Research Councils UK Energy Programme Strategy Fellowship

Summary of Workshop on

Transport Energy

Working Document

August 2013

This is a report of a workshop held to support the development of the Research Councils UK Energy Research and Training Prospectus at Coventry Transport Museum, Coventry on 11-12th June 2013

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Research Councils Energy Programme

The Research Councils UK (RCUK) Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £625 million in research and skills to pioneer a low carbon future. This builds on an investment of £839 million over the period 2004-11.

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

In 2010, the EPSRC organised a Review of Energy on behalf of Research Councils UK in conjunction with the learned societies. The aim of the review, which was carried out by a panel of international experts, was to provide an independent assessment of the quality and impact of the UK programme. The Review Panel concluded that interesting, leading edge and world class research was being conducted in almost all areas while suggesting mechanisms for strengthening impact in terms of economic benefit, industry development and quality of life.

Energy Strategy Fellowship

The RCUK Energy Strategy Fellowship was established by EPSRC on behalf of Research Councils UK in April 2012 in response to the international Review Panel's recommendation that a fully integrated "roadmap" for UK research targets should be completed and maintained. The position is held by Jim Skea, Professor of Sustainable Energy in the Centre for Environmental Policy at Imperial College London. The main initial task is to synthesise an Energy Research Prospectus to explore research, skills and training needs across the energy landscape. Professor Skea leads a small team at Imperial College London tasked with developing the Prospectus.

The Prospectus will contribute to the evidence base upon which the RCUK Energy Programme can plan its forward activities alongside Government, RD&D funding bodies, the private sector and other stakeholders. The tool will highlight links along the innovation chain from basic science through to commercialisation. The tool will be flexible and adaptable and will take explicit account of uncertainties so that it can remain robust against emerging evidence about research achievements and policy priorities.

One of the main inputs to the Prospectus is a series of four high-level strategic workshops and six in-depth expert workshops taking place October 2012 - July 2013. Following peer-review, the first version of the Prospectus will be published in November 2013 and will then be reviewed and updated on an annual cycle during the lifetime of the Fellowship, which ends in 2017.

This document reports views expressed at an expert workshop held in June 2013. These views do not necessarily represent a consensus of workshop participants nor will they necessarily be endorsed in the final version of the Energy Research and Training Prospectus.

Contents

List of Acronyms

AC	Air Conditioning
ACARE	Advisory Council for Aeronautics Research in Europe
APU	Auxiliary Power Unit
BEV	Battery Electric Vehicle
BIS	Department for Business, Innovation & Skills
BM	Business Model
CASE	Collaborative Awards in Science and Engineering
CBA	Cost Benefit Analysis
CCS	Carbon Capture and Storage
CDT	Centre for Doctoral Training (also referred to as DTC)
DECC	Department of Energy and Climate Change
DFT	Department for Transport
DOE	Department of Environment (US)
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
ETI	Energy Technologies Institute
EU	European Union
EUED	End Use Energy Demand
EV	Electric Vehicle
EV2G	Electric Vehicle-to-Grid
GDP	Gross Domestic Product
GHG	Green House Gas
GPS	Global Positioning System
GSE	Ground Support Equipment
HS2	High Speed 2
HVAC	Heating, ventilation, and air conditioning
ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IEA	International Energy Agency
IP	Intellectual Property
KTN	Knowledge Transfer Network
LCA	Life Cycle Assessment
LCVP	Low Carbon Vehicle Partnership
LNG	Liquefied Natural Gas
MARKAL	Market Allocation (Model)
NAIGT	New Automotive Innovation & Growth Team
NCAP	New Car Assessment Programme

NERC	Natural Environment Research Council
OEM	Original Equipment Manufacturer
PHEV	Plug-in Electric Vehicle
PI	Primary Investigator
R&D	Research and Development
RCs	Research Councils
RCUK	Research Councils UK
TRL	Technology Readiness Level
TSB	Technology Strategy Board
UKERC	UK Energy Research Centre
V2G	Vehicle to Grid
V2V	Vehicle to Vehicle

1   Overview

This document summarises the outcomes of a workshop held on 11-12th June 2013 to identify key research and training needs relating to transport energy. In terms of scope, the workshop covered the following areas, which fall under the Transport sector, as defined by the EU/International Energy Agency (IEA) energy R&D nomenclature:

- Analysis and optimisation of energy consumption in the transport sector
- Efficiency improvements in light-duty vehicles, heavy-duty vehicles and non-road vehicles
- Public transport systems
- Engine-fuel optimisation
- Use of alternative fuels
- Fuel additives
- Diesel engines
- Stirling motors, electric cars, hybrid cars

The workshop was organised with input from Miles Elsden from the Department for Transport (DfT), Jillian Anable from the University of Aberdeen and Andy Eastlake from the Low Carbon Vehicle Partnership (LCVP).

There were 32 participants at the workshop (excluding the Fellowship and facilitation teams), most of whom were academics and researchers falling within the communities supported by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC). In addition, a number of participants were from private sector and government organisations.

The meeting was professionally facilitated by the Centre for Facilitation Services Ltd in association with the RCUK Energy Strategy Fellowship team. This record of the meeting constitutes a working document, intended to capture the outcomes of the workshop. It represents an intermediate step in the production of a full Energy Strategy Fellowship report, which will set out the prospectus for energy research and training needs relating to energy infrastructure. It has two purposes; a) to provide a resource which can be 'mined' in order to produce the prospectus document; and b) to provide an account of the workshop for comment by the participants and for archival purposes.

2 Introductory Presentations

To familiarise the workshop participants with the scope of the workshop, two introductory presentations were made. The first of these was from Jim Skea (Energy Strategy Fellow) who outlined the rationale behind the RCUK Energy Strategy Fellowship and key activities, noting the role of the Prospectus in informing the future design of the RCUK's Energy Programme. He explained how the Energy Transport workshop formed part of a wider programme of work being undertaken through the Fellowship, including five other expert workshops, three strategic workshops and three light touch reviews.

The second of the presentations was from Aidan Rhodes (Research Fellow, Energy Strategy Fellowship) who provided a summary of the key outputs from the first two of the three strategic, cross-cutting workshops that preceded the Transportation Energy workshop. He highlighted outputs that were most relevant to the transport sector.

2.1 Strategic Workshop 1: Energy strategies and energy research needs

A key message from the first workshop on "Energy strategies and energy research needs" was that people's expectations about progress towards a low carbon economy lagged behind what they thought was desirable. Focusing on vehicle transportation technologies, people had expected the deployment of battery-electric and hydrogen vehicles to fall below desirable levels by 2050, while the adoption of internal combustion engines (ICEs) would still be greater than desired.

It was also highlighted that the participants of Strategic Workshop 1 concluded that research on energy use in transportation had only medium relevance to UK energy futures; that the UK possessed strong scientific capabilities in transport energy and that the UK possessed average industrial capability in this area. However, scientific and industrial capabilities in relation to hydrogen and fuel cells were seen to be lower.

2.1 Strategic Workshop 2: The Role of Environmental Science, Social Science and Economics

It was difficult to present high-level conclusions from the second strategy workshop on the role of environmental science, social science and economics, but some "nuggets" were presented:

- Promoting energy demand research was like Sisyphus pushing his stone up the hill;
- A disproportionate effort has been put into kit as opposed to behaviour;
- There is an over-reliance on economics in the design of energy policy;
- Instrumental social science that helps answer policy questions is popular with funders but it rests on a foundation of fundamental, critical work;
- Language matters, but natural scientists often form the view that a social scientist's first question when approaching a subject is to question terminology and meaning;
- Research Councils can and have forced better interdisciplinary working.

2.2 Participants Reactions to Strategic Workshop Results

Participants were then asked to record their reactions to the outcomes of the strategy workshops under three headings: what surprised, delighted and disappointed them. These were discussed in table groups and the outputs are recorded in Table 1.

Table 1: Participants' reaction to the results of strategic workshops

Surprise	Delight	Disappointment
Inter/multi-disciplinarity		
- Academic incentives do not encourage interdisciplinary working	-Interdisciplinarity	- Not enough inter-disciplinarity
	- Inclusion of the interdisciplinary approach - social sciences etc.	- That behaviour & kit are considered separately and language is still an excuse
	- Interdisciplinary barriers in research needs to be addressed	- Academic system works against multi-disciplinary research
	- That the research councils have successfully encouraged interdisciplinary research	
	- Multi-discipline 'delight'	
	- To hear recognition that incentive system scuppers interdisciplinary research	
	- Interdisciplinary work/research is critical in transport	
	- Delighted that the UK is considering how to incentivise multi-disciplinary research	
Social Sciences		
- Behaviour to take a key step	- Recognition that too much effort put on kit not behaviour	- Wooly output from social science workshop
	- That the role of social sciences in understanding transport energy futures is being considered at all (behaviour being critical)	- not enough behaviour
	- Social science given such a high priority : very important	- No energy demand reduction
	- Some inventory of behavioural science	- Not enough demand side thinking - too much supply side
	- That social scientists are asking what is the fundamental questions to be answered	- Not further forward in recognising the need to change in demand/behaviours
Structure of Academia & Research		
- That the inhibiting effect of the academic incentive system is controversial		- Academia seen as a barrier
		- Academic barriers extend to research councils definitions of scope
Scenarios & Projections		
- Range of 'Forecasts' given wisdom of electric future		- Expected and preferred rates. Is this pessimistically admitting that we won't perform as well as we could/should? Or is this realism? Seems defeatist...
- That it is possible to make 50-year predictions about energy balance		- Lack of recognition of strategic shocks - completely new tech/solutions
- Spread of future scenarios		
- Consideration of previous roadmaps		
- What are the black swans?		
Technology & Infrastructure		
- Focus on technology		- Technological conservatism

- Nuclear fusion as a viable technology		- Over focus on technical fixes
Transport Specific		
- Narrow Focus: Land transport oriented	- Wide range of EV solutions	- So many 'hoped' for 70% electrical and 10% hybrid > they should look at the numbers
- f it's ICE for the next 20-30 years, why is there not more research into advanced liquid fuels?		- No mention of NAIGT auto council roadmaps
- High proportion of technology in use today to be around in 2050		- Road focus
- Unrealistic expectations for BEV uptake by 2050		- Lack of focus on demand side which is crucial for vehicle purchasing
- Positioning of UK transport research capability		- Seems only road focus
- Degree of pessimism on 2050 position		- Narrow perspective of transport = passenger car
- That transport seemed to mean only road transport		- Too much assumed (or concentrated on) passenger vehicles
- Continuing optimism on electric vehicles		- How is this linked to other strategy work in this world e.g. ETI, ACARE + flight path 2050
- No mention of autonomous vehicles		- Belief that petrol will dominate in 2050
- Surprised decarbonise electricity while moving transport demand to electricity		- No mention in workshops of 2 fastest growing parts of energy (and transport) system : int'l aviation and shipping
		- Focus on EVs too much
Structure of Project		
- The number of workshops organised	- That is it being done	- Will outputs be so general as to hide key topics?
- Previous workshops unknown, would have been good to be involved.		
General		
- Breadth of topics / focus areas	- It's happening at all	- What about consumer resistance?
- Summary seemed partial and quite specific	- Breadth of engagement	- Industry light touch
- Lack of focus on real actions	- The fact we're all here	- Emphasis on electricity
	- The depth of discussion so far	
	- Research capability	
	- How are you going to translate these observations to conquering those influences?	
	- How are we going to reduce the impact of economists in decision-making?	

Once the group had recorded their thoughts they were then asked to highlight some key points that they thought were important highlights of the discussion. These serve to summarise the outputs of the table above and include:

Delighted:

- A transport specific workshop was being held, giving the impression that not many of these types of events took place and brought the community together.

- Importance of understanding travel behaviour was acknowledged, along with the more general importance of the social sciences to transport energy research
- Importance of inter-disciplinary research had been acknowledged and in turn supported, but disappointed that this still faced barriers in the UK

Disappointed:

- Strategic workshops only focused on road transport and no other forms of transport, such as international aviation and shipping.
- Little discussion around different scenarios, given that these demand different solutions. Also, little discussion of unexpected futures.
- Strong emphasis on fuel cells and EV's as the 'holy grail' for decarbonisation. Needs to be more focus on ICEs (also surprised by this)
- Lack of joined-up approach in academia and the research councils – too 'siloed'
- Although growing, not enough focus on demand side of transport energy. Also, a lack of a link between demand-side and supply-side transport issues
- Too quick to develop a myopic view of transport, e.g. passenger car becomes central focus – much bigger picture required
- Technology forecasts were too conservative - can change occur faster than this?
- Little talk about backcasting and policy drivers.

Surprised:

- Mix of transport technologies, in terms of the dominance of petrol, lack of dominance in hybrids.
- Grouping of transport holistically as a catch-all for logistics and technology etc. Might be some room for segregation
- Academic incentives not encouraging interdisciplinary working
- Spread of future scenarios for technologies
- Energy efficiency didn't feature much, e.g. more efficient vehicles and transport
- No obvious consideration of previous work and road-mapping that had gone on
- So many academics are prepared to predict 2050

3   Helicopter View of the Research Terrain 'As-Is'

Matthew Hannon from the Fellowship Team began this section by presenting a diagram showcasing the key dimensions of the transport energy sector, listing the various modes of transport available as well as key concepts regarding transportation purposes, processes and infrastructure.
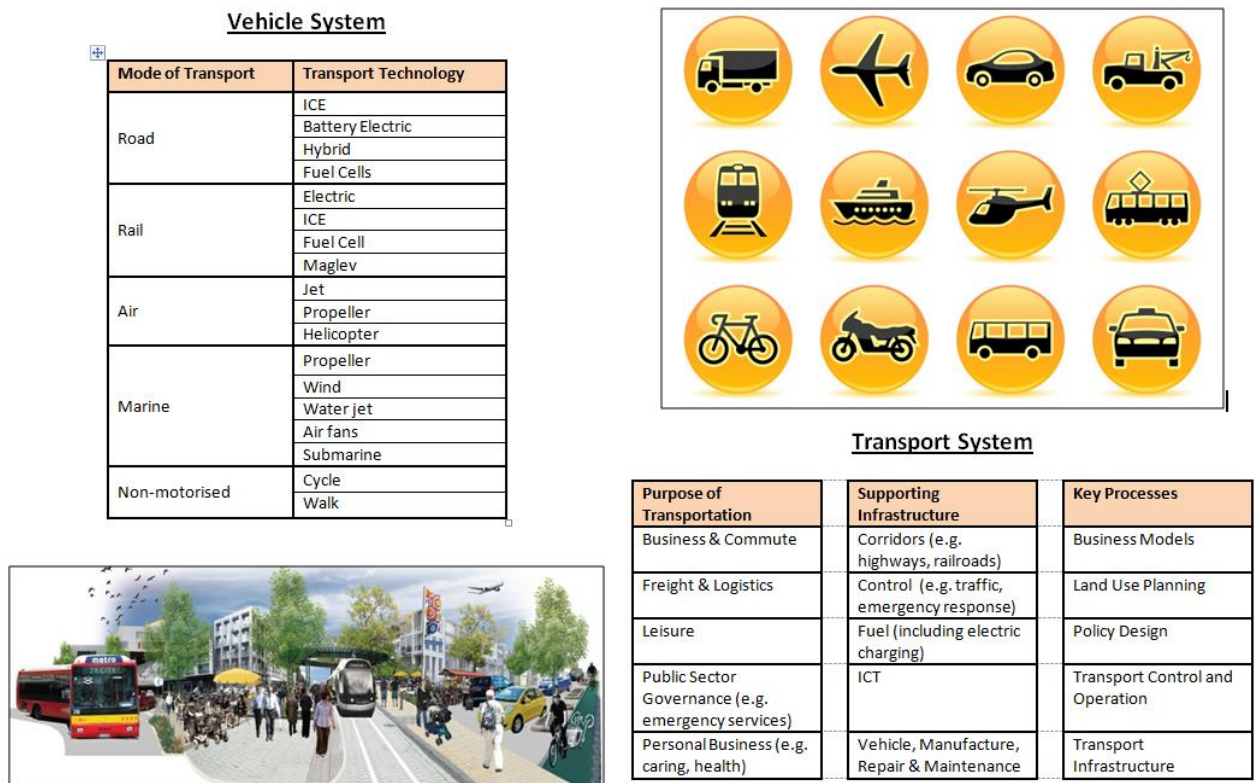
Vehicle System

Mode of Transport	Transport Technology
Road	ICE
	Battery Electric
	Hybrid
	Fuel Cells
Rail	Electric
	ICE
	Fuel Cell
	Maglev
Air	Jet
	Propeller
	Helicopter
Marine	Propeller
	Wind
	Water jet
	Air fans
	Submarine
Non-motorised	Cycle
	Walk

Transport System

Purpose of Transportation	Supporting Infrastructure	Key Processes
Business & Commute	Corridors (e.g. highways, railroads)	Business Models
Freight & Logistics	Control (e.g. traffic, emergency response)	Land Use Planning
Leisure	Fuel (including electric charging)	Policy Design
Public Sector Governance (e.g. emergency services)	ICT	Transport Control and Operation
Personal Business (e.g. caring, health)	Vehicle, Manufacture, Repair & Maintenance	Transport Infrastructure

Figure 1: Diagram of key concepts in transport energy

The participants were then divided into table groups, and given a task to prepare a briefing on the energy infrastructure research terrain as it is now. The participants were allowed a short time for individual reflection before feeding their insights into a group discussion. The group then distilled what they considered as the 'key themes' onto post-it notes, which they arranged on a wall chart according to the below x-y axes:

Table 2: Helicopter view of UK's current research terrain

	Mode of Transport	Transport Infrastructure	Transport Control and Operation	Land Use Planning	Policy Design	Business Models	Travel Behaviour
Inter-systems Linkages	Acquisition, use and ownership of data	ICT <-> Travel			Incrementalism versus step change/radical change.		What is the ultimate goal in freedom of mobility?
International System	Decarbonisation of aviation/shipping?	Assessment of different technology options, life-cycle thinking, (cradle-cradle), consistent comparisons.	Regulatory Environment – greatest influence, but slow to respond?			Whole-life energy model, cradle-to-cradle. This may not be life-cycle analysis but something else. Going far beyond the energy 'use' phase.	
National System	Transport energy – demand and supply			Land use and urban planning	New Appraisal Mechanisms		
Urban/Rural Region	Expanding discussion beyond road-based transport – air, walking and biking.		What role will autonomous vehicles have? Are they game-changers?		Impact of transport on air quality and quality of life.	Inertia/investment in current system. Behaviour, infrastructure, vehicles, travel behaviour. Business models, roles of industry & government, risk.	
				Multi-Modal: ICT-Land Use-Transport Connectivity		Life-cycle analysis for GHG and other impacts including safety.	Cannot change behaviour until we understand it: Symbolism, aspirations, new models of ownership.
Neighbourhood	Non-motorised modes: urban planning, consumer attitudes.	Modelling of technology adoption and impacts on infrastructure.					
Household							Transitions in behaviour – demand side. Effectiveness of policy.

