PRISMA Liquid Air Battery

Summary

Innovatium developed the PRISMA (Peak Reduction Integrating the Storage and Management of Air) Liquid Air Battery, a novel Liquid Air Energy Storage System (LAES). PRISMA differs from any other storage technology. It adopts a 'whole system approach' by integrating liquid air energy storage with compressed air systems, which are widespread and energy intensive processes. This approach offers multiple benefits:

- Improves the energy efficiency of the clients' process by virtually eliminating part load and blowdown losses in compressors.
- Avoids peak tariffs.
- Increases renewable penetration of the grid.
- Provides demand side response services.
- Participates in daily wholesale energy and balancing market.
- Offers hours of backup supply of compressed air.

Reducing energy consumption is not always commercially viable. However, PRISMA offers an additional commercial benefit: Its grid services can be sold to suppliers and reduces the payback relative to other storage and battery technologies (both of which tend to be greater than five years).

As part of the demonstration process, we connected PRISMA to the existing compressed air system at the Aggregate Industries Cauldon cement plant. The data showed an energy reduction of 22%.

PRISMA would benefit sectors such as aggregates, food and drink, automotive, pharmaceutical, chemical, and electronics. In this case study we focus on the aggregates sector.

The Industrial Energy Efficiency Accelerator (IEEA)

The IEEA programme supports the development of innovative technologies that will help industry reduce energy consumption and cut carbon emissions. It focuses on innovations with large potential cross-sector energy and carbon reduction impact - either new technologies or established technologies applied to new sectors. Over £15 million in public and private funding has been committed to develop solutions through partnerships between technology developers and industrial companies willing to test technologies on-site. The programme is funded by the UK government (BEIS) and managed by the Carbon Trust, with support from Jacobs.

Introduction

Having spent many years working within the compressed air industry, the Innovatium team saw first-hand the challenges of decarbonising and becoming more energy efficient. The team wanted to challenge itself and identify a solution that could overcome these challenges through truly innovative, unproven technology. The PRISMA Liquid Air Battery is the result of four years of research and development, supported by the IEEA programme, transforming the way in which the industry consumes energy.

The PRISMA Liquid Air Battery has the potential to reduce users' energy bills by up to 25% while providing them access to the additional benefits noted above. Rolling this system out across UK industry could significantly reduce energy costs and CO_2 emissions, thereby helping to accelerate the move towards Net Zero by 2050.

Through the financial support from IEEA, we were able to bring this project to life and bring together the consortium of partners. This was essential in delivering a positive outcome.

About the innovation

The PRISMA system is essentially a mini-liquefaction plant contained in a single vacuum insulated tank. It can hold up to 150 times the amount of energy as liquified air compared to existing compressed air storage systems. Energy recycling is the key to PRISMA's efficiency.

While charging, the liquid air store is supplied with ambient temperature compressed air. This air is then chilled to -150°C through the 'sensible coolth store' to the condensation point where liquefaction begins. In the same vessel, this saturated air passes to the second 'latent coolth store' which contains a unique Phase Change Material (PCM). There the air is fully liquefied and can be stored for long periods in the integrated vacuum storage tank. When needed, the whole cycle runs in reverse to provide hours of clean, dry compressed air for client demand. Typical industrial compressors cycle between high and low load, and often spend time idling. The Prisma system is charged using a small efficient compressor which is run continuously, taking excess air capacity from the main compressor thereby smoothing its operation, with peaks in demand supplied from the store, is how the energy saving is achieved.

This is the first time PCM is used in an industrial demonstration at cryogenic temperatures. It is a critical driver of PRISMA's performance.

