K. Qadir, Cygnas Solutions

Re-purposing of Decommissioned Pipeline Bundles For Subsea Hydrogen Storage

K. Qadir, Cygnas Solutions , Dr I. Jalisi, Cygnas Solutions
Martin Goodlad

CYGNAS DNA

Our Values

- Extensive experience across a range of Industries
- Passion for Innovation with a wealth of Engineering Know-how
- Solutions for Companies transitioning to Industry 4.0 leveraging our multi-sectoral experience
- Experienced in Asset Integrity & Management, RBI, RAMS & Fitness For Service
- Advanced Engineering Analysis, AR, IOT and Consulting Services across a range of verticals

HONESTY

INNOVATION

VALUE FOCUSED

ENGINEERING INSIGHT

DELIVERING ON INDUSTRY 4.0

Key Technologies and Domain Expertise

Life Extension

IOT Devices

Risk Based Asset Management

ML Based Monitoring

ML Digital Twins

Code Driven Assessments

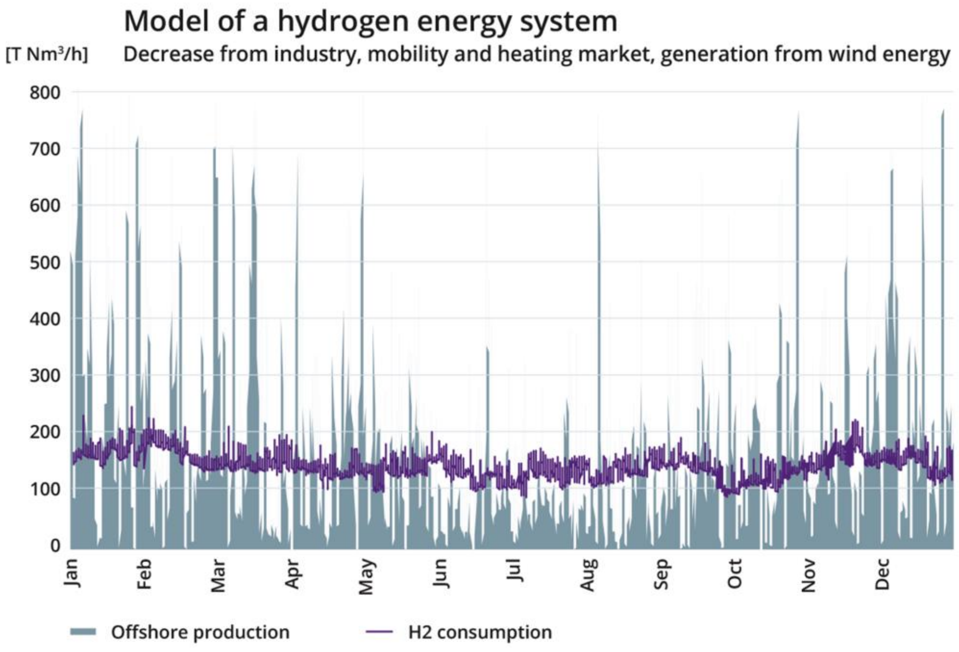
Agenda

- Hydrogen & its Importance in Energy Transition
- What are the Challenges for Hydrogen Storage?
- Offshore Wind Farms in North Sea
- What are Pipeline Bundles?
- Advantages of Bundles for Design & Technical Specs
- Pipeline Bundles Decommissioning
- Why Pipeline Bundles for Hydrogen Storage?
- Concluding Remarks

Hydrogen & Its importance in Energy Transition

Hydrogen & Its Importance in Energy Transition

- A main challenge to shift to renewable energy sources is: how can the energy be effectively stored and made available as required?
- H2 can be produced using electrolysis as required. around 55 MWh of electrical energy is required to generate one ton of hydrogen.
- H2 can produce energy where required without any polluting by products and helps industrial decarbonisation.
- Hydrogen can be stored, transported by pipelines, and has high energy density.



Offshore Wind Energy Production projected – [4]

Innovation and Excellence in Engineering

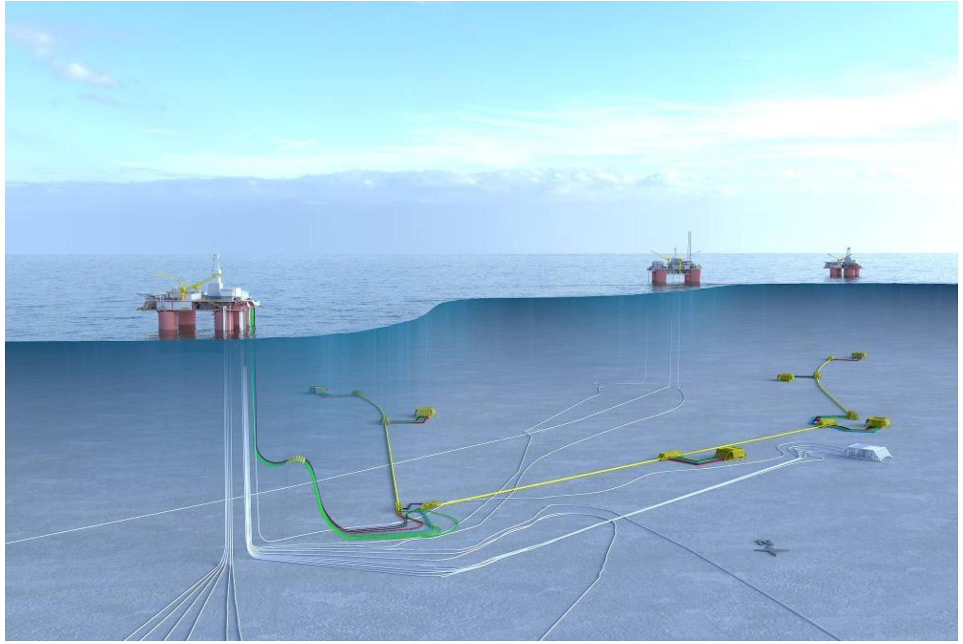
What are the Challenges for Hydrogen Storage?

