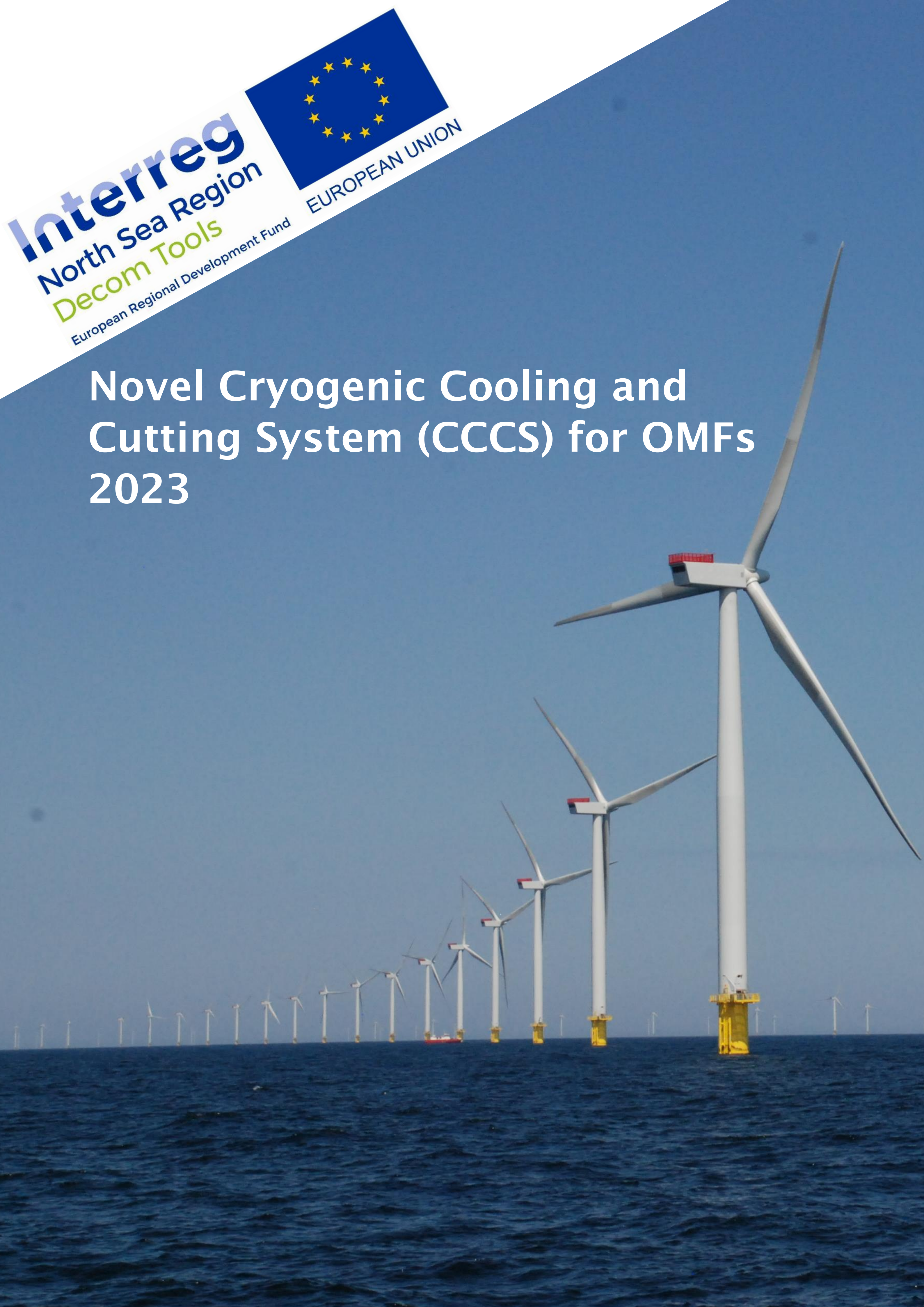
Interreg
North Sea Region
Decom Tools
European Regional Development Fund

EUROPEAN UNION

Novel Cryogenic Cooling and Cutting System (CCCS) for OMFs 2023



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2 Current cutting techniques competent

The seven most common cutting techniques employed in the offshore industry are Diamond Wire (DW), Abrasive Water Jet (AWJ), Laser Beam (LB), Plasma Arc (PA), Oxy Arc (OA), Shear Cutting (SR), and Explosives (EX). These methods are some of the most widely used cutting methods for offshore structures and piping. They are compared below in Table 1 on an array of different parameters and criteria.

