CryoUsers 2024 Conference Summary

2nd – 4th September

University of Leeds

The Delegates and Sponsors arrived on the Monday afternoon and shared coffee and an evening meal before the full meeting started on the Tuesday. The meeting began with an address to all by the organising committee followed by a full program of talks, highlighted below.

SIVL and Polycold Cascade Systems | Steve Alford & Richard Booth, GRE

GRE has developed many different applications to enable delivery of a wide range of projects, which includes, designing, manufacturing and testing (including x ray coded welding) of bespoke systems, including, liquid nitrogen systems where bespoke designs have been produced to ensure liquid nitrogen at the valve avoiding flash gas heating the system. GRE also provide helium systems.

GRE use a LIDAR system which scans and essentially provides a detailed lay out which avoids using manual measurements reducing the risk of human error, this means everything can be confidently made off site to help with installation.

GRE have also invested in a Pump and flush automated system where components can be left overnight within a 100°C oven to ensure all moisture has been removed.

There was also a presentation on an Auto cascade refrigerator which utilises a single compressor and multiple refrigerants on a closed cycle system to achieve temperatures down to -80°C. This system can be automated to ensure temperatures can be available at certain times. The system is portable and can be used at different sites. A cost comparison was provided against the use of liquid nitrogen.

Cryogenics for Power and Energy, a Winning Ticket | Pascale Dauguet, AirLiquide

An overview was given on how cryogenics applications are supporting the transition from traditional energy sources to cleaner energy systems.

Presently many companies and institutional projects are associated with fusion, many of them use high-temperature superconductors for magnetic confinement. Current institutional projects (e.g. ITER in France etc.) are large TOKAMAK-type reactors requiring low-temperature superconductors and associated cryogens. Offshore wind power could also benefit from cryogen-supported superconductivity, as it can address the shortage of rare earth materials as well as improving the cost and feasibility of long-range high-voltage DC power transmission both onshore and offshore. Cryogenic systems are also used to capture, purify, and transport CO2.

Liquefaction and precooling of H2 is a key part of clean energy, with applications for liquid H2 for fuelling motor vehicles, planes and shipping. A description was given on how the H2 systems work including some of the systems AirLiquide have built for liquefaction or reliquefication of LH2; One of the key components for this is a turbo-Brayton system, which can be modular and capable of liquefying up to an impressive 3tonnes/hour expected LNG flow at 113K. These systems are very useful for reliquefying LNG in transit, so carrier ships do not lose product and are also well suited for high-temperature superconductivity applications.

ISIS Pulsed Neutron and Muon Source Cryogenic Moderators Systems | Justin Miles, ISIS

The cryogenic moderators in use on the 2 target stations at ISIS was presented, with an overview of the role of moderators in the ISIS accelerator facility, the physical equipment, challenges of remote operation due to high radiation, and what operation of the moderators typically look like. The moderators help filter the beam so all particles exiting are closer in energy and momentum than when it enters.

Both Target Stations at ISIS have two cryogenic moderators: TS1 has liquid methane at ~110K and liquid hydrogen at ~20K, while TS2 has *solid* methane at ~40K and liquid hydrogen at ~17K. TS1 has a methane cold box and a bespoke Stirling cryo-generator, its hydrogen moderator has 1 compressor and 2 cold boxes. TS2 has a helium compressor and 2 helium cold boxes for the methane and hydrogen moderators.

For the methane moderators, the energy deposited by the beam generates methane breakdown products which interfere with the moderator's ability to work. The moderators thus must be flushed and refilled (daily) with fresh methane to keep them operating correctly. The moderators are replaced every after 2 cycles due to wear and tear from normal operation.

Due to the demanding operating conditions of running cryogenic equipment in the beamline, work with the moderators is done via remote handling. There are many things that can go wrong – in addition to the failure modes common to cryogenic applications, there are also all the concerns with vacuum failure and leaks, interlock problems, power and water cooling, compressed air and ventilation failures. Hydrogen moderators which can lead to more radiation problems if too much gets generated.

Refrigeration & Special Gases | Jaroslav Jezek, Haugh/Sauer

An overview was presented of the product lines and applications of the Sauer Compressors Group, with the technical specifications that allow Haugh compressors to provide a competitive product for a variety of applications. Their compressors are oil-free, which reduces contamination of the gas as well as being more environmentally friendly than oil lubricated compressors.