NESMF Transforming a Circular Economy Through Manufacturing

Hydrogen & Its Importance in Energy Transition

Hydrogen and Pipelines

- Methane has 3 times the calorific heating of H2
- Though as hydrogen can flow 3 times as fast the same pipeline can transport 3 times the volume and an energy transportation only slightly less.
- Embrittlement (HIC) can be an issue which is process where atomic hydrogen enters the metal lattice and can embrittle the steel which can accelerate crack propagation. This can potentially reduce service live by 20 to 50%. Not like H2S where effect order of magnitude higher than H2 gas.
- Fracture is an issue if there are high dynamic loads and cracks already exists as well as the grade of steel used.

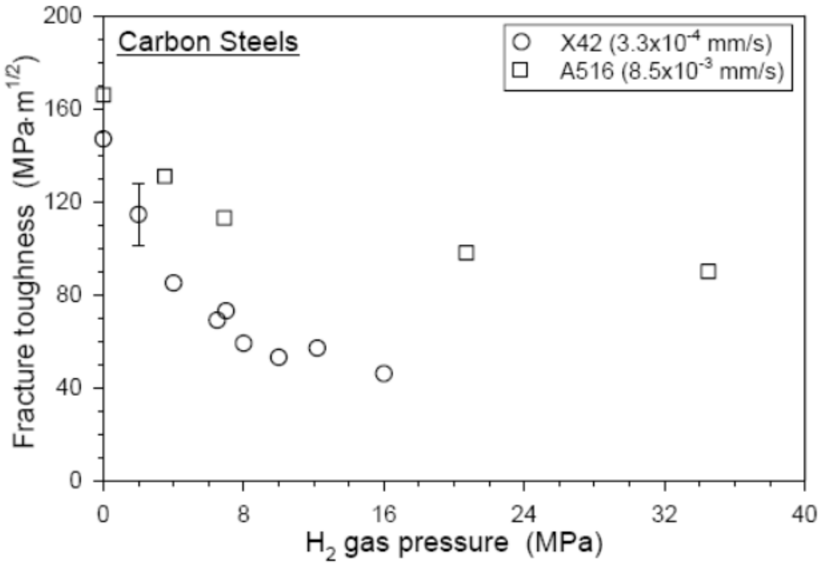


Subsea Pipeline Infrastructure– [4]

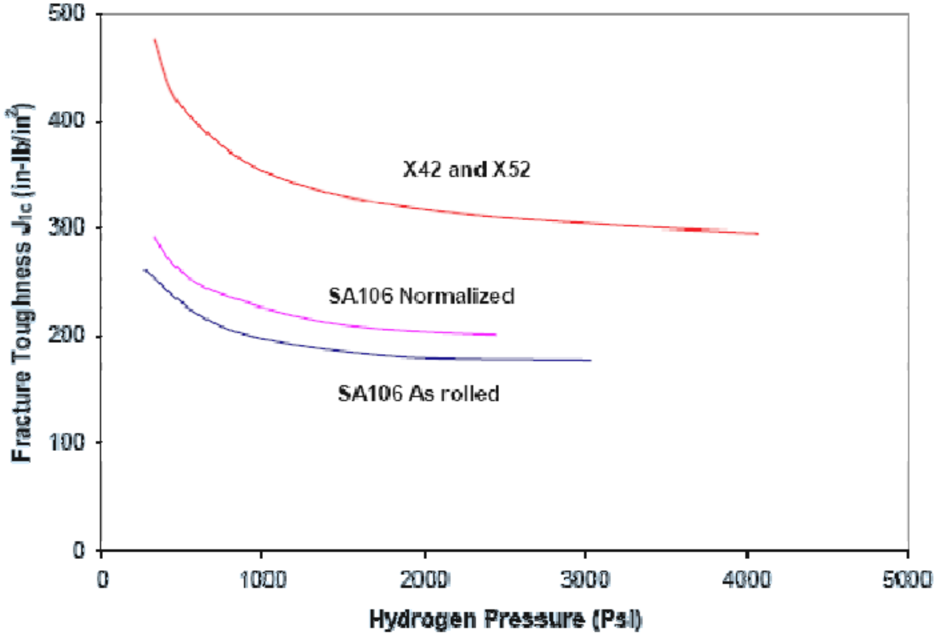
Hydrogen & Its Importance in Energy Transition

Hydrogen and Pipelines

- H2 permeation depends on pressure, temperature, Hydrogen purity, stress, strain, material state, presence of defects and material composition.



KIC for Carbon Steels , reaching limit around 20MPa– [5]



KIC for Line pipe steels at loading rate of 0.002 in/min– [5]

Innovation and Excellence in Engineering

Offshore Wind Farms in North Sea

Offshore Wind Farms In the North Sea

- Government ambition of adding up to 50GW by 2030 to offshore wind, of which 5GW from floating offshore wind in deeper seas is expected.
- Wind energy produced offshore is increasing in many countries around the north sea.

Operational wind farms [edit]