Each group were given two minutes in plenary to present their key themes from their discussions. The following is a distillation of the table discussions and the plenary presentations, focusing on the main emerging themes of the discussions.

- Decarbonisation of aviation and shipping was brought up. Currently, there seems to be no clear answers for decarbonising these in an economic manner.
- The nexus between ICT technologies, transportation and land use has been getting more complex in recent years. ICT technologies have led to a new level of connectivity in the transport system. This leads to new opportunities in transport modelling, which need to be explored. It also leads to a group of new issues, such as privacy worries when acquiring data. New governance and regulatory models will be needed to handle data.
- Urban planning and attitudes of consumers to new and updated transport technologies are extremely important to technology adoption. New transportation business models can emerge from sensitive urban designs.
- We need to understand the composition of travel demand in the future and whether it will always increase – this is a key assumption behind many current transport models and may be inaccurate in some circumstances.
- To understand changes in behaviour, we need to understand the value people place on specific transportation – this isn't always economic, as can be seen by people's attachment to specific cars or car models. Changes in behaviour do not always come slowly – sometimes step changes in behaviour can happen surprisingly quickly. Autonomous vehicles and new models of car ownership were suggested as two possible examples of future step-changes.
- Research needs to ensure that every mode of transport is covered fully, and to move further beyond road-based transport. Air travel, walking and cycling were all suggested as important to study, and to understand how policy changes influence these transport modes and inter-modal shifting and behaviours.
- There is an issue with transportation on the local environment, particularly on air quality. This is a particular problem with road transport. Life cycle analyses (LCAs) for greenhouse gases and other environmental impacts are important.
- There is a 'chicken-and-egg' problem with transportation infrastructure – without supporting infrastructure, customers will not adopt new technologies, but the infrastructure is not economically viable to install without a wide customer base.
- We need to understand the ultimate goal of our transport-mobility system. Is it to offer freedom of mobility or efficient mobility, especially considering population growth?
- There is a huge amount of inertia/lock-in in the current transportation system, due to large investment and entrenched behaviour. The regulatory environment is also important, as it has a great influence in the products we use, but is often very slow to respond.
- There is currently a vast amount of data that researchers can access, and even greater quantities are expected in the future. How do researchers analyse this data to avoid becoming 'data-rich, but knowledge-poor?'

4 How well placed are we to tackle existing transport energy research challenges?

Working individually, people were asked to identify how well placed the UK currently is in terms of transport energy research capabilities so that we can meet the challenges of the future. They were invited to score these on a scale of 0-10 (0 = no chance, 10 = well setup) and explain their score on a post-it note. The following graph (Figure 2) shows the distribution of the 31 post-it comments.

The average score given by the group was 5.6 +/- 1.9, which represents a relatively high and well clustered set of scores. Interestingly, none of the participants assigned very high capability scores (i.e. 9 - 10) and very few participants assigned very low scores (i.e. 1 – 3). A very strong theme emerging from the comments is the relative strength of the UK's fundamental science in the transport energy field, coupled with perceived weaknesses in research translation and application, as well as undertaking interdisciplinary transport energy research due to the tradition of disciplinary 'siloed' research. It is worth noting that the comments appear to converge more tightly than the quantitative scores.
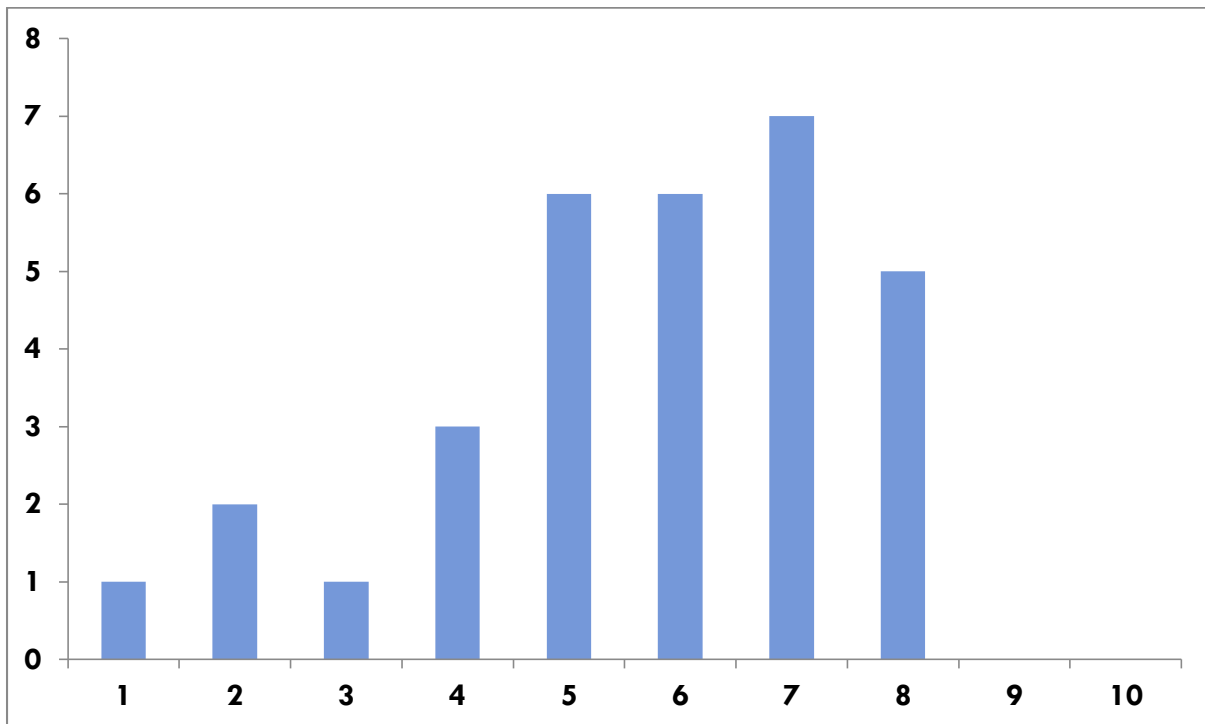

Figure 2: Distribution of perceived UK transport energy capabilities

Table 3: UK's perceived capability levels to address existing energy research challenges

High capability levels			
7	**8**	**9**	**10**
Strong academic team – less able to deliver action/implementation (too important to pick a direction) Pretty well set-up. The rest is policy and price signals etc.	The research capability is there. The question is: 'will industry/government use it?'	No Scores Assigned	No Scores Assigned
Individual disciplines excellent – lack of integration. The 'capability' is there but not at all interested!	Good connection across the blue sky –innovation – product chain (+operations)		
Good capabilities but not enough interdisciplinary thinking. Too much 'keeping all options open'. Not enough on behaviour. Strong academic capability. Disconnect to implementation. Need to factor market pull as well as tech push. Sector well enabled with strengths. Research enablers not as important as social/political context.	R&D capability is pretty good, but implementation, strategy and political will is lacking.		

Medium capability levels		
4	**5**	**6**
Too many assumptions being made about customer behaviour and infrastructure costs. Reality is different!	All capabilities present, but needs to be better joined-up. (Interdisciplinarity) in order for the UK to fully capitalise on alternatives.	Although good on some academics and analysis, the lack of a big vehicle manufacturer + the associated government contacts can slow things on the technology side.
Lack of funding, lack of coordinated support plan, lack of vision.	Insufficient interdisciplinarity, lots of research capability and many opportunities for funding	Plenty of fundamental output and ability but pathways to implementation are to torturous and political,
	The research capability is largely there. The supporting policy drivers (to make things happen) are not.	Silos and lack of transition into delivery (getting better)
	The UK is well positioned relative to other countries, but challenges in future are unlikely to be met by any country.	Certainly we're going in the right direction, but more needs to be done.
	Too many silos. Too concentrated in a small number of places.	Pockets of expertise – knowledge transfer needs to be better

Low capability levels			
0	**1**	**2**	**3**
No Scores Assigned	Unable to translate research into change nearly fast enough	Because we think it is a 'future' challenge when because of climate change and cumulative emissions, it is a 'current' challenge requiring more focus on what we can do with existing tech and behaviour.	Too few social scientists (not economists) and too few who know how to do a high methodological field study.

5 Research 'Hotspots' and Broader Themes for Future Energy Research

5.1 Introduction to the Exercise

This exercise was designed to identify a range of topics that participants believed should be subject to additional UK-led research in the future, and which should therefore constitute an important part of the RCUK Energy Strategy Fellowship's *Research Prospectus*.

5.2 Methodology

5.2.1 Overview

In order to identify future energy research opportunities for the UK in the field of transport energy, the participants were first invited to identify 'research hotspots' that could provide valuable insights, should (further) research be conducted into them. A 'research hotspot' was defined as follows:

> 'A **Research Hotspot** is a potentially valuable area of future research, which has been identified by the Expert Workshop participants. It is an area in which the experts believe research challenges will emerge in the future. It may be a broad and overarching question or problem'

To help guide the participants, a couple of good-practice examples of hot spots were presented from the previous Fossil Fuel and CCS workshop.

5.2.2 How Were the Research Hotspots Generated?

The first part of the process involved the participants working individually to generate some initial ideas about potential hotspots. The second part required the participants to form pairs to discuss and record these hotspots with a partner. These were recorded on post-it-notes

Once the pairs had discussed and recorded the hotspots they were then asked to place these on a wall chart, which incorporated similar axes to those used in Helicopter View of Research Terrain 'As-Is' exercise (Table 2) with one amendment made by the participants. Next to the *Transport Mode* category on the X axis, the participants added *Transport Technology*, as a means of capturing the more technical aspects of transport energy. The purpose of these axes was to act as a guide for participants to place their hotspots, with a view to clustering related hotspots.

The participants first browsed the wall chart in order to develop a feel for the types of research hotspot that other participants had generated. Participants were then prompted by random image cards in order to identify any further research hotspots that might have been omitted. At the same time, participants were encouraged to comment on existing hotspots. This resulted in a noticeable increase in the numbers of hotspots and comments.

5.2.3 Clustering Hot Spots at Different Scales

During the clustering exercise, participants grouped together similar hot spots in order to create research clusters representing potentially important energy infrastructure research themes. The clustering was performed by groups corresponding to four broad, thematic categories that had emerged from the hotspots exercise. These were:

- Systems and infrastructure
- Technology & fuels
- Policy & business models
- Transport behaviour

Participants were asked to join one of these four groups. Once all of the groups had clustered the hotspots, they then named them clearly and concisely in a way that would be meaningful to non-experts. Each group was assisted by a facilitator who ensured that each member of the group had the opportunity to provide input and that the groups had clustered all their hotspots within the time available.

5.2.4 Grouping the Clusters Together

Participants then worked together to aggregate the research clusters into 'super-clusters'. Each group shared one of their clusters with the other groups, who were encouraged to identify any related clusters. Using a system of green, red and yellow cards, participants could confirm their support for a super-cluster, veto it or provoke further discussion. While a number of potential super-cluster arrangements were suggested by the participants, more often than not these were rejected by one or more of the group because they were uncomfortable with further aggregation.

Prior to the 'super-clustering' exercise, a handful of hotspots had not been assigned. During the 'super-clustering' exercise, participants moved certain hotspots from their original clusters and transferred them to others.

5.3 Results

In their four groups, the participants grouped the large number of research hotspots into 26 different clusters. These clusters were subsequently aggregated by all the participants into 21 'super-clusters'. These super-clusters are outlined in the tables below, along with the associated clusters and hot spots, which illustrate the research foci that make-up these broader research areas.

Cluster 1 – Infrastructure options for immediate and rapid decarbonisation

Cluster Name(s)	Hotspots
1 – Infrastructure options for immediate and rapid decarbonisation: using the old and supporting the new	*Infrastructural Flexibility* - Ensure flexibility in use of existing and new technology/infrastructure - Avoid lock-in and path dependency - Infrastructure flexibility to step-change/ or new technology o Flettner rotors on tankers/ports or LNG/diesel/ports
	Infrastructural History - Backcasting: what happened to the 'great technologies of the future' and what can we learn from that? - Consider old transport models where appropriate: o E.g. livestock, horse & cart, bicycles/self-powered, canals/river transport
	- Understanding and modelling consumer choice in transitioning to low carbon transport system
	- If this represents a low carbon drivers, how to support incremental push on exiting technology whilst incentivising new potential step-change technological innovations

Cluster 2 - Demand side policy

Cluster Name(s)	Hotspots
2 – Demand side policy	- Future transport planning and policy (rail and integration)
	- At what vehicle age does it become beneficial to buy a new vehicle in terms of energy & emissions? o For old & new ICE, PHEVs, EVs?
	- More fundamental 'mental' understanding of personal and public transport – how to encourage sustainable mobility?

Cluster Name(s)	Hotspots
	- Mechanism to undertake 'CBA' behavioural policies
	- Equitable opportunities for access to new technologies and transport modes
	- Transport regulation & optimisation e.g. signalling, route planning etc

Cluster 3 - Alternative mobility services

Cluster Name(s)	Hotspots

3 – Alternative mobility services (e.g. car share, bike share, on-demand services etc)	*Innovative Transport Services and Business Models*
	
	- Business models and barriers to different models of personal transport (e.g. collective taxis, electric rickshaws etc)
	- New models of car ownership
	- Vehicle ownership forms:
	    o Car and bike sharing and business model forms
	- Peer-2-peer car clubs
	- Relationship between novel technology (e.g. autonomous vehicles) and novel business models
	- Making public transport private (e.g. private pods)
	- Alternative mobility technologies & services: Cable cars, sky lifts, conveyors belts, shopping carts, trolleys, strollers, prams, skateboards, surfing, submarines
	- More flexible shared/collective mobility options
	    o Options via ICT
	- Role of the regulator

	- The role of motorcycles for personal transport
	- What is needed to enable door-to-door public transport? o Multi-mode, ticketing etc

Cluster 4 – Transport system modelling and policy making

Cluster Name(s)	Hotspots
4a – Infrastructure modelling, reinforcement, transport modelling, regulation and optimisation	*Modelling* - Modelling transport energy on the large and the small scale - Developing a model for transport sector power demands

	Infrastructure
	
	- Electric infrastructure:
	    o Grid reinforcement
	    o Increasing requirements, not just transport but heat for example
	    o Decarbonisation
	    o Induction
	- Energy storage potential for V2G to provide energy storage for power sector

	- Reviewing transport as an energy vector
4b – Supply side policy – understanding and forecasting modelling	*Modelling* - Integrated transport systems and future transport modelling – How to generate and trust forecasts - Need to develop an integrated ICT – transport – land use model (both methods and data). For example for e-mobility, virtual activities, V2V communication
	- Impact on transport in moving from small populations and lots of resource to large populations and reduced resources
	- Adapting to impacts of climate change on transport services
	- Urban and rural connectivity: o Complete transport needs and recognition of differences

Cluster Name(s)	Hotspots
5 – New business models and pricing	*Transport Market Mechanisms* - How to make a 'carbon pass' work? - New ways of paying/financing/pricing transport infrastructure – focus on new market mechanisms
	Evaluating the 'cost' of travel - Policy & business – how to calculate the cost of travel based upon the energy used and emissions generated - Trading – Carbon emissions, noise and time in aviation
	- Research alternatives to UK sustainable aviation roadmap (assuming the same demand)

Cluster Name(s)	Hotspots
6a – Economic use of ICT as an enabler of ability	- Impact of innovations in other areas (e.g. ICT, 3D printing) on transport energy e.g. travel demand
	- Business models for new technologies including the impact of new mobile communications and the 'internet of things'
6b – Connectivity: multimodal, M2M, I2I, M2I, man-machine etc	*Autonomous Systems* - Autonomous systems – knock-on learning, link to connectivity - Research into how to manage a transition to 100% automation of driving (e.g. interaction between automated and human-driven vehicles)
	- Multimodal connectivity and intelligent systems

Cluster Name(s)	Hotspots
7 – Data: ownership, use, analysis, collection and integration – path from data to information to knowledge	- Data sharing – mixing (free) public data with private (data markets, micro payments etc). Managing the resultant IP

	- Data – acquisition, use, ownership, storage, privacy etc
	  o What should be the balance between data for knowledge generation and data to inform business & policy decisions?
	  o What should be the timescale for use and resultant impact?

	- Develop data fusion techniques to draw together big data sources

Cluster Name(s)	Hotspots

8a – Strategic/Whole-Systems Policy	- Policy – Developing a proper understanding of the outcomes of current EU and/or other policy making in terms of low carbon outcomes, whether policy is delivering to intended targets
	  o This is to provide lessons for future policy cycles
	  o To ensure robust policy evaluation is built in from the start

	- Policy frameworks to influence at a global scale and/or recognise interconnections and influence from elsewhere
	- Lifecycle analysis of energy, emissions and materials for policy and strategy development
	- Policy on transport energy materials and recycling

Cluster Name(s)	Hotspots
8b – Industrial Policy	*International Engagement* - The international dimension – Who leads, cross-cultural collaboration, technology exchange? - Develop links between emerging transport energy sector and effective industrial policy so that UK gains benefits in terms of IP, employment creation and GDP growth - So that the UK is world leader in design and production of these new technologies (link to models of open innovation and TSB catapults) - Job creation and inward investment stimulated by new technologies

Cluster 9 - Measuring and assessing system attributes

Cluster Name(s)	Hotspots

9 – Measuring and assessing system attributes	*Modelling & Scenario Building*
	
	- Uncertainty/scenario planning:
	  o Whole system modelling
	  o Robust roadmaps for future worlds
	  o Take account of possible disruptions, policy frameworks etc
	  o Technological boundaries
	- Development of models to encapsulate whole of life cycle energy thinking
	
	Comparison of different transport solutions
	
	- Research into boundaries and metrics framework to enable valid comparison between different transport energy solutions
	- Understanding of total cost of transport movement to assist in deciding on low cost/low carbon options
	- Create consistent framework for comparing the abatement potential of different technologies, systems and services
	- Better understand of the sources of energy and apportionment of these into different transport sectors/modes
	
	- Holistic perspective to include all transport impacts
	- Noise, air pollution, equity, safety, access, carbon etc
	
	- Balancing the need for new infrastructure with protection of natural environment (e.g. HS2). Development of appraisal mechanisms
	
	- Determine the 'optimum' vehicle/mobility fleet for a community to ensure a vehicle is optimised for a specific use
	
	- Technologies with global energy impact – even if they do not do much for the UK energy budget (i.e. UK economic and global carbon impact)

Cluster 10 – Transport fuels

Cluster Name(s)	Hotspots

10a – Alternative fuel options (e.g. gas, liquid, electricity) from point of view of:
 	
• Suitability
• Availability
• Impacts (e.g. socially, environmentally, economically etc.)
	Gas
	
	- What is the role for natural gas?
	  o Technical
	  o Lifecycle
	  o Market/policy
	  o Consumers behaviour
	- Where will this gas be sourced from (e.g. biogas?)
	
