Undercover Zero

NZIP Industrial Hydrogen Accelerator

Zero Emission Laundry

Stream 2A Feasibility Study Final Report

Department for Energy Security & Net Zero

Funded by the Department for Energy Security and Net Zero

Document Information		
Document Title	UCZ IHA 2A feasibility Report Final V3 PUBLIC COPY 20230505	
Date of Issue	5th May 2023	
Status	Final	
Checked by:	Paul Bearham – Technical Director	05/05/2023
Approved by:	Peter Hillman – Managing Director	05/05/2023

Version	Date	Purpose of Amendment
1.1	18/01/2023	First Submission
2.0	08/02/2023	Draft Amendment
3.0	28/02/2023	Final (Public)
4.0	15/03/2023	Finalised draft (Public)
5.0	05/05/2023	Finalised details (Public)

Glossary

ASME	American Society of Mechanical Engineers
ATEX	Atmospheres Explosible
CAPEX	Capital Expenditure
CE	European Conformity
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent gases
DBB	Double Block and Bleed
DEFRA	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero (DESNZ)
DNO	District Network Operator
DNV	Det Norske Veritas
DTU	Demand Turn Up
EA	Environmental Agency
FTE	Full Time Equivalents
GHG	Greenhouse Gas
GWP	Global Warming Potential
HAZID	Hazard Identification
HEX	Heat Exchanger
HV	High voltage
H_2	Hydrogen
IHA	Industrial Hydrogen Accelerator
ISO	International Standards Organisation
LRQA	Lloyds Register Quality Assurance
MAPP	Major Accident Prevention Policy
MW	Mega Watt
NGED	National Grid Electricity Distribution
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
OPEX	Operational Expenditure
O_2	Oxygen
PED	Pressure Equipment Directive
PER	Pressure Equipment Regulation
PID	Piping Instrumentation Diagram
PR	Public Relations
PV	Photovoltaic
RE	Renewable Energy
R&D	Research and Development
SOx	Sulphur Oxides
SSOP	Steam System Optimization Program
TLV	TLV Euro Engineering UK
TQP	Technology Qualification Plan
TRSA	Textiles Rental Service Association
TSA	Textile Services Association
TRL	Technology Readiness Level
UCZ	Undercover Zero
UKCA	United Kingdom Conformity Assessment
ULEZ	Ultra Low Emission Zone
WP	Work Package
ZEL	Zero Emissions Laundry

Table of Contents

1.0 Executive Summary

Undercover Zero's project delivers a Department for Energy Security and Net Zero (DESNZ) Industrial Hydrogen Accelerator (IHA) Stream 2A feasibility study into the production and use of hydrogen in an industrial application.
Undercover Zero are committed to developing the world's first zero emission laundry which is the test site on which the feasibility study will be conducted. With our partner, Steamology, Undercover Zero bring an innovative hydrogen-based, zero emission steam generation system, powered by renewable resources, to the industrial laundry sector. Steamology deliver scalable and modular solutions for industrial steam heat and power applications, utilising unique hydrogen steam generators. The feasibility study gathered evidence to support the Stream 2B hydrogen fuel switching system demonstration project.

The technical solution proposed by Undercover Zero, involves the production of hydrogen using an onsite electrolyser to power a high-pressure steam generator which can power direct steam or thermal oil industrial laundry machinery.

The technical design of the proposed renewable powered demonstration system includes the following elements:

- Electricity supply through 425kW of solar photovoltaic (PV) and grid connection;
- AEM Multicore 1MW electrolyser;
- Hydrogen compression & storage 360kg @200 bar;
- Oxygen compression & storage 3500kg @200 bar;
- Mk.3 Steamology steam generator supplied with hydrogen, oxygen and water. Combustion of hydrogen in a 100% oxygen environment.

The objectives of the feasibility study were to research the cost effectiveness of the hydrogen fuel switching technology when applied to an industrial laundry application. Furthermore, the study aimed to understand the design, implementation and delivery requirements for an end-to-end hydrogen solution, from initial power input through to industrial end use. Undercover Zero seek to develop stakeholder knowledge and awareness of these solutions and to disseminate accordingly, developing new commercial relationships and building market awareness.

The process, capable of producing high quality steam to demand, follows the equipment load curve; this reduces waste from traditional boiler systems with poor response to changes in thermal load. The ramp up for the steam generator takes seconds, this removes the need to fire up traditional boilers some hours before use and makes the system extremely efficient by its instantaneous nature. The zero-emission solution enables direct integration of a hydrogen-based fuel system into a primary industrial marketplace.

Currently, the laundry industry uses direct steam or thermal oil heating systems to power processing equipment. Undercover Zero aim to disrupt the laundry industry by delivering a commercial solution that is cost effective and can be easily integrated into an existing industrial laundry. The final solution has been designed to be a standalone containerised offering that can be coupled to either direct steam, thermal oil, or a combination of both. This ensures that an efficient and sustainable system can be installed with minimal disruption and negate the requirement for any capital expenditure on replacement laundry equipment.

Site plans have been drawn and the heating system has been reviewed to provide the steam requirements for laundry cycles. Computer Aided Design drawings are complete for varied direct steam and thermal oil schemes. The demonstration phase will enable further monitoring and detailed identification of the duty cycles for all laundry equipment that can utilise the technical solution. This will be demonstrated across daily, monthly and seasonal fluctuations, providing peak and load demand required for the steam generators. The cycles shall highlight significant reductions in consumption and quantify the reductions in emissions for the whole product cycle. The key laundry site challenges for decarbonisation are the ability to access renewable energy and onsite storage of fuel.

To evidence size and scale of the technology required, the feasibility study needed to investigate the true demand loads for energy, water and steam within the industrial laundry processes. Renewable energy usage has been modelled for a variety of laundry loads in order to minimise cost; there will be further investigation through the demonstration phase.

Suppliers have been sourced for the provision of the electrolyser, storage and compression, with additional hydrogen and oxygen supply confirmed should it be required. This agreement de-risks the onsite production of hydrogen and oxygen ensuring continuation of the steam generator testing programme, should onsite production be interrupted. Undercover Zero have mapped out a preliminary two-year scheme, sourcing the necessary electrolyser, to enable delivery of the demonstration from May 2023 to February 2025.

Permits and licences have been investigated, allowing necessary discussions and planning with relevant agencies and supporting industries to commence. These include the water abstraction license from the Environment Agency, the disposal of trade effluent collaborating with South West Water, and complying with the Health and Safety Executive for the safe storage of hydrogen and oxygen. Planning permission for the demonstration site has been granted.

The Undercover Zero solution offers a wider application across other heat process industries such as pharmaceuticals and breweries, where the challenge around offering low carbon hydrogen solutions may currently be the availability of hydrogen both geographically and economically. The introduction of renewable driven hydrogen steam generator technology will provide a business case for local expansion of hydrogen availability, powered by renewable sources, which can be disseminated across alternative industries. Stream 2B IHA support would give the partnership the opportunity to develop the commercial delivery of the steam generator units so that post project delivery, the technology and learning can be disseminated and commercialised in a timely manner.

The UK laundry industry alone produces circa 4 million tons of carbon per annum (scope 1 & 2), whilst processing over 53 million items per week (Hatch Regeneris 2020). Undercover Zero's hydrogen solution will disrupt current laundry practices by introducing zero emission technology and removing carbon dioxide, nitrogen oxides, sulphur oxides and other particulates. The feasibility study establishes that the Stream 2B project is conducive to supporting Undercover Zero’s ambition to deliver the world’s first zero emissions laundry.

2.0 Introduction and Overview

2.1 Project

The laundry industry traditionally uses both direct steam and thermal oil heating systems to power equipment. In the UK these systems are powered by natural gas. Undercover Zero (UCZ) aim to disrupt the laundry industry through delivering a hydrogen powered and commercially viable system which is cost effective, reduces negative environmental impact and can be incorporated into existing laundry primary heating systems. In order to develop a commercially workable process, UCZ are working with Steamology, who design and manufacture unique hydrogen steam generators for industrial steam heat and power applications. UCZ are also engaged with laundry specialists Girbau who design, deliver and install complete, sustainable, innovative laundry solutions worldwide and Planet A, who are specialists in engineering, architecture, renewable energy (RE) and energy efficiency.

The resulting solution proposed by UCZ involves the renewable-powered production of hydrogen using an onsite electrolyser, alongside onsite hydrogen storage that powers the steam generator providing direct steam or thermal oil to the industrial laundry machinery as shown in figure 1.

Figure 1: Summary of the system, from renewables to laundry processing.

The steam generator uses hydrogen and oxygen, which combusts inside the steam generator at high temperatures, and subsequently produces no Carbon Dioxide (CO_2), no Nitrogen Oxide (NO_X), no Sulphur Oxides (SO_X) and no particulate matter.

Steam generators can be combined in multiple units (figure 2).

Figure 2: Combined steam generators

UCZ have identified a site in Cornwall suitable for the demonstration phase. The feasibility study enables UCZ to carry out a comprehensive review of the proposed demonstration site at Zone 4, Tolvaddon in Cornwall, looking at safety, energy systems, services, and planning.

The UCZ team have reviewed three model laundries; a small commercial, a light industrial, and a full industrial laundry (see Appendix UCZ1 for typical equipment for each size of laundry). All designed and modelled to operate on the demonstration site, including the installation of renewables (with grid connection) to match the energy requirements.

Working with global laundry equipment supplier Girbau, UCZ has established three typical laundry sizes of the scale of many laundries worldwide (See Appendix UCZ1: Laundry Capacity and Equipment). The Stream 2B demonstration would be carried out using the small commercial laundry model which can then be scaled up once the testing has been completed on the existing site, to the capacity of the full industrial laundry.

This approach will enable accurate theoretical modelling of the energy (electrical, hydrogen and oxygen) and water consumption for each sized laundry. This real-life data will enable all capacity laundries to be modelled.

The Stream 2A feasibility study has enabled UCZ to further develop the hydrogen fuel switching concept and gather evidence to support the demonstration in Stream 2B. The study gathered evidence on the core and ancillary technologies, the performance and costs of the system, and enables the development of a delivery plan for Stream 2B demonstration.

2.2 Objectives

The four key programme objectives of the feasibility study are to:

- prove the feasibility and evidence the cost effectiveness of hydrogen fuel switching for zero emission laundry (ZEL) operations at scale
- improve understanding of how to design, implement and deliver a hydrogen solution on a specific industrial site by working with end-to-end suppliers from power, planning, procurement, through to implementation
- develop stakeholder knowledge, confidence, and awareness of the hydrogen end-to-end system solutions by two dissemination activities
- develop new commercial relationships and build market awareness of industry actors with engagement across a supply chain committed to Scope 1 emission reduction and social, environmental, and economic sustainability (See Appendix UCZ3)

2.3 Technology Options Appraisal

UCZ and Steamology are working together to provide a green alternative which can generate large amounts of heat. The feasibility study considered alternative forms of laundry heating systems. Potential options to heat a zero carbon laundry include:

1. electric resistance steam boiler (renewable energy)
2. hydrogen combustion steam boiler (green hydrogen)
3. direct electric resistance heating of laundry equipment (renewable energy)
4. electric induction heating of laundry equipment (renewable energy)
5. hydrogen combustion thermal oil boiler (green hydrogen)

Options 1 and 2 both require a conventional steam system, albeit with atypical energy input. The design of these systems utilises the boiler volume itself and the distribution system as a storage buffer that allows variable and peak instantaneous heat demand to be met. However, these large and extended systems also result in significant losses; one trade journal puts the average losses for a combustion boiler steam system at 43.7% in relation to the fuel input (Paffel, 2020). Of this, 18.6% losses are associated with combustion, leaving 25.1% losses from the steam system itself; these losses would occur for the electric steam boiler system (Paffel, 2020).