One product line has magnetic coupling, allowing a hermetic seal that is gas-tight to the leakage rate of 0.001 up to 0.0001 mBar*L/sec. Their integrated electric motor line also has a very small leakage rate. Haugh compressors can run up to 500Bar with a wide variety of refrigerant and specialty gases.

Example applications of Haug compressors were given: compressing of Per-Fluor-Propane to cool the inner detector of ATLAS at CERN, developing greener commercial refrigerant R-473A at Koura & Star Refrigeration (UK), standard servicing of refrigeration systems containing R404a or SF_6 , production of C_2ClF_3 for microelectronics at Astor (Russia), production of silane for microelectronics and photovoltaics at Klydon (ZA), and Xenon recovery from a radioactive decay measurement done by Westfälische Wilhelms University (Germany) and Gran Sasso National Laboratory (Italy).

Thermodynamics for Cryogenic Application | Alex Jones, ISIS

A tutorial on thermodynamics for cryogenic applications was presented. After introducing the Laws of Thermodynamics, the difference between heat, temperature, and energy were discussed. This led

into the concepts of heat capacity, followed by an exercise to calculate some thermodynamic values for a home water heater, and latent heat with an exercise on microwaving pasta sauce. After this foundational information thermodynamics in systems were discussed, using the laws of

thermodynamics to explain how heat and energy are constrained in refrigeration systems. Starting from the theoretical Carnot refrigeration cycle, practical refrigeration systems were outlined including the vapour-compression (reverse-Rankine) cycle common in commercial refrigeration, and the Stirling cycle as well as the gas (reverse-Brayton) cycle combined with the Joule-Thompson process to achieve cryogenic refrigeration.

The next topic was thermal transport, including conduction (helium consumption due to heat leaks from wiring), radiation (helium consumption due to heat leaks from radiation, with an aside on insulation/superinsulation), and convection. Thermal expansion was also presented and the necessity of considering thermal expansion/contraction coefficients for cryogenic applications. The talk was finished with a tutorial examining one of the big complications when considering the thermodynamics of new cryogenic systems looking at problems finding or taking data for the thermal expansion, thermal conductivity, or heat capacity of materials, and getting the right information for the treatment of your materials.

Cryogenics for the US Navy | Al Guerra, Kelvin International

A summary of Kelvin was presented along with its core technology which includes LN_2 and LOX generators, cryogenic instruments and controls, LOX service/maintenance for the US government, and cryogenic converters for the US Navy. A problem of how to fill submarine flasks quickly with pure N_2 that was solved for the US Navy was discussed. Kelvin International's portable high-pressure N_2 system can fill a sub flask in minutes to hours, with purity guaranteed. The KIC system is efficient at producing high-pressure nitrogen, will operate reliably with low maintenance. KIC supplies certified operators to the US Navy as part of the service and operations contracts.

A schematic of a converter was explained with operation modes and flow paths – filling subs or storage cylinders, pressure raising, liquid flow paths, priming for a liquid transfer, and refilling the tank attached to the converter.

The next section discussed 'sailor-proofing' the cryogenic equipment – how Kelvin International keeps everyone safe by ergonomic design and proper access control. This includes a basic visual HMI interface to display all important operating parameters, with many additional settings restricted by access codes.

Kelvin International provides shipboard and pier-side solutions that couple to commercial trailer tankers or companion ISO tanks, as well as several standalone vehicles such as a specially designed diesel-powered converter the size of a standard vehicle trailer for submarine bases. Kelvin International also supplies static converters for both LN_2 and Aviator Breathing Oxygen grade of LOX – these produce gas from liquid product. An image of their COGS-KLOX liquefier, which generates ABO-grade LOX illustrated some of what Kelvin International offers beyond the scope of the presentation.

Sample Environment & Helium Recovery: Wet or Dry, that is the Question | Richard Down, ISIS

Information was presented on how ISIS Cryogenics equipment impacts carbon footprint, including comparing wet and dry systems, as well as the CO_2 impact of the newly added LN_2 precool system for

ISIS Cryogenics' helium liquefier. After a brief overview of ISIS's goals to reduce CO_2 and current progress towards this, core equipment was outlined with its cryogenics uses with calculations of the carbon footprint.

