'Smart City' - Intelligent energy integration for London's decentralised energy projects

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Executive Summary

Context

This report presents the key findings of the Greater London Authority (GLA) funded project 'Smart City - Intelligent energy integration for London's decentralised energy (DE) projects'

London, as with many cities, faces future challenges relating to: growth; urbanisation; pollution; resource efficiency; and a changing climate. London's population is projected to grow by 12% over the next 20 years. The resulting demands and pressure on energy infrastructure and resources obliges city infrastructure and consumers to adapt intelligently to ensure efficient, affordable and sustainable solutions.

Technologies, systems and services that can enable the efficient and sustainable management of energy production and use are becoming commercially available. In the context of the *Smart City* agenda, London intends to demonstrate the integration of these emerging opportunities by specifying and piloting secure, flexible, low carbon and growth-stimulating energy infrastructure that is cost-effective and actively managed. This study examines how smart technology and services can integrate the production and use of energy at the local level, to provide a more sustainable and efficient system

The Mayor's Climate Change Mitigation[1] and Energy Strategy and the Decentralised Energy Capacity Study[2] have forecast the accelerating deployment of decentralised energy (DE), in London over the next 15 years to facilitate the supply of 25% of London's energy from local sources by 2025. This deployment of DE will include extensive use of decentralised energy and to a certain degree, the deployment of district heating networks.

The Government's Electricity Market Reform white paper[3] (DECC, 2011) recognises the potential for DE in demand side response, helping to manage supply and demand for heat and power at the distribution network level, particularly through the deployment of thermal stores and heat networks.

Project Aims

The overall aim of this project was to understand and demonstrate the role that 'smart' could play in the optimisation of DE production, transmission and distribution in London and the management of energy demand and the benefits such an approach would deliver.

The project has considered how an intelligent energy system might evolve in London in the period up to 2050, the key technologies that could be deployed, and the organisational structure and key actors required to support an intelligent and integrated energy system.

It has also looked at a possible system architecture and the functional specification issues that may need to be considered when bringing forward decentralised energy projects in London.

Benefits for London

The aim of an 'intelligent' energy system is to deliver secure, affordable, low carbon energy while making the best use of London's existing energy infrastructure and reducing the need for investment in new infrastructure. This might for example be achieved by managing demand and generation more effectively at the local distribution level to reduce peak demands and the need for investment in additional network capacity.

This project has been funded through the GLA's Low Carbon Capital programme which aims to generate inward investment, job creation and innovation, facilitating the transition to a low carbon economy and positioning the capital as a leader in energy technologies and services.

London is already leading work in this area through projects such as: 'Low Carbon London'[4], one of the first projects to be funded under Ofgem's £500 million Low Carbon Networks fund and 'Source London', London's network of electric vehicle charging points, and through actively seeking other opportunities for intelligent energy pilots – which this project will inform.

Technology companies are already establishing London as a centre for showcasing new technology and are collaborating with and investing in London's research institutions to push forward innovation in these areas. Examples include The Crystal, Siemens' £30 million visitor attraction and global knowledge hub in the Royal Docks, and Cisco's recent collaboration with Imperial College London and UCL to create a Future Cities Centre in the Capital.

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[1] Delivering London's Energy Future: The Mayor's Climate Change Mitigation And Energy Strategy. GLA. October 2011

[2] Decentralised energy capacity study Phase 2: Deployment potential. GLA. October 2011

[3] Planning our electric future: A White Paper for secure, affordable and low carbon electricity. DECC. July 2011.

[4] http://lowcarbonlondon.ukpowernetworks.co.uk/

Project Scope

Smart technologies can be integrated at every level on the energy network - from power stations, through transmission, distribution of heat and power and right down to individual smart appliances, smart controls, micro renewables or electric vehicles at the building level. This project has a focus on London as a potentially autonomous city in energy terms - on opportunities at the local and regional level, rather than at the national level (in electricity network terms – the distribution network level rather than the transmission network).

The project is not about smart grids (i.e. electricity networks); it is about an intelligent, efficient urban energy system capable of heat storage, electricity demand-side management and active network management providing electricity generating capacity when required to support the electricity distribution network.

Project Outputs

Technology Review

A review of smart technologies that may contribute to London's Energy system was undertaken in the period January and mid February 2012, and their relevance for London was assessed. A table summarising this assessment is included at Appendix C.

It is by no means exhaustive and will require regular review given the fast pace of change in this area, across numerous fronts. Policy and regulation is emerging, the market is evolving and new technologies and solutions are continually being tested and trialled.

Key players

Smart energy is being talked about by Government, policy makers, regulators, academics and almost every business across the utility, energy, IT, engineering, controls and consulting sectors. The challenge for a city is to understand the perspective of these various organisations, mapping skills (and/or projects or products) and to try to facilitate a joined up and collaborative conversation that runs end to end from energy generation, through transmission and distribution to the consumer. This is not a straightforward task and is often made more difficult by the different commercial interests of the key players who would need to deliver and operate a more intelligent energy system. Figure 1 shows some of the players identified as part of the market review.

Ofgem's Low Carbon Networks Fund[5] aims to bring some of these players together and has provided funding for Distribution Network Operators (DNOs) to work with partners to pilot new technologies, new commercial arrangements and demand response mechanisms.

Three focus opportunity areas for London

Following the initial technology and market review three focus areas were identified for further analysis and assessment:

1. The potential role of heat networks and their associated thermal storage and combined heat and power plant in balancing energy demands and supply at a local distribution level (see section 5);
2. The role of demand side management at building or aggregate level to reduce energy demands, balance local energy supply and demand and reduce the need for network reinforcement (see section 6);
3. The role of distributed generation and electric vehicles in last mile electricity grid balancing (see section 7).

In addition the team reviewed the communications infrastructure layer that will need to evolve to bring the 'intelligent energy system' together (see section 8) and considered the market issues around creating sufficient incentive for active network management and demand side responses at the distribution scale.

Together these areas reflect the project team's view that the main opportunities for intelligent energy in London are likely to be demand side management and network balancing at the distribution network level including making optimum use of decentralised energy generation and heat storage.

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[5] http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/Pages/lcnf.aspx

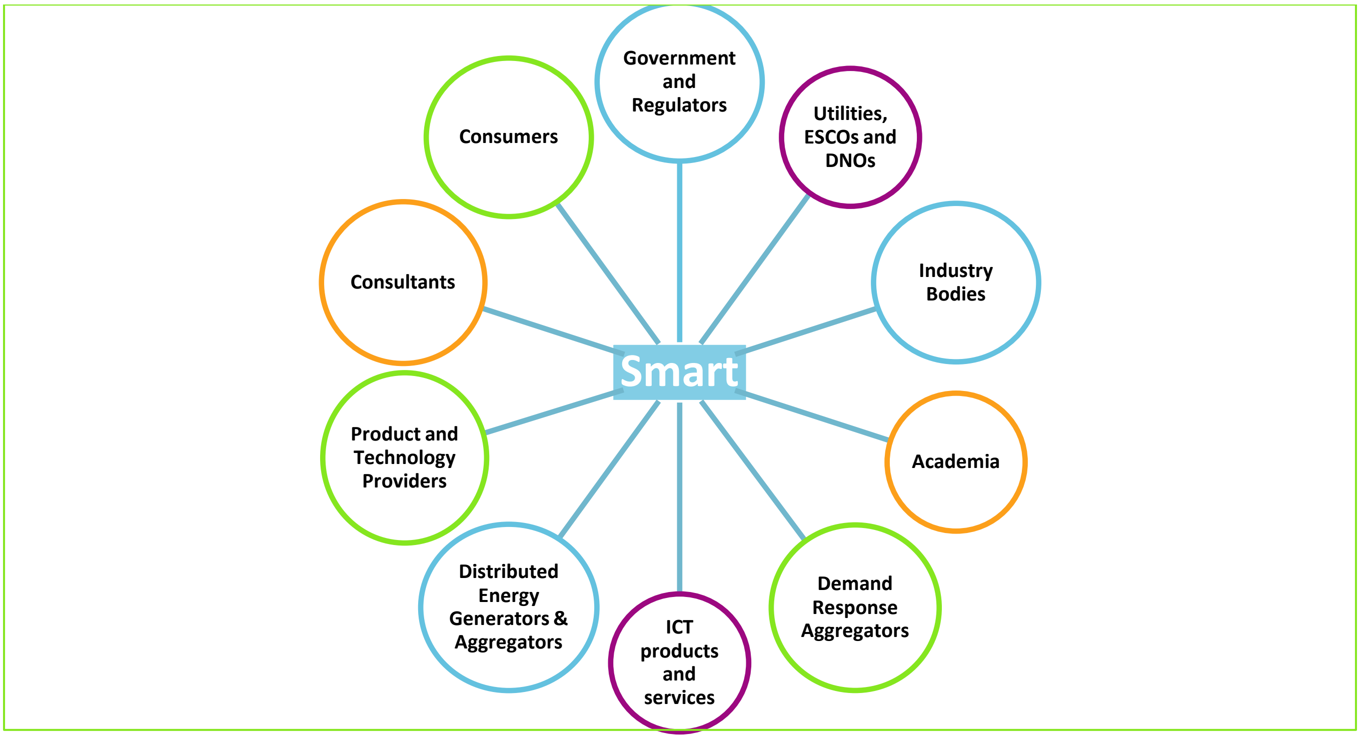

Figure 1: Key players for the development of intelligent energy networks

Key Findings

The Role of Heat Networks

As noted in DECC's Heat Strategy, 2012[6], heat is the most significant energy demand nationally – more significant than electricity or transport. Of London's energy use in 2008, around 51% was supplied through non-transport fossil fuels (mainly gas for heating in buildings) - accounting for around 30% of London's CO_2 emissions.[7]

The market for heat in the form of steam or distributed hot water (district heating) is expected to grow in London over the next 10 to 15 years. District heating is being promoted by the GLA, and heat networks are expected to make a significant contribution to the GLA's target for 25% of London's energy to be supplied from decentralised sources by 2025. Emerging heat networks and associated thermal storage offer an opportunity for local electricity network balancing. At present there is little regulatory framework addressing district heating in the UK, but if this develops in response to market growth, it is important that it encourages greater integration in the way heat and power networks are managed.

The review of the role for heat produced as a cogeneration product with electricity identified a number of key points:

- CHP is typically designed to use the heat produced by the engine rather than rejecting it to the atmosphere (for economic and environmental reasons). Assuming the system has not been designed to dump heat, the demand response that can be provided by CHP engines is limited by the capacity of the heat storage available and how quickly the heat can be dissipated for useful purposes after the heat store has been charged.
- Gas engine CHP plant linked to thermal storage could be used to provide a demand response in spring, autumn and summer at times when the CHP engine is not running or is not running at full capacity. In winter, when the CHP engine would be expected to be running at full capacity, a demand response would not be available. In summer the demand response available will be lower or less frequent than in spring and autumn as the demand for heat will be lower and it will take longer to dissipate any stored heat.
- From a current DNO viewpoint, in order to offer a reliable demand response multiple CHP assets would need to be aggregated within a defined distribution boundary. This form of aggregation already occurs for offering a demand response from standby generation plant and would seem plausible for CHP operators.
- For hydraulic reasons there is likely to be only one main heat store serving each heat network, so heat storage is likely to be located at the energy centre, although storage could also be located at a dwelling level. '
- Storing surplus power as heat through the use of electric boilers has potential but will require a power surplus to occur on a regular basis before this market develops. It would however be relatively easy to retrofit electric heating to energy centre heat storage.
- District heating will be beneficial in reducing peak power demands regardless of whether it provides a smart demand response as it will reduce the number of electric heating systems installed. This will potentially provide a benefit both at the local distribution scale, in avoiding upgrades to the capacity of the primary or local substations serving the distribution network, and in reducing the capacity of power stations required to meet peak electricity demands.

In terms of the functional specification for new district heat plant and energy centres, it may be sensible to consider maximising thermal storage, identifying where additional thermal storage capacity may be accommodated in future and how direct electric boilers may be connected to thermal stores, if market incentives develop that would support the additional costs of these measures. In the short term lack of an identifiable revenue stream is likely to limit investment in such measures.

The system architecture and control functions required to deliver the capabilities set out above are discussed in section 3.

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[6] The Future of Heating:- A strategic framework for low carbon heat in the UK. DECC. March 2012.

[7] London Climate Change Mitigation and Energy Strategy. GLA, October 2011.

Demand Side Management

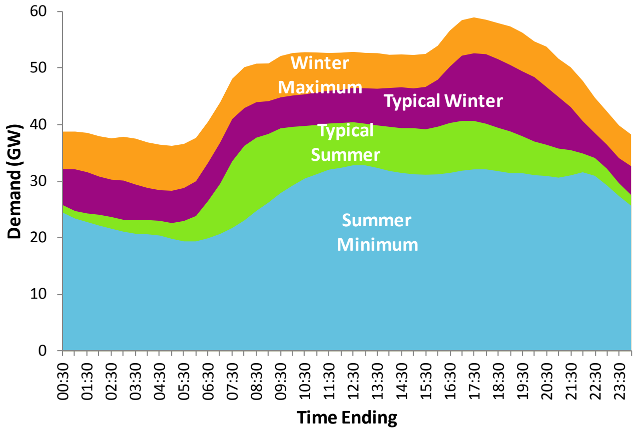

Figure 2: Summer and Winter Daily Demand Profiles 2010/11. Source: National Grid's National Electricity Transmission System Seven Year Statement, 2011

Considerable investment is required in the UK's energy transmission and distribution networks as we shift from an energy supply system dominated by oil and gas to one where an increasing proportion of energy production will be met by intermittent large scale wind and decentralised renewable energy resources. Increased use of electric heating as the grid decarbonises and use of electric vehicles to combat poor air quality will create greater demands for electricity in cities. The increased use of air-conditioning and shifts to seven day trading patterns are also increasing demands for electricity in cities. The additional investment in infrastructure required to deal with these issues could potentially be reduced by managing demands more effectively and balancing supply and demand within and across local heat and power distribution networks. This is an issue which has been recognised by policy makers, the energy industry and technology providers worldwide and which has led to extensive research and business development in the smart technology area.

Figure 2 shows current national demand profiles for power in winter. National Grid predicts that by 2020 these will remain similar to today. Post 2020 they expect demand profiles to flatten, supported by the development of smarter grids including the roll-out of smart meters and the impact of time of use tariffs.

Sustainability First have estimated that the maximum technical potential for demand response nationally in 2010 was 18GW (winter) and 10GW (summer) and that this could grow to 23GW (winter) and 12GW (summer) by 2025 under a scenario that assumes wide uptake of efficiency measures and heat pumps.

National Grid envisage that the main sources of demand response are likely to come from electric space and water heating in homes, wet appliances and refrigerators in the home, air-conditioning and refrigeration in commercial buildings, and use of electric vehicles, CHP, heat pumps and other renewables linked to storage.

A role is seen for linking PV to battery storage as one of the better ways of addressing the intermittency of PV generation, but this will be reliant on the emergence of economic battery storage.

Electricity market reforms are being undertaken with the aim of incentivising demand management. Smart meters will also be installed in every home. These will link to a Home Area Network, enabling wireless communication with some equipment installed in the home, as well as with DNOs and suppliers via the Data Communications Company being established by DECC. Businesses and the public sector will also have smart or advanced energy metering.

A range of intelligent control devices are already emerging for helping to reduce heating energy use in homes and energy use from wider services systems in commercial buildings.

Intelligent controllers for domestic appliances are also emerging and work is being undertaken to develop vehicle to grid energy solutions. With the roll-out of smart meters these will be able to offer a dynamic demand response to help balance demands at the distribution level, provided that sufficient economic value and incentive can be created.

What is clear for most of these applications is that from a specifier's perspective, the detailed control and functionality will be in the hands of product manufacturers and service providers who will design products to communicate using standardised operating platforms that can link with the smart meter, typically wirelessly via a Home Area Network or Local Area Network. The key consideration for specifiers at this stage is to be aware of the emerging product offers and to consider the future space requirements and power connection requirements for emerging products such as battery storage and car charging points.

Aggregators are likely to play a significant role in demand response. Aggregators are already offering demand response in existing balancing arrangements at the national grid level such as the STOR programme.

The key issue is to bring demand response and aggregation down to the distribution level, to play a role in balancing loads and addressing stresses within the local low voltage distribution network.

The commercial incentives for doing this are at present limited, but the smart meter roll-out will provide a system and mechanism around which incentives for demand responses could develop.

Actions by some in the value chain can create impacts for others, for example aggregation of a demand response in a local geographic area could be offered as a grid balancing response but might be unhelpful at a local distribution level. For example, a retailer or aggregators might contract with a group of customers in a small geographic area to provide demand response via electric vehicles or fuel cells for wholesale market benefits. However, if delivered in a small geographic area this could have a significant impact on the distribution network's ability to cope with peak demand, if there is a mismatch between peak demand periods for network and wholesale purposes. The government is still consulting on how information would be shared and it is not yet clear in what timescales it would be made available; however the need for co-ordination will become increasingly important.

Some existing policy instruments such as fixed rate Feed In Tariffs and Renewable Heat Incentives may in the short term act against some demand responses emerging, where these offer a greater revenue stream than might be available for a given demand response.

The business models of DNOs have traditionally been based around investment in assets and there will need to be significant commercial value and confidence in the robustness of demand response for this to offer an alternative to network reinforcement. Use of system charges make up a small proportion (c.17%) of current domestic electricity tariffs, making it difficult to see how action at the distribution level would currently be incentivised.

This implies the need for substantial market reform and our future systems architecture envisages a role emerging for a distribution systems operator (DSO) who will have a role similar to that of Elexon who balance electricity supply and demand at the transmission level for National Grid: balancing energy demands at a distribution level across both power and gas networks and potentially also heat networks. However the development of smart networks is likely to be driven largely by those entities which can realise the most value from them – key parameters will include distribution network capacity and the demand profile for power, its availability and price.

Potential market relationships are shown in Section 3. The range of potential demand response technologies and services and the organisational structure in which they might operate is summarised in Sections 3 and 6.

Communications

Developing intelligent energy networks will require the application of communications technology to enable more dynamic 'real time' flows of information, and more interaction between energy providers, distributors, suppliers and consumers. The theory is that if network operators are able to gather, distribute and act on information about the behaviour of all participants (generators and consumers) it should be possible to improve fault responses, flatten energy demand profiles through demand side management and reduce carbon emissions by relying less on carbon intensive peaking power generation plant. This in turn should improve efficiencies, improve asset utilisation, and avoid or delay infrastructure investment and help to stabilise energy prices for consumers

Additional infrastructure will be required to bring data and control from smart meters to allow more intelligent management and operation of local distribution networks. This will be a critical element for London, and will need to be considered in discussion with UK Power Networks (UKPN) and considering national activity – in particular the Government's roll out of smart meters and establishment of a new national data hub: the DCC. With the level of investment planned nationally in the DCC communications network for smart metering, extending this capability to provide appropriate communications services beyond meter reading to support demand response, distributed micro-generation control, and other Distribution Network Operator (DNO) requirements will be beneficial.

The DCC will be a key bridging point between current electricity, gas and heat networks and the future.

As we move forward heat, electricity and gas networks will become more closely interlinked and managed, requiring a supporting common IT and communications infrastructure.

Despite the obvious uncertainty on precisely how regulations and the market will evolve the review of ICT has identified some key points relating to the future system architecture:

- The smart meter roll out means that all homes will have a Home Area Network, enabling wireless communication between a variety of demand management products and generation sources, using a common industry protocol such as ZigBee, KNX or an equivalent. Manufacturers and energy suppliers/distributors will develop applications and commercial propositions that take advantage of this.
- The external interface from the smart meter will be a communication module possibly employing Power Line Communications to transfer data back to a data concentrator at substation level. A range of possibilities exist for how data would be communicated to the DCC from this point but have included satellite in other countries.
- Command and control signals for district heating could be expected to operate over the same infrastructure implemented for power and gas as this will reduce cost and enable data to be used in an integrated way.
- Active network management at distribution level will require new control telemetry at substation level. This telemetry will allow networks to be managed closer to their design limits.

- The large volumes of data required to enable active network management at a distribution level are likely to favour self-managing local intelligent electronic devices.
- Distributed network management will improve the resilience of the network. Self-managed local areas will have less reliance on centralised control and also will be more resistant to security attacks.

The specific control functions relating to an intelligent energy system are discussed further in Section 8 and as far as they can be determined at this stage and are illustrated and summarised as part of the Systems Architecture and Functional Specification in Sections 3.

System Architecture and Functional Specification

Section 3 of the report provides in text and diagrammatic form a summary of the potential system architecture that might evolve for an intelligent integrated energy system in London. It sets out the key components, key organisations and potential control arrangements that would be required, and the implications of this for future energy system specifications. The overall system architecture for an intelligent energy network in London as envisaged in this report – incorporating the findings from the three focus areas above – is shown in Figure 3 below. The system architecture is discussed in more detail in Section 3.

One of the key aims of the work has also been to consider the 'functional specification' that could be applied to decentralised energy projects in London to pilot some of the principles as we move towards an intelligent energy system. This aims to help inform strategy and the development of intelligent energy systems in London and to engage key players in this area to view opportunities within a system-level context. Section 4 sets out some of the system integration issues and likely control functions that specifiers and product developers will need to consider.

Finding a way forward

It is intended that the outcomes of this project will help inform actors in London's energy market and energy masterplanners (for whom the key findings on the role of heat may be particularly relevant) as well as more generally informing the GLA's dialogue with key players in the intelligent energy field. It is also intended to inform future pilot projects by GLA and others.

It must be recognised that there are many different ways in which London's energy demand and supply systems might ultimately evolve in the future, which will be influenced by changes in regulatory structures, wider economic pressures and global market developments. This study has sought to capture just one plausible vision of how things could emerge based on current policy objectives and emerging service offerings in the intelligent energy area.

The work presented here cannot be considered exhaustive and was conducted over a relatively short time frame. This project has attempted to capture the wide extent of the opportunities for intelligent energy in London. The work has highlighted a wide range of organisations engaging in this area, many with long research programmes and significant funding. The learning from these programmes over the next few years will help to inform policy decision making and explore further some of the issues and barriers identified through this project.

This study has provided an overview of how an intelligent decentralised energy system might emerge in London and what its potential components would be. The rate at which this future system might evolve will be dependent on how quickly the required regulatory incentives and mechanisms are put in place.

As noted above a broad range of product development and research is already being carried out around all the potential components of the intelligent energy system set out in this report, including through Ofgem's Low Carbon Network Funding. However, larger pilots and demonstration projects are likely to be required that test a combination of the technologies over a full distribution area, as well as the market mechanisms and alternative customer contracts needed to incentivise and reward demand response. This will be necessary to provide DNOs or a future systems operator with the confidence that active network management and demand response offer a sufficiently effective and resilient alternative to investment in network reinforcement.

TSB have recently announced that they will be making £25million available for a future cities demonstration project, and the Energy Technologies Institute (ETI) are planning a £100million five year Smart Heat research programme. The European Union FP7 framework programme has also recently announced a major new round of funding around Smart Cities including energy[8] These are just some of the potential routes for further testing and demonstrating the intelligent energy systems envisaged in this report.

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[8] http://ec.europa.eu/research/participants/portal/page/cooperation?callIdentifier=FP7-SMARTCITIES-2013

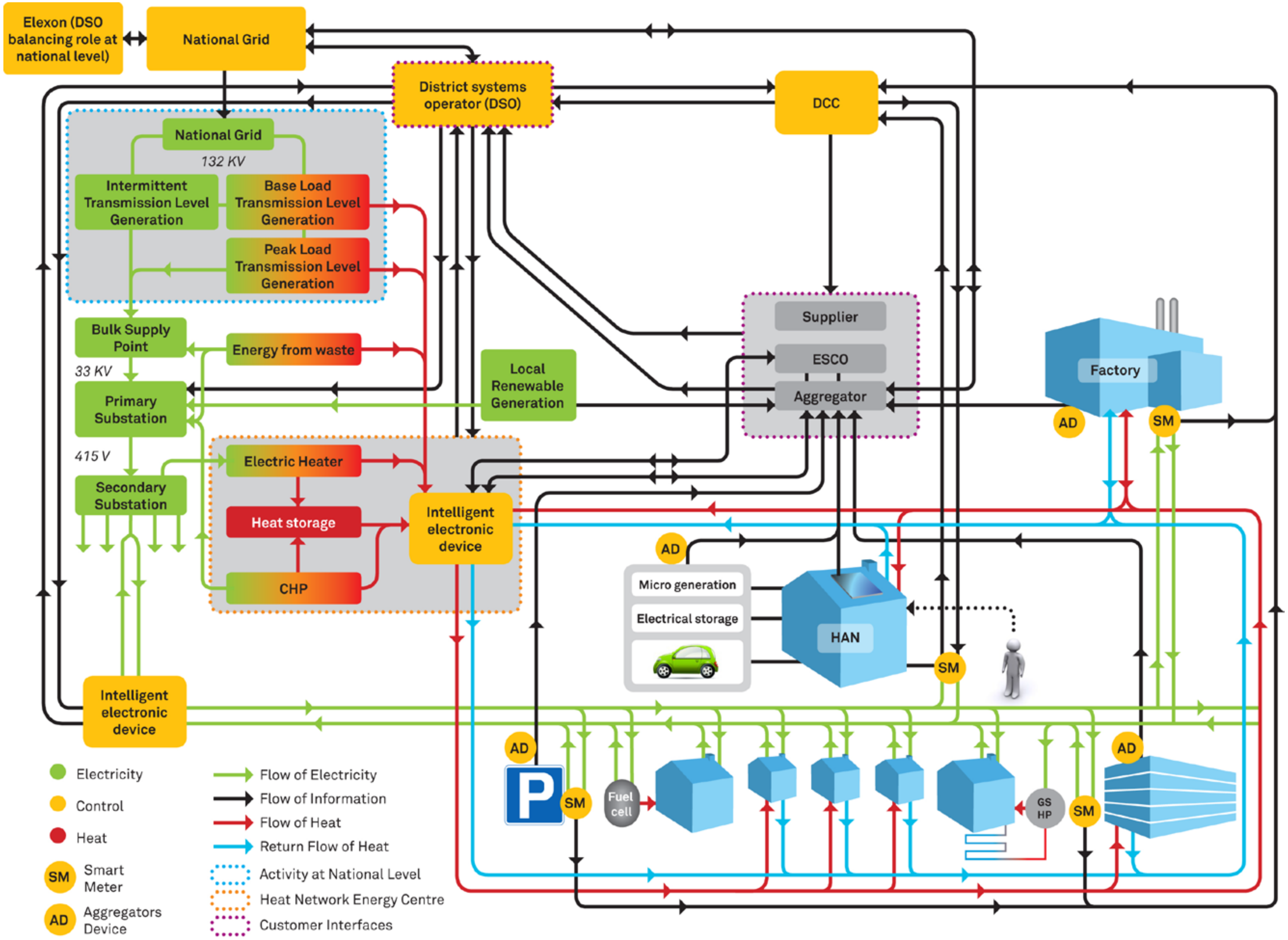

Figure 3: Intelligent Energy System Overview

Structure of the report

The report has the following structure:

Glossary of terms – refer to here for explanations of any non-technology specific terms

1. **Introduction –** explaining the context, aims and approach of the project;
2. **Summary of London's Current Energy Networks** – outlining the set-up and operational arrangements for London's current heat and electricity networks;
3. **High Level System Architecture** – setting out one view of how an intelligent and integrated energy system might emerge including high level overview of the technologies key control linkages and organisation responsible for system control and management. This focuses on the overall architecture; heat networks; building level and network control level.
4. **Functional Specification –** providing a summary of some of the key functional requirements and likely control inputs and outputs for some of the components that developers of future decentralised energy schemes in London may need to consider;
5. **The Contribution of Heat** – this section focuses on the different ways in which heat networks and CHP generation plant could contribute to an intelligent energy network;
6. **The Contribution of Demand Side Management –** this section considers the potential for demand side management.
7. **The Contribution of Distributed Generation –** considering the role of distributed generation technologies and management;
8. **The Communications infrastructure –** setting out the communications infrastructure which is likely to be required to enable active network management and incentivise demand responses.
9. **Summary and Next Steps –** considering the implications of the report's findings and potential next steps for the development of intelligent energy networks in London;
10. **Appendices –** including:
    1. **Bibliography / Further Reading –** including key studies informing this report
    2. **Glossary of technologies** – this is the technology review undertaken as part of this project. Technologies which may be part of an intelligent energy system are set out here. Refer to here for explanations of technology-specific terms
    3. **Technology Relevance Matrix –** assessing the relevance of the various technologies for London. This assessment has informed the choice of focus areas for the main report.

Glossary of Terms

Below is a glossary of some of the terms used in this report. For terms referring to individual technologies, please see the 'Glossary of Technologies' in Appendix B.

Aggregator or Demand Response Provider (DRP)	A company authorized to act as an intermediary between the independent system operator and end-use customers to deliver demand response capacity; also Curtailment Service Provider or Demand Aggregator.
Ancillary Services	Ancillary services support the reliable operation of the transmission system as it moves electricity from generating sources to retail customers. Such services may include load regulation, spinning reserve, non-spinning reserve, replacement reserve, and voltage support.
Backhaul	Backhaul is the process of getting data back from an end user to a node in a major network.
Base Load	Most commonly referred to as baseload demand, this is the minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements.
Capacity Payment	A payment received in exchange for making electrical capacity available.
Communication Protocols/Standards	Communication protocols have been developed for building-level smart technologies in order to allow different control devices to interoperate with each other. Examples include ZigBee (a wireless mesh network protocol) and KNX (which operates on a variety of transmission/communication media).
Connected Load	The sum of demand ratings for all of a facility's electric consuming equipment.
Curtailment	The process of decreasing electricity demand.
Data Collectors/ Concentrators	Interface between individual meters and the data warehouse.
DCC	Data Communications Company. The new entity that is being created by DECC and licensed to deliver central data and communications activities. DCC will be responsible for the procurement and contract management of data and communications services that will underpin the smart metering system.
Demand Side Response	The reduction of electricity demand at the end-use customer level in response to high wholesale electricity prices, system resource capacity needs, or system reliability events. This reduction can be achieved through curtailment (e.g., turning off lights, raising temperature setpoints) or self-generation (e.g., turning on backup generators). End-users may receive payments for participating in demand response programs. Demand Response programs address supply and demand issues and present a win/win/win opportunity for regulators, utilities, and end-users by increasing grid reliability while helping to keep energy prices low.
Demand Response Dispatch	A specific period of time when the demand response program administrator (ISO, utility) calls for load curtailment from its program participants.
Demand-Side Management (DSM)	The planning, implementation, and monitoring of strategies designed to reduce or shift electric consumption or improve energy efficiency at an end-user facility; usually refers to utility-administered programs.
Distribution	The delivery of energy to end-use customers from transmission facilities.
Distribution Automation	A class of technology that lets electricity utilities monitor and remotely control their power distribution networks with two-way computer networking and computerized data handling.
Distributed Energy (DE)	Synonymous with Distributed Generation.
Distributed Generation (DG)	Electricity generation that is located close to the loads being served.
Distribution Network Operators (DNOs)	The companies which operate and maintain the electricity distribution network in different regions of the UK.