	Renewable energy
	
	- Renewable energy/harnessing for transport e.g. wind for propulsion (e.g. ship), wave power

Cluster Name(s)	Hotspots
	- Is renewable energy (e.g. solar, wind etc) truly benign? Is there a long-term global impact?
	Biofuels - Research the scope for commercially viable, sustainable biofuel production in UK for aviation - Research into advanced bioenergy for transport use - Bioenergy – impacts on nature and natural environment
	- Understanding impacts of new resources and their recovery
	- Hydrogen – cost, reliability, storage, infrastructure, distribution
10b – Framework for assessment of environmental impacts of transport fuels (e.g. GHGs, air quality, end-of-life etc)	- Holistic assessment of fuels
	- End-of-life fuels
	- LCA of alternative and current energy technologies or changed operations
	- Alternative fuels – implications for non-CO_2 (e.g. in aviation)

	- Impacts of emissions
	  o Air quality
	  o Climate change
	  o Local vs. global
	- What are the trade-offs between these impacts?

Cluster 11 – Transport energy storage

Cluster Name(s)	Hotspots

11 – Energy storage	*Battery technology*
	
	- Research required into the following battery topics:
	  o Energy density
	  o Chemistry
	  o Reuse/recycle
	  o Vehicle to grid
	  o Battery life
	  o Battery management
	- Batteries – what do we require for them to be able to 'change the game' in terms of:
	  o Energy storage capability
	  o Acceptable recharge speed
	  o Long life
	  o Weight/mass
	- Do we need batteries to be as good as an ICE vehicle, from the consumer's point-of-view?
	- Battery and battery vehicle re-use:
	  o Power management (different capacitors, age, degradation etc)
	  o Power electronics
	- Balancing cells – one large management system?
	- Environmental impact of batteries e.g. manufacture
	- Role of batteries in grid reinforcement and domestic back-up

	- Portable energy storage: batteries, supercapacitors, flywheels o Can energy stored in these technologies be recovered from elsewhere partly?
	- Improved energy storage devices and energy management o E.g. gas storage, electricity storage
	- Alternative power sources and power generation o Fly wheels, hydrogen, batteries powered by solar, wind, geothermal, fission and fusion?

Cluster Name(s)	Hotspots
12 – Conscious and non-conscious motivations of travel behaviour	*Understanding travel behaviour* - What consumers do, as opposed to what they (or others) say they do - Understanding behaviours and needs for mobility and connectivity - This is needed to inform policy interventions - Segment/subdivide or characterise transport sectors to fully understand factors that shape adoption (e.g. different types of fleets, personal, business usage etc) o Also, differences in attitude in terms of risk, safety, cost and reliability
	- Acceptability of autonomous systems, e.g. norms, liability etc o How does this transition play-out through mixed fleets
	- Understanding the market (including irrational/intangible aspects of purchasing decisions and behaviours)
	- Impacts of walking and cycling on health, energy and travel o How do we achieve change across these domains?
	- Rebound effects o How to prevent the 'rebound effects' of people driving more frequently if they have access to zero carbon personal transport (e.g. EVs)

Cluster 13 – Cities and travel

Cluster Name(s)	Hotspots
13 – Cities	- Why can't some cities change and adapt, whilst others can't? What can be learnt from successes? o Winners & losers: If change happens, what happens to those cities that can't or won't change?
	- City design to meet people's transport and other needs e.g. green spaces
	- Urban logistics and changing distribution patterns
	- Using vehicle-grid and vehicle-house smart grids to balance local loads and improve the efficiency of EVs

Cluster 14 - Resilience, adaptability and flexibility

Cluster Name(s)	Hotspots
14 – Resilience, adaptability and flexibility	- Mega events and their impacts on the transport systems
	- Resilience of transport, infrastructure in order to handle extreme natural and man-made events
	- Operational optimisation to improve efficiency whilst maintaining resilience
	- How can we manage safety and perceptions of transport safety/danger

Cluster 15 - How should we manage aviation demand?

Cluster Name(s)	Hotspots
15 – Aviation – How should we manage demand?	- Public perception of various mechanisms for 'rationing' UK aviation (flights)
	- Sustainable tourism and the challenge of low carbon aviation (social and generational issues)
	- The challenge of demand management in aviation – Can we target and improve business connectivity without aviation?

Cluster 16 - Limits to demand for transport/mobility

Cluster Name(s)	Hotspots

Cluster Name(s)	Hotspots
16 – Limits to demand	*Exploring the factors limiting travel demand* - What physical limits (e.g. time, body size, space etc) of people, constrain demand for transport services? - What are the physical limits of people that are important? - How does technology affect the ability to travel or not to travel? What are the effects on energy?
	- We are time poor, so rather than make transport faster, do it while we sleep or eat? o 'Efficiency of time' not 'transport'
	Developing bounds (realistic) for transport demand models – validate econometric models

Cluster 17 - Impact of social media/new forms of communication on travel demand

Cluster Name(s)	Hotspots

17 – Impact of social media/new forms of communication on travel demand	*Demographic differentiation*
	
	- How do we understand future transport demands including demographic and social shift?
	- 'Travel behaviour of the 'social media generation'
	- Generational impact of travel behaviours
	- Impact of changing societal expectations of transport:
	    o Ageing
	    o Youth

	New patterns of interaction and impact on 'need to travel' - Research into emerging practices that might replace or change personal travel as a means of fulfilling these motives - Impacts of new patterns of social interactions - Research into personal motives for travel
	- Methods of measuring the impact of social media and communication on travel and transport need to be developed

Cluster 18 – Vehicle-systems integration

Cluster Name(s)	Hotspots
18 – Vehicle systems integration – Trying to optimise every single piece of energy consumption in vehicle/system	- Low cost transmission (electrical) system – primarily for rail o Does this have application beyond rail?

	- Systems integration at the vehicle-level:
	    o Hybridisation
	    o Thermo-cycles
	    o Hydraulics
	    o Chemical
	    o Mechanical
	    o Electrical

	- Optimising PHEV and regular HEV technology, including all energy demands:
	    o Refrigeration (freight)
	    o A/C (passenger)

Cluster 19 - Low carbon aircraft

Cluster Name(s)	Hotspots
19 – Low carbon aircraft	- Holistic view of trade-offs in the design of aviation technology
	- Low emission 'airside' vehicles at an airport, including GSE

	- Low carbon fuel and power sources for aircraft on stand-by
	    o APUs
	    o Fuels e.g. liquid, bio-fuel, duel fuel etc

Cluster 20 - What are the barriers for technology change and how do we resolve conflicts?

Cluster Name(s)	Hotspots

20 – What are the barriers for technology change and how do we resolve conflicts (e.g. safety vs. light weight/ new fuel vs. existing)	*Risks and safety concerns of new technology*
	
	- Trade-off between perceived safety and energy – conflicting desires
	- Risks of new technology roll-out – Unintended consequences of new technology could harm future adoption/uptake, such as safety failures
	    o E.g. Failure of power network to cope with demand and/or failure of alternative fuels to meet demand.
	    o E.g. Development of over-reliance on limited resources (e.g. rare earths, lithium) and associated geo-political issues

	- Real world fuel economy – Bring test bench closer to the real world so that we better understand the CO_2 production questions and can therefore help mitigate this
	- Technology lock-in and lock-out – Traditional thinking and use of infrastructure is stopping new and radical thinking

Cluster 21 – Changing transport behaviour

Cluster Name(s)	Hotspots
21a – Making transport attractive and providing good information	- Public transport in the regions – make it a pleasure to use
	- Making public transport 'sexy' – i.e. desirable and the norm
	- Better real-time operational information and communications (not by apps)
21b – Making behaviour change happen	*Incentivising new behaviour* - Education – Exploring how schools and get kids hooked on using less energy - Behavioural drivers of transport choices of different groups and segments - Make it fun to encourage change in behaviour - How to persuade individuals to care about the amount of energy that they use. If they do not already worry about the environment of financial considerations
	- Don't forget the 'user fun' aspect of transport and journeys – driver pleasure
	- Why would people change? Built in habits, barriers, expectations…. o What do we have to do to overcome inertia of change?
	- Personal travel data logger equipment

	- Eco-driving:
	    o Assessing and testing its impacts
	    o Driver information interface

	- Shifting destination choice (not mode choice)

6 Reflections on Day 1

At the beginning of Day 2, the participants were asked to reflect in pairs about the work of the previous day. They were then asked to complete the following statement: "During our deep-dive discussions today - please bear in mind …………..". The 'deep-dive' exercises took place after this period of reflection and involved the participants examining the research hotspots that were identified on Day 1 in much greater detail. The following points were raised:

- … the **timing of carbon reduction measures matters**

- … we're **not just talking about passenger transport**

- … **the global picture** - we've got a huge international energy footprint. Other people are competing for the same finite resource, particularly for biofuels

- … **the key barriers underneath all of this.** If you don't remove those, no matter what else you do you can't make progress (e.g. batteries for electric cars). Some of these are technical but also behavioural, e.g. the value proposition for an electric car is a little worse than current ICE cars

- … that all previous technological developments in the transport sector have resulted in **more mobility, higher speed but not more efficiency**. What is going to be different this time?

- … how **people will use and interact with innovative transport technologies**

- … there are **unique characteristics of the transport sector** that doesn't exist in other energy sectors. For instance, Formula 1 is responsible for a lot of R&D and transport innovation - how can we link these innovation chains to what we're doing?

- … it's **not just about carbon emissions**, but also energy security, affordability, oil shocks etc

- … **a lot of work has already been done** to lay out strategies in certain aspects of the transport sector, e.g. aviation, or other areas of energy

- … **the way behaviour and technology interact with each other** in the context of transport

- … for a lot of the stuff on the clusters we already know what works and what doesn't in a technical sense. So it's about **implementation and delivery** and figuring out how to do that.

- … that a lot of solutions to reduce energy in transport don't lie in what we see as the "transport sector". Instead a lot of it is in **urban planning, or industrial policy**. The 'nuts and bolts' of the transportation aren't the only determinants of the amount of energy used in transport.

- … it's also about **energy, materials and manufacturing** that are required to produce the 'nuts and bolts' of the transport system

- … we're dealing with a large legacy fleet and infrastructure, so changes and **improvements to ICEs still have a big role to play**, e.g. incremental improvements in efficiency. Even in the most optimistic scenarios we're talking 10% penetration of EVs by 2030.

- … how **innovations in sectors beyond transport,** (e.g. 3D-printing) may impact upon the transport sector (e.g. may reduce the need for freight due to localised manufacturing capabilities).

7 Research Cluster 'Deep-Dive' 1: Communities

7.1 Introduction to the Exercise

In this exercise, participants were asked to identify key research questions relating to the research clusters and super-clusters that had been identified on Day 1, as well as any potential challenges that might be encountered in undertaking this research and what might needed to be done in order to address these challenges.

7.2 Methodology

Participants formed into similar interest groups and each group was allowed to select whichever research clusters/super clusters they wanted to examine in greater detail, which are outlined in Table 4.

Table 4: Community groups and their selected clusters for Deep-Dive 1

Group	Selected Clusters/Super-Clusters	
	No.	**Description**
A	1	Infrastructure options for immediate and rapid decarbonisation
	12	Conscious and non-conscious motivations of travel behaviour
	21b	Making behaviour change happen
B	9	Measuring and assessing system attributes
	10	Transport fuels
C	3	Alternative mobility services
	8	Whole-system/industry-wide policy making
D	5	New transport business models and pricing mechanisms
	19	Low carbon aircraft
E	14	Resilience, adaptability and flexibility
	18	Vehicle-systems integration

To assist the deep-dive process, each team was provided with an activity sheet with a set of questions and suggestions as how each question could be approached. The questions were as follows:

1. What are the main research challenges we need to address for our research to be first class in terms of both excellence and impact?
2. To address these challenges what would you like to see change? For example consider:
3. What needs to happen in terms of coordination and alignment to maximise success in your research area?
4. What do we need to have in place to ensure we are ready to address these research challenges (e.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)?

Alongside these questions, the participants were encouraged to thing in more depth about the type of research questions they would like to examine. Responses to these questions were recorded both on the flipcharts and by note takers, after which the groups reported back their key outputs in plenary.

7.3 Summary of Results

This exercise generated a large volume of data. Key themes are presented in the main text. The detailed outputs are documented in Annex A.

7.3.1 Important Areas for Future Research

- **Transport Policy** – Examining different policy mechanisms and governance arrangements to driving a transition to a sustainable, secure and affordable transport energy system. Particularly mechanisms in relation to influencing choice of transport mode, fuel and destination, such as carbon allowances, subsidies, taxes etc. Also understanding the broader impacts of transport policy making on the transport energy system

- **System-wide analysis of transport energy systems** – Approaching energy issues holistically, being sensitive to a multitude of factors and viewing the system as a whole

- **Flexibility and resilience of transport energy infrastructure** – Examining how we can integrate existing transport infrastructure with alternative modes of travel or vehicle technologies. Explore how changes to existing infrastructure may impact upon their resilience

- **Costs of and trade-offs between different transport energy futures** - (e.g. new transport infrastructure)

- **Changing travel behaviour** - Exploring the factors responsible for shaping decision making around transportation and consequently, travel behaviour. Explore ways to achieve transport behavioural change and associated impacts/benefits

- Establishing **frameworks/models capable of analysing transport energy system change**, particularly with a view to inform transport policy

- **Transport Fuels –** Exploring the opportunities to utilise alternative fuels and how a reliance on different transport fuels will have different impacts on the transport and broader energy system

- **Alternative mobility services and business models** – Identifying alternative ways of satisfying our mobility needs and the types of business models that can provide these services in an economical manner for both provider and consumer

- **Freight & logistics** – Understanding how to improve the efficacy and efficiency of freight systems via logistics

- **Aviation** – Examine the opportunities to reduce emissions across the airport system, not just in the aircraft (e.g. 'on-stand', baggage management, taxiing etc). In relation to aircraft, explore opportunities to retrofit existing and emerging aircraft fleet

- **Vehicle-System Integration –** Exploring how vehicles and the systems in which they exist can be better integrated, rather than vehicles operating in isolation from one another. How can this be achieved and what are the potential benefits?

7.3.2 Key Requirements to Undertake this Research

- **Inter-disciplinary transport energy research centre/lab** – something that brings together the various communities that are engaging in transport energy research, which not currently engage with one another much. Need figureheads to lead this inter-disciplinary research, who are responsible for bringing together different strands of research. Inter-disciplinary research networks could support this centre's operations, holding workshops & conferences

- **Test facilities for radical and incremental innovations**, both technical (e.g. infrastructure, vehicles etc) and non-technical (e.g. business models, transport management approaches, policy mechanisms etc)

- **Mixture of disciplinary and inter-disciplinary transport energy research** – strike a balance between researchers 'digging deep into' specific aspects of the energy system, whilst others work on more system-wide, cross-cutting issues that demand a systems perspective
- **Academia-industry-government collaboration** – Promote collaborative R&D between these three parties to help generate innovations and drive them through the innovation chain to commercialisation. Effective communication/knowledge-exchange of research outputs by academia could help to ensure outputs are used and collaboration occurs. TSB's Transport Catapult centre could prove an effective platform for this
- **Joint funding between RCUK and other R&D bodies –** Help 'join-up' the innovation chain by issuing jointly funded research calls that require RCUK to engage with other R&D bodies e.g. ETI, TSB etc) to ensure that transport energy research moves beyond TRLs 1 & 2 and towards commercialisation
- **Data infrastructure** - Need for a central and accessible database of transport energy data, which can be accessed by researchers. Wealth of potentially insightful data that is privately owned but should be made accessible if possible. Data will also help validate transport models
- **Transport Models** – Need to develop new transport models, which are:
    - validated using 'read data'
    - capable of examining the whole transport energy system
    - sensitive to a combination of technical and social factors
    - draw together existing models
- **Research funding calls** to promote systems-wide transport energy research, as well as funding that enables international studies of transport energy systems, capable of identifying important lessons for the UK and/or more indirect benefits for the UK (e.g. reduction of transport GHGs in developing countries)
- **PhD Training** - A combination of project and DTC funded PhDs that focus on a combination of specific and system-wide issues, specific to transport energy. CASE studentships with both industry (e.g. Shell, BP) and government (e.g. DfT, DECC, BIS) could help build bridges between academia and other sectors

8 Research Cluster 'Deep-Dive' 2: Community Cross-Cutting

8.1 Methodology

Participants were split into four groups, which constituted a mix of the community-based groups that were formed in the previous deep-dive exercise (Section 7). The groups were asked to examine the remaining clusters/super-clusters, which are listed in Table 5.