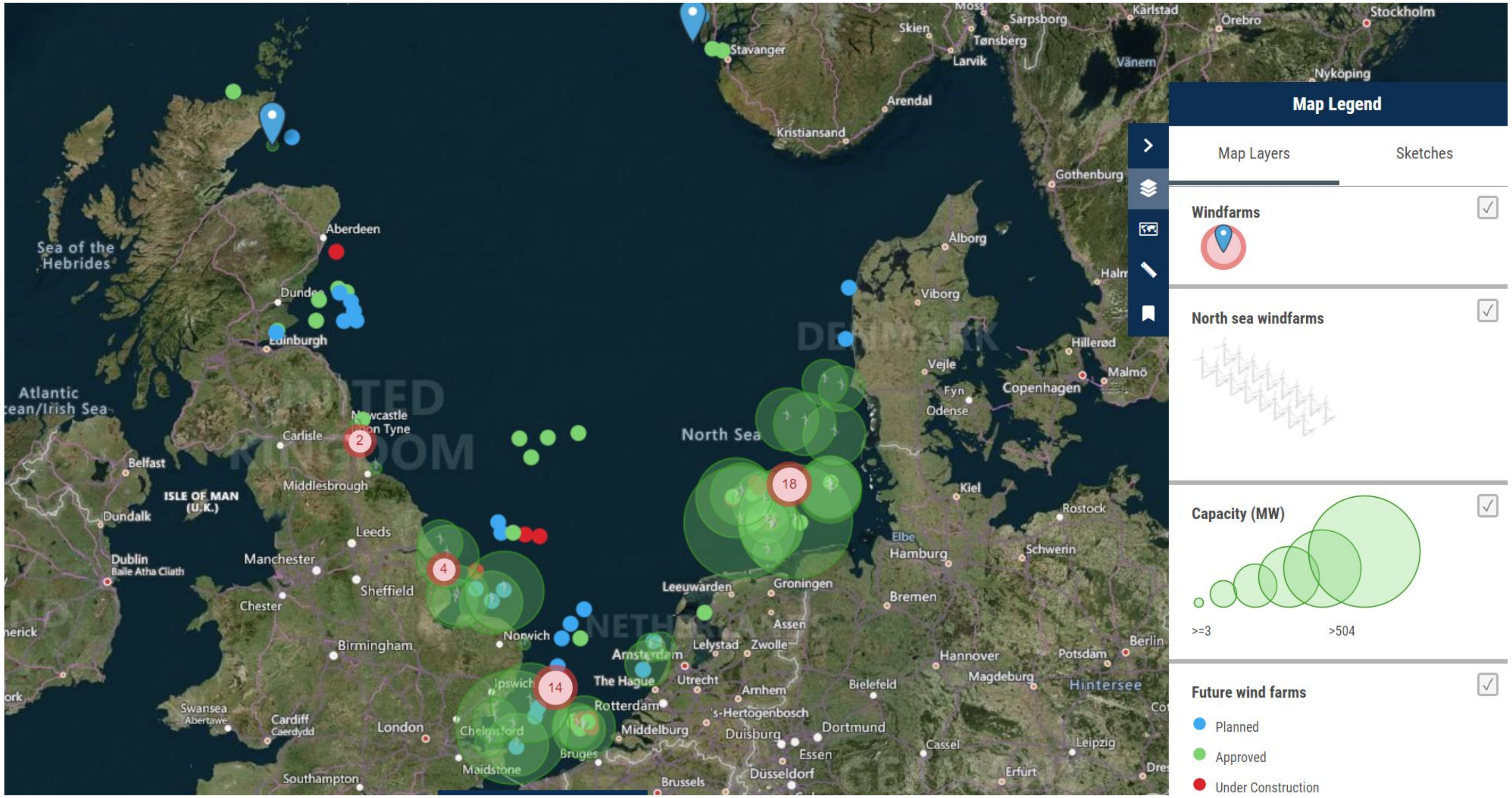
The list can be sorted by clicking the triangle symbols at the top of each column.

Wind farm	Country	Location	Cap. (MW)	Turbines	Commissioned	Build Cost	Cap. fac.	Depth range (m)	km to shore	Owner
Dudgeon	United Kingdom	53°15′00″N 1°23′0″E	402	67 × Siemens SWT-6.0-154	2017	£1.5bn			32	Equinor Statkraft
Humber Gateway	United Kingdom	53°38′38″N 0°17′35″E	219	73 × Vestas V112-3.0	2015	€900 million		10-18	10	E.ON
Westermost Rough	United Kingdom	53°48′18″N 0°08′56″E	210	35 × Siemens SWT-6.0	2015	€1,000 million		10-25	8	Ørsted
Lincs	United Kingdom	53°11′0″N 0°29′0″E	270	75 × Siemens SWT-3.6-120	2013	£1,000 million		10-15	8	Centrica, Siemens, Ørsted
London Array	United Kingdom	51°38′38″N 1°33′13″E	630	175 × Siemens SWT-3.6	2013	£1,800 million		0-25	20	Ørsted, E.ON UK Renewables, Masdar
Teesside	United Kingdom	54°38′50″N 1°05′40″W	62	27 × Siemens SWT-2.3	2013	£200 million		7-15	1.5	EDF-EN
Greater Gabbard	United Kingdom	51°56′0″N 1°53′0″E	504	140 × Siemens SWT-3.6-107	2012	£1,500 million		20-32	23	SSE Renewables
Sheringham Shoal	United Kingdom	53°07′0″N 1°08′0″E	317	88 × Siemens SWT-3.6-107	2012	£1,100 million		12-24	17	Equinor 50% Statkraft 50%
Gunfleet Sands 1 & 2	United Kingdom	51°43′0″N 01°12′50″E	172	48 × Siemens SWP-3.6-107	2010	£300 million		2-15	7	Ørsted
Thanet	United Kingdom	51°26′0″N 1°38′0″E	300	100 × Vestas V90-3.0MW	2010	£780-900 million		20-25	11	Vattenfall
Lynn and Inner Dowsing	United Kingdom	53°07′39″N 0°26′10″E	194	54 × Siemens SWP-3.6-107	2009	£300 million	37%	6-11	5	Centrica 50% TCW 50%
Beatrice	United Kingdom	58°06′20″N 03°05′35″W	10	2 × REpower 5M	2007	£35 million	20%	45	23	SSE and Talisman Energy