Table 1 - Comparison of the different conventional cutting techniques employed in the industry based on different performance measures.

Cutting Technique	DW	AWJ	OA	LB	PA	SR	EX
Type	External	External/Internal	External/Internal	External/Internal	External/Internal	External	External/Internal
Cost	High	Highest	Lowest	Medium	Low	Low	Low
Cutting Speed (S_c)	Low	Low	Medium	High	Highest	High	Instant
t_w 12.7 mm (XS)	[1]50 mm/min	950 mm/min	500 mm/min	1000 mm/ min	2200 mm/min	[2]N/A	Instant
t_w 25.4 mm (XXS)	[1]50 mm/min	365 mm/min	400 mm/min	900 mm/ min	1100 mm/min	[2]N/A	Instant
Productivity	Medium/low	Medium/ low	Low	Highest	High	High	Lowest
Precision	High	Highest	Low	Medium	High	Lowest	Lowest
Kerf Width	0.2 mm	0.7 mm	0.1-1.0 mm	>2.0 mm	>1.0 mm	N/A	N/A
Quality	High	Highest	Low	Medium	low	Lowest	Low
HAZ Width	None	None	0.05 mm	0.4 mm	0.92 mm	None	N/A
Thermal Deformation	None	None	Medium	High	Highest	None	High
Energy Consumption	Medium	High	Medium	High	Highest	High	Low
CO_2 Consumption	0.5 - 1 kg/hr	5-10 kg/hr	10 - 50 kg/hr	20 - 30 kg/hr	20 - 100 kg/hr	55 kg/hr	Negligible
Safety Risks	Small fragments and cuts	Small fragments, abrasive mud and cuts	Hazardous vapours, burns and gas explosions	Hazardous vapours, aerosol and burns	Hazardous vapours, dross and burns	Small fragments	Fragments and explosive waves
Environmental Impact	Medium	Medium	Medium	Low	Low	Medium	High
Ambient Applicability	All	All	Non-Explosive	Non-Explosive	Non-Explosive	All	Non-Explosive
Material Applicability	All Steels	All Steels and Composites	All Steels, but mostly Carbon Steel	Non Reflective Steels	All Steels	All Steels	All Steels
Maximum t_w	+300 mm	+300 mm	+300 mm	[3]+120 mm	50 mm	+300 mm	75 mm

[1] The DW cutting applies directional diameter cutting and not circumference cutting, like the six other cutting techniques.

[2] The cutting time for the shear depends on the pipes D_O, as documented by the test carried out by (Fisher.com, 2022).

[3] Current development of laser beam cutting, has showed that it would be possible to a seel w_t equal to 120 mm for decommissioning underwater, as documented by the test carried out by (Neilson & Baxter, 2023).

3 The CCCS is a novel cutting system which applies

The CCCS is based on the Ductile to Brittle Temperature Transition (DBTT) phase shifting principles, which occurs in structural carbon steel grades below sub-zero temperatures. One such structural carbon steel grade is the ISO EN 1.0577 (355J2), which is commonly applied for manufacturing Offshore Monopile Foundations (OMFs).

3.1 Cryogenic Cooling

Table 2 - Data Specifications for the Transient Heat Transfer Model of Cryogenic Cooling.

Carbon Steel Specifications:	**Liquid Nitrogen [LN_2] Specifications:**
Type: **ISO EN 1.0577 (S355J2)**	Temperature: **-196 °C**
Thermal Conductivity: **50 W/m*K**	Heat Transfer Coefficient: **128 W/m²*K**
Density: **7850 kg/m³**	**Ambient Specifications:**
Specific Heat: **470 J/kg*K**	Bedrock Temperature [t_a]: **20 °C**
OMF Wall Specifications:	Heat Transfer Coefficient: **25 W/m²*K**
Wall Thickness [b]: **100 mm**	**Cooling Element Specifications:**
	Surface Width Size: **100 mm**
Impact Energy (IE) depending on Cooling Temperature:	
Impact Energy @ 20 °C: **210 J/cm²**	
Impact Energy @ 0 °C: **135 J/cm²**	
Impact Energy @ -45 °C: **15 J/cm²**	

