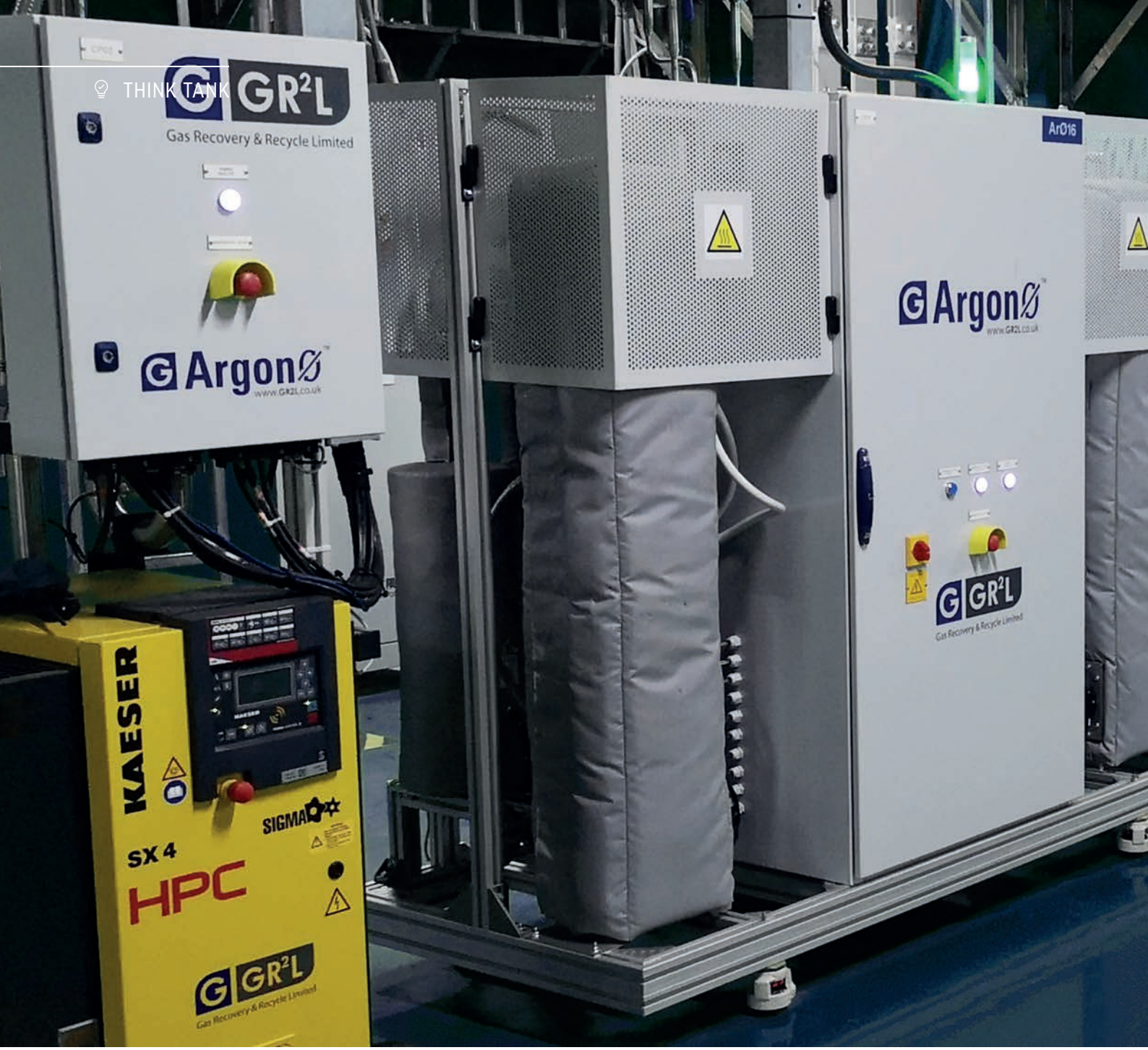
