Infrastructure Interdependencies Timelines

The development of this report was led by:

- **The Institution of Civil Engineers**

The following engineering institutions and bodies supported and contributed to the development of this report:

- The Chartered Institution of Highways & Transportation
- The Chartered Institution of Water & Environmental Management
- The Institute of Water
- The Institution of Chemical Engineers
- The Institution of Engineering and Technology
- The Institution of Mechanical Engineers
- The Nuclear Institute
- The Royal Academy of Engineering

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For further information please contact:

Thomas Man, Programme Manager Engineering the Future, The Royal Academy of Engineering

thomas.man@raeng.org.uk 020 7766 0654

Engineering the Future is a broad alliance of engineering institutions and bodies which represent the UK's 450,000 professional engineers.

We provide independent expert advice and promote understanding of the contribution that engineering makes to the economy, society and to the development and delivery of national policy.

Introduction

Engineering the Future (EtF), the alliance of engineering professional bodies hosted by the Royal Academy of Engineering, has created a 'snapshot' of UK infrastructure policy across the five infrastructure areas, energy, ICT, transport, waste and water that form the UK's national economic infrastructure. Phase One[1] of this project presented this information in the form of parallel timelines with a short narrative to explain the nature of interdependencies and why they have an important role in the development of government policy. The timelines provide a convenient and accessible way to assess policy and planning across the sectors of the UK's economic infrastructure. The linear presentation allows the reader to begin to visualise the interdependencies and opportunities and see, at a glance, where and when events resulting from lack of capacity, co-ordination or planning are likely to occur.

These timelines provide a framework from which interdependencies between and among infrastructure polices and plans can be further examined. Phase Two of the Infrastructure Timelines project embarked upon deeper interdependencies analysis. The current timelines were frozen to enable attendees to test EtF's timelines, alongside other interdependency tools currently in development at a workshop involving many of the constituent members of EtF. Further information about this workshop is detailed in the following chapters. As the timelines evolve and the ability to analyse interdependencies develops it should enable EtF, academics and government departments to identify areas where a lack of discernible policy could lead to wider failures in interdependent sectors of UK national infrastructure or where synergetic opportunities presented by those interdependencies should be captured.

The lead for government policy over the five infrastructure areas is shared across a number of Departments of State, sometimes with strong delineation and sometimes with wide cooperation. Policy is constantly developing and, as policies are consulted on and published, the overall landscape will change; this is evident by the changes that have occurred between the Infrastructure Timelines Phase One and Phase Two reports. These changes are discussed in Appendix A titled Significant Changes since Phase One. The timelines should continue to provide an updatable tool that can chart the changing policy and delivery landscape.

Recommendations

1. Policy makers should utilise interdependency analysis and the Infrastructure Timelines to plot current and future policies and align policy development where necessary.

2. Government departments should improve the coordination and communication between and among regulators and asset owners.

3. Further research and implementation of interdependency analysis is required building on the research currently being undertaken by a number of UK universities and commissioned by government.

[1] http://www.engineeringthefuture.co.uk/government/pdf/ETF_InfrastructureTimelinesUpdate_2012.pdf

Project Steering Group

The Project Steering represents a number of the constituent members of EtF and sector experts. The group has been invaluable in providing direction, constructive criticism and expert advice to inform the report through all of its stages.

- Professor Tim Broyd (Chair), Vice President, ICE
- Jane Barron, Divisional Director, Mott MacDonald
- Professor Brian Collins, Professor of Engineering Policy, UCL
- Paul Davies, Head of Policy, IET
- Mike Galvin, Managing Director, Network Investment, Openreach
- Professor Patrick Godfrey, Professor of Systems Engineering, University of Bristol
- Martin Grant, CEO Energy, Atkins
- Professor Jim Hall, Director of the Environmental Change Institute, University of Oxford
- Richard Ploszek, Growth, Productivity and Infrastructure, IUK
- Philip Spittle, Transport and Distribution, Stobart Group

Understanding the Timelines

The Infrastructure Timelines, which can be viewed below in Diagram One, are based on current known policies and plans (as set by government and by operators and owners) and expert opinion from the professional engineering community. These are dynamic and evolving and, as such, do not provide a completely comprehensive coverage of policies and plans.

They show significant planning in some areas of national infrastructure and a paucity of planning in others. They also show that planning in some infrastructure areas, such as ICT, has naturally much shorter time horizons as technological development and replacement is much more rapid than in other areas, such as transport. It is important to note that the issues driving the policies and plans vary across sectors, ranging from high level policy commitments such as carbon emission reduction, to commercial developments such as 4G mobile communications.