Options 3 and 4 require major design changes to the laundry equipment and would need an additional system for water heating. Whilst these designs might evolve over time, the replacement of existing laundry equipment will be expensive, and the uptake of new equipment slow. This pace of change is not in keeping with the need to decarbonise industrial heat. Both options are not currently incorporated within existing laundry equipment.

Option 5, whilst similar in some respects to the UCZ solution, it relies on the combustion of hydrogen in a conventional boiler arrangement. As such, the hydrogen fuel is mixed with air for combustion which will result in the production of N_2O and is therefore not a zero emissions solution.

In contrast to options 1 - 5, the proposed UCZ solution utilises the high-power combustion of hydrogen in a 100% oxygen environment (stoichiometric combustion). This has the following advantages:

1. the technology provides near instantaneous steam on demand, thus obviating the need for the buffer provided by a conventional steam system; losses of up to 25.1% for a steam system will become negligible (Paffel, 2020).
2. unlike a conventional boiler, the instantaneous steam generators will not require blowdown (purging) procedures, again reducing losses.
3. combustion in an oxygen environment rather than air (as in a conventional boiler fuelled with hydrogen) will not produce any nitrous oxide (N_2O). Therefore, the UCZ laundry heat provision will be zero greenhouse gas (GHG) emissions rather than simply zero CO_2. Nitrogen is the main constituent of air and is oxidised

whenever a fuel is combusted in air. The resulting N_2O has 298 times the global warming potential (GWP) that CO_2 holds. (Climate Change Connection 2020).

4. The UCZ solution for the intermittency of wind and solar generation is to produce green hydrogen and oxygen from the renewables via electrolysis. The proposed storage of hydrogen and oxygen is viable to cover several days heat load of the laundry, far exceeding the capability of any viable electrical energy storage.

5. Producing green hydrogen can not only decarbonise* industrial heat, but it can also play a vital role in facilitating the continued decarbonisation of Great Britain's electricity. Progress has been made in decarbonising (CO_2e) Great Britain's electrical power system since 2016. However, continued increases to the 'penetration of renewables' makes system control progressively more difficult and expensive. Balancing the system whilst harnessing all the renewable power available is difficult. Flexibility and storage provided by demand turn up (DTU) and battery systems is time limited and often falls short of the objective to never curtail the precious zero carbon generation. Electrolysers can provide DTU readily and, providing that there is a hydrogen offtake, the DTU is not time limited.

*NB decarbonisation relates always to the reduction or elimination of all CO_2e gases.

Comparison to direct electrification

Direct electrification is an ideal solution in principle. The challenge of intermittent renewable energy (RE) means that electrical supply may not be able to meet demand and that grid electricity may need to be purchased at expensive tariffs and without green credentials. Storage is required and flow battery technology could be favourable to lithium ion to store surplus RE on site.

Electrical resistance steam boilers are available at the size and capacity (25kW [35kg/h] – 4000kW [5600 kg/hr]) suitable for industrial laundry demands, but electrical boilers have a fixed response rate and efficiency (Pirobloc Electric Steam Boilers, 2023). The steam generator technology, like batteries, provides a time shift for RE intermittency to deal with mismatch in supply and demand through hydrogen storage.

The round trip efficiency of Battery storage systems varies between 68% for vanadium redox flow batteries and 86% for lithium ion batteries (US Department of Energy 2020). Unlike electrolysis the losses are not immediately recoverable as useful ~50°C heat. The long-term operational expenditure (OPEX) of the hydrogen route with the lifetime of electrolysis, compression, gas storage and steam generators, is most likely to favour hydrogen over battery storage.

2.4 Laundry Heating Technology

The Stream 2A feasibility study examines the use of hydrogen produced steam to feed thermal oil as a primary heating source for industrial laundry operations, as an alternative to the current process using direct steam produced from natural gas. The feasibility study also concludes that hybrid systems may exist which use both steam and thermal oil within industrial laundries.

Conventional steam systems and thermal oil systems can both be replaced with the steam generator solution proposed by the UCZ solution with minimum disruption and cost. The Stream 2A feasibility study examines the relative benefits, duty cycles and costs of implementing the hydrogen fuelled steam generator solution as the primary source of heating.

The hydrogen steam generator's ability to operate in seconds reduces the thermal inertia of a heating system, allowing the heat supply to more closely follow the heat demand than conventional steam heating systems.

The thermal oil system has a greater thermal inertia than any steam system, but the steam generators will be able to supply large amounts of heat instantly, to provide the initial heat needed to raise the thermal oil to the required temperature of 220ºC.

To enable the significant changes required in the industry and force the introduction of a zero-emission hydrogen-based solution it is essential that the hydrogen steam generator solution offers an efficient, cost effective and viable alternative to traditional methods.

2.5 Project Conclusions

In conclusion, the feasibility has proven that everything is in place for the end to end demonstration phase. The equipment on a long lead time, like the electrolyser, compression and storage, have an agreement in place with the suppliers to supply the equipment to carry out the scaled testing during May 2024 – February 2025. The demonstration project will allow further confidence for key stakeholders, from suppliers to customers, especially being able to visit the demonstration site and seeing the system under test, through a series of workshops. Throughout the demonstration great commercial relationships will be built and further work will be carried out to develop a business funding model for future customers in the laundry and other sectors.

3.0 Main Outputs and Findings

3.1 Technical.

The laundry sector is typically a high-volume sector that relies on heavy utilisation of energy, water, chemical and aggressive mechanical action to ensure quality wash processing. Real analysis of true energy duty cycle is not readily available, and indeed is even unknown by the machinery manufacturers. Full duty cycle loading is available but applying this to actual wash processes has never been compiled.

UCZ, Steamology and Girbau have conducted studies throughout this feasibility stage to accrue real time energy data in a range of laundries, both nationally and internationally (see appendix ST1 for real life data). The data recorded has outlined the typical duty cycle of a gas fired boiler and industrial laundry equipment. UCZ have undertaken data monitoring in;

A large industrial laundry with a capacity of up to 800,000 items per week. Primary energy systems are a mix of steam and thermal oil.
Heating Equipment
1x Attsu FT6000 N. Gas Thermal Oil Boiler, 7000kw.
2X Attsu Steam Boilers
(Figure 3)

An industrial laundry with a capacity of up to 500,000 items per week. Primary energy systems are a mix of steam and thermal oil.
Heating Equipment
1x Pirobloc GFT 090, N. Gas Thermal Oil Boiler, 1500 kW.
1x Pirobloc GFT 040, N.Gas Thermal Oil Boiler, 600 kW.
1 Ferroli, Vapoprex HVP Steam Boiler.

An industrial laundry with a capacity of 500,000 items per week. Primary energy system is steam.
Heating Equipment
1x Cochran Equinox, Oil or N.Gas Steam Boiler, 7165kW.
1x Cochran Thermax 4, N. Gas Steam Boiler, 5685kW.

Figure 3: Washer/extractors and a thermal oil piping network. Reviewing the real time data alongside the theoretical energy duty cycles has enabled the peak operating demands of the three model laundries to be calculated.

Integrating the steam generator technology as the primary heating source enables the release of energy upon demand. The resultant output of heat via direct steam and / or thermal oil via a HEX optimises the total energy required and balances to the load demand of the laundry equipment. This pulsed solution ensures that energy is only generated when the laundry operation demands it. Matching renewable energy to the onsite demand is key to delivering a commercially optimal zero emissions facility.

It is important to demonstrate the energy flows and the right mix of renewable energy to supply green hydrogen, these outcomes will be further informed through the demonstration phase. In particular, the graph below in Figure 4, from unpublished work by Planet A, illustrates two intuitive outcomes for verification; the relative cost of green hydrogen can be minimised by accessing economy of scale in procurement and by high renewables and electrolyser utilisation. Note that this graph shows the cost differential to the lowest cost outcome which is given as one. Renewable energy is variable and intermittent. The energy system requires some flexibility, the renewable energy and the electrolyser may not operate at maximum efficiency. Options are to give or take from the grid, to maximise the loading capacity.