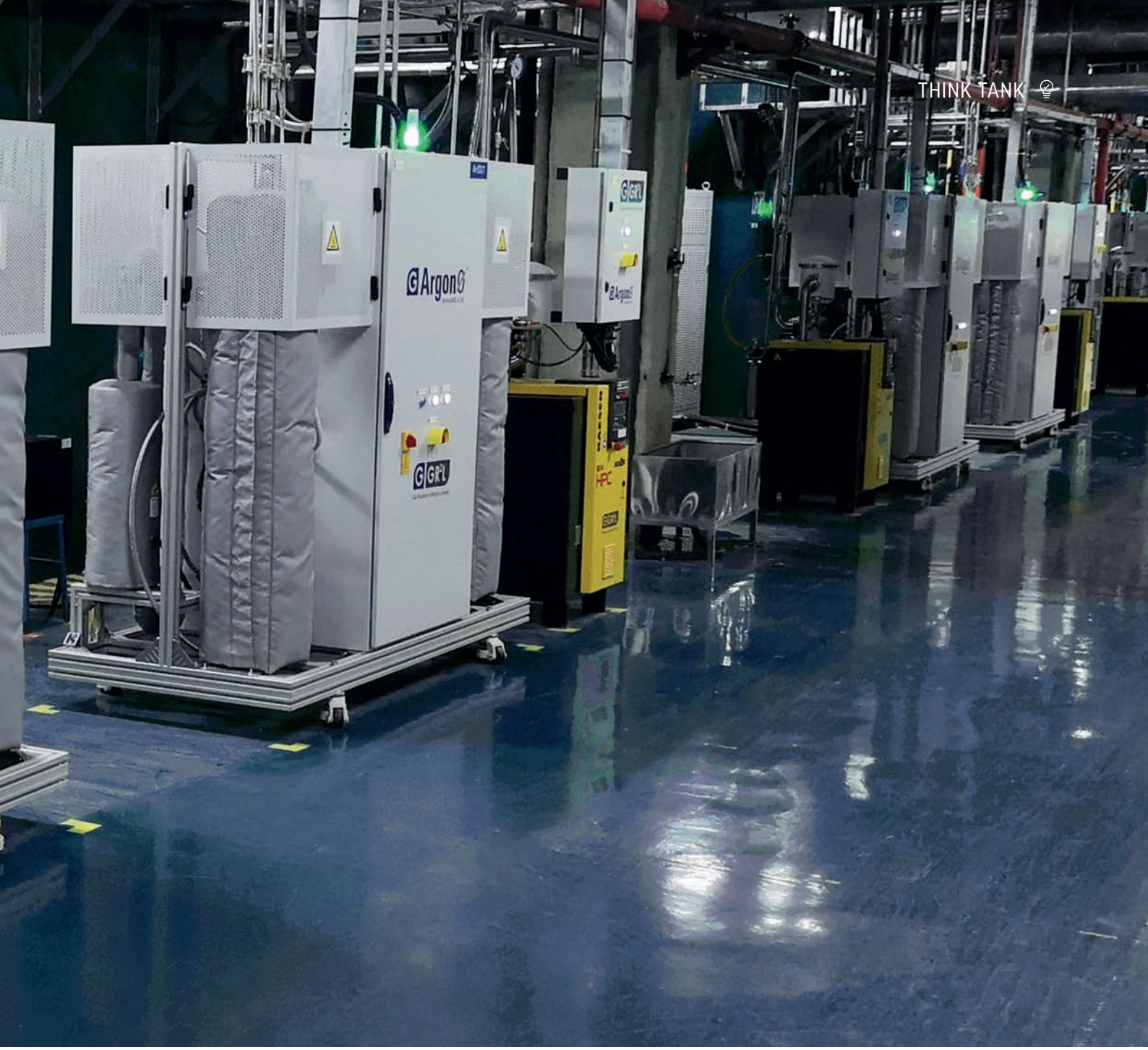


