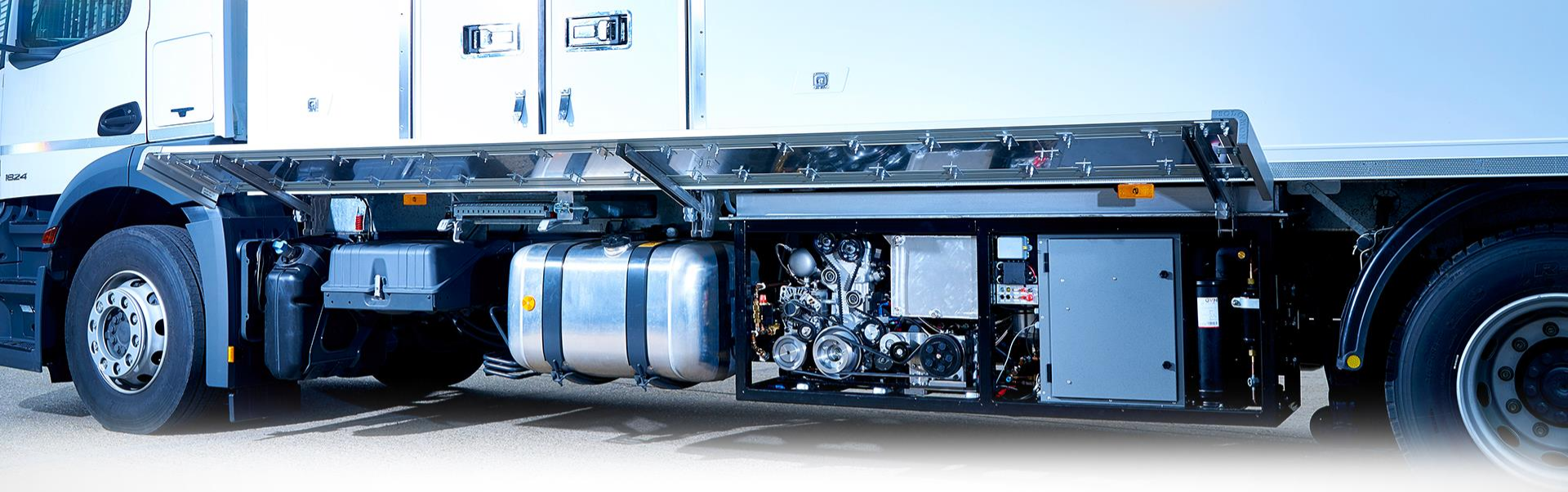
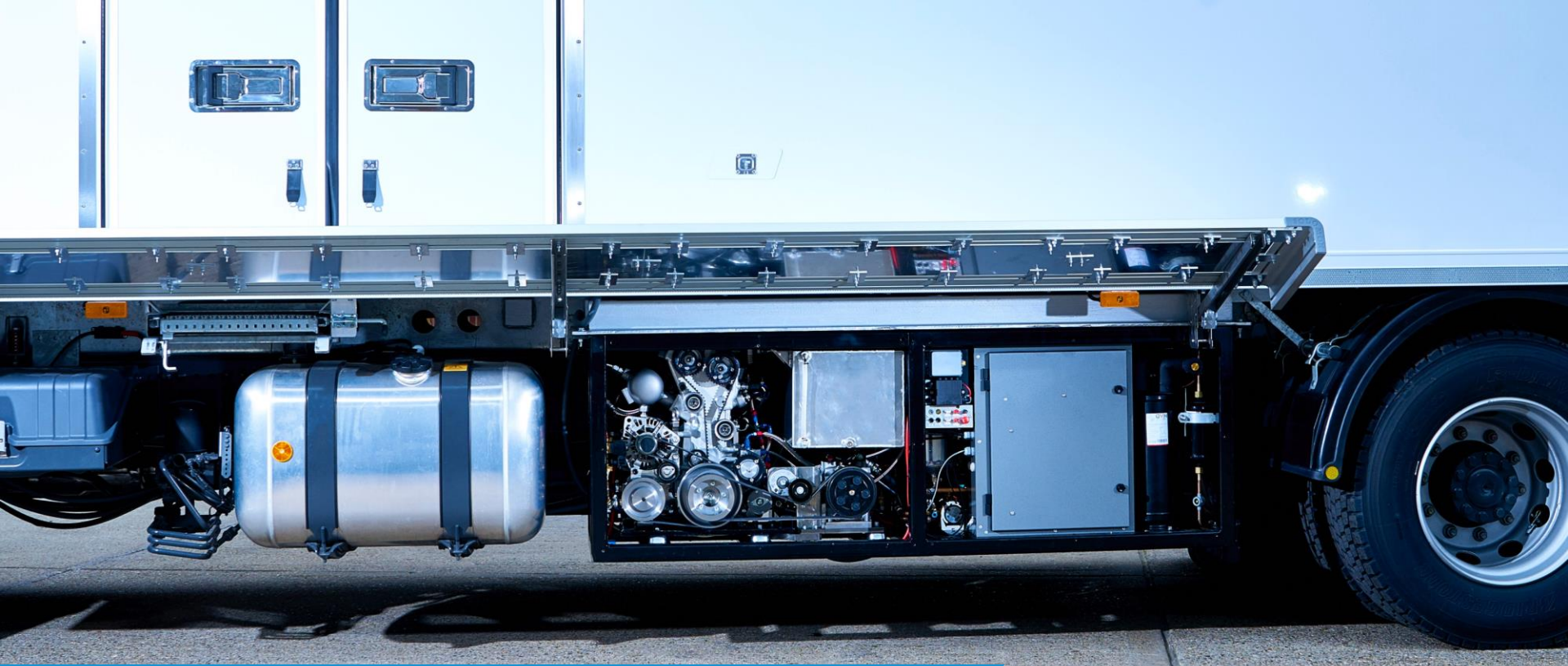