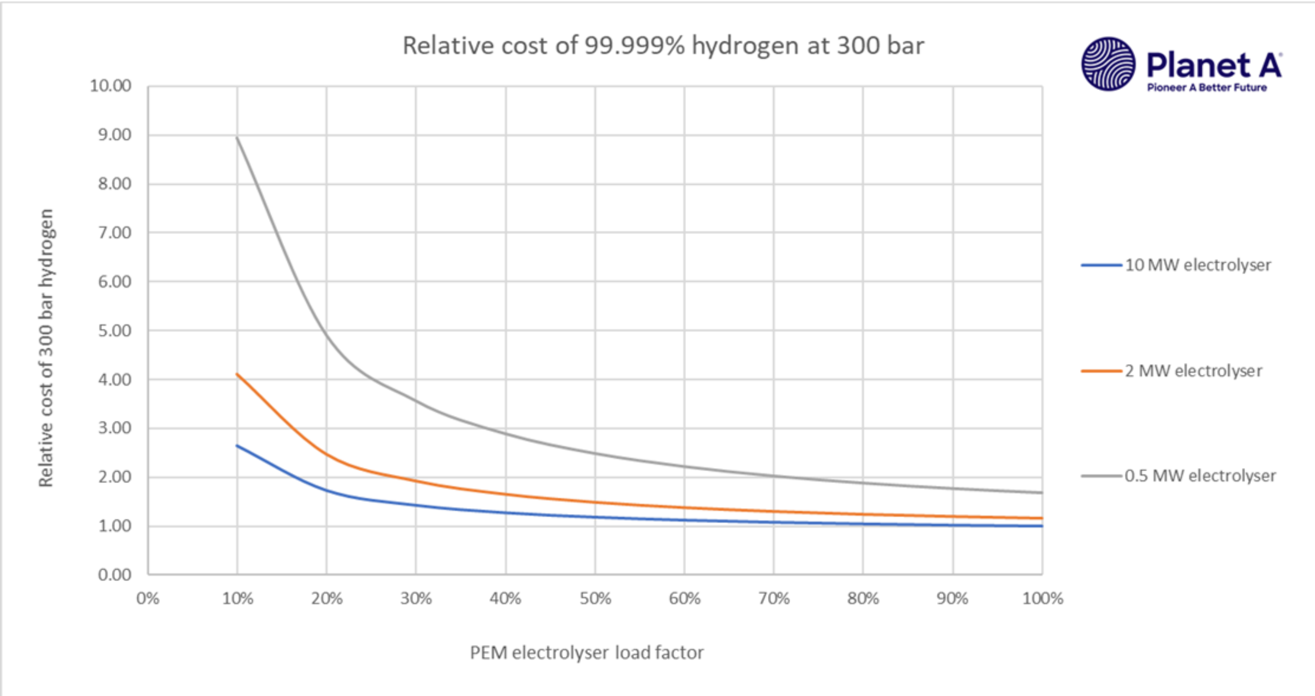


Figure 4: Relative cost of hydrogen

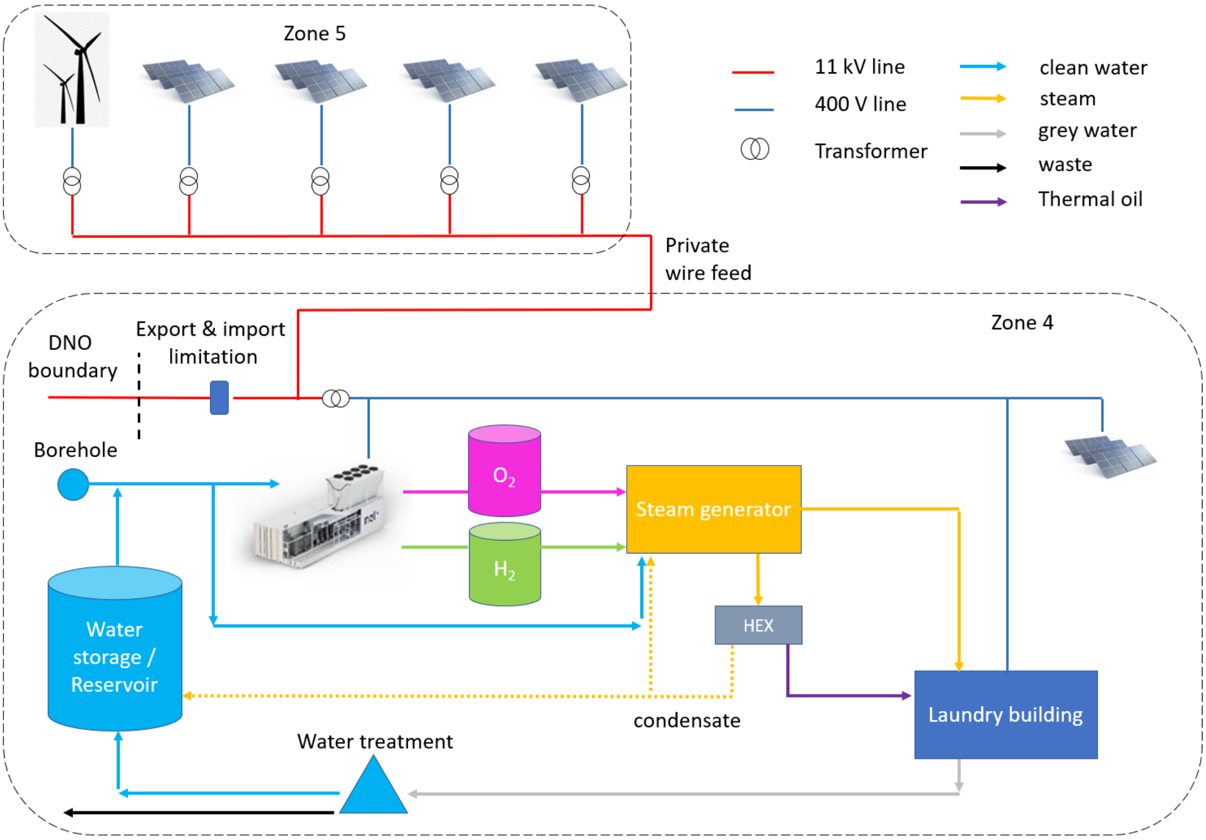


Figure 5: Site schematic across Zone 4 & Zone 5

Figure 5 represents the site layout; Zone 4 is the proposed site for the demonstration and the hydrogen production, and Zone 5 is the area considered for future expansion of renewable energy assets (solar and wind) to supply the site with additional green electricity. The focus of the demonstration project is in Zone 4 including 425 kW PV capacity, connected to the 400 V site electrical system. The PV electricity feeds the electrolyser, which produces hydrogen and oxygen, these are then combusted to produce steam. The HEX feeds the laundry. The water cycle is shown in blue.

An 11 kV grid connection provides supplementary power (where renewable energy utilisation has been used up) and might facilitate power export subject to the outcome of G99 applications. Any export agreement will be subject to time and power-based limitations which will be observed via the export limitation system in line with the grid connection agreement with National Grid Electricity Distribution (NGED).

The power feed from renewables will be monitored in real time and the electrolyser will be energised accordingly. This control strategy prevents the electrolyser from drawing grid power when this is not intended. Prioritising the use of renewables will provide a cost benefit, and a carbon benefit to the project. During the demonstration phase the electrolyser will not be operating at a high load factor. UCZ is currently obtaining planning permission for Zone 5 for wind and solar PV, to enable the electrolyser to run at its optimum load factor.

It is key to the project deliverables to understand the true steam duty cycle of an industrial laundry.

Three laundry layouts have been produced for commercial, light industrial and full industrial applications and have been used to form the basis of the duty cycle analysis. The typical duty cycle has been calculated using the individual machine specifications and working directly with the technical team at Girbau, the machinery manufacturer. The charts display the maximum steam load against the machine processing timed cycles. A breakdown of the full duty cycle for a commercial laundry is included (see appendix ST2).

The steam demands are:

- 4,100 kg of steam over one day with a peak demand of 813 kg/hr for a small commercial laundry
- 21,119 kg of steam over one day with a peak demand of 3,531 kg/hr for a light industrial laundry
- 32,677 kg of steam over one day with a peak demand of 4,959 kg/hr for a full industrial laundry.

This forms the capacity load demand to be used to balance the steam generator capacity output.

The Steamology steam generators are currently at mid technology readiness level and are undergoing a process of continuous design, test and development iteration. Detailed design work has been undertaken and the new Mk.3 Steam Generator design suitable for use in industrial steam pressures and temperatures. The focus of this package of work has been to move the operating pressure down from the typical 40 bar running down to 10 bar and increments in-between.

To achieve the reduction in operating pressure various activities have been undertaken, including bolt tightening torque analysis, water nozzle sizing and gasket compression analysis. These activities have contributed towards adjusting the zero-emission steam production to be in line with standard industrial steam practises. The Steamology steam generators can now be fitted to existing steam and thermal oil heating systems. Extensive collaboration with the industrial steam industry has resulted in a retrofittable design.

Associated support hardware has been redesigned to include local hardware inclusive of gas metering, water control and associated sensors.

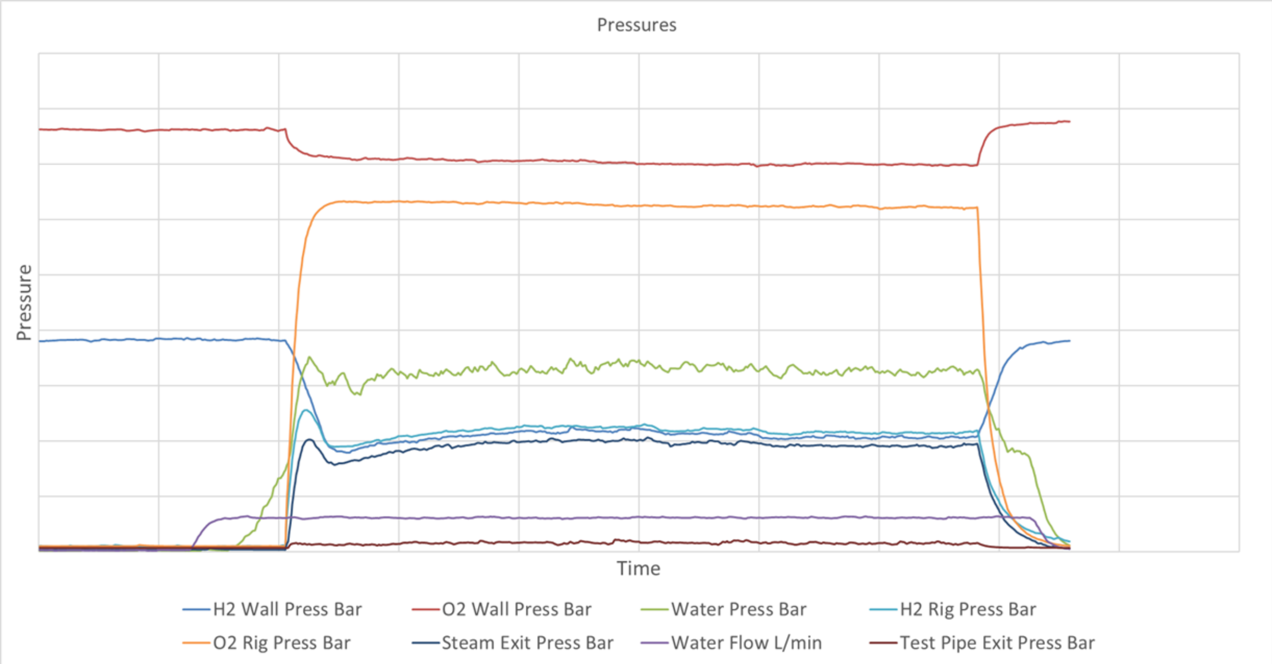


Figure 6: Example of data points gathered during the test and development of the steam generators in the custom data logging test cell

Steam Generator Testing

The steam generator testing program focussed on the characterisation of the steam generator for an output pressure of 10 bar. This acts as a benchmark for future testing at the same and other pressures and flow rates.

The hydrogen-powered steam generators operate at high pressure (40 bar) and high temperature (400°C) producing superheated steam quality when operating in power turbine applications. The team have been developing the steam generators to operate at a range of lower temperatures and pressures more suited to effective heating applications integrated with standard steam components. This work concentrated on lower pressure (10 bar) saturated steam (~185°C) as well as 22 bar and 32 bar pressures suitable for the international standard steam pipework ratings known as PN25 and PN40. The combustion of hydrogen and oxygen takes place at an extremely high temperature (2500°C) and, in order to reduce the temperature to 185°C, the ratio of combustion gases, additional water and system pressure require adjustment and tuning. This work has involved modifications to both the control software and the water, gas and steam hardware.

In developing the steam test cell and heat steam exhaust a modular design configuration has been developed for testing up to 2 x Mk.3 Steam Generators outputting into a dual output steam header. This has provided testing capability for both permutations of the proposed solution for either a steam-to-steam exchanger or steam oil exchanger (see appendix ST3 for system schematic).

Various test equipment to measure the quality and quantity of the steam produced alongside the gas and water temperature, pressure and flow rates has been included to fully quantify the energy transfer, enabling full testing and evaluation of optimal heat delivery system. The scheme is fully detailed for deployment for the demonstration phase.

The CAD design has been prepared for the test cell scheme, which includes 2 Mk.3 Steam Generators. This includes the framework to support the steam generators and all associated pipework hardware, which allows the application of double block and bleed (DBB) principles into the testing.

The project team have been working closely with TLV Euro Engineering UK (TLV) who are steam industry experts. This work includes the specification of pipework, connections, valves, measurement and steam conditioning. Selected layouts have been developed into CAD system models and Bills of Materials have been developed to inform the project costing as well as define the test cell equipment required for continued development and sub assembly test. Validation drawings have been prepared for all outsourced hardware.

The team at Steamology have the in-house capabilities to develop mechanical engineering steam and gas systems, as well as complex electronic hardware and software. It is typical for organisations to outsource the development of control software to contracting specialists incurring significant cost and communication challenges. Steamology has developed its own controller hardware and software with highly skilled internal resources. The controller is in its third iteration and can communicate in an integrated industrial control system. It would be preferable to use an industrial available controller with certifications already in place, this would potentially speed up the certification of the steam generator system.

A survey has been conducted to understand what controllers are commercially available that match the specification of the steam generator. All the commercial units researched are currently more expensive and do not offer the full range of functionality. In the short term the team will continue using the inhouse developed controller and explore the challenges of self-certifying with the specialist supply chain that has been developed.

To review the site heat system, a high-level system schematic including a maximum of two steam generators to provide the peak steam requirement in the commercial duty cycle has been developed. This schematic includes the energy demand modelled and an input calculated to satisfy demand based on collective assumed system efficiencies.
The HEX and steam generator integration CAD layouts have been completed for various scenarios including: steam to thermal oil HEX, steam to steam HEX and direct steam injection.

1. steam to thermal oil HEX.
    a. potential 5x steam generators to provide a total load of 3000kg/hr.
    b. DBB isolation principles used on each steam generator
    c. steam generator output feeds into a steam header
    d. steam traps from steam header
    e. DBB isolation used on output from steam header to oil HEX
    f. all traps and outputs feedback to hotwell

2. steam to steam HEX.
    a. potential 5x steam generators to provide a total load of 3000kg/hr
    b. DBB isolation principles used on each steam generator
    c. steam generator output feeds into a steam header
    d. steam traps from steam header
    e. DBB isolation used on output from steam header to steam-steam HEX
    f. DBB isolation used on output from steam-steam HEX
    g. all traps and outputs feedback to hotwell

3. direct steam injection.
    a. potential 5x steam generators to provide a total load of 3000kg/hr
    b. DBB isolation principles used on each steam generator
    c. steam generator output feeds into a steam header

Hydrogen Production, Compression and Storage
UCZ have researched several electrolyser, storage and compression companies and reviewed their specifications, availability, and lead times.

