**Round Table 2 – Transport**

13th March 2013
Institution of Mechanical Engineers

| Participants | Company |
|---|---|
| **Prof. Colin Garner (Chair)** | **Loughborough University** |
| Dr. Andy Atkins | Ricardo |
| Philippa Oldham | IMechE |
| Nick Rodgers | Productiv |
| Bob Austin | Productiv |
| Dr. Marcello Contestabile | Imperial, OLEV |
| Dr Chris Brace | University of Bath |
| Dr. Andrew Simpson | Wrightbus |
| Simon Palmer | Bergstrom |
| Ian Bacon | SMMT |
| John Raquet | Spiritus consulting |
| Toby Peters | Liquid Air Energy Network / Dearman Engine Company |
| Jeremy North | Dearman Engine Company |
| Michael Ayres | Dearman Engine Company |
| Dr Henry Clarke | Dearman Engine Company |

**Aim of Discussion**

- To identify the attributes of liquid air technology and the possible transport applications.
- To discuss the potential benefits to the UK PLC and how policy can influence the future of liquid air technologies.

## 1. Attributes of liquid air technology for transport purposes

The round table discussion began with an introduction of the liquid air technology and its attributes that are potentially relevant to transport applications. The participants agreed the following likely attributes as most valuable (*not presented in any order*).

| Attributes | Comments |
|---|---|
| Benign | The technology has no scarce or toxic materials. |
| Zero emission | This is particularly important when operating in enclosed environments. |
| Low cost | |
| Mature infrastructure and equipment | Fuel + driver operated filling systems are available, etc |
| Fast fuelling time (100litres/minute) | Compared to EVs that take hours to charge, fuelling time for liquid air takes just a few minutes. |
| Low environmental impact | No scarce materials used, long lifecycle, recycling. |
| Waste heat to power | Can harness low grade waste heat (low complexity and no competitor for low grade heat recovery) |
| Reciprocating technology/Mature base technology | |
| Ease of maintenance | Mechanical process, not chemical |
| No expensive/exotic materials required | Whole of life cost<br>Recycling<br>More immune to cost fluctuations |
| Lair, LN2 easy to store | Can be stored at low pressure |
| Piston engine so likely to be robust/rugged | Difficult to break |
| Non combustive | Could be valuable for mining applications, etc |
| Symbiotic / Compatible with other technologies | e.g. IC engines (waste heat to power or intercooling), waste cold from LNG regasification, waste heat from cooling for the built environment, etc |

## 2. Transport Applications

The round table considered the potential role for liquid air as a working fluid/'fuel'. A cryogenic fuelled engine could be deployed as either the prime mover – the only or principal source of power in a vehicle – or in a supporting role to recover waste heat from a conventional IC engine (or fuel cell). In this secondary role the liquid air device can either be used to produce shaft power to reduce the load on the primary engine, or to power auxiliary functions such as refrigeration or as an intercooling system to cool the IC engine cycles.

The three main applications that the participants were keen to discuss are listed below.

- **Zero Emission Vehicles**

  It was concluded that liquid air technology could compete with battery and fuel cell technologies as a power source, given speed of refueling and low cost. Zero emissions engine demand in industrial ZEV applications is specifically driven by air quality. The round table was particularly enthusiastic about warehouse vehicle applications such as forklifts where the vehicles operate in enclosed environments.

- **Refrigerated Transport**

  Refrigeration currently accounts for approximately 8% of a chilled delivery vehicle's diesel consumption, as well as significant emissions including refrigerants. The group noted that Linde, Messer and Air Liquide are already using liquid nitrogen for refrigeration purposes but the Dearman technology can offer cooling *and* provide a power source, thereby offering enhanced economic value. Refrigeration units are normally replaced every 5 years, suggesting there could be a significant retrofit market.

- **Hybrid with an Internal Combustion Engine - Waste Heat to Power**

  The participants discussed both the Ricardo liquid nitrogen split cycle engine - which uses liquid nitrogen to achieve isothermal compression in a split cycle engine – and also an auxiliary secondary liquid air engine to recover waste heat from the cooling loop or exhaust of the prime mover IC engine. The power from this second unit could either be used to supply hotel loads on a constant power basis or used more like an electric hybrid to peak shave the IC engine's operation. 60% of the available energy of every litre of diesel is lost to atmosphere through the radiator and the exhaust. Participants stressed the unique ability of the liquid air engine to harness low-grade waste heat from the radiator cooling system at low capital cost and felt that high levels of efficiency make the technology commercially exciting as a hybrid with petrol and diesel IC engines.

  Packaging was identified as a key challenge, especially in buses where space taken up by increased fuel storage means less space for passengers. On some duty cycles, it is a challenge to get sufficient range using hydrocarbons and therefore pure liquid air technologies (like all zero emission options) are not suitable for such applications but could benefit from an appropriate hybrid approach.