Table 5: Cross-community groups and their selected clusters for Deep-Dive 2

| Group | Selected Clusters/Super-Clusters | |
	No.	Description
A	4	Transport system modelling and policy making
	6	Transport, ICT and connectivity
B	20	What are the barriers for technology change and how do we avoid conflicts?
	11	Transport energy storage
	-	Freight & Logistics[1]
C	2	Demand-side policy
	16	Limits to demand for transport/mobility
	12	Conscious and non-conscious motivations of travel behaviour
D	15	How should we manage aviation demand?
	17	Impact of social media/new communications on travel demand
E	7	Data: ownership, use, analysis, collection and integration
	13	Cities and travel

To assist the deep-dive process, each team was provided with an activity sheet with a set of questions and suggestions as how each question could be approached. The questions were as follows:

1. What are the main research challenges we need to address for our research to be first class in terms of both excellence and impact?
2. Whose job should it be / who is best placed to undertake this research?
3. How might the different funding bodies collaborate to address these questions (how to bridge the interfaces to integrate)?
4. What do we need to have in place to ensure we are ready to address these research challenges (e.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)?

Alongside these questions, the participants were encouraged to thing in more depth about the type of research questions they would like to examine. Responses were recorded both on the flipcharts and by note takers, after which the groups reported back their key outputs in plenary.

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[1] This subject was added as the participants believed that it had been somewhat overlooked and deserved further attention

8.2   Summary of Results

This exercise generated a large volume of data. Key themes are presented in the main text. The detailed outputs are documented in Annex B.

8.2.1   Important Areas for Future Research

- **Integrated modelling** of transport, behaviour and electricity networks to provide more accurate forecasts of needs and usage, so that policymakers and local government can make better transport decisions.

- **Data standards and requirements** – a great deal of transport data has been collected by commercial organisations and not the government, and government hasn't released some data. Data requirements and standard formats should be agreed in depth between interested parties, and legal barriers surmounted if possible.

- **ICT Fragmentation -** ICT will undoubtedly play a big part in the future of transport, currently however the supply chain is very fragmented, with lots of different supply chains and stakeholders. There isn't much available data for researchers to work out what the impact of ICT has so far been on transport energy

- **ICT and social media -** This is a very business-focused area, with a lot of people attempting to make money from the sector. The programmers and computer scientists who work in this space don't necessarily understand the whole sector, and common terms of reference need to be set. Social media will play a large and unpredictable role in future transport operations, and is an important area of future transport energy research.

- **Applications of social media -** Participants mentioned several specific applications of social media – tweeting informing commuters if trans are delayed, coordination in local areas to share delivery costs and GPS applications that collect traffic data from their users to route around heavy traffic congestion. Research should be done to see how these constantly-evolving applications change transport behaviour and demand.

- **Freight logistics -** Logistical data is very important to discover demand patterns and how best to optimise systems. There are very thin margins in freight logistics – this could put off investment in more advanced systems. There are research questions in dispatching and optimisation systems and social science, to understand drivers' behaviour.

- **Autonomous Vehicles -** Some key legal questions – whose fault is it if an autonomous car collides with a driven vehicle? Are autonomous vehicles the 'ultimate answer' to road transport, and should we be heavily working towards this goal?

- **R&D timescales -** Where should resources be put – step change or incremental change? Over what timescales should we focus our research efforts? Scrappage schemes can accelerate the introduction of new technologies, and reconditioning for older vehicles needs to be investigated.

- **Transport energy storage -** Energy density vs. power density – both are important for vehicles. No current standardised batteries for battery swapping – electric card are designed from scratch currently. Research into a common transport energy storage cell is important. The type and characteristics of the energy storage technology needs to be mapped against the vehicle and service required.

- **Limits to transport demand -** To predict future demand, it needs to be understood how people's transport needs are changing. Are they travelling more than historically, and by which modes? Do we understand the motivations and drivers behind travel and travel demographics?

- **The rebound effect –** More efficient vehicles will lead to cheaper travel, which will mean that people will travel more. However, this limit is not infinite – people will only drive more up to a

certain point. There are physical time and space constraints with transport as well – the number of vehicles that can fit on the road etc. More modelling work is needed to understand the strength and the limits of the effect.

- **Alternatives to travel -** What technologies and behaviours help to reduce peoples' travel needs? Videoconferencing has been seen as an alternative to physical meetings – does it work and are people using it? There is also a balance – if travel costs go up, at what point will people switch more to tele/video conferencing? Is this also a generational issue – do younger generations need to meet people in person less than older generations do?

- **Aviation demand -** Air travel for holidays and business is important to a lot of people. How can you best manage this demand, and how can you convince people to fly less without a 'nanny state' backlash? This is a heavily international question – even if you limit flights in the UK, there could still be heavy growth globally.

- **Smart cities and urban travel -** Cities require a complex and integrated transport structure, including public transport and congestion-management. The priorities and demand patterns of city-dwellers need to be understood, and the characteristics of the city (size, economy, transportation infrastructure) need to be understood in creating transportation architecture. ICT has a big role to play in shaping urban transportation networks and 'Smart cities' are an important research priority in this area, where there are already big academic and commercial international research initiatives.

- **Data ownership and use:** Data collection and interpretation is very important in this field. A lot of transportation data is proprietary, and there are significant privacy implications with demand data. A procedure to standardise and resolve the legal implications surrounding data usage would be very valuable to researchers. Initiatives to collect data on transport modes such as walking and cycling, which are more difficult to measure, would improve our knowledge of these areas significantly.

8.2.2 Key Requirements to Undertake this Research

- **An interdisciplinary transport think tank** was brought up many times as a good way to reduce fragmentation in this sector, and to bring together technologists, modellers, economists and social scientists. Can get 'the best brains in the country from academia, industry and government' to work together in one space and consider transport energy?
  - In this regard **Catapult Centres** were seen as important initiatives, both doing R&D in their own right and by providing a 'platform' for researchers to collaborate and inform policy. They need to be of a size to have a 'critical mass' of researchers working in them, and need to have good links and coordination with other research programmes and centres.

- **Cross-Research Council thinking -** EPSRC looks mostly at transport energy from the technology angle. However, more and more of the research questions in this area deal with behaviour and demand. Collaborations and research project coordination between EPSRC and ESRC should be considered.

- **Collaboration with ICT -** The Digital Economy Catapult and the Digital Economy TEDDI call should be linked to transport energy programmes. PhD students could be seconded to software development companies to understand the ICT sphere.

- **Logistics and freight industry collaborations –** To reduce fuel costs and improve sustainability credentials, the industry is very interested in research collaborations.

- **Artistic and graphic designers** would be a useful addition to teams researching demand and behaviour.

- **Secondments** are a very effective way to bridge the gap between academia and industry/government.

- **Industry awareness -** In this sector, industry is often not as aware of the large academic research programmes happening. More active engagement with industry would provide them with a better overall view of the research landscape.
- **International collaboration -** A large number of transportation energy issues are international in nature, and therefore international collaboration is very valuable in this area. EU projects, especially in the upcoming Horizon 2020 programme, could be used to provide significant funds for research, especially in whole-systems and modelling work, which industry are less likely to fund themselves. The IEA also runs transport systems modelling programmes.
- **Larger projects -** A common view was that research projects needed to be larger and longer to properly incorporate the interdisciplinary, whole-systems nature of the work. Projects could be focused more on solutions to specific problems, instead of focused on methodology.
- **Data interpretation methods -** Transportation data tends to be very large in size and difficult to interpret. Research into better methods and software to interpret this data into useful findings is important to underpin a lot of the key research problems.
- **Data collection and collaboration -** Data companies such as Google collect a large amount of transport data – collaborative initiatives between companies like these, researchers and city planners and civil servants would extend the knowledge base considerably further. Individuals should be encouraged positively to share data with benefits.

9 Reflective Writing

9.1 Process

The purpose of this exercise was to ensure that the finer detail generated during the workshop was not lost. It provided participants with the opportunity to build upon ideas they had formulated during the clustering and deep-dive exercises and allowed them to flag any broader issues they wanted to raise. Participants were provided with three options for the reflective review session:

Option One: *Independent Reflection*

> A room was set aside for individuals to work on their own to record their thoughts and ideas.

Option Two: *Chat Room*

> A room was provided for participants who wanted to talk through their reactions to the themes and research ideas. A note taker was present to record the discussions.

Option Three: *Reflect and Chat*

> Participants in this room first reflected individually and subsequently joined together in groups of three to discuss their individual reflections. This enabled participants to develop their ideas by 'bouncing' them off other members in their group.

Participants were encouraged to post any written output from this session into a reflections post box or email their thoughts to the organisers.

Please note that after the workshop invitees were provided with a draft copy of the workshop report, which they were encouraged to provide feedback on. Any feedback provided by invitees is marked with an * to identify it as a post-workshop reflection.

9.2 Outputs

9.2.1 Future Research

- *Critiquing Mobility** – Little discussion around whether mobility/transport is a good thing, however in many ways it can be regarded as a waste of materials; land; energy; time; and sometimes of lives. Therefore, strategies to reduce the perceived 'need' to travel could be important in the future.
  - One interesting exception might be forms of transport (e.g. bicycling) where time spent on the bike can improve a combination of fitness and happiness. Therefore, some modes could be counted as 'less wasteful' than others.
- **Land Use Planning -** Land use mentioned a few times but insufficiently covered
  - E.g. Geospatial location of activity opportunities is a key driver of travel patterns
- **Implications of Low Carbon Transport -** How flexible is zero carbon transport and what implications will it have for the resilience of the transport system?
- **Systems Perspective -** Electricity, communications and transport networks increasingly interdependent and future research should be sensitive to this
  - A whole systems approach because the system is big, cross-modal, large infrastructure dependencies and multi-parameter optimisation
- *Prioritising Focus on Medium-Term Technologies -** If mitigating energy sector CO_2 emissions and the UK 2050 CO_2 target are the key issue then we should focus particularly on those technologies that will come 'online' over the next 15-20 years as they will dominate the

transportation system at mid-century. In turn, this reduces the importance of some of the technologies that are unlikely to come 'online' within this period.

- **Transport Infrastructure & Lock-In -** Infrastructure locks countries into good or bad transport patterns.
  - Developing countries have the opportunity to leapfrog this stage, given that their transport system is much less developed
  - Developed countries can still radically reduce their energy demand by utilising existing infrastructure (i.e. existing railways allow more efficiency travel in developed countries). This must be explored further
- **Technology – Behaviour Interface** - How does technology shape social norms? What is the added customer value of new technology solutions?
- **Consumer Transport Behaviour -** How do we change social norms and export these 'positive' norms abroad?
  - E.g. How do we ensure these vehicles light, small, fuel efficiency vehicles, not large gas-guzzling status symbols?
- **Travel Demand Models –** Need to improve the linkages between travel demand and transport energy demand models
- **Future Transport Demand in Developing Countries -** How will we manage the 2 billion new vehicles expected to come 'on-line' over the next 30 years in the developing world?
  - Must think about transport in a global context
- **Drivers of Freight Demand -** Freight transport mostly studied independently from the drivers i.e. consumption, which is partly why we are unable to analyse the trade-offs between virtual and physical retail activities
- **Transport Demand & Marine Transport** – What role does marine transport have to reduce demand for other modes?
  - What is the potential for inland waterways and UK coastal shipping to reduce road freight?
  - What is the potential for marine passenger transport to reduce demand for aviation?
  - How can novel marine transport (e.g. ship) technologies be incentivised and ensure they fit with the existing system?
  - What are the options for low carbon UK water transport – technical, operational and behavioural? Also, what are the key barriers?
- **Transport Efficiency –** Designing and building very lightweight vehicles reduce energy demand for transport significantly and can be achieved irrespective of the drivetrain/fuel technology, helping to reduce the risk of lock-in to a particular technology pathway. Opportunities in the following:
- **Walking & Cycling -** Best options for short trips (in transport, energy and carbon terms) but which policies, measures and interventions do we need to implement to make a transition to a Dutch style, active travel culture happen?
  - Education and cycling proficiency in schools – 'getting them early'
  - Cycling infrastructure
  - Teach vehicle drivers how to be aware of cyclists (more emphasis on this in driving theory/practical test?)
  - *The electric bicycle offers a much more cost-effective, user-friendly and purpose-applicable use of battery electric technology than battery electric cars. Additionally it has emerged with little policy or financial support. Little is known about its potential impact on transport energy systems and more research is required.
    - Downsizing the energy needs 'on board' (e.g. more efficient on-board HVAC)
    - Micro-harvesting of energy in motion

- Considering every 'drop' of energy in the complete transport operation (e.g. motive, load/unload, lighting etc) to optimise efficiency
- Reduced vehicle mass (e.g. reduce ration of unladen mass to laden weight)
- Improved aero dynamics
- Reduced rolling resistance
- Alternative powertrain technologies
- Development of alternative fuels
- Examining driver behaviour (e.g. eco-driving)

- **End of life vehicle management –** Research into the following:
  o Design for disassembly
  o Reuse
  o Remanufacture
  o Closed loop recycling

- **Life Cycle Analysis** - Although covered by the overarching Life Cycle Thinking work, the embodied energy of both vehicles and the wider transport infrastructure has received little attention. Opportunities to research the following:
  o *Manufacturing* - Sources of energy; energy demand & yield; low temperature process; reducing hot working; assembly & disassembly processes
  o *Materials* (utility, CO_2, energy intensity, recyclability)
  o Balancing of embodied and use phase emissions (e.g. fuel) and energy savings
  o Examining the lifetime period of the technology

- **Liquid Air**
  o Liquid air as a fuel/energy vector, has 2 key potential applications:
    - Use expansion in an internal steam engine to drive pistons
    - Use of a tank of LN_2 /LA as a source of 'cooling/cold' to enhance thermo cycles in engine/other on-board energy recovery or refrigerant systems
  o Future research:
    - Does work but has some problems around infrastructure such as H_2
    - Need to explore the plausible applications for road, rail, shipping etc, particularly if refrigeration is required

9.2.2 Needs to Undertake Research

- **Need for more social science transport research -** The dominant model of behaviour in transport research is rational choice theory; however we know this is hopelessly wrong. Need to increase the ratio of psychologists and social scientists vs. economists working on transport studies to increase the use of more valid motivational m theory and models

- **Collaboration with industry –** Opportunities for collaborative research projects:
  o Need to work with industry to understand at which point they would be incentivised to go beyond the easy & quick wins in transport energy efficiency and engage with more radical step changes
  o Motorsport acts as a showcase for new road transport technologies. This must be exploited via joint or collaborative R&D

- **Strategisation –** Important to assess the options available to make informed decisions with an integrated roadmap for implementation leading us to 2050 – don't jump straight to the solutions! Use backcasting approaches to identify key steps

- **Methodology -** The methodological quality of field research on transport behaviour and behaviour change is often very poor. Uncontrolled studies of no value are very common. We need to improve training in research methods and reject methodologically weak R & D proposals more readily

- ***Showcasing Technology Through British Motorsport** – This could play a key role in show-casing/demonstrating technologies that could catalyse system change. New ideas can be developed, implemented and demonstrated on an international stage in less than a year. Note that anti-lock braking, aerodynamics, efficient IC engines, lightweighting, materials technologies, tyre technology, KERS systems have all come from motorsport already.
    - Technology can also be demonstrated via public-facing, local services, such as high-tech and low energy post-office vans.
- **Combination of 'Blue Sky' and More Practical Research –** We are spending most of our research funding on 'blue sky' research that may never be implemented. It might be far better to have a route map to serious emissions reductions through a series of practical, economic and socially acceptable steps. This should focus on getting maximum reductions in the near term, transitions to larger reductions in the long-term.
- **New Funding Mechanisms for International Research -** At present there is no funding mechanism to support research into low carbon emission vehicles/transport for the developing world BUT GHG emissions and climate change represent global issues and need global solutions. The funding mechanisms focussed on UK Plc cannot address this issue and we need a radical change in research funding policy in this area to enable this.

10 Key pointers for the Research Councils – start/stop/continue

Participants worked in groups of three to list the three issues that have emerged for each person during the workshop. They were asked how the Research Councils could assist in terms of things they could:

- Start doing/do more of
- Continue to do
- Stop doing/do less

The responses were recorded on flipcharts and each group reported back verbally on one issue they had identified. Table 6 below presents the outputs of this exercise.

There was a clear preponderance of requests for the Research Councils to prevent 'siloing' of research and to encourage interdisciplinary collaborations and collaborations with industry. There was also a desire to move away from the focus on CDTs for PhD training purposes into more grant- supported PhD students. The desire for a clear joint vision, strategic themes and cross-Council programmes were clearly signalled.

Table 6: Suggested Actions for the Research Councils

Start doing/do more of	Continue to do	Stop doing/do less
Research Focus		
Transport focus to be added	Do more joint calls in transport/transport & energy	Stop funding low methodological quality research in transport
National > International focus	Digital economy funding	
Focus on operational exploitable topics > value added	Focus on low carbon agenda	
Identify what research will be funded by industry and what will not		
Research style		
Encourage more collaboration between academics rather than creation of large silos	Continue funding fellowships and expand funding	Treating strategic topics within discipline silos
PhD Student funding on research grants, not just DTCs	Continue to fund research in aviation/airports to promote efficiencies, competitiveness + improved environmental performance	Don't silo RC by domain
Longer funding periods		Less creating big silos
More cross-discipline PhDs?		
Faster funding model for smaller and time dependent projects		
Start funding research for internationally relevant, not just UK relevant projects		
More communication & dissemination of results		
Encourage partnerships and broader participation		
Research process		
RCs to work together more	Interactions/link research community	Fewer managed calls, more responsive mode funding.
More responsive mode funding	Interact with wider communities (LCIP)	Stop sandpits
National Transport DTC (industrial)	Link with TSB (RCUK - TSB)	CDT model for PhD

(Including MSc)		
Proper not pseudo cross-council funding	Sandpits but 2-3 days, not 5!	Stop focus on doctoral centres
Too few reviewers who understand (fully) multidisciplinary (have specific training)		Part return to project PhDs
More interdisciplinary research similar to energy programme		
Provide funding to enable movement of research staff between institutions as part of National Programmes of strategic importance		
Better Evaluation of research impacts upon grant completion		
Start funding research for internationally relevant, not just UK relevant projects		
Common agenda and assessment framework		
Engagement of KTNs		
Other		
More equal ownership to RCUK EP across research councils	Open access to data and reports	Less duplication –we already have a lot of information
Do more linking of separate research projects to enable links to be exploited e.g. via web, conferences	Striving for excellence being a "can do"	

11 Final Observations and Outstanding Questions

Jim Skea and Matthew Hannon presented their observations on the workshop. Jim observed that this workshop had created the largest numbers of clusters thus far in the prospectus process, which reflects on the fragmented nature of the transport community. The scope of transportation research also connects with issues from many of the other Fellowship workshops – bioenergy, energy storage and fossil fuels in particular. Matthew commented that he was impressed with new and interesting ideas in this sector, including the synergies occurring between novel business models and vehicle design, as well as ideas around lowering the carbon footprint in aviation before planes become airborne. It is very difficult to exclude parts of this sector in an analysis, as all components interact with each other in many ways.