Dry systems are typically CCR based with a sample change vacuum pump and a temperature controller, and a typical wet system comprises of a cryostat, a pump for the sample change and a second pump for the variable-temperature insert, and a valve or temperature controller. ISIS also has some instrument-based cryogenic systems, where CCRs are used to cool graphite analysers which replaced 500LLHe/day. Other ways ISIS Cryogenics increases sustainability and decreases carbon footprint, and cost is via their Helium recovery system.

ISIS Cryogenics recaptures helium from dewars and wet systems and stores this gas, then reliquefies to supply most of the helium for experiments. 3 Sauer compressors take low-pressure gas from the gas bag and compress it up to 200Bar, the gas then goes through a PLC-controlled manifold to high-pressure storage cylinders. The ISIS Helium Recovery system has a Linde TCF20 liquefier which produces 480L/day, although this number will approximately double once the LN_2 precool is active.

Calculations presented highlight that liquifying recaptured helium is green but not carbon neutral. The LN_2 precool results in a reduction of CO_2 produced per LL He reliquefied. Calculations for Helium bought by ISIS has a carbon footprint ~160% that of reliquefied He, calculated from when it is extracted as a byproduct of LNG extraction through delivery to ISIS. Some smaller reliquification systems and their CO2 footprints were also presented, with larger-volume systems having a smaller footprint per LLHe. All liquefaction systems have smaller footprints than buying in helium and larger and more efficient systems such as adding LN_2 precool have smaller CO_2 emissions. A liquefier is greener but the capital costs of CCRs are lower.

Although some cryogenic systems are greener than others, CCRs are an integral part of ISIS operations and allow the facility to offer a wide range of extreme conditions.

The Supply of Specialty Gases from Tunstall & the Eco Origin Initiative | Simon James & Robert Severn, AirLiquide

A brief overview of AirLiquide was provided, followed by in-depth explanations of the air separation process, options for mixing specialty gases, and the new line of environmentally friendly bulk air gases. AirLiquide is present in 80 countries, with over 4 million customers & patents in the industry and health sectors and offers a wide variety of gases. The first section of the presentation covered the fundamentals of air separation and the process of producing commercial gases – beginning from atmospheric air intake and compression through purification, heat exchange, distillation, and liquefaction, and continuing to the equipment required for this process.

Air Liquide's Tunstall facility in Stoke-on-Trent produces specialty gases, including mixtures and high-purity gases up to 7 grade (99.99999% purity). Tunstall is also the UK's only methane production facility, with the methane plant operating 24/7. For gas cylinders, there are 2 mixing filling options: the Transfill option for filling smaller volume containers from larger ones or the Floxfill option for gravimetric filling of individual cylinders via manual or automatic blending panels and the capability of up to 20-component mixtures. Alternatively, the Accublend option dynamically blends gases and analyses the mixture prior to filling cylinders, resulting in nominally identical mixtures in 2-16 cylinders with a blend tolerance of 1-5% and analytical accuracy of 1-2%.

The Eco Origin line of bulk air gases from AirLiquide are climate-smart gases with up to 88% reduction in CO_2 emissions per unit of product. This is achieved via a combination of using renewable

electricity to power the air separation units, continuously implementing improvements in the air separation units to maximise efficiency and reduce energy usage, and reducing transport emissions. Liquid gas transport is ebbing progressively with conversion to alternative trucks and fuels, routes/logistics optimised, and all residual transport emissions are climate-compensated.

Diamond Light Source: Superconducting Cavities & Helium Refrigeration | Adam Rankin, Diamond Light Source

Superconducting cavities and helium recovery/liquefaction system at DLS were presented. Diamond is a third-generation 3GeV synchrotron facility serving over 7000 researchers a year, 86% is owned by UK government through UKRI/STFC and 14% by the Wellcome Trust. Electron bunches are steered around the storage ring by dipole magnets and insertion devices, and a series of Radio Frequency (RF) cavities top up the energy of the beam bunches by coupling energy to each bunch as it passes through the cavity.

The RF cavity straight has space for 3 RF modules; since these modules are superconducting, they require the cell to be immersed in liquid He. An AirLiquide Helial 2000 provides 24/7 closed-loop support for the RF cells, with minimal plant shutdown. Other components of the system are a Kaeser compressor, oil removal module, 2000L liquid storage dewar, 2000L liquid equivalent gas storage and N_2 vaporiser, PC supervision of system, and system PLC output into an EPICS controls system.

