The Dearman Engine COMPANY

EXECUTIVE SUMMARY

The Dearman Engine Company Limited (DEC) is developing a novel, zero emission, piston engine that runs on liquid air (or liquid nitrogen); the exhaust is cold air.

Working with Ricardo, a leading, award-winning global engineering consultancy, and our engineering partners (attached), we are on track to deliver a test engine by end 2013, for testing and demonstration in Q1, 2014. We also intend to deliver a "proof of concept" vehicle by Summer 2014 to prepare for full application specific field trials; and are working with MIRA ((Motor Industry Research Association), the UK's foremost vehicle engineering design, test and development centre) on this programme.

With our engineering and commercial teams, we have defined likely first products for market. At this stage of development, three groups of significant industrial applications for the technology have been identified:

(i) ***a stand-alone zero emission engine (ZEV) exhausting cold air***; for city vehicles and highly relevant for multi-billion $ global on-and off-highway applications, including industrial (e.g. fork-lift trucks), mining and inland waterways applications, as well as the built environment.

(ii) ***a very high yield low-grade heat energy recovery system***; to be integrated with an internal combustion engine (or fuel cell); *this could practically increase overall fuel efficiency by up to 30%.*

(iii) ***a cost-effective and zero-emission combined power and cooling solution*** (applicable to mobile refrigeration – a multi-billion $ global retrofit market). *Refrigeration currently accounts for approx. 8% of a chilled delivery vehicle's diesel consumption.*

The Dearman engine is underpinned by a wider programme to develop liquid air as a new "Energy Vector" led by the Royal Academy of Engineering, the Institution of Mechanical Engineering, the Centre for Low Carbon Futures and a number of Universities and industrial parties.

THE CORE TECHNOLOGY
(please see summary attached)

The Dearman engine, invented by Peters Dearman, operates by boiling liquid air to produce high pressure gas that can be used to do work.

The Dearman Engine Company owns all IP, including that generated by Ricardo in the development programme.

TECHNOLOGY BENEFITS

The engine is likely to have key advantages in terms of:

- Capital Cost
- Non-combustive and non-flammable fuel
- Durability/lifetime
- 7x more energy dense (by volume) than compressed air
- Stored at atmospheric pressure
- Waste heat to power
- Rapid re-fuelling

Additionally:
- Potential to exploit large parts of the existing powertrain supply chains and expertise.
- Substantial pre-existing infrastructure to support early deployment.

LIQUID AIR AS AN ENERGY VECTOR

Although cryogenic liquids are widely used in industry, their adoption as an energy vector (critically harnessing wrong-time renewable energy to replace fossil fuels) is only just beginning. However the potential is recognized as huge and liquid air is rapidly becoming part of the low carbon energy solution.

- Air is abundant and available without cost;
- Existing infrastructure to support early adoption;
- Mature supply chain/components;
- Storage is at low pressure: safe and low cost
- There is no fuel combustion risk.

Furthermore liquid air technologies are uniquely able to recover low-grade waste heat from sources such as thermal generation, data centres and industrial processes, or internal combustion (IC) engines in vehicles and convert it into power.

A six-month study on the potential of liquid air as a new and sustainable energy vector will be presented at a one-day conference at the Royal Academy of Engineering on Thursday 9th May. Published by the Centre for Low Carbon Futures, the report investigates whether liquid air could provide a credible alternative to existing energy storage systems and low carbon transport solutions to better harness renewables and deliver energy security; and if so what could its economic value be to UK PLC?

The white paper is based on contributions from a wide range of energy experts including world-class consultancies such as Arup, Poyry and Ricardo, the German industrial gases company Messer, and academics from the Universities of Leeds, Birmingham, Strathclyde, Brighton and Imperial College.

See Royal Academy of Engineering and Centre for Low Carbon Futures conference – 9th May 2013

LIQUID AIR – ENVIRONMENTAL VALUE

Although cryogenic liquids are widely used in industry, their adoption as an energy vector (critically harnessing wrong-time renewable energy to replace fossil fuels) is only just beginning. However the potential is recognized as huge and liquid air is rapidly becoming part of the low carbon energy solution:
- Air is abundant and available without cost; - Existing infrastructure to support early adoption; - Mature supply chain/components; - Storage is at low pressure: safe and low cost; - no fuel combustion risk.