As well as providing this visual mapping capability, the timelines should be used to identify where positive and negative interdependencies exist both within infrastructure sectors and across multiple sectors. Engineering the Future has and will continue to utilise the timelines to provide examples of where this may occur. In providing these examples and explaining when, where, how and why they may occur, interdependencies experts and engineers will assist decision makers with their current and future policy decisions.

The timelines are colour-coded to indicate where policies and plans appear to be in place (green), where the outcome of plans or delivery may be less certain or where policy statements are expected (amber) and where crises have been predicted unless action is taken (red). Beyond the known plans in the infrastructure sectors, there is some speculation by engineering experts (blue) which could impact on future plans. In many cases, the speculated developments represent areas where policy decisions will be required based on technological or behavioural developments that are currently far from certain; for example, if plug-in hybrid or fully electric vehicles come to dominate the UK market in the 2020s, a substantial increase in electricity generating capacity is likely to be required but there may also be opportunities to adapt infrastructure to take advantage of load spreading and vehicle-to-grid energy storage.

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UK INFRASTRUCTURE TIMELINES

	2010 - 2020 (2012)	2021 - 2030	2031 - 2040	2041 - 2050
Transport				
Road – Major Schemes	Devolve funding for major local transport schemes to new local transport bodies (LTBs)			
Highways - Strategic Roads Network	Privatisation of highways; Tolling of new roads			
Maintenance	Highway Maintenance Efficiency Program; Hand-off to Local Govt			
Higher Temp Road Surfaces	Increased temperature resilient paving specified in 2008			
Autonomous vehicles		*Progressive introduction of autonomous road vehicles (freight)*	*Autonomous passenger vehicles*	
Rain resilience/drainage	20% increase in drainage capacity specified in 2006 (60yr life)			
EV Infrastructure	Plugged in Places; Home and Workplace charging	Public Charging through Regulated Asset Base		
Rail – West Coast Mainline		West Coast Mainline southern sections capacity reached without HS2		
Thameslink	Phase 1; Phase 2			
Crossrail	£14.5 billion funding envelope (excluding rollingstock)			
HS2		London - Birmingham; Manchester and Leeds		
Network Rail Control Period 4	£9.6 billion for stations, electrification and freight; Control Period 5 - £7.2bn of investment			
Air – Runway capacity	Davies Review; Sustainable Aviation capacity policy		London Airport capacity exceeded without sustainable avn policy	
Maritime – Port infrastructure	London Gateway announced; UK Port Capacity adequate - interactions with other modes taken into account in planning			
Waste				
Landfill	Landfill requirements reduce through current legislation (landfill Tax) and increased recycling/reuse			
Recycling – EV Batteries		First EV batteries coming to EoL - no recycling/reuse schemes planned		
MSW & C&I	Expansion of composting up to 60% recycling of MSW & C&I	Some waste infrastructure decommissioned	Emphasis now on reuse and recovery of material (Stranded Assets?)	
Resources	Resource Security Action Plan; Waste Plan for England			
Disposal – Energy from Waste	Anaerobic digestion for food waste and incineration with energy recovery for residual waste	Decentralised EfW + CHP & small scale gasification and pyrolysis	*Gasification and pyrolysis providing some transport fuel*	
Nuclear Waste	Rejection by Westmoorland Council of the Deep Geological Disposal facility			
Geological Disp Nuc	Planning; Boreholes, Surface investigation	Select Site; Start of Construction	First Waste emplaced	
Energy				
EMR	Capacity Mechanism; Carbon Floor Price; Feed In Tariff For Difference; RO Closed to new generation			
Electricity – EV Infrastructure	Public EV infrastructure	Home and Workplace charging (assuming non-hybrid remains policy and subject to grid reinforcement/smart grid)		
Smart Meters	Foundation trials; DCC established and Mass Roll-out	Smart meter data available to support smart grids		
Smart Grid	Local Trials (Low Carbon Network Fund); Basic active network mgt across sample areas	Advanced active network management across network (Smart Grid 1.0)	Extreme network stress. Smart Grid 2.0 including self healing, islanding etc.	
