Vytok Ltd

Super-Green, High Temperature Heat Pump For Distillery Electrification

Green Distilleries Competition

REF: GD158

Department for Business, Energy and Industrial Strategy

TRN 2564/08/2020

PUBLIC REPORT

Table of contents

List of figures

Glossary

Heat pump	A device for recovering waste heat, raising its temperature and delivering it to perform a useful task.
HTHP	High Temperature Heat Pump - a heat pump that elevates waste heat to a higher temperature than conventional heat pump technology.
VHTHP	Very High Temperature Heat Pump - HTHP that delivers heat above 100° C. Although this category applies to our system, for simplicity HTHP-only is referred to in this document.
GWP	Global Warming Potential.
Refrigerant	The working fluid that carries heat around the heat pump. A “heat pump” and “refrigerator” are interchangeable terms.
Turbocompressor	A type of gas compressor, similar to a car turbocharger, that uses a very high speed “fan” (impeller) to increase the gas pressure.
COP	Coefficient of Performance – a measure of “efficiency” in heat pumps that measures how much heat energy is delivered to a process compared to how much energy is used to power or pump the overall system. Heat pumps are notably efficient in delivering several times the heat for the energy put in.
Still pot	The large vessel in a gin still where water and alcohol are heated to create the flavours and boil off the mixture for downstream collection.
Condenser	Cool water is passed through a pipe to condense the gin vapour back into a liquid. In the process the cool water is warmed up and is a source of “waste” heat that can be recovered.
Condensation temperature	A property of a heat pump that relates to the temperature it can provide heat at. It comes from the fact that a gas inside the heat pump is condensing into a liquid and giving out heat in the process.
Piston	A common type of general compressor that compresses gas using pistons that slide up and down inside cylinders.
Scroll	A type of compressor with a pair of interlocking spiral vanes. When they rotate within each other, gas is squeezed between the changing spiral voids and gets compressed.
Screw	A type of compressor that compresses gas by squeezing it between two interlocking and rotating screw-shaped shafts.
Heat exchanger	A device that usually brings two gases or liquids close to each other (without touching) so they can exchange heat. One cools down, while the other heats up.
Thermodynamic	Related to the science of studying heat flow and its interaction with machines and the surroundings.
Magnetic bearings	A type of bearing for supporting a rotating shaft that levitates it on a magnetic field so there is no friction and no need for oil.
Parametric (analysis)	Running engineering simulations and changing numbers (parameters) to see the effects. Often used to get the very best result within limits.

1 Executive summary

Vytok is developing a first-of-a-kind, super-green, high-temperature heat pump (HTHP) to allow distilleries to switch from fossil fuels to electricity and decarbonise the distilling process. We are working with a London-based gin and whiskey distillery to develop and test a pilot system. We estimate a potential to save around 90 tonnes of CO_2 per year in this distillery alone. It will recover heat from waste condensate water - normally discarded down the drain - and return it as superheated steam to the still pots.

Heat pumps are established technology for space and water heating at temperatures up to 60° C. To provide high temperature process steam at 150° C or above, there is only a handful of research groups able to do this but not at commercial scale.

At heat delivery temperatures above 100° C, water (also known as R718) is actually one of the best working fluids (“refrigerants”) for HTHP because of its thermodynamic properties. It is not used commercially because compressing steam in a heat pump cycle is very difficult. Steam has a low density and requires extra work to compress it as part of the heat pump cycle, compared to other commercially developed refrigerants.

Steam is best used in a HTHP with high speed turbocompressors, a specialised technology not available to most heat pump manufacturers or researchers, who mostly use established piston, scroll and screw compressors. Our expertise in very high speed turbocompressors and oil-less magnetic bearings, as well as our partnerships with industry-leading academic and commercial groups (University of Bath, Newcastle University, PCA Engineers) makes us ideally placed to bring oil-less R718 turbocompressors to the market and enable environmentally sound, efficient heat recovery possible for creating high temperature process steam from waste heat.

Beyond distilling, our HTHP is suitable for any industrial process heating application requiring high temperature steam. Europe-wide, the opportunity for CO_2 savings for HTHP is estimated at 146 Mt/yr CO_2 [19] - 300 times that for the UK distilling industry.

The potential for CO_2 savings from electrification of distilleries is large and HTHP is the most efficient way to do it once the technology is perfected. We believe that as an energy carrier economy, electricity is a long way ahead of hydrogen or biofuels, for example, and is the best solution if distillery and other process heating decarbonisation is to be accomplished quickly.

The feasibility study showed that our HTHP is technically viable and can be manufactured in modest volumes for the target cost of €250/kW, about half that of industrial heat pumps today.

2 Overview of the project

Vytok’s founders came from a background in high-speed turbomachinery, including heat pumps. Heat pumps are not new technology but the delivery, or “condensation,” of very high temperature heat above 100° C - suitable for process heating - is still an active area of research. Water as a working fluid, more conventionally referred to as the “refrigerant” in a HTHP has clear thermodynamic and environmental advantages, reported widely in the research literature [15]. An example efficiency (coefficient of performance or “COP”) comparison between water (R718) and other conventional refrigerants is shown in Figure 1 for an illustrative HTHP simulation model with a temperature lift (the difference between the temperatures of the waste heat and delivered heat) of 70° C [16].