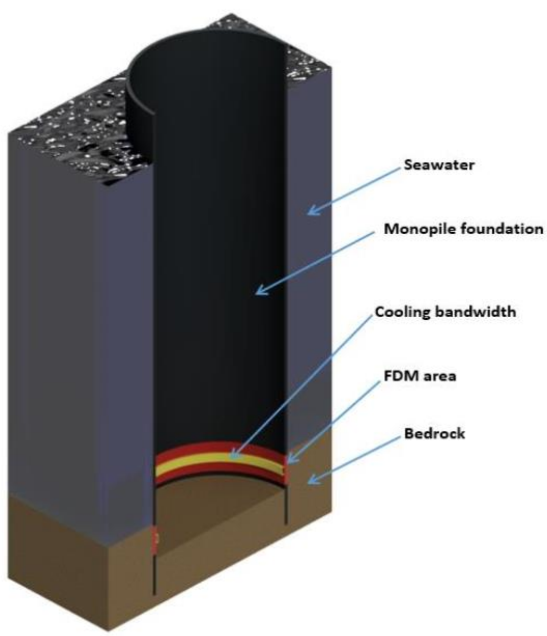

Figure 1 - 3D Model showing the OMF with the Cooling Element (in yellow) and the FDM Area (in red).

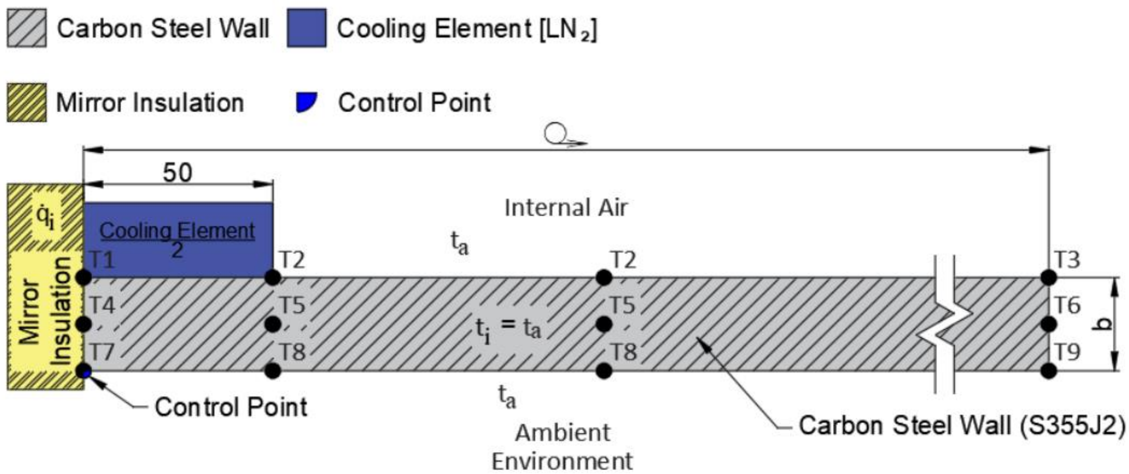

Figure 2 - 2D Model for the Analysis of Cooling Time to reach -45 °C @ the Cooling Point depending on Ambien Conditions.

Figure 3 - DBTT Phase Diagram for ISO EN.10577 (S355J2).

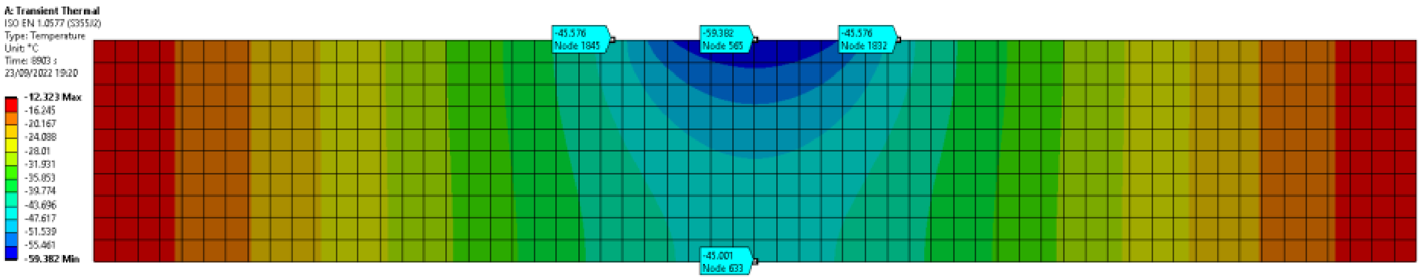

Figure 4 - Transient Heat Transfer Simulation for the OMF Wall to reach -45 °C (15 J/cm2) on the outer surface of the wall.