Distribution Systems Operator (DSO)	The DSO is not an entity that exists at present but which might emerge in future as an organisation with a responsibility for managing, power, gas and heating energy supply networks in an integrated way.
Electricity Grid	A system of power providers (generation) and consumers connected by transmission and distribution lines and operated by one or more control centres.
Electricity system reliability	The degree to which the performance of the elements of the electrical system results in power being delivered to consumers within accepted standards and in the amount desired. Reliability encompasses two concepts, adequacy and security. Adequacy implies that there are sufficient generation and transmission resources installed and available to meet projected electricity demand plus reserves for contingencies. Security implies that the system will remain intact operationally (i.e., will have sufficient available operating capacity) even after outages or other equipment failure. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on consumer service.
Electricity congestion	A condition that occurs when insufficient transmission capacity is available to implement all of the desired transactions simultaneously.
End-user	The ultimate consumer; a business or individual that purchases electricity for its own consumption.
Energy Masterplanners	Energy Masterplanners are those preparing strategic or operational plans for how London's energy needs could be met in a more integrated way by looking at potential energy demands and potential decentralised energy supply sources at an area wide level or across multiple end users.
Home Area Network (HAN)	The HAN will be used for communication between smart meters, in home displays and other devices in consumers' premises.
KNX	KNX is a communications protocol for intelligent buildings that uses on open system interconnection standard created and administered by the KNX Association. KNX is the successor to, and convergence of, three previous standards: the European Home Systems Protocol (EHS), BatiBUS, and the European Installation Bus (EIB).
Latency	In a network, latency, a synonym for delay, is an expression of how much time it takes for data to get from one designated point to another.
Load	The amount of electric power delivered or required at any specific point or points on a system.
Network operators	The companies that are licensed by Ofgem to maintain and manage the electricity and gas networks in Great Britain. In future a role may emerge for a heat distribution network operator.
Off-peak	Period of relatively low system demand; periods are designated by utilities individually.
Outage	The period during which a generating unit, transmission line, or other facility is out of service.
ORC	Organic Rankine Cycle. Thermodynamic process for converting heat to power.
Peak	Period of relatively high system demand; periods are designated by utilities individually.
Peak demand or peak load	The maximum load during a specified period of time.
Peaking Capacity	Capacity of generating equipment normally reserved for operation during the periods of highest loads.
Peaking Plant	A power plant that normally operates only during peak load periods.
Price Response	The reduction of electrical consumption at the customer level in response to wholesale electricity price signals.
Prime Mover	A machine that transforms energy to or from thermal energy or pressure, to or from mechanical energy. Typically an engine or turbine.
Reserve Margin	The amount of unused available capability of an electric system as a percentage of total capability.

Specifier	For the purposes of this report a specifier is anyone procuring or selecting products or system components that relate to the use, supply or storage of energy, or that help control energy use.
Smart Asset Management	Utilises new data flows from the network to enhance asset management capabilities and performance and develop new asset management processes and principles.
SMETS	Smart Meter Equipment Technical Specification.
Spinning Reserve	The reserve generating capacity running at zero load and synchronized to the electrical system.
TSO	Transmission Service Operator.
Transmission	The flow of electricity over interconnected electric lines from a generation facility to local distribution lines.
Transmission and distribution loss	Electric energy lost due to the transmission and distribution of electricity.
Thermal limit	The maximum amount of power a transmission line can carry without suffering heat-related deterioration of line equipment, particularly conductors.
Time-of-use (TOU) pricing	A tariff under which the price per kilowatt-hour depends on the time of day, e.g. varying in response to levels of demand and generation availability at different times.

1 Introduction

1.1 Project Overview

AECOM supported by Poyry and Wipro were appointed by the Greater London Authority (GLA) to deliver the project 'Smart City - Intelligent energy integration for London's decentralised energy projects'. This project focuses on how London's energy networks can be 'Smart enabled' and how London's existing and proposed district heating networks (and associated energy generation and storage capacity) can be better controlled to help manage, and balance, energy supply and demand across local energy networks in the capital.

'Smart' is a current buzz word for City leaders worldwide. The term is used generically to describe opportunities for Information Communications Technology (ICT) to drive efficiencies across the economy. In reality these efficiencies can be wide ranging, inter-related and often complex. They can cover everything from improved communications and data access to transport planning, governance or resource and energy efficiency.

1.2 Project context

London's population is projected to grow by 12% over the next 20 years. This growth, together with an expected rise in the use of electric vehicles and heat pump technologies is likely to combine to increase energy demands, and will place considerable pressure on London's aging electricity infrastructure.

Climate change is already happening and London aims to lead the world in its response to this. It has set itself a target to reduce its CO_2 emissions by 60% by 2025, and sees decentralised energy generation as a key part of hitting this target, whilst at the same time providing security of supply, through diversity of energy generation.

The Mayor has set out through the Climate Change Mitigation and Energy Strategy that 25% of London's energy should be generated from local energy sources by 2025, and programmes are already in place to support boroughs and developers in delivering these low carbon local networks. The vision is that these networks which start out small, will grow and join up, to take heat from a variety of sources in the future.

The obvious next step then is to consider how these heat networks can be controlled – responding to energy demand, carbon and price signals - to increase efficiency. This could include, for example, ensuring heat is taken from the lowest carbon source at any given time or by allowing surplus electricity to charge embedded energy storage, potentially helping avoid the need to close down or "curtail" renewable generators or switch on more carbon intensive power generation plant. It is hoped that by providing strong leadership in this area London can generate inward investment, foster innovation and can create employment opportunities.

The aim of an intelligent energy system would be to deliver secure, affordable, low carbon energy while making the best use of existing infrastructure and assets and reducing the required investment in new infrastructure.

1.3 Project aims and approach

The project was carried out from January 2012 to July 2012. Its main aims were to:

- **Provide an overview of the 'Smart' technology and market landscape in the UK** – reviewing current and emerging technologies and pilots, including heat, power and communications networks, energy transport, storage, generation, monitoring and control and building-level smart appliances. This work is summarised in the 'Glossary of Technologies' and 'Technology Relevance Matrix' in the appendices.
- **Identify key delivery agents**;
- **Identify key intelligent energy opportunities for London.**

The above aims were addressed in the first stage of the project, a market review, carried out in January and February 2012. The findings from the market review helped inform the focus and objectives for a second stage of work carried out from March to June 2012, the findings of which are the main focus of this report:

- **Investigate key intelligent energy opportunities for London.** This has involved research in three focus areas, to consider the potential contributions to an intelligent energy system from:
    1. The potential role of heat networks and their associated thermal storage and combined heat and power plant in balancing energy demands and supply at a local distribution level;
    2. Demand side management (DSM) – at building or aggregate level to balance local energy supply and demand;
    3. Distributed generation and electric vehicles – for 'last mile' grid balancing
- **Consider the communications infrastructure that will be required** to deliver the Smart City vision.
- **Develop basic systems architecture diagrams** to help communicate the important linkages and key elements of an intelligent energy system for London.

- **Develop a 'functional specification'** which describes the 'integration issues' for the technologies we envisage on a future energy network.

What a 'functional specification' constitutes has been the subject of much debate within our team, and with the GLA. The approach taken has been to develop plausible system architecture and to highlight the key considerations for specifiers that can be identified now. Detail beyond what is included in Section 4 is considered to be inappropriate at this stage given the uncertainty on how the market and regulation will develop and the scope and timeframe of this study.

For each of the three areas of focus the approach was the same and consisted of:

- A literature review to help understand the key issues in each area.
- Stakeholder consultation to further understand the key issues and challenges.
- Basic modelling or research to estimate the relative contribution that different components within the intelligent energy network could make (e.g. potential contributions from DSM, thermal storage and distributed generation).
- Development of system architecture diagrams that aim to illustrate the template components, their key control linkages and the organisations that might play a role in managing a future intelligent energy system.

In each of the focus areas the aim was to consider the following:

1. How much impact can these technologies have in altering energy profiles on a building or district level – and therefore how do these things rank in terms of their potential for balancing energy demands?
2. How can these technologies be intelligently controlled for maximum benefit?
3. What are the technology and deliverability challenges?
4. What are the market and regulatory challenges?
5. What if any evidence exists on assessment of potential carbon savings?
6. Can these technologies delay investment in power infrastructure elsewhere? Can they deliver a cost saving?
7. What are the key findings that are relevant to a 'functional specification'? What are the key technology integration issues?

More broadly, the project aims to engage policy makers, decentralised energy scheme developers, technology developers, energy suppliers, generators, DNOs and others to encourage collaboration around the delivery of intelligent energy systems and to raise awareness of the opportunities in London and the links between the different areas of activity which are at present sometimes quite fragmented.

The intention of this report has not been to provide definitive answers to the above questions but rather to set out ideas for further debate by those involved in decentralised and smart energy projects in London. The areas of opportunity and potential systems architecture identified for intelligent energy networks for London, are also just one view of how systems might evolve. In this rapidly developing area, it should be recognised that there is uncertainty around how intelligent energy systems will develop in practice, and particularly around the regulatory and market changes that will need to develop to enable an intelligent energy system.

As well as inviting debate through the production of this public report, the views of a range of stakeholders have already been sought during the project through a series of meetings, and several seminars attended by the project team. Organisations met with have included London's distribution network operator, UK Power Networks, research leaders in the field (UCL, Imperial College), renewable energy aggregators, demand side response aggregators, communication and energy management systems providers, smart technology providers, smart metering and consumer behaviour experts and smart grid modellers. The work of a wide range of organisations has also been drawn upon in writing this report – a summary of these sources is provided in the Bibliography at Appendix A.

The following sections of this report summarise the current state of play in London's electricity and heat networks, and then set out the findings of the approach outlined above: setting out a potential system architecture and functional specification, and then describing the research undertaken in the three key focus areas in more detail. The appendices provide a bibliography, glossary of technologies (the technology review), and a summary of the technologies relevant to London.

2 Summary of London's current networks

2.1 Introduction

In order to understand how an intelligent energy system might evolve in London, it is important to have a basic understanding of how heat and power are currently supplied in London. This section aims to provide a summary of the current energy system in London and some of the challenges it faces.

2.2 Heat

2.2.1 Key Players

The heat market is currently dominated by the supply of gas for use in heat only boilers. This is supported by a gas market similar to the electricity market with a gas distribution network delivering natural gas to individual properties.

District heating is being developed in some areas of high heat density in London and a future vision for London is that hot water or steam networks will offer an alternative to gas for the distribution of heat from a variety of heat sources and will bring potential new major players into the heat market.

These players will include fuel suppliers to CHP plant, including gas suppliers but will also include ESCOs operating the energy conversion plant and district heating networks, and may include large power generation plant and energy from waste plant operators who supply heat into district heating networks from their generating stations.

Aggregators of heat and power and consumer billing companies may also have a role to play as this new market emerges

At present there is limited regulation of district heating networks in the UK, but in future as wider area networks develop there may need to be greater regulation of the industry.

2.2.2 The Physical System

Currently the majority of heat supplies in London are single site solutions with heat supply from a heat only device that supplies heat to a single building. Some existing sites have large enough heat loads to support CHP, and other sites have existing small scale heat networks, such as Pimlico, which has operated since 1950, or new developments such as Royal Arsenal, Woolwich.

The technology review (see Appendix B) outlines a wide variety of heat supply devices already being used in London. This project considers those that are linked to the electrical grid, incorporating both electric heating and Combined Heat and Power (CHP). CHP units range in size to meet demand, and can include large CHP generation plant operating with a steam cycle down to micro CHP units that meet a single dwelling heat demand. Within London there are existing gas fired CHP engines, at micro scale of 50kW up to systems of around 5 MW. Larger units at the top end of this scale can produce power and heat in near equal proportions. The systems are designed to operate at maximum output for as much of the year as possible and are generally designed to utilise the heat generated.

Large scale CHP is popular for district heating in Europe but has smaller penetration within the UK - schemes such as Sheffield and Nottingham being the major examples. SELCHP expect to start sending heat into the community in Southwark and there are other opportunities across London for similar heat offtakes. These plants can usually operate in power only mode when there is no heat demand and can modulate to supply significant amounts of heat into a large network as it is required. The power output of the large CHP unit will drop as the heat offtake increases – the opposite of the engine based system.

Opportunities exist to link sites together to provide a multi site, multi user network. Examples of this sort of network would include the Kings Cross redevelopment and the Olympics Park network. Heat transmission between smaller networks is envisaged in the future for London. This will be facilitated by larger transmission size pipes. The pipes can be hydraulically connected, allowing water to flow between networks, operating at the same flow and return temperatures. This allows the greatest opportunity for sharing energy generation plant for supply of heat from site to site maximising the use of the most efficient heat generation plant.

Larger scale, area wide networks supplying heat across whole sections of a city already exist in Europe, such as Helsinki, Turin and Copenhagen. The opportunities for this type of network are being explored, but no networks of this scale are yet installed in London. It is expected that large scale area wide networks will grow from the smaller networks over time.

The drivers for new heat networks include the delivery of cost effective low carbon energy into new developments and the economies of scale of larger heat prime movers[9] compared to

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[9] A prime mover is a machine that transforms energy to or from thermal energy or pressure, to or from mechanical energy.

smaller individual scale units.

2.2.3 The Market

There is currently a limited market for district heating in London. Currently heat is predominantly generated from gas either via combined heat and power engines or from heat only boilers.

New buildings are required to meet increasingly challenging carbon reduction targets in building regulations (Part L) and London's additional energy related planning policy. In these buildings simple gas fired heat only boilers are unlikely to be sufficient to deliver carbon targets, unless coupled with renewable technologies. Often new developments in London utilise communal/district heating systems connected to combined heat and power (CHP).

Existing consumers are generally supplied with gas for heating, and have no obligation and weak incentives to move away from this heating solution.

While gas prices generally remain lower than those for heat from lower carbon options (due to increased maintenance costs typically associated with low carbon technologies and passed back to the consumer through service charges) the 2 tier market is likely to remain, with new properties gradually becoming more significant.

If the cost of heating older properties with gas becomes unattractive then we may start to see more retrofit of district heating to existing buildings utilising CHP or other technologies. It is possible that some of the costs of this could be met in future through the Green Deal initiative and perhaps using Energy Company Obligation (ECO) funding or revenue from allowable solutions.

2.2.4 Balancing Supply & Demand

Heat network control is heat led[10], with heat demand from hot water instantaneous, and space heating when rooms are required to be warm. Whether on a single site or an aggregated load the demand profiles are met by a heat generation system that delivers to this demand.

The output profile of the prime heat supply device, such as CHP or biomass boiler can be smoothed through the use of a thermal store. Typically this heats water at night to ensure there is sufficient hot water available during the morning peak.

Thermal stores allow the heat production and heat demand to be decoupled to an extent. The size of the thermal store determining the level of independence the supply plant has from the demand. The thermal store is a large hot water tank, which is filled with hot water when fully charged and cold water when uncharged. Currently heat storage where installed in London typically includes relatively small stores designed to maximise small scale CHP operating hours.

2.2.5 Heat Challenges

Altering the demand profile

There is limited potential to significantly alter heat demand profiles (i.e. time of demand) through demand side measures. Domestic hot water must always be available to use whenever a tap is turned on and space heating is largely driven by external temperatures and occupancy, although time of demand for space heating can be altered to some extent through building design and building control systems. Steady improvement in existing building stock insulation and a step change in heat demand from new buildings will lower the overall demand for heating, but this will not impact significantly on times of demand, either through the day or over the year.

For electric storage heating and homes operating on an Economy 7 style tariff, demand management has existed for some time, with lower tariffs at night being used to incentives the heating of hot water and charging of storage heaters at night. The aim of this was to create a demand for electricity at night and reduce peak demand for electricity at other times. The poor control of storage heating and the high carbon emissions currently associated with electricity generation mean that storage heaters are now rarely installed in new buildings that can be supplied by gas or district heating.

Integrating thermal storage

The key challenge for heat, just as for electricity, is decoupling heat supply and demand. (i.e. storage)

If the most simple and cost effective, unpressurised thermal

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[10] Heat led means the CHP unit in combination with other heat sources is sized to meet the heat demands on the system rather than the power demands and that operation of the plant is controlled in accordance with the need to meet the required heat demands on the system, rather than meeting a power demand.

store is to be used then there can only be one thermal store on the entire district heating network. This is due to the control challenges in charging and discharging heat from multiple stores into the network when they are hydraulically connected.

A single thermal store can be charged with excess heat from anywhere on the network, but only at the current operating temperature of the network. During summer this temperature is likely to be much lower than the winter, and the thermal store capacity will drop due to the lower temperature difference between flow and return temperatures. Alternatively the network could be operated at winter temperatures, but there would be a loss in heat efficiency from most heat sources, and increased heat losses from the network.

2.3 Electricity

2.3.1 Key Players

In respect of the electrical network in London, there are 5 main players:

1. Electricity Generators
2. The Transmission System Operator (TSO) - National Grid (NG)
3. The Distribution Network Operator (DNO) – UK Power Networks (UKPN)
4. Electricity Suppliers
5. Electricity Consumers - Customers

In addition to the above there are a small number of independent network operators who own and operate small scale private electricity networks in London, some of which link to embedded generation operators running small scale generation plants connected to the UKPN network, e.g. CHP plants, PV. Currently decentralised energy generation does not contribute significantly to meeting London's energy demand but is expected to in future.

Most of the UK's major generators are located outside of London. Power for London, as for the rest of the UK, is typically provided from a range of large-scale generation sources including fossil fuels, nuclear and renewables and is transported to the demand centres through the electricity transmission system. National Grid owns and is licensed by Ofgem to operate the high voltage electricity transmission network in England.

Distribution is the operation and maintenance of assets which allow electricity to be transferred from the Transmission Bulk Supply Points via the Distribution Network to domestic consumers and businesses. Transformers are used to reduce the voltage in steps, until it is delivered to domestic consumers at 230V. Large industrial sites may connect to the distribution system at higher voltages or connect direct to the transmission network.

Suppliers are the companies that supply and sell electricity to the customer (end user). The suppliers are the first point of contact when arranging an electricity supply to domestic, commercial and smaller industrial premises. Customers enter into a commercial contract with their chosen supplier to pay for the electricity they consume.

2.3.2 The Physical System

At the most basic level the UK's electricity system can be considered in three parts.

The transmission network operates at between 400 and 132 kilovolts in order to minimise losses. The TSO ensures the stability and reliability of the transmission network by balancing the demand against the available generation whilst maintaining statutory frequency and voltage levels. The transmission system in London and the South East consists of three circumferential transmission 'rings' around the Capital, interconnected by radial circuits.

These networks were originally developed to secure supply for the capital from the major oil and coal generation plant in the Thames Estuary and the Midlands as well as handling the transfers to and from the interconnector with France, located in Sellindge, Kent. Going forward the Electricity Networks Strategy Group[11] has outlined two key challenges for the electricity networks of London. These are aging cables within London and the need for reinforcement of infrastructure connecting London to the North - East to service the development of onshore and offshore wind, potential new Nuclear and clean coal and gas-fired generation developments and new interconnectors with Europe.

The number of major generation sources within London has reduced in recent years with much of the associated sub-transmission systems being assimilated into the distribution

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[11] Electricity Networks Strategy Group, Our Electricity Transmission Network: A Vision for 2020, 2009

network. This has resulted in a range of distribution voltages (e.g. 22kV, 33kV and 66kV). Steps are being taken to remove plant operating at these intermediate voltages but there remains significant 66kV distribution within the central areas and 33kV is still the predominant distribution voltage in the outer areas of London. In summary electricity is taken from National Grid's 400kV and 275kV networks at a number of 'Supergrid' sites and distributed to customers through a succession of networks operating at various voltages ranging from 132kV down to 400/230V. Most substations built from the early 1980's utilise direct transformation at 132kV/11kV and it is the intention to further rationalise this over time.

The London distribution network supplies 2.25 million customers with a peak time electricity demand of 5,417MW within an urban and densely populated area of only 665 square kilometres. Almost all of the network is underground.

2.3.3 The Market

During the early 1990s, the UK's electricity and natural gas industry changed from a Government controlled monopoly to a competitive market. During this process a commodity market for wholesale electricity transactions and natural gas delivery was established. Electricity and natural gas is now traded in large volumes with prices driven by traders' perceptions of the relationship between supply and demand, based on detailed analysis of economics, short and long term weather forecasts, international events such as natural disasters and politics. The British electricity market is now one of the most liberalised in the world, with a well-established regulatory framework. The existing market is divided into two parts:

The retail market operates between electricity suppliers and consumers. This includes domestic, commercial and industrial consumers. Some very large industrial plants may choose to participate in the wholesale market and contract directly with generators. The wholesale market operates primarily between electricity generators and suppliers requiring them to contract directly with each other.

Over 95 per cent of electricity generated is traded directly in the wholesale market. The remainder is traded indirectly to match supply and demand. Supply companies build up their contractual positions to satisfy daily and seasonal variations in demand through a variety of contracts with generating companies, some of which may have been signed a year or more in advance. A considerable amount of trading, however, is carried out in the last 48 hours before the actual time of supply, as companies refine their forecasts of the likely profile for electricity demand in the light of the latest weather conditions and other factors.

Much of the complex administrative procedures involved are contracted out to a private sector company, Elexon. The administrative costs are recovered from generators and suppliers through Balancing Services Use of System charges.

2.3.4 Balancing Supply & Demand

National Grid has the responsibility for balancing generation and supply across the UK electricity network on a continuous basis. They monitor and control all operations on the Transmission Network from a Central Control Centre located in Wokingham, Berkshire.

Supply can be increased either by increasing the output from existing generation stations or by bringing new (reserve) generation on line. Demands can be reduced either by regulating voltage or through cutting or reducing demands at source. Voltages can only be reduced by up to 6% although typically this is only used for short durations as consumers tend to negate the benefit quite quickly. (i.e. if the lights go dim, consumers switch on more lights). A number of large industrial plants often negotiate lower tariffs with energy suppliers in return for accepting that their electricity supply may be interrupted or curtailed to help balance the overall system. Gas storage capacity and imports and exports of electricity through interconnectors can also provide resilience against increasing demand or temporary losses in supply. Smart meters and associated control devices potentially offer a much greater opportunity for DNOs to balance supply and demand in the network. The Network Control interface between National Grid and the DNOs is located at the Grid Supply Points where clear lines of demarcation in respect of operation and safety are established. UKPN has 3 operational areas, London, Eastern and South Eastern which are all monitored and controlled from a single Control Room located in Ipswich, Suffolk. They also have a back-up facility to cover for any catastrophic failure at the Ipswich centre. Network loadings, status alarms and all switching operations on the electricity network are sanctioned and controlled from the Control Centres.

2.3.5 Power Challenges

Government led initiatives to reduce carbon emissions, drive energy efficiency and security and encourage uptake of renewable and decentralised energy are presenting significant challenges to the electricity industry. These challenges are driving many innovation projects to help develop a deeper understanding of the dynamics of the electricity network and to identify technological solutions which will allow the TSO and DNOs to continue to operate the electricity network in a safe and reliable manner.

Each of the licensed bodies serving London, i.e. National Grid and UK Power Networks and SSE, produce comprehensive 5 to 7 year planning statements, setting out their capital programmes which are designed to meet the changing demands on the electricity network and to identify the additional infrastructure required to cater for known and projected commercial development. The plans are regularly reviewed to take account of changing government policy, specific development applications and advances in technology.

A comprehensive view of the likely development of the national transmission system in the period to 2020 can be found in the ENSG report "Our Electricity Transmission Network: A Vision for 2020.[12]

In respect of the Distribution Network, UKPN have identified some emerging trends linked to both government initiatives and lifestyle changes which include:

1. Growth in air conditioning & cooling load increasing the level of electricity demand in the summer months.
2. An increase in larger and taller buildings producing high point loads often coupled to a requirement for duplication of supply to provide resilience in the event of network faults.
3. Lifestyle changes with increased evening activity and 7 day trading arrangements.
4. Increased levels of distributed generation and CHP plants leading to difficulty in managing fault levels on the distribution network.

Looking further ahead there will be greater demand for electricity with greater uptake of electric vehicles and greater use of electricity for heating as the grid decarbonises.

As London's temperature increases, in response to climate change, this will increase cooling demands for air-conditioning and place greater stress on the operational limits and carrying capacity of substation transformers.

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[12] http://www.nationalgrid.com/uk/Electricity/Operating+in+2020/

3 A high level 'system' architecture

3.1 Introduction

This section consider how an intelligent energy network system architecture might evolve between now and 2050 - including the key energy supply and demand management assets, the organisations owning and controlling those assets and the coordination and communication that will need to take place between them.

It is likely that there will be two distinct levels at which demand and supply will be managed. One is at the transmission level bulk supply [13] using grid balancing mechanisms that are already well established and described in Section 6.2.1. The other will be at the local distribution level with demands, distributed generation and storage being managed to reduce peak loads, prevent faults and avoid unnecessary investment in additional distribution capacity. The term local distribution level refers here to the distribution and supply networks that sit between the primary substation and people's homes and businesses. The extent to which the latter mechanism will emerge will depend on price signals and how the regulatory framework evolves to support this, but the literature reviewed to date and our conversations with those active in the smart energy area suggest this will happen to some degree.

Figure 6 and the accompanying text below provide an overview of the high level system architecture that might accompany these two broad levels of demand management and the potential components of the future energy system for London.

We have then taken components of this and described the likely system architecture in more detail, including some of the functional specification issues required to make this work and of relevance to future specifiers.

It should be recognised that this is only one view of how an intelligent energy system for London might emerge and the precise direction that is ultimately followed will be dependent on the future decisions made by policy makers, regulators and the market. The work that has underpinned our view of how systems will evolve is set out in sections 5to 8 of this report.

3.2 High Level System Architecture

One of the aims of this study has been to attempt to map out the system components and control mechanisms that will be needed to deliver an intelligent energy system in London so that a functional specification can be developed for their deployment whenever the opportunity arises. The specific components and required control interactions relevant to the home, energy centre and distribution network are summarised in the following diagrams and accompanying text.

3.2.1 Assets

Key assets will include the electrical distribution network, structured largely as it is today but with increased telemetry and fault protection available at the local substation level as well as at the primary substation. This telemetry will allow active control at a distribution level.

District heating networks will cover large parts of London in particular clusters of development or local centres with high heat densities or where sources of waste heat can be utilised. Some of these will be linked into larger transmission networks utilising process heat from a variety of sources. Some homes not connected to heat networks will have fuel cells and other micro-renewables offering a distributed generation source. PV will be common on homes and buildings and electric vehicles will be widely used. Storage will be available in the form of hot water as large heat stores in energy centres and potentially within dwellings.

Energy centres will include electrically-heated boilers linked to heat stores to provide a demand response to peaks in intermittent generation or troughs in demand. Battery storage will be available in the form of electric vehicles and possibly in association with PV systems. All homes and buildings will have a smart meter with a communications module capable of communicating wirelessly via a Home Area Network (HAN) to appliances installed in the home and externally to the Data Communications Company currently being established by DECC. (see below for an explanation of the DCC's role) .

National Grid and Elexon - Balancing the Demand and Supply at the Bulk Supply Point

National Grid and Elexon (or a future equivalent) will maintain their function of ensuring that sufficient electrical power is available at the bulk supply point to meet demand. This will be done through mechanisms such as frequency controls, the STOR programme and fast reserves with some changes to the rules and thresholds applying to these mechanisms to accommodate a broader range of demand response services. Demand Response provided by specialist aggregators, ESCOs and supply companies will play an increasing role.

DNOs - Maintaining Capacity within the Distribution Network

Distribution Network Operators (DNOs) or an equivalent organisation will continue their role of ensuring there is sufficient delivery capacity within the distribution network. They will also continue to report back faults, current status and anticipated demands to National Grid and Elexon.

However as levels of distributed generation and storage increase a demand management function is expected to develop at the distribution level, as the data management requirements of managing this centrally will be too great. There

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[13] Bulk supply is high voltage electricity typically transmitted at 132KV and delivered to bulk supply points where is transformed down to lower voltages for distribution.

is the potential for a regulatory framework to emerge that favours demand management and system balancing at the distribution level where this can offset investment in additional carrying capacity or generation. We have assumed this framework will emerge but the precise mechanisms for this and likely roles of regulated bodies are currently uncertain.

As identified in Section 6 there is a role for managing peaks in demand or supply through storage of power as heat. The proposed system architecture envisages a role emerging for a Distribution Systems Operator (DSO) that would be responsible for managing heat, gas and power distribution in an integrated way and which could take on the existing functions of the DNO in addition to a local distribution balancing role. The DSO would rely on an increased network of Intelligent Electronic Devices (IEDs) embedded in local heat and power networks, substations and energy centres to provide system status reporting and control.

The DSO would contract with ESCOs, aggregators and suppliers to provide demand responses aimed at shifting peak demands or local stresses on the distribution network. Suppliers will be incentivised to introduce tariff structures aimed at shifting demand peaks or potentially providing a dynamic demand response.

Demand Response Aggregators

Companies such as Enernoc are already offering contracted demand response to the Short Term Operating Reserve (STOR) programme and our system architecture envisages this will become more common place, with new demand response services emerging. Examples would include Ceramic Fuel Cell's long term goal to create virtual power stations made up of many fuel cells, and similar concepts emerging for electric vehicles. ESCOs could aggregate demand responses linked to hot water storage utilising CHP engines to curtail demand or electric boilers to increase demand. Demand aggregation could be offered by specialist aggregators or by ESCOs or potentially in future by energy suppliers using dynamic time of use tariff structures. In all these cases the aggregator would act as an interface between the customer and National Grid/Elexon or the DSO contracting the demand response. Third parties such as aggregators and ESCOs could bring new value, competition and innovation in Demand Response, but also, potentially, they bring some risk to others in the value chain, plus add a layer of complexity in terms of benefit-sharing and multi-party agreements.

Aggregation could also potentially be contracted directly between the DSO and customer. This might be a logical route for existing DNOs who also own ESCOs.