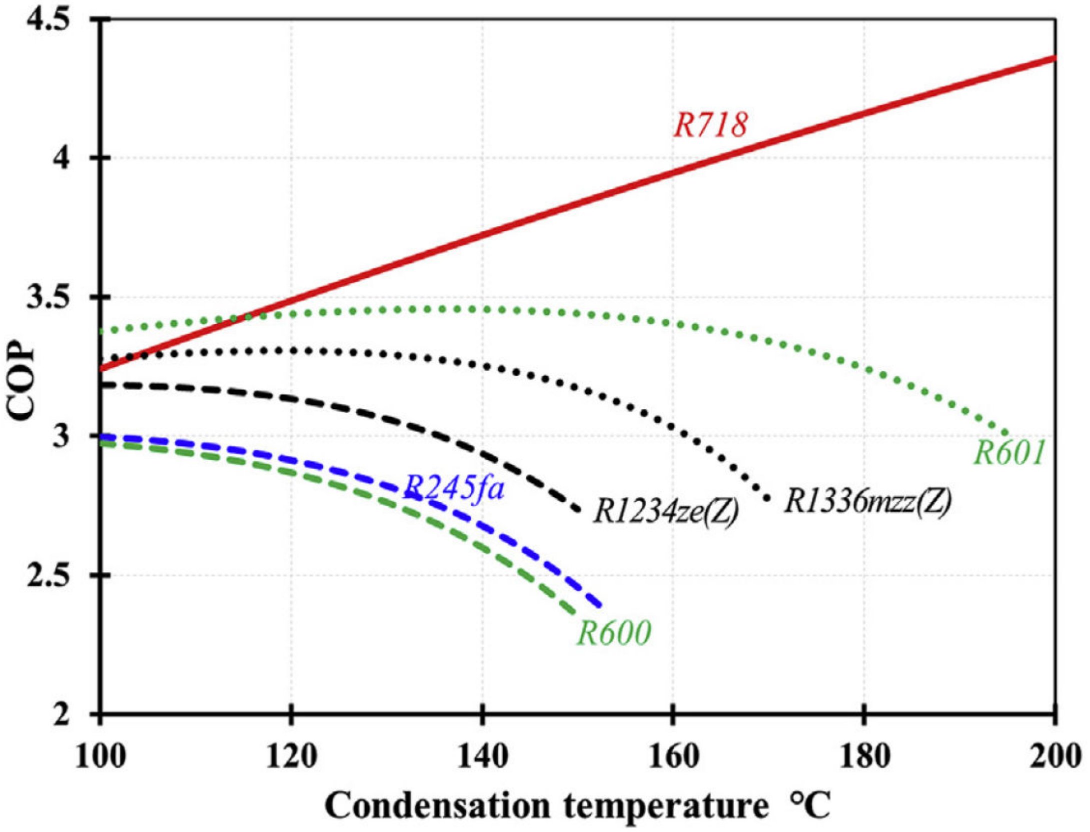

Figure 1: Efficiency of water compared to other commercial refrigerants

The heart of any heat pump system is the refrigerant compressor. Steam requires more energy to compress than many other commercial refrigerants because of its low molecular weight and low density. Companies and researchers looking to capitalise on the advantages of water as a HTHP refrigerant usually use existing piston, scroll or screw compressors because of their availability & maturity but they are not the best technology, having too low a flow rate, being large and expensive and requiring oil lubricants that contaminate the refrigerant.

The ideal compressor technology for using water would have the following characteristics:

- Oil-free to avoid refrigerant/heat exchanger contamination and lubricant management problems, including pooling;
- Uses a turbocompressor to achieve a high volumetric flow of steam at the desired pressure ratio and at a high efficiency;
- High speed operation to make a large reduction in compressor size;
- Competitive cost and long life.

Our objective is to match the compressor technology to the refrigerant and balance of plant to enable the best HTHP system possible. Performance and sustainability must be as high as possible to reduce existing barriers to industrial heat pump implementation.

2.1 Alternatives

Operating within our company's expertise in high speed turbomachinery, we considered other options.

Mechanical Vapour Recompression (MVR)

MVR involves taking waste process steam and compressing it directly to raise its temperature before reintroducing it back into the still heating jackets. We have prior experience with MVR. MVR (also known as an "open-cycle") can be efficient but requires a good quality steam flow and must be matched specifically to the process. A closed cycle HTHP is more applicable to a wider array of industrial heating applications, which is important for commercial scalability.

Organic Rankine Cycle (ORC)

In Rankine and Organic Rankine cycles (the latter used generally for lower temperatures), waste heat can be used to generate electricity directly, which has an economic value. We believe ORC is a worthwhile technology to investigate but having no experience, the commercial development time would be many years longer.

ORC may well become a complementary technology for Vytok in the future, since it is crudely a heat pump running in reverse and much of the technology in turbomachinery, bearings, drives and control would be shared. HTHP and ORC are also complementary depending upon the "spark gap," or differential in the price of electricity and gas. HTHP is intended to displace gas boilers and makes more economic sense when electricity is cheap and gas is expensive (which is not currently the case in the UK). ORC has a greater payback when the value of electricity is high relative to the heating fuel.

3 Experimental/modelling results and conclusions

3.1 CO_2 savings

CO_2 savings are derived from the emissions that result from driving the HTHP compressor (by an electric motor) versus those that are released when natural gas is burned in the boiler. The grid electricity used to drive the HTHP has an emissions factor associated with it depending upon how renewable the average generation capacity is at any point in time. The CO_2 emissions factors are taken from the BEIS Government Conversion Factors for Company Reporting of Greenhouse Gas Emissions (2020) and shown in the following table.

Natural gas emissions factor	kg/kWh	0.184
Grid electricity emissions factor	kg/kWh	0.233

Assuming that the HTHP is providing steam to the stills, which operate for 48 hours per batch and for 2 batches per week, for 50 weeks per year, the heat pump would operate for a total of 4800 hours per year. The resulting savings are shown in the following table.

Savings associated with reduced gas use	kg/year	112,185
Emissions associated with increased electricity use	kg/year	22,390
Net savings for our collaborating distillery	**kg/year**	**89,795**

3.2 Bearings and rotordynamics

Our turbocompressor operates at very high speed (160,000 RPM) and there are not many companies able to do this effectively. We have been working with the University of Bath’s Centre for Power Transmission and Motion Control to simulate and optimise the high-speed behaviour (“rotordynamics”) of the turbocompressor and the oil-free bearings that will support it. We have arranged for an innovative, hybrid magnetic bearing system, which is predicted to give stable and reliable operation.

3.3 Cost

Working with manufacturing group, Productiv Ltd in Coventry, we have analysed the complex turbocompressor for production cost and feasibility. Productiv’s engineers have extensive automotive and manufacturing experience, enabling us to get a reliable estimate on supply, assembly and tooling costs for scale-up. Their work has confirmed we are able to achieve our target HTHP price to customers of about €250/kW.