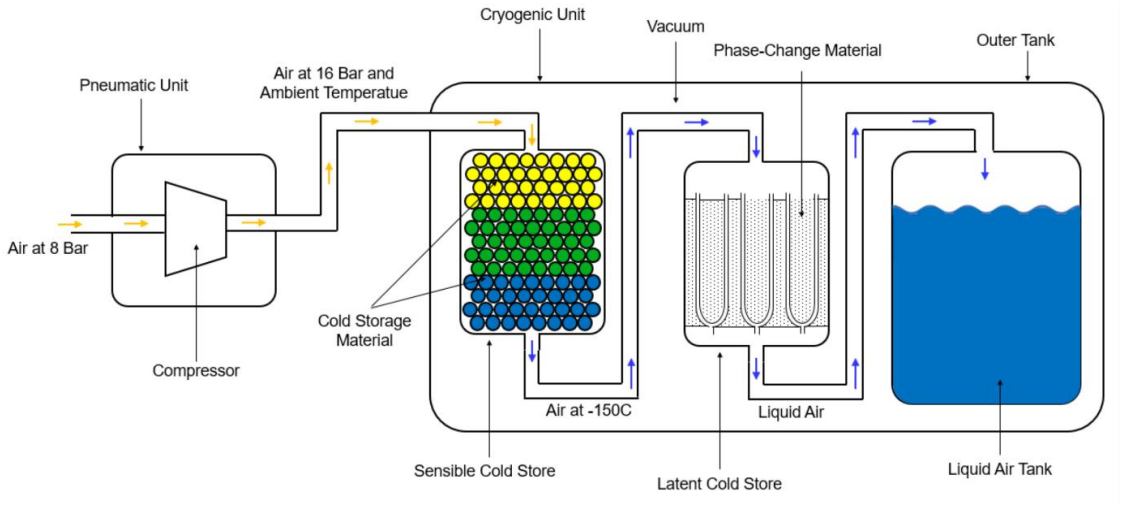

Figure 1: The PRISMA process diagram

Figure 2: Adrian Alford (CTO) talking about the Sensible Heat Store

Figure 3: Simon Branch and Adrian Alford with PRISMA

The demonstration

PRISMA at Aggregate Industries, Cauldon, Staffordshire, UK

Through the IEEA programme, Aggregate Industries became the industrial end user partner for the project in 2018. Following extensive research and development, the demonstrator unit was placed at Cauldon in early 2022. Aggregate Industries is the UK subsidiary of Holcim and their Cauldon plant is one of the largest cement factories in the UK.

Globally, cement is the second most consumed substance after water and contributes nearly £1 billion annually to the UK economy. However, its manufacture is an extremely energy and carbon-intensive process, emitting 4 million tonnes of CO_2 annually in the UK alone. Compressed air is a very important tool in cement production. It can be used for a wide variety of processes, from conveying raw material to suppressing dust. Nonetheless, it is inherently expensive and inefficient. Only 10% of the electrical energy input goes to producing useful mechanical work. PRISMA has been designed to address these inefficiencies.

PRISMA was sited next to the compressor house at Cauldon and was connected to the existing compressed air system by a single airline. Five main compressors run constantly at an approximate efficiency rate of 60% with an air loss rate of 33%. The annual running costs are over £1 million.

Figure 4: Exterior of Cauldon Cement Works

Figure 5: Interior of compressor house at Cauldon

Development

The PRISMA demonstrator represents over three years of development by the Innovatium Team, supported by key partners including Wessington Cryogenics and the University of Birmingham. The system was fabricated at Wessington's facility in County Durham where off-site testing was also conducted to iron out issues before shipping it to Cauldon cement works in March 2022 to be installed and commissioned.

Installation and trials

The system was installed adjacent to the compressor house at the Cauldon site, with a 7 bar input airline connected and the output airline attached, feeding 7 bar air back into the compressor output lines.

Figure 6: Simon Branch recording data

Figure 7: The installation of PRISMA at Cauldon

Monitoring

For the PRISMA project, we measured the client's existing energy consumption to produce compressed air. The client's system consisted of 5 x 275kW oil-free reciprocating compressors with desiccant dryer air treatment. Using a power meter, we measured the input energy consumption of their 275kW peaking compressor. The output compressed air flow figure from the existing compressors was derived using compressor manufacturer data and site knowledge of use case air consumption. Similarly, the efficiency of the PRISMA booster and liquefaction system was measured using both power and flow meters, so a comparison could be made. The testing and measurement took place over three separate days in April 2022.

Results

Quantifying the improvement in efficiency and carbon emissions of the PRISMA system over the existing compressors required energy consumption (kWh) per unit volume (m^3) calculations. The specific energy consumption of the existing compressed air system at Cauldon Works was 0.214 kWh/m^3. With the PRISMA system in operation, the specific energy consumption of the compressed air system was 0.166 kWh/m^3, representing and improved energy efficiency by 22.4%.