List of Windfarms in the UK. Wikipedia

CYGNAS
Innovation and Excellence in Engineering

Offshore Wind Farms In the North Sea



Ref. Mangomap.com

NESMF
Transforming a Circular Economy Through Manufacturing

Offshore Wind Farms In the North Sea

Bundle Location in the North Sea

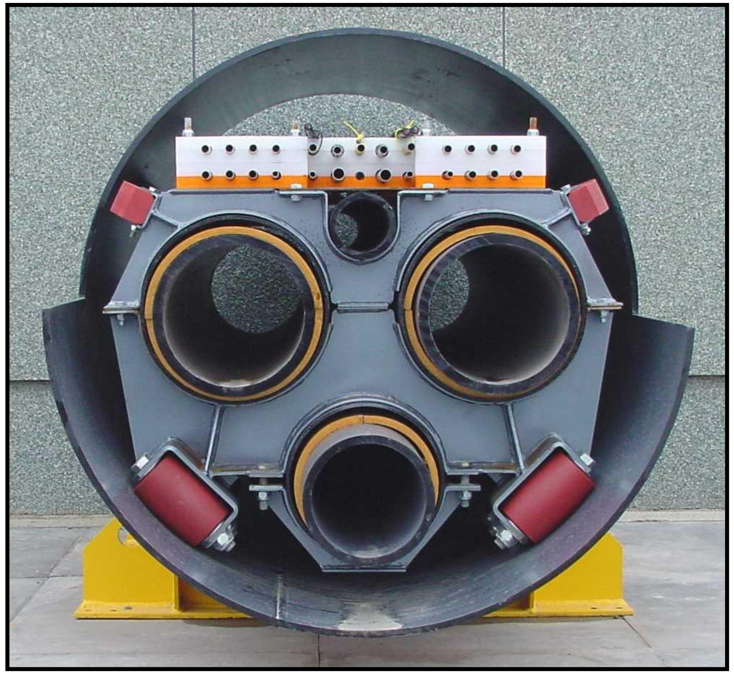
Subsea 7 Presentation

CYGNAS
Innovation and Excellence in Engineering

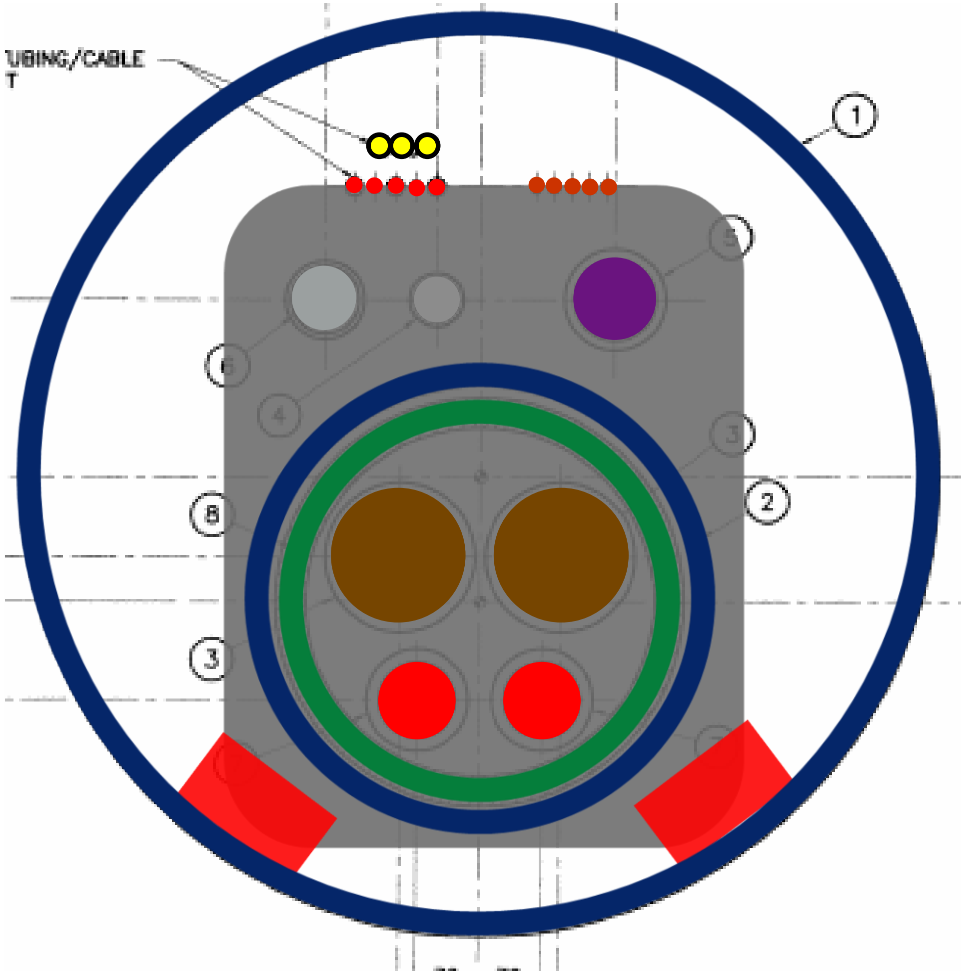
What are Pipeline Bundles?

Introduction to Pipeline Bundles

- Pipeline Bundles consist of a carrier pipe containing individual pipelines and umbilical components which are carried by spacers on rollers.
- Pipeline Bundles terminate in Towheads.



Introduction to Pipeline bundles



- Hot Water Heating
- Production
- Insulation
- Sleeve Pipe
- Gas Lift
- Scale Squeeze
- Methanol Injection
- Control Tubes
- Chemical Injection
- Power & Signal Cables
- Carrier Pipe
- Main Spacer

Introduction to Pipeline Bundles

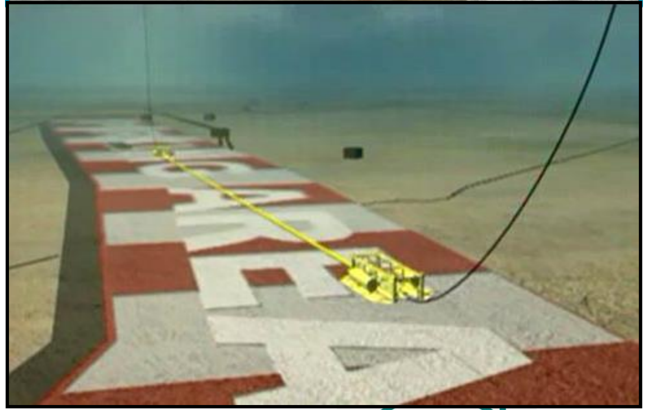
- Fabricated onshore in a single length – 7.6km long fabrication site.
- Longest, moveable man-made structure in the world.
- Installed using Controlled Depth Tow Method (CDTM).
- Over seventy five Pipeline Bundles installed in the North Sea and Norwegian Sea regions by Subsea 7 mainly if not all from Wick.