The demonstration site has been designed to comply with the safety guidance issued by BOC for safe storage of hydrogen and liquid oxygen.

The agreement that UCZ has in place to supply hydrogen and oxygen for the duration of the demonstration phase if required, de-risks the onsite production of hydrogen and oxygen and maintains the steam generator testing programme.

3.2 Regulatory

The multiple regulatory streams which need to be applied for within the Stream 2B demonstration phase have been considered and planned for within the feasibility study. UCZ are using the table (Appendix UCZ2: Regulatory Considerations for the Project) to track required regulatory requirements. The key regulations considered throughout the project has been, connections to the electricity grid, the planning permission for the hydrogen and oxygen production equipment (full consent received February 2023), the disposing of trade effluent collaboration with South West Water and mitigating the risk through by on-site monitoring and reuse. Complying with the Health and Safety Executive to confirm to the Storage of Hydrogen and oxygen (Pure Energy to provide hydrogen consultancy and final design solutions for the demonstration project), hazard identification for the steam generators working with DNV, Atmosphere Explosible ATEX and Pressure Equipment regulations. All of which have been followed and these are part of the scheduled reviews throughout the project. A range of EN, IEC and AD European conformity documents have been utilised as part of the design work. Which will lead to overall compliancy certification for CE and UKCA marking. The safety measures have been planned into the overall demonstration project timeline.

3.3 Performance of the Solution

Steamology steam generators are extremely efficient in converting the full (HHV) chemical energy of the hydrogen into thermal energy. The products of combustion of hydrogen and oxygen are only steam and heat. All of the steam and heat generated enters the workflow as useful thermal energy. This operates in a closed loop, there is no exhaust pipe with waste heat or emissions. This does not happen with competitive combustion boilers. The rapid rate of response and the scalable delivery of steam (turn down ratio) from very low to very high heat loads that have been developed in the feasibility study will be benchmarked against commercial scale boiler systems in a future demonstration project.

Typically, boilers are measured using 100° C water input and that heat is available from the electrolysis plant and the condensate loop. The closest declared technology we have seen is 20.7 kg hydrogen per tonne of steam (Project Hyladdie, 2021). A conservative figure of 19 kg H_2 per tonne of steam has been applied in modelling the performance outcomes. The steam generators have been successfully tested across a range of pressures 10 – 40 bar in the full data logging test cell.

-

Comparisons have been made to existing natural gas systems and to direct electric heating with grid supply, the results shows that the system is comparable to these fuels.

Note that in this case, the grid electricity used to compress oxygen is also included; whilst this is not required by the low carbon hydrogen standard, it is an essential part of the process and is therefore included here. It should also be noted that the use of the low heating value (LHV) by the standard is inappropriate in the case of the Steamology units which do not suffer from any parasitic load in vaporising water, steam being the required output. Conventional boilers fuelled by hydrogen will suffer this parasitic load with steam being discharged in the exhaust stream. Applying the high heating value of hydrogen will reduce the emissions intensity further.

3.4 Expected CAPEX & OPEX Costs for the System

3.4.1 Capital Expenditure (CAPEX)

The capital equipment for the demonstration will consist of hydrogen and oxygen production, compression and storage, site installation, grid connection, leasing the Undercover Laundry for demonstration, and the new laundry test equipment. The equipment has been selected for a number of reasons including lead time for supply, product efficiency, product reliability and how it links as an integral part of the whole solution. The 1MW electrolyser has been selected as it creates not only the hydrogen at pressure (15 bar) but also the oxygen which reduces the need for boost pumps if taking the oxygen from atmosphere. These gases are compressed up to 200 bar, but the compression is a high cost, so a cascade storage facility will be using the 10 modules for hydrogen and 5 modules for oxygen. These can then be used to store the gases at a lower pressure and compressed further if RE is available or cheaper grid electricity can be used (at night) to compress from one tank to another. This way of storing the gases will be more effective by utilising accurate weather forecasting, to maximise the efficiency of the system. The storage solution has been selected to provide not only the cascade system but to provide modular storage that can be scalable for modelling a range of laundries.

The demonstration site has been designed to provide the end to end solution from solar PV to hydrogen/oxygen production. The capital equipment provides 370KG of H2 storage @ 200 bar and 3250 KG of O2 storage @200 bar.

3.4.2 OPEX

The main OPEX cost is the electricity cost and the hire of the existing laundry which includes the staff, existing machinery & equipment (not the test laundry equipment), linen, consumables (chemicals and water) and general energy for lighting.

3.5 Carbon Emissions Savings and Contributions to Net Zero Targets

Retrofitting existing fossil fuel laundries, changing from a thermal oil or steam boiler, will allow the laundry industry to have a rapid deployment of the hydrogen steam generator solution, without the need for costly and carbon hungry manufacturing of new laundry machinery. Girbau is a global manufacturer of laundry equipment and has researched the carbon emissions of the company according to scope 1, 2 and 3 (see appendix UCZ3 for Definitions of scope 1, 2 and 3 emissions). It shows that scope 3 for Girbau accounts for 99% of total greenhouse gas emissions, 97% of that is accounted for using sold products. (see appendix UCZ4 Girbau Gardenia Project – GHG emission reporting). This is predominantly through the energy required to operate the machinery (commonly natural gas). By changing this to the ZEL, this downstream scope 3 CO_2e emissions can be effectively tackled across the supply chain.

The graph below demonstrates the GHG emissions associated with heat provision for the commercial, light and full industrial scale laundries. Three scenarios are shown for each:

- conventional gas heating of thermal oil and water.
- hydrogen electrolysis via grid power + steam production and heat exchange.
- hydrogen electrolysis via onsite renewables + steam production and heat exchange.

Green book values are used for grid electricity and BEIS carbon factor 2022 for the emissions intensity of natural gas.

Emissions are based on the equivalent heat demands given as steam demands in section 3.1. Compression of hydrogen and oxygen are assumed to be via grid electricity in the case of green hydrogen, as shown in Table 4. Gas boilers are assumed to operate at 85% efficiency with respect to the high heating value of the fuel.

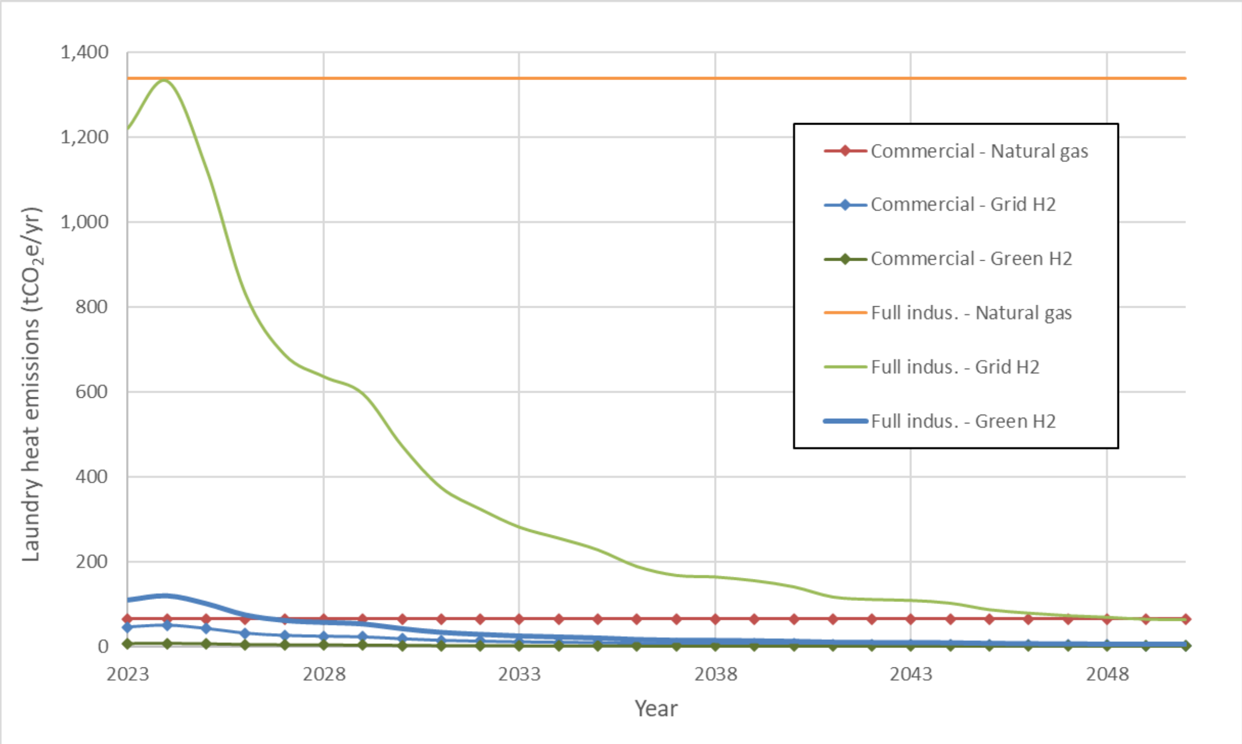


Figure 7. Modelled GHG emissions associated with heat for two laundry scales and for three fuel types – natural gas, hydrogen via grid powered electrolysis and green hydrogen.

The steam generator solution has been designed to have extremely limited environmental impacts and produce clean green steam. This is because the only product of combustion of hydrogen in oxygen is steam. No CO_2, NO_x, SO_x or particulates are created in the production of steam. There is no opportunity for fugitive emissions while the steam is created. To negate fugitive emissions on the gas supply systems, best practise from gas creation, storage and use will be adopted. All the steam created by combustion joins the steam output and can be used in an open or closed loop steam circuit. In a closed loop the condensed steam can be returned for electrolysis. The combustion takes place without impacting air quality.

During electrolysis, there are some low-level fugitive emissions of hydrogen, oxygen and water. This will be monitored and recorded throughout the demonstration project.

3.6 Tests, Results and Conclusions

The three model laundry option site layouts, and integration with the electrical grid connection, renewables, hydrogen production and storage, the test laundry and Steamology ISO containerised solution including thermal HEX and steam connection, have been developed. The three laundry models have been developed to make sure this site, and similar locations, can supply the energy to produce and store the green hydrogen and oxygen. The steam generator technology can be applied to existing or new laundries. The Stream 2B demonstration site will be for a smaller laundry which will be scalable to a full industrial laundry.

The steam generator testing has been carried out at 10 bar to establish whether the operation at the lower pressures is suitable for direct laundry equipment. The testing carried out was successful. The next tests were carried out at a high pressure suitable for the thermal oil systems. 70% of Girbau sales are for thermal oil systems, so being able to replicate and replace conventional fossil fuel thermal oil boilers will enable a fast roll out of the emission free technology, without changing or adapting the laundry machinery.

The new design for the Steamology International Standards Organisation (ISO) containerised system will now include steam generators linked to both a steam-to-thermal oil HEX and a steam-to-steam HEX. This allows greater flexibility for testing and demonstration during Stream 2B, giving a comparison between the steam and thermal oil equipment and their efficiencies, especially in terms of duty cycle linked to thermal inertia. Increased efficiency will also come from the rapid response of the steam generators reducing the thermal inertia of the system.

Using the test cell, further modelling of the thermal oil HEX, including a thermal load, will continue during Stream 2B, to further ascertain the benefits of the use of thermal oil versus direct steam to the machinery.

Greater laundry system efficiencies can be found by integrating the electrolysers rejected waste heat (48ºC) from the thermal cooling system into the laundry hot water heating. This is in addition to the high-quality heat that is available from the steam generators condensing loop, which will be utilised to generate hot water for the laundry washing cycles. All of these increase the efficiencies across the laundry models.

