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RBE Down, AT Jones, CR Lawson, O Kirichek

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STFC Author Identifiers (ORCIDs)

Author ORCIDs are provided where available.

Alexander T. Jones	0000-0001-6224-5749
Christopher R. Lawson	0000-0002-9675-854X
Oleg Kirichek	0000-0002-4670-5036

Carbon Footprint of the Helium Recovery System at the ISIS Facility

Richard B. E. DOWN[1*], Alexander T. JONES[1], Christopher R. LAWSON[1], and Oleg KIRICHEK[1]

[1]*ISIS Neutron and Muon Source, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Didcot, OX11 0QX, UK*

**E-mail: richard.down@stfc.ac.uk*

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Helium is a finite global resource, which is becoming vitally important to recover and reuse as it continually diminishes. The helium recovery process is well known and incorporates plant machinery that can consume significant amounts of power, thus contributing to a facility's already large carbon footprint. The drive to reduce carbon footprint, and therefore lessen the impact of climate change, is gathering momentum. Here we have assessed the CO_2 produced per liquid litre of helium, when processed by the ISIS helium recovery system, and compared it with the estimated carbon footprint of liquid helium that is supplied by the gas companies. This allows us to comment on the contribution helium recovery can make in the pursuit of net zero.

KEYWORDS: liquid helium, helium recovery, helium liquefaction, carbon footprint

1. Introduction

The United Kingdom government has set the ambitious target of reducing greenhouse gas emissions to net zero by 2050, inspiring a number of changes in society in order to facilitate this momentous transition [1]. United Kingdom Research and Innovation (UKRI), the government organisation responsible for research and innovation funding, is aware of the integral role that science plays in the global response to climate change. As such, UKRI sets out the goal of reducing carbon emissions from their estate and operations to net zero by 2040.

In Fig.1 we present a photo of the helium recovery (HR) system of the ISIS neutron and muon source, which provides liquid helium for the cryogenic sample environment of neutron scattering and muon spectroscopy experiments. The ISIS HR system became operational in May 2017. Initially 50% of the helium used at ISIS was recovered, and since the system's effectiveness has significantly improved, the recovery rate exceeding 90% in the last couple of years. A Linde KryoTechnik liquefier was added in July 2017, which quickly became an integral part of the ISIS HR system. Thanks to the HR system the amount of liquid helium bought in to replenish the stock has decreased six fold in the last five years.

Fig.1. Helium Recovery system of the ISIS neutron and muon source.

The HR process is well known [2, 3] and incorporates plant that can consume significant amounts of power, thus contributing to a facility's already large carbon footprint. The drive to reduce our carbon footprint, and therefore lessen the impact of climate change, is gathering momentum. In this work we have assessed the CO_2 released per liquid litre of helium processed by the ISIS HR system. The main components have been taken into consideration, including high-pressure compressors, instrumentation, Linde KryoTechnik TCF20 cold box, screw compressor, building infrastructure and safety systems. Furthermore, once the carbon footprint had been obtained, a comparison was carried out to see how in-house helium production compares with liquid helium that is supplied by the gas companies. To do this we have explored the liquefaction process, the methods of transportation that are employed, the time taken to transport and the liquid boil off rates during the delivery process.

2. Carbon Footprint of Helium Recovery and Re-liquefaction

The ISIS HR process consists of several distinctive stages. At the first stage, low pressure helium gas is collected and stored in a large gas balloon. After that, gas is compressed by recovery compressors and stored in 200 bar MCPs (multi-cylinder packs). When liquid helium is required for the facility's cryogenic operations, the high-pressure gas is re-liquefied by a Linde TCF 20 liquefier and stored in a 2000 l liquid helium storage dewar. Finally, liquid helium is redistributed into transport dewars and delivered into the experimental halls where it is transferred into cryogenic equipment.

The parameters used in the ISIS HR Carbon Footprint model are presented in Table I. By using the known speeds for the liquefier and recovery compressors, the run time required for the production of 1 l of liquid helium can be calculated, and hence the energy consumed found using the measured power inputs. This gives a carbon footprint of 450 g

CO_2/ l for liquid helium produced using the ISIS HR system. Once the helium has been produced, it is transferred into a transport dewar for experimental use, incurring an approximate 10% boiloff loss. Hence, each litre of helium used experimentally requires 1.1 l to be produced, giving an overall carbon footprint of 500 g CO_2/ l He.

Table I. Parameters used in ISIS HR carbon footprint model.

Parameter	Value
Helium expansion ratio	757:1
Recovery compressor speed	44 m^3/ h (technical specification)
Recovery compressor power input	25 kW (technical specification)
Grid CO_2 (g CO_2/ kWh)	233.14 (Carbon Trust [4])
Linde TCF 20 liquefier speed	20 l/ h (technical specification)
Linde TCF 20 power input	30 kW (measured for compressor, cold box and ancillaries)

3. Carbon Footprint of Helium Supplied by Gas Companies.

At present, helium is extracted from natural gas wells alongside the majority methane product [5]. Helium is separated from the extracted gas by cryogenic distillation during the production of liquefied natural gas (LNG) [6] and is then itself liquefied for transportation. Here, we assume the same carbon footprint for helium liquefaction as we achieve with our Linde TCF 20 liquefier, 450 g CO_2 / l He, however, the significantly larger plant at an LNG facility is likely to be slightly more efficient than ours. Due to the cryogenic distillation process used to separate the helium from the natural gas, the liquefaction of natural gas is a necessary step in the production of liquid helium. The carbon footprint associated with the liquefaction stage of LNG production is 6.2 g CO_2 / MJ [7] or, equivalently, 232 g CO_2 / m^3 of input natural gas at standard temperature and pressure. One possible route of helium supply starts with helium extraction from the Qatar natural gas fields, which have helium concentration 0.04% [8]. Hence, in order to produce 1 l of liquid helium, requiring 757 l of helium gas, 1900 m^3 of natural gas must be liquefied, giving a carbon footprint of 440 kg CO_2/l for the separation of 1 l worth of liquid helium.