Argon recycle delivers improved cost-base, reduced CO_2 footprint and increased sustainability



High purity argon, better than 99.9998%, is used as a shield gas in the production of silicon ingots, to be fabricated into wafers, for solar cells and micro-electronic devices. The argon is used to control the gaseous impurity levels present during the manufacturing process to an acceptable level. In response to the trend in the solar industry for yet higher efficiency solar panels, the argon purge gas flows used in the CZ ingot pullers have increased by up to 100% in the last 5-10 years, with current purge flows in the 80-100 l/min range, higher purge gas flows translate directly into silicon wafers with fewer defects and improved carrier lifetimes resulting in solar cells with improved efficiency.

CZ furnace hall

The supply of high purity argon is primarily a by-product of the air separation process generating oxygen used in steel making. This means, at best, the supply of high purity argon is essentially fixed and at worst in shortening supply as air separation units are moth-balled in line with reducing steel manufacturing capacity. The laws of 'supply and demand' dictate that the argon price will increase. This is precisely what is being seen in the market, with argon prices increasing by as much as 50% in the last couple of years in some territories even during the Covid-19 pandemic.

There is also a growing requirement for all elements of the Solar PV supply chain to reduce their carbon footprint with some geographies and energy companies, for example in Europe, moving to only approving panels for sale and installation with a low manufactured carbon footprint. After the electricity used to directly heat the CZ ingot pulling furnaces the carbon footprint associated with the purchase of high purity liquid argon, for the inert purge gas, contains one of the highest CO_2 equivalent footprints.

For manufacturers faced with this 'triple whammy' of increasing argon usage, rising argon prices and having to reduce their CO_2 footprint, investing in the Gas Recovery and Recycle Limited ArgonØ™ argon recycling systems, which can reduce the facility argon usage by at least 95%, is a highly attractive proposition! Ultra-High purity wafers for use in micro-electronic chip applications typically utilise 30 to 50% more argon as for the solar PV application but with purities in the 99.999999% level, so argon recycle is even more attractive in this sector.

The ArgonØ point of use recycle system

A typical silicon furnace hall will have up to 100+ silicon ingot furnaces consuming upwards of 12 million litres of high purity argon gas per day. In order to recycle the argon, it first needs to be recovered from the exhaust lines of the vacuum pumps associated with the individual furnaces, then purified and returned to the argon furnace purge supply line i.e. closed loop recycling. Gas Recovery and Recycle Limited (GR2L) has designed the ArgonØ™ to recover, purify and recycle exhaust purge gas from both CZ and DS vacuum furnaces.

GR2L is the global leader in point of use argon recycle with more than 75 systems installed worldwide which are continuously recycling over 360,000 m^3/day of argon and saving its customers millions of USD per year. The ArgonØ™ system achieves gas recycle rates of better than 95%, at purities exceeding the industry expectations. The system is Point of Use and can connect to multiple vacuum furnaces, subject to a maximum recycle flow limit of approximately 20 to 25 m^3/hr for each ArgonØ™ system, this typically results in 4 CZ pullers being connected to one ArgonØ system.