3.7 Benefits

The steam generator solution has significant advantages over traditional fossil fuelled, gas and oil-fired boilers, including rapid response, high turndown rates, continuous operation through service intervals, no NO_x and reduced chemical treatments and disposal. The process has the potential to reduce volatility of future fuel costs and carbon taxes and potential of extensions to Ultra Low Emission Zone (ULEZ) controls.

The UCZ solution delivers a matched demand by pulsing the steam generator as required to maintain steam capacity and ultimately temperature output. As this is essentially hugging the demand curve, the proposed hydrogen driven steam generated system can compete against traditional fuels by simply negating the need to always run. Traditional boilers require an extensive ramp up and cool down periods, whereas in the Steamology steam generator it is almost instantaneous, being up to temperature and pressure within a few seconds.

The steam generators are robustly built with zero moving parts and can be “hot” swapped for servicing. This is a major advantage over traditional boiler systems which require time to produce adequate steam for the laundry machine processing.

The UCZ hydrogen driven steam solution is flexible and can be adopted into the current laundry offering of either direct steam or thermal oil. The intention is that the units will be integrated with minimal disruption, cost, or interference to day-to-day laundry operations. The units have been designed and will be supplied in a containerised solution; therefore, the site utilities and layouts can be adapted with no disruption.

Hydrogen fired boiler technology is gaining traction and the adoption of hydrogen is a viable commercial solution. However, conventional boilers modified to operate on hydrogen do not gain system efficiencies, and only reduce emissions rather than eliminating them completely. In addition, these systems still face challenges relating to water abstraction for hydrogen creation, and water treatment costs for the boiler. It is essential to note that our proposed zero emissions system not only removes carbon emissions, but also emissions of NO_x and SOx, which other hydrogen systems do not address.

Direct electrification has challenges of grid connection, time, cost, availability of supply, and limited tariff options which creates fixed operating hours. Renewables are by nature intermittent, so require an energy storage system and time shift of energy offered by the hydrogen solution. The UCZ solution maximises the use of renewable energy, storing renewable electricity as hydrogen to provide continuity of supply negating the need for a chemical battery.

Through the utilisation of renewables, there will be long periods of running where there will be an excess of energy generated from wind and sun. UCZ will have the flexibility to benefit from this excess energy and utilise it to manufacture hydrogen, through electrolysis that can be stored. This stored hydrogen and oxygen can be used to either create more steam for the laundry, or to deliver energy back to the grid at key peak times.

3.8 Key Lessons Learned

3.8.1 Feasibility Study Phase

The steam generator testing has proven the operational outputs for running on a 10 - 40 bar range. This has been achieved with consistent and stable capacity and consistent data. Working with Girbau, UCZ have established an improved understanding of real-world duty load cycle at system and machine level and this key data ensures that the study will prove a balanced supply to demand. The high rate and rapid response of heating deliverable by the Steamology equipment will save energy compared to direct electrification of heating. The test data gathered shows high fluctuations in thermal demand.

The study has identified that the scalable steam generator solution can be adopted as the primary heating source for any configuration of industrial laundry, as the modular approach for laundries makes it easy to scale up. In addition, the study allowed for increased knowledge of industrial laundry operations to ensure that the technology and processes are aligned to current industrial laundry processes. Data gathered so far underpins capital and operational justification for the procurement and operational benefits and savings of the steam generator solution. Feasibility study research has established that the zero emission technology can be integrated to provide heat for both direct steam and thermal oil solutions.

Through the feasibility study UCZ have gained an improved understanding of the compliance roadmap for the Steamology steam generator as well as the hydrogen generation, storage and utilisation on site. The site has been verified for suitability and usage for hydrogen production, including handling and storage, and for the integration of renewables to the electrolyser facility. UCZ have identified the necessary site safety protocols and compliance which will underpin the required procedures for conformance, and the necessary permits and regulatory requirements have been established. UCZ are engaging with the relevant agencies to ensure that all regulatory requirements are met.

During the study it has become increasingly apparent that the production of pure oxygen, through the manufacture of hydrogen, may pose additional benefits worth exploring during the demonstration phase. This will be in addition to the hydrogen fuel switching project and identifies an additional hydrogen-related benefit to the industry.

3.8.2 Risks, Challenges and Uncertainties

Through increased engagement with the industry and sector users, UCZ have recognised a common factor in decarbonisation of industrial laundries in that reducing energy usage, and sourcing more carbon friendly alternatives, has not until now, been a priority for asset owners and operators. Due to increasing financial and environmental pressures, suppliers of equipment are only now prioritising real-life energy usage beyond the sale of the capital equipment. The primary data has been recorded from real-world laundry shift patterns. So far this has been completed at individual laundry machine level and with individual boiler systems.

Currently, the supply chain of hydrogen production equipment, compression and storage is experiencing rapid growth challenges, with material and technology maturity constraints as it aims for a 10GW UK hydrogen production ambition by 2030, recently increased from 5GW ambition. Hydrogen equipment warranties currently only offer 1-2 years on CAPEX assets with 20-25 year life. It will take time for industry to mature.

The industry is not mature enough for the insurance industry to quantify and evaluate risks. UCZ and Steamology are working with various insurance companies to develop a way of covering liability and protection of assets.

4.0 Stream 2B Project Delivery Plan

4.1 Industrial Fuel Switching

The next phase of work will: -

- demonstrate the significant potential for industrial GHG emissions reduction via the implementation of zero emission hydrogen steam technologies,
- demonstrate this technology within an industrial laundry test site that will deliver the objectives applicable to the UK steam and heating industry, targeting net zero,
- establish the commercial viability of an industrial fuel switching solution that can be adopted within the industrial laundry sector,
- undertake work in Stream 2B that will identify exact need for, and solutions to strengthening supply chains and skills for industrial decarbonisation around the UK
- install 1MW electrolyser, compression and storage for hydrogen and oxygen,
- set up the demonstration site to encompass the hydrogen generation and steam generators,
- develop, commission, and test the steam generator systems to provide real world data analysis against gas fired solutions,
- disseminate to the laundry industry including business/financial planning for future sites,
- evidence, demonstrate and disseminate potential benefits to alternative industrial sectors.

4.2 Engineering Design for a Demonstration

The team has developed the engineering design for the next stage demonstration. This builds on the schematic shown in figure 5 and is easily scalable by adding more units. The electrolyser, hydrogen and oxygen compression and storage, will be installed on site, whilst the Steam generators are installed and testing into the container, so that the commissioning will commence as soon as the tested container arrives.

4.3 Estimated Cost

The estimated project CAPEX for the demonstration is £3M-£4M.

4.4 Continuation of Research and Development of Hydrogen

UCZ and partners have strong ambitions to continue R&D far beyond the demonstration phase, UCZ has already engaged with additional industrial sectors to determine how hydrogen can be integrated into existing manufacturing practices.

4.5 Permissions and Permits

4.5.1 Planning Permissions

Full planning permission is required for Zone 4 (site development) and this has been submitted and has been approved (decision February 2023).

4.5.2 Environmental Permits

UCZ and Planet A will expedite the environmental permitting to include the abstraction licensing for the bore holes, mitigation of trade effluent and water storage within the proposed storage and recycling system. The project team have explored the Industrial Emissions Directive (air, water & land pollution), Environmental Agency (EA) policy, and other required environmental impact and ecology assessments required for the site.

4.5.3 Electricity Connections

The site grid connection is required for power before the RE is integrated. The district network operator (DNO) has agreed a solution to connect the 11KV to the existing network and once the renewables are in place this will reduce the capacity required by 6MW. This will provide capacity relief for the DNO in an already constrained area. The estimated time frame for the connection is 4-6 months but this will not delay the project due to timely project management and execution.

4.6 Safety Plan

UCZ have identified specialist companies who will aid and deliver a full safety plan for the Demonstration. TLV are globally recognised as design and installation specialists for any type of steam systems. Pure Energy have 20 years plus of experience with the design, hardware installation, production and storage of Hydrogen and Oxygen. Pure Energy will be advising and monitoring relevant safety procedures/protocols throughout the demonstration at Tolvaddon. Steamology are working with global certification experts DNV to develop the certification and compliance for steam generator operations.

Key hazards for the project are, safe production, compression, and storage of hydrogen and oxygen, maintaining safe distances as the developed site plans. Maintaining proximity of public, work force from the hydrogen/oxygen equipment. External consultants will provide independent level of guidance.

5.0 Value, Future Plans and Dissemination

5.1 Social Values.

UCZ has created social value through the feasibility study of Stream 2A by employing high-end staff and bringing additional wealth to the region. The site is situated in one of the country’s highest deprivation areas, Camborne, Pool and Redruth. During a demonstration there will be a range of direct high-level jobs created, such as hydrogen specialists, digital technologies, and chemical, mechanical, electrical and electronic engineering.

UCZ and Steamology will upskill their own staff and other companies’ personnel through training in the management, maintenance, and the servicing of the technology.

The solution has the potential to reduce the carbon footprint of the laundry industry, through allowing renewable energy to be used within the sector. It is primarily a natural gas using sector and direct electrification is not suitable, so introducing hydrogen/oxygen combustion enables a transition to RE. This solution also reduces water extraction compared to other hydrogen systems and also has zero particulate pollution or other GHG. The industry currently has no verified GHG emission data. This is going to be part of the demonstration project to conduct a global study of emissions. Unverified figures calculated by UCZ comparing existing laundries estimates that the UK industry is ~4MtCO_2e annually. Traditional fossil fuel boilers and other Hydrogen in air combustion boilers still produce NOx and particulates. The steam generator solution will remove this and therefore improve the air quality.

UCZ have opened discussions with local businesses regarding future options for the use of the steam and heat to improve their direct emissions.
One of UCZ’s priorities is to challenge the next generation, by engaging with local schools and colleges. UCZs long term ambition is to open a research and design (R&D) facility which can educate and inspire by teaching and demonstrating how green technologies work, including green hydrogen systems.

UCZ’s objectives align with the Department for Environment, Food and Rural Affairs’ (DEFRA) announcement in August 2022 for a new framework to use best practice and best available technology to prevent and minimise industrial emissions and their impacts on the environment (Department for Environment & Rural Affairs 2022).

5.2 Benefits

The main benefits for the project are derived from the emissions savings and the increase in the technology readiness level, leading closer to commercialisation of the steam generator technology. Essentially within the next 5 years all laundries could become emission free for their transport and processing. The steam generator solution has the potential to be exported across the world utilising the sales presence and distribution of Girbau. This would create growth for the UK economy.

It is important to be able to demonstrate this technology and throughout this it will enable UCZ to develop further innovative projects to key customers and stakeholders, that will lead to further water saving or carbon reducing technologies.

5.3 Dissemination Plan

UCZ developed a simple dissemination plan for the Stream 2A. Due to the short project length two small dissemination events were to be held to outline the project to key stakeholders, local representatives and other business leaders. The two dissemination events were held at Pool Innovation Centre, Cornwall. At the first event on Friday 13th January 2023, presentations were given by the UCZ team, Steamology, Planet A Solutions, and Girbau. This presentation was delivered to a range of local industrial leaders, Local Enterprise Partnership members and local council members. The second event, on Friday 20th January 2023, presented the same information but to local Members of Parliament, council cabinet members and other interested parties.

The technology will target key areas around the world for dissemination based upon future use and sales. The UK is a key market where lowering emissions and decarbonising the textiles sector is of high importance to this project, along with making a significant contribution towards UK's 2050 net zero ambitions. Other key countries around the world that will be targeted will be linked to countries with good or developing hydrogen infrastructure.

5.4 Application of Hydrogen Fuel Switching Across Industrial Sectors

In order to assess the relevant benefit of the technology within a broader industrial context, UCZ are presently reviewing all additional applications for the hydrogen-based steam generator solution within alternative industrial sectors. Beyond industrial laundries, addressable industries will include food & beverage, pharmaceutical, injection and rotational moulding, chemical, manufacturing and packaging.