At present aggregators such as Enernoc employ their own control systems at the customer's premises to monitor status and initiate a demand response, and in commercial properties this often links into the customer's building management system. We have referred to these as the 'aggregator's device'. Companies like AVC who install PV systems have telemetry installed that will enable status to be reported across all their installations. Aggregators may choose to continue using their own control interface or could potentially monitor using data from the Data Communication Company. Unlike electricity supply companies it is understood that aggregators and ESCOs are likely to need to pay for data from DCC. Some aggregators may also require data on a more frequent time interval than will initially be available through the DCC.

Data Communications Company DCC

The DCC is currently being set up by DECC. Its responsibility will be to collect data from smart meters and make this available to DNOs, suppliers, and potentially aggregators. It is currently envisaged that smart meters will have the capability to communicate around 140 separate data items including tariff rates and updates, tamper alarms and diagnostics and meter reading. The required functionality of the smart meter is defined in SMETS, the Smart Meter Equipment Technical Specification, which is currently at draft stage. Whilst the DCC is currently envisaged to provide only certain information at certain resolutions, the specification could extend in the future.

Generators

Generators may receive signals to increase or decrease their generation at different times to match supply or help balance network constraints. The generators who are vertically integrated with supply businesses may be able to cope with selling fewer units (due to demand response) if the revenue can be made back in other ways (e.g. by improved efficiency by increasing market share, or developing new energy services). However, standalone generators whose only source of revenue is to sell units of electricity will have little interest in selling fewer units. National Grid use constraint payments at the national level to incentivise generators to switch off when they need to balance their system. Energy storage could also play an increasing role. Generators who are able to aggregate many small decentralised generation sources and to group these within local distribution network areas, may be able to obtain revenue for grid balancing demand responses if a mechanism develops that rewards balancing activities at the local distribution scale. At present the availability of Feed in Tariffs would favour continued generation and export.

Suppliers

Balancing and settlement arrangements are already available for industrial buildings, but these are not currently sufficiently incentivised in other sectors, where suppliers do not receive sufficient benefits for incentivising consumers to reduce demand. A number of suppliers are planning to trial new multi-rate TOU tariffs. Some are looking at Critical Peak Pricing (CPP)[14] tariffs which are a form of dynamic TOU tariffs; the peak periods and associated prices are not fixed in advance as in static TOU tariffs, rather they are communicated to customers a short time before they begin. Smart meters open the door for smarter settlement, where suppliers and consequently consumers could realise financial benefit as a direct result of their own actions to reduce or shift load. Suppliers may include "License Light"[15] suppliers such as London boroughs and their energy services companies.

Consumers

Apart from limited time of use tariffs there is currently little financial incentive for domestic and smaller business customers to change their electricity use profile because they do not receive relevant price signals within their tariff structures. In the future smart meters will facilitate the marketing and uptake of new tariffs. The mechanisms used for eliciting a demand side response from consumers may either be active – a command and control approach, potentially involving consumer input, or more passive – a tariff-based approach.

3.2.2 Commercial Relationships

Figure 4 and Figure 5 illustrate the potential commercial relationships between parties in an intelligent energy system. Parties' roles and relationships are considered in more detail in Section 6. Figure 6 provides a system-wide overview of a potential intelligent energy system for London.

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[14] Critical peak pricing (CPP) is the practice of setting much higher unit prices on a limited number of occasions when the energy supplier experiences excessive demand and signals this to the consumer.

[15] License Light refers to proposals by Ofgem to introduce new licensing arrangements that would make it easier for energy companies, including DE schemes, to supply electricity to homes. Proposals are discussed in the Ofgem document: Distributed Energy - Final Proposals and Statutory Notice for Electricity Supply Licence Modification. 6th February 2009

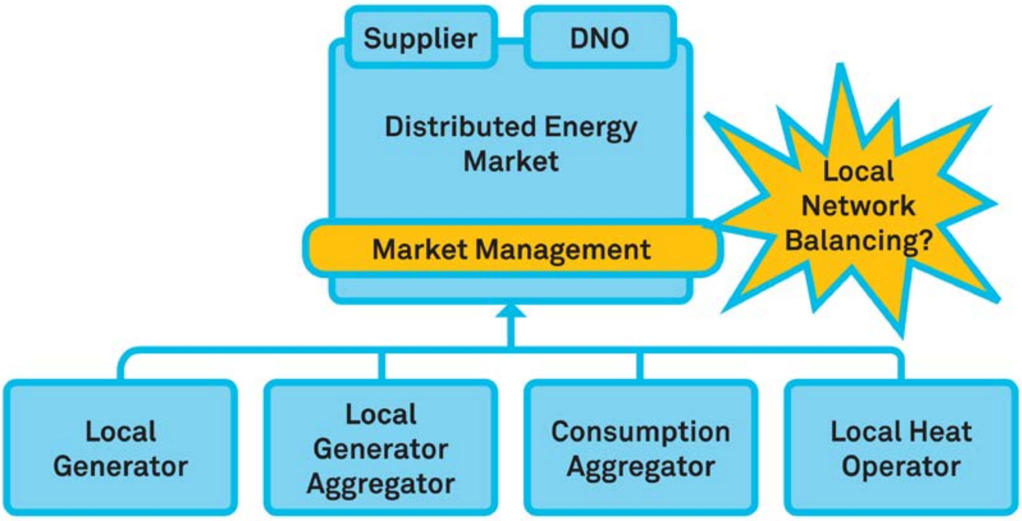

Figure 4: Potential commercial relationships

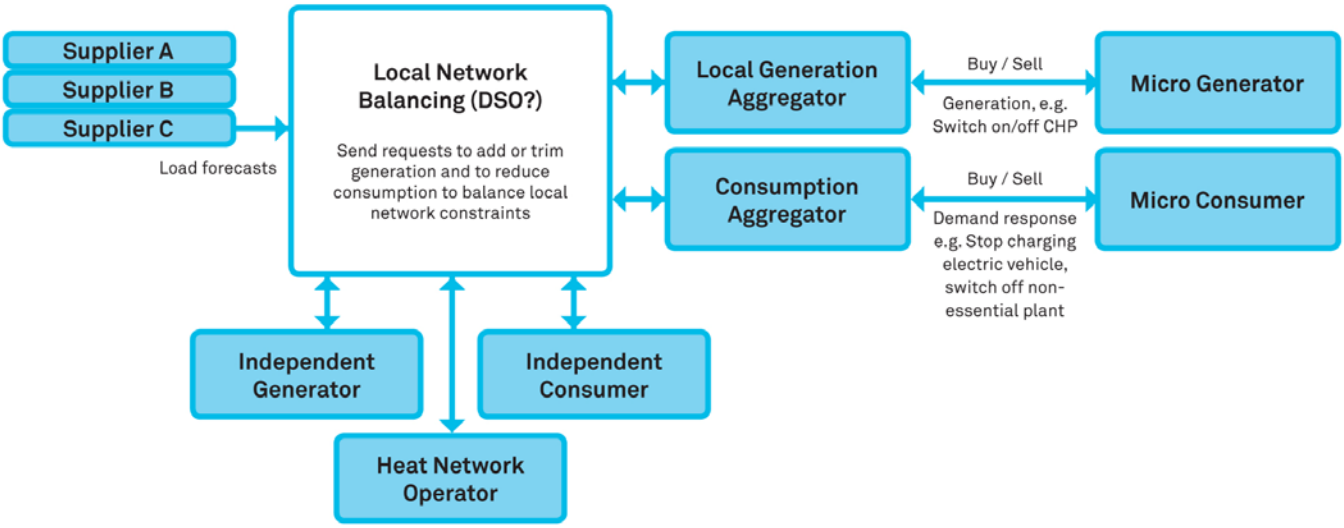

Figure 5: Potential commercial relationships showing detail

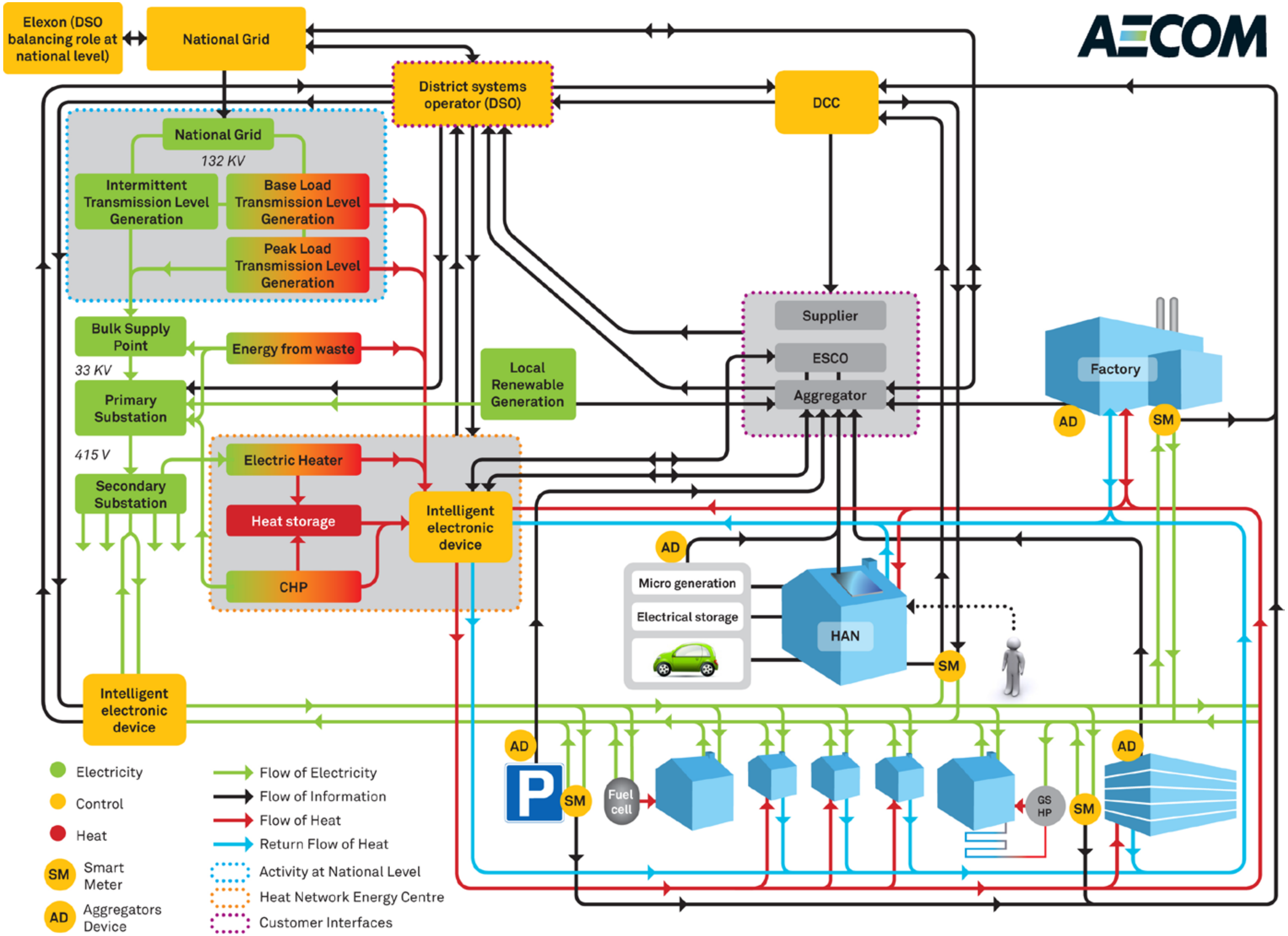

Figure 6: Intelligent Energy System for London Overview

3.3 Heat network Smart System Architecture and Functional Specification

Figure 7 sets out in diagrammatic terms the typical components of a current heat network and energy centre and how these might interface in control terms in the future.

3.3.1 Current Heat Network Components

At present heat networks in London are typically served from local energy centres comprising gas engine CHP units, gas boilers providing peak capacity and standby loads and thermal stores. Heat is circulated through a flow and return heat network to supply heat demands in homes and businesses, typically via a heating interface unit or heat exchanger at the premises. Some energy centres may also include biomass boilers or bio-fuel CHP engines.

Some networks may be served from sources of waste process heat from industrial processes or power generation and while relatively uncommon at present, in future this will play an increasing role in providing secure, low carbon and affordable heat.

3.3.2 Current Heat Network Control Situation

Currently the primary control of the heat network is to maintain a return temperature sufficient to meet consumer demands. As the temperature of the return water to the energy centre drops more heat is sent to the network, through a combination of increased temperature and flow rate. There is typically no link between the consumer's heating system controls and controls in the energy centre.

The dispatch of heat in the energy centre will depend on the equipment in the energy centre, but typically small loads will be met by a gas boiler, and as the loads increase up to the minimum threshold of the CHP engine the heat is supplied from the CHP unit. As heat loads exceed the maximum heat from the CHP engine then gas boilers pick up further heat load. Heat accumulators (thermal stores) are employed to minimise the heat supplied from gas boilers and to maximise the use of the CHP engine. The engine may be forced to shut down if fault levels on the DNO network require it.

Some existing energy centre control systems learn the heat profiles of a network, increasing heat supply just prior to a peak demand to ensure flow temperatures are maintained for consumers at all times.

In general plant is operated to maximise the revenue for the operator, though in some cases additional constraints may apply, for example running biomass boilers to meet annual renewable contributions agreed through planning.

3.3.3 Intelligent Heat Network Components

In the immediate future the system components at the energy centre will remain unchanged, however, as regulatory systems emerge that provide greater reward for demand management a number of potential changes could be introduced at the energy centre to capitalise on the available revenue streams. Larger thermal stores could be provided to enable CHP engines to offer a constrain on demand response when local network conditions favour additional local generation, or space could be allowed to accommodate these in future. Electric boilers could be incorporated in the energy centre to offer a demand response when there is a surplus of generation capacity locally or nationally. The potential for these is discussed in section 5.

3.3.4 Intelligent Heat Network Situation

A future control system will still operate the hot water network with a variable flow and temperature, with primary control on the return temperature in order to meet connected demand.

In a smart heat system the consumer demand may also be managed in a more sophisticated manner through integration with control signals at the consumer's premises, to manage peak demands or to take heat when there is an excess of heat generation. The energy centre operator could send and receive signals to and from an intelligent energy controller in the home or business consumer's premises either via the smart meter or through the operator's own smart device linking into a HAN or local area network.

The main change in energy centre operation in a smart system would be the dispatch of heat supply technology according to messages relating to the value of heat, power, demand response or grid constraints on the network. As set out in Section 50 there is scope for CHP engines to be constrained off or on, in response to demand aggregation or demand response signals issued by the DSO, ESCO or specialist demand aggregator. Constrain on is only likely to be possible in spring and autumn and for limited time periods in summer, with availability being linked to the size of storage available.

At times of peak generation for example during times of high wind and solar availability, CHP could be constrained off. This constrain off demand response could be further increased by converting surplus power in the network to heat using electric boilers located at the energy centre. For these demand responses to be practical the value of demand response would clearly need to exceed the value available from the export of electricity.

As a result the control inputs and outputs within the smart cities architecture would be more numerous and the control functions for dispatching energy supply more complex. These are shown below, with new inputs and outputs expected marked in blue.

Main Control Inputs Intelligent System

- District Heating Return Temperature
- Outside Temperature
- Thermal Store Level
- “Learnt” heat use profiles

- Intelligent building control demand information
- Grid constraints – "Constrain on"/"Constrain off"

Main Control Actions Intelligent System

Dispatching heat supply from:

- Prime mover supply (e.g. CHP plant)
- Electric heating
- Thermal Store (Heat in/Out)
- Heat Only Boiler (To meet all residual heat demand)

Main control of heat output

- Vary flow rate
- Vary flow temperature

Main control of power output

- Generation on to reduce demand
- Generation off to increase demand

Control Outputs:

Power

- Current generation
- Maximum generation available
- Current demand
- Maximum demand available
- Duration of maximum generation/demand available
- Response time

Heat

- Demand requests to building/smart HIU controls – Higher/Lower heat demand requests
- Thermal store heat demands.

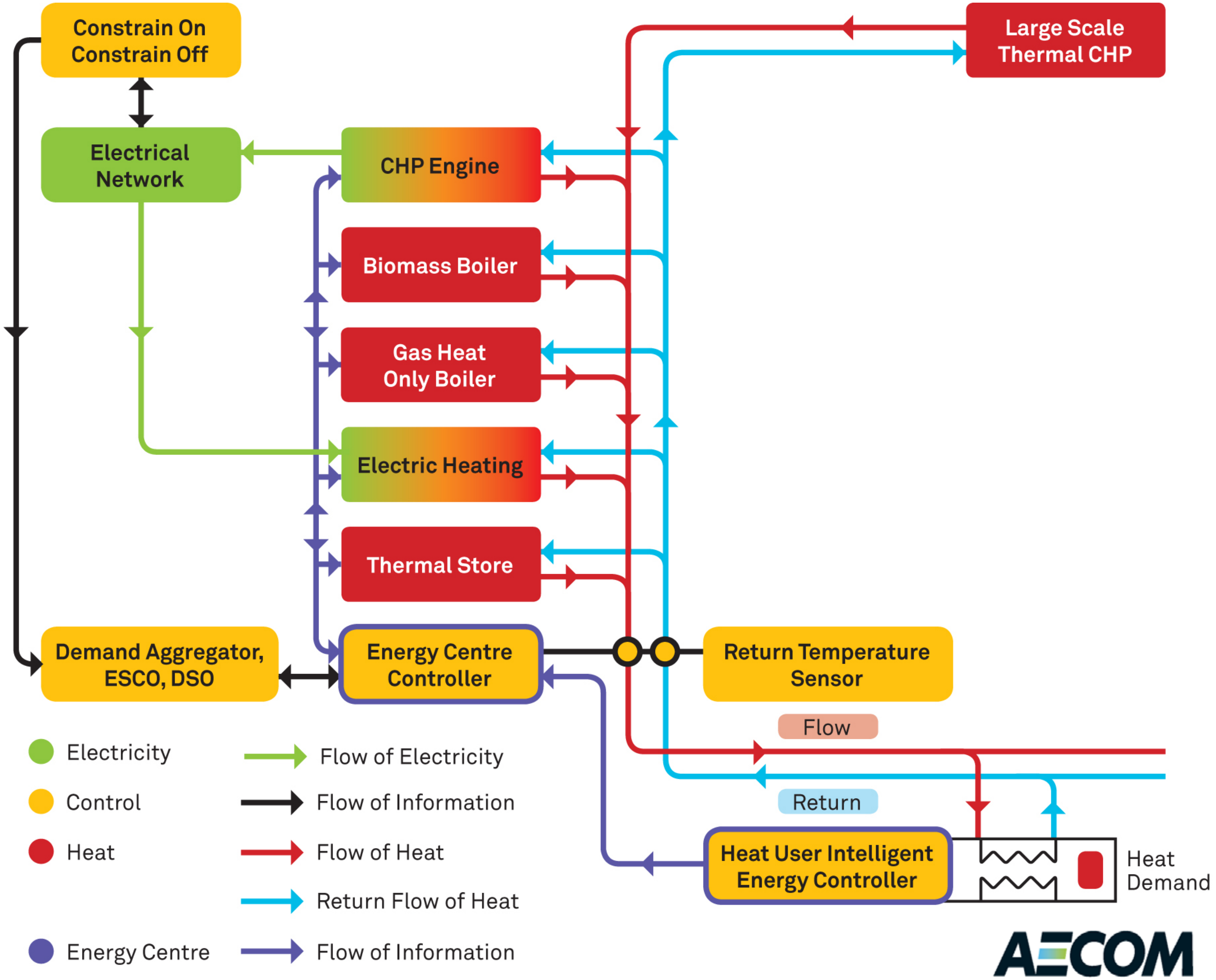

Figure 7: Future Heat Network and Energy Centre Architecture – with heat user intelligent energy controller

3.4 Building Level Control Architecture

There is a wide range of intelligent energy responses that can be enabled at the building level. Figure 8 provides an overview of the system architecture in the home, but similar architecture would apply for larger consumers such as offices and industrial buildings. For commercial buildings the home intelligent heat controller would be replaced by an intelligent building management system controlling air-conditioning and ventilation systems. For larger industrial premises and users with backup generation the backup generation would also provide an opportunity for demand response, and this is already an established practice, with demand aggregators such as EnerNoc specialising in this area.

3.4.1 The Smart Meter

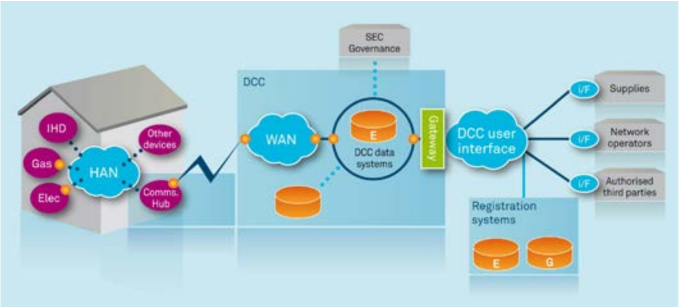

Figure 8: Home System Architecture Overview (Source: DECC, reproduced AECOM)

For homes as with commercial buildings the smart meter will be a key component of the system architecture, providing the interface between suppliers, ESCOs, DNOs, DSOs, aggregators and the systems within the building. The external interface of the smart meter is a communications hub that will send and receive signals from the Data Communications Company who will in turn relay those signals to suppliers, DNOs and authorised third parties which could include aggregators.

As set out in section 8.4 power line carrier (PLC) technology is likely to be used to transmit the data signals over the “last mile” low voltage electricity supply network from a modem in the home to a data concentrator at the local low voltage sub-station.. From here a range of options exist for sending collated data to and from the DCC, including the use of satellite. The process of transferring collated data between the local network and the central control centre is referred to as backhaul. Suppliers will be obliged to provide a smart meter for measuring gas and electricity consumption as part of the Government’s smart meter roll out programme. The minimum requirements for the smart meter are being defined in the SMETS which is currently at draft stage.

The key regulatory requirements for the smart meter roll out are to measure gas and electricity use and provide an In Home Display (IHD). The smart meter will utilise a Home Area Network (HAN) for doing this.

3.4.2 The Smart Meter Home Area Network (HAN)

The internal interface between the smart meter and consumer’s systems in the building is via a HAN or a Local Area Network (LAN) in the case of commercial customers. The HAN will utilise wireless technology to communicate between the smart meter and devices in the home. One of the communication systems meter suppliers are considering for the HAN is the ZigBee standard. ZigBee is a low-cost, low-power, wireless mesh network protocol developed by the ZigBee Alliance. The Alliance publishes application profiles that allow multiple equipment manufactures to create interoperable products that communicate with each other. Existing examples of technologies using this protocol include wireless thermostats and wireless light switches.

The minimum regulatory requirement for the Home Area Network is that an In Home Display Unit is provided that can display data on tariffs and energy use and cost transmitted from the gas meter and electricity meter, however, the HAN offers the potential for much wider communication with devices in the home. It also provides the opportunity to gather data from heat meters and to transmit this to the DCC alongside gas and electricity data to enable more integrated control of energy networks.

Some examples of the emerging demand response opportunities are illustrated on Figure 9 and control and specification issues are discussed below.

While the smart meter will provide a key route to communicating data to and from the home or consumer this will not be the only route. As noted previously some aggregators already have their own communications hubs installed in commercial premises and may continue to use these where more frequent reporting of system status is required than that available from the Smart Meter.

3.4.3 Intelligent Heat Control

Companies are already offering smarter heating control devices for use in the home. These can utilise temperature sensors in different zones, external temperature sensors, planned occupancy periods, required set point temperatures and learned heat profiles to optimise the point at which space heating and hot water systems are switched on and the flow of heat to different zones of the home. Passivsystems are one company offering products in this area. Users can use a simple interface on their home PC or mobile phone to set their standard heating and hot water demand profiles and to alter these when their needs change. A control hub in the home communicates wirelessly with temperature sensors and the heating system controls and to the home's broadband connection to enable remote monitoring.

This form of control can already be applied to better manage energy demands in any home. In future it could utilise additional information on tariffs or constrain on or constrain off commands sent via the smart meter HAN to offer further demand responses in relation to local energy network priorities. Product suppliers will develop their own control specifications for this in response to demand and from a developer or consumer specification viewpoint they would simply need to ensure the products specified are compatible with the wireless technology adopted for the smart meter and ensure equipment is located to avoid any disruption to the wireless signal.

Figure 9 illustrates a home linked to a district heating network but with hot water storage located locally and with an electric immersion heater forming part of the hot water storage. These would not necessarily be present together in all homes but have been illustrated to show different demand response possibilities.

Homes on economy 7 tariffs are already incentivised to heat their hot water at an appropriate time of night to help shift national demand profiles, and in future the smart meter could be used to control this demand response in relation to local distribution demand profiles. Homes with electric water heating could also potentially offer a demand response at times of excess generation from wind or solar. The home's intelligent heating controller could either control this on the basis of required hot water availability (set by the user) and time of use tariff rates, or in response to command signals issued by an aggregator. The aggregator would need to know the available storage potential, which could be communicated from the hot water thermostat via the HAN. Whether such an approach develops will be dependent on the costs of other demand responses relative to this one.

The district heating network operator could potentially utilise the presence of intelligent heating controllers in the home to optimise demand responses offered from the energy centre. If constraining on CHP systems to offer a demand response to the electricity network, heat could be stored both locally within the energy centre thermal store, but control signals could also be sent to charge the hot water cylinders of homes with local hot water storage rather than heat exchangers. The key data to enable this would include the volume and current temperature of the local storage in each home.

The home's intelligent heating controller could potentially receive data on the available time of use tariff rates for electricity and heat and optimise hot water heating source and storage build up to achieve lowest cost to the user, using a combination of electric immersion heating, heat from the district network, or from a gas boiler or heat pump where not connected to a heat network.

In specification terms there may be value in retaining hot water cylinders within dwellings with electric immersion heater back up, as well as in specifying heat meters with potential to communicate with the HAN using wireless heating system control, so that the central control interface can be easily upgraded as new functionality is added to enable demand balancing by the DSO at the distribution level.

3.4.4 PV and Micro Renewables Monitoring

The metered output from PV systems and micro renewables could be accessed through the HAN. If battery storage costs reduce sufficiently battery storage could also be provided alongside PV generation to help reduce the variability of output on the local distribution network and to shift the local demand profile by increasing the proportion of power that can be directly consumed in the home. They could also be controlled to charge in low demand periods and discharge at periods of peak demand although the current flat-rate tariff structure of the FIT acts as a disincentive for this. In terms of specification space might need to be allowed for this battery storage in the future.

At present PV systems are most likely to be constrained off in the case of network faults, or are otherwise regarded by DNOs as masked load as they currently make a very limited contribution to generation at a local level. With wider take up rates their contribution to local generation will become significant. The DSO or third party aggregators will benefit from having more accurate data on the current PV or micro renewable generation over a defined distribution area, both as part of developing learnt generation profiles but also to constrain off other generation at the distribution level if fault levels are being approached. If battery storage is implemented they would need to understand the current charge and available capacity of this storage.

The metered output and charge levels could be communicated from the system inverter via the HAN to the smart meter and then via the DCC to the DSO. As noted above some PV system installers already have the telemetry installed to aggregate PV generation data across a defined geographic area.

Where PV systems are installed they should in future have the functionality to communicate system status over a HAN. As usage increases network operators will need to consider reverse power flows and impact on fault protection within the low voltage network, which has not currently been designed for this.

3.4.5 Electric Vehicles and Battery Storage

Parts of London already exceed national limits for NOx and particulates and the widespread uptake of electric vehicles is likely to remain a key policy objective.

The likely use pattern of Electric Vehicles means they can potentially be charged over night between the evening and morning peaks in power demand. If not in use during the day they could be charged in the period between morning and evening peaks, potentially utilising power from PV or other micro generation in the home.

Stored energy in car batteries could also be released during peak demand periods to help manage loads at the local distribution level at times when this would not impact on required vehicle availability. Tariff structures could be developed to incentivise and enable vehicle charging at appropriate times of the day in the same way that Economy 7 tariffs have incentivised the use of night storage heaters. At a more sophisticated level, third party aggregators, or the future DSO, could aggregate demand responses from electric vehicles to commence charging or discharging to manage demand at the distribution level.

In terms of system architecture the home charging point would require a power management controller or “Smart Charger” that would communicate via the HAN and through the smart meter to the DSO, energy suppliers or third party aggregators. It could also communicate via the HAN with the power management controls of a PV system or other micro renewable installed in the home.

On the car battery side its control inputs would be battery charge level and required vehicle availability, which would be a control input required from the customer. This data would in turn be communicated to the DSO, suppliers or aggregators. On the HAN side the smart charger control input could be time of use tariff information for power supply and export, current generation from PV and current power consumption in the home. It might also have the ability to record learned data.

Based on these control parameters the smart charger would optimise the charging pattern to achieve lowest cost for the consumer while meeting the user’s availability requirements. Potentially an external user interface such as a mobile phone or remote PC could be used to change the required availability when the consumer’s plans change. Based on the reported charging status and availability requirements DSOs, suppliers or aggregators could potentially dispatch price signals or constrain on or off command signals to trigger demand responses based on an agreed tariff/aggregation arrangement with the customer.

From a functional specification perspective the key issue for new developments or retrofit in London, will be the physical space required for charging points and the power connection to those power points. Much of the new housing in London has shared under-croft parking and existing parking is often on street parking. For homes other than those with a garage or driveway allocating a charging point for individual cars would be problematic. The control function would therefore need to be able to identify the vehicle and its owner and to know whether the customer was part of the agreed aggregation scheme. This could potentially be addressed through wireless communication between the car and charging pedestal, with the vehicle communicating the necessary customer details and vehicle availability requirements.

3.4.6 Smart Appliances

Appliances where the use cycle can be shifted such as washing machines or driers and fridges/freezers offer the potential for providing a demand response. At the simplest level those on Economy 7 Tariffs can already programme washing machines, bread makers etc to come on at night to take advantage of lower cost tariffs. In future smart controllers could be programmed for when the wash cycle needs to be completed. The smart controller on the washing machine would use tariff information from the smart meter communicated via the HAN to determine the lowest cost time period in which to carry out the wash. Technology companies are currently developing control hubs to act as the interface between the smart meter and appliances equipped with the required control functions. In specification terms the developer or consumer would need to purchase appliances and the required control hub which will have been designed to communicate with tariff and command information from the smart meter.

Appliances such as fridges and freezers that are equipped with dynamic demand controllers are already being trialled. These sense the voltage levels on the network which fluctuate at times of increased network stress. When the fridge controller detects network stress it will delay its cooling cycle for as long as the issue persists or until further delaying the cycle would result in the fridge temperature dropping outside the required range. Such use patterns could also potentially be triggered remotely by DSOs as short term demand responses. Appliances using a ZigBee protocol could pick up constrain on or off signals from the DSO via the smart meter HAN.