3.3 Internal and external cutting

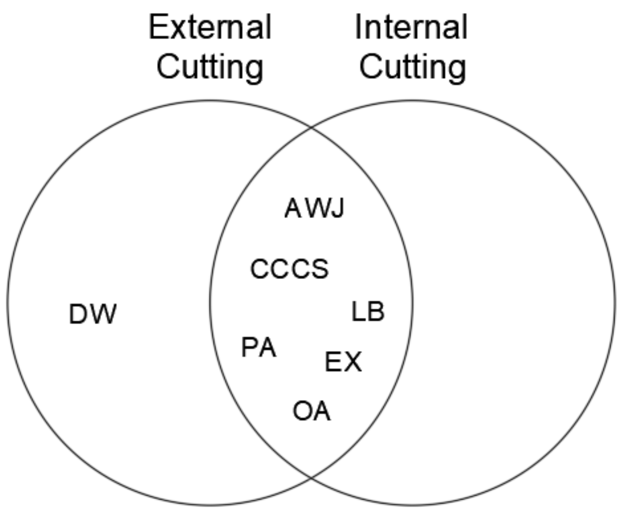

Figure 5 - Venn diagram illustrating the applicability of different techniques for internal and external offshore cutting operations.

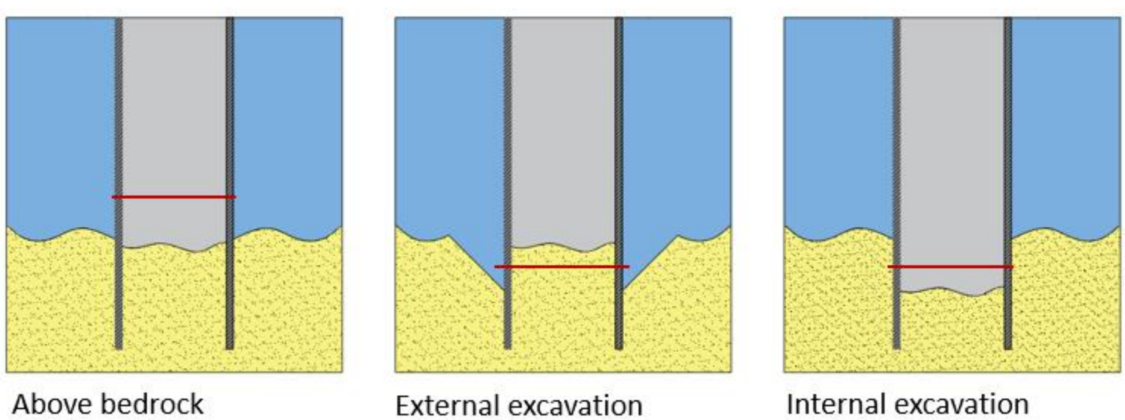

Figure 5 – Methods of cutting process for internal and external cutting of the OMF wall.

3.4 Concept Design for the CCCS

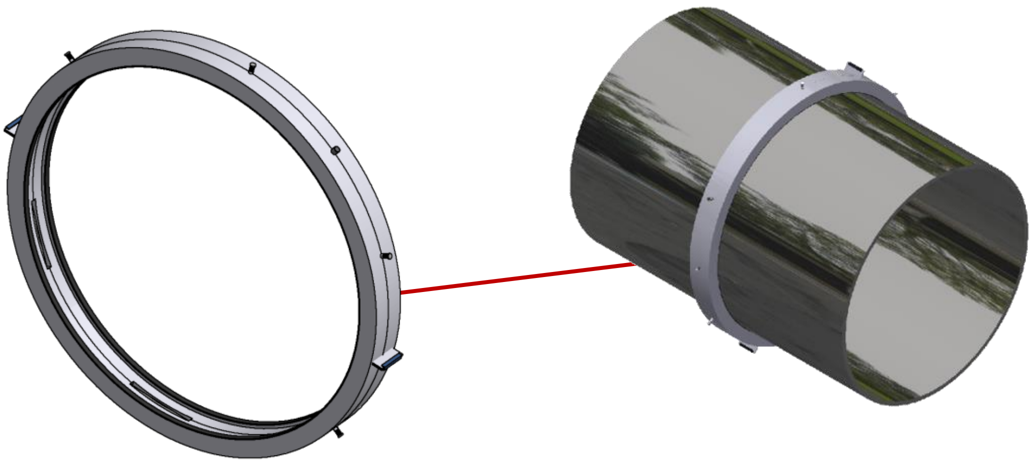

Figure 7 - Concept for the external CCCCS.