3.4 Heat pump performance

A series of thermodynamic models and parametric optimisations were simulated for our HTHP circuit by Newcastle University. The objective is to determine the required performance specification for the compressor and to predict the COP (coefficient of performance, or “efficiency”) of the HTHP because this controls the economic payback. A higher COP means less energy goes into driving the HTHP compared to the heat energy delivered to the still pots. A summary of the key HTHP performance is shown in the following table.

Evaporator Duty	kW	95
Total Compressor Work	kW	20
Condenser Duty	kW	114
Condenser Steam Mass Flow	kg/hour	188
Steam Delivery Pressure	Bar (atmosphere)	2.7
COP	(effective “efficiency”)	5.7

3.5 Compressor analysis

PCA Engineers, based in Lincoln, are internationally-renowned consultant designers of turbocompressors. We are working with them to design the compressor impellers, diffusers and volutes that are central to be able to achieve the demanding performance specifications for a water-refrigerant HTHP. Their analysis gives the following compressor characteristics.

Compressor type	Two-stage, intercooled centrifugal
Impeller diameters	80, 57mm
Impeller rotational speed	160,000 RPM
Steam outlet temperature	220° C
Pressure ratio	6
Efficiency	75%

3.6 Conclusions

Our HTHP is technically innovative but feasible. We will manage the risks of bringing this product to market by breaking the rollout into discrete stages, collaborating with the best academic and commercial expertise, testing subsystems thoroughly and seeking independent validation to bring confidence to the market.

4 Description of the demonstration project

4.1 Fuel switching

Our plan for fuel switching is to displace fossil fuel-powered boilers with electrically-driven HTHP to provide distillery process heating. As the grid transitions to greater levels of renewable energy, carbon savings will continue to improve.

HTHP needs a waste heat source from which to recover energy and then raise its temperature for process heating. Our project will demonstrate the recovery of still condenser heat, which is currently discharged down the drain. Distilleries do not like wasting heat and there is a lot of it. Our collaborating distillery uses the 70° C condenser waste water for cleaning but there is only so much cleaning to be done. The general industrial problem with “low grade” (low temperature) heat is that the cost of recovering it greatly exceeds the cost of generating new heat, especially when the price of fossil fuels is so low.

Our project will demonstrate how this waste heat can be recovered. In the future, when the price differential between electricity and fossil fuels reduces to encourage decarbonisation, then we will have the technology demonstrated to accelerate the shift.

4.2 Process intensification

Newcastle University has a very strong process intensification research group and describes it as follows:

“Process Intensification is the strategy of making dramatic reductions in the size of unit operations within processing plants whilst maintaining production objectives. The ultimate aim of process intensification is an order of magnitude reduction in the volume of processing equipment for no loss of productivity.”

Distilleries, like many process plants, have gas boilers, tanks, pumps, control equipment and long pipe runs that take up space and are expensive to install. Our HTHP, following the principles of process intensification, will compact the waste heat recovery and heat delivery system into a much smaller space. Figure 2 shows schematically how process intensification will reduce the space required for our system.

Process intensification is central to achieving better economic returns to drive technology adoption. Research by Newcastle University has shown that in larger process installations, up to 80% of plant costs are in civil engineering, structures and pipework to support the equipment.

Like lower temperature domestic heat pumps, HTHPs are mechanically more complex than boilers and capital costs are higher. This will be offset by lower installation costs and lower total cost of ownership as the costs of carbon emissions rise in the future.

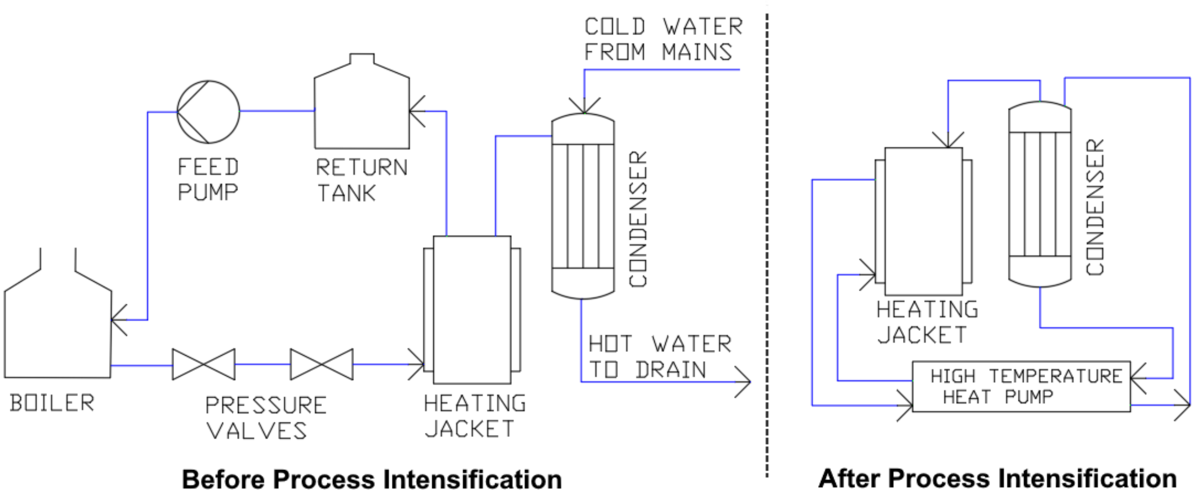

Figure 2: Process intensification schematic

4.3 Corporate strategy

Vytok is a company formed to respond to a market-pull in next-generation turbocompressors requiring long life, oil-free operation, high efficiency, compact size and low total cost of ownership.

High temperature heat pumps (HTHP) is an active and emerging area of development because of its potential importance in the role of decarbonising heat. The compressor is by far the biggest challenge to solve in realising very high temperature condensation for industrial heat (150° C and above) and this is where our efforts are focussed. Over time, our strategy is to have the best core compressor technology, which will then be licensed to, or manufactured for, system integrators.

5 Design of demonstration

5.1 System architecture

An indicative system diagram of the HTHP system is shown in Figure 3. The HTHP will be installed near the gin still pot and will run in parallel with the existing gas boiler system to ensure there is no process disruption in the event of a malfunction during pilot trials.