Engine Expo Stuttgart
31st May 2016

Dearman.

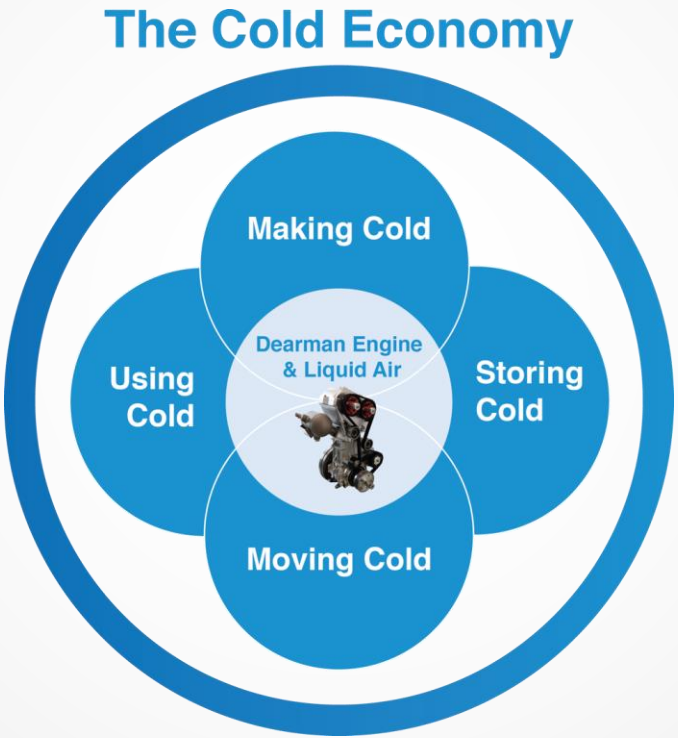
Agenda

- The Cold Economy
- Introduction to Dearman
- Dearman Technology
- Dearman Applications



The Cold Economy

Dearman Engine & The Cold Economy



Delivering clean Cold & Power wherever required

Why Cold Matters?

- 70% of food is chilled or frozen when produced in UK, Europe
- 50%+ of a data centre energy demand is for cooling load
- Refrigeration and air conditioning cause between 7% and 10% of global CO_2 emissions
- Global air conditioning load projected to grow 33 times this century
- Lack of cooling costs UK €15.7bn in lost productivity per year
- 2M die per year from lack of cold chain for vaccines

Emerging Markets Two Extremes

40% of food is lost post-harvest

If developing countries had same level of cold chain as UK, could save 200M tonnes of perishable food.

Asian Pacific middle class could grow six-fold to 3.2 billion in 2030, two thirds of the global total, and its spending power could rise from $5 trillion to $33 trillion.