Grid Reinf	Consistency with National Grid Gone Green Plan	Further heavy reinforcement to 400kV network, especially if EVs and electric heating widespread		
Dist Reinf	Mainly asset replacement and LCNF trials	Potential major network reinforcement at all voltages, depending on EV electric heating and smart grid progress		
Gas	Construction of gas fired stations			
Off-shore Gridand Interconnection	OFTO Deployment; Offshore network for UK	*Emerging EU Supergrid*		
Nuclear	FOAK construction (3rd generation design); Nuclear Industrial Strategy	Fleet Delivery (3rd generation)		Fusion demonstration plant
Storage	Likely to become important on GW scale/24 hour scale (Technical breakthroughs required?)	Likely to become important on 10s of GW, more than 24 hours?	Integration of heat, hot water, and other non-electrical as well as one system	
CCS	Need demonstrator built; GW Scale deployment on both gas and coal generation + CO2 pipelines		*Emphasis for CCS moves from coal and gas to biomass and MSW*	
Large Scale Renewables: Offshore Wind	Cost reduction requires infrastructure and volume orders; Massive scale deployment			
Tidal barrages		*Possible Severn Barrage only if mass EV take up and many other factors satisfied*		
Biomass	Deployment to limit of sustainable resource availability	*Commercialisation of new mass biomass feedstocks ,algae etc?*		
Offshore Marine	Research, Development and Deployment	*Possible GW scale deployment?*		
Microgeneration – Microgeneration (Solar)	Grid parity for solar PV; Distribution networks under active management to accept reverse flows	Everyday use of solar PV on a wide range of surfaces		
Heat/Built Environment/Energy End Use				
Insulation and Building Performance – existing buildings	Whole house retrofit for energy efficiency commercial demonstrations and trials	Refurbish entire building stock to high fabric efficiency and air-tightness standards		
Insulation and Building Performance – new buildings	BRREAM Excellent as minimum standard for all new non-domestic buildings	Very high efficiency standards for all new buildings		
Heating and Community Energy	Demonstrations and large scale trials of CHP, trigen and heat pumps and community/district energy schemes	Large scale deployment of CHP, trigen and heat pumps at various scales, fully integrated within community/district energy schemes		
Gas		Review and decision on future role of gas networks		
Electricity Applications	Continuous improvements mandated in energy efficiency of industrial drives, industrial controls, and white/brown goods	Smart white goods mandated		
Lighting		Full move to LED lighting		
Fuels – Petroleum refining	Refinery Reconfiguration or Decommissioning			
Gas	Increase bulk storage			
Biofuels manufacture and dist	Demo Commercial Scale Biomass to Liquids	*Commercial-scale deployment of Biomass to Liquids cellulosic-ethanol and bio-SG*		
Hydrogen		*Possible evolution of hydrogen feedstock as use for spilled (i.e. surplus) wind energy*		
Shale Gas	Tax breaks for extraction			
Water				
Environmental	Water Bill Introduced; Competition for business customers			
Water Framework Directive	Carry out plans; Review; Meet Directive/Second Phase of WFD (1st Management Cycle); Natural Ecosyetms White Paper	2nd Management Cycle		
Flooding – Separation of runoff and waste	SUDS retrofit and new development			
Resilience/Protection	80 new flood defence projects planned			
Water use	Water Companies 25 year Water Resources Management Plan. Increased interlinking of networks expected.			
	Drought Management Plans (revised every 3 years)			
Regulation	PR14 separate price controls for retail and wholesale services			
Local Treatment		*Local treatment technologies possibly alleviate lack of access to abstraction*		
Abstraction	Restoring Sustainable Abstraction policy to be published addressing unsustainable abstraction up to 2027			
ICT				
Broadband – Rural Broadband	Creating the best broadband in Europe by 2015			
Adequate BB to all	Adequate broadband access and capacity by all that require it (Estimate)			
Fibre to Cabinet	BT reach 2/3 of UK			
IPV6	Migration from IP4 to IPV6 Core + ISP's service offering			
Gov – Capacity			Internet of things	
PSN	Installation and migration of services to PSN			
Mobile – 4G/LTE	EE 4G 2012 - 0.8, 2.6 GHz Auction 2013; LTE services evolve			
Femto / mesh technology	Femto / Mesh networks established			
Space – GNSS – Galileo	Launch 1st 2 sats; Launch 3rd/4th sat; 22 satellites in full operation			