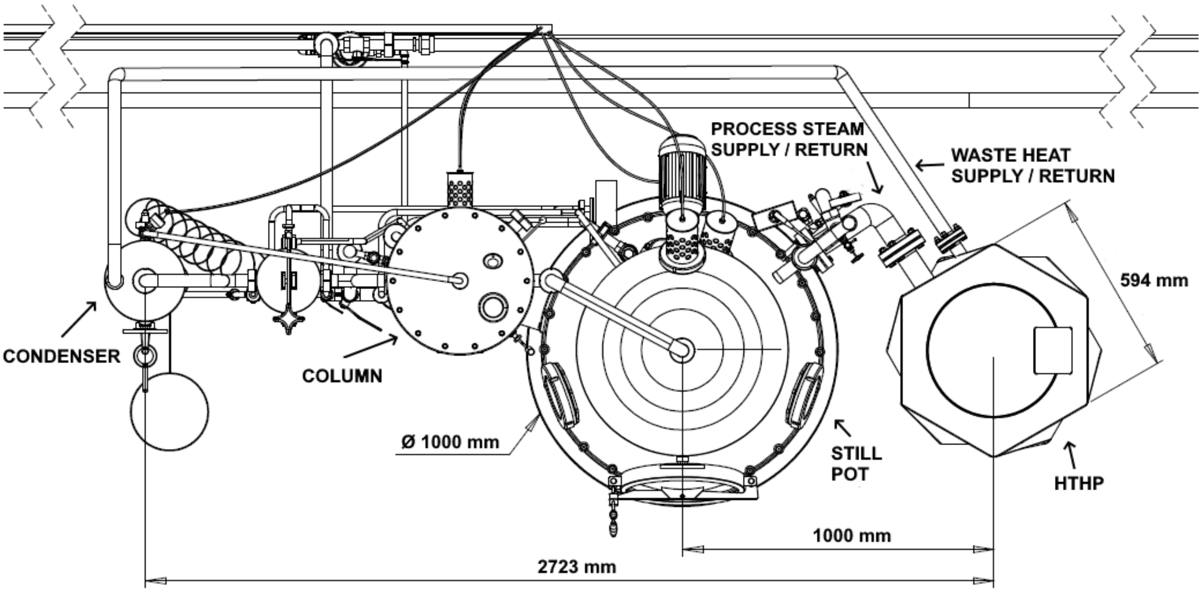

Figure 3: Pilot trial general layout

A photo of one of the gin still pots at our collaborating distillery is shown in Figure 4. The current steam entry pipe is visible to the left and enters the stainless steel heating jacket wrapped around the copper pot. The high temperature steam from our HTHP will enter via a tapping into this pipe at a suitable location to be confirmed.

At the far right can be seen one of the condensing columns that will supply the waste heat water as in input to the HTHP. At about 70° C, it does not need hard piping. Our aim is to keep physical disruption in the plant to a minimum.

Figure 4: Distillery still pot (London)

5.3 HTHP compressor

An illustration of the core compressor system for the HTHP is shown in Figure 5 .

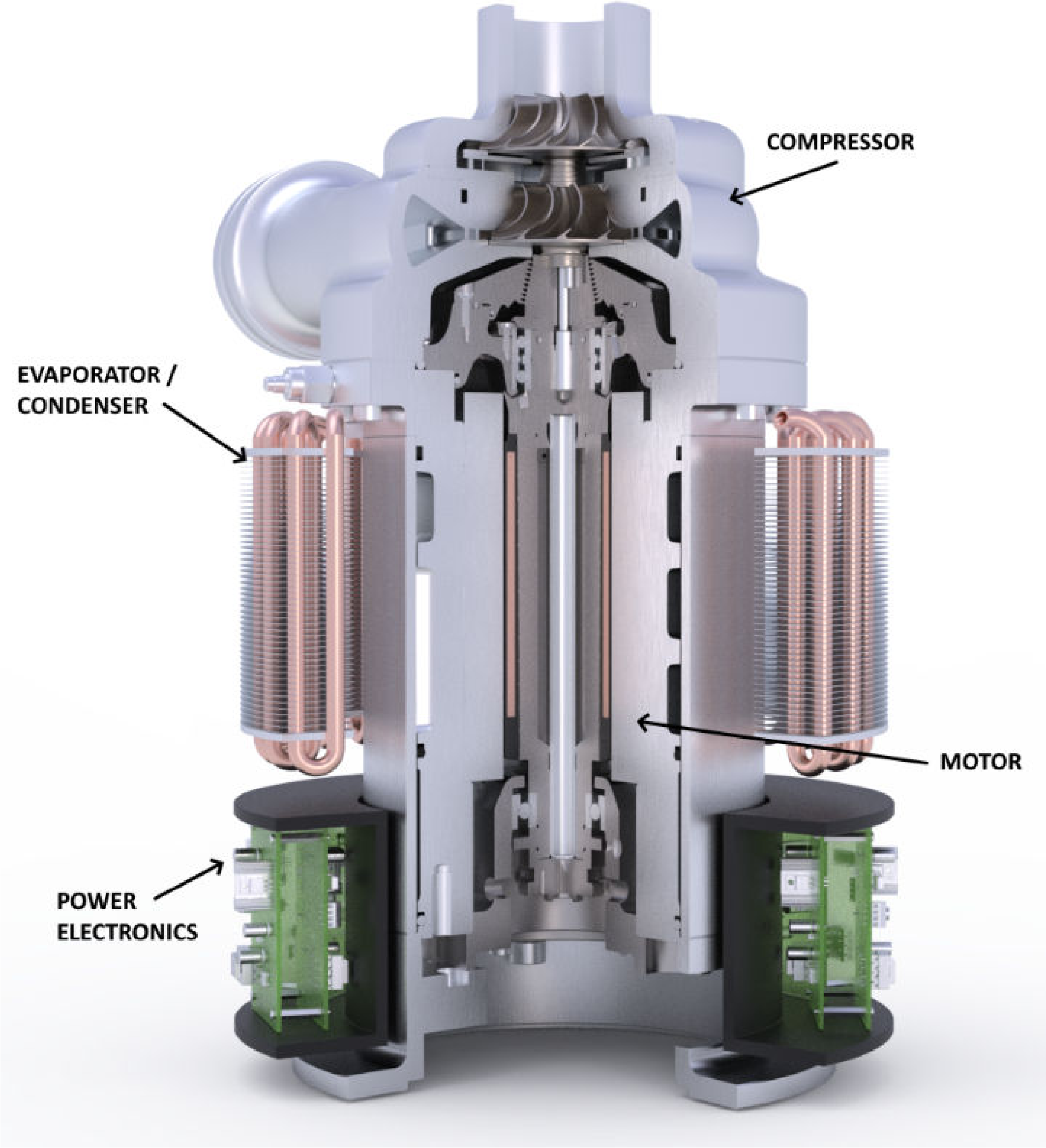

Figure 5: HTHP core compressor and drive motor

In Phase 2 of this project, the focus will be primarily on the design of the compressor because it represents the highest technical risk and is so central to proving the performance of the overall system in both carbon saving and in economic terms.