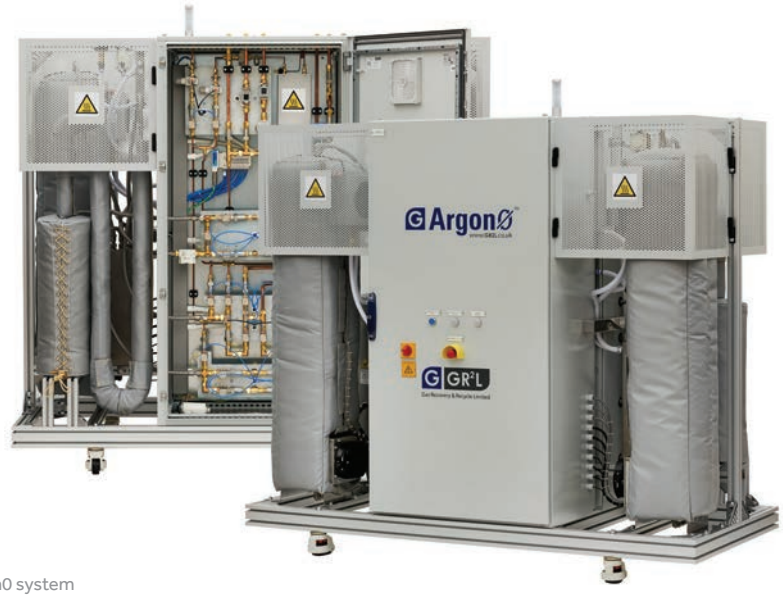
The exhaust gas from a CZ puller furnace is typically contaminated with predominantly carbon monoxide and hydrogen in the 300 to 3,000ppm range along with lower levels of moisture and carbon dioxide although levels up to 6,000ppm of these contaminants can be seen during the recharge process. These gases primarily originate from reactions of moisture and silicon monoxide with process chamber components such as the heaters and insulation.

The ArgonØ system purifies the contaminated exhaust gas recovered from the vacuum pump through a two-step process. In the first step the carbon monoxide and hydrogen are combusted in a solid-state combustion reactor to carbon dioxide and water respectively.

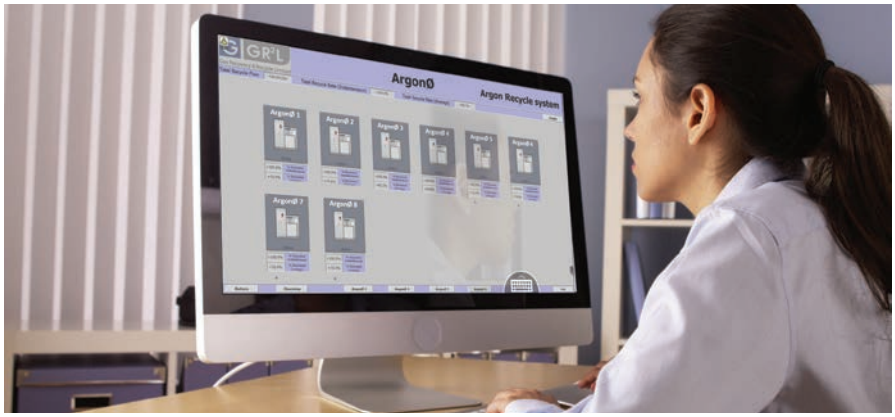
The process utilises a unique patented chemical looping combustive purification technology where no gas phase oxygen is used, guaranteeing the recycled gas is oxygen free. In the second step, the carbon dioxide and water are removed by adsorption onto a zeolite based material resulting in a high purity exit gas to be directed back to the process.

The system includes a gas sensor for the continuous monitoring of the purity of the recycled gas stream. The sensor detects for both oxygen and combustible gases and if out of specification gas is detected the system will respond in <5 seconds to switch the purge gas feedback to house argon and protect the process.

The ArgonØ™ system combines two pairs of reactor/adsorber vessels. One pair online and the other being regenerated and in standby allowing 24/7 argon recycling. No



Argon0 system



PC workstation

other gases or chemicals are needed for the regeneration of the reactor vessels other than compressed air. With few moving parts the system has an uptime of 99.9% and is designed such that most routine service and maintenance can be conducted with no interruption to system operation.

While the ArgonØ™ has an inherent recycle rate better than 98% the operational factory recycle rate is slightly less due to argon losses from the process such as during recharge or the opening and reloading of furnaces, when argon escapes into the atmosphere rather than being delivered to the ArgonØ™ for recycling.

In one location in Asia, ArgonØ™ systems are connected to 60 CZ pullers and have been operating for >18 months without any unscheduled downtime and were retrofitted into the facility with minimal disruption to the production schedules. These ArgonØ™ systems have reduced the facilities argon spend by 94 to 96% giving savings in the order of millions of USD each year.