The ambition is to further encourage wider industry adoption through the development of a hydrogen-powered zero-emission industrial park, the first in the world. This will deliver the energy, heat, steam and water required to support ancillary sectors. These sector synergies will further reduce the collective carbon reduction and emission for Cornwall and can be scaled nationally and worldwide.

5.5 Development and Commercialisation

The technology is designed to be retro fitted to all current industrial laundry equipment, both direct steam and thermal oil. This makes it extremely commercial and accessible with the potential to deliver a significant reduction in UK and global carbon emissions whilst being cost effective. With the planned configuration and installation methodology, this can also be achieved with minimal cost and disruption to the current laundry operations set up.

The generator technology is patented and readily manufactured with traditional machines skills and materials. The business model incudes joint ventures and licensing opportunities with suitable global industrial steam partners many of whom, like TLV, have existing robust inhouse and subcontract supply chains, with the skills, capability and capacity to manufacture steam generators. Existing business models are in place allow the steam generator systems to be certified, manufactured, and installed in a short time period.

Reference List

Climate Change Connection (2020) *CO2 equivalents* [Online] Available from: https://climatechangeconnection.org/emissions/co2-equivalents/ [Accessed 9th December 2022].

Department For Environment & Rural Affairs (2022) *New Framework to Tackle Industrial Emissions Across the U.K* [Online] Available from: New framework announced to tackle industrial emissions across the UK - GOV.UK (www.gov.uk) [Accessed on 1st January 2023].

Hatch and Regeneris (2020) *The Economic Value of the Textile Services Sector to the UK Economy* [Online] Available from: Hatch Regeneris Report 2020.indd (tsa-uk.org) [Accessed on 6th November 2020].

Paffel,K., (2022) *Steam System Thermal Cycle Efficiency.* [Online] Available from: https://www.plantengineering.com/articles/502971/ [Accessed 4-11-2022].

Pirobloc Electric Steam Boilers, 2023-Pirobloc-Electric-Steam-Boilers.pdf

Project Hyladdie (2021) *B.E.I.S Green Distilleries Competition Phase 1 Report.* [Online] Available from:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/978975/HyLaddie_Phase_1_Feasibility_Report.pdf [Accessed on 3rd January 2023].

List of Appendices

Undercover Zero – Appendices Index

UCZ1	Laundry Capacity and Equipment
UCZ2	Regulatory Considerations for the Project
UCZ3	Definitions of scope 1, 2 and 3 emissions
UCZ4	Girbau Gardenia Project - GHG emission reporting
UCZ5	BOC Safety distances for bulk gaseous hydrogen
UCZ16	Safety Distance for liquid oxygen storage

Steamology – Appendices Index

ST1	Recorded Data Thermal Oil Boiler
ST2	Steam System Duty Cycle – Analysis Data from Laundry Systems Commercial Duty Cycle Graph
ST3	Design Package for Test Cell

Appendix UCZ1

Laundry Capacity and Equipment

	Capacity	Laundry Equipment		
Laundry Size	Weight of items per week (KG)	Washers/ Extractors	Dryers	Ironers
Small Commercial	86,000	1 - HS6032 2 - HS6057 1 - HS110	1 - ST1302	1 - PC80 2 roll
Light Industrial	352,000	1 – HS6032 2 - HS6057 1 - HS110 1 -Tunnel Washer 1 - Press	6 - ST1302	1 - PC80 2 roll 1 - PC120 3 roll
Full Industrial	463,000	1 - HS6017 2 - HS6024 2 - HS6057 2 - Tunnel Washer 2 - Press	2 - ED660 14 - ST1302	1 - PB5132 2 - PC80 2 roll 2 - PC120 3 roll

Laundry equipment and processing capacity model, operating 24 hours per day, 7 days a week, used for data modelling.

Data Sheets for the laundry equipment: -

- HS6110 wash extractor - HS Series HS6110 (girbau.com)
- HS6057 washer extractor – HS Series HS6057 (girbau.com)
- HS6032 washer extractor – HS Series HS6032 (girbau.com)
- HS6024 washer extractor – HS Series HS6024 (girbau.com)
- HS6017 washer extractor - HS Series HS6017 (girbau.com)
- Tunnel Washer - Batch Washer TBS-Multi (girbau.com)
- Tunnel Washer Press - Water extraction press SPR-50 (girbau.com)
- ST1302 Dryer - Dryer ST Series ST302 (girbau.com)
- ED660 Dryer - ED Series ED660 (girbau.com)
- PC80 Ironer - Flatwork Ironer PC Series PC80 (girbau.com)
- PC120 Ironer – Flatwork Ironer PC Series PC120 (girbau.com)
- PB5132 Ironer - PB Series PB5132 (girbau.com)

Appendix UCZ2

Regulatory Considerations for the Project

Area of Regulation	Reference	Description	Authority	Link
Electrical connection – renewable energy	G99	Requirements for the connection of generation equipment in parallel with public distribution networks	Energy Networks Association	G99
Electrical connection – limiting export of renewable energy	G100	Technical Requirements for Customer Export Limiting Schemes	Energy Networks Association	G100
Electrical connection – grid supply (site import)	Grid connection agreement	High voltage (HV) supply to the site in conversation with district network operator (DNO)	National Grid Energy Distribution	New Connections
Water Abstraction	Abstraction License	Required for borehole water abstraction	Environment Agency	Abstraction License
Disposing of wastewater and Trade Effluent Charges	Wastewater and Trade Effluent	Three phases of successive water treatment are considered. The use of settling tanks, storage reservoirs, and UV filtration is incorporated into the business model.	Ofwat	waste water and effluent
Planning Permission	Planning Permission	An application for planning permission has been submitted for Zone 4 where Undercover Zero is currently waiting for a decision, with an application in parallel being drawn up for Zone 5.	Cornwall Council	Planning
Hydrogen and Oxygen Storage	Health and Safety	Detailed site storage plans complying with Health & Safety regulations have been completed which can inform other industry on best safety practice. Compliance under the Hazardous Storage Regulations & the Dangerous Substances and Explosives Atmosphere Regulations 2002.	Health & Safety Executive	Control of Substances Hazardous to Health (COSHH) Dangerous Substances & Explosive Atmospheres Regulations 2002
Hazard Identification (HAZID)	Health and Safety	Steamology has completed a preliminary HAZID workshop with Det Norske Veritas (DNV) to assign risk rankings to identified equipment and risks. This forms the foundation of future HAZID workshops that would be conducted as part of stream 2B. This is managed under the Management of Health and Safety at Work Regulations	Health & Safety Executive	Legal duties – Managing health and safety at work - HSE
Atmospheres Explosible ATEX)	Health and Safety	Steamology has an increasing knowledge of ATEX requirements, driven by reports prepared by DNV	Health & Safety Executive	ATEX and explosive atmospheres

		which identifies the intricacies of ATEX approval with the system in the context of an industrial steam application		
Pressure Equipment (Safety) Regulation	Health and Safety	Steamology's Steam Generator falls within scope of certification with the Pressure Equipment (Safety) Regulation (PER). The Mk. 3 Steam Generator is designed for future compliance with the Pressure Equipment (Safety) Regulation (PER), which is the most relevant mechanical certification.	Health & Safety Executive	Pressure Equipment (Safety) Regulations 2016
Industry Standard Integration & key design standards	Industry Standards & Compliance Certification	Workshop run between Steamology and TLV at the beginning of the project identified the industry standard integration of the Steam Generator with downstream steam components. An initial Piping and Instrumentation Diagram (PID) has been developed with TLV (steam system experts). **EN ISO 12100** – Safety of machinery – general principles for design – risk assessment and risk reduction **IEC 61508** – Functional safety of electrical/electronic/ programmable electronic safety related systems **IEC 62061** – Safety of machinery – functional safety of safety-related control systems **IEC 61511** – Functional safety – Safety instrumented systems for the process industry sector **IEC 60079-1** – Standards concerning explosive atmospheres **ISO/TR 15916** – Basic considerations for the safety of hydrogen systems **AD2000** – Guidelines for meeting essential safety requirement of the Pressure Equipment Directive	European conformity (CE) Mark & UKCA	CE Mark UKCA marking
Steam Generator Compliance and Certification Planning	Compliance and certification planning.	Steamology has engaged with Lloyds Register Quality Assurance (LRQA) to further develop compliance and certification planning. Addressing the following directives: - -Pressure Equipment Directive -Council Low Voltage Directive -Industrial Machine Directive -Electro-Magnetic Compatibility -ATEX Directive	CE Mark & UKCA	CE Mark UKCA marking

Appendix UCZ3

Definitions of scope 1, 2 and 3 emissions for Girbau

Scope 1, 2 and 3 Emissions Statement

The Greenhouse Gas Protocol supplies the world's most widely used greenhouse gas accounting standards, and is the only globally recognised standard for emissions calculations.

Whilst scopes 1 & 2 remain largely within a company's **direct** emissions produced on site or **indirect** bought in (such as grid electricity use), Scope 3 accounts for **indirect** value chain emissions, looking upstream and downstream from the source.

The study undertaken by Girbau of their own Scope 1, 2 & 3 emissions is representative of the laundry industry and provides great insight into the scale of the challenge in decarbonising the supply chain. Scope 3 emissions for the laundry industry can be reduced through effective provision of products which may run on zero carbon fuels, the impact of which is reflected in the Scope 1 & 2 emissions across the value chain, and downstream of the value chain from source. The company at source measuring scope 3, may then record the decarbonisation effect within the Scope 3 accounting for *Use of Sold Products* (see figure 11).

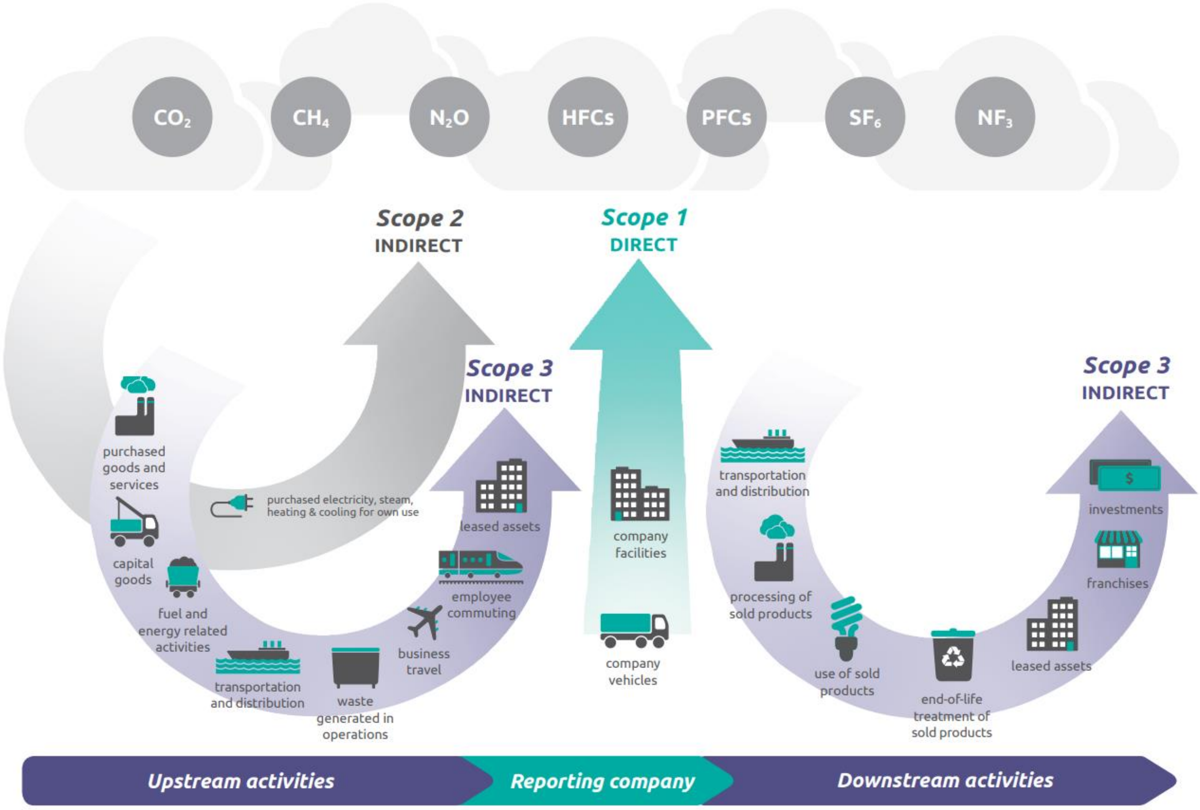
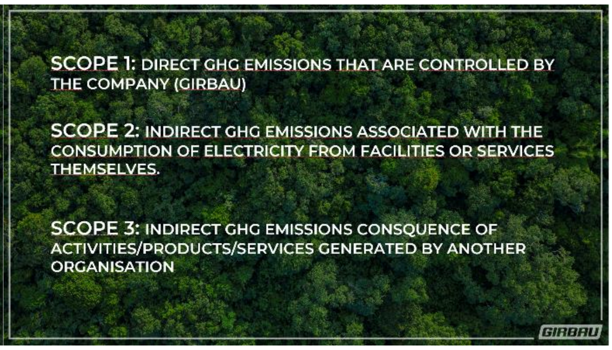
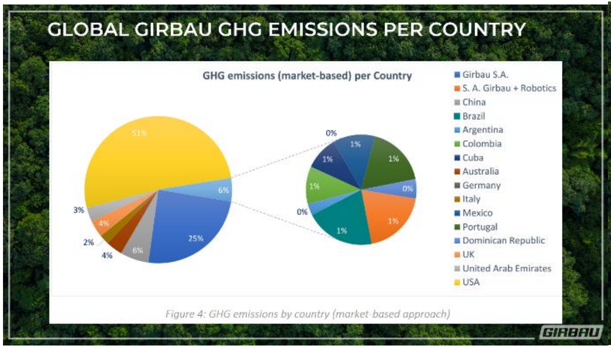