5.4 Deliverable

For Phase 2, Vytok will deliver a skid-mounted, pilot-scale HTHP, fully integrated and tested. It will be designed to deliver nominally 100kW of heat but the final specifications will depend on an energy audit of the distillery plant we will connect with.

The HTHP will be CE-compliant and safe. It will require a three-phase electrical supply and four major water connections to the distillery (waste heat in/out, high temperature steam in/out). It will also feature an internet connection so the system can be remotely monitored for performance and reliability. It is important our engineers are able to act promptly to any issues and reducing as far as possible any inconvenience to our collaborating distillery.

5.5 Data acquisition

The pilot HTHP plant is focussed on testing the overall system performance and will contain subsystems, such as the drive motor, electrical drive and heat exchangers that are not part of the final commercial product.

The acquisition of real-world data pertaining to hot water and steam flow rates and temperatures, and the thermofluid performance of the compressor, will be key in de-risking the development of a full HTHP product in the following stages of commercialisation.

6 Benefits and barriers

6.1 Payback

The economics of heat pumps compared to gas boilers are determined by the ratio of prices between gas and electricity. The average utility prices, taken from the BEIS Industrial Energy Price Statistics (2019) are shown in the following table.

Gas	0.0248 £/kWh
Electricity	0.129 £/kWh

The cost savings rate associated with running the HTHP derive from the cost of running the heat pump compressor versus the cost of supplying the same heat using a gas boiler. Assuming that the HTHP is providing steam to the stills, which operate for 48 hours per batch and for 2 batches per week, for 50 weeks per year, the heat pump would operate for a total of 4800 hours per year. Our analysis showed a cost saving compared to operating a gas boiler of £0.57/hour, giving an annual cost saving of £2,759/year. This can be used to estimate the target capital cost for a given payback period.

Payback period	**Capital cost**
2 years	£5,520
5 years	£13,800
10 years	£27,600

Our target price to customers is about €250/kW, twice that of a boiler and half that of current industrial heat pumps. The unfavourable price differential (“spark gap”) between electricity and gas in the UK is evident. It would take close to 10 years to pay the system capital cost back, whereas it needs to be two-to-three. This will naturally happen as the price of carbon rises but illustrates the current challenge for decarbonisation.

The European Heat Pump Association (EHPA) reports that uptake in heat pumps is very much higher in Nordic countries such as Sweden, Finland and Denmark when it is not possible to artificially sustain low gas prices. Where electrification is the main carrier of energy, heat pumps are commercially more successful because of their high efficiency.

6.2 Barriers to uptake

Below is a table of adoption barriers, typical for new heating technologies [20], and proposed mitigation activities.

Barrier to adoption	**Proposed mitigation activities**
High capital cost and long investment cycles	Innovative design, process intensification and manufacturing methods with our partners to achieve target costs for 2 - 3 year paybacks.
Limited financing	As above. Our goal is to help make it possible for distilleries to invest off the balance sheet rather than making large infrastructure investment decisions.
Risk of not meeting required product quality or changing character	As a heating-only solution, there should be a low adoption risk by only substituting one source of steam for another.
Risk of production disruption	System is run alongside existing heating solutions until customers are confident enough to displace their boiler completely.
Shortage of skilled labour	Our product is intended to be more like a plug-and-play consumer product than an industrial installation. Specialist installers not needed and complex functions are remotely monitored.
Shortage of demonstrated technologies	Focus on successful pilot demonstrations. Emphasis on reliability and customer satisfaction before promoting widely.
Lack of reliable and complete information	Heat pumps will become more acceptable and understood as industry electrifies. The best short-term strategy is to provide reliable pilot projects that can be referenced by others.

6.3 Scaling

We are developing a modest-sized HTHP capable of delivering 100 kW of heat that is ideal for pilot scale. We anticipate this will eventually be a final product at this scale, suitable for many small companies in the food and beverage industry. We do not want to go smaller than this because the thermo-fluid challenges of steam compression become difficult. Scaling up is easier for compressor and bearing design and it will up to the market response if building larger machines is commercially, rather than technically viable. For larger heat demands, we expect connecting multiple, smaller units to maintain economies of production scale will be a more likely route while the market is developing.

7 Costed development plan

7.1 Project costs

Top level costs for phase 2 work packages are shown in the table below. Over the course of the project, we expect to add 7 more people to the team, largely in technical roles.

Component	**Costs (ex VAT)**
WP1 - Compressor Sizing and Concept Design	£178,189
WP2 - Detailed Compressor Design	£268,002
WP3 - Electrical Drive Development	£171,786
WP4 - Fabrication and Assembly of Compressor	£339,271
WP5 - Fabrication and Assembly and Commissioning of Test Rigs	£153,484
WP6 - Test: Functionality, Integrity and Performance	£172,804
Misc costs including reporting	£34,338
Total Cost	**£1,317,874**

7.2 Business plan

Our vision is to supply the best and most sustainable, electrically-driven, high temperature heat pump core technology to OEMs around the world. Initially we will supply complete heat pump systems in order to span the complex system interdependencies. Over time, we recognise the value of not competing with the myriad heat pump suppliers and their sales and support channels but to provide the innovative core technology for their products. We will continue to invest in developing better heat pump technology to accelerate the transition to electrically-decarbonised industrial heat.

A high level plan for our business and initial product rollout is shown in Figure 6.