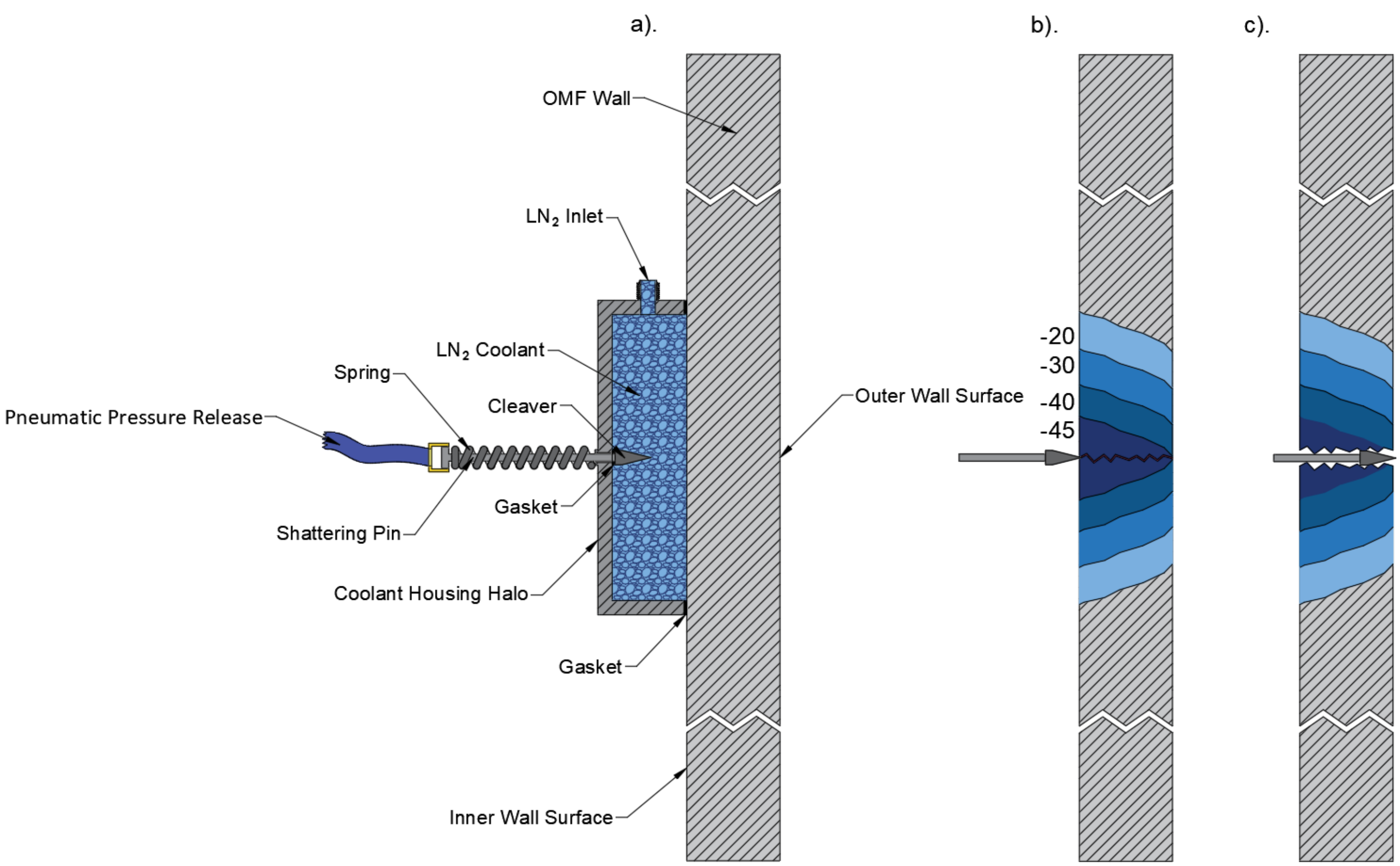

Figure 8 - a) Cross Section View of the ECCS applied on the inside of an OMF Wall
b) Cooling area of the OMF Wall and Fracture Line
c) Full Fracture of the OMF Wall.