A question was asked on industry engagement – 'how broad has engagement been thus far in the prospectus process?' The reply was that there has been a broad industry engagement with the process, with the workshops aimed to split 50:50 on academic and industry/government/research council participation. The workshop was complimented on the quality of the facilitation coordination, especially as the participants generally did not consider there to be such thing as a single transport community.

12 Annex A – Detailed Outcomes of Research Cluster Community 'Deep-Dive'

12.1 Group A

12.1.1 Cluster 1 - Infrastructure options for immediate and rapid decarbonisation

Key research questions?

Real long-term costs of transport infrastructure

- Can we monetize (or otherwise quantify) all the different infrastructure options so that they're in one frame, and can start grappling with what the right decision is? The development of a 'common currency' to support holistic decision making that takes into account the whole spectrum of costs associated with deploying a new infrastructure, i.e. not just construction but also vehicle running costs for example
  - o Such an economic framework may need to take into account rebound effects, e.g. reducing the cost of transport may increase the number of miles travelled.
  - o The framework would be sensitive to different and potentially conflicting priorities: e.g. speed, time, safety, carbon, cost etc
- No one winner - If there is no one winner but several, how do we figure out which combination of winners works best? What combinations fit and how do we assess them
  - o "Automotive road maps" do exactly that. Matrices of different techs in cars/trucks, what's the timeframe for them to be introduced. Such technological roadmaps exist already BUT is there specific research that needs to be done, e.g. specific case study research?
- The cost of the infrastructure is so huge it is difficult to decide to do anything. Therefore, how do we make trials and quick tests of innovative approaches in a cost-effective way to decide what to scale up

Approaching efficiency holistically

- Need to understand and map out all inefficiencies in the current transport system in order to identify the best places and approaches to tackle them
- How can infrastructure, vehicles, policy business models etc be designed in tandem to maximize transport system efficiency? i.e. Instead of just looking at the cost of a bridge or the cost of a new tyre on itself, can we design solutions that favour overall/holistic savings and optimization.

Impacts of low-carbon transport transition

- What do we lose if we go for a low-carbon society? Identifying the penalties, e.g. if we decide we want to change behaviour so that nobody drives anymore, what bits of society fall apart?

Policy & Market Mechanisms

- What's the best strategy to decarbonize AND ensure energy security? There is no transport energy strategy in England (maybe in Scotland?). We know dozens of policy options that work in other countries, so why can't we implement something similar here?

- o Which policies should be implemented to encourage incremental vs. radical innovation?
- What are realistic and achievable implementation pathways? What governance structure would support these?
- Market forces not aligned with climate challenge - how can we design proper incentives and policies to get around that
- Commercial structure of the transport sector often promotes inefficiency e.g. trucks going around half-empty to reduce time lag; train companies not really operating in a competitive environment in UK due to 'managed monopolies'. How can policy and market mechanisms be restructured to promote competition AND energy efficiency?

Infrastructure Flexibility

- How can we adapt existing infrastructure for new technologies? We need to identify and assess current infrastructure and possible flexibility of use/improvements:
  - o e.g. if we have very lightweight new vehicles do we want those on the same roads as very large heavy trucks (we want even larger trucks for higher efficiency). Do we want separate lanes for lightweight vehicles to improve safety? What about autonomous cars?
  - o How far can current vehicles be pushed e.g. ICE, considering whole system of: driver, chassis, engine etc
  - o What methods are there to reduce emissions of existing fleet? E.g. retrofit, fuels etc
- What are the long-term costs of retaining the flexibility and compatibility of existing infrastructure and new stuff vs. the costs of doing a radical infrastructural overhaul.
  - o Need to assess the costs, impacts, benefits of very radical and rapid change, i.e. step vs. gradual change. For example, if we move faster than other countries to radically change our own transport system, are we going to hurt our own industry and competitiveness?
- To what extent can we integrate new technologies into existing infrastructure? E.g. autonomous vehicles onto existing road network
  - o Also, what can we bolt on to existing vehicles? E.g. CO_2 capture.

What are the main research challenges?

- **Research agenda promotes non-holistic research** - When funding calls come out, they tend to say "you can't just address only one aspect but all or several of them"? This serves to undermine holistic transport energy research
- **Lack of focus on transport energy issues in research centres** - Energy research centres typically engage in only a small amount of transport energy research. Consequently, the links between the transport and broader energy system are not fully understood
- **No clear plan to 2050** - The UK carbon plan says we basically need zero-carbon cars. The rest of the transport sector is largely neglected, with the focus mainly being on reducing transportation needs. Very grey area
  - o UK hasn't articulated a vision of the future (e.g. what mobility will look like), only a vision of carbon in the future. Is it just an assumption that we do the same stuff as now but with different technology? This is a problem
- **Lack of capability to truly think about radical alternatives** – We normally come back to road transport and focus on incremental changes e.g. a lighter car.
  - o A Tyndall Centre conference called '*The radical plan*', which focuses on generating examples of significant radical change and bring those together. It's peripheral in the

conventional research agenda and not really appreciated as serious research – a need to get real radical thinking out there.

- **Relationships between academia & industry -** For incremental developments there needs to be closer connections between academia and industry.
  - o Commercially the transport sector incorporates large international vertically integrated corporations. As such it's very difficult to interface with the complete industrial portfolio and thus difficult for small research teams or one-man shops to really play a role and to get new innovative ideas through. While it may look like those individuals/researchers that engage are not very powerful or have no visible impact, this is still how ideas start percolating through these large organizations.

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?

- **Research calls to promote holistic transport energy research** – Research agenda must provide funding for holistic research that looks at the transport energy system as a whole, not just isolated parts of it.
  - o An opportunity for a separate call in itself to review all existing research in this area to construct a holistic view of the transport energy system, which can help people assess how changes in one area might compare to changes in another.
- **A balance between disciplinary and inter-disciplinary research** - Is there a danger that too much focus on inter-disciplinarily would lead to a dumbing-down of research as it would no longer be in-depth enough? You need a lot of in-depth disciplinary research so that interdisciplinary researchers can work off of that deep research and compare it.
  - o Need a framework that is capable of integrating both deep/specific research with broad/holistic/inter-disciplinary research
  - o This may impact upon peer review and revamping it/new ways of peer review? i.e. having specific and holistic peer review streams
- **Transport Energy Research Lab** - We need a cross-cutting national transport research centre specifically for transport, similar to a US DOE national lab or the RCUK's EUED centres. This will help bring together transport specific and energy related research communities, which don't normally engage.
  - o This should not only focus on energy users but also energy vectors
- **Blue sky thinking research funding** – Enable more thinking around issues such as radical transport system changes, without many of the constraints normally imposed upon RCUK funded research e.g. need for an impact plan. Current system means it is hard to go beyond incremental tweaks.
- **Clear pathway to 2050** – A robust set of scenarios and priorities that relate to both radical and incremental transport change
- **Academia & Industry Relationships** – Effort must be made to build a closer relationship between both academia and industry to ensure collaborative research is undertaken and that the outputs from academia are effectively fed through the innovation chain towards commercialisation and not lost
- **PhD training within research projects** – Make some provision for project-funded PhD, outside of DTCs, as it used to be.
- **Data curation –** Need for a central and accessible database, which can be accessed by researchers. Important to ensure it is designed to be easy to navigate and utilise
- **Test facilities** – Need for fast access to non-bureaucratic hardware test facilities to rapidly test innovative prototypes and ideas

12.1.2 Cluster 12 - 'Conscious and non-conscious motivations of travel behaviour' & Cluster 21b - 'Making behaviour change happen'

Key research questions?

Importance of behavioural change

- How important is behavioural change? Aviation is good example: if you want 80% reductions there are simply no aviation technologies that can deliver that. So you really have to think about the demand side if you want to remain realistically able to deliver these deep reductions.

Achieving behavioural change

- How have existing travel behavioural norms been established?
- What travel perceptions and behaviours do we desire? What methods are available or suitable to drive behavioural change?
- What do we have to do to make behaviour change happen? Do we force it and push it through against public opinion OR are there better ways to do it?
  - o Are we changing something that people fundamentally like (e.g. classic car driving) or have chosen to do to fulfil another desire (e.g. travel to go on holiday) or is this a necessity and one they have little control over? How does this impact upon the acceptability of changing people's travel behaviour?
    - ▪ Explore the difference between travel needs and desires
  - o Is it the remit of the energy and transport research agenda be to try and figure out how to make behaviour change happen to reduce transport needs or is this for other organisations (e.g. private sector) to explore how they can meet demand most efficiently?
  - o How could we effectively inform consumers of the relative energy efficiency of different modes of transport?
- Protecting consumer choice when altering travel behaviour - One way of having choice but without directing it would be to have personal carbon quotas for transport. Is this in any way feasible?
  - o Are carbon quotas compatible in a market that is based around consumption? So living further away from work is good in that framework because it increases the consumption of transportation and the profits of companies. Do we need a more fundamental change to the system to promote behavioural change?
  - o How can we change current UK transport behaviour norms without policies that are perceived of being 'backwards' or symptomatic of a 'nanny state'
- At what points do we believe we will have a sufficiently strong understanding of data around travel behaviour to make decisions about how we should try and change it?
- What conflicts exist between societal and personal aspirations with regards to travel? How does this shape travel behaviour?
- What conflicts exist between approaches to promote the efficiency of vehicles and reducing distance travelled?
- How can we ensure that novel transport technologies are adopted post early-adopters e.g. with EVs they were adopted decades ago but never got beyond early adopters.

Implications of Behaviour Change

- How will some behaviour change approaches have the reverse effect? E.g. Making information more freely available to consumers to plan their travel routes is expected to play a key role in

shaping sustainable transport behaviours BUT it is possible that doing could make travel easier/cheaper, increasing the distance they travel, increasing energy and emissions use.

Education

- How do you educate children? What role do certain actors play in shaping travel behaviour e.g. parents, media etc?

Travel Safety

- Perceptions of safety and risks inform travel behaviour, e.g. some people don't use buses because they think its unsafe. Also, some people feel like they need big cars because they feel safe:
  - What gaps exist here between perceptions of travel safety and the reality of it
  - Implications of safety choices on other people's safety? E.g. Do more kids get killed by getting hit by large cars vs. without them?

What are the main research challenges?

- **Social Science** - Social science not really geared up to understand whether and how society can change radically and quickly? It has in the past.
- **Transport Models** - A lot of existing tools, e.g. the models used in transport, are really focused on small incremental changes and existing stuff, not understanding completely new paradigms and radical system step-changes.
  - It's also a problem of acceptance. Existing scenarios and model are kind of add-ons to existing economic forecasting methods. Perception of the tools and making transformative and radical tools become mainstream. Problem is that the conventional economic forecasting and modelling approaches are so entrenched it's difficult to establish new methods.
  - Pontification problem: we're putting a lot of effort into models and yet another model and tool. But that maybe takes away resources from more radical tests of solutions.

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?

- **Greater Social Science Engagement** - ESRC type stuff, e.g. Psychology, social science etc
- **Develop Models Sensitive to Radical Changes** – A need for new models that take into account radical changes rather than just incremental ones. Therefore, we are able to understand what impact more radical approaches to behavioural change will have alongside the less radical ones, helping to inform our decision making.
  - RCUK could run a programme to support people working on modelling within government to inform policy, in order to better link up better with people developing new models? This could be centred around a specific transport issue, where a PhD student developing a model works alongside a government department to solve that specific issue
- **Social test beds -** Establishment of "shooting from the hip testbeds" that allow to quickly figure out what radical solutions could be most fruitful before building more detailed models to assess them in more detail. Undertaking experiments like in epidemiology
  - We also know that there is a huge disconnect between what people say they will do and what they will actually do? These testbeds will hopefully cut this out.
  - Location? You could get small villages to bid for being testbeds. Incentivise local participation AND ownership!
- **More training and teaching** – Indication that the UK would benefit from more PhDs examining drivers of transport behavioural change and means to achieve this. Also, this should be situated alongside a strong base of teaching on the subject

- **Promote government use of research outcomes** – This could be promoted via government part-funded CASE PhD studentships

12.2 Group B

12.2.1 Cluster 9 - Measuring and assessing system attributes

Key research questions?
Establishing a Framework to Evaluate Transport System Attributes

- Creating a framework as a guide to the impacts specific policies will have on certain goals. e.g. what is the effect on: sustainability/social inclusion/mobility/CO2 reduction etc.
  - Need to develop a framework, with a set of measures, that is capable of assessing the collective impact of different technologies/solutions
- Need to establish a yardstick to understand where we are today, in order to understand where we are going to be tomorrow.

What are the main research challenges?
- **Designing the framework:**
  - Setting the boundary of such a framework – what are the most appropriate boundaries?
  - Double counting & missing impacts
  - Developing metrics (single, weighted etc.) for such a framework – where do the measurements stop?
  - Integration of existing tools
  - How to integrate social impacts, barriers and unintended consequences?
  - How do we compare different impacts?
  - Cohesive and systematic techniques and methods of transitioning between scales, both temporal and spatial
- **Data:**
  - What data should be inputted into such a framework?
  - Where is this data?
  - How can we parameterise the framework using existing data?
- **Identifying potential abatement options from framework outputs**
  - What timeframes should be attached to these abatement options?
- Concern that **framework might be too 'big' for policymakers** to use effectively. Concern it might be stuck to the confines of academia and not 'use properly'. Need to explore a strategy to ensure such a tool will be applied.
  - Is it better to put forward something simpler, which could actually be implemented, rather than something complicated that doesn't stand a chance?
  - Need to consider who will use this research and how it can be 'packaged' to ensure they use it effectively

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?
- **People & data to validate models** – Got the computer power but need the data to validate our models and the people capable of collecting and analysing this.
  - Recently we've run short of these types of people, especially computer scientist, communications, graphic designers, sociologists, applied statisticians, complexity scientists, industrial ecologists, control engineers, environmental scientists etc
  - Need to identify means of encouraging these people to apply their tools to transport. This may require a different funding programme; research networks; and/or a greater number of workshops & conferences around transport energy to bring these communities together in the same room at the same time
  - Data access collection and curation is important

- o Need to ensure that these models are sufficiently transparent to validate e.g. MARKAL models very hard to get near. Want to know how the data was collected, who by, what method etc.
- **Problem focused research strategy –** We require a more pragmatic approach to research, where methodology is constructed with aim of getting the necessary answer. We should not be wedded to any specific methodology e.g. modelling, just for the sake of it
- **Collaborative research & large teams** – To measure and assess the system attributes of the transport energy system will require a large team of researchers working collaboratively across multiple disciplines
  - o Interdisciplinary figureheads will be important to manage, direct and bring together these teams e.g. Jim Skea – 'Skeaites'
  - o Often these teams will be full of people that might not normally work together
- **Communicating research outputs** – Need to communicate the results in a way that they will be used by organisations outside of academia
  - o Need the kind of people who have actually interacted with politicians before to help present the data. E.g. copywriting/graphic designs/diagrams etc.
- **PhD training in Transport Energy Systems** – Some kind of CDT in this area would be useful to ensure researchers become highly skilled in measure and assess the system attributes of the transport energy system
  - o Systems skills are much harder to learn than experimental skills
  - o Unclear which department such an inter-disciplinary research centre would sit within
  - o Training PhDs is good, but got to have a mechanism to get existing people who could work in this field to work together. However, often worried they will become jack of all trades and master of none

12.2.2 Cluster 10 - Transport fuels

Key research questions?

Content of fuels

- Embodied Energy & CO_2 of different transport fuels.
  - o Means by which this can be altered by fuel recycling

Impacts of fuels

- Impacts on:
  - o Energy security
  - o Land-use change
  - o Air quality
  - o Health
  - o Equity
  - o Geopolitical tensions
  - o Transport infrastructure (e.g. lock-in)
- Downstream impacts of fuel choice on transport technology and behaviour
  - o Downstream impacts e.g. electricity > electric cars, hydrogen > hydrogen cars, but other fuels (e.g. bio) maybe don't have the same kind of downstream impacts
  - o To what extent are these impacts unintended?
- What are the impacts for a failure of either security or resilience of fuels. Either current or future?
- What are the various timescales of these impacts?
- To what extent are these impacts synergistic, i.e. what are the interactions of these impacts?

Market & Policy

- Regulatory challenges of transport fuels
- Understanding the role of subsidies on transport fuels

- Can have a policy for fuels, but hard to design policies to encompass all transport issues (or wider transport issues)
- To what extent should we have equality in policies for fuels?

Fuel Production Process

- What is the efficiency of fuel production?

Appropriateness of Fuels

- To what extent can we match the fuel to a specific socio-technical context (e.g. EVs not great for long-distances, limiting their role in rural areas)?

Utility and usefulness of energy

- Measuring utility of fuels: by exergy, by cost, by energy etc.
- Assessing each fuel source from a level footing

Technical

- Storage of Hydrogen something that needs to be solved
- Viability of CCS for transport emissions?

What are the main research challenges?
- Access to empirical data
- Inertia of industry and how it will affect research priorities. Also, inertia of infrastructure system i.e. lock-in
- Where to draw the system boundary?

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?
- **Access to commercially-sensitive data -** the problem is that the data on this subject tends to exist more in the commercial world, rather than in the public space. This might be resolved to some extent by additional academia-industry collaboration.
    - Historic data that is well in the past, that isn't going to affect people any more, should be publicly available)
- **Industry Supported PhDs –** Structures in place to encourage the part-industry funded PhDs (e.g. Shell, BP). This will help sow the seeds for academic-industry collaboration and maybe help release some of the commercially-sensitive data BUT need to ensure this encourages non-bias research. For instance, if you're continually sponsored by Shell/BP, then is the research that reliable?
- **Broad variety of skills -** Different emphasis on what kind of people you need. For instance, more engineering/historian type people to look at the past and the impacts of transitions from one fuel type to another BUT more policy/regulatory people to examine policy mechanisms designed to promote utilisation of certain fuels
- **New set of metrics –** There is a need for new metrics that are sensitive to the unique characteristics of transport fuels, to help assess their relative strengths and weaknesses. For instance:
    - Need a way of measuring utility of fuel on an equal basis? e.g. general thermo-dynamic education. Translating thermo-dynamics into the real world and helping it to inform policy

- Need an accounting measure for CO2 land-use change (particularly distinct from the rest)
- **A Zoom in and Zoom out perspective** - Need to keep the perspective of the big picture when focusing on something smaller, such as the lessons from history or previous experience
- **Promote transparency & validation of research**

12.3 Group C

12.3.1 Cluster 3 - Alternative mobility services

Key research questions?
Why do people travel?