The PRISMA system's maximum outlet flow was designed to provide 10% of the full flow of one site compressor that would be sufficient to demonstrate the technology and its ability to scale. Whilst the 22.4% savings would be possible at full scale, the actual efficiency saving measured at site where only 10% of the system flow is replaced were 5.4%. This is summarised with the corresponding CO_2 reductions in the table below.

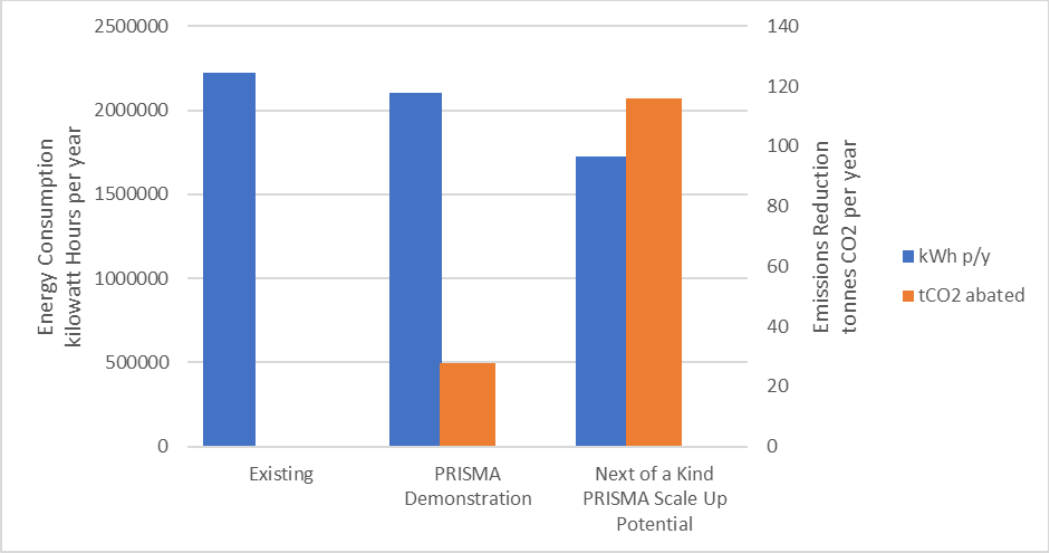

Figure 8: PRISMA actual energy and CO_2 savings of demonstrator and projected scaled-up savings for site

Some factors need to be considered alongside these results. The non-productive, or parasitic, power of the system has been measured and included. However, the top-up cooling using liquid nitrogen to maintain the cold temperatures, has not been included in our calculations and will marginally increase PRISMA's energy consumption on future systems. The results were also based on short duration tests cycling six times over three separate days due to site constraints. Further near-term continuous testing is planned that will integrate improvements learned from the demonstration at Cauldon.

Offloading compressors using the PRISMA liquid air energy storage system to operate the site a reduction in energy consumption from the averaging baseline and is viewed by the electricity grid as equivalent to power generation and therefore can be sold to a supplier as grid balancing and in the future, wholesale arbitrage. This allows the PRISMA system to be charged when electricity is at its lowest cost and discharged when the price is high, ultimately generating significant revenue. The advantage of the PRISMA energy storage system over Li-ion batteries is that there is no restriction on the number of cycles it can perform daily and across its predicted 25–40-year lifetime. The ownership model for the PRISMA system means that the monthly lease is covered with income generated above and beyond paid to the client. This model provides energy, carbon and cost reductions from day one, with no initial outlay for the PRISMA system other than installation costs.

Future impact

Industry accounts for 27% of all electricity consumption in the UK (DUKES - 2020), and compressed air production consumes 10% of this on average. That's 11.7TWh per year, equivalent to over 4 $MtCO_2$ emissions pa (BCAS – 2020). As such, integrating liquid energy storage into compressed air systems presents a unique opportunity to reduce emissions and help the UK move towards its Net Zero 2050 target. As part of the project, Innovatium commissioned a third-party study into the UK market. Here, primary consideration was given to the size of potential industrial sectors and how attractive each of these are with respect to the energy used for compressed air. This report backs up existing knowledge and informs the go-to-market strategy for target sectors such as chemical, food and drink, paper, pharmaceuticals and minerals/aggregates.