Subsea 7 Wick Site

Advantages of Bundles for Design

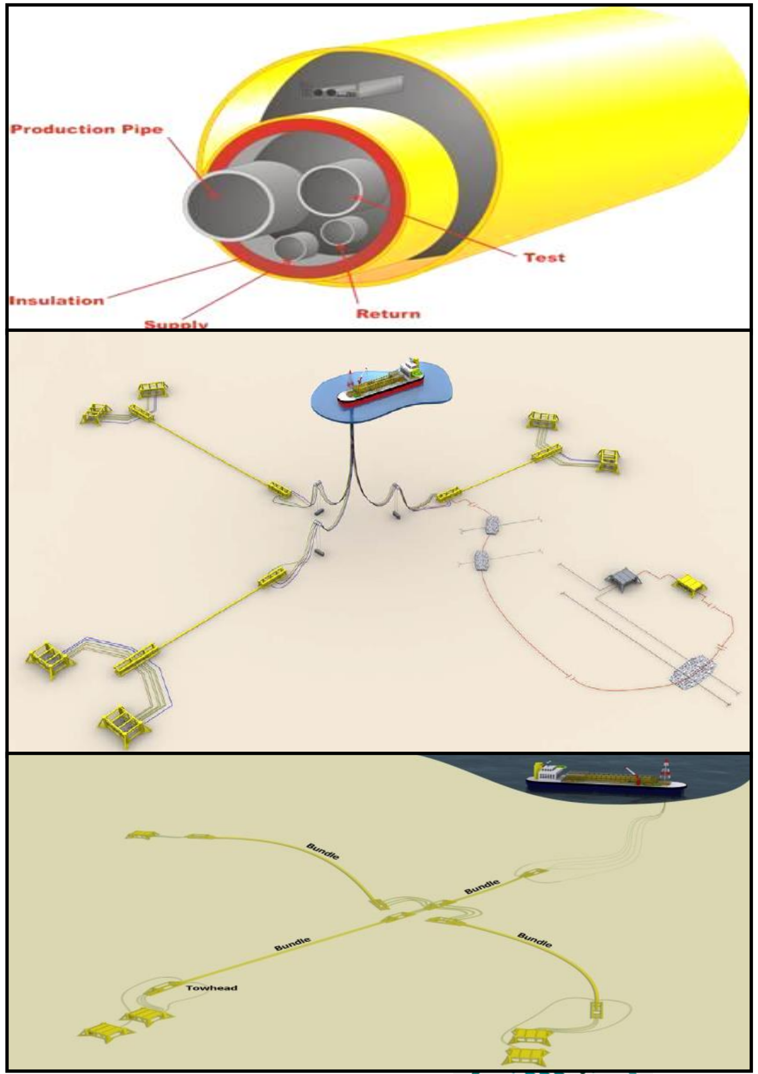
Advantages of Bundles for Design

- Provide a second barrier of protection due to the carrier.
- Onshore welding and system integration test
  - Strength test, valve operations, etc.
- Pipeline Bundle installation
  - Mitigates need for expensive pipelay spread
  - Towheads replace large structures.
  - Low stress / fatigue process beneficial for H2 storage.
  - Reduced installation corridor in congested fields



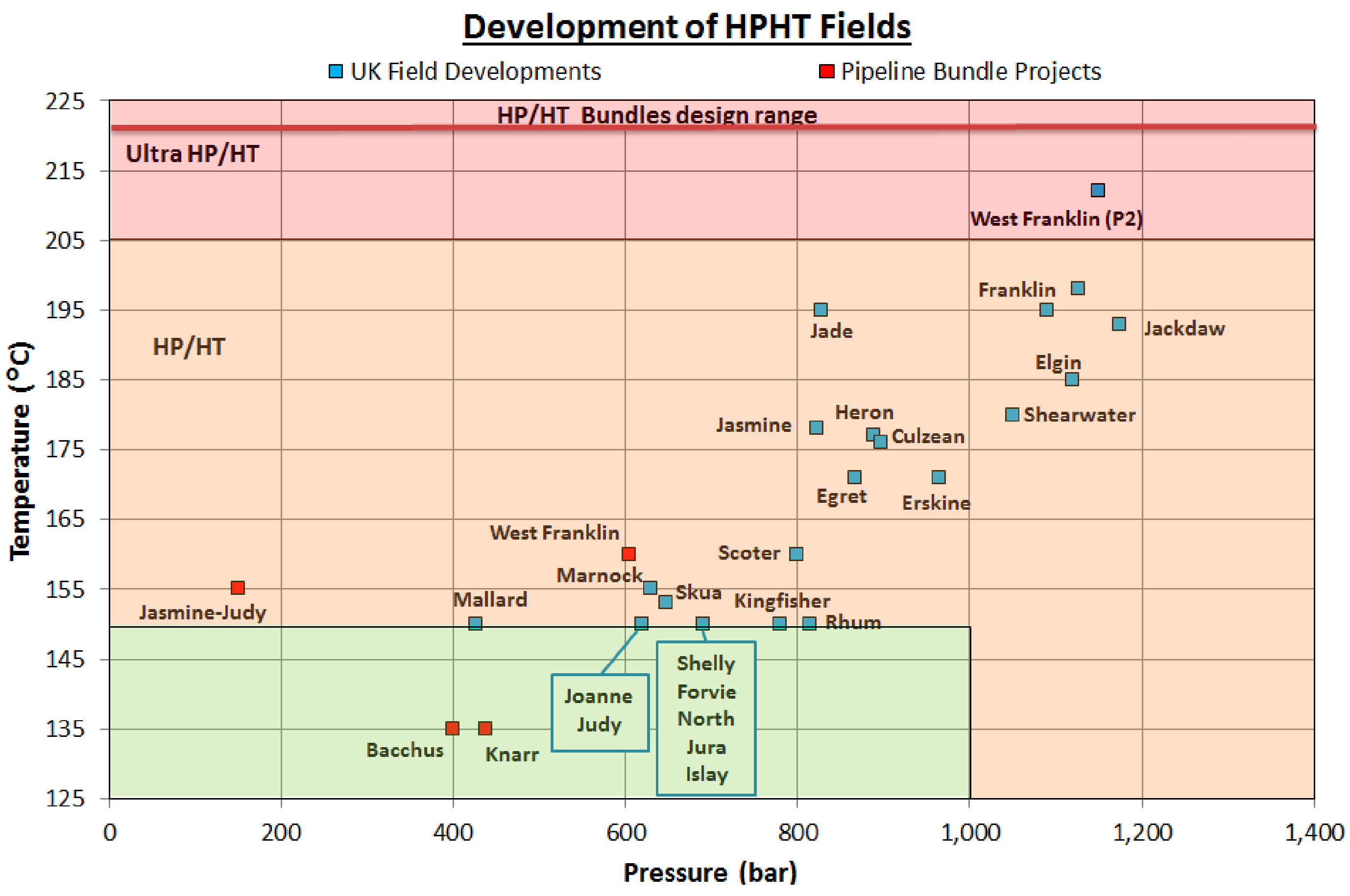
Advantages of Bundles for Design

- Efficient insulation systems
  - High thermal performance
  - Low cost materials available
  - Thermal / electrical heating systems
- No need to trench / Rock-dump
  - No risk due to soil type.
  - No risk of upheaval buckling
- Bundle Pipelines are in a protected environment due to the Carrier.