- Need to go back to human motivation – why do people want to travel, to be mobile?

Freight & Logistics

- Adapt national hubs (e.g. B&Q) and take down to the regional/local level. Online deliveries lots of returns, inefficient. Full lorries into big hubs, coming back full.
- How do you incentivise green deliveries? Scale economies are the key issues.
- New models of delivery may be less energy efficient but more efficient socially (e.g. home supermarket deliveries). Don't have modelling capabilities to answer these questions.

Transport business models

- What are the current dominant transport business models? Which current models are working, which are not?
    - Could some manufacturers move towards being mobility service providers rather than car sellers? What would be the associated benefits?
    - Look at models that have failed in the past? Why did this happen? Why did they change?
    - What has happened in analogous industries?
- Do car clubs really result in reduced energy/emissions?
- Where do car clubs work? Geography matters - rural areas v London is different.
- Car sharing - People don't arrive at work at the same time now.
- Barriers - People value a car for other things e.g. intrinsic value; status
    - Is this social norm changing? E.g. younger people different. How durable is this change of attitude/behaviour considering that people tend to still have an emotional attachment to a car.
- What conditions enable people to switch to new ownership patterns? Which vehicles are best suited to these new ownership models?
    - Electric vehicles as well as autonomous vehicles. High up front cost, better suited for car sharing rather than ownership. Better risk management. Parking an issue

Mobility Service Decision Making

- Which factors are responsible for determining choice of transport? E.g.
    - Geography – rural vs. urban
    - Transport services available
    - Public transport is wage dependent - Wealthy people don't like sharing public space with poor people.

- Understanding how the need for mobility and choice made around satisfying this need vary with different demographic segments e.g. parents; rural habitants etc
  - Opportunities for autonomous vehicles in rural environment? Could this promote access to mobility and improve equity?
- To what extent is consumers' decision making long or short term?
- How does the ability to undertake other activities whilst travelling influence choices e.g. working on the train?

What are the main research challenges?/ To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?

- **Industrial collaboration** - Buy-in needed from manufactures etc. needs partners from different sectors. With regards to car ownership models, high-profile companies capable of extending alternative models should be engaged with e.g. Hertz & car club model
- **Testing –** Need an integrated testing environment to test alternative mobility services
- **Transport models** - New modes of delivery may be less energy efficient but more efficient socially (e.g. home supermarket deliveries). Don't have modelling capabilities to answer these questions. Need a 'net transport systems model', based on DfT/TfL models. Important that:
  - Technological fixes allow different models to talk to each other.
  - Social data, e.g. attitudes etc, are fed into the models
  - Ensure the model represent a common tools that can achieve local level modelling that is driven by different data outputs
- **Data -** Data connection/mining critical, e.g. Stobart have data but don't make full use of it. Transport catapult can help but important that first the questions that need asking are defined and then the Catapult model is designed to help answer the right questions, e.g. via data curation:
  - People Worried about IP etc. design collaborative models to solve IP problem - background IP etc, who is best place to exploit. Open/free innovation system a key enabler to make progress.

12.3.2 Cluster 8 - Whole-system/industry-wide policy making

Key research questions?
Impacts of Transport Policy

- To what extent does transport policy/activity affect economic activity, even though economic growth is now less transport intensive? Need to ensure that policy doesn't hinder economic development
  - Where is value added for different vehicle technologies. For example, where are batteries made? UK Is now capturing value added from assembly.
- How does transport policy impact upon equity, particularly in relation to prices and taxes, e.g. people/companies are priced out of job market
- Impact upon jobs market – What are the current skills in the UK and how will transport policy change this skills base?

Policy Mechanisms

- Pricing has not been explored enough in the UK - Can we introduce prices for peak/off-peak travel? Could this be applied to ICE road vehicles?

- o Understand pricing initiatives - road, petrol and carbon taxes for road travel
  - o What incentives can we design to complement pricing policies?
- Design policies to de-incentivise travel e.g. Personal carbon budgets - Charge people for miles travelled instead of annualised VED etc.
- Freight - Penalties for unsustainable loads?
- Focus specifically on aviation policy – Is aviation fuel currently subsidised or not?
- Policies that achieve more than just carbon related objectives

Other

- Can we refine and/or standardise LCA approaches for transport energy?
  - o How do we look at transport energy - well to wheels? Haven't worried about non-tailpipe emissions. Ricardo-AEA got different answers to the life cycle question.
- How sustainable are alternative technologies? e.g. some questions are not being asked about rare earth metals used in EV for instance
- Understand commodity markets better with food and transport competing, given the overlap with fuels – a more holistic analysis

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?

- **Need to link modellers, policy researchers and policy makers** – This could be achieved via the Catapult
- **Capitalise on research output** - UK industrial policy should be about developing technology/models then sell/export/licence the model. UK is uniquely placed.
  - o Good at ideas, run from the risks of exploiting new technologies. TSB is meant to redress this problem. Taking longer term view.
  - o We have the models - they need applied in policy domain

12.4 Group D

12.4.1 Cluster 5 - New transport business models and pricing mechanisms

Key research questions?
Carbon pricing & travel caps/allowances

- Moral jeopardy of travel caps and pricing mechanisms
  - o What happens if someone burns up their travel allocation e.g. holiday, sickness etc but cannot fulfil other needs
- Acceptability and use of these mechanisms – people don't like rationing
- Mechanics of carbon pricing
  - o What would such schemes look like?
- Practicality side of delivering these
  - o How would be deliver these schemes? How do we deal with the complexity of delivering these?
- Need some case studies to see if these kind of things work? Large scale texts e.g. communities, university campus, country?
- What should the different levels of rationing be e.g. self-employed delivery man vs. office worker

- What might be the benefits of these schemes e.g. quieter roads mean less time travelling
- Implications of less travel on public financing
  - e.g. less fuel bought = less fuel tax. How do the government make this up? Road tolls?

Business Models

- What kind of business models would encourage mixed travel?
- Relationship between regulatory framework and business model innovation
  - What regulations impact upon car clubs for instance?
- Will manufacturing companies' business models have to change, given that they are focused on built-in obsolescence and want to sell you a new car in a few years?
- Relationship between business model and technological innovation:
  - Do we already have the vehicles to support these business models? Do we need further technological innovations that are better suited to BMs. Getting designers involved to design a more suitable car in the context of a new BM e.g. car sharing.
  - Are these BMs in synthesis with vehicles of the future?
    - E.g. do EV vehicles work in a car sharing scheme in terms of how far we drive them
  - Autonomous vehicles and their impact on business models – The car could come to you rather than you go to it
- Service oriented business models
  - Do you cost in the through life carbon price in its pricing? Most of it in the manufacturing
  - International comparisons - Examine international applications of new transport business models e.g. US.
  - Car clubs –
    - Urban area might work but not at a rural level e.g. small towns. What kind of business models might work better there? Rural mobility business models
    - How much money are Zipcar making and other car clubs? Are car clubs profitable?
    - Mix modal fleets and car clubs. How can the two be brought together?
  - Car sharing – More popular in the US but how has it been applied in the UK? E.g. Liftshare.
  - Car clubs vs. car sharing. How can we separate the two? Is this a commercial vs. not-for-profit model? Not necessarily…
  - Attitudes towards these new business models. Losing independence and privacy of having your own car. How does this impact upon value propositions? Freedom of car ownership
  - Operationalisation of business models - Are car clubs going to privately or publicly owned e.g. in other countries they tend to be owned by the bus companies

What are the main research challenges?
- Research into these areas demands a truly inter-disciplinary research approach but current research system is not structured to support inter-disciplinary research, which is key here:
  - In the context of university and RCUK drivers, it was perceived to be far easier sticking in a single discipline.
  - Perception that if you work for one research council it is difficult to engage with another e.g. if you are funded from EPSRC it is difficult to get funding from NERC
  - Believed that research funding tends to follow departmental routes

- o Concern that important research questions often fall between the territories of the research councils.
    - ▪ Whose territory is it? Will it fall through the gaps?
  - o Concerns that joint-research council programmes are not really cross-council e.g., Global Uncertainties; Energy Programme etc. This is because they continue to sit within and be managed by a single Research Council
  - o Few truly inter-disciplinary academic journals
- Few incentives for academics to operate outsides the traditional boundaries of academia
  - o Less certain future doing a mixture of things compared to if you are 100% academic

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? / What do we need to have in place to ensure we are ready to address these research challenges?

Travel and Carbon Pricing Research

- **Government engagement** - Research projects into this must engage government to ensure that the research outputs are 'listened to' and that the research is conducted in such a way that any suggested schemes are deemed realistic/deliverable.
  - o DfT needs to work with DECC to bring transport within the broader carbon allowances/pricing schemes. Researchers need to be aware of the need for this relationship when designing their research
- **European discussion around travel pricing** to because travel isn't just limited to UK.
  - o How could we deliver international transport carbon pricing schemes?

Business Model Research

- More active RCUK led research into transport business models:
  - o Most research into innovative business models has been undertaken by businesses 'testing the waters'. More active research into transport business models by universities alongside ad hoc testing by businesses.
  - o The two could be brought together by getting innovative transport businesses (E.g. Zipcar) to work alongside RCUK funded research projects
- Need to draft in legal expertise to help understand the regulatory landscape these business models are being applied in and whether they are legal and will work
- Bringing together the more risk adverse organisations (e.g. bus companies, LAs, TfL etc) with the riskier organisations (e.g. entrepreneurs) as part of applied/active research:
  - o Can their objectives be synthesized? Should they be synthesized? If they were what benefits could be harnessed?

General

- **Joint funding between RCUK and other R&D bodies -** Joint funding from EPSRC & TSB for instance e.g. ChoiceRail – a TSB/EPSRC programme
- **Truly inter-disciplinary PhDs -** Do we have PhDs doing inter-disciplinary transport research? e.g. Rich McIlroy – Psychology & engineering expertise to explore the application of haptic foot pedals. PhDs tend to need to be very specific/focused, channelling students towards a more disciplinary research focus.
- **Leaders of inter-disciplinary research** - Who leads inter-disciplinary work because people are disciplinary by nature. E.g. Transport component of a business school?

- Difficult for Transport centres to sit alone and so tend to sit underneath a larger faculty e.g. engineering. This pervades through the nature of the centres
- **Academia-industry-government collaboration** - Transport Catapult as a centre for inter-disciplinary transport energy research that brings together academia, industry and government:
  - Designed to bring different parties together e.g. academics, businesses, consultants etc. within a centre of excellence. Secondments encouraged.
  - If we develop things in these centres, we are also able to sell these abroad, improving impact – 'spinning IP out'.
  - Need to ensure that the centre isn't just engineering focused and that business models become a key focus of the centre for its duration
- **Greater separation between research and teaching centres**
  - Disciplinary departments which are responsible for teaching (e.g. Geog for BSc) alongside independent research centres may allow for more inter-disciplinary research
- **Cross-departmental research groups** may help to bridge the divide between disciplinary silos.
  - Academics aren't normally 'born networkers' which presents a key barrier to inter-disciplinary research.
  - These links may not be obvious and need some work to identify and nurture

12.4.2 Cluster 19 – Low Carbon Aircraft

Key research questions?

Retrofitting Aircraft

- Much of the aircraft that will be around in 2040 are already being built or designed, so big focus on retrofitting the current stock BUT this will be difficult as aircraft are designed as integrated systems, which can be updated quite regularly.
  - Question around what low-carbon retrofit changes can be made that ensure the aircraft is still safe and legal, e.g. lighter landing gear

Airport Vehicles

- 'Rag bag' of different types of vehicles e.g. tractors; snow clearing; baggage vehicles, most of which use red diesel, which is very cheap because it is not road transport.
- This area largely untouched by research. Research that is being done is being led by airports but with little external support

Powering up at stand

- Little research into fuel sources for on-stand aircraft.
- Airlines may use their own 'plug in' source (e.g. APU) or contract with the airport to use their systems but many airlines want a quick turn-around e.g. Easyjet and use their own systems to save time
- Smaller airplanes use APUs because there is no plug in, which are run off jetfuel. Batteries might replace these systems but they're very expensive.

Taxiing to runway

- Might there be other means of taxiing adopted that are more efficient? E.g. electric tugs (see Virgin's trials)

Baggage & People

- Innovative weight saving options e.g. Samoa airlines charging people by their weight
- Can we avoid transporting non-essential items and source these instead at destination e.g. take less clothing and launder these at destination:
    - Baggage delivery services – e.g. Japan, travellers often use these and do not take their bags on the bullet train. These services often utilise road transport that has a lower carbon footprint, sending the bags ahead a day early. Currently these services exist but are often too expensive; maybe an issue of scale (economies of scale) and a lack of a carbon price
    - Are there safety benefits of not having 'potentially hazardous' baggage on board? Less safety checks = less time at airport = less human traffic
    - Can airlines remove non-essential items from their aircraft? e.g. duty-free packaging. Thomson have tested this.

Airports as integrated systems

- Need to better understand how the airport system fits together and where the key linkages lie
- Need to understand the actor network surrounding the airport system, i.e. who the key stakeholders are and what their various responsibilities and incentives are
- Airports are linked to the wider transport system (e.g. motorways, trains etc). The linkages between these need to be examined to make getting to and from airports via public transport easier
    - What systems would help this integration? E.g. town planning; international journey planners etc

What are the main research challenges?

- **Unsure who is responsible for these research subjects** - The UK very fragmented around air travel, meaning there are multiple stakeholders e.g. BAA; airlines; contractors; manufacturers etc. For research to be undertaken it is essential that researchers have a clear understanding of which stakeholders are responsible for which tasks (e.g. powering up of aircraft at stands) at airports so that these can be engaged with
- **Poor research links between industry and academia** – Academia isn't doing enough to engage with UK aviation industry (e.g. UK sustainable aviation). Whilst there are some good relationships with the manufacturers (e.g. Airbus) other stakeholders, in particular the airlines (e.g. Virgin, BA), are currently very poor
- **Unsure what private sector R&D being undertaken** - We have a poor understanding of what aviation R&D companies (e.g. Rolls Royce; BAA) are undertaking. Need to build a picture of this to ensure we avoid duplication and to also identify potential public-private research partnerships

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? What do we need to have in place to ensure we are ready to address these research challenges?

- **Test facilities at smaller airports –** Explore opportunities to develop test facilities at smaller airports where innovative airport management systems and be deployed in a 'real world' context. Important to test these systems on a live audience to understand their real impact

- **Devise a policy neutral research strategy** - Have to consider how we will support this type of research without environmental taxes on airlines – public not keen; not supported internationally.
- **Build research links between academia & industry** – Important to build relationships with industry (e.g. airlines; airport operators etc) to encourage them to engage with the research process. At present they seem willing but do not undertake much research. Getting these 'big players' to engage will promote the low-carbon aviation research agenda.
  - *Government support* - Need to get researchers to talk to DfT and get some political support in order to use this as a lever to garner support from industry. The money will follow this, which can be used to deliver field trials
- **Identify opportunities for cross-fertilization via knowledge exchange** - Opportunities for knowledge exchange across TRLs, sectors and aviation research areas that could yield valuable innovation. For example, providing aircraft manufacturers and airport operators with insight into crew & passenger behaviour is likely to have an important impact upon the design of both airport and aircraft.
- **Balance TSB's research portfolio** – Concern that TSB is currently too focused on the technical aspects of aircraft/airports and not enough on the more social aspects. Important to balance this focus between social and technical. A suggestion that the Catapult centre will explicitly focus on some of these more social aspects (e.g. business models) and be structured to encourage engagement from a broad range of organisations (including airlines), thus encouraging a more diverse and balanced research portfolio
- **PhDs in aviation systems thinking** - Thinking of the airports as an integrated whole and one that is linked with other systems. An appreciation of technical aspects but also of political & social aspects (e.g. stakeholders vying for dominance and contrasting incentives)
  - Some work is already being undertaken at UCL, Bristol (systems centre) and Southampton (Nick Jennings) in this area

12.5 Group E

12.5.1 Cluster 14 - Resilience, adaptability and flexibility & Cluster 18 - Vehicle-systems integration

Key research questions?

Technology

- Where will technological innovation make the biggest impact?
- What vehicle architectures give substantial CO_2 reductions in the short term, whilst continuing to give adequate mobility performance? – safety, speed, comfort etc

Transport Fuels

- Are we using the right fuel in the right applications? – one size does not fit all e.g. hydrogen
- Should we be using gas to generate electricity or to power transport? Can switch to a dual-fuel fleet in ten years – but nuclear power plants take longer to build. However, there's 28 million cars – convincing all those drivers to switch is very difficult.
- Which fuel should new cars use, if not electric? This isn't clear and has implications for both vehicles and transport infrastructure. Some vehicle types, e.g. hybrids, will not need an entirely new infrastructure compared to others such as hydrogen which will.
- How can we develop a modular power train that is adaptable to fuel changes?

Vehicle Stock Replacement & Optimisation

- Around 35 years till 2050 – This equates to around two cycles of complete vehicle replacement. How can we replace all cars with low-carbon alternatives in this relatively short timescale?
- Optimisation of the 'vehicle' within the context of what it has been designed to do. Is there a way to prevent people making many shorter journeys, which are very inefficient?

Operations, Logistics & Freight

- What ICT technologies do we need to optimise logistics and traffic management?
- Logistics will play an important role in infrastructure change, integration and management, especially in promoting efficient.
  - e.g. Instead of a lorry going back empty, could be full of another company's products. Empty running is about 28-30% currently, and not improving. Freight industry runs on narrow margins – interventions need to be economically viable.
- What is the best way to transport goods to the point of use?
- To better understand freight operations we need to examine them at different scales – each scale is a different system (i.e. local, regional, national, global)
- How do we manage traffic flows to reduce congestion and associated environmental impacts?

