Period	2021-2024
title	Final report of Stirling Heat pump project
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abstract	

HELLO STIRLING Final report

Preparation

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Executive Summary (Public)

Stirling Heat pumps offer many benefits over conventional Rankine vapour compression heat pumps as they do not rely on traditional damaging, poisonous or flammable refrigerants. Stirling cycle machines are gas cycle machines with no condensing liquid phase and only contain a few grammes of Helium which has no GWP or ODP is not poisonous or flammable. In operation Stirling units can easily go down to very low temperatures where Rankine cycle machines will not work (ultimate refrigeration and cryocooling). Stirling units also have the advantage that they can operate at higher reject temperatures, 70°C for DHW is easily achieved without any significant increase in system pressures and unlike conventional vapor compression systems they do not have to operate near critical point conditions.

Table 1. Comparison of vapour compression refrigerants and Stirling HP working fluids

		Traditional Vapour Compression VC					Non Condensing Stirling Cycle
		Traditional Refrigerants		Natural Refrigerants			
Name		R22	R134a	Propane	Anmonia	Carbon Dioxide / Cascade	Helium, Nitrogen, etc.
Class		HCFC	HFC	C3H8	NH3	CO2	Nobel Gas
R Number		R22	R134a	R290	R717	R744	R704
Status New Equipments		Banned	Banned from 2025	Good	Good	More complicated	Good
Status Retrofit		Banned	Banned from 2025	No	No	No	No
Flammable		no	no	2.1-9.5%	14.8-33.5%	No	No
PFAS							
Poison Safety IDLH		>10,000ppm	>40,000ppm	2100 ppm	300 ppm*	40,000 ppm	None
ODP		0.055	0	0	0	0	0
GWP		1810	1370	3	0	1	0
Heating/Cooling Western Europ (heatpump)	Functional	NA	NA will be banned	Ok	Ok	Ok	Ok
	Practical	NA	NA will be banned	Yes	No	Complicated	Product under development
AIRCO: > 25-45	Functional	NA	NA will be banned	Ok	Ok	Ok	OK
	Practical			Yes	No	Complicated	Product under development
Domestic Hot water - Radiator systems	Functional	NA	NA will be banned	Ok	No	Doubtfull	Ok
	Practical			Yes	No	Very Complicated	Product under development
Freezing minus 80	Functional			No	No	No	Product under development

During this programme a number of novel Stirling Heat Pump variants were built to optimise the beta Stirling engine for use as a Water/Water (W/W) heat pump, design changes included:

- New copper to water accepter and rejecter heat exchanger designs
- Bespoke tube in tube accepter heat transfer Head design
- Back-end heat recovery coil (or Jacket)
- Electric acceptor Head design for easier and more accurate testing and validation.
- Improved Regenerator design for heat pump operation.
- Various shell side accepter heat exchanger options for water Heat Pump operation

Detailed testing was carried out to aid the design and optimization of improvements and to investigate the control requirements of the Stirling for heat pump operation. The main things hindering high performance are the lack of displacer amplitude reducing both heating output (kW) performance and efficiencies. The performance was also limited to some extent by input power limits on piston amplitude and instabilities at high powers related to the Piston displacer phase angle.

Performance testing has shown that the change in COP was lower than vapour compression machines at moderate temperatures but at the extremes the performance loss was lower at higher temperatures for Domestic Hot Water the unit would be able to operate with no issues and still give high heat pump efficiencies. However, the current seasonal COP is unlikely to match those from standard vapour compression machines.

Two initial Stirling heat pump field trials we started and have provided already valuable information for the protection and control of the heat pump installation. One unit acting in an A/W (Air/Water) configuration and a second installation as W/W where both heated and cooled water can be used.

A large amount of knowledge was gathered during the Hello project on the design and operation of Stirling heat pumps. The importance of the Heat Exchangers, regenerator and the piston displacer dynamics. All of which contribute to the performance and operating stability of the heat pump. The use of phasor modelling can explain some of the key changes we see when changing from a Stirling in power producing (generating) to an electric driven Stirling heat pump.

Key Learnings and Conclusion
While significant progress was made in developing and optimizing the Stirling heat pump, we were not able to fully achieve our original objective of demonstrating a highly efficient Stirling heat pump for low-temperature difference applications. However, through extensive experimentation and theoretical analysis, we have developed a much deeper fundamental understanding of the system's limitations and operating principles.

Our key conclusions are as follows:

1. **Limitations in Heat Exchanger Design for Low ΔT Conditions:** For applications with low temperature differences (ΔT), the absolute amount of heat transferred per unit cross-sectional area in a Stirling system is inherently high. As a result, the design of the heat exchangers reaches practical limits where further improvements are not feasible. This fundamentally restricts the suitability of Stirling systems for low-temperature difference heat pump applications.
2. **Fundamental Differences Between Stirling Engines and Heat Pumps:** A critical insight gained from this work is that the operation of a Stirling engine with a given geometry cannot be directly translated to a heat pump application. The fundamental physics governing the system dynamics, including the displacer amplitude, gas densities, and regenerator function, differ significantly between power generation and heat pumping modes. These differences impose performance constraints that must be considered in future designs.

These findings provide a strong theoretical foundation for future Stirling-based thermal technologies, helping to refine the scope of viable applications and guiding future research toward areas where Stirling systems can offer a distinct advantage.