Pipeline bundle Storage Pressure Range

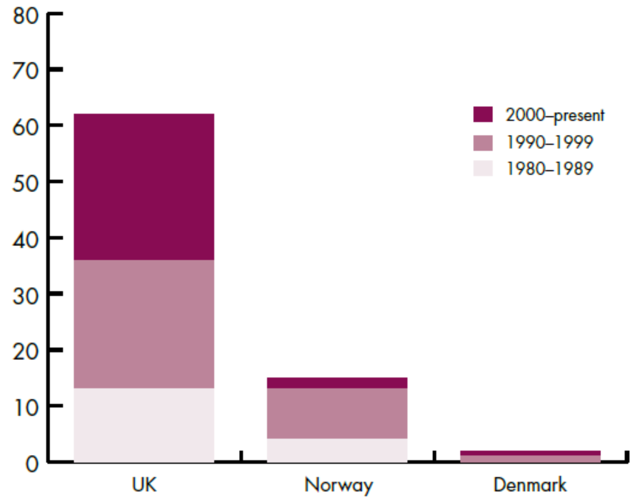
- .

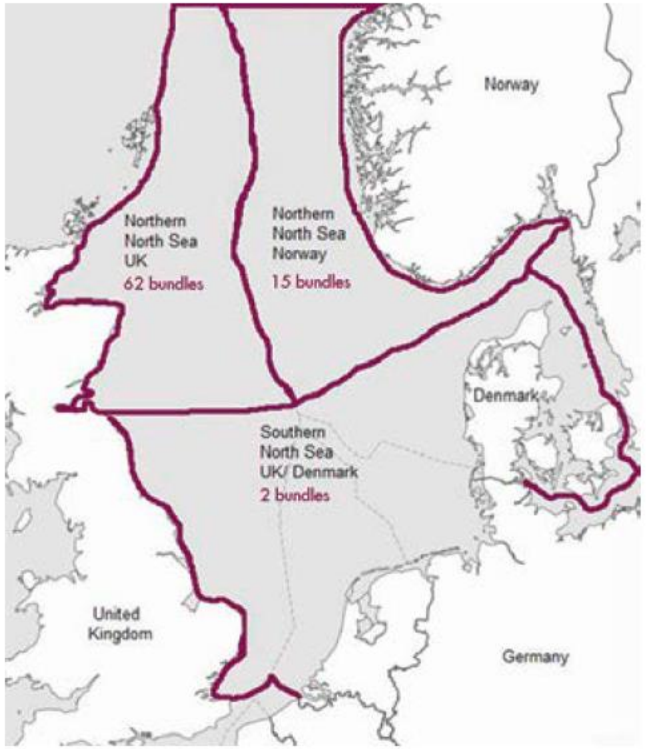


Pipeline Bundles Decommissioning

Pipeline Bundles Decommissioning

- The first bundle was installed in the North Sea in 1980 and since then more than 70 bundles have
- Bundles are not restricted to one per field.
- The size and length of the bundle will impact on the potential decommissioning methods to be considered.





Bundle Distribution in Northsea

Pipeline Bundles Decommissioning

Decommisioning Options

- Re-use at another site
- Full removal to shore for disposal at landfill and/or recycling of materials
- Removal for deep water disposal
- In place' decommissioning.

In place decommissioning is more often than not the preferred method.

OUTSIDE DIAMETER OF CARRIER PIPE	NUMBER OF BUNDLES	%
0 – 500 mm	4	5 %
500 – 750 mm	32	43 %
750 mm – 1 m	24	32 %
More than 1 m	15	20 %

Bundle Population by Diameter [3]

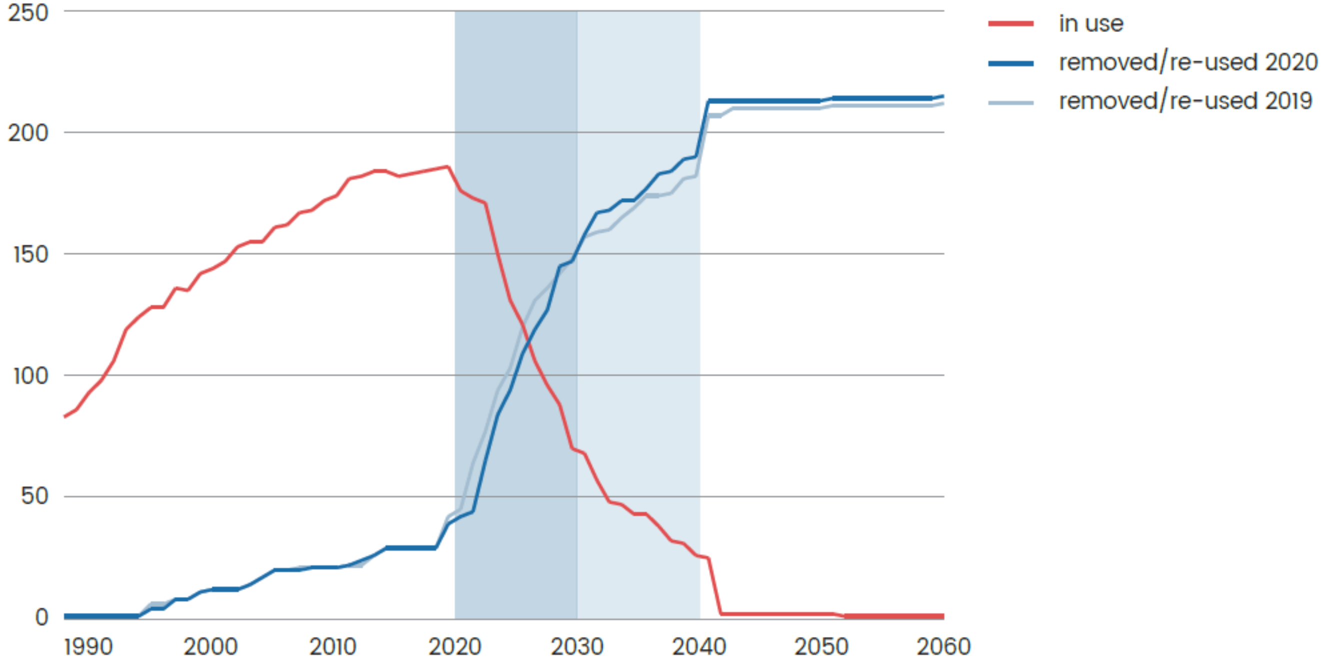
BUNDLE LENGTH	NUMBER OF BUNDLES	%
0 – 2.5 km	19	26 %
2.5 – 5 km	28	38 %
5 – 7.5 km	27	36 %