People

- How do we encourage the public to drive more fuel efficient vehicles and adopt more sustainable transport behaviours? (e.g. car sharing, multiple passengers per car, bus usage, 'non-travel' etc)
  - How does this play out in developing countries where there will be an influx of new vehicle owners

Vehicle-System Integration

- Need to better define what we mean by vehicle system integration
- Optimising energy through vehicle system integration - not individual vehicles but using fleets and types more efficiently.
  - Where will new vehicle technologies make the biggest impact, which types and sizes of vehicles? One size of vehicle technology does not 'fit all', e.g. cars, buses, lorries, vans etc.
  - How many journeys are single-occupancy, even buses?
  - Inefficient movement of freights and people:
    - Least efficient freight vehicle is the family car – weighs a tonne and carries 20kg of shopping from the supermarket. Shut supermarket car parks, move to online shopping. However, the problem there is the people – wouldn't like it!
    - A lot of congestion is caused by the school run. Would make a difference if we could reduce this – need to provide a sensible, real alternative. Traffic flow is a critical problem to solve to improve efficiency.
  - How can we minimize the impact of electricity demand from EVs on generating capacity?

What are the main research challenges?

- **Peer-review** – reviewers are often just experts in one discipline, and can't easily review interdisciplinary projects.

- **Little opportunity to undertake international research** - UK research funding system is geared towards supporting transport research with a tangible benefit to the UK and not research further afield that may have more indirect, international benefits. This UK-focused research framework means valuable lessons from other countries may have been missed

To address these challenges what would you like to see change? / What needs to happen in terms of coordination and alignment to maximise success in your research area? What do we need to have in place to ensure we are ready to address these research challenges?

- **Change research funding system to enable UK researchers to engage in research on international transport issues** that doesn't necessarily benefit just UK Plc.
  - This may not be as effective in the long term – for example, vehicles for China and India are far more important for reducing emissions than vehicles for the UK, but far more difficult to justify large research proposals in that area. RCUK should pool resources with opposite numbers in other countries to provide funds for projects of this nature.
- **Inter-disciplinary working** - are strong technologists, people who understand logistics, people who understand behaviour, and get them to work together in an interdisciplinary group, e.g. Supergens. This may take the form of an Isaac Netwon Institute, which co-locates mathematicians for three months, working on a specific topic. TSB Transport Catapult may provide a forum to. Need to ensure it accomplishes the following:
  - Not just concentrate on technology
  - Requires high-level coordination
  - Need to have a number of these groupings concentrating on different questions.
  - Draw together all experts and key stakeholders – do not exclude
  - Better links to government chief scientists – good link between academic and policy worlds.
- **CDT in transport –** Need a National Institute for Doctoral Training in Transport. Centre should:
  - Have a strong inter-disciplinary focus - Part of PhD training should be working in teams with people of different disciplines. PhD training currently too specialised – missing the big picture.
  - Incorporate a 'PhD Plus', that involved three-months working with industry
  - A national initiative to coordinate training like this – works at TSB level, but not at EPSRC level.
- **Peer-review –** Need reviewers that are skilled in inter-disciplinary transport research and can therefore critically review this type of research
- **Strategic management of transport energy research –** Need a more strategic management of the research programme, rather than a number of isolated smaller projects that may not relate to one another
- **Data -** Vast quantity of data which would be useful – for example mobile phone companies know when people are moving. Need a national resource/database
- **Accelerate innovation through the innovation chain -** Mechanisms needed to take this research from TRLs 1-3 to 4-7 rapidly – rapid accelerated deployment. EPSRC needs to work closer with TSB to ensure this gap can be bridged, and also working with industrial partners and stakeholders from the very beginning of the project.

13 Annex B – Detailed Outcomes of Research Cluster Cross-Cutting 'Deep-Dive'

13.1 Group A

13.1.1 Cluster 4 – Supply side policy

Key research questions

- Linking transport and electricity networks – co-designing the two to ensure integration.

What are the main research challenges?

- **Does the right data exist?** - Yes to some extent but we haven't utilised it to some extent. Often it has been withheld by government but this is starting to be released e.g. by Treasury. Still some of it isn't freely/easily available. Some legal barriers around access to it. Much of the data was collected commercially rather than by government. Therefore, sensitivities about who owns it.
    - We would be able to better model demand if we had access to the necessary data e.g. Marine data – all gathered by private entities, which we don't really have access to
- **Existing models -** Most of the current existing models couldn't cope with the data that we have or could have. Maybe we need to change the models so that it fits the available data e.g. Electric vehicles – Many of the models rely upon that consumers will make decisions around the cost of these vehicles BUT this might not be the case in the short term. Need to change the model to be more sensitive to the fact that consumer preferences change.
    - Transport demand forecasts are often incorrect – supply side policy exists to fulfil this demand. If demand forecasts are wrong then supply policy will be wrong. Demand forecasting hasn't truly taken into account behavioural processes
    - Supply side models try to 'cater' for the demand rather than 'changing' that demand. So the questions that the models are based around need to be changed so that they are designed to alter demand rather than just manage it
    - More integrated modelling could help to provide more accurate forecasts; more effective policy and a more effective transport system
- **Policymaker Expertise** - Huge gap in policymaking skills. The policymakers don't tend to have the necessary expertise to design and deliver effective policy. Government doesn't have the technical capability; they've been deskilled and contract out research to other orgs e.g. Highways Agency contract out to consultants such as the Transport Research Laboratory. They don't have technical capability and thus the ability to make sensible decisions.
    - Are the right minds thinking about this? And how do we get them to do it (e.g. not 27 year old philosophy grads)

Whose job should it be/who is best placed to undertake this research? / How might the different funding bodies collaborate?

- Need to get the best brains in the country from academia, industry and government to work within a common space to develop the necessary models to support and inform transport supply policy. Catapult may be the platform to bring together energy & transport modellers,

policymakers etc and provide a space for them to think about these. Help decide how modellers should inform policy. Questions around how it should be structured:

- o Funding and/or physical facility?
- o An interdisciplinary transport energy research think tank
- o Focus on bringing together experts not the students
- o Need linkages to some extent with other think-tanks/catapults e.g. Future Cities

What do we need in place to ensure we are ready to address these?

- **Improve modelling processes for policy making** - Need to explore what is right and wrong with the models to help ensure that policy is accurately designed to promote an integrated system. Need to get the various modellers together to discuss the pros and cons of these different models.
  - o Need to get experts together to interpret the outputs of these models and identify synergies between them. We are too focused on saying 'the model says this so we should do this'. We must critically assess them.
  - o *Policy Strategy* - Policy should be a plan, which is not something a model can provide. Policy needs to be a set of long-term objectives, alongside long-term developments (identified by model), in a structured manner.
- **Data** - Data requirements should be discussed in depth. Need to get deep into the issues at hand before saying 'we need this data' and developing e.g. data warehousing

13.1.2 Cluster 6 – Connectivity & ICT

Key research questions?

- To what extent could ICT shape travel behaviours e.g. reduce or increase distance travelled by both people and freight?
  - o e.g. making sure your package arrives when you're there NOT when you're out, avoiding an extra trip
- Interface between social media and ICT management of transport - e.g. provision of local travel information via Twitter for examples.
  - o What is the impact of social media on travel patterns. E.g. aspirations to travel; substitution of travel (e.g. people happy to communicate online rather than in-situ)
  - o Last minute decisions for travel – social media can trigger a need to be somewhere else

What are the main research challenges?

- **Fragmentation** – Lots of different aspects of industry, supply chains, consumers. Need to capture a lot of different stakeholders and processes around ICT improved travel.
  - o Not sure what research is being conducted at present in this areas
- **Business focused** – people wanting to make money out of ICT travel apps
  - o Some useful stuff being generated but we're unsure what the implications of these ICT outputs for energy and travel demand.
  - o We don't actually know what ICT and apps' impact on transport has been, so we don't know what signals to send to this market to ensure that they are developing these applications correctly
  - o How should we incentivise the development of apps that improve our travel efficiency?

- o Computer scientists who develop these apps and aren't so much challenge or problem focused. They just want an outlet for their code/software and are happy to make some money from it. How do we develop synergies between the software industry and the travel/energy concerned industry.
  - o Are transport & energy issue sensitive people helping to write ICT applications/apps?
  - o Very difficult to work with computer scientists. E.g. terms of reference. Makes inter-disciplinary ICT research difficult

Whose job should it be/who is best placed to undertake this research?

- **Universities** because software companies probably aren't that bothered about the impact of their software in the wider system. A real academic study, by social scientists, of the impacts of these apps
- **Bringing in the software companies at some stage** – how do we do this? Would it be valuable?
  - o Business, economics and policy question around how we incentivise software companies to develop apps that are capable of managing travel/energy demand BUT need to first understand how they are impacting upon the travel system.

How might the different funding bodies collaborate?

- **Cross-council funding programmes to link ICT & Energy** – e.g. Transforming Energy Demand Through Digital Innovation (TEDDI) call, which linked both RCUK's Energy & Digital Economy programmes.
- **Inter-catapult communication/collaboration** – To what extent will the Digital Economy work with or communicate with the Transport Catapult?

What do we need in place to ensure we are ready to address these?

- Need to do an **impact evaluation of the research** on energy and travel demand
- **Data** – need the software companies to provide you with the necessary data to understand how the apps have been applied/where/when/who
- **PhD centres** – 3 Digital Economy centres are funded and have PhDs. Is there enough of a transport and energy focus here?
- **PhD secondment scheme** - Develop a scheme to enable PhDs to be seconded into the real world to engage with the ICT sphere and to gain valuable experience about what travel/energy software looks like
  - o Similar model to EngD? Time split between industry and academia acting as a link between the two
- **Governmental lead on ICT** - ICT doesn't really have a natural government department, which means there something of a lack of policy/regulation. Not the political buy-in to travel/energy ICT 'for the greater good' research because there isn't the necessary department. BIS & DfT could step up to the mark and fly the flag for this research area.

13.1.3 Special Focus: Freight & Logistics
Group A were given the task of focusing on Freight & Logistics, which a number of participants believed had been somewhat missed during the clustering exercise.

Key research questions?

Drivers of Freight

- What is generating the need for the movement of goods? What are the drivers? E.g. e-commerce, business-2-business interactions.
  - 'Just in time' manufacture – generates a lot more freight movement
  - Supply chains dictates a lot of how freight and logistics play out
- Consumers typically want their goods quickly and often from afar – What are the factors responsible for shaping these drivers?

Freight System & Management

- Integration of freight system across modes
- Distribution of logistics hubs – Different ways of managing and organising freight systems
- New business models for delivery – e.g. consolidation centres for delivery – bringing multiple delivery firms together for one drop of multiple products NOT multiple different drops by different companies (Royal mail basically do this)
- Research into 2-way freight flows – i.e. picking up when you drop off. Avoiding empty running (approx.. 28% of all truck trips)
- Disconnect between truck drivers and logistics firms - the truck driver is operating efficiently in a 'small world' with few levers to pull. It requires a more systemic view to ensure that all the drivers are operating efficiently together as an integrated unit not just efficiently on an individual basis

International Freight

- Opportunities to look across national boundaries of freight and the interfaces/linkages there

Air Freight

- Gap around aviation freight

Road Freight

- Aerodynamics of freight vehicles
- Not enough research into vans and their freight contribution. Loads of vans but we're not sure due to a lack of data, what on earth they are doing. Limited information – 'white van man syndrome'.

Personal Freight

- Personal transport – e.g. supermarket car parks. Get rid of the least efficient vehicles which are the family cars. Get more efficient vehicles running more efficacious journeys to deliver the goods to the homes
  - How can we, via informatics, make the home deliver as effective as possible e.g. so people do not need to travel to the post office to pick it up?
  - How can we get consumers to get more efficient personal cars because these deliver a lot of personal freight?

What are the main research challenges?

- **Data** - How open is the logistics data?
  - David Cebon's group currently building a big logistics database. Also developing a business model to make this widely available.

- **Varying Levels of Capability** – Don't have very much on the demand for logistics side – understanding this demand but some expertise on shipping, rail and air but quite siloed. Will need to link up with these.
- **Freight companies operate on tight margins** so they will only adopt measures that are obviously and immediately financially attractive. It will be a challenge to get these companies to collaborate and/or adopt some of the more innovative freight ICT technologies, management practices, vehicles etc given that they will incur an upfront cost.

Whose job should it be/who is best placed to undertake this research?

- Universities in collaboration with industry

How might the different funding bodies collaborate?

- Industry funding is very important and they are willing to put money in. Why? To reduce fuel costs and improve sustainability credentials e.g. John Lewis.
- EPSRC doesn't have strong freight transport policy.
    - Transport subsumed under Energy theme. Scope here for it.
    - What was traditionally funded through EPSRC was through engineering
- ESRC has no discreet transport focus BUT big need for social science focus

What do we need in place to ensure we are ready to address these?

- **Broad range of skills** - Need vehicle engineering and logistics expertise to ensure efficient deployment of these vehicles but also social science to understand demand drivers. UK currently strongest around vehicle technology but weaker in terms of social science freight and logistics research:
    - **Social science** led freight & logistics project - Explore some of the more obscure, less technical linkages that make-up the freight system and that can be taken advantage of to improve its optimisation. Multidisciplinary but led by social sciences
- **Businesses on board** to improve efficiency
- **Supportive policy framework** – Need a policy framework that provides opportunities for freight innovations to be developed and implemented e.g. UK law prohibits very long vehicles on UK's roads, limiting UK R&D in this field.

13.2 Group B

13.2.1 Cluster 20: What are the barriers for technology change and how do we avoid conflicts?

Key research questions?
Safety

- Trade-offs between safety and other characteristics – e.g. Aerodynamic shapes often don't pass pedestrian safety criteria.
- Use materials that give you safety. Can you get round safety by developing vehicles that can't crash. What assumptions have we locked ourselves into that blocks out alternative solutions. Get out of constraints -get beyond the focused question.
- Barriers often relate to people's different requirements. Why do people drive too fast/tailgate? Safety criteria to compensate for bad driver behaviour.

- Would people accept modifying vehicle so couldn't rear-end? NCAP is a barrier -you have to implement passive safety before you get the highest rating which requires active management.
- Whose fault is it if an autonomous car collides with a driven vehicle?
- What technology can you put in place to enable people to drive better?

Step-change vs. incremental innovation
- Should we put all our money into step change as opposed to incremental change? Research question - what is the best approach. What's the optimum approach to timescale? Slow enough to take advantage of learning? Scrappage schemes to accelerate?

Vehicle Innovations
- Energy balance in ships. Energy harvesting at vehicle scale? Can we store small amounts of energy?
- Surface of aircraft PV panels save power?
- Aircraft taxiing?
- Sensors on the sidewalls of tyres - energy from deformation. Smart tyres!
- Fundamental look at the vehicle? Harvest energy on all elements. Suspension problematic.
- Thermal harvesting.
- Reconditioning old vehicles. Upgrading? Change power train? How do you tax a vehicle?
- Bespoke v production line reengineering. Done for buses for air quality reasons. Interface between engine and body.
- What is the best powertrain fuel system going to be? Different solutions for different applications. What will hybridised technology look like? Series? Parallel?
- In-vehicle feedback works for freight, not for private drivers. Lorry drivers have incentive - Energy use and feedback in electric vehicles is under-researched.

Business Model Innovation
- Rolls Royce selling engine hours not engines. Can this business model be applied elsewhere e.g. for batteries.
- How does selling mobility change the barriers? How would it change the technology. Industry wouldn't need to turn models over all the time.
- Now households currently buy 'compromise vehicles' – Could this change with different business models?
- Understand trip usage - select vehicle to suit.
- Shared ownership means moving empty vehicles around. May not be energy efficient.

Other
- What is the right metric for vehicles? Measure the right thing in the right way.
- Artemis driving test cycle - current driving cycle is too gentle. Need a cycle that better reflects real driving conditions. NDC cycle is the current one.

What are the main research challenges?
- **Availability of data** - Companies often won't share data about how their technological/non-technological innovations have performed e.g. Shell started car clubs but won't share the data

Whose job should it be/who is best placed to undertake this research? / How might the different funding bodies collaborate? / What do we need in place to ensure we are ready to address these?
- **Data** - Need a centre which curates all the data. EPSRC should do this. Also, any government funded programme ought to require data curation
    - Change default - publish data and argue for commercial value if it is to remain confidential.
- **Interdisciplinary research** - Need engineers/social scientists to work together.
- **Peer review** – Needs to be structured so that it doesn't penalise inter-discplinarity. A separate, cross-cutting panel of experts could be established for each journal

- **Training needs** - working knowledge training for engineers to make them aware. University job. PhD level most appropriate level, lesson for CDTs.

13.2.2 Cluster 11: Transport energy storage

Key research questions?
Fundamental Questions

- Why do we need energy storage? Get way from liquid fuels. Environment/energy security.
- Debate about electric v hydrogen vehicles.

Batteries/EVs
- Batteries - end of life/re-use/recycling. Batteries used for electricity when clapped for vehicles. Battery management challenges. Whole system or individual.
- Battery swap won't work because manufacturers don't want standard batteries. After use market is also difficult then. Common battery cell may be possible. Ease of dismantling. T-shapes, H-shapes, boxes all used by OEMs.

Other
- Distinguishers for vehicles
- Energy density and power density
- Unusual duty cycles - stop/start
- Regenerative braking in vehicles
- Are high power storage devices more important than high energy storage devices?
- How to match device characteristics with service being provided e.g. flywheel vs. battery? Vehicle systems integration.
- Cross application of storage technologies with non-motive uses.
- Systemic analysis of energy storage and flow - storage volume, E out/E in etc. time and volumes.

Whose job should it be/who is best placed to undertake this research?
- A combination of engineers and modellers

13.3 Group C

13.3.1 Cluster 2: Demand-side Policy; Cluster 12: Conscious and non-conscious motivations of travel behaviour; & Cluster 16: Limits to demand for transport/mobility

Key research questions?

Rebound effect

- Rebound: making cars more efficient, but people drive more but they will only drive more up until a certain limit (see Andreas Schafer's work on limits to travel):
  - Modelling currently only looks at current point, but doesn't consider the real boundaries which people will move towards (e.g. only so many driving hours in a day)
- 50% of finance saved on energy efficiency goes into using more energy in a household. Do people really consciously think this way? What is the trade-off? - e.g. the multiplier effect on the financial side

Factors shaping demand

- Big questions - What are people's needs for mobility? Why do people travel? What are the drivers of mobility?