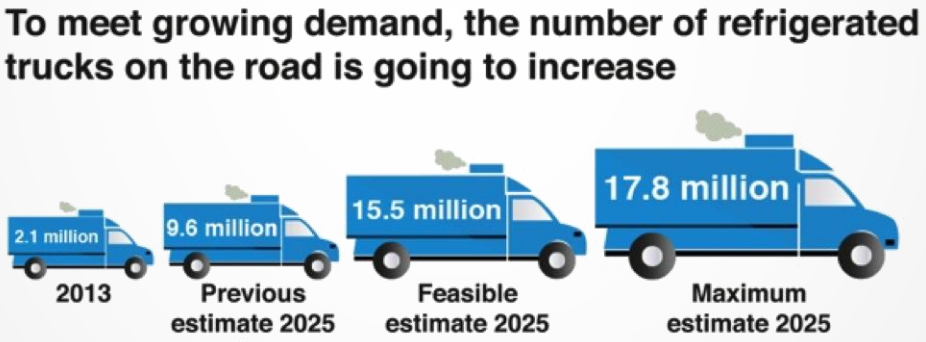
Why Clean Cold Transport

A transport refrigeration unit:

- consumes up to 20% of a refrigerated vehicle's diesel
- can emit up to 6x as much NOx and 29x as much PM of Euro VI engine
- produces significant amounts of CO_2
- uses HFC refrigerants – leaks up to 30% of their total refrigerant charge each year

Why Clean Cold Transport

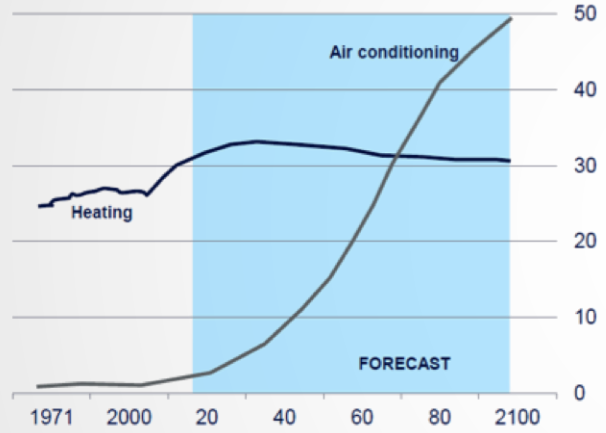
- 20-30% of fresh fruits and vegetables are lost each year in China in the supply chain
- By 2050, food production globally will need to increase by 70% to feed our growing population
- By 2050, 66 per cent of the world's population is projected to be urban; adding 2.5 billion people to the world's urban population by 2050.



- The number of transport refrigeration units on the road by 2030 could emit the same amount of pollution as would be created by more than 800 million diesel cars.