Cryogens from the main manifold feed into the valve box for the RF cavities, and the valve box is LN2 radiation screened. Pneumatic control valves regulate LHe level and pressure, and a helium bypass valve is used for cavity warmup or cooldown. There is also a large atmospheric heat exchanger used during cavity warmup/cooldown. There is also a post-installation SIVL installation which allows top-up of the system while running, without depressurising the dewar.

DLS's helium plant is very reliable, with most cold box trips due to cuts in utility supply Several plant problems were presented and how DLS solved them, such as cold restarts, contamination, a broken flow valve, and instability of a pressure transducer.

Can a Tiny Droplet of Quantum Fluid Stop Uphill-Flowing Liquid? | Oleg Kirichek, ISIS

After a brief historical background and the mechanisms of superfluid helium, recent works were presented in which a collaborator studied a mixed He-3/He-4 film with neutrons as a function of temperature. Superfluid He-4 is composed of a superfluid component, and a normal component. The superfluid transition occurs at 2.17K in He-4, below this temperature the quantum behaviour of the superfluid allows it to defy gravity by climbing vertical surfaces.

The collaboration used neutron reflectometry to study the superfluid helium film in more detail. Taking advantage of the climbing behaviour of the film, they used a specially constructed experimental cell that allowed the film to climb onto a silicon plate and into the path of the neutron beam from a bulk liquid bath of He-3/He-4 below. He-3 produces almost all of the neutron adsorption, allowing the mixture composition of the film to be studied as a function of depth into the film. By changing temperature, they were able to observe He-3 gradually dissolve into He-4 with increasing temperatures above 150mK, an anomaly around 300mK that could be a phase transition, and an unexpected return of the phase separation at 1.5K. Understanding helium film properties and behaviours are important to get the most out of potential applications for He superfluid films such as dilution refrigerators for quantum computers, and qubits based on electron-on-helium.

The CryoUsers community had pre-dinner drinks at the Queens Hotel in the centre of Leeds before a wonderful four course meal which was capped with a selection of fine cheeses and a glass of port. The meeting recommenced the following morning with the following presentations.

Research and Development in the Field of Magnetic Resonance Imaging | Matthew Wooley & Sanjeev Taak, Nottingham

An informative summary of the status of Magnetic Resonance Imaging (MRI) was presented, including recent developments in the field and the role of liquid helium in current and future MRI machines. MRI developed from NMR and is an important medical imaging tool that plays a key role in diagnosing a wide range of conditions such as neurological disorders or musculoskeletal injuries. Since MRI uses magnetic fields and radio waves to generate high-resolution images without ionising radiation, it is a safer imaging technique compared to X-rays or CT (computed tomography) scans.

NMR was discovered independently by Felix Bloch and Edward Purcell in the 1940's, and in the 1970's Paul Lauterbur and Sir Peter Mansfield adapted the principles to enable MRI. The first commercial MRI machines of the 1980's had magnetic field strengths of 0.5-1.5 Tesla, and by the 1990's there were already significant developments such as functional MRI (fMRI), which allows brain activity to be observed in real-time.

Today's MRI machines operate at 7T or more and are capable of fine detail that enables studies of brain connectivity and very small anatomical structures. The stronger the magnetic field, the more detailed the imaging. However, current MRIs are all dependent on liquid helium to cool their magnets and require periodic top-ups to offset natural boil off. Improvements in cryostat and closed-loop cryogenic systems have made MRIs more efficient so they lose less helium, researchers are developing helium-free MRI systems such by using cryogen-free superconducting magnets.

The Helium Market | Hannah Whelan and Jessica Thorpe, BOC (Linde)

An overview of the current state of the global helium market was presented. Crucially, helium supply and prices currently seem much more stable than the past few years. BOC is tentatively forecasting that this will remain the case provided no unexpected events occur to impact the market's supply. Helium is extracted as a byproduct of LNG extraction and has an estimated 6.2 billion cubic feet of global source capability (175 million cubic metres). Global capacity by source is estimated with Qatar at 35%, Exxon Mobil (USA) at 26%, and NA other suppliers in USA at 18% as the three top sources. Linde estimates they hold 22% of global capacity. The helium market has shifted from supply-constrained to demand-driven, due to a combination of downturns in economics & the electronics sector and efficiencies made during the period of global allocation due to shortages.