Control and monitoring

The ArgonØ™ is controlled by a PLC that takes input/output from all the system transducers and valves. It controls the gas flow through the various ArgonØ™ reactors and automatically regenerates them based on the amount of gas that has been recycled. In addition, the PLC has control links to the CZ pullers to open and close the valves that recover the exhaust gas from the various puller vacuum pumps and feed it into the main purifier unit.

These can be discrete hardwired signals from the puller or via an ethernet connection between the ArgonØ ™ PLC and the puller PLC. The ArgonØ™ PLCs are networked together and linked to a central SCADA PC system, where all the system parameters are monitored and recycle rates reported at both the induvial ArgonØ™ level and also site wide level.

The SCADA PC is linked to the Internet providing GR2L engineers the ability to remotely support the ArgonØ™ systems throughout the warranty period. In addition, the SCADA PC is linked to The Cloud, through a secure data publisher, where it reports the key system data on a continuous basis using Aveva Insight. The Cloud based Insight software allows long term performance monitoring of the ArgonØs; average recycle rates, system regeneration frequency, key system temperatures and pressures are all monitored and can be used to trigger email alerts to both the customer and GR2L engineers if the data trend indicates an impending problem.

The Aveva Insight data can be collected into a dashboard view specific for each customer who can log into The Cloud based application and view and download the performance reports as they choose. Within the 12 month warranty period all this remote system monitoring is free of charge, outside the warranty period there is a small service charge for customers to continue to receive this valuable information.

About GR2L

GR2L was founded by Dr Rob Grant FRSC with the objective of commercialising chemical looping combustion technology into the gas purification market. This was jointly developed with Cambridge University. GR2L is a cleantech company specialising in the recovery, purification and recycling of purge gases used in the photovoltaic, microelectronics and the material processing industry sectors.

GR2L's mission is to improve process profitability while reducing CO_2 footprint and increasing sustainability. The company has received numerous awards and grants for its innovate gas processing technology.

GR2L entered into partnership with the UK Gas Technologies group in 2010 to bring their flagship product ArgonØ™ to market.

The UK Gas Technologies Group has a track record in high purity gas installations in the semiconductor and medical markets and is synergistic with GR2L.

For more information please send an email to: sales@GR2L.co.uk

CO_2 footprint reduction

Liquifying air and separating out the 1% argon it contains is a very energy intensive process and results in a bought in carbon footprint of up to 5Kg CO_2 equivalent per $1m^3$ of argon gas. A typical production cell of 4 CZ pullers will have an equivalent CO_2 footprint of about 130 tonnes of carbon dioxide a year, which is similar to the emissions from an average household car driving just over a million miles. By recycling the argon purge gas, the ArgonØ recycle system reduces these emissions by over 90%, a reduction of at least 30 tonnes of CO_2 equivalent per year for every CZ puller in the facility.

In summary the GR2L ArgonØ gives wafer manufacturers the opportunity of reducing their Ar consumption by up to 95% without impacting quality and simultaneously reducing their carbon footprint. Depending on the local argon price, an ArgonØ system can pay for itself in less than 18 to 24 months. The ArgonØ can be retrofitted to existing facilities with minimum interruption to production schedules, as well as be incorporated into new facilities in phase with the vacuum furnace installations.

www.GR2L.co.uk

Rob Grant

Bio

Dr Rob Grant is the founder and CEO of Gas Recovery and Recycle Limited. He has a master's degree and PhD from Cambridge University, UK, and is a fellow of the Royal Society of Chemistry. In 2008 Rob set up Gas Recovery and Recycle Limited to exploit ideas he had for a new gas purification system, based on chemical looping combustion with collaborators at Cambridge University. Rob was previously Head of Technology at Edwards Vacuum, where he was responsible for the company's systems engineering and PV business areas pioneering the introduction of many new vacuum and gas processing technologies.

Rob can be contacted at: rob.grant@GR2L.co.uk