Interdependency Analysis - Methodology

EtF comprises a number of engineering institutions, which have contributed evidence to the research base for the infrastructure timelines. Staff at each of the institutions have engaged with expert members through their various networks and expert groups to gain an insight into the policy and planning taking place across the five main infrastructure sectors.

Research has been contributed by the following institutions in these infrastructure areas:

Infrastructure Sector	Contributors
Transport	Institution of Mechanical Engineers Royal Academy of Engineering Institution of Civil Engineers
Waste	Institution of Chemical Engineering Institution of Civil Engineers Royal Academy of Engineering
Energy	The Institution of Chemical Engineers Institution of Civil Engineers Institution of Engineering and Technology Institution of Mechanical Engineers Royal Academy of Engineering
Water	Chartered Institution of Water and Environmental Management Institution of Civil Engineers The Institution of Chemical Engineers Royal Academy of Engineering Institute of Water
ICT	Institution of Engineering and Technology

The research provided by each of the institutions above has been collated by the Royal Academy of Engineering and Institution of Civil Engineers and used to develop and update the Infrastructure Timelines. The timelines have been reviewed and signed off by the project Steering Group so that they can be used to provide an evidence base for analysis.

The analysis of the intra sector and inter sector interdependencies was undertaken in partnership with The Systems Centre, University of Bristol, utilising the Interdependency Planning and Management Framework (IP&MF)[2] which has been commissioned by HMT, EtF hosted a workshop facilitated by The Systems Centre[3]. This workshop brought together experts in the five key infrastructure sectors. Using the projects, policies and plans outlined in the Infrastructure Timelines, workshop delegates were asked to investigate both intra and

[2] The Systems Centre, University of Bristol & The Bartlett, UCL, 2012, *The Development of a Preliminary Framework for the Identification and Appraisal of Infrastructure Interdependencies with Application to UK National Infrastructure*

[3] The Systems Centre, University of Bristol & The Bartlett, UCL, 2013, *Workshop Application of a Matrix Based Approach to the Identification of Infrastructure Interdependencies - Workshop Report for Engineering the Future*

inter sector interdependencies. Attendees were asked to discuss the intra sector interdependencies using five projects, policies or plans from each sector within the Infrastructure Timelines. They were then asked to undertake a similar activity, but looking across sectors. As well as this, attendees had to indicate whether the interdependence was physical, digital, geographical and/or operational. Table 1 provides an explanation of these types of interdependence.

Table 1 - Description of four Workshop Interdependencies

	Type	Description
P	Physical Interdependency	• A transfer of resources, the output of one element becomes the input to another. This could be further refined to capture the nature of the transfer (e.g. Transfer of people). • A shared physical dependency between the two elements on a third resource (i.e. both elements consume the same fuel or use the same trained staff)
D	Digital Interdependency	• A cyber transfer of information. Again this could be refined to capture additional detail of the transfer. • A shared dependency between the two elements on the transfer of information from a third party source.
G	Geographic Interdependency	• The elements are located in the same place, or within close proximity.
O	Organisational Interdependency	• The elements are linked through a financial or logical mechanism. • The elements are organisationally linked by shared ownership, shared governance, or shared oversight. • The elements are mutually dependent on the services provided by a third party organisation

The formal output from the workshop will be published in the near future and available to access via this link; however, for the purposes of this report, the output has been distilled and analysed into case studies below.

Intra Sector Interdependencies

Using the IP&MF, delegates at the workshop focussed on intra sector interdependencies. The following case studies highlight the types of intra sector interdependencies discussed. Although the physical, digital, geographic and organisational interdependencies were available for analysis, almost 70% of the relationships discussed focussed on either physical or organisational interdependencies; therefore, these are the two interdependencies that will be addressed in the examples below.

Water Resource Management & Flood Risk Management

There are three separate entries on the Infrastructure Timelines that were discussed by the water sector experts. The relationship between the flood defence schemes and sustainable drainage systems, the review of the sustainable licensing regime and the water company Water Resource Management Plans (WRMPs) were shown to have both physical and organisational interdependencies. Flooding is generally considered a risk to multiple stakeholders, including homeowners, agriculture and businesses. In certain situations, storage infrastructure could be built to capture and store run-off, reducing flood risk and also providing a 'new' source of water. This source could be used to reduce river and groundwater abstractions undertaken by multiple stakeholders in a catchment or river basin. This has potential benefits for the ecological status of groundwater and rivers, but also provides a mitigation mechanism during periods of water scarcity as the reliance on groundwater and river abstraction would be reduced. In turn, this has an impact on the WRMPs produced by water companies. They have a potentially new source of water to include in their long term plans, which will also drive their short and long term infrastructure expenditure.

Managing the capture of this run-off will require organisational coordination as water companies, lead local flood authorities and the EA will have to discuss planning, funding, building, ownership and maintenance arrangements. Thus far, the delivery of Sustainable Drainage Systems (SuDS) has been poor and guidance has yet to be provided by Defra. If drainage and storage systems, such as SuDS, is utilised more widely and effectively the EA may be in a position to introduce a level of flexibility into its abstraction licence regime. It is important that the EA engages with this process, as the changes it decides to make to the licences may act as either incentives or barriers to this type of shared scheme.

Transport

Organisational interdependence was considered one of the key areas for focus in the transport sector. In particular, collaboration was seen as important among the groups responsible for delivering the London Gateway project, HS2 (and further iterations), South East Airport Capacity and those responsible for highways funding and management. While there were a number of areas where positive interdependencies exist among these projects, there were considered to be two particular areas of focus.

First, the collaboration on Business Cases in each of the above projects was seen as beneficial to the planning, design, delivery, governance and operation of the projects and policies. It was considered that there is clear value in an integrated transport approach, which should start at an early stage in projects such as the above. If the organisations involved in the stages of delivering these projects engage collaboratively then the multiple benefits can be identified early and actions implemented to achieve them.