A list of applications that were considered can be found in the Appendix below.

## <u>3. UK Benefit / Value added to UK PLC.</u>

After identifying the potential applications of liquid air technologies in the transport sector, the attendees were keen to discuss the benefits and the value added to 'UK PLC'. They emphasized the wider economic benefits in terms of employment, expertise and research opportunities that would arise with the development of a liquid air industry in the UK.

Battery technologies are popular in the US, Germany and Japan because batteries are indigenous industries to those areas. The round table agreed that liquid air could be an opportunity for the UK to develop its own indigenous industry and export it globally.

UK currently produces 2.7 million IC engines each year. The strength of the UK motor industry is also in design and IP, and the potential gains from research opportunities and high value engineering were emphasized. Participants felt that there is an opportunity for the cryogenic industry to cooperate with universities to exploit liquid air further. Broad investment in research into liquid air would place UK in a world leading position in this field. It is likely that with limited additional effort in terms of funding for research, significant progress could be made with liquid air, thus expanding the UK portfolio of technologies.

Continuing with the research theme, participants highlighted the opportunity for SMEs in taking on further research in order to adapt the engine for different uses. Such SMEs could attract external funding and foreign investment that could be used to employ people in the UK.

The round table agreed that the UK has a strong advantage in cryogenics and an opportunity lies in creating value added through high value engineering and integration, rather than simply manufacture. It was also agreed that it would be possible to incorporate UK 3D printing facilities into liquid air engine production.

On job creation, the participants highlighted the importance of whether industry should provide high volume minimum wage assembly jobs, or lower volume more highly skilled jobs. The general understanding was that focus should be on higher value engineering and integration.

In order to make liquid air a UK-led global industry, it was suggested that the Dearman Engine concept could be applied to UK-centric vehicles such as taxis. This is an attractive opportunity from a policy point of view because of the Mayor of London's objective for zero emission taxis by 2020. China is already developing zero emission taxis for export.

The major advantage that was continuously emphasized was the fact that there is an existing supply chain for liquid nitrogen, and excess production capacity of some 8,500 tonnes per day of nitrogen gas, which could be exploited to support initial deployment of liquid air technologies.

## 4. Policy

The round table agreed that liquid air could provide major benefits under the three main themes of UK energy policy: decarbonisation, energy security and affordability. However, they also agreed that the projected benefits may never be realised without appropriate policy support.

The attendees agreed that the scope of many grant funding calls in the UK at the moment is very limited and there are very specific boxes that need to be ticked which make it difficult for new technologies to be successful. The implementation of the Automotive Council Roadmap can tend to be technology rather than outcome driven.

Assessors also need to be aware of liquid air and understand its applications in order to fund related research projects. This is particularly important for grant applications that are space limited, as there is insufficient space for explanation of operating principles and proofs. It was suggested that there could be a mechanism (funded through SMART for example) for technology areas such as liquid air to achieve pre-clearance to apply for government funding programmes so that the assessors can be certain that the technology is credible.

It was highlighted that standardisation and a dialogue about appropriate regulation is needed in good time so that it does not become a barrier to deployment. At the moment there is no attempt to standardise the elements in cryogenic technologies. Standardisation would result in cost savings through economies of scale.

The attendees all recognised that it is important to look at the wider sustainability argument and the Centre for Low Carbon Futures could deliver more information about what liquid air technology could achieve through lifecycle analysis of liquid air and other low carbon technologies.

London Mayor Boris Johnson has plans to make London a zero emission city by 2020 and the round table felt that policy should enable liquid air to compete on a level playing field with other technologies to achieve this goal.

## 5. Conclusions

- The most valuable attributes of liquid air technologies for the transport sector were identified to be the benign/clean technology, cost, the mature and existing infrastructure as well as its compatibility with other technologies.

- In terms of specific applications, the the round table pointed out there are many potential uses for liquid air technologies in the transport sector that included military, marine and airplane applications as well as refrigerated transport and autonomous vehicles that operate in factories.

- It was agreed that policy support is vital in developing the liquid air industry. The challenge lies in educating policy makers and ensuring that liquid air is one of the solutions considered in making London a zero emission city by 2020.

- The round table was very optimistic about the benefits that liquid air as an industry could provide to the UK. These benefits included highly skilled jobs as well as various research opportunities for academics and SMEs bringing further employment and expertise to the UK.

- It was emphasized that liquid air technologies can exploit the already existing excess supply of liquid nitrogen in the UK of around 8,500 tonnes a day.

# Appendix

Supercharger

Airplane applications

ZEV Passenger car

Forklift trucks and other autonomous vehicles around a factory

Getting offshore wind ashore

Electric systems

Start/stop application on bus

Refrigerated transport (food)

Refrigerated transport (Biological)

Military applications

Ferry/water craft

Mining applications