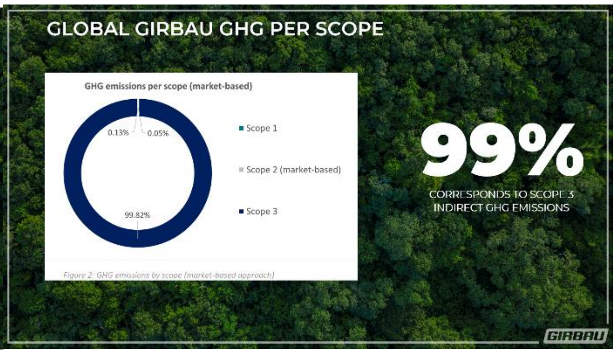
Figure 11; source: description of Scope 1, 2 & 3 emissions
https://ghgprotocol.org/sites/default/files/standards_supporting/Intro_GHGP_Tech.pdf

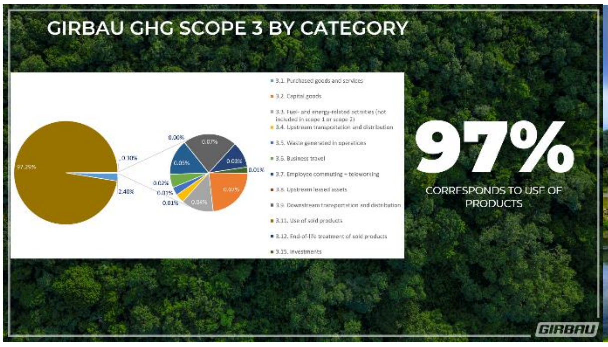
Appendix UCZ4

Girbau Gardenia Project - GHG emission reporting





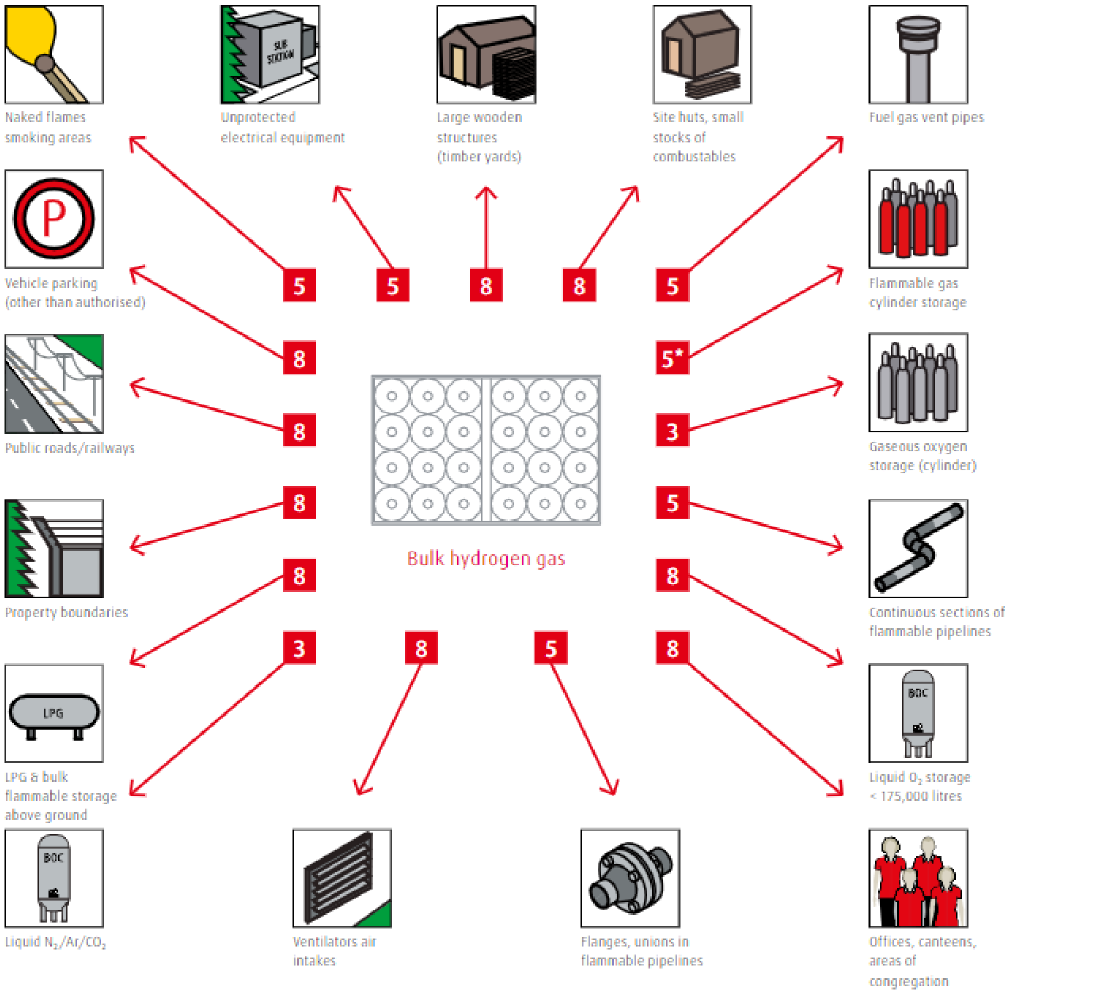




Appendix UCZ5

BOC Safety distances for bulk gaseous hydrogen

Safety distances for bulk gaseous hydrogen.



Minimum recommended horizontal distances for hydrogen bulk gas systems (distance in metres).

Notes

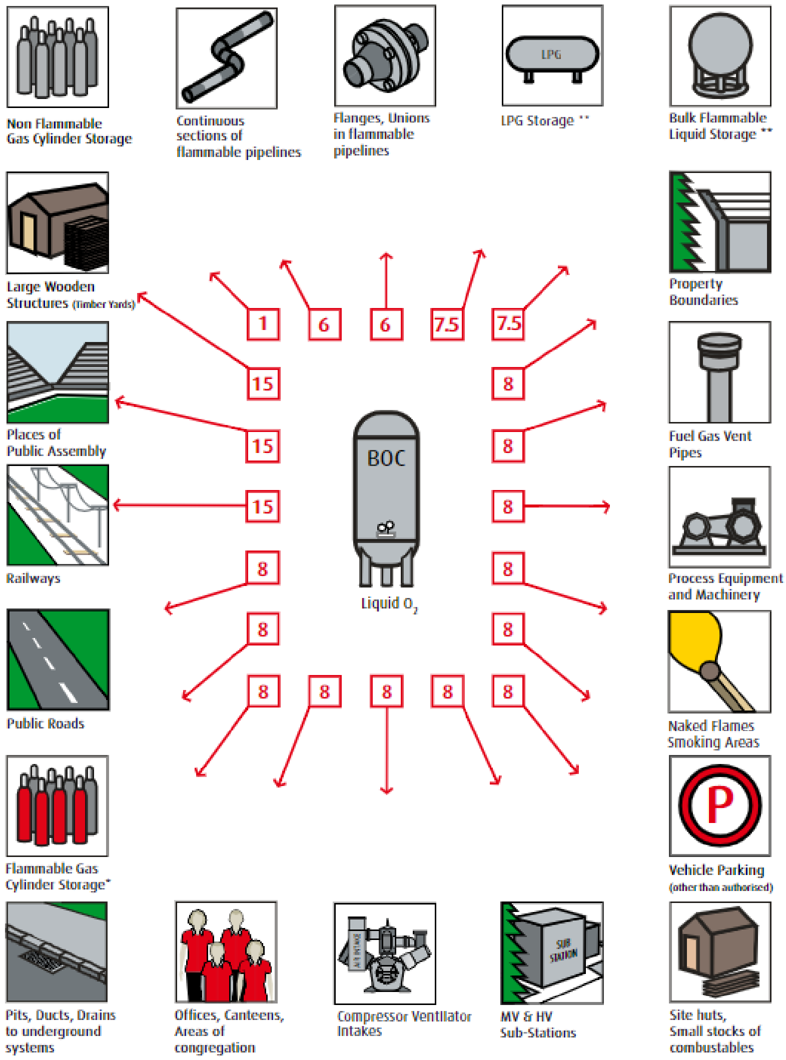
1. Safety distances are defined as the distance from the exposure to any point on the storage system.
2. Installations shall be located outside in the open air. The installations shall not be installed in pits.
3. The installation shall not be installed beneath electrical lines, electrical equipment or wall openings.
4. The distances specified may be reduced by the provision of a suitable non-combustible 2-hr fire resistant wall(s). Fire walls etc should be placed at least 3 metres from the trailer hose coupling and buffer storage manifolds, if the walls are placed closer than this any resulting hydrogen flame would be reflected back on to the trailer or buffer storage.
5. Safety distances are from BCGA CP33. Nitrogen, Argon, Helium and Oxygen distances are from BCGA CP36. Cylinders distances are from BCGA CP4.

*For up to 60 acetylene cylinders this distance is 5 metres. For larger numbers of cylinders, seek advice from BOC.

Appendix UCZ6

Safety Distance for liquid oxygen storage

Safety distances for liquid oxygen storage, 20,000 to 125,000 litres net liquid capacity.



Safety distances for liquid oxygen storage, 20,000 to 125,000 litres net liquid capacity (distances in metres).