Second, the under-utilisation of roads during certain hours was also raised as an area that could be addressed by improved collaboration and coordination among groups responsible for the delivery and management of these projects. Currently highways are available for night time movement of freight; however, local road policies often prohibit movement of freight. Projects such as the London Gateway and increased South East airport capacity will require improved and more efficient movement of freight by the road network. Organisational collaboration in this situation would provide these stakeholders with a clearer view of the limitations of the current road policies, align their objectives to become mutually beneficial and allow them to resolve any issues in the achievement of these objectives. As both HS2 and South East airport capacity projects develop it is also important that the transfer and movement of passengers is considered and integrated. This will require organisational coordination.

Inter Sector Interdependencies

As with the intra sector discussions, approximately 70% of the inter sector interdependencies focussed on the physical and organisational interdependencies that exist. Table 2 illustrates the full range of interdependencies that were discussed and captured at the interdependencies workshop. There are multiple examples of interdependencies contained within the table; however, the relationship between the energy sector and other sectors was seen as particularly important. Therefore, the energy sector provides an excellent case study with which to illustrate infrastructure interdependencies.

Table 2: Infrastructure Interdependencies generated by Workshop

Energy	P: Energy sector provides necessary electricity for operating and cooling ICT sector equipment (e.g. Server Farms)	P: (1) Energy sector provides necessary fuel (hydrocarbons) and lubricants to Transport sector; (2) Energy sector provides necessary electricity for electrified rail and Electric Vehicles in the Transport sector	P: (1) Energy sector is a source of general Waste transferred into Waste sector; (2) Energy sector is a source of Nuclear Waste	P: (1) Energy sector activities (e.g. Shale Gas) can transfer pollutants which contaminate ground water; (2) Energy sector provides necessary electricity to Water sector for pumping etc.; (3) Energy sector requires Water for cooling plant
		G: Co-location. Energy sector utilities and Transport sector assets share physical space		
	O:(1) Energy and ICT sectors can collaborate to create energy efficient equipment; (2) Energy and ICT sectors collaborate on sharing data (hindered by ownership issues)			O: Energy sector requires payment from Water sector for electricity provided to power pumps
P: ICT sector provides necessary resources to Energy sector	**ICT**		P: ICT components in space can become or produce space Waste	P: ICT sector requires protection from flooding provided by Water sector
D: ICT sector provides resources for Smart Grid, Smart Metering, Demand Management, Control and Billing to Energy sector		D: (1) ICT sector can potentially provide digital capability to reduce need for physical Transport; (2) ICT sector provides resources and capability for Transport sector activities: (a) Congestion charging (b) "Boris bikes" (c) Multimodal journey management (d) Global positioning (e) Comms. (f) Tracking (g) Stock control (h) Road use charging	D: ICT sector provides the capability for Waste and recycling 'tagging'	D: (1) ICT provides the capability for Smart Metering and management of/within Water sector; (2) ICT provides the capability for digital control of/within Water sector
		G: (1) Some ICT Plants and Services are geographically linked to the Transport network; (2) Co-location of some ICT physical assets (e.g. telecoms cables) and some Transport assets (e.g. roads)		
O: (1) ICT sector provides necessary control and communications systems to Energy sector during set-up; (2) ICT sector and Energy sector can collaborate to reduce ICT energy footprint; (3) ICT and Energy sectors collaborate on sharing data.		O: (1) ICT sector provides data management capability to Transport sector; (2) ICT sector and Transport sector collaborate on sharing data; (3) ICT sector provides capability for Transport sector to perform Logistics Route Planning; (4) ICT sector provides capability for general operational usage within Transport sector	O: ICT sector and Waste sector collaborate on sharing data	O: ICT sector and Water sector collaborate in sharing data
P: (1) Transport sector provides the capability to move Shale Gas; (2) Transport sector provides the capability to move fuel to power stations; (3) Transport sector could transfer excess heat from vehicle tunnels into Energy sector	P: Transport sector provides capability for JIT delivery for ICT sector	**Transport**	P: (1) Transport sector provides the necessary capability to move Waste; (2) Transport sector creates Battery Waste which requires disposal	P: (1) Transport sector can potentially provide: (a) an obstruction to Water or (b) facilitate its transfer; (2) Permeability of materials used to construct Transport sector assets can affect flood risk
D: Transport and Energy sectors share intelligence information	D: Transport sector relies on ICT sector for Road use charging capability.			
G: Co-location of Transport and Energy assets				G: Co-location of Transport and Water assets to provide utility corridor
O: (1) Transport sector requires network for Electric Vehicle (EV) charging; (2) Sector policies must be aligned to achieve goals (i.e. uptake of EVs and reduction in domestic energy use)			O: Transport and Waste sectors can collaborate to change behaviours on emissions (Nudge, wink, hug etc.)	O: Transport and Water sectors can collaborate on flood management planning rules
P: (1) Waste and by-products can potentially provide a resource for the Energy sector including processes such as Anaerobic digestion; (2) Waste can potentially provide a source of rare Earth metals needed by the Energy sector		P: Waste sector requires Transport sector for (1) Movement of hazardous waste; (2) Movement of general waste; (3) Movement of specific materials that cannot be disposed locally (e.g. Japanese knotweed)	**Waste**	P: (1) Waste sector can potentially produce contaminated water which is transferred to the Water sector; (2) Waste in landfill can potentially cause more Water runoff
				G: Co-location of Waste facilities and Water resources can potentially result in ground water contamination
O: Waste disposal plans may need to be in place before new power stations are approved (especially Nuclear)		O: Separation of Waste at source and separation of Waste at a dedicated facilitate have different transport needs (and affect Efficiency versus Quality)		
P: (1) Water provides a potential means to generate electricity; (2) Water provides a necessary means of cooling Energy plant; (3) Water provides a potential means of Energy storage; (3) Water sector may require Energy for Bulk Water Transfer		P: Water sector provides flood protection for Transport sector assets		**Water**
	D: Water sector relies on ICT Sector for Smart Meters and Demand Management			
		G: (1) Co-location of Transport assets and Water sources can increase the risk of flooding; (2) Water utilities can disrupt Transport network by digging up roads; (3) Water sector utilities can degrade road system due to sub-standard re-instalment		
O: Water sector provides payment to Energy sector for Pumping	O: Water sector collaborates with ICT sector for real time data exploitation to maximise efficiency, energy use and resilience			