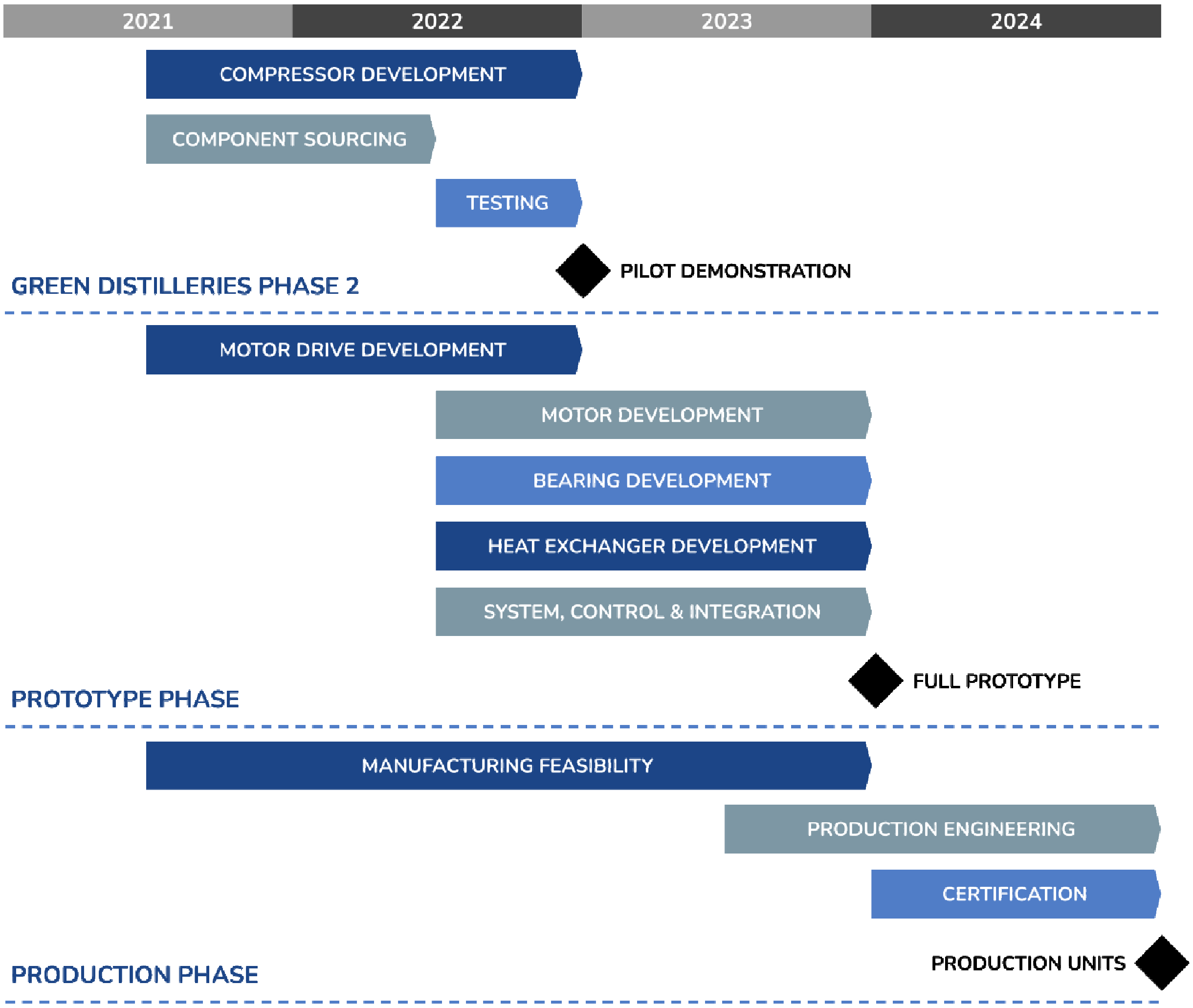

Figure 6: High level rollout schedule

Green Distilleries phase 2
Funded by this project to develop the highest risk compressor systems. This will be combined with off-the-shelf components to complete the pilot demonstration after an 18 month project duration. Architectural development of the other key systems will be investigated as part of phase 2, but will not be fully ready for demonstration.

Prototype phase
Development of the balance-of-plant, especially electric motor, drive, bearings, heat exchangers and control system to complete a full product prototype. This will take a further 12 months after the completion of the Green Distilleries project.

Production phase
Production is key to business success and is often given too little focus in the new product lifecycle. We are partnering with Productiv Ltd to consider all production issues from day one with a goal to be ready for first off-tool production systems 12 months

after prototyping. We plan to set up initial manufacturing operations in Coventry. Our cost estimates are based on 1000 units-per-annum to ensure very large volume manufacture is not required to be commercially viable.

7.3 Funding

Vytok's founders are experienced in commercialising new technology and fundraising for technology ventures. This project funding will get us to pilot phase, at which point the job of raising private equity finance for commercialisation is considerably easier. We have a network of clean-tech investment companies to approach and the environment for compelling, green technology to help achieve net-zero is improving constantly.

8 Rollout potential

8.1 Market and drivers

Growth in distilleries has been rapid over the last few years and as of 2020, there were about 550 distilleries registered with HMRC. Most of these are smaller distilleries and the fastest growth has been in artisan gin.

Larger organisations are often formally committed to sustainability, e.g. the Scotch Whiskey Association's 2009 Environmental Strategy. Larger distilleries are driven by reportable performance metrics and have resources to dedicate to sustainable activities. Our market entry is with smaller firms, such as our collaborating distillery in London, that have fewer resources and expertise available.

While larger distilleries "must" become more sustainable, smaller distilleries often "want" to. Their differentiators include artisan flavours, ethical practices and environmental concerns. Our product offers a plug-and-play solution for them that does not require much space or installation and commissioning complexity. It is more like buying an appliance and plugging it in.

The distillery market is small compared to the market for industrial heat decarbonisation but is an attractive one for establishing our technology. Establishing 50 reference sites, or 10% of the market, would ensure we were on a strong growth trajectory in our business plan.

8.2 Fuel switching options

Some distilleries have made noteworthy efforts to move towards sustainability, such as Bombay Sapphire's BREEAM accreditation and Dalmunach's heat recovery system. The challenge for the majority of distilleries that are not as well resourced is transitioning to clean heat by making more use of off-the-shelf solutions that don't require greenfield sites, major plant redesign or strong visions from founders. Speed of transition to net-zero emissions needs solutions for the many that can be quickly implemented.