Liquid air and nitrogen are zero-emission fuels at their point of use, offering the same potential for dramatic local air quality improvement as electricity or hydrogen; the materials used in the engine and its fuel tank are commonly known with low environmental hazard in disposal.

Greenhouse gases from the liquefaction process require consideration as the liquefaction plant is usually electrically powered. However, most large-scale liquefaction already uses off-peak electricity with a lower carbon intensity than this average; and by 2030, it has been estimated that the Dearman Engine ZEV using fuel liquefied with off-peak electricity, including surplus renewables, would have a lifetime carbon footprint similar to a 2030 electric vehicle (with lower risk in terms of exotic materials). For other applications, the comparison is even more favourable.

- A heat-recovery hybrid system would offer carbon break-even today (with savings in operating cost and fossil fuel use), and a CO_2 saving of 25-40% by 2030.

- A refrigeration system offers a very significant 80% saving today compared to a diesel-auxiliary system, with potential for 98% by 2030.

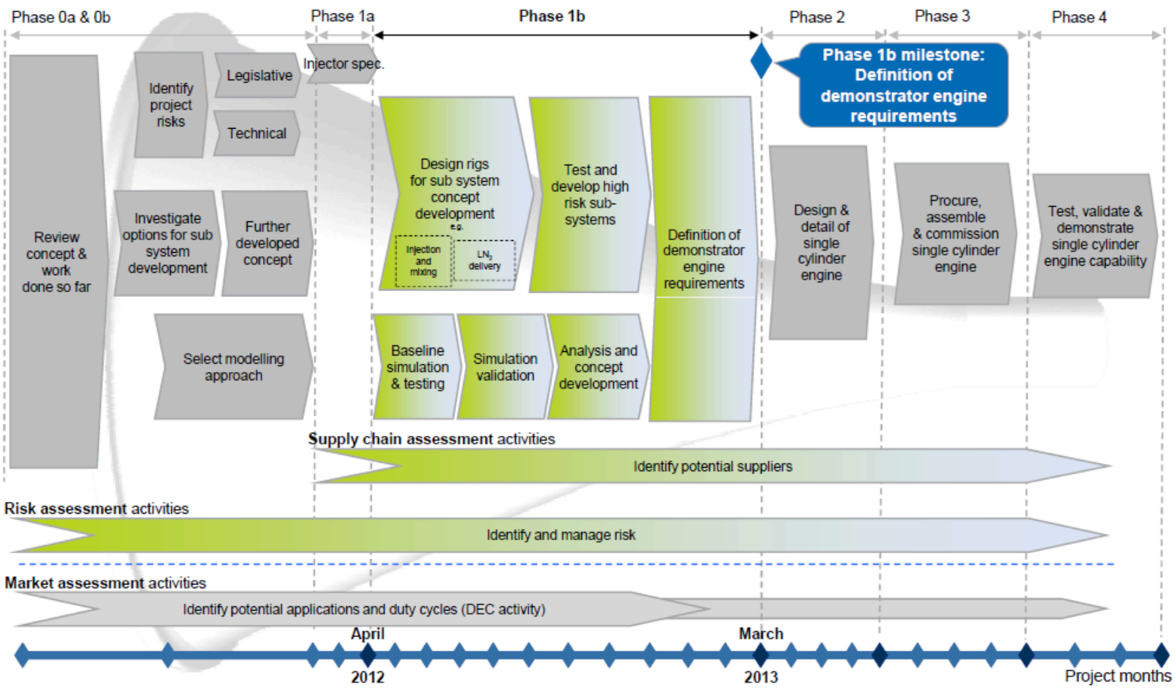
TECHNOLOGY DEVELOPMENT – SUMMARY

The engine was the subject of a 4 year PhD at Queen Mary University of London as well as independent analysis at the University of Leeds. The work delivered a "proof of concept" engine which produced positive power and specific energy competitive to lead acid batteries.

