently mounted composite tubes for transportation

- Approved as New Work Item 9/2011
  - Same basic scope and requirements as DOT SP-14951
- CD circulated 8/2012, OK for DIS
  - Meetings in Paris and Munich to resolve comments
  - TC58/SC3 asked for 2nd CD vote
- Scope revised
  - Added Type 3
  - Limited pressure to 1000 bar
- WG agreed to limit energy to 3,000,000 bar-liters
- 2nd CD circulated 3/2013, OK for DIS
  - Meetings in Paris and London (3x) to resolve comments
  - Draft updated based on comment resolution
- Scope revised to reflect new SC3 approach
- DIS ballot voting from 19 Feb 2015 to 19 May 2015

COMPOSITE CYLINDERS
AT HYDROGEN REFUELING STATIONS

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50 MPa – 531L
Bulk/Cascade storage on a European Hydrogen Refueling Station.

95 MPa - 255L
Tanks for quick top-fill make the Refueling Stations complete.

95MPA TRANSPORTABLE STORAGE IN JAPAN

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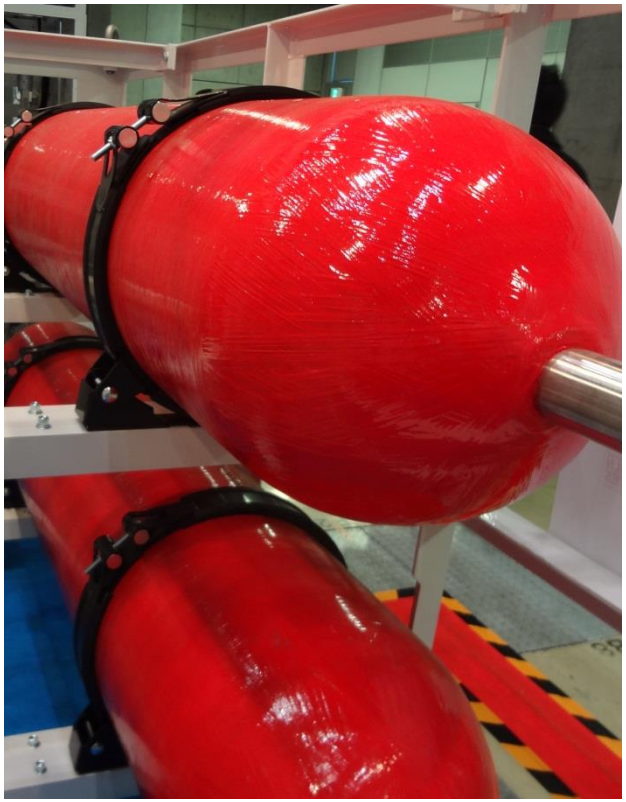

Hexagon Lincoln 95MPa ground storage for the Japanese hydrogen Refueling station market presented on the Tokyo FC EXPO 2013 in a Taiyo Nippon Mobile Hydrogen Refueling Station

FC EXPO TOKYO 2015

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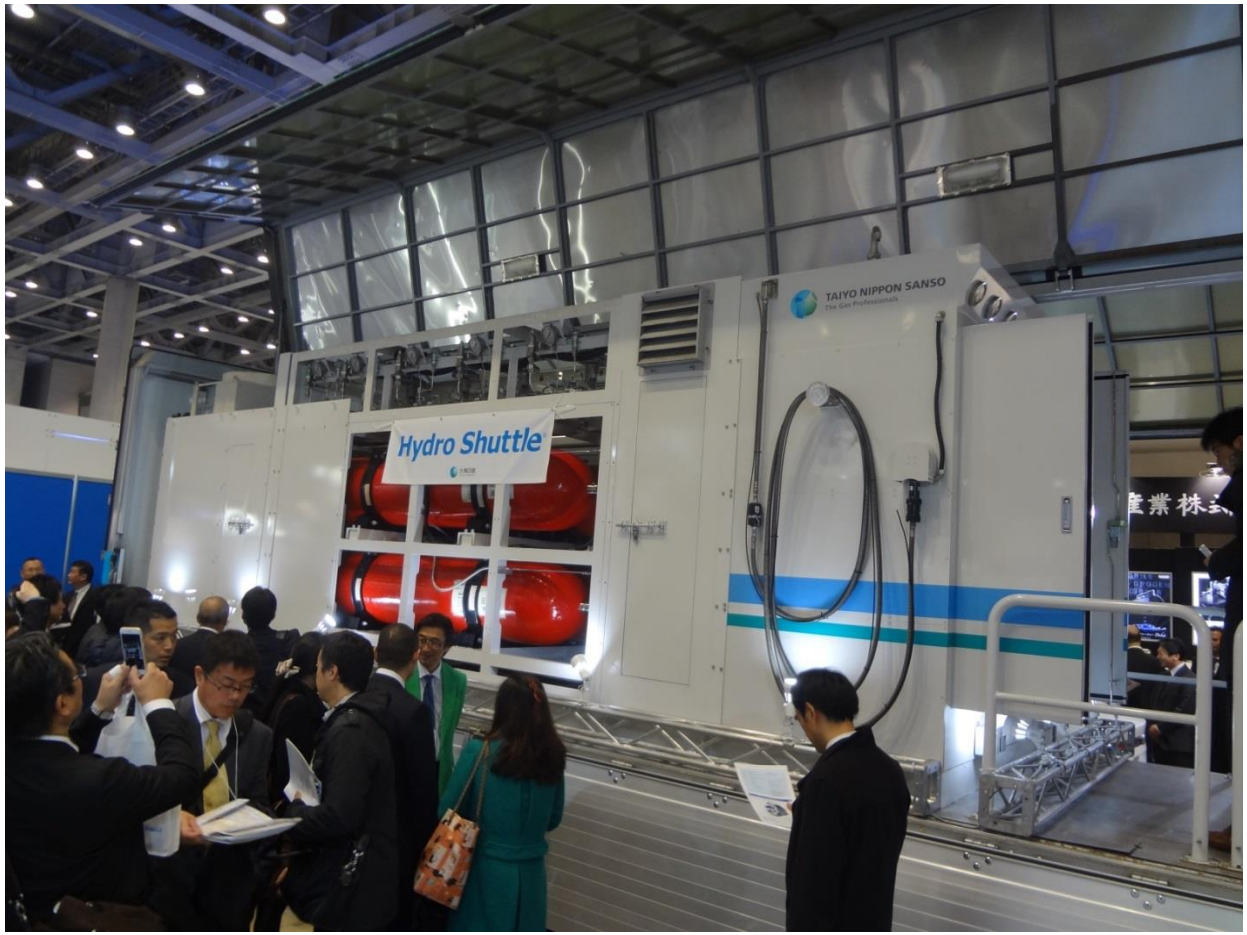

MOBILE HYDROGEN REFUELING STATION WITH HEXAGON LINCOLN 95MPA KHK APPROVED STORAGE

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THANK YOU

Per S. Heggem,

Director, Hexagon Global Hydrogen Team,

Hexagon Lincoln and Hexagon Raufoss.