Options such as solar, biomass and (in the future) hydrogen may be viable but electrification has the benefit of being an incumbent, universal and ever-expanding energy carrier. Building a hydrogen economy, for example, is a formidable challenge and may not happen in time to achieve national emissions goals. A key obstacle to electrifying process heat is the lack of efficient and reliable technologies, especially in the UK where electricity prices are very high compared to natural gas.

8.3 Scaling

We are positioning our product more like a plug-and-play appliance than a piece of industrial plant in order to change the perception of sustainable heating technology. It will be compact, sited next to the still and need very little of the piping and installation required by gas boilers.

In small production volumes, it is best to retain a single product size to avoid incurring design and tooling costs for various sizes. This may be a 50kW or 100kW unit, for example. If more heat is required then another HTHP is installed. With larger market volumes, outside the distilling sector, opportunities may exist for having a range of product sizes.

Applicability to other sites, or any other sector, is limited only to the existence of a waste heat source for recovery. Steam for process heating is a standard requirement across many sites and sectors, ensuring strong scalability for our technology and for our business.

9 Route to market assessment

9.1 Significant risks

Development of novel technologies carries considerable risk. Vytok is a new technology company whose key people are very experienced in risk management of new product development from technologies emerging from university research.

Risk	Management
Project time and budget delivery.	● Good project management practices, particularly frequent review against target specifications. ● Personnel experienced in project management with high technical risk projects. ● Cost/time estimation using benchmark information from previous projects. ● Technical stretches are measured and failure won't bring down the project. ● Choose partners who are acknowledged experts in their field.

Modelling or testing shows that economics of the system make the product less commercially attractive.	● Establish a portfolio of follow-on commercial opportunities in other markets and sectors. ● Finer market segmentation to explore smaller but more compelling opportunities. ● Publications through university links to establish contact with new R&D and market directions.
Raising equity capital for growth.	● Capital raising activities are ongoing. ● Continue exploring grant funding support options. ● Flexibility to be retained in project scope to reduce technical risk and cost of delivery. ● Focus on milestone delivery to increase attractiveness to investors.
System or subsystems do not meet performance specifications.	● Collaboration with good research groups reduces technical risk. ● Periodic oversight from external reviewers increases scrutiny on technical risk. ● Reducing technical jumps between iteration cycles provides early warning of technical risk. ● More time at conceptual phase uncovers technical precedents and reduces costly learning from mistakes.

9.2 Route to market

Step 1 is a successful pilot where system performance and efficacy is critical to demonstrate. Data acquisition is important for product development but more importantly for commercialisation is as a reference site for the distilling industry and investors. Seed capital raised.

Step 2 is to win further test sites for our full prototype systems following up 12 months after the pilot launch. We expect smaller distilleries to have fewer barriers to adoption, especially for those looking for assistance to move into sustainable operations ahead of the curve. Start-up capital raised to fund the prototypes.

Step 3 is to complete the production planning and testing for the first commercial units following 12 months after prototyping. Vytok takes charge of winning advanced orders, supplying and servicing products in the initial stages. Series A capital raised to go into production.

Step 4 is building the sales operations in the company and selling to both the distilling industry and other industrial process customers.

Step 5 is looking for extended sales channels, such as distributors, to increase market coverage, including European sales.

Step 6 is based on the expectation that Vytok would transition into a component supplier to original equipment manufacturers (OEM). Higher volume manufacture is set up in the UK, making the high value and technically difficult HTHP technology while continuing investment into new technology to maintain competitiveness. Star Refrigeration in Scotland has already expressed an interest in the product and have written a letter of support to this application. They know that industry will have to move towards decarbonised heat, are actively looking for solutions to the problem and are excited about the ideas that are being put forward here.

9.3 No regrets

Our HTHP system will be connected in parallel with the existing distillery steam circuit. In the event of a system fault, the existing boiler system can continue to supply process steam. We will not put commercial production at risk while our system is being developed.

9.4 Other sectors

Beyond distilleries, heat pumps able to deliver high temperature steam will be able to serve many industrial sectors. As a technology for recovering waste heat and raising its temperature, there are few aspects that are specific to any one application or sector.

A consortium of European heat pump research groups recently published an overview of the opportunity for industrial heat pumps [19] in which they estimated heat pumps had the potential to cover 37% of the process heat industry. The recoverable energy by some key sectors is shown in the following table.

Food & beverage	123 TWh/annum
Pulp & paper	230 TWh/annum
Chemical	119 TWh/annum
Machinery	41 TWh/annum
Non metallic minerals	43 TWh/annum

This recovered energy corresponds to possible CO_2 emission reductions of 146M tonnes/annum, of the order of 300 times that of the UK distilling industry.

The decarbonising of industrial heat is a huge challenge for countries trying to achieve net zero carbon targets, especially as the pathway is not as clear as it is for electricity generation and transport. With electrification as a key energy carrier, heat pumps, because of their very high efficiency, will be an inevitable part of the solution.

10 Dissemination

Our approach is to begin by raising awareness of the benefits of HTHP in distillery decarbonising by publishing both academic and commercial literature for the industry. This will be followed by on-site trials, where interested parties can view the early product and become aware of the benefits.

10.1 Publications

We have planned academic publications with Newcastle University in the following journals.

Publication	Academic Impact Factor
Journal of the Institute of Brewing	1.5
Applied Thermal Engineering	4.7
Applied Energy	8.8

We have been in contact with the editor of the Journal of the Institute of Brewing about submitting a publication tailored more to the interest of the brewing and distilling industry. Our second paper for the energy journals will be more academically focussed, catering to the wider chemical and process industry. We have also contacted the editor of Brewer & Distiller International about producing a general interest article about the HTHP technology, benefits and applications.

10.2 Association membership

Our company will participate in association membership of the Institute of Brewing and Distilling, the British Distillers Alliance and CeeD Scotland, the latter of which has strong contacts into the brewing and distilling industry.