3.4.7 Smart User Interface

The smart meter roll out requires that as a minimum an In Home Display is provided to report energy use and price. This will receive tariff information from suppliers and metered energy use from gas and power meters via the HAN. The functionality of the In Home Display could be extended to include data on water and heat consumption and cost, PV generation rates and the status of other systems in the home.

The data could also be reported through other user interfaces including TVs, PCs linked to the HAN or remotely to a tablet or mobile phone. Both PassivSystems and Savant who we talked with as part of the study already offer mobile phone and tablet applications that link to controllers in the home to enable remote monitoring of heating and other systems.

The most likely use of such remote access would be to change availability requirements where they depart from pre-programmed patterns. For example bringing the heating on early if you decide to work from home, or making sure the car is charged for an unexpected trip.

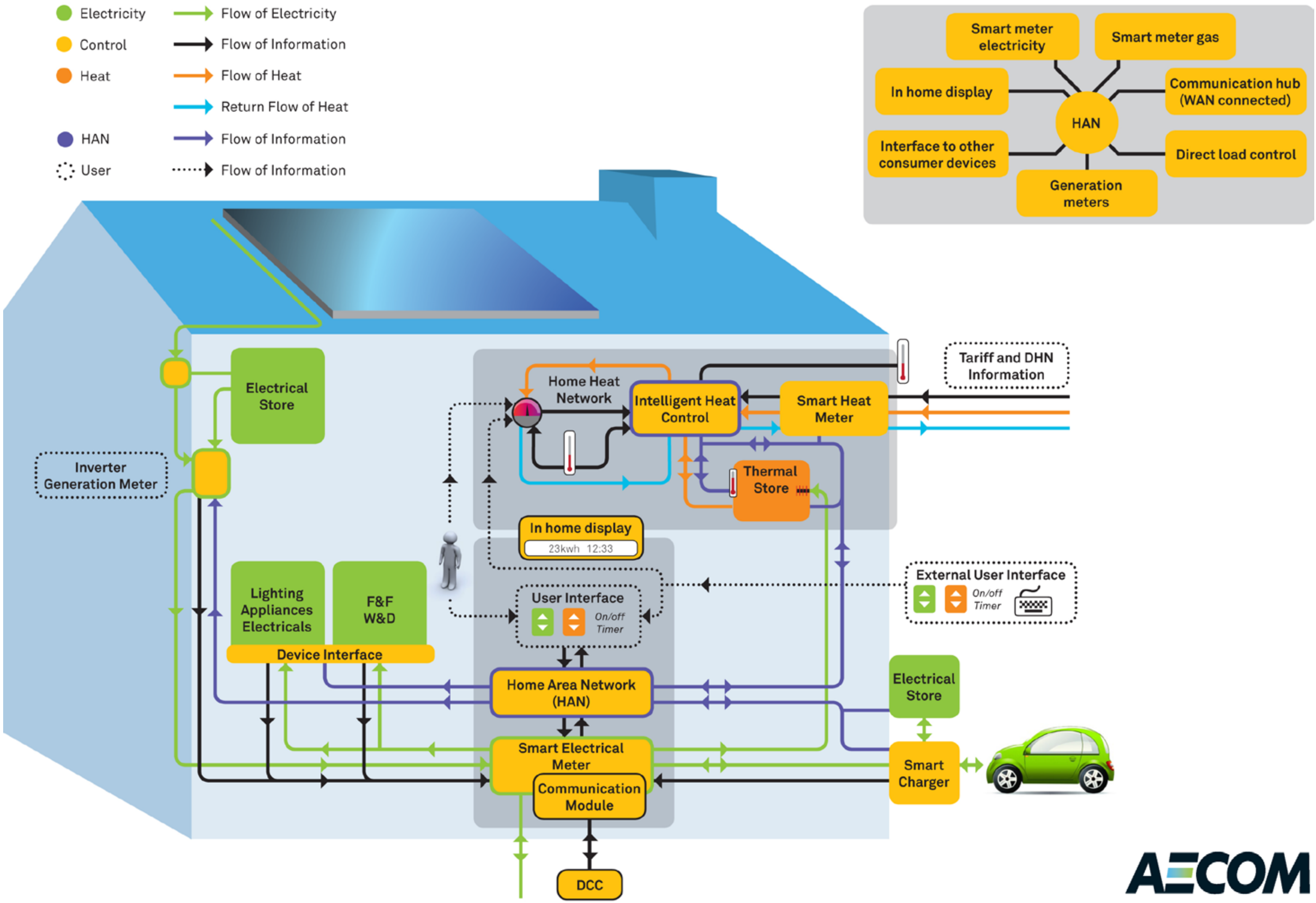

Figure 9: Building Level System Architecture

3.5 Network Control Architecture Considerations

Utility organisations currently have comprehensive network control facilities in place and utilise specific applications and systems to facilitate the provision of field information and provide the capability of remote switching.

Network control rooms will in the future be required to maximise the service they provide. With the headroom on network capacity decreasing, there will be an increasing need to deploy technology to further protect the network in times of constraint and maintain quality of supply. Some of these will also monitor and give an accurate picture of the health of assets in the field. These technologies will provide inputs to the network control centre to allow improved management of the network and its assets.

Figure 10 provides a summary of the system architecture applicable at the substation level. Sensors will monitor key system status output including transformer core temperatures and the current being drawn on different circuits and will feed this back to an intelligent electronic device which will manage control functions locally and also report system status to the DSO's control room or receive command controls from the DSO.

Network technology availability is improving and will continue as developments continue, with many vendors considering the needs of a future integrated network capability. Network control devices will assist in fault management, asset management and active network management. These devices will require to be integrated with the network operator, and also intelligent electronic devices.

With the deployment of more monitoring and control onto the networks a balance between automation and manual intervention will need to be considered. Increasing the volume of monitoring on the network will also increase the volume of data which will be available to the network operators. Being able to manage the increasing volume of data and make informed and accurate decisions will become increasingly challenging. It will therefore be necessary to deploy a level of intelligence into the future networks so that automation of control can be available.

As centralised computational requirements become more complex the use of distributed intelligence within network devices will become the norm. This will have the benefit of allowing some parts of the network to operate as an autonomous unit, given a set of operating parameters or limits. This type of deployment will also have the additional benefit of adding resilience to the network through self-managing algorithms which may avoid issues where the security of centralised control is compromised. That said having many critical field devices will provide a large number of potential targets for disruption and ways to protect and defend these assets will have to be devised.

Applications are available within the market to enable remote control of networks and deployment of intelligence on the networks, and these are already in use within all DNOs. However, these will not be capable of providing the necessary complex level of control and automation in the future integrated energy network.

In summary, the future network control facility will have access to complex applications and systems which will have the capability of monitoring the operating conditions of the network, review current status and intervene via remote switching as the need arises. However, this facility will become more of a passive facility as increased automation is introduced onto the networks and sophisticated algorithms control or 'self-heal' the networks when abnormal conditions arise. The main actions and inputs to facilitate network control are summarised below.

Main Control Actions

Dispatching power from:

- Bulk Supply points
- Distributed Renewable Generation
- Energy Stores
- PVs
- CHPs

Main control of power output:

- Voltage
- Frequency
- Circuit Capacity Constraints
- Demand Side Management
- Despatchable Generation

Control Inputs:

- Maximum generation available
- Voltage thresholds
- Demand
- Demand Side Management
- Network constraints
- Time and Duration of maximum generation/demand available

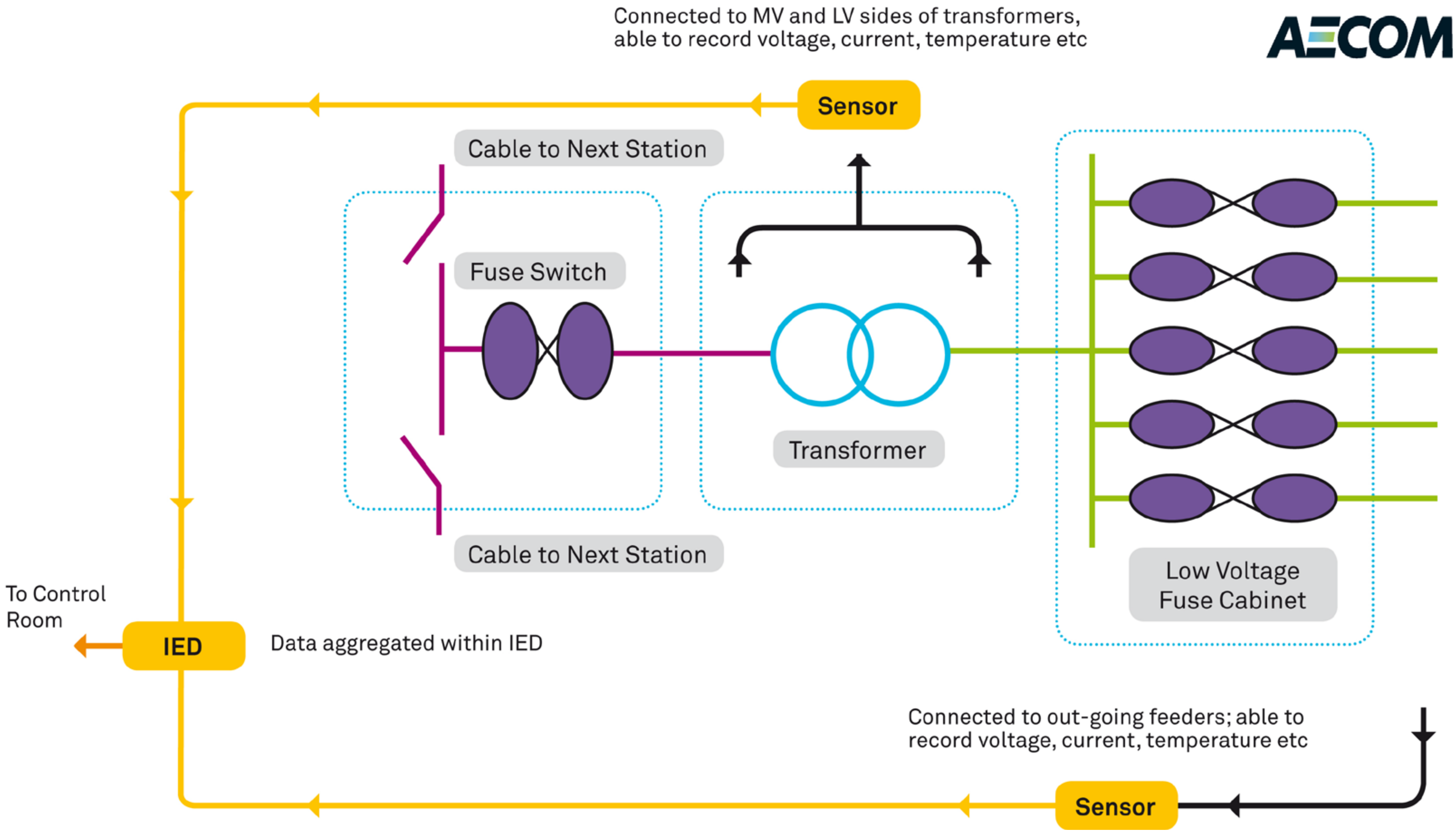

Figure 10: Substation Control Architecture

3.6 Summary

It has not been possible within the scope of this study to assess whether sufficient value could be created for the end user, DSOs, energy suppliers, or aggregators to justify all the potential demand responses set out above but the potential exists for all of them.

At present the use of system charge for the distribution of electricity forms a relatively small element of the price of electricity and a new regulatory framework would need to emerge that promotes these kinds of responses. Similarly flat rate Feed in Tariffs and Renewable Obligation Certificates will potentially act as a barrier to some of the options discussed above where they involve components that would currently attract these incentives.

While some demand responses such as improved heating controls offer the possibility of a genuine reduction in energy usage, many are aimed at minimising future investment in infrastructure.

Section 4 sets out a summary of the functional specification issues for project developers and product suppliers that we have been able to discern from the research undertaken to date. This would need to be developed further as service offerings and industry standards develop.

The following sections summarise the background research that has been undertaken to inform the systems architecture proposed above.

4 Functional Specification Summary

One of the aims of the project was to identify the functional specification that the developers of decentralised energy projects in London might need to consider when bringing projects forward, if they are to contribute to and obtain benefit from, the development of an intelligent energy system in London The project also sought to identify some of the key control functions that smart products and appliances and network components would need to have.Having considered the system architecture for an intelligent energy system in section 3, it is apparent that the functional specification for many of the elements of the intelligent energy system will be in the hands of component manufacturers who will develop products that utilise common communications protocols based around the HAN and the functionality of the Smart Meter. This will in particular be true for the demand management systems associated with the home.

Similarly the detailed functionality of the wider communications required for DNO/DSOs to manage demand at the distribution level will inevitably be influenced by how the regulatory system evolves and will ultimately be delivered by technology companies and controls manufacturers developing the relevant tools and components in response to regulatory and market requirements.

In terms of specification of future decentralised energy projects in London the main consideration will include any physical space requirements and the availability of a power source and grid connection for some components such as car charging, PV battery storage, and electric boilers in energy centres.

The following table sets out a summary of some of the key functional requirements and likely control inputs and outputs for some of the components that developers of future decentralised energy schemes or product developers may need to consider. It is intended that this functional specification will help inform the development of pilot projects for testing integrated approaches to demand management and intelligent decentralised energy schemes in London,

The table is not exhaustive and greater detail will need to be developed around this as service offerings mature and as industry protocols and specifications are agreed through the Government's Smart Meter roll-out programme and wider regulatory reforms.

.

Technology Name, Description	Specification Issues	Future Potential Control Functions
Smart Template Specification Home		
Smart Meter	Smart Meter should be designed to meet DECC's Smart Meter Technical Equipment Specification (SMETS) which is currently in draft. Consider extending meter reading ability to heat for homes on heat networks. Consider appropriate location for in home display.	**Outgoing** Gas meter readings Power meter readings Utility usage and costs to In Home Display (IHD) Tamper alarms **Incoming** Tariff rate updates Fault signals
Intelligent	Specify products using Wireless technology compatible with the	**Control Inputs**

Heating Control	protocol adopted for the Smart Meter Home Area Network (potentially ZigBee or similar). Consider zoned temperature control and external temperature sensors in addition to conventional control parameters. Consider wireless controls compatible with HAN. Consider location of control equipment to enable uninterrupted wireless control. Install electric immersion heaters where local hot water storage is available. Retain local hot water storage where space and cost allow.	External Temperatures Internal Temperatures Hot water temperature and volume Occupancy and temperature set points Learned warm up profiles Tariff values and demand response commands from power, heat and gas utilities and aggregators **Control Outputs (Internal Systems)** Heat hot water from gas or heat Heat hot water from electricity Space heating on or off **Control Outputs External** Hot water temperature and volume Available hot water storage capacity
Micro-renewables	Provide metered output with remote reading capability via the HAN. As products emerge consider Intelligent power management controller linked to battery storage. Allow space for future battery storage, consider location of intelligent power management for wireless control.	**Control Inputs to Intelligent Power Management** Generation rate Power export tariff Power purchase tariff Fault level constrain off commands Demand response contract commands Battery storage availability (in home or in vehicle) Hot water storage levels Current heat price **Control Outputs Internal** Charge in home battery storage Charge vehicle battery Charge hot water cylinder **Current control Outputs External** PV/other renewable generation rate Power consumption in home Available battery storage capacity and duration

Electric Vehicles	Consider retrofitting of charging points to existing development. Consider implementation of charging points in new development. Consider intelligent battery power management in relation to emerging grid to vehicle technology advancement.	**Control Inputs to Intelligent Power Management** PV Generation rate (if linked directly to a home) Power export tariff Power purchase tariff Fault level constrain off commands Demand response contract commands Current battery charge levels User availability requirements Vehicle and user ID **Control Outputs to Vehicle** Charge vehicle battery storage Discharge vehicle battery **Control Outputs External** Available battery storage capacity and duration User availability requirements
Appliances	Consider specifying smart appliances as these emerge on the market along with more dynamic time of use tariffs. Communications systems will need to be compatible with Home Area Network.	**Control Inputs to Intelligent Power Management** User requirements Time of use tariffs Demand response contract commands Voltage frequency Information on cycle status (cooling, washing etc) **Control Outputs Internal** Electronic alerts Switch off / delay appliance Run appliance **Control Outputs External** Available demand side response capacity and duration User availability requirements

Home User Interfaces	In Home Display to be a statutory requirement of Smart Meter roll out. Consider options for: - Additional functionality beyond statutory requirement - remote access to In Home Display - intelligent user interface for updating control parameters.	**Control Inputs** Tariff Information Metered data for heat, electricity, gas Metered data for micro-renewables Potentially wider system status as functionality develops Potentially user requirements ie vehicle availability, when my washing is needed, heating set points etc **Display Outputs** Energy consumption and costs Potentially Wider system status
Commercial and Industrial Demand Aggregation		
Standby Generation and demand aggregation	Provide system switching to enable standby generation to be offered as a demand response without interruption to supply Explore demand response contracts with aggregators and consider aggregator's control requirements. Consider links from aggregators control hub to building management systems Identify non-essential loads offering demand response	**Control Outputs to Aggregator** Current building demands essential uses Current building demands non-essential use Availability of generation capacity **Control Input from Aggregator** Switch on standby generation Switch off standby generation
Smart Template District Heating Network		
Heat Storage for demand response	Consider space for additional hot water storage and maximising this, particularly at the energy centre. Provide space for and consider provision of electric boilers if demand response market develops. Consider opportunities for intelligent control at the heat customer premises. Consider demand response contracts as part of connection	(Note: below the additional control signals compared to those required for a current heat led scheme are included in blue) **Main Control Inputs Intelligent System** District Heating Return Temperature Outside Temperature Thermal Store Level "Learnt" heat use profiles Intelligent building control demand information Grid constraints – "Constrain on"/"Constrain off" **Main Control Actions Intelligent System**

	arrangements. Where they will not significantly compromise engine efficiency, consider multiple smaller engines rather than a single unit for a given heat demand to improve resilience of power supply offered.	***Dispatching heat supply from:*** Prime mover supply (e.g. CHP plant) Electric heating Thermal Store (Heat in/Out) Heat Only Boiler (To meet all residual heat demand) ***Main control of heat output*** Vary flow rate Vary flow temperature ***Main control of power output*** Generation on to reduce demand Generation off to increase demand **Control Outputs** ***Power*** Current generation Maximum generation available Current demand Maximum demand available Duration of maximum generation/demand available Response time ***Heat*** Demand requests to building/smart HIU controls – Higher/Lower heat demand requests Thermal store heat demands.

Smart Template Electricity Network Control		
	Consider greater use of distributed intelligence on low voltage supply network. Consider the implications of the increased volume of data on data management systems. Consider balance between automation and manual intervention. Develop fault protection in relation to reverse power flows Develop open standards based integration mechanism between networks and 3rd party applications. Consider integration between storage assets, network operator control room, and field deployed intelligent control devices.	**Main Control Actions** ***Dispatching power from:*** Bulk Supply points Distributed Renewable Generation Energy Stores PVs CHPs **Main control of power output** Voltage Frequency Circuit Capacity Constraints Demand Side Management Despatchable Generation **Control Inputs** Maximum generation available Voltage thresholds Demand Demand Side Management Network constraints Time and Duration of maximum generation/demand available

5 The contribution of heat in an intelligent energy network - a heat network architecture

5.1 Introduction

As noted in DECC's Heat Strategy, 2012[16], heat is the most significant energy demand nationally – more significant than electricity or transport. Of London's energy use in 2008, around 51% was supplied through non-transport fossil fuels (mainly gas for heating in buildings) - accounting for around 30% of London's CO_2 emissions.[17]

Given the proportion of primary energy consumption that heat represents and London's policies supporting the development of decentralised heat networks it is important to consider the role heat as well as power can play in an intelligent energy network for London. The opportunities for improving the overall efficiency of energy use by integrating a heat network through smart communication with the electricity network are highlighted in this document, together with the technical constraints in respect of heat generation and storage technologies.

This section aims to:

- Outline the opportunities for 'heat' as part of an integrated intelligent energy network to improve overall energy efficiency
- Consider the role of thermal storage in facilitating the uptake of heat generation technologies
- Consider the scale of benefit that heat technologies including thermal storage can deliver in terms of grid balancing and stability and avoided investment in infrastructure
- Provide a summary of findings and outline the important issues that should be carried forward into a 'Smart' functional specification for London.

5.2 Opportunities for heat networks to contribute to a Smart City

Within traditional district energy systems hot water is produced to meet consumer demands. Heat is generated and power consumption or production is incidental to the heat demand.

The opportunity for a smart city future to utilise heat network assets to deliver benefits to the power grid is explored in this section. Smart systems could be employed to move from heat demand led operation to power led or a hybrid combination of the two. The benefits of this switch could include:

- better use of assets
- power demand management
- power generation management.

The potential to realise these benefits is explored in this section and suggestions for ways in which these benefits may be realised are outlined.

Heat networks can contribute to a smart city solution where heat interacts with power. There are three ways heat and power are linked:

1. Generating heat from power
2. Generating power from heat
3. Operating Combined Heat and power plant

Opportunities around each of these interactions are described further on the next page.

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[16] The Future of Heating:- A strategic framework for low carbon heat in the UK. DECC. March 2012.

[17] GLA, London Climate Change Mitigation and Energy Strategy, 2012

Options for linking heat and power		
Heat from power	Heat Pumps	A heat pump uses power to raise low grade heat from ground or waste heat sources to useful levels. Governed by the "coefficient of performance" (the number of units of heat obtained per unit of power used) heat pumps have a role to play in future energy systems. Heat pumps require significant investment and a supply of low grade heat. As a result they are used as the prime source of heat generation. Smart systems might enable the more intelligent use of existing heat pumps where they are already installed through the use of building controls or thermal stores. Retrofit of a heat pump to an existing energy centre would be difficult given the spatial constraints of the low grade heat source, such as borehole water or industrial waste heat.
	Direct electric heating	Direct electric heating is relatively cheap and compact to install, thus while it offers no coefficient of performance gain (i.e. is much less efficient than heat pumps) it could be installed relatively easily, connected as an additional back-up boiler but operated intermittently as energy prices allow. The carbon implications of utilising direct electric heating would need further consideration, at present average grid emission factors would argue against the use of direct electric heating, but as the contribution of renewables to energy supply increases this may be an appropriate demand response particularly at times of high wind availability. A shift to an intelligent energy system may need to be accompanied by a shift to more complex approaches to account for carbon emissions in regulation. Current calculations of carbon factors in energy supply from electricity require a standard grid factor to be applied. It is likely that high carbon factor power would be turned off in over-supply conditions due to the inherent flexibility of these plant and the higher marginal cost of generation. This means that the standard grid factor methodology may penalise carbon calculations using electrical heating.
Power from heat		Generating power from heat is current technology in large thermal power stations. Lower grade heat and heat in smaller volumes does not currently allow economic generation of power. It is not expected to be economic to generate power from excess heat on a district energy network.
Combined heat and power		Combined heat and power allows heat to be generated concurrently with power, and there may be smart opportunities to operate CHP plant in such a way as to offer additional value from the generation There are two distinct classes of CHP to consider, small scale gas engines and large scale thermal plant based CHP and both offer different value.
	Large Scale Thermal CHP	Large scale thermal power plants include gas fired Combined Cycle Gas Turbines (CCGT), Energy from waste or biomass CHP plants. These plants all generate high temperature steam which is passed through a steam turbine generator to generate power. If some of that steam is used for heating as well as power then the overall efficiency of the plant is improved, however power output is reduced slightly. Typically for every 1 MW of power lost around 7 MW of heat is produced, though this varies from plant to plant. These thermal power plants tend to be large, and useful heat can be provided to a large scale heat network. The generation is typically connected at higher voltage and thus contributes to the top down generation model, rather than the distributed generation model. The operational drivers vary, but typically a CCGT such as Barking Power station, will already modulate throughout the day between 0 and 300MW power output according to the wholesale power price and power demand. This is unlikely to change under a smart city regime. An energy from waste (EfW) plant is operated to manage waste volumes and will not alter the waste throughput to offer grid benefits, the output may not be smooth given fluctuations in waste.

Options for linking heat and power		
	Gas engine CHP	Gas engine based CHP is distributed generation ranging from micro-generation in buildings to larger units supporting DH networks with outputs of up to 10MWe. For these units heat is generated as a by-product of power or vice versa, and the more power generated, the more heat, at a ratio of around 1 to 1.5. Gas engine CHP is currently operated to meet the heat loads of a network, but CHP can be operated to generate local power as it is needed for the grid rather than the heat needed in the network, provided heat can be stored in a thermal store until it is needed.

Table 1: Various opportunities for linking heat and power

5.3 Standard DH design for small and medium sized heat networks

Typical heat network energy plant is designed based on economic requirements with a prime heat source that is low cost and low carbon such as a CHP engine or a biomass boiler. This unit is operated at full output for as many hours per year as possible. The peak heat demand is met through heat only boilers that supply fewer MWh per year.

To reduce the heat demand variation a thermal store is commonly used to store excess heat that the prime heat source can produce when demand is low and utilise this stored heat during peak times rather than a heat only boiler. Typically this is of most use during spring/autumn to deal with diurnal variation where there is a base load of zero but still significant peak demand use.

In operating a heat led DH network with a thermal store the emphasis is typically maximising the operating hours of the prime heat source at full load without wasting heat. This ensures more optimal running of the prime heat source and in the case of CHP helps reduce CO_2 emissions.

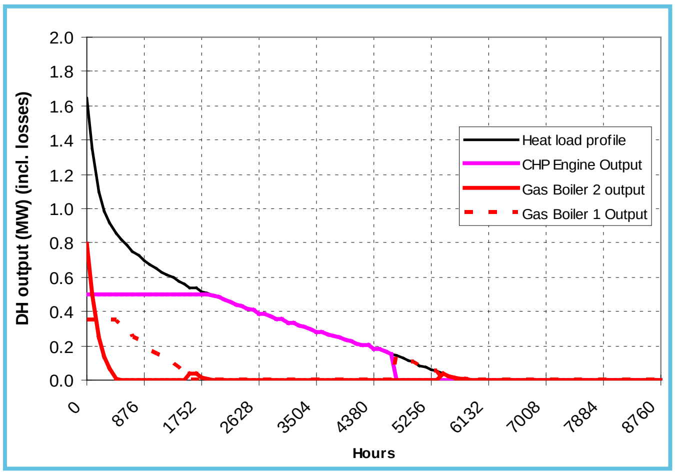


Figure 11: Heat source demand profile without thermal store

5.4 Thermal storage

If an energy centre unit supplying heat to consumers is to be operated in a “power led” mode as part of a smart city solution then it must be capable of decoupling the time of heat demand from operation of heat supply.

In order to achieve this heat storage is required.

Thermal storage is fundamental to enabling greater integration of heat and power in the ways identified in *Table 1* and flexibility in order to deliver potential smart city benefits. The amount of thermal storage available is a limiting factor.

5.4.1 Integrating thermal storage

If the most simple and cost effective, unpressurised thermal store is to be used then there can only be one thermal store on each heat network. This is due to the control challenges in charging and discharging heat from multiple stores into the network when they are hydraulically connected.

A single thermal store can be charged with excess heat from anywhere on the network, but only at the operating temperature of the network. During summer this temperature is likely to be much lower than in winter, and the thermal store heat capacity will drop due to the lower temperature difference between flow and return temperatures. Alternatively the network could be operated at winter temperatures, but there would be a loss in heat efficiency from most heat sources, and increased heat losses from the network.

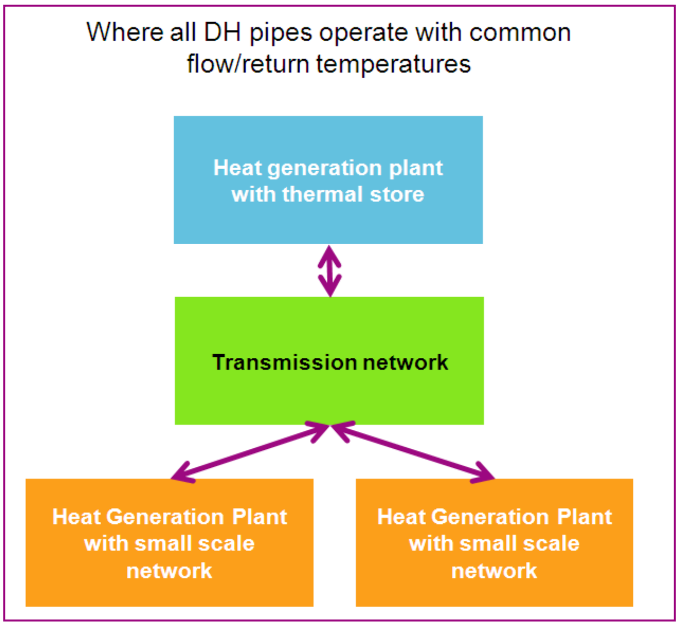


Figure 12: Single network, single operating temperature using a single thermal store.

A single thermal store at the Energy Centre is preferable as it can be simply controlled, is hydraulically simple to accommodate and allows high grade heat to be stored. A single thermal store is likely to be more cost effective than multiple storage points on a network.

Due to space constraints it may not be possible to install a single thermal store at the energy centre. If additional local thermal stores are used these need to be hydraulically isolated through a heat exchanger to avoid pressure control problems within the hot water network. This can either be achieved by isolating parts of the network with a thermal store or by hydraulically isolating the thermal store.

Heat can only flow from hot to cold, thus one of two options must be adopted - either the thermal stores must operate at a higher temperature than the district heating network or the network sections must cascade in temperature, as shown in Figure 13. If the network is cascaded, heat can only flow from the hottest sections to the coolest, restricting the ability of distributed heat generation plant to heat other network sections.

The resulting disadvantage of a thermal store being hydraulically isolated is that it would need to operate at higher temperatures, and this would likely mean it would need to be pressurised to prevent it boiling and the grade of heat used to charge it would be increased. This would increase the installation and running costs of the thermal store, and in some cases prevent it being used because such high grade heat is not available.

The final option for thermal storage is to provide a thermal store within each property. This would allow the thermal storage to buffer the heat demand; however the space requirement for the hot water tank sometimes deters the use in individual dwellings. This may be an opportunity if retrofitting district heating to properties previously served by older gas heating systems or electric heating systems which will typically incorporate space for hot water storage.

Individual dwelling thermal storage will support hot water use peak management, but not space heating peak heat use as space heating is still normally delivered through instantaneous heat exchangers.