Energy Sector Interdependencies

The Energy sector is strongly linked to each of the other four sectors and therefore provides a useful example of infrastructure interdependence. The uncertainties regarding aspects of EMR and delays over the announcement of the Energy Bill have caused some concern regarding the UK's ability to confront the 'trilemma'[4] of security of supply, reducing carbon emissions and the provision of competitive energy costs. Ofgem recently reported that spare electricity generation capacity could fall from the current figure of 14% to only 4% by 2015[5]. This could have a significant impact on the UK's energy security and also the resilience of other infrastructure, much of which relies on a secure supply of electricity.

The energy sector provides necessary power to aspects of the ICT sector, such as cooling equipment, and relies on ICT for control systems. There is also a mutually beneficial relationship between ICT and Energy when the two sectors collaborate to create energy efficient equipment. Evidence from the workshop indicates that this partnership approach is currently inhibited by organisational and ownership issues that prevent best practice in the sharing of data. Smart metering, which has now been delayed by a further year, creates dependencies between energy, IT and communications. A high level of design solution and security is required of the IT and Comms in order to achieve functionality and public acceptance. Privacy is essential but at the same time it is beneficial for companies developing innovative solutions to home energy management to be able to access data with customer consent. Ofgem, DECC, Ofcom and the Information Commissioner need to work together with the industry to resolve these issues. While acknowledging the importance of confidentiality and ethics in data exchange, EtF recommends that the appropriate sharing of data is incentivised to ensure the door is open for entrepreneurial activity.

Energy distribution and Transport assets can share the same physical space (route corridors) and the Energy sector provides the Transport sector with fuel (petrol and electricity for Electric Vehicles (EVs) and rail) and lubricants. The workshop on interdependencies identified the need to align Transport sector and Energy sector policies in order to avoid a potential failure from a lack of interdependency planning. This failure was seen as particularly concerned with the possible increase in electricity demand should there be a significant switch to electric vehicles and the government policy to electrify the rail network, which is currently underway and highlighted on the Infrastructure Timeline. There are particular transport projects, such as the development of the London Gateway, where electrification of the network will allow use of electric traction for rail freight all the way through the network. This would have a wider economic benefit. While there is some suggestion that domestic EV charging may take place in off-peak periods, there is still a need for interdependency planning in this area. There is a need to ensure policy concerning the uptake of EVs and the development of the supporting infrastructure supports policy concerning energy use and vice-versa. There is also a requirement for the development of a recycling and/or waste policy for spent EV batteries. The infrastructure timelines show that there is currently no policy in place to reuse or recycle EV batteries as they begin to come to their End of Life period in approximately 2015.

Energy is also important to the water sector as electricity is required for pumping and many waste water processes. This key relationship is emphasised by the successful attempts by some water companies to generate their own electricity from renewable sources or from waste by-products generated by certain processes. Water is also required for cooling within a number of electricity generating processes. This could be challenging in the future,

[4] "trilemma" Paul Golby of EON's description of the UK's problems of decarbonisation, security of supply and affordability

[5] Ofgem (2012) http://www.ofgem.gov.uk/Markets/WhlMkts/monitoring-energy-security/elec-capacity-assessment/Documents1/Electricity%20Capacity%20Assessment%202012.pdf

particularly in situations where inland water sources are required for cooling purposes. According to the *Climate Change Risk Assessment*[6], published by Defra in January 2012, lower river flows in summer caused by climate change may impact on the amount of freshwater inland energy stations can abstract for use in cooling. This is should be a significant factor in the EA's approach to reviewing the abstraction licence regime.