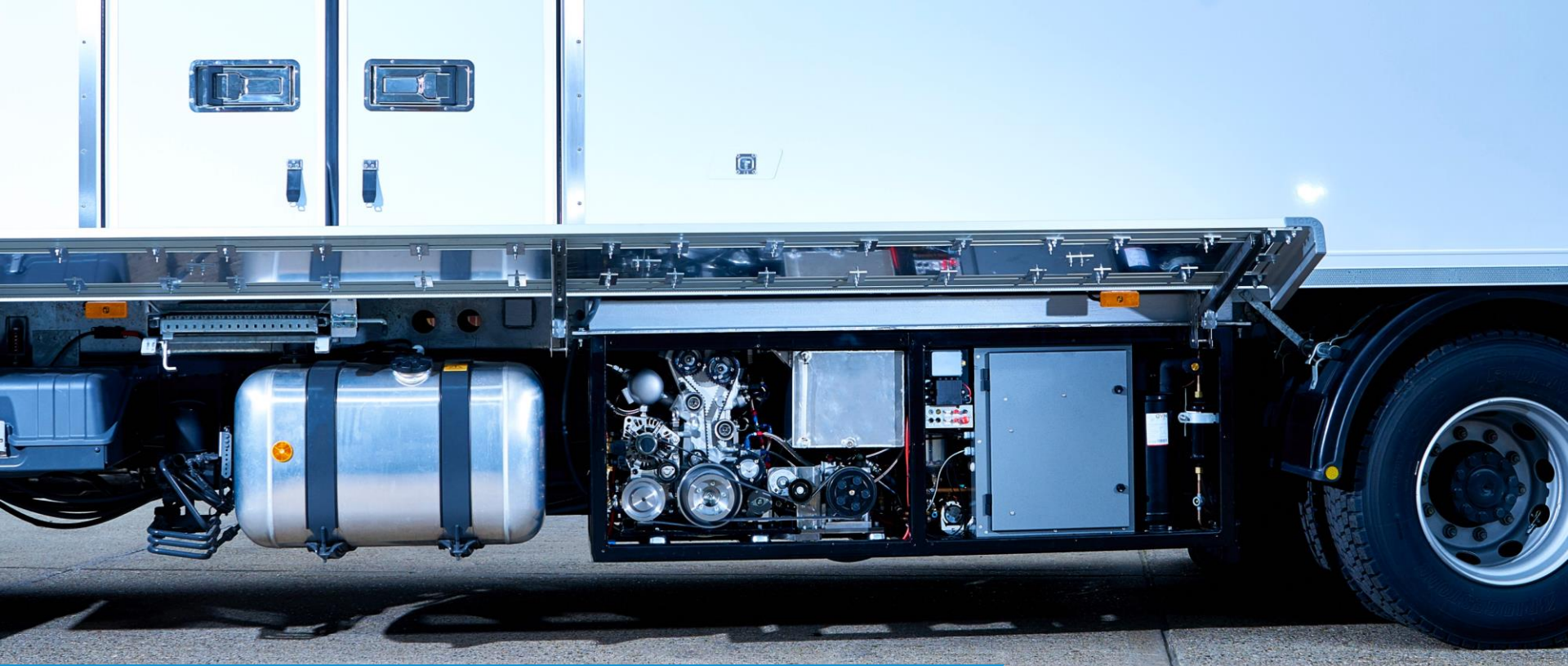
Why Clean Cold? Built Environment

Figure 5: World forecast energy demand for space heating and space cooling
World energy demand, exajoules



Developing country aircon energy consumption to rise from 300TWh today to 10,000TWh in 2100.

Global space cooling to consume more energy than global space heating by 2060 and 60% more by end of century – heat remains flat.



Introduction to Dearman

Developing a Business from an Innovative Technology

Where Dearman began - 2012

Independent validation and fundamental research 2012 - 2014

University of Brighton

Loughborough University

RICARDO

Science & Technology Facilities Council

UNIVERSITY OF BIRMINGHAM

On-vehicle testing – 2015
Commercial trials - 2016

Dearman company info

- UK based SME
- ~65 full time employees. > 65% technically focused
- Developing novel zero-emission technologies to provide clean cold and power for:
  - Transportation
  - Logistics
  - Built environment.

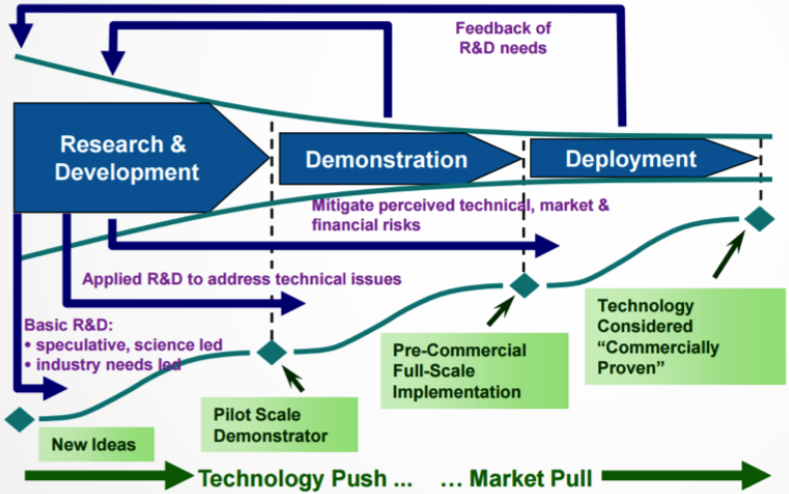
- Transport refrigeration is first application. Fleet deployments from 2016. Project supported by Hubbard/Zanotti and Air Products.
- Consortium based approach to technology development >€8m in UK government and partner funded projects.
- Company recently closed €25m funding round sufficient to support activities through initial industrialisation
- Dearman is committed to delivering technology that operates better, is cheaper to run and improves the environment.