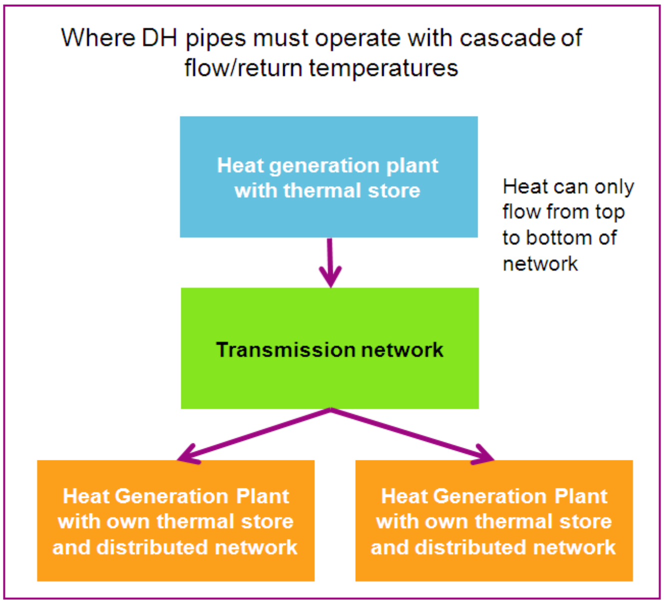


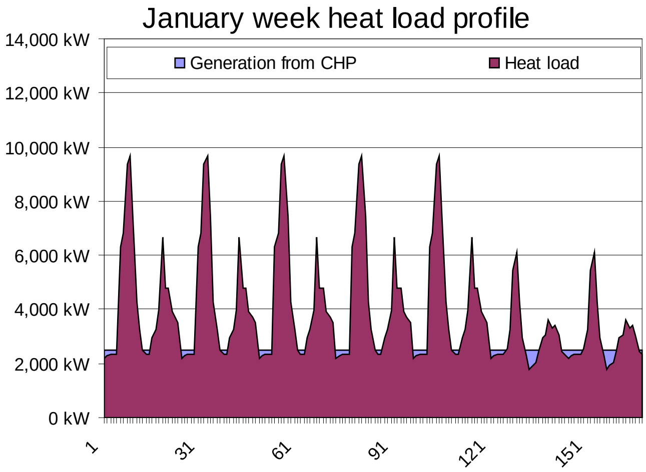
Figure 13: Multiple thermal stores with cascading flow and return temperatures

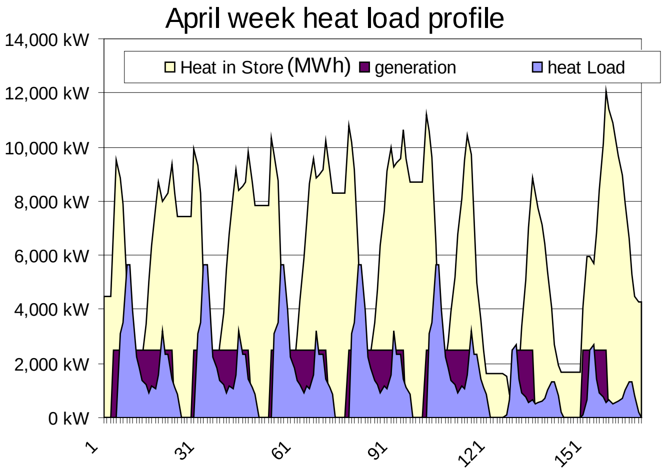
5.4.2 Thermal store sizing

If we consider a scheme that delivers heat to around 5000 homes with a peak demand of around 10MW and utilise typical figures we might select a suitable gas engine of around 2.5MW heat output, around 1.2 MW power output and a thermal store of around 10 MWh.

Such a store would have a volume of around 270m^3 and would be around 5.6m in diameter and 12 m high. This is a very large space to find, and many networks have smaller stores that utilise less space but have shorter running hours on the CHP engine.

Heat profiles shown on the following page illustrate the extreme case of the CHP engine utilising the thermal store to deliver the absolute maximum heat, with no heat being offered by the heat only boilers, except where the CHP generation cannot produce enough heat. In a real CHP energy centre the gas engine would not be operated like this, particularly in the summer, but these cases are presented to show the maximum power export that an energy centre could give throughout the year.

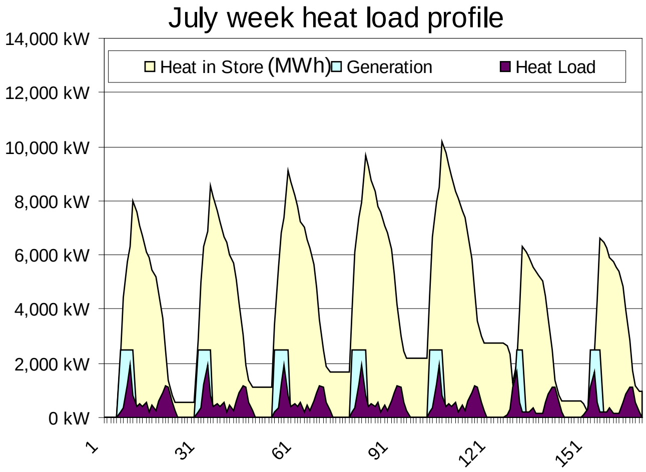




In January the CHP engine is operated at full load 100% of the time, with additional heat produced by the back-up boilers. The option to deliver additional power at this time is not available, though the electrical generation could be turned off and heat met through electric or gas boilers depending on market signals or grid constraints.

In spring and Autumn the heat load becomes insufficient to allow 100% operation of the CHP engine - generation is intermittent or the engine could be operated at partial load, however to do this the energy centre requires a significant thermal store or to load follow.

Depending on the time of day and the thermal store status additional generation could be offered or the generation could be turned off. In a smart city future the power production profile could be adjusted to meet grid or market needs if sufficient thermal storage was available.



In July the thermal load is so small that if the CHP engine is to be used it must utilise thermal storage and must operate only intermittently. The CHP generator could be turned on for short periods as required by grid or market, but could not be operated again until the heat load had reduced the heat in storage and this could take around 24 hours or more.

We can conclude that the opportunity for power led operation relies on thermal storage and a DE network can offer the greatest flexibility to a smart system during spring and autumn when assets are not fully utilised but there are still significant heat loads.

5.4.3 Smart network thermal storage

A thermal store could allow CHP plant to be operated in such a way as to supply more or less power to the power network and therefore provide a demand response. The thermal store size could be increased to enable heat sources to be operated in a way that provides a smart capability.

If a "Constrain on" signal was received from the grid operator or demand aggregator to deliver 1.2MW of power for 3 hours then an additional thermal storage capacity of 7.5 MWh would be required. This would require increasing the store volume to around 460m^3. A 16.4MW thermal store – approx 6.5m diameter and 14m high would provide this capacity.

In order to operate with a capacity of "Constrain on" generation available to the grid or distribution network, then spare thermal storage would need to be available to store all of that heat for use over the following day or days. The "constrain on" service would not be able to be offered again until the heat had been utilised, which could take a number of days. Engine cooling radiators could be installed to reject heat for emergency situations, but the carbon and cost consequences of heat rejection would need to ensure that this was a rare event.

As set out in section 6.2.1 the Short Term Operating reserve currently requires a minimum demand response of 3MW, available at least three times a week with a recovery period after provision of not more than 20 hours. This is a transmission level trading mechanism. There is no equivalent distribution level trading mechanism. In a future Smart regulatory framework these rules could potentially be shifted to accommodate the example above or demand aggregators could aggregate responses across a number of systems to meet the 3MW threshold.

The thermal storage required to offer grid support on a "constrain on" basis is outlined in the table below. This table anticipates that the capacity, particularly for gas engine CHP would be aggregated across a number of sites rather than offered at a single site. It is based on a 3 hour response (higher than the 2 hours required by STOR) as UKPN indicated that this was the timescale within which they need to repair loss of supply.

No of new homes heated	Homes	200,000	20,000	2,000	200
Large thermal plant power flexibility	MWe	15.4	1.5	0.2	0.0
Gas Engine power flexibility	MWe	66.7	6.7	0.7	0.1
MW heat generated	MWth	100	10	1	0.1
MWh heat to store	MWh	300	30	3	0.3
Store Dimensions	m^3	8108	811	81	8
Diameter	m	17.3	8.0	3.7	1.7
Height	m	34.6	16.0	7.4	3.5

Table 2: CHP flexibility required to meet requirements of 3hrs capacity on standby – indicating thermal storage required.

5.4.4 Role of Local Thermal Storage in Homes

As part of our analysis we looked at a sample area of London encompassing the Upper and Lower Lea Valley, The Royals and Beckton Waterfront. In this area, 37,517 of the 163,617 existing homes were fitted with hot water tanks with immersion heaters served by economy 7 electric tariffs. This represents a total water volume of around 7880m^3 assuming tank sizes of 210 litres. This storage volume is similar to the centralised thermal storage volume indicated in Table 2 for a district heating system serving 200,000 homes. In a smart system these electric immersion heaters could be switched to be controlled by a smart meter to offer heat storage of hot water to be used in the home. Provided the hot water tanks are well lagged this could effectively re-distribute energy demand for these households. To some extent this is already happening as owners of homes with economy 7 tariffs would typically charge their hot water tank at night, but as base load from electric vehicles becomes more significant or as intermittent renewables create less predictable demand profiles, then there may be a benefit in controlling the charge up of water storage in a more dynamic way.

For housing connected to district heating networks then heat interface units could utilise hot water tanks to supply hot water and the tanks would provide a hot water store which when aggregated across many properties could provide some heat load management. Calorifier consumer units do not offer the same benefits to the consumer of space saving and do not allow such low return temperatures compared to a plate heat exchanger. They also lack the ability to send heat back into the hot water network at times of high demand, negating some of the benefits of thermal storage.

5.4.5 Gas fired CHP engine implications

The options for using CHP as a demand response in winter are limited as the CHP heat offtake is likely to be less than the demand at almost all times. Therefore the CHP engine is likely to be operated flat out with no upturn in power output available, while turning down the power output will be costly as the lost heat will need to be found from heat only boilers.

In summer the heat demand is so low the engine is unlikely to be operated normally. The CHP engine could be run for a short period of operation to alleviate a power grid issue despite a very low heat demand but the thermal store would need to allow the heat to be stored and used over a longer period rather than wasted.

In spring and autumn a heat accumulator is likely to offer some flexibility on when the CHP engine can operate. The operation of the engine with a conventional design will be constrained at times due to too much heat in the thermal store and no further heat demand or due to already being run at capacity due to a high heat demand.

5.5 What can heat offer the market?

Heat networks fitted with CHP or electrically sourced heating can offer "constrain off" and "constrain on" electrical generation responses and in extreme circumstances could offer demand at times of excess generation on the grid.

Heat can support smart cities if specified in a way that offers the technical capability. However, in order to offer "constrain on" and "constrain off" power capability at all times then carbon and cost savings would be lost in the winter and the operating hours of the unit would likely be even lower or would require significant extra storage capacity.

The ability to provide a power sink at times of high supply would require investment in an electric heat source and would rely on thermal storage.

All of these issues would negatively affect the economics of an energy centre delivered under current economic conditions, however offering some smart capability some of the time may be offered with relatively little extra investment.

If energy centre plant is to be specified to be able to offer a constrain on and constrain off power capacity function at all times, then the value of that capacity must be very high and it must be bankable. In addition there must be a clear business case in investing in an electric heat source and this would be hard to justify until such grid surpluses occur on a regular basis.

There are benefits that a CHP energy centre can offer for relatively low additional capital investment. These would be interface to allow the controls system to operate from power demand. This would allow energy centres with gas CHP engines and thermal stores to offer in spring a dynamic "constrain on" and "constrain off" power response service at different times of day or week, in winter a "constrain off" power response service and in summer a limited "constrain on" power response service.

There are two potential market mechanisms that could support this. The first is a power generation/demand market response that could link into existing markets related to grid balancing.

5.5.1 Grid balancing market

So long as a heat demand is available then heat could be generated from CHP when power prices are high, but could be generated from power when electrical prices were low, or if in extreme cases of excess generation power prices were negative. In order to make most advantage of this market opportunity then thermal storage would allow heat to be generated at the most profitable times from any source, and heat used as it is required. The thermal storage and electrical heating capacity to do this would need to be justified on a market that is currently not giving the price signals in the UK to deliver this but may in the future. Aggregation of generation sources may allow power led operation of multiple heat schemes to trade in volumes relevant to the grid balancing market.

5.5.2 Grid stability market

Currently there is little value in supporting the power distribution network by offering distributed generation to support network overloading at critical points such as transformers. Discussions with UKPN envisage that there could be value in offering generation that could be called upon to deliver power at times when the distribution network is stressed.

This service could allow an energy centre operator to operate normally through winter, then to offer over the summer the ability to provide additional power to the grid for a period of time equivalent to charging completely the thermal store. If the thermal store was in use then the power available to the grid could change in real time and the capacity offered to the grid at any particular time could have a value.

If this value, at any point on the network, for any given power, could be calculated at the time when a connection agreement is offered then it would allow an investment decision to be made that could influence the energy centre design, particularly it may help to justify investment in more thermal storage.

A worst case is that in summer additional power generation is requested at a time of low energy demand.

The thermal storage required to offer 1 MW of generation for 3 hours is approximately 4.5MWh. This would need around 120m^3 of storage capacity.

5.5.3 Changing the Long Term Demand Profile

District Heating and cooling may be expected to be inherently helpful in managing the expected future increases in peak energy demands. This is because two energy demands expected to grow significantly in the near future are heat pumps and electric powered air conditioning. Greater deployment of district heating and cooling would mitigate the growth of these electrical peaks, regardless of any smart technology deployment.

5.5.4 What impact could CHP with thermal storage make to Power Grid Management?

The potential advantage of constrain on and off commands from the DSO is to alleviate HV hardware, in particular transformers, when they are operating at full load.

Information regarding the usefulness of distributed energy with thermal storage to manage energy flows in London's power grid was discussed with UKPN. Discussions with UKPN suggest that the reliability of a single engine to offer demand/generation response was not sufficient to meet the grid code requirements and could not offer value. Aggregated engine response or multiple smaller engines on a single site may be able to offer better reliability than a single larger unit. This approach has yet to be utilised. In addition the aggregated load would need to be located within the same local network to support the network asset.

While some limited substation constraint information was provided it was not site specific and no load profiles were provided by UKPN due to data sensitivity issues.

The range of transformer dimensions provided is from 9.6 MW to 340 MW, and the average is 75MW.

Data on current excess power capacity on 10 transformers suggests transformers that are stressed need additional capacity in the range 3 to 20 MW, generally in the summer. Comparison with Table 3 suggests that heat networks with smart capabilities must be aggregated to large heat loads to offer support in the order of magnitude that may support transformer constraints. In addition multiple generators would need to be available in order to give the redundancy required by a grid operator to utilise this capacity rather than invest in additional distribution capacity.

National demand profiles set out in section 6.2.3 suggest a national early morning lull in demand of around 38GW to an evening peak demand of 60GW for the UK. Assuming there are approximately 23million homes in the UK, the power demands for an average block of 10,000 homes and their associated commerce and industry would range from 16.5 to 26MW. A community of 10,000 new homes and supporting services is very roughly the scale of community that would support A 10MW district heating scheme which as we have shown might offer a demand response of around 1.2MW of power over 3 hour period. These figures are of course very crude and ignore a range of factors including reduced diversity of community against the national average but they give an approximate feel for the proportionate impact the demand response might have.

5.6 Conclusions from the heat review

The review of the potential role for heat identified a number of key points:

- Large scale thermal cycle plants such as Barking Power Station or energy from waste plants are unlikely to be operated to provide a dynamic demand response at the distribution level where smart systems are expected to operate as they are trading at transmission level. They are however an important part of an intelligent energy system if process heat can be linked into district heating networks. This is because the overall system efficiency will improve where process heat from power generation can be utilised for heating buildings or hot water.
- Gas engine CHP plant could be used to provide a demand response primarily in spring and autumn when assets are not fully utilised but when there are still significant heat loads. Only a limited response

could be provided in summer, because then the thermal load is so small that if the CHP engine is to be used it must utilise thermal storage but must operate only intermittently due to the limited demand. Extra electricity generation could not be provided in winter as the CHP engine is operated at full load 100% of the time to meet heat demands, although the electrical generation could be turned off as a demand response subject to market conditions.

- This demand response would require available heat storage and from a current DNO view point, in order to offer a reliable demand response multiple assets would need to be aggregated within a defined distribution boundary. This form of aggregation already occurs for standby generation plant.
- For hydraulic reasons there can only be one heat store serving each heat network, so heat storage is likely to be located at the energy centre, although could be located at a dwelling level with more limited use.
- Storing surplus power as heat through the use of electric boilers has potential but will require surplus's to occur on a regular basis before an investment case develops it would however be relatively easy to retrofit.
- District heating will be beneficial in reducing peak power demands regardless of whether it provides a smart demand response as it will reduce the number of electric heating systems installed. This will potentially provide a benefit both at the local distribution scale, in avoiding upgrades to the capacity of the primary or local substations serving the distribution network, and in reducing the capacity of power stations required to meet peak electricity demands.
- In terms of the functional specification for new district heat plant and energy centres, it may be sensible to consider maximising thermal storage, identifying where additional thermal storage capacity may be accommodated in future and how direct electric boilers may be connected to thermal stores, if market incentives develop that would support the additional costs of these measures. In the short term lack of an identifiable revenue stream is likely to limit investment in such measures.
- It could be useful to undertake further work with UK Power Networks to identify areas where they require demand side response to help manage their network constraints. This could be considered as an additional parameter for CHP feasibility studies – potentially providing optimisation opportunities.

While schemes are currently specified as heat led there is only limited additional specification that is necessary to allow power led or hybrid schemes to be operated. Any additional installed plant should be low cost, at least until a market develops for additional power led operation revenue that can justify investment.

The system architecture and control functions required to deliver the capabilities set out above are discussed in sections 3 and 4.

It is expected that the main control of the heat network would still be from the Energy Centre or Energy Centres and would as now be based on the return temperature being controlled by variable temperature and flow rate, the key difference in control would be the way in which heat sources are dispatched to meet that heat demand.

What does this mean for a typical Type 2[18] (multi-site mixed use) DE scheme in London?

Type 2 Scheme Characteristics Assumed

A typical Type 2 DE project might connect around 6,000 new properties and some other mixed use developments. This development might be served by 3MWe of gas engine capacity with 4.5 MWth of heat available from the engine, with a peak heat load of around 15 MWth.

Intelligent operation opportunities

The Network might be operated in a heat/power led hybrid mode with a thermal store, depending on season and economics.

Potential operational benefits

- By incorporating a heat store with 245 m^3 capacity the DE plant could offer flexibility to generate at 3MWe for 2 hours with no heat load, and this capacity can be offered to the Short Term Operating Reserve (STOR). The scheme would be able to offer this service for periods during spring and autumn when the engine is offline, but there is sufficient heat load to empty the thermal store in 20 hours. During winter the engine is likely to be operated as a heat led unit, while during summer the low demand for heat would mean the unit would not be able to discharge heat at a sufficient rate to provide a regularly available demand response.

- Aggregation of similar units across London would allow services to be offered to STOR and to the DNO to make the best use of the generation assets from a revenue and carbon perspective.

- Incorporating electrical heating in the energy centre would allow the scheme to switch from electrical supply to demand when excess electrical generation is supplying the grid, at distribution or transmission level. This service could be offered year round, but is greatest in the winter.

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[18] *Powering ahead - Delivering low carbon energy for London*, GLA, October 2009, categorised decentralised energy schemes into a number of types.

6 The contribution of 'demand side management' in an intelligent energy network

6.1 Summary

6.1.1 The systems architecture diagram

The proposed systems architecture diagram set out in Section 3 (Figure 6) contains a number of components aimed at driving greater levels of demand side management (DSM) across the industrial, commercial and residential sectors. Elements within the diagram which support this include, for example, the illustration of better user control within buildings, a wider role for aggregators in load shifting and the proliferation of intelligent electronic devices. This section of the report aims to provide some justification for why these components appear within the systems architecture diagram, and more widely why demand side management is important in the context of a future intelligent energy network for London.

6.1.2 What is demand side management (DSM)?

The term Demand Side Management (DSM) refers to the modification of consumer demand for energy, most commonly through technology interventions (automatic response to signals), financial incentives or behaviour change programmes. Usually the goal of DSM is to encourage consumers to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttimes and weekends. This management of peak demands does not necessarily decrease total energy consumption but could be expected to reduce the need for investment in networks and/or power plants. It has the potential to reduce CO_2 emissions, in cases where the peaking plant is the most carbon intensive. DSM includes Demand Response, which is the response to DSM by consumers, and Demand Reduction, where an overall reduction in energy consumption is achieved.

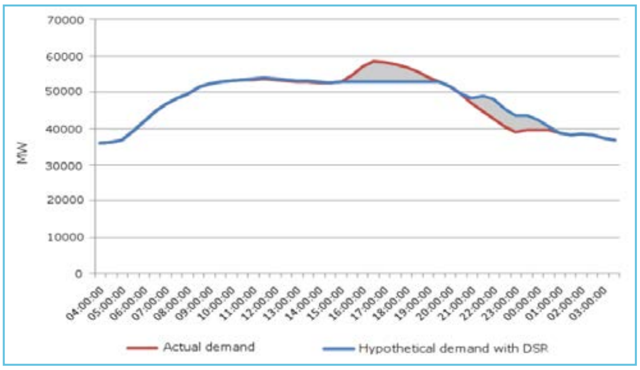

Figure 14: Illustrative Load Shifting Profile (Source: National Grid and Ofgem analysis - Ofgem, Demand Side Response: A Discussion Paper, 2010)

Figure 14 shows actual demand for a typical winter's day in GB and a hypothetical demand profile with 10% Demand Response (i.e. peak demand shifted to earlier and later in the day).

6.1.3 Current state of play (existing)

In the UK there are currently two main mechanisms for consumers to alter energy use patterns and thereby potentially help balance generation and demand. For large consumers (or aggregators) with ability to shed over 3MW of instantaneous load they can contract directly with National Grid and receive payment for the balancing response they can provide. Quite often in these examples, although the demand is shed from the Grid it is provided instead by some form of onsite back-up generation meaning that the end user doesn't necessarily need to alter their energy consumption profile. Consumers that do not have sufficient scale, or are otherwise unwilling, to contract with National Grid can still reap some financial benefit through demand side management, by signing up to a time of use (ToU) charging system with their utility provider (e.g. Economy 7) where charges vary through the day to promote energy use outside of the normal peak demand times.

These two mechanisms, although they can deliver similar outcomes, are quite distinct. The demand side market for the larger consumers is already well established. The financial incentive is sufficient to attract large consumers to engage in the Short Term Operating Reserve (STOR) programme, it is relatively simple to manage and the benefits to the networks are clear. The benefits of demand side management on the lower voltage networks (e.g. aggregated from homes and businesses) is less clear, as are the regulatory and commercial levers that would need to be pulled to drive increased uptake at this scale. Whilst there is a lot of talk – in all world electricity markets - about DSM in homes and businesses, in practice the commercial drivers for this are currently limited and there is limited practical application on the ground.

6.1.4 The opportunity (future)

The coming together of existing (and proposed) financial drivers and ability to better measure, monitor and report energy use through improved information communication technology (ICT) is seeing a number of businesses developing products and services in the areas of DSM and active network management.

In general the UK's electricity transmission network is already managed in an active way up to the bulk supply point with sophisticated balancing arrangements in place. The major opportunity seems to be in bringing similar levels of monitoring and control to the low voltage networks – below the substation level. This would enable, for example, aggregation and network balancing at a much finer granularity.

This opportunity has been highlighted in a number of debates on the future evolution of the energy market. The previous Government's Low Carbon Transition Plan (July 2009)[19] highlighted the need for a more flexible energy system to meet the goal of an 80% reduction in carbon emissions by 2020 and in Ofgem's Discovery consultation (February 2010)[20] it was stated that although industrial and commercial consumers are already active in demand side response, participation could be increased and extended to the mass market if short-term price signals are sharpened and barriers removed. The Energy Networks Strategy Group, in its Smart Grid Roadmap[21], has highlighted the role for more active network management. Furthermore, the Energy Market Assessment of March 2010[22], noted that enabling better demand side response would be pursued in all of the options set out for energy market reform. The current Government is continuing with the previous Government's programme to roll-out smart meters to all customers. This creates the potential for domestic and small business customers to play a more active role in the energy market. The high level potential for demand side management in the UK is set out in the bullets below.

Energy potential

National Grid estimate that present-day typical demand side response reductions are between 0.5 and 1GW during TRIAD[23] periods[24]. In separate analysis Sustainability First have estimated that the maximum technical potential (2010) is 18GW (winter) and 10GW (summer) and that this could grow to 23 (winter) and 12 (summer) by 2025, this is based on their Green scenario modelling. The Sustainability First analysis is technically focussed and takes no account of commercial or regulatory barriers.[25]

Financial potential

Ofgem have produced a discussion paper on demand side management[26], for which they have made some estimates of the potential financial benefits that could arise. They state: 'The indicative benefits of consumers shifting 5% and 10% of their electricity use in order to flatten peak demand could lead to the following potential financial impacts, which are indicative only:

- £0.4m to £1.7m daily wholesale cost savings (based on a sample of days);
- £129m to £536m annual avoided capital costs for new generation (based on a sample of days); and
- £14m to £28m annual avoided capital costs for networks.

These figures refer to the benefits of shifting peak demand only and do not capture the full benefits of smart grids, which have been estimated to be much higher (e.g. by Ernst and Young[27]). Estimates of the impacts of demand side response also vary significantly. A useful review has been carried out by the University of Surrey's Centre for Environmental Strategy which provides more information on the costs and benefits of different demand side responses.[28]

Carbon potential

Provided that carbon is priced appropriately, the level of demand response estimated by Ofgem (see above) would immediately lead to a daily reduction in carbon emissions of up to 0.5% (between 800 and 2,550 tCO_2 per day based on the same sample of days), equivalent to emissions from about 135,000 households. Ofgem has stated that these benefit

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[19] DECC, UK Low Carbon Transition Plan, 2009

[20] Ofgem, Discovery Consultation http://search.ofgem.gov.uk/search.aspx?aid=6581&pckid=755724950&pt=6018936&sw=discovery

[21] Energy Networks Strategy Group, Smart Grid Routemap, 2010

[22] HMT & DECC, Energy Market Assessment, 2010

[23] Triad demand is measured as the average demand on the system over three half hours between November and February (inclusive) in a financial year. These three half hours comprise the half hour of system demand peak and the two other half hours of highest system demand which are separated from system demand peak and each other by at least ten days.

[24] National Grid, Operating the Electricity Transmission Networks in 2020. 2009, updated June 2011.http://www.nationalgrid.com/NR/rdonlyres/DF928C19-9210-4629-AB78-BBAA7AD8B89D/47178/Operatingin2020_finalversion0806_final.pdf

[25] Sustainability First, GB Electricity Demand – Context and Baseline Data, 2011

[26] Ofgem, Demand Side Response - A discussion paper, 2010

[27] Ernst and Young, Smart Grid: A race worth winning - A Report on the Economic Benefits of Smart Grid, Smart Grid GB, April 2012.

[28] University of Surrey, A review of current and future costs and benefits of demand response for electricity, 2011.

estimates are likely to be conservative.

6.1.5 The challenge

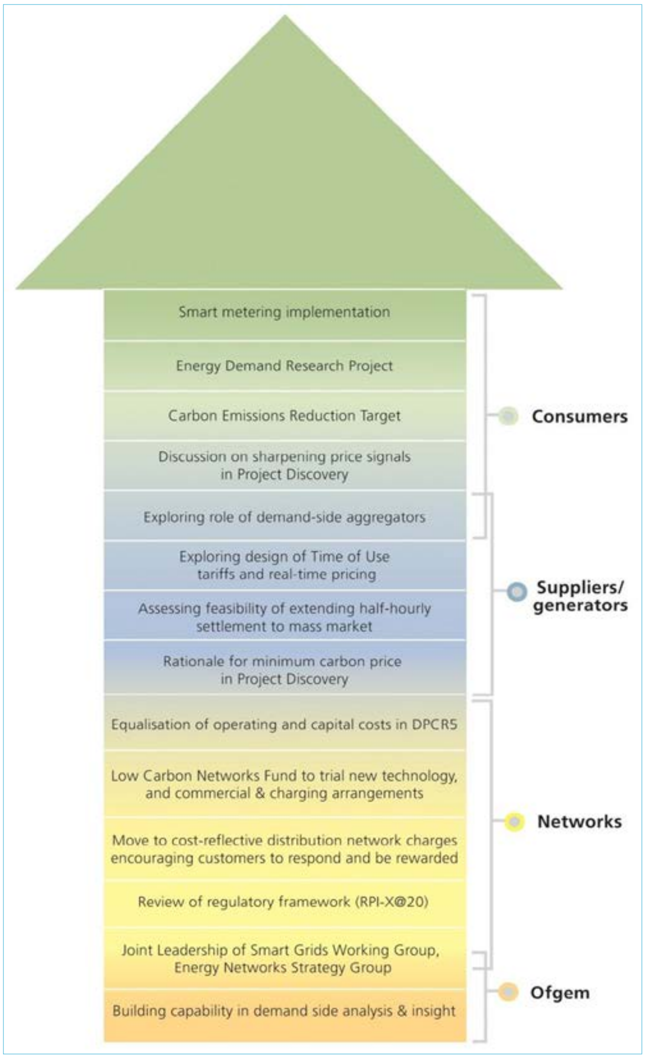
There is a good degree of technology confidence amongst companies promoting products which would help facilitate DSM on the low voltage networks. What is less clear is the commercial and regulatory context and 'route to market' for these companies and products. It is not always clear where the majority financial benefit sits. Is it with the consumer, with National Grid or with the Distribution Network Operators (DNOs)? And if the latter how can the DNOs engage in, and take value from, DSM? DNOs have traditionally been conservative, accepting low but secure long term return on their investments. The traditional 'value' within a DNO is in their network infrastructure. Much of the value in DSM and distributed generation is in control and optimisation (e.g. software) rather than in hard infrastructure. It is not clear how this value can be captured by the existing businesses operating in this space.

The Government has recognised this challenge through the White Paper: 'Planning our electric future: a White Paper for secure, affordable and low-carbon electricity'[29]. The White Paper states that: "the UK electricity market faces an unprecedented challenge over the next 30 years or so if it is to deliver on the triple ambitions to deliver secure, low carbon and affordable electricity supply". In practice the challenge is made more complicated as existing generation plant is due to close, demand is projected to rise and generation (or demand response) is likely to be much more diverse.