In Q4 2011, the management team and Ricardo designed a technology development programme to deliver

- an optimised and fully characterised demonstration engine by end of 2013,
- three months of testing and demonstration during Q1, 2014 and
- a technology roadmap.

The programme has clear gated stages with peer review to reduce risk and minimise development costs and time to commercialisation. It has been extended to include a first proof of concept vehicle/ integration mule.



Phase 0 – 2011

As 'Phase 0', during Q4, 2011, Ricardo undertook a rigorous independent technology review, engine feasibility study, development of a detailed risk register, and a review of market potential.

Along with validating the work to date and the "proof of concept" engine, the engineering team from Ricardo stated that *"there are numerous practical applications for the technology in the future market place. The technology is likely to compete with hydrogen fuel cell and battery electric systems in zero emission applications. The low cost and simplicity would benefit the penetration of this technology. In the longer term, the technology could also be suitable for small vehicles operating in urban environments."*

Ricardo additionally

- found no road-blocks or challenges to a commercial engine for which potential engineering solutions were not identified.
- believed that existing, simple, mature technology and components could be used, thereby delivering an efficient and cost effective route to a proficient system and significantly reducing the cost of development and first commercial deployment.

Additionally it was noted that using liquid air (or liquid nitrogen) as a fuel has the advantage of relying on the existing industrial gases global distribution infrastructure. It could even be generated in remote sites using renewable energy sources to drive small liquefaction plants.

The Company appointed an advisory panel of experts from Universities of Loughborough, Brighton, Leeds and Queen Mary and the Science and Technology Facilities Council Rutherford Appleton Laboratory to peer review the work of Ricardo; they strongly endorsed the team's findings.

Phase 1 – 2012/Q1 2013

During 2012, the Company funded Ricard to undertake:

(i) design, procurement and testing of the injector system (called Phase 1a);

(ii) development and optimisation of the key engine sub-systems (Phase 1b);

Using both high-speed photography at the University of Brighton and a mixing rig at Ricardo to measure rate of pressurisation and peak pressure, Ricardo has successfully executed all planned test points for the injector.

This addressed the main risk identified by Ricardo - injection. The programme subsequently moved to the mixing and heat transfer processes necessary to achieve peak efficiency and power. Injector development has also now moved from achieving liquid injection to developing a more production ready solution.

Given the success of the injector programme, the team (Ricardo, peer review panel and DEC) has brought forward second order aspects of the full engine design, e.g:

- Sealing the expansion chamber;

- Heat Exchange Fluid freezing;

- Lubrication;

- Heat Exchange Fluid delivery, control, removal and heating.

The advisory panel has also been expanded to include engineers from University of Birmingham and E4Tech to expand the breadth of expertise available to the project.

"This is still a very compelling and exciting technology that could potentially open up significant new markets and opportunities. The programme of work is progressing very well and is answering many important technical and commercial questions. No major barriers to the technology have yet been identified. Valuable new knowledge, ideas and IP are being continually generated. There are a number of important questions that will be addressed as the team progresses through the well-defined programme. I continue to be very impressed with all the team members and the organisations involved with this work." Professor Colin Garner, Perkins/Royal Academy of Engineering Professor of Applied Thermodynamics at the Wolfson School of Mechanical & Manufacturing Engineering.

Phase 2 – 4 current through to Q1 2014

Critically potential showstoppers identified by Ricardo in Phase 0 have now been downgraded to performance challenges, which the Phase 2 to 4 work will seek to address. The key areas of focus are the LN2 injection mass and the frictional and parasitic losses; which will determine the range of applications, especially in ambient operation.

Following successful conclusion of the Phase 1 programmes, the company this year is undertaking with Ricardo;

- The design and build of a full single cylinder test engine in operation by Q1, 2013.
- Three months of engine testing and demonstration during Q1, 2014.
- Additional engineering resource and technical advisory services to support the engine build programme, deliver ancillary systems and build the IP portfolio
- Commercial development and market analysis activity supported by Ricardo and E4Tech to include product mapping, cycle analysis, market research and economic modelling

Additional work

The company is also planning to execute the following additional projects over the next 12 months that will de-risk elements of future development along with accelerating exploitation of new opportunities:

- Mobile system installation and demonstration of waste heat to power and cooling on a vehicle with MIRA;
- Preparation for a refrigeration unit prototype – (power and refrigeration unit);
- Develop and test "advanced" injector concepts with the Science and Technology Facilities Council's cryogenics team.