Partnership Approach to Product Development

Dearman's Alignment with Government Technology Funding

Department of Energy & Climate Change

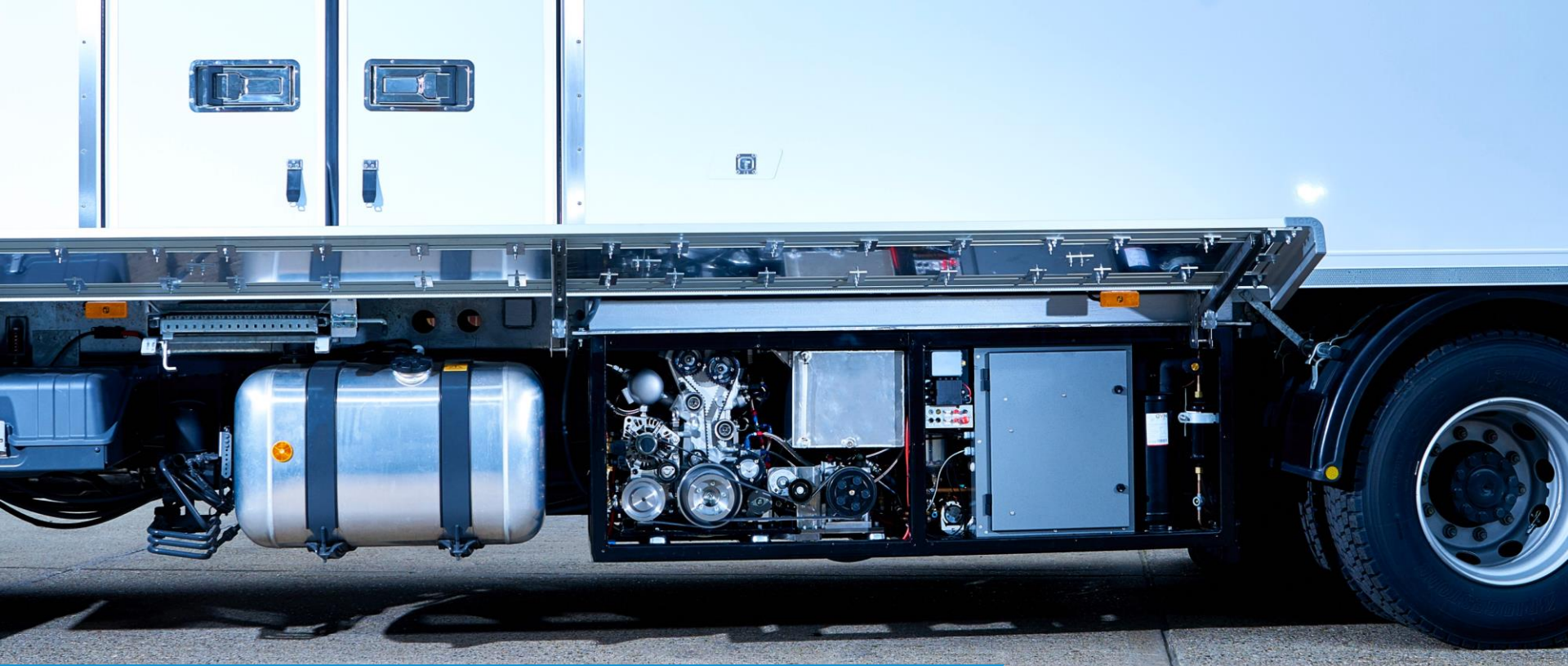
Technology development cycle



Innovation is often presented as a chain and feeding back learning to support future technology development is essential.

UK government support

- The UK government has demonstrated strong support for liquid air technologies including Dearman, because they believe in its ability to:
- Achieve significant air quality and CO_2 improvement with limited state intervention
- Offer a strong business case for deployment across a range of applications
- Fuel and operating cost savings available to UK companies
- Exploit UK capabilities in mechanical engineering and low temperature systems.
- ***Support demonstrated through grants & collaborative funding from Innovate UK and Advanced Propulsion Centre (APC), totalling ~€8m to date***



Dearman Technology

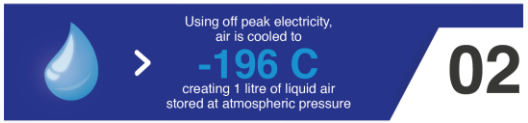
Liquid Nitrogen :
a Novel Energy Vector

Why Liquid Nitrogen?