The Linde group's new US source in Freeport, Texas was projected to be commissioned in 2024, with 180MMCF. Due to sanctions, the Russian sources (Irkutsk and Amur) are not available to supply indefinitely. Two new sources in Qatar are projected to come online in the next couple years – Qatar IV in 2027, and Qatar V in 2028. As far as Forecasting goes, the MRI market is expected to be flat as the number of installations increase but the more efficient newer models consume less product. The Electronics sector, which has a cyclical demand, was projected to have an increased demand in 2024 after a period of decreased demand. The emerging application of helium to pressurise liquid fuels for rockets is expected to increase He demand.

In terms of prices, the extended shortage has driven source costs up for all suppliers, and tensions in the Middle East currently are restricting westbound Qatar shipments & increasing freight rates. The current market's demand-driven status means that these other factors are not expected to drive costs to the consumer up. BOC forecasts stable pricing provided no significant geopolitical events occur. There is a possibility for prices to come down if the cost to suppliers comes down. It is anticipated that prices will not climb drastically like the past few years because the market has reached equilibrium after the Russian sources were removed from the picture via sanctions, and the efficiencies implemented during the years of global shortage/allocation coupled with a reduced demand has eased pressure on the market.

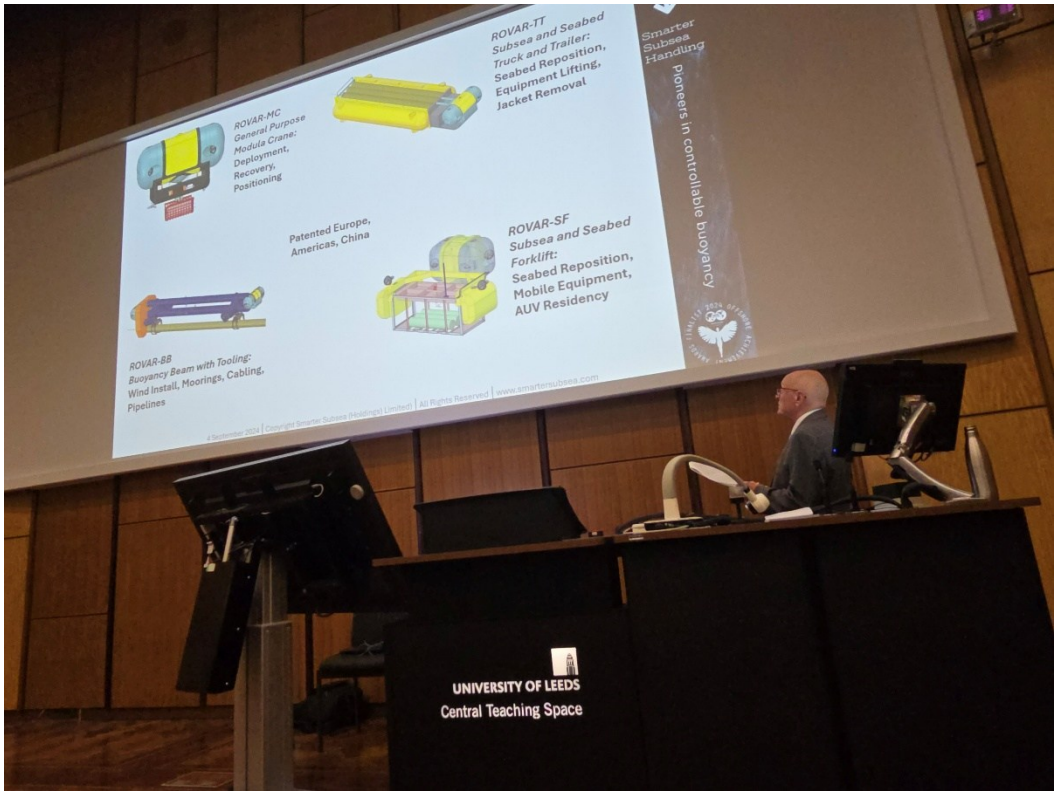
Safety | Bob Wiltshire, PGS / Wiltshire Cryogenic Consultants