- Time - Is 1 hour the limit to demand?
  - Thought to be the historical limit. Whether it is walking 4 miles or driving 30 miles
  - This is the speed-time-distance triangle
  - Traffic has got no faster in London over the last 100 years or so
  - What is the acceptable amount of time that you want to allocate to travel?
  - We're time poor, money rich, and connectivity rich, therefore how do we want to spend our time?
- Space constraints:
  - Number of vehicles that can fit on the road
  - Limits to size of vehicle based on size of people
  - Practicalities - people won't drive something the size of a house
- Price - Is it a price-driver that means people aren't buying cars? Will people come back and buy more cars with a booming economy?
- How might technological innovation alter the factors shaping demand? e.g. the way we view time spent on transport. Is technology going to change these limits?
  - e.g. autonomous vehicles, ICT on trains, serving as an office
  - e.g. 3D printing from a freight perspective
- Transport supports lifestyles, so how are people's lifestyles changing?
  - Are they travelling more?
  - Do you move to be able to travel more easily?
  - Do you stay closer to your family?
- Do we truly understand the motivations and drivers behind travel now?
  - This is subject to a lot of research now, but is also a research question moving forward.
    - Drivers of mobility.
  - Research into different demographics and how they travel, but little on the energy side.
  - Energy use in transport is something inherent.
- Do we know policy's effect's on drivers of mobility?
- Urbanisation's effect on people's mobility, e.g. level of infrastructure in place; the proximity of things
- Important to understand the cultural trends and how this affects mobility
  - E.g. Social stigmas associated with riding a bus, leading to empty buses?
  - E.g. Status of owing a vehicle - Seem to have moved away from young people buying cars in the West, but status symbol association of car is growing in China and India
- To what extent are recent changes in travel behaviour likely to revert to traditional behaviours? Need to understand the permanence of changes.
- Need to incorporate these various factors and their inter-relationships into a coherent model to help us predict travel demand

Different types of demand

- Moving goods is different than moving people – It is less of a social thing.

Cost analysis

- Undertake a 'Cost-Benefit Analysis' of different behavioural policies?
  - Do we fully understand the effects of current policies on transport behaviour and demand?
- Energy cost vs. travel cost
- Energy Budgets - understanding the energy budgets of different demographic segments?
  - E.g. Is it young urban professionals, not owning a car but travelling regularly internationally.

Reduce the need to travel

- What about stopping people travelling and alternatives to travel? What are the limits e.g. We tend to value face-to-face over videoconferencing

- o Will increasing travel prices increase people's desire to find means of avoiding travel?
- What is stopping people doing conferences/workshops virtually?
  - o Is it a lack of a physical presence?
  - o Is it a lack of connectivity?
  - o People still don't do this, but why not? Do we really understand why not?
- How does this change with different demographics? E.g. are young people more willing/able than old?

Demand Predictions

- What are the future travel and activity patterns, according to different population cohorts?
  - o Need to understand the needs and demands of future generations.

What are the main research challenges? / Whose job should it be/who is best placed to undertake this research? / How might the different funding bodies collaborate? / What do we need in place to ensure we are ready to address these?

- **Multi-disciplinary research teams -** Need to bring people together and have people working together, otherwise you don't get the full answer e.g. Economists, technologists, physicists, mathematicians, designers, engineers, social scientists, economists etc.
  - o Need to build these teams around the problem, which should be coordinated by PIs
  - o Difficulty is convincing the PhDs that they are going to get a good PhD out of it
- **Peer-review -** Problem is that the academics that peer-review have a more singular disciplinary working approach

How might the different funding bodies collaborate?

- **Cross council research funding?** Where does the money come from - is there a central pot? There is, led by EPSRC, the Energy Programme that other research councils can tap into.
- **Non-RCUK involvement** - Some of this in TSB's and DfT's space? Could industry also be involved as a funder?
  - o Whole systems stuff is often too broad to get industry funding. Very hard to get them to fund anything too specific in this area. Therefore, often reliant on government funding

What do we need to have in place to address these research challenges?

- **Secondments** - Very effective way to bridge the gap between industry/government/academia
- **Inter-discplinarity** – UKERC and RCUK's Energy Programme promotes cross-cutting research projects that cut across different disciplines. These should continue.
  - o **Large solution focused, inter-disciplinary projects** - More large projects are needed with an interdisciplinary focus, that are solution focused rather than methodology-focused, instead of smaller teams tackling a range of problems
- **Greater awareness of research landscape** - Often not aware of all these massive programmes going on. Need a much better understanding of the funding landscape
  - o UKERC do publish some landscape documents on this but important to also incorporate research being conducted outside of RCUK, e.g. Energy Research Partnership, Low Carbon Innovation Group
- **Identify who is the research user** – Need to identify who will be using the research outputs (e.g. DfT) or taking them further via applied R&D (e.g. TSB). Important to have interested parties on the receiving end of academia.
  - o Could engage with strategic research bodies e.g. Google/IBM/Microsoft, who may have an interest in this area
- **National energy research labs** - Like in the US or Fraunhofer in Germany? Benefits in terms of critical mass of people looking at a range of these problems

- o How well have these centres worked abroad? US the views are that these labs are that not working particularly well.
  - o Will the Catapult centre be a suitable version? - £30m going into each catapult over 5 years, which should mean it will to some extent. Concern that it is too industry/commercialisation focused?
- **Internationally coordinated research** - A lot of these issues are international issues, therefore collaboration is easily possible, and should be done. Horizon 2020 has a lot of funding (approx. £10bn over the next 4 years for transport) - Could this help to fund this kind of systems research?
  - o BIS leads the UK's interaction with Horizon 2020, whilst the DfT sits on the transport programme board, and has some say in how this is run BUT is there a problem with UK researchers accessing European funding? Lots of upfront effort involved, and too many partners etc. tends to mean that UK researchers avoid doing EU projects. Need to explore how this can be addressed
  - o KTNs could play a key role in drawing international partners together. Also what role could the IEA play considering that they run a lot of transport research programmes
  - o An optimum number of partners (e.g. 30 in a European project is just way too hard to coordinate), optimum number seems to be 6 partners

13.4 Group D

13.4.1 Cluster 17: Impact of social media/new communications on travel demand

Key research questions?

Media and Travel Reduction

- To what extent does media reduce the need to travel or increase it?
  - o Telephone reduces need to travel but also enables lots of home delivery services.
  - o Internet the same: reduces some travel, e.g. internet banking, and probably increased freight loads. Smaller consignments to homes rather than larger ones to shops.
  - o Supply chains a lot more international but not sure how that was driven
- Trying to boil down the question: what is the net effect of social media on transportation demand or use?
  - o How can you quantify the impact? Knock-on consequences. You can't model the whole world and all interactions just to understand social media effects.
  - o Also in different countries there are different issues: e.g. in Africa use of mobile phones to transfer money may reduce the need for travel.
- What does social media do to transport energy? - We understand what it does but we struggle with what it has to do with transport.
  - o E.g. bus companies have Twitter accounts where they post updates about buses that were cancelled.
  - o There is such a system in London where information is gathered from people on commuter lines (called Train Delays).
  - o Another example: use of social media on campsites. Coordinate amongst campers that have to travel to nearest town to get supplies so that they have to do less individual trips.
  - o Potential application for car sharing and commuting.
- So social media in our sense: people networking and exchanging information for their own purposes.
- Are there enough case studies around to do some sort of assessment? Or is the whole area too quickly developing and changing around?
- Social media as a data source. Text mining, also, using location information from tweets. Even something simple: can pick up tweets people send while traveling by train? And figure out if there is some common theme?

- Could be an effective means of getting information, which could help inform approaches to alter travel behaviour
  - E.g. you could use it to ask people questions, getting data off of asking questions on Twitter

Gameification

- Gameification – Ways of making sustainable travel behaviour more fun:
  - E.g. Getting a badge or carbon credits for having walked 10 miles a week or 20 miles a week.
  - Analogy - People modify their vehicles. Not for efficiency but because they enjoy modifying them to compete with others.
- There is a research question around the longevity of change. That's problem with gamification: it's very short-lived, games become boring very quickly. So are these all just short-term things? Is there something more fundamental than these short-term things?
  - The timeframe is significant because the social media comes and goes, how long will Facebook be around? But also the limitations because only a segment of society is using it. So for research purposes it may be difficult to use.

Crowdsourcing

- Potential applications of crowd-sourcing for managing traffic - "Waze": it figures out where congestion is by pulling in data from all the people running the Waze app on their smartphones.
  - Security of crowd sourced information: manipulating data that is gathered from phones to manipulate traffic, "cyberterrorism"
  - Coordinating so that there are less individual journeys, whether that is with cars, buses, airplanes...
  - Sell seats in chunks and let other people figure out how to optimise their usage based on social media

Whose job should it be to undertake this research?

- So far it's not evaluative research, it's more about **product development**
- Are there **research centres** for social media?
  - Transport and society centre. But lack of IT knowledge, understanding how to get this data and analyse this. Bournemouth Uni also

How might funding bodies collaborate to solve these questions?

- EPSRC - would be looking at it from the point of view of technology rather than society. They would want to be developing new products. Innovative rather than evaluative research. So **EPSRC may need to collaborate with ESRC**, e.g. digital economy.

What should be in place to tackle these challenges?

- **Social media champions** - You **need somebody to champion this**. Struggling to find interesting research in here (not everybody in the group has anything to do with social media at all). So we'd need champions from within the users themselves to champion the need and usefulness of the research?
- **Better methods** - Techniques to handle these large data sources beyond just analysing the numbers - "What does a click on a website really mean?"
  - The data point you have might be the reaction to the reaction, difficult to separate the noise from the signal
- **Project-based funding** - One of the problems with the DTCs now is that the PhD students disappear in the DTCs and you don't get to interact with them interdisciplinarily. Traditionally in

the research projects it was better, you'd have interdisciplinary teams sitting around in the project meetings and the PhDs would get involved with the stuff going on... difficult to get that with DTCs.

- **Interdepartmental PhDs** - crossovers between computer science and sociology. Not enough of that exists yet.
- **Demonstrator projects** to prove benefit and value of this type of research to the wider research community.
- **Longitudinal studies** to understand the long-lasting implications. Permanency of social-media induced changes.

13.4.2 Cluster 15: How should we manage aviation demand?

Key research questions?
Aviation and Policy

- Can you disaggregate between types of journey or activity?
  - E.g. increase prices for rich people flying a lot but not for the people doing family visits once a year. But this gets toward very top-down heavy-handed regulation.
- What is the link between aircraft manufacture and economic development? E.g. construction of an airport
  - There is no empirical evidence that there is actually economic development from air travel. A lot of double counting, un-robust data.
- How do you get government policy to address things that people consider precious to their individual choices and lifestyles? These are ignored at the moment and there is huge opposition to the nanny state.
  - Why flying is seen as a status symbol?
  - What are the effects of frequent flyer programmes and e.g. people being driven to fly domestically in the UK rather than take the train because they can collect frequent flyer miles that way
- Could including VAT on flights reduce flying? A slight increase of 10%, 20% won't get people to stop flying. If you could at least stop it from growing that would be ok.
  - This approach could help to keep total flights stable, then the problem is managing demand and making people that fly a lot fly less so that people currently not flying can fly.

Demand management and efficiency

- We are managing demand already e.g. via not building airports. If they don't build more capacity than prices would rise but government has decided to build more capacity e.g. around London. What impact does broader government transport policy have on transport demand e.g. choosing to expand UK airport capacity
- Increasing fuel use efficiency of existing techs: e.g. turboprops, trade-off between fuel savings and increased noise levels of turboprops vs. modern jet engines.

Global aviation emissions reduction

- Air flights can make the 80% reduction possibility impossible. It's a fundamental problem even with efficiency increases. They are projected to be below flight growth, so absolute emissions are still growing. If they keep growing anywhere similar to where they have in the past, 80% reductions become impossible. Comes back to fundamental problem of how to get people to fly less voluntarily without giving them the impression that they're being constrained or being told not to do something.

- International dimension - We've only been talking about the UK. E.g. in 20 years, 50% of world aviation might be Chinese domestic flights. How do we address this?
- Who and where should we influence? E.g. employers rather than employees?
  - Need to research better alternatives e.g. trains across Europe, make it as easy to book trains as it is to book flights.

13.5 Group E

13.5.1 Cluster 13: Cities and travel

Key research questions?

City Characteristics

- What happens to cities which can't or won't change to new paradigms?
- Understand the priorities of city dwellers.
- City design for mobility – mode interconnection and flexibility. Any solution or architecture in a city has to be scalable to city size and adaptable to city structure.
- People who can characterise the effect of transport changes on health and standards of living in the city
- London is a small country in terms of scale of economic output and population – TFL is therefore in an excellent position to determine the evolution of its transport system – in a way other UK cities are often not. Case study analysis could be useful of this.
- What are the key differences between transport energy issues between megacities like London and smaller regional cities like Manchester, Birmingham etc

ICT and Systems

- Logistics and autonomy – can ICT systems increase energy efficiency?

Vehicle to Grid

- Vehicle-to-grid – damages the batteries and shortens their lifetimes. Is there a less destructive way: slower cycling, trickle charging?

Main research challenges / Whose job should it be/who is best placed to undertake this research?/ How might the different funding bodies collaborate? / What do we need in place to ensure we are ready to address these?

- **Inter-disciplinarity** - Need people who understand both transport systems and logistics as well as energy usage – two different skillsets, and quite difficult to find.
- **City specific funding calls** - Funding bodies should create a funding call to explore the links between **city transport and energy use** further
- **Research collaboration** – need industry and local authority collaboration. Linking into existing city networks. Engage public key stakeholders. Foster existing academic links.

13.5.2 Cluster 7: Data: ownership, use, analysis, collection and integration

Main research challenges

Data use and ownership

- A lot of useful data is proprietary to somebody – often privacy implications as well.
  - Unlocking proprietary data important.
  - What is the value of data? What is the quality of data, and is it in standard formats?
  - Best practice guidelines for data analytics.
  - Data from private companies – would Amazon provide data on parcel delivery statistics, for example?
- Data security
- Data processing - How do you get the data into the best format for interpretation and presentation?

Smart Cities and Data

- Smart cities – how do they fit into data usage and collection?
- Don't want to reinvent the wheel – companies have already done quite a lot of work on smart city data. Therefore, how do we best utilise current trials and research projects.
- Public response – what will people do if they don't like the amount of data they're collecting on transport journeys etc?
- What about modes that don't collect data easily – walking, cycling? How do we manage data collection for these? E.g. mobile phone?

Whose job should it be/who is best placed to undertake this research?/ How might the different funding bodies collaborate? / What do we need in place to ensure we are ready to address these?

- Who's **best placed** to undertake this data collection? Google? Data analysts? Web hosts?
- **Need an independent database**
  - Who's **most motivated** to deal with and use the information? City planners, Connectivity/communication specialists.
  - **Need collaboration** to get hold of data sets that may be propriety, appeal to corporations social responsibility objectives.
- **Encourage sharing data** – frame it in a positive way with benefits.
- **Greater public ownership** - Take steps to ensure greater public ownership of captured data
- **Stronger and more useful guidelines for standardised data**

14 Annex C – Agenda

Tuesday 11th June	
10.15	Arrival and Registration
10.30	**Session One:** *Introduction* Introduction to the purpose and process of this Expert Workshop and the overall development plan to create an Energy Research and Training Prospectus
	Discussions and activities to share current thinking about the current research and research strategy for this sector
12.15	Lunch
13.15	**Session Two:** *Exploring the Research Themes* Discussions and activities to identify and develop potential research themes from different perspectives
	Session Three: *Reflection and Summary* Activities to reflect on the various different emerging research themes and their relationships
17.30	Coach departs outside Transport Museum to Ramada hotel
19.00	Drinks Reception and Dinner
Wednesday 12th June	
8.30	Coach departs outside Ramada hotel to Transport Museum
9.00	**Session One:** *Introduction to Day Two*
	Session Two: *Deeper Analysis of the Emergent Research Themes* Discussions and activities to explore emergent research themes more deeply, with the aim of identifying drivers and barriers to these different future research themes
12.00	Lunch
13.00	**Session Three:** *Further Development of Research Themes* Discussion and activities to further shape the prospectus
	Session Four: *Summary and Next Steps* Short session to collate feedback on next steps for the research councils and to summarise the key outputs of the workshop, as well as the next steps in the development of the prospectus
16.00	Event Finishes

15 Annex D - Attendance List

Surname	Forename	Organisation
Anable	Jillian	Aberdeen
Axon	Colin	Brunel
Bell	Christine	Centre for Facilitation Services
Bois	Adam	Cambridge
Bows	Alice	Manchester
Brand	Christian	Oxford
Bristow	Abigail	Loughborough
Cebon	David	Cambridge
Chapman	Nigel	Centre for Facilitation Services
Cullen	Jonathan	Cambridge
Dodd	David	Rolls Royce
Eastlake	Andy	Low Carbon Vehicle Partnership
Elsden	Miles	DfT
Fergusson	Malcolm	Freelance Consultant
Hannon	Matthew	Fellowship Team
Hawley	Gary	Bath
Hemsley	Mike	Fellowship Team
Hiles	Toby	TSB & Transport Systems Catapult
Hill	Graeme	Newcastle
Hochgreb	Simone	Cambridge
Holtum	David	EPSRC
Hutchinson	Allan	Oxford Brookes
Jarvis	David	Coventry
Kadhim	Rafat	Rail Safety & Standards Board
Kammerer	Iris	Fellowship Team
Larner	Sam	SMMT
McCulloch	Macolm	Oxford
McIlroy	Rich	Southampton
Paling	Chris	Manchester Metropolitan
Parkhurst	Graham	UWE
Parry	Iwan	Transport Research Laboratory
Pfenniger	Stefan	Fellowship Team
Qiao	Jun	ETI
Rhodes	Aidan	Fellowship Team
Sivakumar	Aruna	Imperial College
Skea	Jim	Fellowship Team
Skippon	Steve	Shell
Tight	Miles	Birmingham
Wadud	Zia	Leeds
Wenner	Clare	Renewable Energy Association