The Government has accepted the broad industry consensus that current market arrangements will not deliver the scale of long-term investment needed, at the required pace, to meet these challenges. Nor will they give consumers the best deal. Government has committed to an Electricity Market Review and is consulting on a range of potential changes. They hope to deliver a revised framework that will offer reliable and well administered contracts that are trusted by investors, and that help to achieve a diverse portfolio of generation to meet energy and carbon goals as efficiently and cost-effectively as possible.

The White Paper makes it clear that, under this proposed improved framework, Government would expect demand side management to play a greater role in the future. Specifically, in relation to opportunities at a building scale or across the lower voltage networks, it states:

"The introduction of Smart Meters could increase the opportunities for DSR, for example through greater use of time or price sensitive tariffs. To automatically respond to variable tariffs or wholesale prices, consumers would need equipment (to complement Smart Meters) that will reduce demand automatically by turning off non-essential electrical devices. This, in conjunction with the likely electrification of heat and transport which could significantly increase the amount of discretionary demand, could lead to greater participation of the demand side in the wholesale market."



An outline Of Ofgem's activity across the supply chain to facilitate demand side response. (Source: Ofgem Discussion

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[29] DECC, Electricity Market Reform (EMR) White Paper, 2011

Paper: Demand Side Response, July 2010)

6.1.6 Aims of this section

This section aims to:

- Outline what DSM is, and the various ways it is currently employed in the UK, and London
- Consider the scale of benefit that DSM can deliver in terms of grid balancing and avoided investment in infrastructure from industrial, commercial and residential sectors
- Set out examples of the different available demand responses
- Discuss where the majority value from DSM might lie
- Set out the companies active in this space together with their products, services
- Set out the key challenges and opportunity for greater uptake of DSM in London, across the various consumer groups
- Set out the issues that should be carried forward to project level

6.2 Current state of play - Existing Demand Side Management approaches and contribution in the UK

6.2.1 Top down mechanisms

Currently National Grid has two basic means of balancing the electricity grid, both of which can include (in part) DSM. These are termed 'reserve services' and 'frequency control'. The approach taken depends mainly on the required speed of response.

Frequency control

System frequency changes continuously and is controlled by the second to balance system demand and generation. Where demand is greater than generation, the frequency falls, while if generation is greater than demand, the frequency rises. National Grid has a licence obligation to control frequency within the limits specified in the 'Electricity Supply Regulations', i.e. ±1% of nominal system frequency (50.00Hz) and must therefore ensure that sufficient generation and/or demand is held in automatic readiness to manage all credible circumstances that might result in frequency variations. National Grid maintains System Frequency through three separate Balancing Services, two of which can include elements of DSM. These are firm frequency response by which providers contract with National Grid to deliver at least 10MW demand/generation response when an instruction is received, and frequency control demand management which acts through automatic interruption of consumers' supply for a minimum of 30 minutes when the system frequency drops below the low frequency relay setting on a particular site – consumers offering this must provide at least 3MW in total 24hours a day

Reserve services

Reserve can be either short term operating reserve (STOR) or fast reserve. STOR is a manually instructed delivery of active power through generation and/or demand reduction and, like frequency control, has certain requirements (minimum 3MW total, must be available within 240minutes and for 2 hours, at least 3 times per week, and have a recovery period of not more than 20 hours, plus communications and monitoring). Commitments to STOR can be committed (available at any time) or flexible (a total of hours of service across a season is indicated). Aggregators are already bringing large consumers into the STOR programme. Fast reserve is manually instructed rapid and flexible change in active power output or demand (delivers in 2 minutes, at least 25MW/minute, for a minimum of 15 minutes and 50MW). This is typically provided by standby power generators.

6.2.2 Bottom up mechanisms

In addition to the 'command and control' DSM managed by National Grid (see above) there is also an element of DSM that can (in part) be driven from the bottom up, by individual consumers. The primary driver for end user (consumer) engagement in DSM is through time of use (ToU) charging.

Clearly ToU charges are (or will be) structured by the major utilities and are (will be) designed to deliver similar outcomes (i.e. peak reduction and load shifting) as the top down mechanisms described above. Despite this, ToU charging should still offer some financial benefit to consumers willing to actively participate in DSM at the home or business level.

Examples of ToU charging are described further below.

Economy Seven

Economy 7 is an electricity tariff originally designed to make use of baseload electricity at night and improve the cost effectiveness of electric heating systems for customers by charging less for using electricity at night time. Two separately metered tariffs are provided for electricity – one low tariff for the night, and another peak tariff (higher than conventional tariffs) for electricity used during the day. It's called Economy 7 because for seven hours every night (normally from 1am until 8am, although times can vary between suppliers) electricity costs considerably less than the standard daytime rate.

Economy 7 tariffs are typically used in combination with electric storage heaters and an increased capacity hot water cylinder (typically 210 litres for a modern home) to utilise as much energy at night as possible. Storage heaters discharge their heat through the night and the following day, with any shortfall in heat during the day topped up with direct electric heaters. To make the most of Economy 7 tariffs customers can install timing devices on key electrical appliances such as dishwashers, washing machines and tumble dryers, as well as ensuring hot water boilers and storage heaters are switched on fully overnight, during the 'off peak' hours.

Whilst Economy 7 has been effective at time altering peak demands on the electricity networks it is non-responsive as a heating system and has high CO_2 emissions associated with it compared with gas systems.

Existing electrical heating systems could offer the potential for a power sink at times of high wind availability as well as utilising base load. Increased volume hot water tanks in homes on Economy 7 could also be used to offer distributed thermal storage. Despite some of the failings with Economy 7 it has demonstrated the potential to alter demand profiles by time of use charging. Take up of this tariff was 20% as recently as 2008.[30]

Economy 10

Some suppliers also offer tariffs with three different time periods known as Economy 10 tariffs. These are similar to Economy 7 but may offer a middle rate time slot in addition to the peak and off-peak rates. An example of this is EDF Energy's Eco 20:20 tariff.

Dynamic Teleswitching

Around 1 million customers who are on ToU tariffs have Dynamic Teleswitching functionality on their multi-rate electricity meters[31]. Dynamic Teleswitching enables the supplier or local Distribution Network Operator (DNO) to remotely "switch" a consumer's electricity supply through radio signals. This functionality allows suppliers to vary the time at which electricity is supplied to electric storage heaters under Economy 7. It also allows DNOs to manage constraints on the network and prevent overloading. Dynamic Teleswitching is a technology that enables DSR and is a precursor to more widespread automation that could be introduced.

Trials

The Energy Demand Research Project (EDRP) was a major research study (c. £20 million) funded jointly by industry and DECC and managed by Ofgem[32]. Over 60,000 households (18,000 with Smart Meters) took part in a number of activities designed to test demand management, including issues such as more frequent billing and information, smart meters, visual display units and community engagement. The study reviewed work done between 2007 and 2010 by the 4 utility project partners - SSE, E.ON, Scottish Power and EDF. A full analysis of the project findings was published in 2011.

The key findings from this analysis are summarised below:

- Reductions in energy consumption following energy efficiency advice were not always seen, and were typically under 5% of annual consumption. Providing benchmarking data may lead to additional reductions.[33] Use of online services was not shown to realise energy reductions with trials showing this is likely to be largely due to lack of engagement with the sites.[34]
- Existing literature does not provide direct evidence of the impact of installing a smart meter without any other interventions, and EDRP findings were mainly in line with this, but two of the EDRP trials (E.ON and SSE) provide the first evidence on this, showing that some aspect of the experience of getting a smart meter can itself prompt a reduction in energy consumption, particularly gas consumption (savings of around 3%). The clearer effect for gas consumption makes sense in the context that simple one-off changes (e.g. reducing a thermostat setting) can have big effects on gas demand.[35]
- Real time displays (RTDs) typically bring about a reduction in energy consumption but the percentage savings vary widely and appear to depend on climate. The trials provide greater certainty on the magnitude of effects in the UK,showing a small (1%) significant effect.
- The EDF trial (under EDRP) was the first to test heating controls integrated with RTD, with a positive response from consumers, but the change in gas consumption could not be analysed.
- EDRP did not provide convincing evidence of an overall reduction in demand due to time of use tariffs. There were, however modest effects on shifting load from the peak period. The EDF data showed that the effect is stronger with smaller households (1 or 2 people), thus providing a clear focus for where such interventions should be targeted. [36]

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[30] BERR Impact Assessment of Smart Metering Roll out for Domestic Consumers and Small Business

[31] Ofgem's analysis referenced within Ofgem, Demand Side Response - A discussion paper. Ref: 82/10 (2010)

[32] AECOM, Energy Demand Research Project: Final Analysis http://www.ofgem.gov.uk/Sustainability/EDRP/Documents1/Energy%20Demand%20Research%20Project%20Final%20Analysis.pdf

[33] The SSE UK trial which used benchmarking is one of the clearest pieces of evidence for an effect of benchmarking

[34] EDF and SSE trials tested online services.

[35] What makes the difference in respect of the smart meter intervention cannot be stated with certainty but there was a clear difference between E.ON and SSE, which set out to explain to customers what they were receiving, and Scottish Power, which ran a blind trial.

[36] This comes from the EDF and SSE trials, both of which showed a stronger load-shifting effect at weekends than on weekdays. Estimates of the magnitude of shifting effect vary with trial but were up to 10%.

- Across all the trials, there was limited evidence of how different population segments were affected by the interventions although some trials did suggest small households, consumers identified as fuel poor and (as might be expected) high consumers were more likely to save energy overall.[37] The deployment of smart meters through the trials proved difficult (e.g. due to signal strength, meter location within property, and data faults and validation issues). Many of the problems would not arise now (2012) due to the learning from these trials which is already being fed into the government's smart metering programme and procurement of the DCC.
- Delivering the trials has demanded a range of different skills from the suppliers. Installers need the right technical skills to complete jobs and need additional training to be able to install both gas and electricity meters and to deal with any unforeseen safety or legacy issues. Softer skills are essential too, so that installers can clearly explain the new technology to customers. Customer advice services will need to build up their knowledge of the new technology to be able to answer consumer enquiries.

A number of suppliers are planning to trial new multi-rate TOU tariffs. Some are looking at Critical Peak Pricing (CPP)[38] tariffs which are a form of dynamic TOU tariffs; the peak periods and associated prices are not fixed in advance as in static TOU tariffs, rather they are communicated to customers a short time before they begin. The issue (or potential for) smarter tariffs is addressed in a paper produced by Elexon titled: 'Smarter settlement – making the most of tariff innovation'[39]. This paper explains the limitations of wholesale electricity settlement without half hourly data and explains how smart meters open the door for smarter settlement, where suppliers and consequently consumers could realise financial benefit as a direct result of their own actions to reduce or shift load.

Automated devices

Dynamic-demand control devices switch appliances on and off in response to changes in the balance between supply and demand on the electricity grid or in response to prices. These devices can be either retrofitted to existing appliances or installed when appliances are manufactured (i.e. smart appliances). The devices are best suited to appliances, such as refrigerators, air conditioners and hot water heaters, which run on cycles (i.e. switch on for a period then switch off). Dynamic-demand control devices have not yet entered the mass market.

International Examples

Some countries have successfully implemented innovative tariffs that use visual display units and smart meters or electronic alerts (website, email or text messages) to provide a strong price signal to households to reduce demand at peak periods. For example, in France, there are around 350,000 domestic and 100,000 non-domestic consumers signed up to a critical peak pricing tariff which provides day-ahead price information to consumers via internet, text or in-home visual display units. The tariff has daily peak and off peak pricing periods and day of the year pricing[40]. The trials prior to roll-out of this CPP tariff revealed that, on average, customers did respond to higher pricing by lowering usage at peak periods and the majority of customers were satisfied with the programme and made savings on their electricity bills.

TOU studies of summer energy use in North America have shown peak demand savings of between 2.4% and 10.6%, and overall savings from small negative values up to 6% but typically around 3%. One UK study found an overall conservation effect of 3.1%. Another reported a 1% reduction in usage compared with baseline consumption, but with no control group comparison.[41]

Even if suppliers offer innovative tariffs to stimulate demand response, it does not necessarily follow that consumers will take them up. The market structure plays an important role. For example, in most of the US, there is no retail competition in electricity supply. Therefore, the regulator is able to set specific

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The effect was weaker in the SSE trial and this may be because awareness of the intervention was limited.

[37] See the Energy Demand Research Project: Final Analysis report writeup of the EDF and E.ON trials for more information.

[38] Critical peak pricing (CPP) is the practice of setting much higher unit prices on a limited number of occasions when the energy supplier experiences excessive demand and signals this to the consumer.

[39] Smarter settlement – making the most of tariff innovation' http://www.elexon.co.uk/wp-content/uploads/2011/10/Smarter_Settlement_Final.pdf

[40] The year is divided into: blue days (low rate); white days (medium rate); and red days (high rate).

[41] AECOM, Energy Demand Research Project: Final Analysis http://www.ofgem.gov.uk/Sustainability/EDRP/Documents1/Energy%20Demand%20Research%20Project%20Final%20Analysis.pdf

tariffs (such as dynamic tariffs) as a default. In contrast, in the UK, where there is full retail competition, consumers would need to actively choose to switch to a tariff that facilitates DSR. The state of Texas most resembles the UK in terms of market structure and adoption rates in Texas for dynamic pricing have been among the lowest in the US. Given this learning from the Pecan Street Smart Grid demonstration project (Austin, Texas) will be particularly relevant for London and the UK[42].

In the face of frequent supply shortages, some countries have implemented direct control, for example, from 2005 South Africa implemented a radio switch programme for electric water heaters to help overcome severe electricity shortages. The programme connects radio-controlled units to electric water heaters, allowing them to be switched on and off by remote control. South Africa, also operates a power alert system programme, whereby viewers of particular television stations are alerted when the electricity network is under significant stress and can follow on-screen instructions to facilitate electricity reduction (e.g. switching off unnecessary appliances), thereby maintaining supply.

6.2.3 Current DSM contribution in the UK

In their National Electricity Transmission System Seven Year Statement, 2011, National Grid summarise the UK's typical electricity demand profiles. The typical winter and summer profile is shown in Figure 15.

The winter profile is explained by National Grid, as below:

Winter Profile –Typical Weekday (i.e. Maximum Demand Day)	
00.00 – 03.00	Time-switched and radio-teleswitched storage heating and water-heating equipment
06.30 – 09.00	Demand build-up to start of working day
09.00 - 16.00	Plateau for working day – mostly I&C demand
16.30 - 17.30	Rise to peak in lighting load and increased domestic demand outweighing fall-off in I&C load
18.00 - 00.00	Demand reduces. >50% of the load is domestic.

The typical summer weekday profile is as above but without the effects of storage heating demand and with a later onset of evening lighting load.

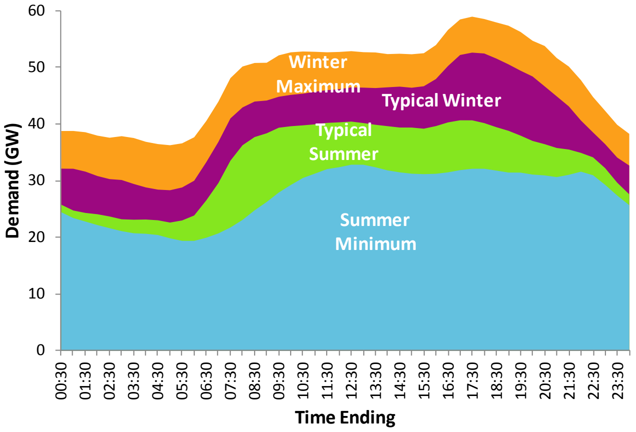

Figure 15: Summer and Winter Daily Demand Profiles 2010/11. Source: National Grid's National Electricity Transmission System Seven Year Statement, 2011

Ofgem have analysed the breakdown of the evening peak load, based on autumn and winter profiles as follows:

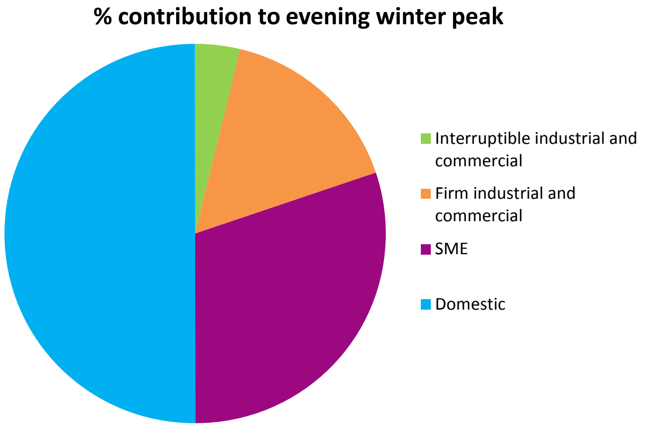

Figure 16: Ofgem estimate of evening (15:30-19:30) peak-load breakdown, based on autumn and winter data. Source: Sustainability First, GB Electricity Demand - Paper 1, 2011

It is important to note that 50% of the evening winter peak is from residential because this is one of the hardest sectors to manage, and quite often the areas of high residential occupancy are also the most challenging in respect of integrating new infrastructure, due to availability, and cost, of land.

National Grid has reported that present-day typical DSR reductions in the UK are between 0.5 and 1GW during TRIAD

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[42] The Pecan Street Project, Working Group Recommendations, Austin, Texas, 2010. http://www.pecanstreet.org/wordpress/wp-content/uploads/2011/08/Pecan_Final_Report_March_2010.pdf

periods.

Sustainability First have estimated that the current technical potential (2010) is 18GW (winter) and 10GW (summer).

6.3 The opportunity - Potential contribution from Demand Side Management

The volume of 'discretionary' load across all sectors in the UK is lower than for other countries where DSM techniques are more widely used (e.g. USA, Southern Europe). This is due to less extreme weather, and therefore less air-conditioning load, a high use of natural gas to provide heating (i.e. less reliance on electrical heating) and the high value placed upon time – consumers are unwilling to inconvenience themselves for a small financial saving when the effort and time required is high.

Future scenarios for decarbonisation of the electricity grid leading to the greater use of heat pumps, climate change leading to higher average temperatures and greater demand for cooling and technology development in to, for example, electric vehicles, suggest that in the future the UK may have a greater discretionary load. The role of DSM could be more important in the future, especially when the planned closure of existing generation plant is considered.

It was originally intended for this study to use demand profiles for a range of building types within a defined study area to determine the potential for demand response and the benefit this could offer in terms of alleviating network stresses. Complications in securing high quality data have prevented this from being possible. Instead, to support the systems architecture produced, we have used national level data (i.e. literature review) to highlight the major opportunities for DSM across three specific sectors.

Projections of future flexibility in electrical loads depend upon a range of assumptions about how the UK will decarbonise nationally, and associated uptake rates of new technologies, which will mean that long term projections in particular are uncertain and need to be reviewed over time. The full impacts of mass uptake of new technologies such as electric vehicles and heat pumps are also still being explored through research and pilots such as those under the Low Carbon Networks Fund. Despite these uncertainties, several organisations have made predictions into the medium term and have undertaken useful research which gives a broad indication of where opportunities are likely to be in the future. Some of these predictions, which are underpinned by a range of grid decarbonisation scenarios are summarised below.

6.3.1 National Overview

National Grid - 2020 Estimates for Demand Response

National Grid has provided estimates of the potential for future DSR in their Operating the Electricity Transmission Networks in a 2020[43] consultation report. In the period to 2020 they expect peak demand to follow similar patterns to today and expect peaks to be of a similar magnitude, with economic growth and new demand (such as from electric vehicles and heat pumps) being offset by increases in energy efficiency and decentralised energy generation. Against this background they expect to have a total operating reserve of 7.3GW by 2020, and a potential total 2GW of demand response available at peak, with approximately half of this potential in the industrial and commercial sector (see table below) – with most new services coming from the commercial and SME sector due to the roll-out of advanced meters. DSR potential can be seen as avoiding the need for investment in operating reserve, which will need to increase nationally and to become more flexible by 2020, mainly due to increased wind generation. Post 2020 they expect demand profiles to flatten, supported by the development of smarter grids including the roll-out of smart meters and impact of Time of Use tariffs.

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[43] National Grid, Operating the Electricity Transmission Networks in 2020 http://www.nationalgrid.com/NR/rdonlyres/DF928C19-9210-4629-AB78-BBAA7AD8B89D/47178/Operatingin2020_finalversion0806_final.pdf

Table 3 below summarises where the National Grid expect the key DSR opportunities to lie in 2020, by sector, at UK level

Domestic			
Load Type	Total Load (GW)	% Assumed Captured	Resulting DSR Load (GW)
Wet Appliances – shift to off-peak	2.0	5%[44]	0.2
Refrigeration - short duration dynamic response	1.8		
TOTAL DOMESTIC	3.8	-	0.2
Industrial and Commercial			
Air Conditioning	2.8	30%	0.84
Refrigeration	2.6	10% (food safety taken into account)	0.26
TOTAL I&C	5.4	-	1.1
New Sources (in combination with storage)			
Heat Pumps (winter)	4.5[45]	(12%)	0.57[46]
Electric Vehicles	1.8	(6%)	0.1[47]
CHP	7		No significant change
Other Renewables (PV, EfW, Biomass, AD)	8		
TOTAL ALL SECTORS (excl. CHP/renewables)			1.97

Table 3: Demand side response opportunities

Separately Sustainability First are undertaking the study 'GB electricity demand – realising the resource'[48] which provides some useful analysis of daily profiles in different sectors and assessment of where they think the main DSR opportunities may lie, both now and in 2025.

To inform this analysis they have created an electricity demand model (the 'Brattle Electricity Demand Model) focused on exploring maximum technical potential for electricity demand reduction and flexibility in Great Britain, through creating a half-hourly load curve by month through the calendar year for each major electricity end-use across different sectors. It does not assess the commercial or other practical realities of realising this potential. The model is then used to identify where there may be scope for shifting demand at different times of the day and year. The model is based on data from a range of sources (e.g. DECC, Dukes and Elexon).

Sustainability First's analysis is ongoing but they have initially suggested the potential for DSR from 'other heating', water heating, refrigeration, domestic wet appliances and compressed air in two time periods, and from EVs in 2025. The analysis focuses on shifting demand from the evening peak. A summary of there resuts is shown in Table 4.

	Winter weekdays		
	2010	2025 – BAU Scenario	2025 – Green Scenario
Potential for DSR (GW)	18	24	23
Max Demand (GW)	56	67	57
Domestic	50%	50%	48%
Commercial	28%	32%	28%
Industrial	23%	17%	16%
EV		1%	8%

	Summer weekdays		
	2010	2025 – BAU Scenario	2025 – Green Scenario
Potential for DSR (GW)	10	13	12
Max Demand (GW)	36	45	37
Domestic	63%	49%	40%
Commercial	16%	35%	31%
Industrial	21%	14%	14%
EV		2%	15%

Table 4: Potential demand response in 2010 and 2025 across domestic, commercial, industry and electric vehicles (EV). (Source: Sustainability First)

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[44] National Grid note that this figure is not evidence-based and that there could be greater potential for DSR from appliances as this market is developed.

[45] Based on the DECC 2050 Pathways 'low' scenario; equivalent to meeting 20% of building heat demand by electric heating.

[46] Based on assumption that half of heat pump demand can move from evening peak in winter. The delivery of heat pumps' DSR potential will depend on amount of thermal storage available.

[47] Based on an estimated 1.1million electric vehicles (approx. 4% of cars, in UK, 2007), plugged in upon arrival at home, and an average 36km/day journey based on DfT forecasts, resulting in a 22KWh battery depletion of 25%.

[48] Sustainability First, GB Electricity Demand Project http://www.sustainabilityfirst.org.uk/gbelec.html

The analysis shows that the potential for DSR increases in 2025 over the evening peak. Sustainability First also suggest that the morning peak may become more significant in 2025 for system balancing should it coincide with lower wind speeds as Poyry suggested in their North European Wind and Solar Intermittency Study.[49] There is less shiftable load in Sustainability First's greener scenario for 2025, mainly due to a higher uptake of heat pumps in this scenario, which it has been assumed would reduce the potential for shifting space and water heating loads, and also due to energy efficiency reducing overall demand. This means that based on their assumptions the potential for shiftable load could reduce by 2025, at times outside of the evening peak when electric vehicle load could shift.

6.3.2 Heat Pumps and Electric Vehicles

Imperial College London and the Electricity Networks Association have assessed the impact of heat pumps and electric vehicles on the grid.[50] The instantaneous increase in load due to simultaneous charging of an electric vehicle and operation of a heat pump which might occur in the evening could be over 10kW per household. Their analysis shows that heat storage of around 25% of daily heat demand would be enough to flatten the national daily demand profile, based on their modelling of full penetration of electric vehicles[51] and heat pumps, taking into account efficiency losses.

In Sustainability First's business-as-usual case the system peak would almost double due to heat pumps and electric vehicles, increasing by 92% (out of which 36% is contributed by electric vehicles, and 56% by heat pumps. If demand side management is applied, the peak increase is only 29%. It is assumed that heat pumps are used in the day and electric vehicles are charged at night. It is noted that in urban areas, network reinforcement requirements due to increased penetration of electric vehicles and heat pumps will largely be due to thermal overloading of LV feeders, and some of these costs might be avoided should DSR be applied successfully.

The extent to which price signals will influence output from CHP, renewable and nuclear generation is seen as being unclear by National Grid and so they assume no significant change in the DSR potential due to these technologies. They do however note the potential value of thermal storage for CHP, and that there could be value in PV being developed in combination with storage to allow self-balancing: storing excess power at low-cost periods and exporting it at peak periods – although the current flat-rate tariff structure of the FIT currently acts as a disincentive for this. National Grid notes that a proportion of its reserve requirements may become more decentralised.

6.3.3 Sector Specific Opportunities and Constraints

Domestic Opportunities

Sustainability First's modelling provides an average weekday half-hourly domestic demand profile for each calendar month as well as a breakdown of domestic electricity consumption by end-use, as follows:

▪ Consumer electronics and computing	28%
▪ Lighting	16%
▪ Cold Appliances	15%
▪ Wet Appliances	15%
▪ Space Heating	14%
▪ Water Heating	6%
▪ Cooking	5%

Imperial College and ENA have produced similar analysis. The Imperial College/ENA also made estimates for the potential for shifting loads over time, according to what might be accepted by customers, based on surveys conducted. The estimates are provided in Table 5 below.

Appliance	Shifting Capability (hours)	Cycle Duration (hours)
Washing Machine	1-3	2
Dishwasher	6	2
Washer-dryer	3	4

Table 5: Suggested appliance DSR shifting capabilities. Source: Imperial College London and ENA, Smart Metering Benefits, 2010, based on EU IEE Smart-A project data

In line with National Grid, Sustainability First concludes that the most likely sources of household DSR are:

- On-peak electric heat;

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[49] Poyry, *North European Wind and Solar Intermittency Study*, 2011

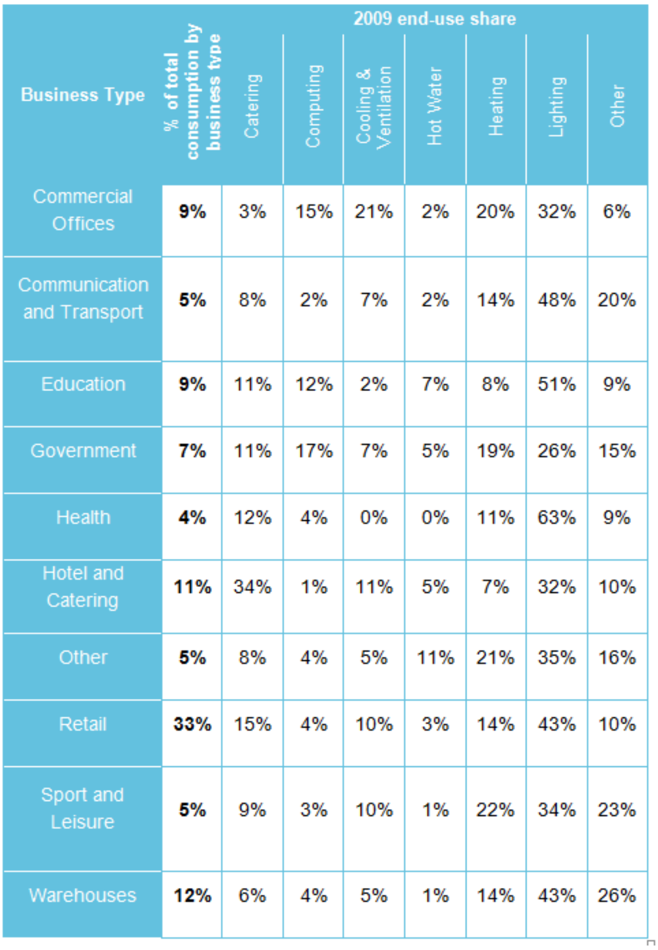
[50] Strbac et al., Imperial College in collaboration with the Energy Network Association, *Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks*, 2010

[51] Based on a Government-projected penetration of 1.7 million cars by 2020 (approximately 5% penetration), Committee on Climate Change, Meeting carbon budgets – the need for a step change, 2009.

- On-peak electric water heating;
- Wet appliances; and
- Refrigeration – subject to widespread uptake and proven technology for flexibility; and existing stock-turnover.

Public and Commercial Demand Profile

Table 6, based on DUKES data, shows electricity consumption in the non-domestic sector (excluding agriculture) broken down by end-use.



Business Type	% of total consumption by business type	2009 end-use share						
		Catering	Computing	Cooling & Ventilation	Hot Water	Heating	Lighting	Other
Commercial Offices	**9%**	3%	15%	21%	2%	20%	32%	6%
Communication and Transport	**5%**	8%	2%	7%	2%	14%	48%	20%
Education	**9%**	11%	12%	2%	7%	8%	51%	9%
Government	**7%**	11%	17%	7%	5%	19%	26%	15%
Health	**4%**	12%	4%	0%	0%	11%	63%	9%
Hotel and Catering	**11%**	34%	1%	11%	5%	7%	32%	10%
Other	**5%**	8%	4%	5%	11%	21%	35%	16%
Retail	**33%**	15%	4%	10%	3%	14%	43%	10%
Sport and Leisure	**5%**	9%	3%	10%	1%	22%	34%	23%
Warehouses	**12%**	6%	4%	5%	1%	14%	43%	26%

Table 6: Commercial and services sector electricity breakdown by end-use 2009. Source: DUKES 2009, updated July 2011, Table 5.6

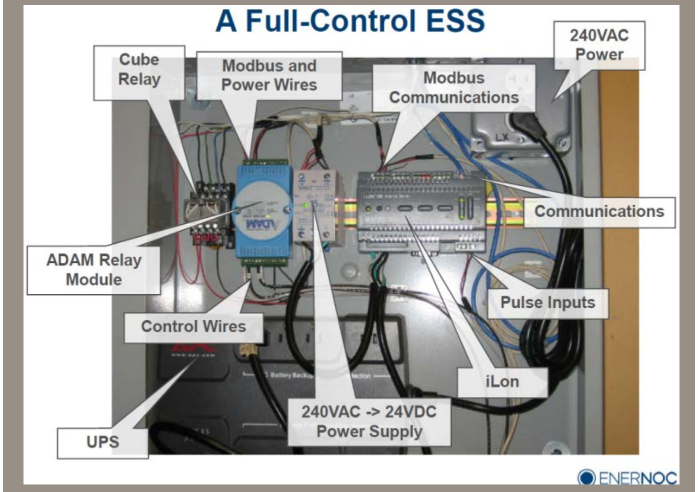
Data is not available by time of day or year; however Sustainability First concludes from the available data that the most likely sources of commercial DSR are:

- Heating;
- Cooling and ventilation;
- On-peak electric heat;
- On-peak electric water heating;
- Wet appliances used in catering, hotels and hospitals – although they note they currently have no basis for estimating the demand attributable to these.