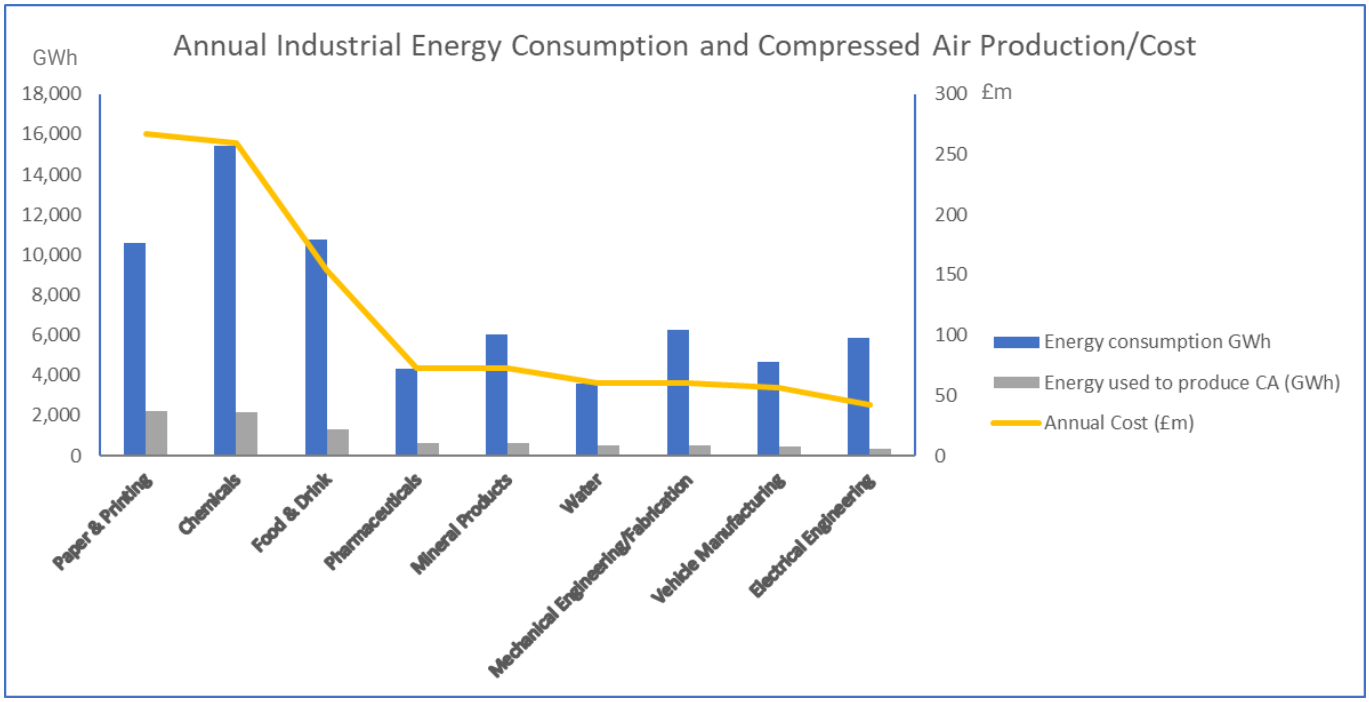

Figure 9: Annual industrial energy consumption and compressed air product/cost

In the UK alone, the total addressable market across these sectors covers 10,000 sites. As the focus is on the largest and most energy intensive sites, this narrows the pool down to around 2,000 target sites. The impact of incorporating PRISMA across these sites is significant, not only in terms of reducing energy costs, but also in terms of reducing CO_2 emissions. It is estimated that 100,000 tonnes of CO_2 could be saved annually based on efficiency savings alone.

**Average annual CO_2 emissions per site: 1,300 tonnes.*

Innovation lessons

The PRISMA project was launched to address a specific need within a widespread application: compressed air. During the project, both domestic and international policies adapted quickly to address the issue of global warming. A key learning from the project was to increase market awareness and analyse changing regulation, as this can alter commercial models. However, the general trend is to place a higher value on carbon reduction technologies.

Adaptability to change for all the project partners was displayed throughout the project, dealing with challenges across technical, infrastructure, personnel, and the project deliverables areas.

The PRISMA system has completed a short test and demonstration cycle. Now, following the IEEA project, we are planning to incorporate the learnings from the project into a commercial product. One that has design improvements to cut cost and improve performance and efficiency. A key part of the commercialisation step is to engage with partners who are essential to energy markets integration, especially those who may be unfamiliar with this type of technology. Supply chain partners, who have the design capability and a high standard of quality system, will also play a critical role.

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