Shale gas extraction is viewed by government as a potential source of energy to improve the UK's energy security. Although the viability of shale gas extraction is still unclear, there is interdependency with water that must be considered carefully. Water is required as part of the fluid used in the hydro-fracturing process. The process produces a brackish by-product that has to be disposed of carefully. Recycling wastewater where possible would reduce the volumes of wastewater in need of disposal as well as reducing the burden on freshwater abstractions. Wastewaters can be diluted with freshwater and then reused in subsequent fracturing operations[7]. It is important that DECC, HSE and the Environment Agency collaborate on the development of fracking and that regulation is utilised to manage the water and environmental risks concerned with the process.

[6] Defra January 2012 Climate Change Risk Assessment for the Energy Sector p.20 http://randd.defra.gov.uk/Document.aspx?Document=CCRAfortheEnergySector.pdf

[7] Shale gas extraction in the UK: a review of hydraulic fracturing (2012) http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

Conclusions & Recommendations

The infrastructure timelines can be used as part of an interdependencies toolkit, which includes the Interdependency Planning and Management Framework (IP&MF), which has been commissioned by Her Majesty's Treasury (HMT) and currently in development by The Systems Centre at the University of Bristol in collaboration with the Omega Centre at the Bartlett School of Planning and the Bartlett School of Construction and Project Management, both at University College London. Comparing policy, planning and project timelines across the infrastructure timelines should enable government departments to collaborate with other departments in order to identify the interdependencies that their particular policies may encounter elsewhere. The identification of these interdependencies should allow government departments to work together in order to mitigate any future issues that may occur and plan policies that are aligned. The infrastructure timelines should continue to evolve as a dynamic visual aid to inform the development of government policies.

1. **Policy makers should utilise interdependency analysis and the Infrastructure Timelines to plot current and future policies and align policy development where necessary.**

This will be useful when developing policies that have clear relationships with other areas of policy, such as the electrification of the railways and energy policies on security of supply. The timelines are particularly useful in highlighting areas of physical and organisational interdependencies, which are vital in enabling collaboration and avoiding unintended consequences of policy development. The workshop and infrastructure timelines have also highlighted that necessary or critical interdependencies could give rise to a potential failure, should there be a lack of interdependency planning. The risk of failure increases if one sector's reliance on another is taken for granted or is completely unacknowledged. The importance of resilient infrastructure means that all government departments should consider the interdependencies of their areas of competence with other sectors before and during policy development. This will provide a platform for more resilient infrastructure and also for more efficient and intelligent infrastructure networks.

2. **Government departments should improve the coordination and communication between and among regulators and asset owners.**

Interdependencies between and among infrastructure sectors are numerous and complex. The interdependency workshop held by Engineering the Future and Bristol University confirmed multiple intra sector and inter sector interdependencies. Based on the outputs from this workshop it is evident that these relationships exist on a physical and organisational level, particularly when it comes to interdependencies between and among government policies. In each sector, regulation is overseen by different organisations and assets are often owned and managed by different and multiple asset owners. These factors create an immediate barrier to the management and development of a system of infrastructure networks. Therefore, it is important that those responsible acknowledge and collaborate in areas where there are clear benefits of cross-over. One such area is hydro-fracturing, where the impacts of shale gas extraction may have a significant impact on the quality and quantity of water resources. In this instance DECC must collaborate with the Environment Agency to ensure that the development of energy policy does not have a negative impact on the aquatic environment and the competing demands of water abstractors are fully considered.

3. **Further research and implementation of interdependency analysis is required.**

The interdependency analysis presented in this report provides an insight into the nature of interdependencies across economic infrastructure sectors. Evidence from the workshop suggests that sectoral policy-making occurs in silos. Some sectors, such as ICT, are driven by the private sector, but that does not mean that government's role is diminished. As with energy, ICT is fundamental to the everyday functions of many other sectors; therefore, ensuring security of supply, affordability and accessibility to these services is vital to UK Plc.

Appendix A

Significant Changes since Phase One

Since the first Infrastructure Timelines report was published in December 2011, there have been some significant changes to policies and plans in particular sectors. These are highlighted below.