CASE STUDY: ENERNOC

EnerNOC is a demand aggregation business. They help customers to manage their energy demand and to reap financial benefit from contracting with National Grid through the STOR programme.

At customers sites, EnerNOC installs their ENERNOC Site Server (ESS). The ESS is a gateway device that establishes communication from the customer premises to the local ENERNOC data control room and provides near-real time visibility into end-user energy consumption. From the Energy Network Operations Centre EnerNOC's staff can then manage demand and bring on and off stand-by generation to shed load from the Grid at times of high electricity price. EnerNOC respond to signals from the STOR programme and ensure the load reductions happen quickly, efficiently, and consistently for both the utility and end users.



Enernoc Control Device (Source: EnerNoc)

An example of a facility using the EnerNOC service is Salford Royal NHS Foundation Trust, a large teaching hospital in

Greater Manchester. By using their stand-by generators to provide short-term electricity generation during demand response despatches, the hospital reduces its instantaneous energy use (from the grid) by more than 600 kilowatts (kW) and earns annual payments of approximately £15,000. The hospital uses these payments to fund new energy efficiency initiatives.

In discussion with EnerNOC one of the practical challenges they have in signing up new sites for inclusion in the STOR programme is to do with the functionality of switch gear to bring stand-by generation on and off. For smooth operation (especially for critical facilities such as hospitals) there can be no loss in power at switch over.

For cost reasons the switch gear on standby generation has not always been installed that enables this smooth transfer of power and the cost of retrofitting can be a barrier to connection into demand aggregation programmes. Greater awareness of the potential revenue from demand aggregation could provide the justification for installing the necessary switch gear as part of new installations. **This is one consideration for a future specification in London where guidance could be provided.**

Industry Demand Profile

The potential for demand side response from industry is noted to be highly process and sector-specific. National Grid considers it is likely that there are some opportunities remaining in the industrial sector where companies have not yet engaged in DSR through the STOR programme. Sustainability First's analysis supports this assumption, and suggests that the main barriers are financial rather than technical. The table below shows the break-down of industrial electricity consumption by end-use, giving an indication of where DSR potential may lie:

End Use	Percentage of Total Use
Heat Processes	
High Temperature Processes	12%
Low Temperature Processes	17%
Drying	6%
Space Heating	8%
Non-Heat Processes	
Motors	34%
Compressed Air	10%
Lighting	3%
Refrigeration	5%
Other	
Other	5%

Table 7: Industrial sector electricity breakdown by end-use 2009. Source: DUKES 2009, presented in Sustainability First, GB Electricity Demand Paper 2: Initial Brattle Electricity Demand-Side Model – Scope for Demand Reduction and Flexible Response, 2012

6.4 The technologies – products

Numerous products and servies already exist to help facilitate demand side management at the transmission and distribution levels, and for use within commercial and domestic buildings. They include grid management solutions to help DNOs make better use of their existing infrastructure, demand response aggregation services (currently largely focused on large industrial and commercial consumers), smarter commercial building management systems, and home energy management systems. These are further considered in the technology glossary in Appendix B.

6.5 Challenges - Facilitating greater uptake of DSM?

There are a number of challenges to facilitating greater uptake of DSM. These are listed below.

6.5.1 Consumers

Awareness

There is a lack of awareness from consumers that the wholesale price of electricity changes throughout the day according to supply and demand, as this is not generally reflected in the price consumers pay for electricity. Greater visibility of energy price fluctuations might help facilitate behaviour changes/demand side management. But will require the corresponding tariff structures to be in place.

Incentives

Apart from limited time of use tariffs there is little financial incentive for domestic and business customers to change the electricity use profile because they do not receive relevant price signals within their tariff structures. In the long run smart meters will facilitate the marketing and uptake of new tariffs.

Changing Behaviour

Beyond lack of awareness or insufficient financial incentive consumers actually have to adapt their lifestyle to be active in demand management. They may, for example, need to wait to do clothes washing later in the evening. Some power consuming activities can wait, or can even be automated but others are not really time flexible (e.g. cooking).

Limits to discretionary demand

Even where there is willingness to engage in demand side management there will be limitations in terms of how much of the demand can be responsive. Occupancy and size of households and working patterns all have an impact on the degree to which demand patterns can be flexible. Projected growth in electric vehicles and heat pumps will give rise to greater demands for electricity but may also offer some increased flexibility and electric vehicles have potential to store electricity and can be charged out of peak demand times.

Technology

Smart meters and smart appliances that can interact with the smart meter and respond to changing conditions on the electricity network currently have a low level of market penetration, but that can be expected to change with the smart meter roll out programme.

6.5.2 Distribution network operators

In a future 'Smart' London energy flows across the local network will become more diverse and complex. DNOs will need to be able to better understand and manage this to reduce times of network stress and perhaps avoid (or delay) investment in infrastructure upgrade. In order to do this is it clear that DNOs will need firm and aggregated load within known geographies on the network. However they do not currently have a customer interface to be able to incentivise this.

Currently DNOs receive c.17%[52] of the end price of electricity as a use of system charge (passed back from suppliers) as well as fees for new customer (i.e. new development) from connection charges. In the conventional model the more units of electricity they can distribute, the more customers they have and the larger the network the better the returns for the DNO. Nothing in this model acts as a business incentive for demand side management, although there may be potential for negotiation where district energy schemes paying grid connection fees could offer network management benefits to the DNO in return for reduced connection fees.

Ofgem have taken steps to encourage DNOs to assume a more active role in managing flows of energy on their networks, including thinking about the role they could play in facilitating DSR. In the latest distribution price control (2010 to 2015) review[53], they included initiatives that were intended to equalise incentives between investing in new assets or investigating the potential to pursue operational solutions. The purpose of this change is to encourage DNOs to consider the relative merits associated with operational solutions such as DSR. Ofgem also established the Low Carbon Networks Fund to trial new technologies or commercial arrangements to facilitate, among other things, DSR, local generation and energy efficiency.

Role for aggregators

Demand response from homes and businesses is only of real value where it is aggregated and location specific (i.e. relative to the network). This requires further segmentation of energy

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[52] Ofgem, Factsheet 97: Updated Household energy bills explained, 2011

[53] Distribution Price Control Review 5 (DPCR5) http://www.ofgem.gov.uk/Networks/ElecDist/PriceCntrls/DPCR5/Pages/DPCR5.aspx

users and better understanding of use profiles and is highly likely to require a new role in the energy market place, that of the demand aggregator or energy service provider, this could be a retailer, a DNO/DSO or a third party. It is likely that there would need to be direct relations with customers. Aggregators are already working to aggregate loads from larger energy user (as noted earlier) and there is a lot of industry debate about the value in replicating this model at the lower voltages.

Third parties such as aggregators and ESCOs could bring new value, competition and innovation in Demand Response, but also, potentially, they bring some risk to others in the value chain, plus add a layer of complexity in terms of benefit-sharing and multi-party agreements.

6.5.3 Generators

The generators who are vertically integrated with supply businesses may be able to cope with selling fewer units (due to demand response) if the revenue can be made back in other ways (e.g. by improved efficiency by increasing market share, or developing new energy services). However, standalone generators whose only source of revenue is to sell units of electricity will have little interest in selling fewer units.

6.5.4 Suppliers

Balancing and settlement arrangements for non-industrial (i.e. half hourly metered buildings) mean that an incentive offered by a supplier to reduce peak demands and thereby reduce wholesale energy price is then shared across all suppliers. This does not act as a business incentive for a supplier to promote demand response. Ofgem have started to consider this issue. They are considering the potential for half hourly settlement for domestic customers and the potential design of time of use (ToU) tariffs and real time pricing. Elexon have published a paper providing a vision for how the UK could transition to Smarter settlement where the settlement arrangements reflect changes in individual consumer's demand.[54]

6.5.5 Cross cutting issues

Overlaying all of the challenges listed above there is one point which continually comes up in discussion around demand response: Where does the true value lie?

The overall benefits case is quite clear but no individual market actor has a strong incentive to deliver cost or efficiency savings to the benefit of the overall electricity system where the benefit may largely fall to other players – or, worse, impose a new cost on them in facilitating delivery to others.

Actions by some in the value chain can create impacts for others and it is not clear how information would be shared and in what timescales; the need for co-ordination could become increasingly important. For example, a retailer or aggregators might contract with a group of customers in a small geographic area to provide demand response via electric vehicles or fuel cells for wholesale market benefits. However, if delivered in a small geographic area this could have a significant impact on the distribution network's ability to cope with peak demand, if there is a mismatch between peak demand periods for network and wholesale purposes. Eventual agreement on information-sharing may be essential to avoid the risks of financial exposure to unpredictable or unknown demand-response arrangements put in place by others in the value chain.

Industry codes and agreements between all in the value chain (customers, suppliers, networks, aggregators, system operators) will need to evolve and adapt. This includes in respect of embedded generation or micro-generation (when exporting can have an equivalent effect to a reduction in demand).

The economic and practical complexities of many millions of agreements to deliver household and small business demand response where each agreement has a small value could be overwhelming. Aggregation by suppliers themselves, or, by other market actors will be necessary. Third-parties may contract with others (including customers) to deliver demand-response.

Each sector will have different mechanisms for capturing the demand side response potential; for industry this is likely to be pre-arranged through contracts tailored to the individual site's specific needs, and for the domestic sector it is likely to be via tariffs and incentives.

The benefit to each needs to be sufficiently clear to make it worth-while for each to participate and invest in automated equipment etc.

At this stage, whilst there is some understanding of the costs and benefits, there does not seem to be a clear and consistent understanding of the value chain.

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[54] Smarter settlement – making the most of tariff innovation http://www.elexon.co.uk/wp-content/uploads/2011/10/Smarter_Settlement_Final.pdf

6.6 Smart Systems Architecture

The benefits case for Demand Response is too strong for it not to be a material consideration in setting out a future intelligent energy system for London. The detail of what is included in this architecture, and at the project level is of course less clear.

Summarised below are the technologies and players (relevant to demand response) that seem likely to form a part of a future Smart energy network for London.

6.6.1 Technology

Smart meters will be installed in every home and building and the uptake of smart appliances will increase.

These systems will be able to communicate (either directly or via a proprietary system) with active network management systems operating between buildings and the substation level to shed discretionary load in buildings as appropriate to overcome short term network stresses and to reduce peak demand and flatten wholesale energy prices.

6.6.2 Players

The regulatory and commercial landscape will evolve to change the role of existing market players and to facilitate new entrants to the market. There may be an increased role for aggregators in the market or DNOs will evolve to have a customer interface such that they have more control and can incentivise consumers for efficient network operation. A fuller description of players is given in Sections 2 and 3.2.2.

6.7 Project level – Functional Specification

Some of the key things that have arisen from the demand side management literature review and from relevant discussion with industry players, and which inform the systems architecture/functional specification (see Section 3) are listed below

- National Grid has highlighted the need for more automated control and noted that increases in embedded generation will require greater transparency to the TSO, or for DNOs to take a more active role in managing system operations, as well as the potential value that could be realised by suppliers and aggregators through using decentralized storage technologies to shift renewable generation to higher value, higher demand periods, or for DNOs to use storage to manage local network constraints, should the costs of storage come down and value be spread across different parties.
- Refrigeration products would need equipment that could communicate the status of the appliance i.e. where in the cooling cycle it was and for how long any service could be provided for. They could provide a frequency response for the TSO.
- Wet appliances would probably be accessed via a time of use tariff and response could be coordinated via a supplier or aggregator and wouldn't need to include specific equipment.
- Communications infrastructure which can cope with huge data volumes (47M meters reading every 30mins = 2.3billion reads/day) – will require various layers to be interoperable. As set out in Section 8 this will require a combination of Home Area, Local Area and Wide Area networks. (HAN, LAN and WAN)
- The role of aggregation could increase with aggregators providing an interface with the consumer or with suppliers and DSO playing a greater role in aggregation.
- Need for greater interactions in order to manage system demands at the distribution level – DNOs-TSO, DNOs-suppliers/aggregators, particularly around electric vehicles, heat pumps and micro-generation.

7 The contribution of distributed generation in an intelligent energy network

7.1 Introduction

There are two ways of meeting increased demand for electricity and balancing demand at the distribution level. One of these, reducing demand and shifting demand, is covered in Section 6. The other is by increasing and managing local generation and is the focus of this section.

In the future, due to drivers to diversify supply and reduce carbon emissions much of the increased generation is likely to come from renewable generation. Some of this generation will be in the form of small scale distributed renewable generation connected to the power network at the local distribution level. This section explores the opportunities and challenges for integrating increased distributed generation in the local power networks in London.

The section aims to:

- Outline the opportunities for 'distributed generation' as part of an integrated intelligent energy network
- Consider the role of storage in facilitating the uptake of generation technologies
- Consider the scale of benefit that heat technologies including thermal storage can deliver in terms of grid balancing and stability and avoided investment in infrastructure

Provide a summary of findings and outline the important issues that should be carried forward into the 'Smart' functional specification for London.The nature of the distribution network is evolving from a passive network, where all load flows from the top down to a dynamic network with multiple generation in-feeds and demand management systems switching blocks of load resulting in complex multi-directional power flows. The transition to a dynamic network is driving DNOs to revise their current operating regimes and adopt new technologies to control and manage the complexities of the new age networks.

It is in the areas of monitoring and control, largely supported by computing science and enhanced communications capability, where the largest changes are apparent and it is this area which is at the heart of the current "Smart Grid" initiatives. Much has already been done to enable better control of large scale generation and transmission; the real opportunity (similar to demand management) is in bringing these advances down to the next level – to the distribution networks.

7.2 Opportunities for the Future Electricity Networks

Development activity for the future electricity network is focused around a number of key aspects of the distribution network:

- Power Network Hardware
- Distributed Generation (inc Electric Vehicles & V2G Technology)
- Storage
- Network Management & Control
- Demand Side Management
- Customer Engagement

The first four of these are examined in the following sections – the last two are covered in Section 6.

7.3 Power Network Hardware

Power Network Hardware involves the development of new products which will provide the flexibility to operate the distribution network in a manner which is responsive to the changing technical characteristics of the network. The types of products currently under development include fault current limiters, high performance batteries, on-load tap changers, switch actuators, and smart fuses. A lot of the products are either at the technology proving phase or early stages of production. A key challenge will be to achieve a price point for the products which is conducive with widespread application across the distribution network. The ability to enable these devices to interact and communicate to a central control facility is described further within Section 8 of this report.

7.4 Distributed Generation

7.4.1 Photovoltaics (PV)

PV technology continues to improve both in terms of technical performance and cost to install. The availability of Feed In Tariffs has also helped increase the number of installations in the UK. PV can make a contribution to reducing demand in local areas however output is erratic and difficult to predict on a day to day basis which in areas of high take up may cause voltage stability issues for the DNO.

Output is also at its highest at times when demand has traditionally been low, i.e. during daylight hours and the summer months. To gain maximum benefit from investment customers will be required to make lifestyle adjustments and consider storage devices, e.g. hot water tanks, which can maximise use of the low cost energy.

At present PV generation is regarded by DNOs as a "masked load" in that its contribution to the overall network management can be ignored. This position will change in future. The installed capacity of Solar PV increased from 77 MW at the end of Mar 2011 to 1014 MW at the end of Mar 2012. As a mechanism for balancing loads on the electrical network, the use of PV will be limited due to the unpredictable nature of the output.

Currently, domestic PV is isolated from the wider distribution network, as substation infrastructure has not been designed for reverse power flows.

National Grid have noted that one possible 'value proposition' for PV would be for it to developed in combination with storage to enable self-balancing – which however may also create competition in Demand Response – i.e. to store excess power at system low-cost periods and to export power at a higher-price (peak) periods. In practice, the current flat-rate tariff structure of the Feed In Tariff acts as a disincentive for this to develop for the time being, however as battery technology improves and costs reduce this could be a viable proposition, subject to changes to the regulatory support system.

Even relatively short term battery storage could have an impact by using power generated in daylight hours to reduce demand peaks in the early evening peak demand period. A Smart City workshop organised by the London Legacy Development Corporation in 2011 highlighted a pilot being undertaken by the Pecan Street project in Texas to study the benefits of this approach.

PV battery storage is still some way from commercialisation and will rely on cheaper storage becoming available, but the drive to develop low cost battery storage for electric vehicles will also help advance battery storage for PV as well as providing a route to store PV power generation in the batteries of electric vehicles during the day.

7.4.2 Wind

Installation of large scale wind turbines has increased dramatically in the UK in recent years, as the Industry works towards meeting the Government's 30% electricity renewables target by 2020; wind accounts for approximately 26% of the target. The majority of installations to date have been large scale on-shore wind farms; however emphasis is beginning to shift towards offshore installations. Available space limitations will probably restrict any wind driven distributed generation within London to small scale single turbine installations serving large commercial or industrial developments. GLA's Decentralised Energy Study identifies technical capacity for some medium / large scale turbines (0.3MW / 2.5MW) – totalling 2,200MW across London.

Projections of wind generation contribution to the UKs future energy mix are consistently high, ranging from 30% to 50% of generation in 2050 generated by onshore, and predominantly off shore wind installations. There is already 26,554 MW of off shore wind farms in planning some of which will ultimately contribute to the energy demands of London. Installed capacity at the end of March 2012 was 4,632 MW of on-shore wind and 1,838 MW of off-shore wind.

7.5 Storage

The increasing capacity of renewable energy generation introduces new complexities when trying to balance generation to demand due to the intermittent nature of availability. One way to bridge the timing mismatch between renewable generation and demand is to use storage devices to hold the energy until required. In some instances the stored energy may be reintroduced into the network as electricity or may be converted into an alternative energy source, e.g. heat to supply a district heating scheme.

All forms of energy conversion for storage, will involve energy loss, as an inherent part of the process however this may be preferable and more economic than paying constraint payments to generators to turn off wind turbines when demand is low. Use of electricity to produce low grade heat storage is highly feasible and potentially cost effective however production of electricity from low grade heat is not considered viable.

Developing economical technologies to store electrical energy so it can be available to meet demand whenever needed represents a major challenge for the industry. Many variants of battery storage options are available in the market place but none of these are currently economical or physically capable of being deployed within a major city environment such as London. This will change as further research and development is undertaken and as technologies advance; many of the large commercial organisations are currently developing new and economical options for the market however, these have yet to be deployed within a commercially viable project to understand how these can be utilised at scale.

It is recognised throughout the industry that the use of an energy store will enable the optimal use of renewable sources and remove the uncertainty of intermittent generation, which in turn will provide local distributers the ability to call upon local energy stores when demand is at its peak or when network constraints require the network to be re-configured.

Storage devices will be readily available in the future and in various guises; storage of energy generated by renewables could utilise developing battery technologies as one option which has the advantage of immediate dispatch when additional capacity is required.

7.5.1 Electric Vehicles (EVs)

An extensive electric vehicle support infrastructure within the London area could also potentially provide a means to maximise the availability of low cost renewable energy and coupled to vehicle to grid (V2G) technology provide a mechanism to DNOs to manage peak demands on the network.

The UK currently has in the region of 32 million vehicles registered for road use, and transport studies have indicated that on average only 3% of this total are being driven at any point in time. This figure obviously fluctuates across the 24 hour period, e.g. peak work commuter periods, nevertheless this represents a very large potential energy store/energy generator if battery powered vehicles can achieve reasonable levels of penetration within the overall market.

London and other large cities would seem to be prime areas for a high penetration of both private and public transport electrically powered vehicles for the following key reasons:

- High levels of daily commuting over short trip lengths
- Potential high level of localised pollution resulting from conventional transport
- High density customer base to support infrastructure development.

Penetration of EVs in the marketplace has to date been low. DECC estimates show market penetration being of the order of 30% by 2050 however other studies have indicated figures which range from a pessimistic 12% to an optimistic 63%. This range demonstrates the level of uncertainty surrounding adoption of EV technology. The high initial capital cost and the uncertainty regarding battery life span is depressing customer interest. Sales of pure EVs in the UK since 2006 have been in the order of only 2,500.

The vehicle battery and its ongoing maintenance is one of the most significant factors in the cost of EVs. Lithium-Ion technology forms the foundation of most EV batteries currently but many alternatives are being investigated. Lithium-air technology tops the league at the moment in terms of power density and is a quantum leap ahead of lithium-ion however significant technical hurdles have to be cleared before this becomes a feasible production option. The traditional cylindrical battery cell form factor is being replaced by a cuboidal pouch design which is easier to package within the vehicle chassis form factor.

Installation of vehicle charging infrastructure is somewhat of a chicken and egg situation. If penetration remains low or develops at a low rate over many years, commercial bodies are unlikely to direct capital to building the infrastructure to support EVs and make them a positive contributor to the overall energy management portfolio. The current economic situation means Government funding is limited and is competitively sought by other major infrastructure improvements e.g. rail, water, roads etc.

Analysis undertaken by the Energy Technology Institute (ETI) and reported at a recent Energy Institute event, has looked at National Travel Survey data and concluded that 70% of current journeys undertaken by car are within a 40 mile round trip and could therefore be serviced by electric vehicle charging at home. They have concluded that wider roll out of charging networks beyond the home would only gain a further 5% of journeys.

However others see the wider roll out of charging infrastructure as an essential element of achieving high levels of take up.

Work is progressing to develop a standard charging pedestal connection (plug & socket), but currently a number of variants exist. It is unlikely a standard battery will emerge in the short term due to differing vehicle chassis designs and manufacturers preference. This may limit the role that "Battery Exchange Stations" play in the options to deliver a quick charge service to EV vehicles.

V2G applications will increase the duty cycle of the battery and will have an impact on the battery life and performance degradation curve. Opinions are currently divided on the impact of V2G; for every study indicating V2G reduces battery life there is an opposing study indicating that working the battery harder actual increases lifespan. Battery replacement will however be a significant factor in the lifetime costs of an EV and thus have a significant impact on the business case.

Assuming high EV penetration in the London area, V2G, technology has the potential to contribute to the management of the electrical network, by providing a means of absorbing renewable generation when available or at times of low network demand, coupled to the ability of the collective EV battery bank to support the electrical network at times of peak demand.

Control of the EV battery network, will require complex control algorithms to operate and manage the V2G resources. The algorithms will need to enable customers to enter individual lifestyle requirements into the control decisions in terms of when their vehicle needs to be available.

7.5.2 Fuel Cells

Fuel cell technology can be applied to a range of applications including domestic energy production and powering vehicles. A number of vehicle manufacturers are committed to delivering working Fuel Cell (FC) vehicles in the foreseeable future and if successful they could compete with the EV market. As FCs have no high capacity battery, storage capability is limited, but in theory FC powered vehicles could be managed to provide a generation resource either collectively or connected in groups when parked. A number of challenging technical issues have to be addressed before FCs will be suitable for widespread adoption including cost effective extraction, storage and distribution of hydrogen gas to fuel the cells. Existing product offerings have hydrogen extraction as an integral part of the FC unit, however this increases the capital cost significantly and introduces high ongoing maintenance costs.

Fuel cells are seen as a potential opportunity in terms of distributed generation. Ceramic Fuel Cells, who were consulted as part of this study, plan to install the telemetry that would enable multiple fuels cells to be aggregated to offer demand response at a distribution or national level. Currently sizing of fuel cells in the domestic sector has been based on heat demand but in future the driver could be power generation. At present flat rate Feed in Tariffs act as a barrier to this demand response developing.

7.6 Network Management & Control

The role of the potential technologies outlined above will require a much more intelligent energy network. As the network evolves from a passive to dynamic state, much higher levels of status monitoring will be required to allow the continued stable and safe operation of the network coupled to the flexibility to deliver electricity in the most economic manner and facilitate increased granularity in time of use pricing.

The population of sensors on the network will increase dramatically potentially covering every 11kV/LV substation on the network; if we consider that the London area alone has in excess of 17,000 such locations, the scale of the task becomes apparent. Sensors will capture metrics including current, voltage, harmonics, plant status, weather data etc and may be coupled to local computer processors which will directly initiate corrective actions in response to the changing inputs.

The broad implementation of Demand Response (DR) will be important, not only because it will enable smoothing of demand peaks and troughs, which are both carbon intensive in impact and costly to deliver securely with high certainty. Furthermore this will provide an incentive for the investment in technology that may also have additional energy efficiency impacts. This is particularly the case in Britain where the decarbonisation of energy will rely heavily on wind, which can cause local, regional and national uncertainty in supply.

7.6.1 Distributed Generation - Management Issues

Use of distributed generation and storage as part of an actively managed electricity distribution network will require complex control and communication systems to reflect the requirements of all contributors to and users of the electricity distribution network.

One crucial aspect of the widespread deployment of distributed generation is the question of the commercial contracts governing their operation and contribution to network management on an hour to hour/day by day basis. In many cases use of Distributed Generation will be addressing local issues; therefore it would seem more logical for the contracts to be with the DNOs rather than National Grid or suppliers. This could also potentially introduce greater flexibility in the grid connection costs charged to energy developers, where these schemes could provide network management benefits to the DNO (this may particularly be the case where new connections are not included as part of DNOs' forward plans). These are areas of ongoing debate.

In the case of small scale distributed generation such as PV, FCs, and Micro CHP, the role of an aggregator is likely to emerge as a key interface between groups of customers deploying generation devices with similar operating characteristics and/or flexible demand profiles and the DNO. New commercial arrangements, showing cost benefits to the customer, will be required to provide the motivation for customers to participate in energy management schemes and adjust their lifestyle accordingly.

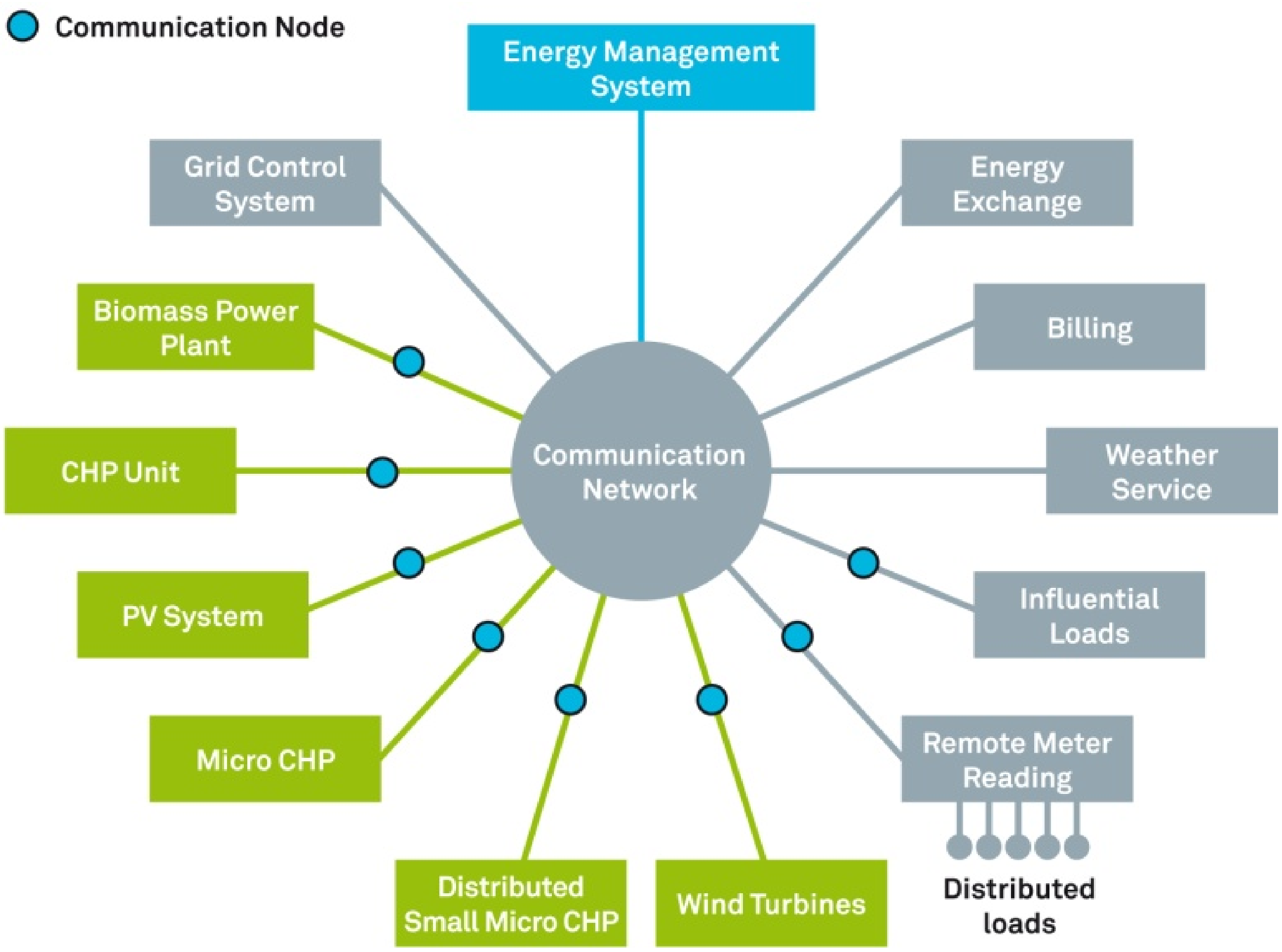

Figure 17: Virtual Power Plant Source mix

In some instances it may be necessary to use software architectures employing distributed intelligence to allow the complexity of the control decisions to be managed, and to segment the management decisions into levels of complexity which can be more easily visualised and managed. This is covered in more detail in section 8.

7.7 Virtual Power Plants

A Virtual Power Plant (VPP) is a collection of distributed generation assets collectively operated via a central control mechanism. Aggregators may build a local hierarchy of VPPs in blocks representing the specific operating characteristics, e.g. cluster of PV or FCs, allowing them to construct economic models to assist in despatch of the generation blocks. To mitigate the impact of the uncertainty regarding the availability of a specific renewable technology, several different technologies can be bundled into the VPP.