We need to store renewable / waste energy to use *on demand* in grid or transport applications

Liquid nitrogen is about storing cold ***and*** power

- Mature industry
- Rapid filling of liquids through pressure and pumped systems
- Distribution is through pipeline or road tanker
- Role in electricity system balancing



Dearman Engine: Operating principle

Process – Operates by boiling liquid air to produce high pressure gas that can be used to do work.

Power + cooling

Inventive Step Heat transfer inside the cylinder through direct contact heat exchange with a heat exchange fluid – patent granted

- ✓ Rapid expansion
- ✓ High pressurisation rates
- ✓ Near isothermal expansion
- ✓ Non combustive

1.

Return Stroke
Warm heat exchange fluid (HEF) enters the cylinder.

2.

Top Dead Centre
Air injected - comes into contact with the HEF causes rapid temperature rise.

3.

Power Stroke
The air expands pushing the piston down. Direct contact heat transfer continues allowing near isothermal expansion.

4.

Bottom Dead Centre
The exhaust mixture leaves the cylinder. The gas is returned to the atmosphere and the HEF is re-heated and re-used.

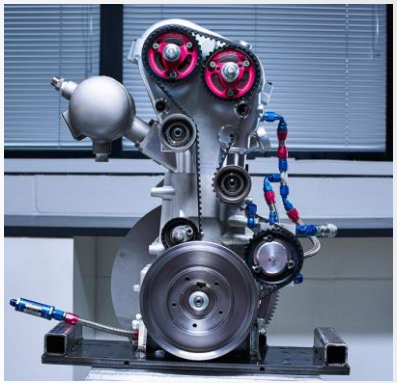
Current Status

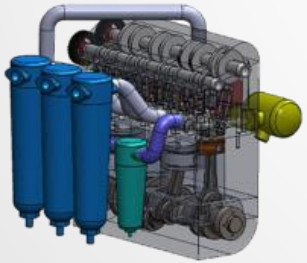
Generation 2 TRU/APU engine for trials
- 30% smaller, 30% more efficient
- Exceeding performance targets

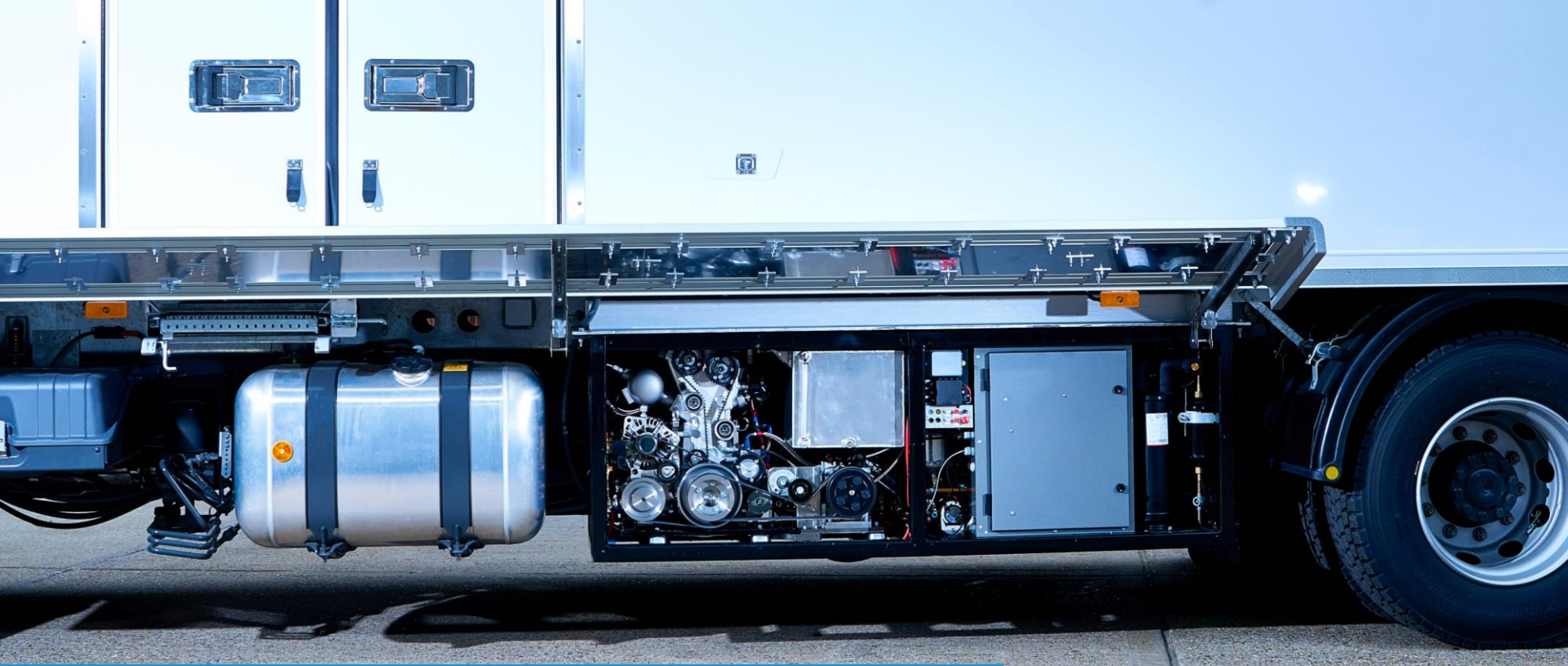
Supporting cryogenic systems
- New, integrated tank & pump: Exceeding performance targets