3.5 Concept for fitting the CCCS to a UROV

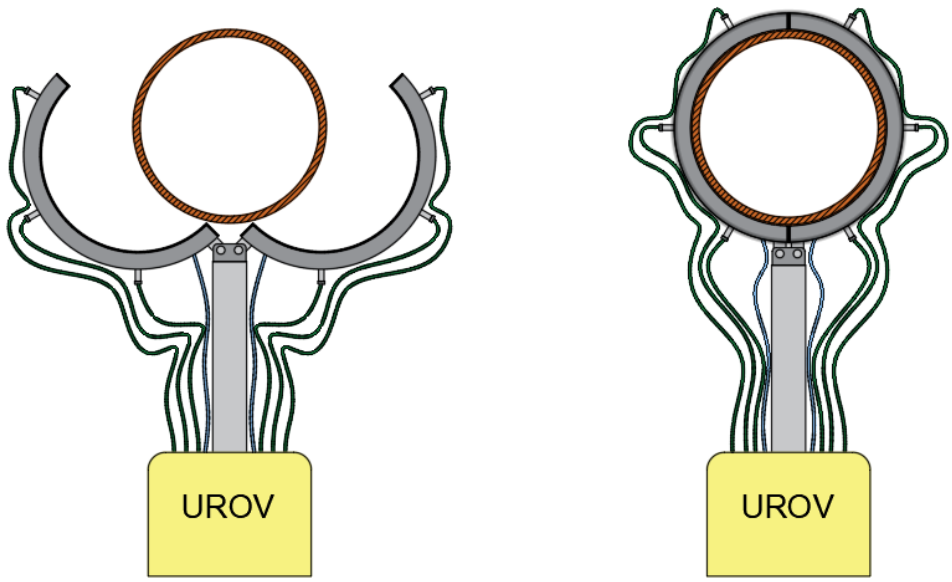

Figure 9 - Concept for the external CCCS fitted on a UROV.

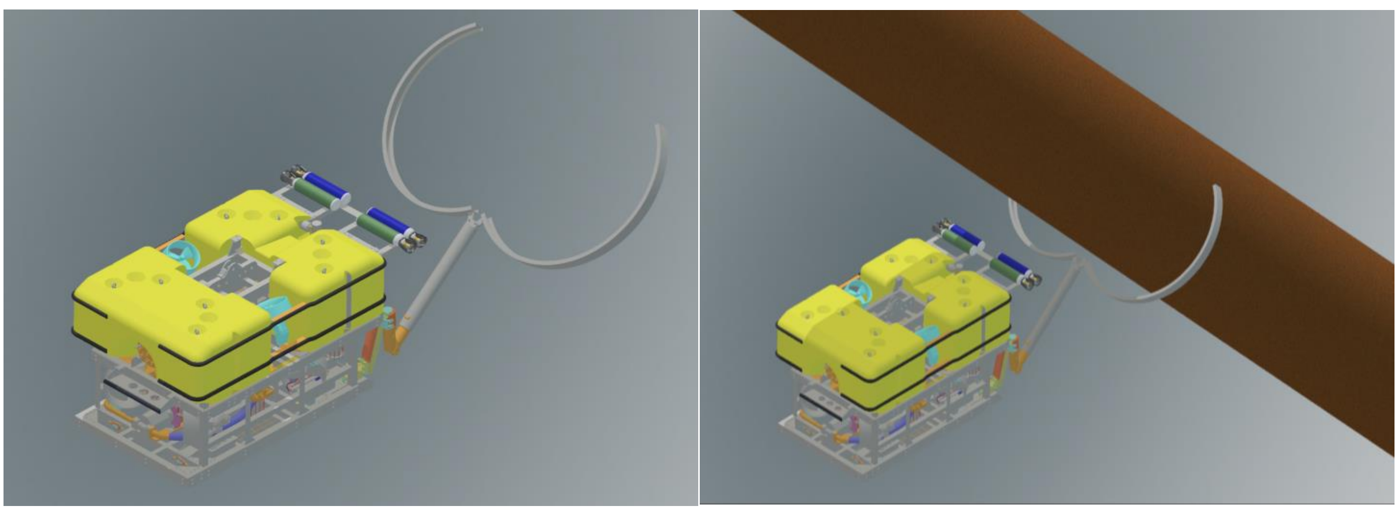

Figure 9 - 3D Concept for the CCCS on UROV caring out external cutting of an Offshore Jacket.