It could be argued that the total carbon footprint of liquid helium extraction should also include the substantial 'upstream' natural gas emissions, for example those associated with well drilling, flaring and other plant [7]. We do not include them here, as these emissions would be incurred for the extraction of natural gas which would take place regardless of demand for helium. The carbon footprint for natural gas liquefaction should arguably not be included either for similar reasons, however, natural gas does not necessarily need to be liquefied for contemporary uses, whilst this step is required in order to separate out the helium.

Once separated from natural gas and liquefied, the helium is shipped from the Port of Ras Laffan, Qatar, to the Port of London, United Kingdom, in specialised 2 twenty-foot equivalent unit (TEU) ISO containers [9], each of which is filled with 36 900 l of liquid helium (40 970 l capacity filled to 90%). This is a distance of 7200 NM (nautical miles) which would be covered in 15 days [10], assuming a ship speed of 20 kn (knots). For a 10 000 TEU container ship, this would consume 2600 t bunker C fuel oil (170 t per day

[11]) leading to 8000 t CO_2 being emitted (bunker C fuel oil assumed $C_{40}H_{82}$). This is 1.6 t CO_2 emitted per 2 TEU carried, hence 43.3 g CO_2 / l liquid helium transported.

From Felixstowe, the ISO containers are transported to Eynsham helium processing facility by 33 t artic lorry over a distance of 250 km. Such a vehicle has a fuel consumption of 35.8 l / 100 km (7.9 miles / gallon [12]), and hence uses 89.4 l of diesel over this journey producing 229 kg CO_2 [4]. Therefore, the liquid helium gains a footprint of 6.20 g CO_2 / l He.

At the Eynsham facility liquid helium is redistributed into transport dewars and is then delivered to Rutherford Appleton Laboratory (RAL) by a 10 t lorry in batches of approximately 1000 l. The distance travelled is 65 km, so with a fuel consumption rate of 23.0 l / 100 km (12.3 miles / gallon [12]), this results in 14.9 l of diesel being burnt and hence 38.1 kg CO_2 being released. Hence, the additional carbon footprint for the liquid helium is 38.2 g CO_2 / l He. For the overall journey from the liquefaction plant to RAL, the total carbon footprint due to transportation is 87.7 g CO_2 / l He. It is, however, important to note that boiloff losses occur from helium vessels over time due to imperfect insulation and due to transfers between vessels. The technical specification of the ISO containers [9] indicates that the loss from these is negligible, however we estimate a loss of 1% per day for a standard transport dewar and a loss of 10% per helium transfer from our own measurements.

When purchasing external helium at ISIS, dewars are ordered in advance in order to avoid any potential supply issues interrupting experimental operations. As such, we estimate on average the dewars stand at ISIS for 5 days before use following 2 days of standing with the supplier, giving an estimated loss of $1 - 0.99^7 = 6.8\%$. We also assume two helium transfers occur, one from the liquefaction plant to the ISO container and a second from the container to the transport dewar, giving a further loss of $1 – 0.9^2 = 19\%$. Hence, there is a total loss of 25% from production to experimental use, meaning for each litre of helium consumed experimentally, 1.3 l must be produced.

4. Conclusion

Here we have assessed the amount of CO_2 produced per liquid litre of helium, when processed by the ISIS HR system, and compared it with the estimated carbon footprint of liquid helium that is supplied by the gas companies. We summarize these results in Table II, and account for the effect of any losses in the final column. According to our model the carbon footprint of liquid helium supplied by a gas company is 712 g CO_2 / l He, whereas liquid helium produced by ISIS HR system is 30% smaller at 500 g CO_2 / l He. If the carbon footprint associated with the LNG liquefaction process is included in these final figures, as discussed in paragraph 2 of section 3, the carbon footprint for helium supplied by gas companies rises to 587 kg CO_2 / l He, making ISIS HR system footprint a comparably negligible 0.08% of this. Furthermore, the carbon footprint of the HR system could be reduced even further by implementing a LN_2 precooling system to the liquefier which, according to the technical data from the manufacturer, would double the helium production for the same electricity consumption, potentially halving the ISIS HR carbon footprint to 250 g CO_2 / l He. We hope that our approach could be useful for organisations who are considering building their own HR system, as it provides a solid grounding from which to assess not only the monetary savings of helium recovery, but also the impact to an organisation’s sustainability.

Table II. Summary of carbon footprints for liquid helium resulting from production, transportation, and overproduction required due to losses.

Helium Source	Production Footprint (g CO_2 / l He)	Transportation Footprint (g CO_2 / l He)	Boiloff Losses (%)	Total Footprint (g CO_2 / l He)
ISIS HR System	450	0	10	500
Gas Company (exc. LNG production)	450	87.7	25	712
Gas Company (inc. LNG production)	440 000	87.7	25	587 000

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