Refrigerated truck trial
- Gen2 full system running on truck
- Duplicate copy on trial in UK with customer starting in a couple of months
- Follow on trials planned for end-2016

High Efficiency Engine
- Underpins stationary and hybrid applications:
- 2-stage engine, 10x power, 2x efficiency
- In procurement, will be made & run at Dearman







Dearman Applications

Applications

Transport Refrigeration

- Zero emissions at the point of use;
- Lower CO_2 footprint; TRU uses 20% of the total diesel of the vehicle
- Better functionality
- Cheaper to run, saving upwards of €1,000 operating cost per vehicle per year.

Auxiliary power and air-conditioning

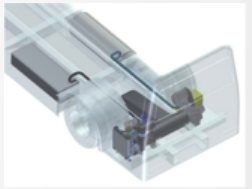
- Efficient cooling of bus/trucks
- Particularly suited to warmer climates, where it could reduce fuel consumption by ~37%
- Integrates with both conventional buses and the growing electric bus market
- Projected payback of 6 months for buses

Back-up power and energy services

- Provision of zero emission cooling and back-up power and/or power-on-demand
- Aimed at refrigerated buildings, data centres and supermarkets (sub 1MW market)
- Payback of between 2 & 3 years without subsidy depending on usage patterns

Engine waste heat recovery

- Recuperating waste energy from internal combustion engine of large vehicles to increase overall efficiency
- Well suited to vehicles in frequent stop start operation e.g. buses
- Payback of around 1.5 years in some duty cycles



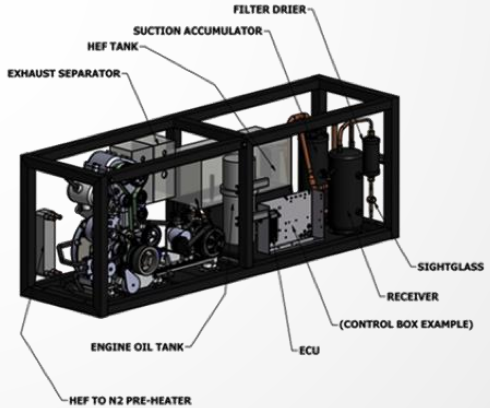
Transport Refrigeration

How it works:

- Frozen pay load is used as heat source to boil the nitrogen, this provides ~2/3 of the cooling
- High pressure gas is fed to the Dearman Engine and converted into power
- Power is used to:
  - Supply fan power
  - Produce more cooling ~1/3

Benefits:

- Zero-emission
- Reduced noise
- Fuel cost saving
- Operational superiority



Dearman System

High-efficiency engine (HE)