For further information, please contact:
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Team

Dearman Engine Company is a spin out of Highview Power Storage. It was founded in 2011 to develop and exploit IP relating to Dearman Engine technology. Its staff and advisors have experience of both technology, business and commercial development in a number of other contexts:

- Toby Peters (founder / CEO) is also a director and founder of Highview. He was a co-inventor of Highview's award winning liquid air energy system and has driven the technology and business from inception through to demonstration and commercial partnerships. He is currently leading a wider industry, academic and policy debate around liquid air as a novel energy vector.

- Jeremy North (Chairman/co-founder) after qualifying as a chartered accountant in the early 1990s, was CFO of one of the UK's most successful publishing houses during its IPO. Since then, he has held a number of CFO and business development roles across a broad spectrum of media, property and technology businesses in Europe, Asia and US.

- Michael Ayres (COO/co-founder) worked at Highview Power Storage as Head of Development where he established the UK's first cryogenic energy storage test facility and was a programme manager for a variety of development projects around cryogenic power systems in UK, US and China.

- Dr Henry Clarke (Lead Engineer – Core Technology) in 2011 completed a 4 year PhD at Queen Mary University of London focused on theoretical aspects and practical testing of the Dearman Engine technology.

- Michael Dearman (Projects Engineer) - A highly practical engineer trained in CAD and experienced in supply chain development, he previously worked in the Highview cryo-energy lab, testing Dearman engines and Highview's turbine technology. He also played a major role in the build of their grid connected liquid air energy storage system at Slough Heat and Power.

The Company is planning to recruit a CTO / Head of Innovation and Technology during 2012

Ricardo is a global, world-class, multi-industry consultancy for engineering, technology, project innovation and strategy. With a century of delivering value, they employ over 2300 professional engineers, consultants and staff.

Advisory Panel

The function of the advisory panel is to provide an additional source of expertise (and a broad range of skills) and provide a peer review process to the work Ricardo is executing with the Dearman Engine Company. The membership of the advisory panel is;

- Dr Steven Begg, Brighton University, Senior lecturer and leader of the gasoline combustion engines group of the Centre of Automotive Engineering at the University of Brighton. *Steven's past and current projects involved working for Ricardo, Jaguar, Ford and BMW*

- Dr Tom Bradshaw, Head of Cryogenics and Magnetics, the Science and Technology Facilities Council (STFC), Rutherford Appleton Laboratory. *Tom has led teams that have supplied cryogenic and cooling systems for satellites launched by the European Space Agency.*

- Professor Yulong Ding, University of Leeds, Director Institute of Particle Science and Engineering. *In addition to holding visiting Professor positions at 6 other universities in China, Yulong has led research projects for Ansteel Corporation, Shell Global Solutions, GSK and Proctor and Gamble. He is actively involved in the development of liquid air as an energy vector in the UK and China.*

- Professor Colin Garner, Loughborough University, Perkins/ Royal Academy of Engineering Professor of Applied Thermodynamics in the Wolfson School of Mechanical and Manufacturing Engineering. W*orks with a broad range of engine and automotive manufacturers.*

- Dr Dongsheng Wen, Queen Mary University of London, Reader in Future Energy. *Prior to completing his PhD at Oxford, Dongsheng completed qualifications in thermophysics and cryogenic engineering in Beijing.*

- Nick Owen, E4Tech, Principal Consultant. *Prior to joining E4Tech Nick was Project Director, Research and Collaboration at Ricardo where he worked on hybrids, electric vehicles, fuel cells / hydrogen, flywheel energy storage and split-cycle engines using cryogen intercooling*

- Dr Athanasios Tsolakis, University of Birmingham, Reader in Thermodynamics. *Thanos has published more than 100 papers in journals and conference proceedings in the areas of fuels and fuel treatments, IC engines, combustion and emissions control technologies. His research covers both fundamentals and industrial applications and he is the named inventor on three patents.*