Transport

- Roads

In March 2012 Prime Minister David Cameron announced that the government would carry out a study into possible new ownership and funding regimes for the nation's strategic road network. Although no formal policy has been instigated, the announcement of this feasibility study indicates a willingness to consider a radical shift from the status quo. Under current plans only new or enhanced roads will be eligible for direct tolling; however, depending on the outcome of the review there may be an expansion of the private sector's role in the operation and maintenance of stretches of the strategic highways network. The review also opens up the potential for significant new investment if predictable revenue streams can be established.

This feasibility study has been entered on to the timelines in amber as it is not yet a formal policy. As a significant part of the feasibility study will investigate the introduction of tolls and possibly shadow tolls, a tolling plan has also been included.

- Airport Capacity

In the first timelines report there was an expectation that a process for establishing a policy on enhancing UK airport capacity would be introduced in the current parliament. While a consultation has been issued covering a range of strategic issues for UK aviation, the core challenge of capacity at UK airports has been deferred. To fill this void the Davies Commission has been established to investigate the options for expanded airport capacity, in particular the vexed question of the size and location of a hub airport in the South East of England. The Davies Commission will publish an interim report before the end of 2013 but will not make its recommendations until after the General Election in 2015. Although the current government has committed to implement the findings from the Commission, and Davies himself has committed to seek evidence across the political spectrum, cross party consensus on the implementation of the recommendations is not yet in place, which casts further doubt on the formation of policy on aviation capacity. This may delay the decision on aviation capacity into the late 2010s if not the early 2020s.

The Davies Commission has been added in green and aviation capacity policy retains its amber status, but has been pushed back to the late 2010s. Dependent on the recommendations from the Davies Commission and the ability of the main political parties to agree a consensus position, there is a risk of further delay which could legitimately lead to a downgrading to red on the timelines.

Water

- Supply

A draft Water Bill was introduced by the Department for Environment, Food and Rural Affairs in July 2012. The main focus of the Bill is to create greater competition for water supply to

business customers. Although limited in focus this Bill has moved from amber to green on the timelines. In addition to this the increased competition for water supply to business customers has been added in amber as a progression should the draft Bill achieve royal assent.

- Flooding and Water Management

The construction of Sustainable Drainage Systems (SuDS) was a significant part of the Flood and Water Management Act (2010). SuDS were envisaged for all new developments and there were also plans to retrofit SuDS were practicable. Unfortunately, the guidance for the implementation of SuDS has not yet been published and developers, Local Authorities and other stakeholders are unsure of who will have responsibility for their construction and maintenance. It is not clear how long it will be before this guidance is published; therefore, SuDS retrofit and new development has been downgraded from green to amber and the timeframe extended into the 2020s.

Energy

- Electricity Market Reform

The Department for Energy and Climate Change introduced the draft Energy Bill in May 2012 in order to progress the process of Electricity Market Reform (EMR). The full Energy Bill was published in late November 2012. The main aspects of EMR are: Contracts for Difference, Capacity Market, Carbon Price Floor, Emissions Performance Standard and Renewables Obligation: Transitional Arrangements. EMR has been added in amber as this bill will have to go through a period of consultation and detailed analysis, as well as debate in Parliament, which means that there is still a level of uncertainty regarding the details of EMR.

The UK government has launched its Nuclear Industrial Strategy, which aims to enhance the UK's competitiveness in the global nuclear market. The UK market for nuclear new build is estimated at £60 billion and this strategy should enable further building, waste management, decommissioning, operations and maintenance; however, there are still potential barriers to the full delivery of the nuclear programme. Hinkley Point was provided planning permission recently and it is important that further delays to planning are prevented to remove any issues around increased costs and delays. Issues covered in the Waste section below also have to be addressed.

A further year's delay to the roll out of Smart meters means that this remains as amber on the timelines.

Waste

The consultation on a Waste Plan for England was due to occur in the summer of 2012. This has been deferred and a Resource Action Plan had been published instead. Both of these plans have been included in amber as it is unclear of the timing of their delivery and what impact they will have on waste policy. The rejection by Westmoorland Council of the Deep Geological Disposal facility in Cumbria also creates an issue for the safe disposal of nuclear waste. This creates significant uncertainty for the geological disposal of nuclear waste and moves it to red on the timelines.

ICT

Much of the ICT sector is driven by the private sector and the timelines show that the sector is due to progress well over the next decade. There are certain factors, such as the saturation of 4G, which bring relative uncertainty to the next stages of mobile technology. The increased use of Cloud Computing and other non-direct and ad hoc connections may require Government to consider how privacy policies are developed and cyber security increased to manage these ways of storing and remotely accessing data.
As the 'internet of things' develops there may well be an issue with the availability of address ranges globally even as the Migration from IP4 to IPV6 core occurs. Issues of decreasing capacity may be encountered around the 2025-2030 period. This is complex as address capacity is managed internationally, and therefore it should be a key strategic objective for the UK government and ICT sector to ensure that UK interests are represented on a global platform.