Current status

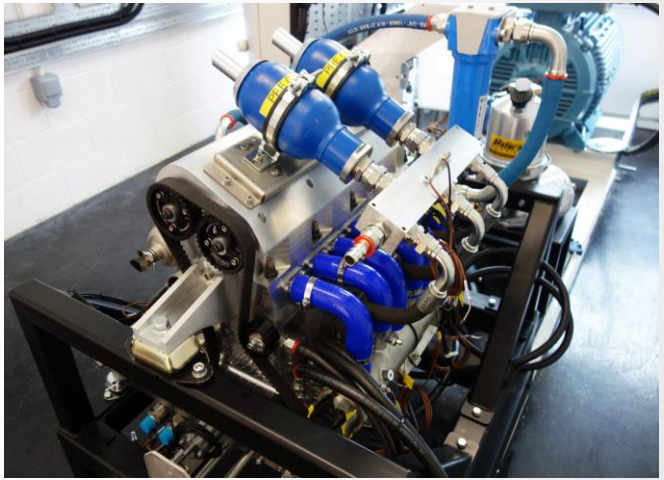
- Design & procurement completed
- Lab testing to commence June 2016
- Bus build commences Aug 2016
- Follow-on vehicle testing and demonstation activities planned at Hobira MIRA

Engine platform features

- Multi-cylinder (4) variant
- 10x power of single cylinder variant
- Waste heat from ICE to enhance Dearman engine performance & overall vehicle thermal efficiency

Benefits:

- Zero-emission
- Fuel cost saving
- Symbiosis with ICE (thermal)



High efficiency engine

HE application as Auxiliary Power Unit

Dearman is also developing an auxiliary power product for bus (and truck) applications.

Providing Air Conditioning & “hotel” load.

Best business cases are also where emissions constraints exist:

i) Ultra Low Emission Zones – eg London

ii) Anti-Idle legislation (US)

iii) Projected city-wide diesel bans – Paris/Amsterdam

Projected fuel savings of 10% to 30% with payback vs diesel of ~5 years

HE application to the Built Environment

Dearman is beginning to develop a low capital cost premium (~20% vs. diesel gensets) product for static applications. These are typically for peak power or back-up and are likely to be served with units (500kW-1MW)

Best business cases are where emissions constraints prevent conventional gensets from pursuing the following revenue streams:

i) Reserve Services - units or sites are aggregated to provide Short Term Operating Reserve Services.

ii) Distribution Network Asset Support – Operators in the UK are beginning to contract services to protect network assets.

iii) End User Energy System Integration – the objective is to reduce energy costs through peak power cost avoidance.

Optimising Liquid Air installations

The Dearman Engine offers three useful characteristics:

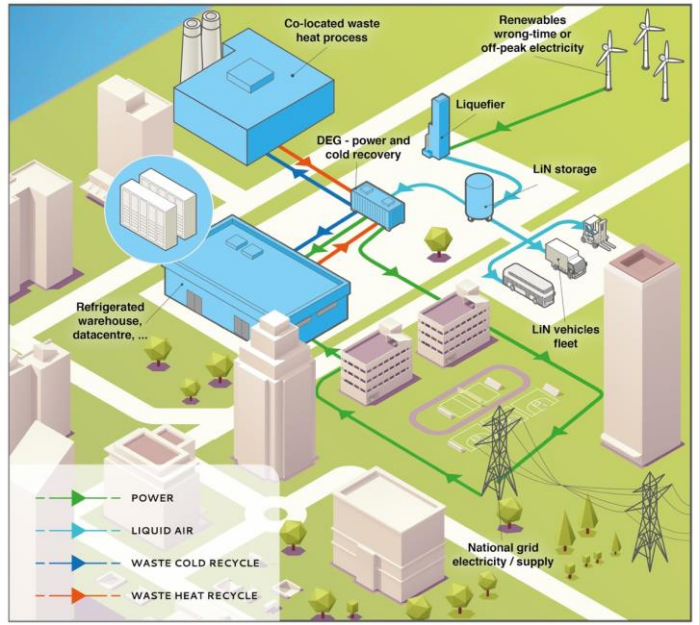
i) Shaft power that can be used to support local demand or be exported

ii) Cooling (because of the low start temperature of the working fluid)

iii) Conversion of waste heat into additional shaft power

Achieving the maximum benefit from these services will require energy system analysis and optimisation for the end user's site.

There are also opportunities to explore interaction with the fleet applications, which will result in substantial quantities of stored cold and power being available in many locations.



Thank you for your attention

If you require further information or would like to visit our Technical Centre for a demonstration please contact Jeremy North or David Sanders as follows:

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david.sanders@dearman.co.uk

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Delivering Clean Cold & Power

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