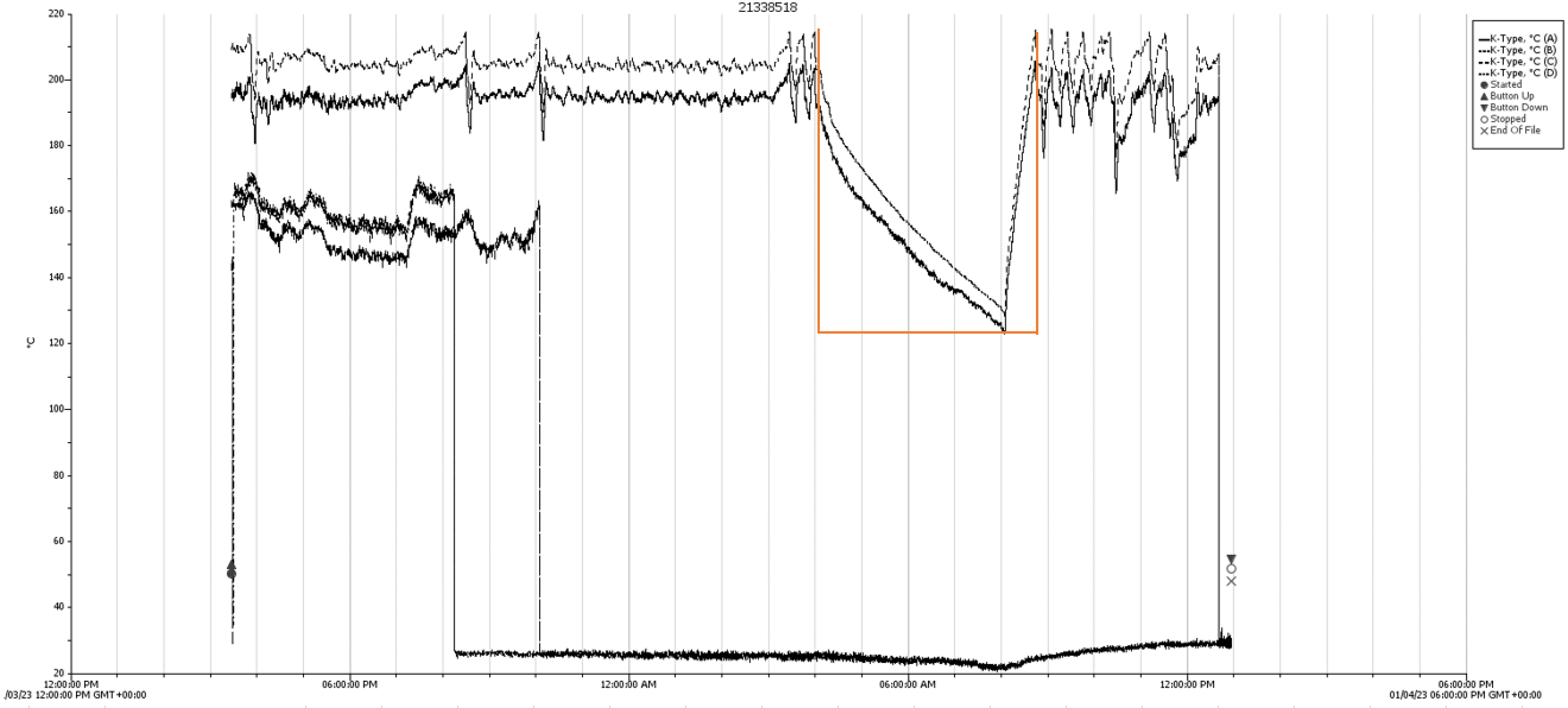
Notes

1. Safety distances are defined as the distance from the exposure to:
   A: Any point on the storage system where in normal operation leakage or discharge can occur, (e.g. fill coupling, pressure relief devices),
   or B: The vessel outer jacket,
   or C: The vessel nozzles.
2. Assumed maximum liquid phase pipework diameter DN15 (½" nominal bore) and flammable gas/liquid up to DN25 (1" nominal bore).
3. For buildings, the distances are measured to the nearest opening in the building – doors, windows.
4. Ventilator air intakes should be at least 1 metres above ground level if within 10 metres of the installation
5. Safety distances are from BCGA CP36.

*Safety distances for acetylene. Refer to BCGA CP6 and ID068 Safety distances for dissolved acetylene.
**For LPG or flammable liquid storage above 4 tonnes, a risk assessment shall be carried out to establish the safe separation distances.

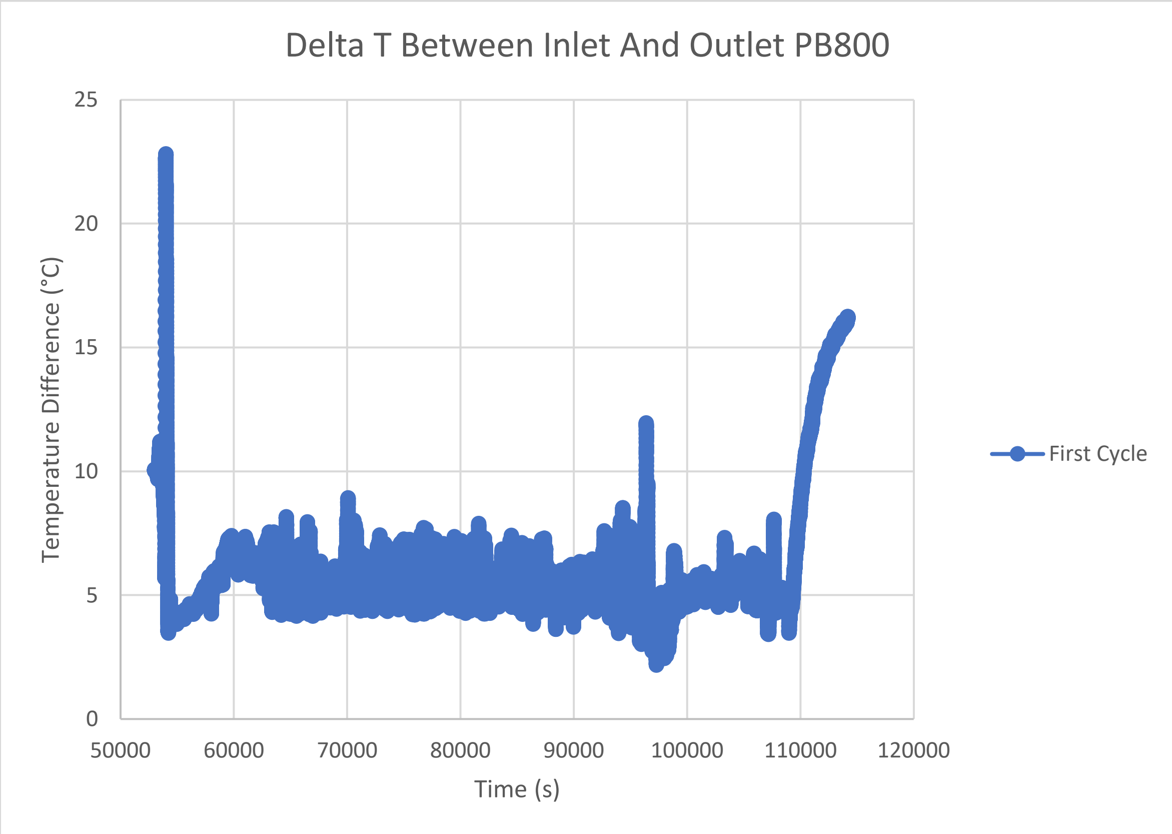
Appendix ST1

Recorded Data Thermal Oil Boiler from Major Laundry



This plot shows the temperature of the outlet manifold from the thermal oil boiler in a laundry.
The orange box shows the temperature drop when the boiler is switched off.
With an assumed capacity of 12000L of oil in the thermal oil circuit, this works out to be roughly 920 kWh of energy lost every day.
This energy could be saved by using equipment with a faster rate of energy transfer, thus reducing the need for large thermal oil capacity.

Assumed Capacity	12000	L
Specific Heat Capacity	0.66	kCal/kg.K
	4.184	kCal to kJ
	2.76144	kJ/kg.K
Delta T End of Day	100	
Energy Lost at End Of Day	3313728	kJ
	920.48	kWh

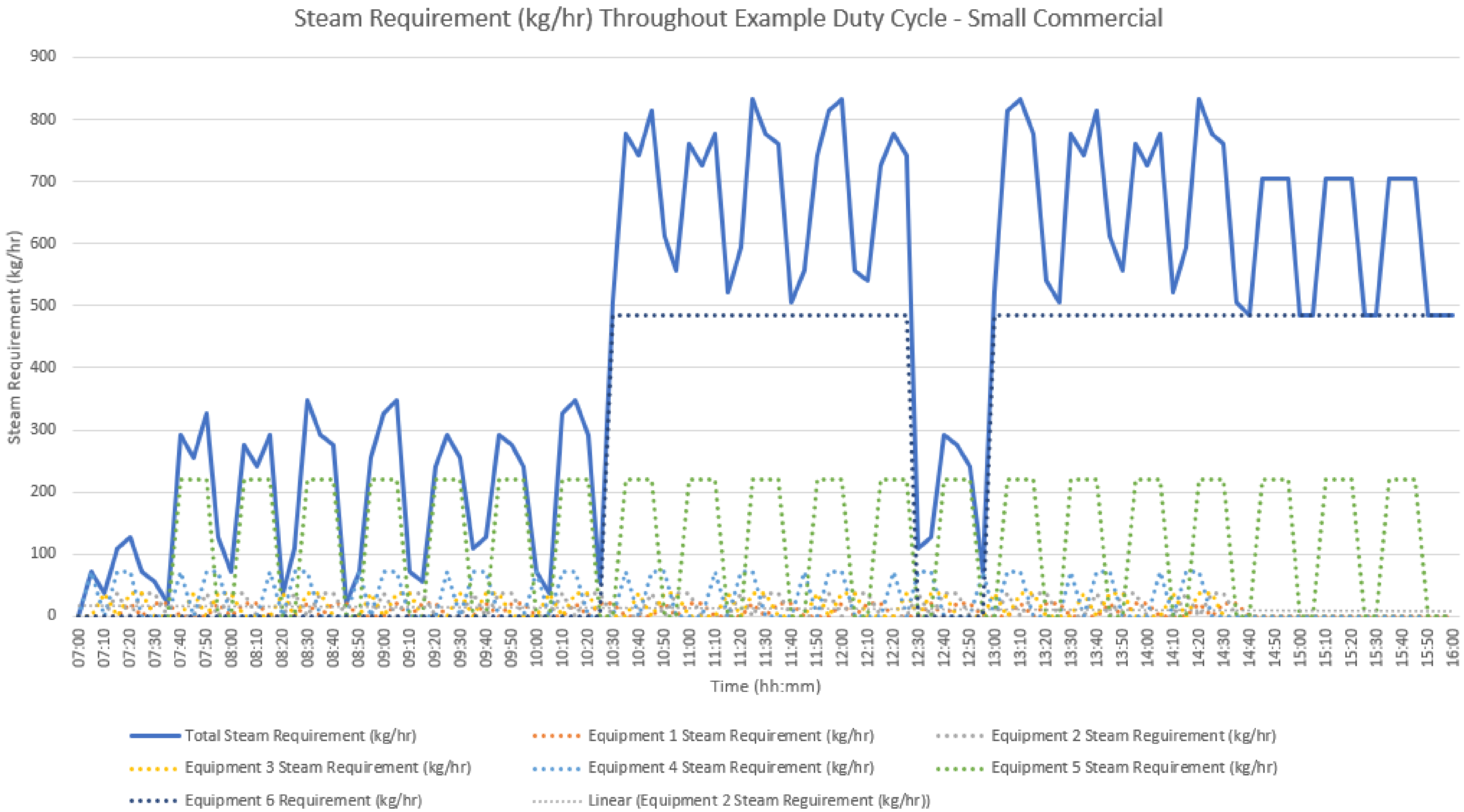


This plot shows the temperature difference between the inlet and outlet of the machine across a full day of operation.

The flow rate of oil through this machine is constant, so whilst absolute energy cannot be calculated without flow data, the relative difference in temperature can be considered directly proportional to the duty cycle for this machine.

Appendix ST2

Steam System Duty Cycle – Analysis Data from Laundry Systems: Commercial Duty Cycle



Appendix ST3

Design Package for Test Cell