Bob presented a very knowledgeable talk on cryogenic safety that shared a lot of material with the cryogenic safety training courses he runs, covering the basic considerations of safely working with and around cryogens. He discussed several case studies of accidents and what can be learned from these situations, the properties of cryogens and how these can pose a safety hazard (e.g. oxygen enrichment, oxygen depletion, expansion from liquid to gas, ice plugs), and general best practices for working safely with cryogens. For best practices, Bob detailed what users of cryogens can do to keep themselves and the surrounding environment safe during decants and transporting vessels, as well as emergency procedures, how to deal with spillages, and how to tell if there is something wrong with your vessel that indicates it needs to be taken out of use until it can be inspected. From using

the proper PPE to ensuring your cryogenic pressure vessel has working relief devices, there are many things cryogen users can do to keep ourselves and anyone in our local work area safe.

Smarter Subsea Handling | Phil Pritchard, Smarter Subsea Holdings Ltd.

Underwater buoyancy systems, an interesting application of cryogenics was presented. Phil explained his novel innovation. The idea is that by using cryogenic storage tanks and controlling how the cryogen boils off into gas, the expanded gas can provide buoyancy to lift items deep underwater. This technology offers the opportunity to make subsea lifting operations more accessible and cheaper because it avoids the costs and waitlist for the few cranes on heavy lifting vessels worldwide, and



these systems also could make routine underwater tasks safer. The Smarter Subsea systems can also be deployed by fishing vessels, which has the double benefits of being much more available than heavy-lift vessels as well as providing employment in the off-season of this seasonal industry.

Smarter Subsea's products have a range of applications, from a general-purpose modular crane that can perform deployment, lifting, and recovery operations to subsea and seabed forklifts and truck & trailers. There is also a buoyancy beam with tooling, targeted at working on moorings, cabling, pipelines, etc. For applications where the buoyancy beam can replace divers by allowing remote control of the work, this increases worker safety. These systems have been patented by Smarter Subsea in Europe, the Americas, and China.

CryoUsers 2024 concluded as a very successful meeting with 13 sponsors and some excellent networking, considerations for the next venue Durham, Manchester and Moreton-in-Marsh.

Program Itinerary

Monday 2nd September

15:00 – Delegates, sponsors arrive, tea and coffee

19:00 – Evening meal

Tuesday 3rd September

08:00 – Breakfast

09:00 – Sponsors area

09:40 – Opening Address - **CryoUsers Committee**

09:45 – Welcome

09:55 – Talk **"SIVL and Polycold cascade systems"** - Steve Alford / Richard Booth GRE

10:15 – Talk "**Cryogenics for power and energy, a winning ticket"**– Pascale Dauguet

10:35 – Coffee, Sponsors area

11:00 – Talk **“ISIS Pulsed Neutron and Muon Source Cryogenic Moderators Systems”**

- Justin Miles

11:20 – Talk “**Refrigeration & Special Gases”** - Jaroslav Jezek – Haugh / Sauer

11:40 – Talk **“Thermodynamics for cryogenic application”** - Alex Jones

12:00 – Lunch, sponsors area

13:30 – Talk **“Thermodynamics for cryogenic application”** - Alex Jones

13:50 – Talk **“Cryogenics for the US Navy”** - Kelvin International

14:10 – Coffee, sponsors area

14:40 – Talk **“Sample Environment & Helium Recovery Wet or dry that is the question”**

- Richard Down

15:00 – Talk “**The supply of specialty gases from Tunstall & the Eco Origin initiative**”

- Simon James / Robert Severn

15:20 – Talk **“Diamond Light Source”** - Adam Rankin

15:40 – Talk **“Can a tiny droplet of quantum fluid stop up-hill flowing liquid?”**

- Oleg Kirichek

16:00 - Community Discussion

18:00 – Pre dinner Reception

18:30 – Conference Dinner – Coach to Queens Hotel

Wednesday 4th September

08:00 – Breakfast

09:00 – Sponsors area

09:30 – Talk “**Research and Development in the field of Magnetic Resonance Imaging”**

- Matthew Wooley / Sanjeev Taak

09:50 – Talk “**The Helium Market” -** BOC

10:10 – Talk “**Safety”** - Bob Wiltshire

10:30 – Coffee, Sponsors area

11:00 – Talk “**Safety”** - Bob Wiltshire

11:20 – Talk **“Smarter Subsea”** - Phil Pritchard

11:40 – Close of meeting, next venue

12:00 – Lunch

13:00 – Finish