Bundle Population by Length [3]

Pipeline Bundles Decommissioning

Decommissioning landscape

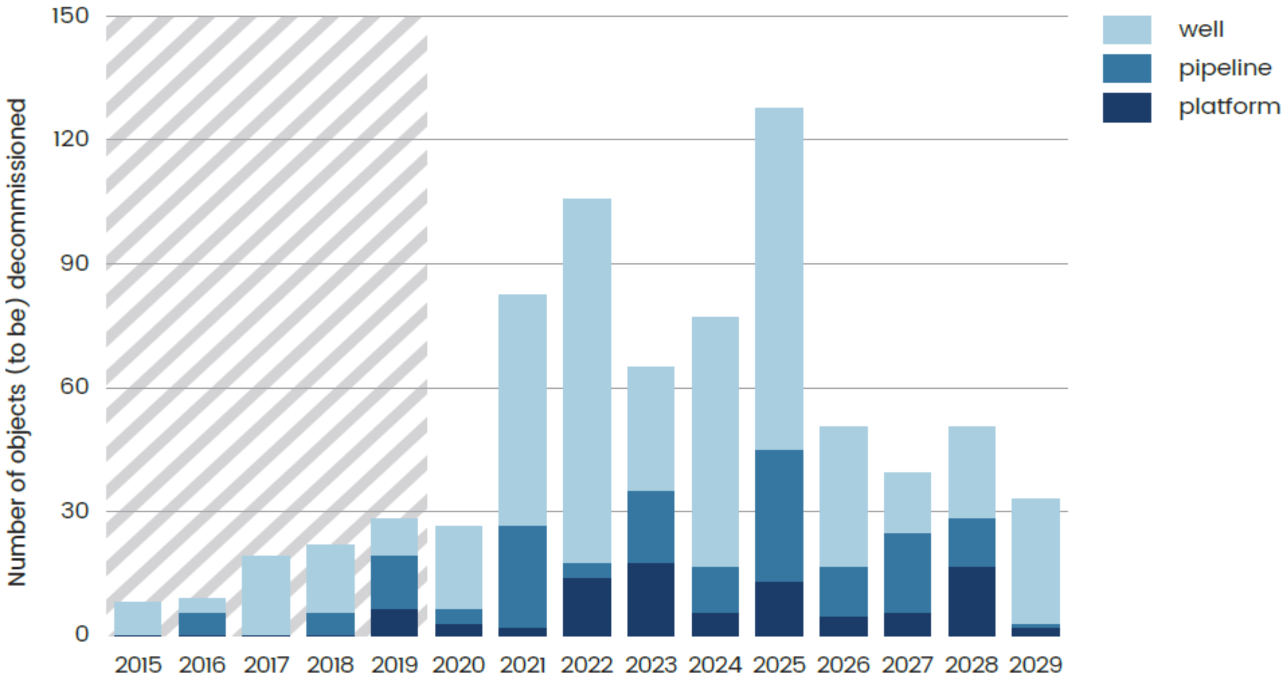
- Lot of assets offshore would need to decommissioned soon.



Number of installed and removed offshore installations Netherlands [1]

Pipeline Bundles Decommissioning

Distribution of assets to be decommisioned.



Realised and forecasted decommissioning – offshore infrastructure [1]

Leadon Bundle Decommisioning

Example

6" Gas Import spool	PL1843	6.63	0.160	Duplex stainless	Gas	6" Gas Import riser base - MLS	Surface laid	Suspended	Flushed with 1600ppm TROS 650
12" Aquifer spool	PL1842.5	12.75	0.124	Duplex stainless	Water	12" Aquifer riser base - MLS	Surface laid	Suspended	Flushed with 1600ppm TROS 650
12" Production spool	PL1842.1	12.75	0.119	Duplex stainless	Production fluid	12" Production riser base - MLS	Surface laid	Suspended	Flushed with 1600ppm TROS 650
8" Test	PL1842.2	8.63	0.131	Duplex stainless	Production fluid	8" Test riser base - MLS	Surface laid	Suspended	Flushed with 1600ppm TROS 650
6" Gas Lift	PL1841.3	6.63	0.155	Duplex stainless	Gas	6" Gas Lift riser base - MLS	Surface laid	Suspended	Flushed with 1600ppm TROS 650

Leadon Subea Pipeline Bundle Decommisioning [2]

Leadon Bundle Decommisioning

Decommissioning of large diameter bundles is recognised as a general industry challenge, with no common approach to the recovery of large diameter bundles. The conclusion of a Joint Industry Project (JIP) report in 2013 was that there was no available technology to enable safe, diverless retrieval of large diameter bundles such as the Leadon bundle. This remains the case.

- Maersk Oil Proposal to bundle decommissioned insitu.
- No free spans were present
- North and South towheads and MLS removed with cut ends rock dumped to render bundle over-trawlable
- An inspection and monitoring regime

Why Pipeline Bundles for Hydrogen Storage?

Why Pipeline Bundles for Hydrogen Storage?

- Sustainable decommissioning which has potential to be profitable.
- Bundle location in the Northsea near Windfarms can act as reserve for Hydrogen to be used to bridge the gap in electrical supply using fuel cells.
- Bundles by there design and the way they are commissioned are low stressed and have high fatigue tolerance.
- Previous life extension studies have shown minimal damage to bundles.
- Possibility to use Carrier pipe which are large diameter and have even larger storage capacity but lower pressure capacity.