5 Cost savings analysis for decommissioning of OMFs

Compering the cutting cost and time for the decommissioning process of an Offshore Windfarm (OWF) with 101 OMFs for removal. Applying the conventional internal cutting technique of AWJ against the theoretical calculations of the novel CCCS method looking at the time savings and therefore the also a reduction in cost.

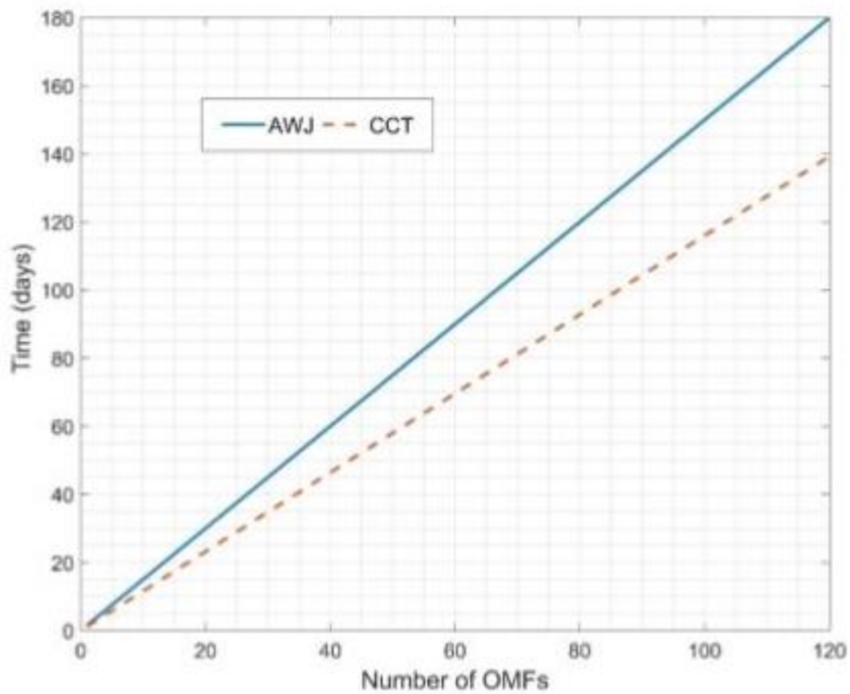

Figure 10 - The resulted foundation removal durations using the AWJ and CCCS techniques for different number of monopiles.

Table 3 - The vessel costs for the foundation removal operation in the Cape Wind OWF with 101 monopiles applying the CCCS and AWJ cutting techniques.

		AWJ				CCCS			
Vessel	Leasing rate (£/day)	Duration per monopile	Overall duration	Cost per monopile (£)	Overall cost (£)	Duration per monopile	Overall duration	Cost per monopile (£)	Overall cost (£)
JUV	100 k	1.50	151.50	150 k	15.15 m	1.16	117	116 k	11.7 m
BV	12.9 k	1.50	151.50	19.35 k	1.95 m	1.16	117	15 k	1.51 m
TB	8.6 k	1.50	151.50	12.9 k	1.30 m	1.16	117	10 k	1.10 m
				Total:	**18.40 m**			**Total:**	**14.31 m**

5 References

[1] Kenneth Bisgaard Christensen, Shahin Jalili, Alireza Maheri (2022) ‘A Comparative Assessment of Cutting Techniques applied for Offshore Energy Structures’, IEEE 2022: 7th International Symposium on Environmental Friendly Energies and Applications (EFEA).

[2] Kenneth Bisgaard Christensen, Shahin Jalili, Alireza Maheri (2022) ‘Cryogenic cooling and cutting system: A novel cutting technique for offshore monopile foundations’, Yet to be published.

[3] Shahin Jalili, Alireza Maheri, Ana Ivanovic (2022) ‘Cost and Emission Analyses of Decommissioning of Offshore Wind Farms Using Reverse Installation Method: Cases of Lincs Limited, Gunfleet Sands, and Horns Rev I Wind Farms’, DecomTools deliverable available from DecomTools, Interreg VB North Sea Region Programme.

[4] Shahin Jalili, Alireza Maheri, Ana Ivanovic (2022) ‘Cost Modelling for Offshore Wind Farm Decommissioning’, DecomTools deliverable available from DecomTools, Interreg VB North Sea Region Programme.