10.3 Trade Shows

We plan to attend the *Worldwide Distilled Spirits Conference* on 05 - 08 September 2021 in Edinburgh. We also plan to attend *drinktec*, the world's leading trade fair for the beverage and liquid food industry. Held in Munich, the event was postponed this year due to covid and will instead be held in September 2022.

10.4 Media presence

We are working with a London-based media company that specialises in working with clean energy companies. They are advising us on ongoing media presence, including website-based news, press announcements, popular articles and social media presence.

11 Conclusions

The objective of the BEIS Green Distilleries competition is to help UK distilleries decarbonise by finding ways to use lower carbon-emitting fuels for process heating anywhere in the drink manufacturing process. Vytok is a new company formed to commercialise research and expertise in motor and compressor technology to provide an electric pathway to distillery heat decarbonisation through the use of high temperature heat pumps (HTHP). Working with a London-based gin and whiskey distillery, our competition entry is to pilot a HTHP system that will recover waste heat from the still condenser, raise its temperature, and then reuse that heat as steam in the still pot. This will eventually allow the gas boiler to be replaced with an electric heating solution. The main conclusions from the feasibility study are as follows.

1. Vytok has investigated the design of a HTHP system for distillery fuel switching from natural gas to electricity and determined that the system and proposed pilot demonstration are feasible.

2. In switching from gas to electricity, large carbon savings are easily achieved; we estimated 90 tonnes per year from our modest-sized collaborating distillery. This is not surprising if electricity is the fuel and also the net savings increase as the grid transitions to renewable generation.

3. Speed is important to transition away from fossil fuels in order to meet the UK's climate objectives. Other fuel options such as hydrogen and biomass may well form part of the mix but electrification is here now and rapidly transitioning to renewables. Our solution does not rely on a hydrogen or biomass economy becoming established, which will take a long time even with strong political will.

4. Our HTHP solution achieves excellent CO_2 savings but to achieve good commercial payback requires a very large reduction in the price of electricity compared to natural gas. The UK is about the worst in this regard Europe-wide. This is an externality we cannot control but it will have to change if the UK is to meet its climate objectives. Our target is for a two-to-three year payback on capital cost to distilleries.

5. There is a lot of research into HTHP for process heating because the efficiency gains in an electrified world are so large. However, we are in a minority of developers in using water (R718) as the refrigerant. Water has excellent thermodynamic properties as a refrigerant above 100° C as well as unrivalled environmental benefits. It does present additional challenges for the compressor design that requires expertise most heat pump companies and research groups do not have.

6. A HTHP for this application is a challenging task but we have assembled commercial and academic partners in the UK and Switzerland to access the best technology and expertise to ensure we can deliver a commercially and technically-viable solution.

12 References

1. Arpagaus et al. (2018). 'High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials'. *Energy*, No. 152, doi: 10.1016/j.energy.2018.03.166
2. The Carbon Trust. (2011). 'Industrial Energy Efficiency Accelerator - Guide to the Brewing Sector'. London: The Carbon Trust
3. Arpagaus, C. (2017). 'European Heat Pump Summit'. Presentation, Congress + Expo, Nuremberg
4. Marina et al. (2021). 'An estimation of the European industrial heat pump market potential'. *Renewable and Sustainable Energy Reviews*, No.139, doi: 10.1016/j.rser.2020.110545
5. Arpagaus et al. (2018). 'High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials'. *Energy*, No. 152, doi: 10.1016/j.energy.2018.03.166
6. Bergamini et al. (2019). 'Thermodynamic competitiveness of high temperature vapor compression heat pumps for boiler substitution'. *Energy*, No. 182, doi: 10.1016/j.energy.2019.05.187
7. IEA Industrial Energy-Related Technologies and Systems. (2014). 'Application of Industrial Heat Pumps'. Paris: International Energy Agency - Organisation for Economic Cooperation and Development
8. Element Energy Ltd (2014). 'The potential for recovering and using surplus heat from industry'. Final Report for DECC, London: Element Energy Ltd
9. Law et al. (2013). 'Techno-economic comparison of a high temperature heat pump and an organic Rankine cycle machine for low-grade waste heat recovery in UK industry'. *International Journal of Low-Carbon Technologies*, No. 8, doi: 10.1093/ijlct/ctt029
10. Law, R. (n.d.). 'Low-Grade Heat Recovery in UK Food/Drink Industry'. Presentation, Newcastle University
11. Wu et al. (2020). 'Experimental investigation on the performance of a very high temperature heat pump with water refrigerant'. *Energy*, No.190, doi: 10.1016/j.energy.2019.116427
12. De Larminat, P. (2015). 'A High Temperature Heat Pump Using Water Vapor as Working Fluid'. Presentation, ATMOsphere Europe, Brussels
13. Bantle et al. (2019). 'Turbo-compressors for R-718: Experimental evaluation of a two-stage steam compression cycle'. Trondheim: International Institute of Refrigeration, doi: 10.18462/iir.icr.2019.0973
14. Bertsch et al. (2018). 'Theoretical Investigation of a High Temperature Heat Pump using a Micro Turbo Compressor and Water as a Refrigerant'. Valencia: IIR Gustav Lorentzen Conference, doi: 10.18462/iir.gl.2018.1201
15. Kilicarslan et al. (2004). 'COP of R718 in Comparison with Order Modern Refrigerants'. Cappadocia: International Mechanical Engineering Symposium
16. Wu et al. (2020). 'The performance comparison of high temperature heat pump among R718 and other refrigerants'. *Renewable Energy*, No.154, doi: 10.1016/j.renene.2020.03.034
17. Zühlsdorf et al. (2018). 'Design Recommendations for R-718 Heat Pumps in High Temperature Applications'. *Proceedings of the 13th IIR-Gustav Lorentzen Conference on Natural Refrigerants*, No.2, doi: 10.18462/iir.gl.2018.1367
18. Moisi et al. (2017). 'Refrigerant Selection and Cycle Development for a High Temperature Vapor Compression Heat Pump'. Rotterdam: 12th IEA Heat Pump Conference 2017
19. De Boer et al. (n.d.). 'Strengthening Industrial Heat Pump Innovation: Decarbonizing Industrial Heat'. Lyngby: DTU Orbit, Technical University of Denmark
20. WSP (2015). 'Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050.' London: Department of Energy & Climate Change

END OF REPORT