Bundle Distribution in Northsea

Why Pipeline Bundles for Hydrogen Storage?

Feasibility Calculations

- Sustainable decommissioning which has potential to be profitable.

$P_{storage}$	207	*bara*	NPS	16		ID_{final}	325.494	*mm*	Length	7	km
Temp	4	*C*	Sch	Sch 160							
Density	15.9538	*kg/m^3*	$ID_{unpressurised}$	325.424	*mm*	A	0.083210273	*m^2*	Vol	582.4719139	m^3
Mass of H_2	10000	*kg*	Bundle Depth	50	m	$L_{required}$	**7.532842856**	*km*			
Vol	626.8099136	*m^3*	P_{sea}	6.034008	*bara*						
			DP	200.965992		Available H_2	9670.484806	kg			
Material Data			**Pressure Effects**								
E	207	GPa	σ_θ	80.76	*MPa*	Outcome based on 100% of fatigue limit	Pass				
α	1.58E-05	mm/mm/C	e_θ	3.902E-04							
$\sigma_{Fatigue\ Limit}$	300	MPa	**Thermal Effects**								
			e_θ	-1.738E-04							
			e_z	-1.738E-04							

Calculation based on NIST data for H_2

Ambient temp at deployment assumed to be 15C

Average seawater density of 1023 kg/m^3 used

Bundle Distribution in Northsea

Why Pipeline Bundles for Hydrogen Storage?

Calculations based on Ship siphoning of H_2 gas

Mass of H_2 Stored (kg)

	Length of Bundle						
Production line NPS	0.00	1.25	2.50	3.75	5.00	6.25	7.50
8	0.00	555.97	1111.93	1667.90	2223.86	2779.83	3335.80
12	0.00	1237.59	2475.19	3927.93	4950.38	6187.97	7425.57
18	0.00	2487.02	4974.04	7461.07	9948.09	12435.11	14922.13

Pressure	207 bar.a		
Depth	90 m		
Pipeline Length	1.25	3.75	6.25
NPS	8	12	18
Schedule	80		

26%	38%	36%
0 - 2.5 km	2.5 - 5 km	5 - 7.5 km

Value of H_2 Stored (USD)

	Length of Bundle						
Production line NPS	0.00	1.25	2.50	3.75	5.00	6.25	7.50
8	$0.00	$3,335.80	$6,671.59	$10,007.39	$13,343.19	$16,678.99	$20,014.78
12	$0.00	$7,425.57	$14,851.13	$23,567.58	$29,702.26	$37,127.83	$44,553.39
18	$0.00	$14,922.13	$29,844.27	$44,766.40	$59,688.53	$74,610.66	$89,532.80

Estimated ROI

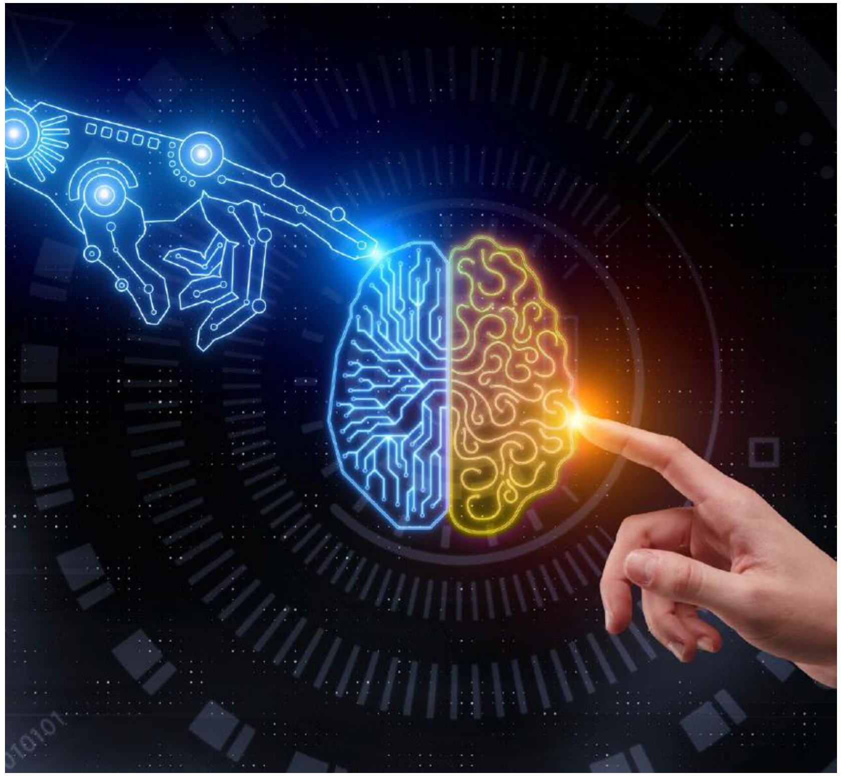
Cost of Ship: $25,000.00

	Length of Bundle						
Production line NPS	0.00	1.25	2.50	3.75	5.00	6.25	7.50
8	-$25,000.00	-$21,664.20	-$18,328.41	-$14,992.61	-$11,656.81	-$8,321.01	-$4,985.22
12	-$25,000.00	-$17,574.43	-$10,148.87	-$1,432.42	$4,702.26	$12,127.83	$19,553.39
18	-$25,000.00	-$10,077.87	$4,844.27	$19,766.40	$34,688.53	$49,610.66	$64,532.80

Concluding Remarks

Concluding Remarks

- Bundles have the potential to be repurposed for H2 storage for windfarms.
- Many bundles would be requiring Decommisioning and with new and current wind farms might offer the best way forward.
- Further work could be carried out on a real opportunity in the North sea.
- Bundles might offer also the platforms to be repurposed to produce and process hydrogen.



References

1. Next Step, "Re-use & decommissioning report", Innovation and collaboration, 2022
2. M Simms, "Leadon Decommissioning Programmes", Department of energy and climate change, 2015
3. Options for decommissioning subsea bundles, OGP Report No.469, 2014
4. P Adams, "Hydrogen infrastructure – the pillar of energy transition", Siemens White Paper 2022
5. Barthelemy, H., "Effect of purity and pressure on the Hydrogen embrittlement of steels and other metallic materials", 2009

Thank you