VPPs allow for the delivery of peak load generation, as well as the ability to match generation with load. VPPs also help to smooth the intermittent nature of smaller scale renewable generation, and for micro technologies, to benefit from distribution level management and controls mechanisms. They effectively aggregate all the generation together so that the assets behave like a centralised plant and enable the impact on the system to be managed.

Figure 17 demonstrates the possible mix of various energy sources, combined together to form various VPPs, which in turn combine to form a local generation system. As local contributing generators continue to grow and connect to the wider network, VPPs will provide a means for these assets to be integrated into the grid without disruptions, becoming part of a local power plant that is not necessarily located in the same geographical area.

7.8 Last Mile Balancing

Last mile balancing could be carried out based on specific asset investments on the network or subsidisation of certain assets with dual consumer and network uses, however it is likely that any balancing will need to be done within the regulatory and market framework established to enable demand response. For example, a DNO could invest in a CHP plant that provides heat to a local heat network, but could cease to provide this heat should there be a constraint on one of its nearby feeders and hence it may want to provide some of the electricity demand within that portion of the network from the CHP instead. This same scenario could be applied to the subsidization of micro-CHP in the home: with a conditional contract this could be utilized for a portion of time each day to generate electricity or heat for a home or set of homes within a local area. Similarly for periods of peak electricity generation it could be possible to use this energy to fill thermal stores either at a network or domestic level.

This sort of functionality is highly likely to require distributed intelligence to ensure the necessary actions can be coordinated in line with other demand responses, and to gather the data required to assess current demand response availability.

The measurements of utilisation of particular assets and resources will also need to be measured, stored and then communicated back to some central balancing or settlement body, in accordance with the regulations and the market model that governs such interactions. The exact functioning of such interactions and the feasibility of the examples mentioned are however not possible to verify without these market arrangements and regulations being in place.

The number of communication interactions that will be required between subcomponents of any such system at a local and/or regional level is not at present known. Therefore it is highly advisable to devise communications systems with spare bandwidth and high reliability as these are likely to be key requirements in systems that have time critical or important components.

7.9 Summary

It is recognised throughout the industry that the existing electrical networks will need to change to meet the future growing demand and diversifying requirements which will be placed upon the aging infrastructure. Initiatives are currently in place to enable DNOs to trial existing technologies and practices in differing ways and also to test developing technologies in a way never trialled before due to lack of funding and appropriate incentives being available.

Technologies are advancing and will continue to develop and facilitate additional improvements in the operation of the network, business practice improvements and the ability to better understand the performance and therefore management of networks.

A new regulatory regime is to be implemented which will bring about a change in how DNOs operate their businesses, this will also provide incentives and also new penalties to encourage change and investments. A number of key points have been identified relating to the future of the electrical networks:

- The existing and aging electrical infrastructure will not cater for the projected increases in demand without significant and strategic intervention
- New technologies are becoming available which will aid improved operations and management of networks
- Regulation is changing and will incentivise innovation within DNOs
- New applications will be required to operate and manage the future, more diverse networks.

8 The communications infrastructure

8.1 Introduction

The fundamental architecture of the power grid is relatively unchanged since it was designed many years ago. To support the future economic growth of the power grid in a sustainable and low carbon way the technologies that control and operate the grid and its connected devices must evolve. The key to an intelligent energy network is the integration of information and communications technologies into the power grid. This convergence of information technology and operational technology will be critical to a sustainable grid which is more cost effective, reliable and supportive of renewable energy sources.

The development of common intelligent communications mechanisms using layered protocols and open standards will allow the system to evolve and adapt to emerging technology and requirements.

From a technical viewpoint there is no real challenge in terms of communications technology and the driving force is usually an economic one. The key is to define and agree standards for information exchanged to enable the connection and use of intelligent generation and controls. Existing communications infrastructure and control applications were designed for a very specific set of requirements. As we move forward with a future set of requirements the existing technology will be required to be replaced or enhanced.

8.2 Current ICT Infrastructure

All the distribution network operators in Great Britain use a Supervisory Control and Acquisition (SCADA) system to bring operational data back from the field and provide capability for remote switching. The communications technology supporting the SCADA infrastructure is a mixture of a number of different technologies such as fibre, GPRS, and satellite.

For intelligent energy technologies to be effective a new approach of information and communications technology will be required. This new technology will not be a simple replacement of existing SCADA infrastructure; it will, in many places, be an additional fabric to bring data and control from Smart Meters to allow more intelligent management and operation of the network. This change will dramatically increase the volume of data and introduce complex processing requirements.

For many years there has been a common data interchange mechanism, the data transfer network (DTN), which supports interaction between suppliers, distributors, data collectors, meter operators and others in the GB market. Additionally there are information exchange standards which define how information is exchanged in the energy market - for example information exchange related to wholesale trading and the balancing and settlement mechanism is exchanged in a defined standard format. In the near term future development in this area is likely to consist of extension to the existing standards to support smart grid and emerging market requirements. The planned rollout of smart metering will introduce a dedicated communication service to support over 140 different message interactions. Some of these messages will be dedicated to providing data to the distribution network operator (DNO) to support outage management, service quality and load management functions.

The roll-out of smart meters into all properties within GB will be the biggest undertaking impacting consumers and the utility industry since the conversion to natural gas in the 1960s and 1970s. The programme is scheduled to commence in 2014 and to be completed by 2019 and is intended to facilitate the biggest transformation in the operation of the electrical networks since they were first constructed.

Energy suppliers and DNOs will gain access to new granular consumption data which will facilitate improvements in the billing cycle and accuracy and enable improved operational knowledge of the networks at the lower voltage level.

Smart meters will enable consumers to gain visibility of consumption data which has previously been unavailable to them. This will be provided via In-Home-Display units and is envisaged will facilitate consumers to become more energy conscious and in its use. This can be further enhanced by the introduction of incentives from energy suppliers to move use of in-home appliances, and therefore demand, to times of the day when demand for energy is lower. It will therefore be incumbent on the energy suppliers to create new tariffs to provide the necessary incentives to consumers.

The introduction of smart meters requires the development of a GB-wide communications infrastructure to enable the transportation of the huge volumes of data which will be created. This new communications capability may in the future also support the additional functionality and operation of the 'smarter grids' of the future.

8.3 Smart Energy Distribution Grid

As we move forward to 2050 the demand on networks is projected to increase significantly; the implementation of demand reduction measures will assist in managing this. The introduction of embedded renewable or other generation at the distribution side will drive a need to measure and manage any impact on supply and power quality. Over the coming years sensors will be attached to the low voltage network, which coupled with information from smart meters will allow the DNO to monitor network performance with improved information. To achieve this, the DNO will receive data from smart meters through the DCC and analyse this data alongside information from sensors attached to the network, allowing a better understanding of the impact on the network from distributed generation and increasing demand.

Asset management will be an important feature in the distribution networks of the future. The move towards an intelligent grid will involve the deployment of new types of sensors to both monitor equipment health and also to actively manage the assets within specified limits. These devices may also indicate conditions where equipment failure is likely to occur in advance of the event. Due to the number of assets, the data volumes and processing requirements of this will be difficult to manage and new approaches to data transmission and storage will be required.

The use of electrically powered vehicles will add to the challenges of the DNO. Electric vehicles are likely to use plug and play technology, which requires significant information interchange between the DNO, the fuel supplier, the customer and the vehicle. For this to work effectively, standard protocols will need to be devised to allow interchange of data relating to the charging point load the vehicle charge and billing.

As the penetration of charging points and electric vehicles increases forecasting models will be required to predict the portable load from these assets. The DNO and potentially the TSO will need to understand the dynamics of the load through forecasts and real-time data. The potential for vehicle to grid (V2G) demand responses will require integration between the vehicle and other local storage assets, controlled by the DNO control centre. This will require a centralised management, or a set of self-managing systems, with overview level communication to control centres. Charging will be a complex area to manage with geographically spread consumer interaction and power flow. Managing the information around these transactions will be critical for accurate billing, other financial instruments and network management.

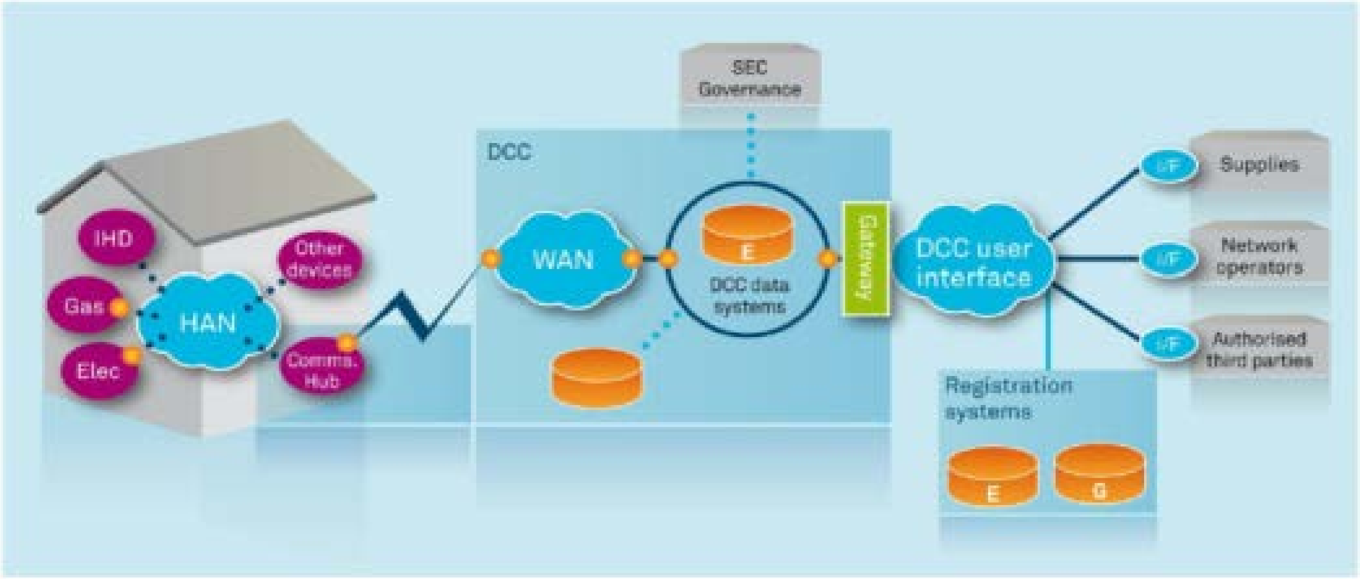

Figure 18: GB Smart Metering Data and Communications Services (Source: DECC reproduced AECOM).

In the future, as storage technologies become more economical to deploy there will be a requirement to support new commercial frameworks and supporting management and control systems.

The DNO will need to support these initiatives through feeding information to enable these new operating models. This could include an interaction with energy aggregators, demand side response and V2G programmes. There could be the potential for localised management and control of network balancing and optimisation of the assets within the area rather than managing centrally, which would require significant overheads.

The planned smart meter roll out in Great Britain will deploy meters and a home area network, which will be connected back to a centralised point for routing to suppliers, DNOs and third parties. This may be a vehicle to support smart grid and other home control services such as interaction with heat networks and electric vehicle networks.

Is identified earlier in Figure 9, the Home Area Network will also provide a vehicle for remote control and management of heating systems and appliances from a range of user interfaces including mobile phones, tablets, and televisions. Passive Systems, Savant and other companies we spoke to are already developing applications with these capabilities.

Demand response will require close to real-time control for aggregated fast response offerings. To do this will require a reliable and responsive communications and data processing infrastructure. The information will need to be handled and processed on demand. Perhaps the DCC communications network will suffice or an alternative dedicated parallel system will be required. Whatever the communications infrastructure required it will require system inputs from Building Management Systems, smart meters, DNOs, suppliers, demand aggregators and others. The Demand Response instruments could be managed by the DNO or could be managed through a third party Demand Operator who has the role of a super aggregator of services across homes, communities and buildings. However this develops it will require a complex set of financial and legal instruments and system integrations. The systems supporting these frameworks must be robust if they are to maintain the health of the critical power infrastructure in times of high load and stress. A fundamental requirement of the DNO is to ensure the availability of power and the safety of those working on or connecting to the network, demand responses implemented at a local level to avoid investment in infrastructure will have to be extremely robust if they are to avoid that investment.

It is not possible today to predict exactly what organisation or organisations will evolve to manage the complex interactions between demand management mechanisms and generation on both the heat and power networks. For the purposes of developing a plausible system architecture we have shown a role emerging for district system operator (DSO) to take on these functions, in practice this role could be split across a number of organisations, in a similar way to National Grid and Elexon managing and balancing the transmission network.

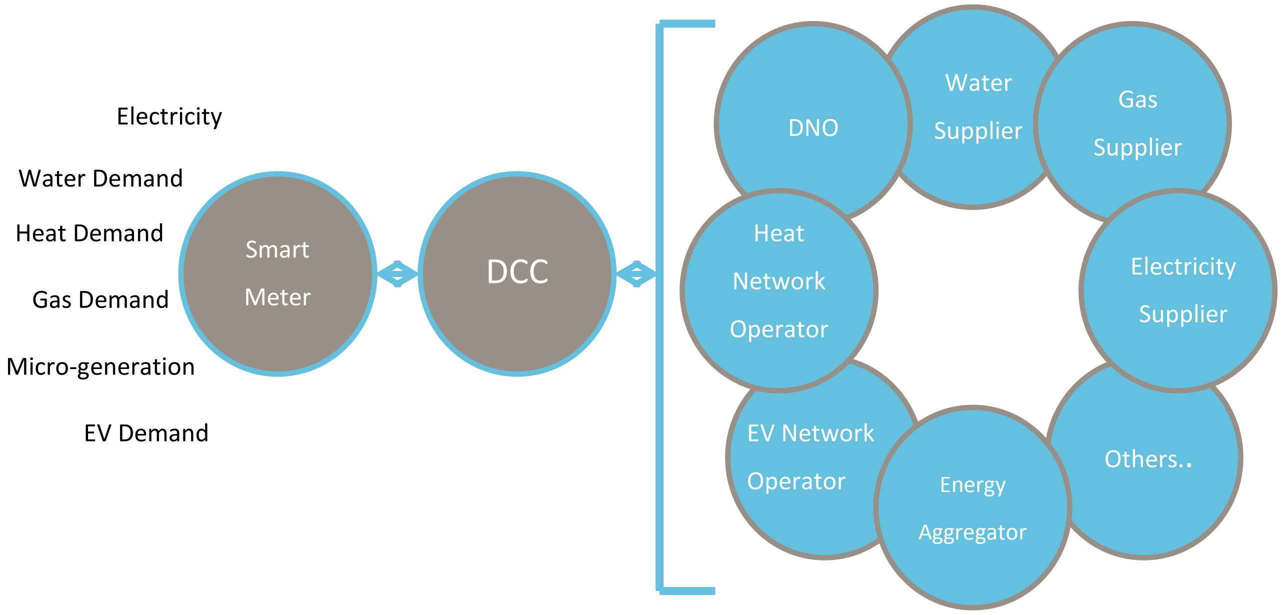

Figure 19: Potential future DCC users

8.4 Smart ICT Infrastructure

The common model for control of electrical, gas, and heat networks is SCADA. SCADA has a centralised design with a master station which monitors conditions at remote stations and manages any necessary analysis and control functions. Given the complexity of the advancing smart grid and emerging markets a centralised approach to analysis and management of complex distributed networks is very demanding. An alternative approach is to manage analysis and control of a network in a decentralised way. By deploying intelligent electronic devices (IED) in the field, local conditions and control adjustments can be performed without the reliance on centralised control. This is an important consideration where advanced network controls require near real-time monitoring and management. The overhead of moving large volumes of data from field sensors to a centralised control point for analysis and action could be considerable. By being able to process and act on the data locally has a vast benefit. This approach could be used for a variety of potential solutions such as real time thermal rating, energy storage management, voltage control and Load Control. As an example there may be a situation where PV penetration is high and cloud transients are causing unwanted fluctuations on the network, a localised controller could effectively balance PV generation, micro storage, and network capacity at a local level.

Case Study: Northern Power Grid: Customer Led Network Revolution[55]

A key technology to be implemented as part of the Customer Led Network Revolution project is Enhanced Automatic Voltage Control (EAVC) which will be applied on assets including primary transformers, secondary transformers and voltage regulators.

Enhanced Automatic Voltage Control (EAVC) offers two significant enhancements over current approaches, namely; measuring and responding to voltage at the point of delivery rather than deep in the network, remote from customers

EAVC, particularly combined with remote monitoring, has the potential to enable the distribution system to be operated closer to design and statutory limits without increasing network risk or reducing performance for customers.

There is some activity in trials of distributed network intelligence through Ofgem's Low Carbon Network Funded projects such as the Customer Led Network Revolution.

The local communications network for these autonomous controllers and sensors could consist of many technologies with selection based on technical requirements and economics.

District heating networks often have large energy consumers and the load is subject to large variations. The majority of current systems are controlled based on the required temperature and flow rates rather than balancing the system as a whole. As technology becomes more sophisticated and new markets develop the control system will have to cope with a more dynamic and fluctuating demand landscape. This will mean processing a larger volume of data and information to make control decisions in a shorter time frame. As demand side management and load control models are applied to heating networks bi-directional communication and distributed intelligence will be required. There are many potential future applications of load control:

- Asset Management – Avoiding peak load on heat exchangers
- Economics – Optimisation of fuel costs
- Carbon emissions reduction
- Supply market competition

As an example, a district heat network load shedding project demonstrated a reduction in daily load variations by using distributed load control to smooth variations in energy demand without impacting the quality of service. Monitoring and controlling district heating systems to provide a demand response will be complex and will need to move towards a distributed architecture to maintain sufficient fault tolerance and computational performance.

Centralised intelligent network optimisation will result in transfer of large data volumes coupled with complex processing power requirements. Localised optimisation through autonomous control elements in the field is the likely future to support advanced network management. Distributed network management will improve the resilience of the network. Self managed local areas will have less reliance on centralised control and also will be more resistant to security attacks.

Communications technologies to support electricity distribution networks command and control have been deployed to meet specific requirements. Primary substations are usually connected to the control centres with fibre and medium voltage (MV) and low voltage (LV) substations are connected typically with radio based communications. At the LV distribution network the number of assets which potentially could be monitored and controlled increases significantly. Over the last few years the main technology deployment within the LV network around Europe has been Smart Metering. There have been many trials using a variety of differing technologies worldwide, with metering manufactures having to keep pace with a variety of communications module options. The main challenge in Smart Metering communications is the last mile connection. Radio based wireless technologies suffer from problems such as infrastructure cost, coverage and premise

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[55] http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=98&refer=Networks/ElecDist/lcnf/stlcnp

penetration. Power line carrier (PLC) technology however can deliver 100% coverage and penetration. A typical smart meter communications infrastructure could be narrow band PLC with a modem at the meter and a data concentrator at the LV transformer – satellite is typical for the backhaul (sending collated data back to a central point). Italy has one of the largest Smart Metering deployments which used PLC technology for the last mile. In parallel with the deployment in Great Britain, France and Spain will be deploying smart metering infrastructure based on PLC for the last mile of their networks.

With the smart metering deployment in Great Britain between 2013 and 2019 it is likely that in the future the DNOs, water utilities, and others will utilise the information from consumer sites through the deployed DCC infrastructure.

Heat networks control devices could in theory utilise the DCC communications infrastructure to read data from the consumer and other devices on the network, and relay data to DNOs and Suppliers. This would for example require Smart Heat Meters linked to the smart meter via the Home Area Network. Given the scale of the DCC communications deployment the economies of scale will likely favour use of the DCC rather than a dedicated infrastructure. Also as the heat network optimisation could result in changing electricity consumption, the DCC infrastructure would be ideally placed to route operating data to the DNO, National Grid and suppliers.

For this reason the system architecture for an intelligent energy system in London set out in Section 3 has assumed the emergence of a Distribution Systems Operator (DSO) who would manage power and heat networks at the distribution level.

9 Summary

The key opportunity for an intelligent energy system in London will be to manage and balance generation and demand at the local distribution level. This will enable distributed low carbon and renewable energy generation to be maximised while limiting the cost and disruption associated with network reinforcement.

Network balancing including trading of generation and demand responses already occurs for electricity at a national level with these activities being managed by National Grid and Elexon. For balancing to occur at a distribution level, District Network Operators will require far greater telemetry built into the assets on the low voltage network and will require a regulatory framework that enables generation and demand responses to be monitored, triggered and controlled in an integrated way at the distribution level. This does not exist at present, but we have set out in Section 3 a system architecture for how this might plausibly emerge in the future and be integrated across power and heat networks.

The proposed system architecture sets out a range of ways that systems could be operated to manage and balance demand against available generation. It has not been possible within the scope of this study to assess whether sufficient value could be created for the end user, DSOs, energy suppliers, or aggregators to justify all the potential demand responses set out but the technical potential exists for all of them.

The business model for DNO's has traditionally been based around investment in new assets and capacity reinforcement. At present the use of system charge for the distribution of electricity forms a relatively small element of the price of electricity and a new regulatory framework would need to emerge that creates value for those able to offer a demand response. Flat rate Feed in Tariffs and Renewable Obligation Certificates will potentially act as a barrier to some of the demand responses set out in this report.

If active network management is to occur at the local distribution level across both heat and power networks, current DNOs, or our suggested Distribution Systems Operator (DSO), will need to have the right regulatory drivers, but they will also require the evidence to provide confidence that demand management can provide a robust alternative to investment in new network assets. Gaining this confidence is likely to require major demonstration projects that can test combinations of system components, commercial arrangements and consumer reaction to demand response signals. This is likely to require integrated demonstration over a local distribution scale.

The functional specification for many of the elements of the intelligent energy system will be in the hands of component manufacturers who will develop products that utilise common communications protocols based around the home area network and the functionality of the Smart Meter. This will in particular be true for the demand management systems associated with the home.

Similarly the detailed functionality of the wider communications required for DNO/DSOs to manage demand at the distribution level will inevitably be influenced by how the regulatory system evolves and will ultimately be delivered by technology companies and controls manufacturers developing the relevant tools and components in response to regulatory and market requirements.

In practice there are limitations on how far a functional specification can go at this stage, while we can identify some of the functions that components will perform and their likely control inputs and outputs to perform these functions, the final specifications for these components are to some extent dependent on the final communication specifications agreed by Government and regulators for the Smart Meter roll-out and the communication protocols adopted by product manufacturers and technology companies in response to these.

The control regime for power supply and district heating networks will be influenced significantly by how DNOs and regulators respond to current trials of technology solutions and demand response mechanisms being undertaken as part of Low Carbon Network funded projects and wider research programmes.

Section 4 provides a summary of the functional specification issues for project developers that we have been able to discern from the research undertaken to date. This would need to be developed further as service offerings and industry standards develop.

The detailed specifications will best be developed by bringing together developers, technology providers, DNOs, and communications and technology providers to implement systems as part of pilot projects looking at the full range of components at a local distribution scale.

This should be a focus for future research through programmes such as Ofgem's Low Carbon Networks fund, the ETI Smart Heat programme, the TSB's Future City Demonstrator and Catapult and through European funded research programmes in this area.

Having reviewed the issues and opportunities around heat storage, demand management, last mile grid balancing and the wider role of communications technology, we have set out in Section 3 the project team's combined view of the intelligent energy system that could evolve. The final way in which London's energy systems evolve will be dependent on the decisions made by policy makers and regulators, which in turn will be informed by feedback from the wide range of research currently being undertaken in this area. It will also be influenced by how the market responds to opportunities arising from technical innovation and regulatory reform.

Appendix A: Bibliography / Further Reading

This bibliography is not comprehensive but represents some of the key reports referenced in and informing this study. It is not an exhaustive list of the extensive literature available on smart grids.

Vision Documents

- Electricity Networks Strategy Group, Our Electricity Transmission Network: A Vision for 2020, 2009
- Electricity Networks Strategy Group, A Smart Grid Vision, 2009
- Electricity Networks Strategy Group, A Smart Grid Routemap, 2010
- Frontier Economics for Ofgem Smart Grid Forum, How to deliver smarter grids in GB, 2011
- IEA, Technology Roadmap: Smart Grids, 2011
- DECC, Smarter Grids: The Opportunity, 2009
- The Climate Group, Arup, Accenture, Horizon, Information Marketplaces: The New Economics of Cities, 2011
- European Commission, European Smart Grids Technology Platform: Vision and Strategy for Europe's Electricity Networks of the Future, 2006
- Poyry for the CCC, Options for Low-Carbon Power Sector Flexibility to 2050

Market

- HM Treasury/DECC, Energy Market Assessment, 2010
- Ofgem, 'Updated Household energy bills explained', Factsheet 97, 2011
- Ofgem, Electricity and Gas Market Supply Report, 2011
- Elexon, The Electricity Trading Arrangements: A Beginner's Guide, Guidance Note, 2009
- Energy Generation and Supply Knowledge Transfer Network, Low Carbon Heat: Commercial Opportunities and Challenges for the UK, 2011
- Bluemark Consultants, 'An Introduction to the Energy Markets': http://www.bluemarkconsultants.co.uk/an-introduction-to-the-energy-markets.php
- Audit Office, The electricity generating landscape in Great Britain, A briefing for The House of Commons Energy and Climate Change Select Committee, 2010
- DECC (AECOM and Poyry), The potential and costs of district heating, 2009

London Reports

- GLA, The London Plan, 2011
- GLA, London Climate Change Mitigation and Energy Strategy, 2011
- GLA, London Decentralised Energy Capacity Study, 2012
- Decentralised Energy for London, Towards a District Energy Manual for London: seeking your opinion, 2011
- UKPN, Long Term Development Statement (LTDS): Network Summary 2011, 2011

Technology Reviews and Value Analysis

- EPRI, Estimating the Costs and Benefits of the Smart Grid, 2011
- US DoE, A Compendium of Modern Grid Technologies, 2007
- Frontier Economics and EA Technology for Ofgem Smart Grids Forum, A framework for the evaluation of smart grids: a consultation document, 2011
- Aviat Networks, Smart Grid Wireless Technology Comparison Chart, 2010
- GridWise Alliance, Realizing the value of an optimised electric grid, 2012
- Ernst and Young, Smart Grid: A race worth winning - A Report on the Economic Benefits of Smart Grid, 2012.
- Imperial College London and ENA, Smart Metering Benefits, 2010
- Bradley and Leach, University of Surrey, A review of current and future costs and benefits of demand response for electricity, 2011

Research and Development Programmes

- Knowledge Transfer Network for TSB, UK Smart Grid Capabilities Development Programme, 2011
- European Commission, Strategic Research Agenda for Europe's Electricity Networks of the Future, 2007

Regulation

- Electricity Networks Association, The Distribution Code and The Guide to the Distribution Code of Licensed Distribution Network Operators of Great Britain, 2011
- DECC, Planning our electric future: a White Paper for secure, affordable and low carbon electricity, 2011

Demand Side Response

- Poyry and University of Bath for DECC, Demand Side Response: Conflict between supply and network driven optimisation, 2010
- AECOM for Ofgem, Energy Demand Research Project: Final Analysis, 2011
- IHS Global Insight, Demand Side Market Participation Report for DECC, 2009
- Blekinge Institute of Technology, Demand side management in district heating systems, 2007
- AECOM for Ofgem, Energy Demand Research Project: Final Analysis, 2011
- Sustainability First, GB Electricity Demand Paper 2: Initial Brattle Electricity Demand-Side Model – Scope for Demand Reduction and Flexible Response, 2012
- Sustainability First, GB Electricity Demand Paper 3 - What Demand Side Services Could Customers Offer in 2010? Industry Electricity Demand, 2012
- Strbac et al., Imperial College in collaboration with the Energy Network Association, Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks, 2010
- Ofgem, Demand Side Response: A Discussion Paper, 2010
- Seebach et al., Costs and Benefits of Smart Appliances in Europe, 2009
- Blekinge Institute of Technology, Intelligent distribution load control, 2008

Smart Metering

- DECC, Smart Meters Implementation Programme, 2011
- Imperial College London and Electricity Networks Association, Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks, 2010
- Mott MacDonald for BERR, Appraisal of Costs & Benefits of Smart Meter Roll Out Options, 2007
- University of Oxford, Environmental Change Institute, The Effectiveness of Feedback on Energy Consumption, 2006
- Enviros Consulting for Defra, The Potential for Behavioural and Demand-Side Management Measures to Save Electricity, Gas and Carbon in the Domestic Sector, and Resulting Supply-Side Implications, 2008
- DECC, Smart meter rollout for the domestic sector (GB): Final Impact Assessment, 2011
- DECC, Smart meter rollout for the small and medium non-domestic sector (GB): Final Impact Assessment, 2011
- DECC, Smart Metering Implementation Programme: Smart Metering Equipment Technical Specifications, Draft to the European Commission, 2012

Electric Vehicles

- The Royal Academy of Engineering, Electric Vehicles: charged with potential, 2010
- IBM, EDISON-Symbiosis of Electrovehicles and Grid, 2010

Storage

- IEA, Dynamic Heat Storage Optimisation and Demand Side Management, 2005
- University of Birmingham, Toke, D., DESIRE UK – Summary of Research Conclusions, 2009

Heat Networks

- Poyry and AECOM, The Potential and Cost of district heating networks, 2009

Other - UK

- National Grid, National Electricity Transmission System Seven Year Statement, 2011
- National Grid, Operating the Electricity Transmission Networks in 2020, 2009, updated June 2011
- Sustainability First, GB Electricity Demand – Context and 2010 Baseline Data, 2011

Pilots

- Ofgem, Low Carbon Networks Fund pages: http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/Pages/lcnf.aspx

- European Commission, Smart Grid projects in Europe: lessons learned and current developments, JRC report, 2011
- Smart Grid Opinions, Project Briefs pages: http://smartgridopinions.com/articles/Project%20briefs
- World Economic Forum, Accelerating Successful Smart Grid Pilots, 2010
- Austrian Institute of Technology, Basciotti, D. et al, Sensible heat storage in district heating networks: a novel control strategy using the network as storage, 2012
- Austrian Institute of Technology, Schmidt, R.R. et al, Smart thermal networks for smart cities – introduction of concepts and measures, abstract for the European Energy Conference 2012: http://energy-conference.eu/
- Shetland Heat Energy and Power, Lerwick District Heating Scheme proposal to The International District Energy Climate Awards, 2011
- Shetland Islands Council, Energy Recovery Plant information pages: http://www.shetland.gov.uk/waste/WCD/energyrecovery.asp
- The Pecan Street Project, Working Group Recommendations, 2010

Appendix B: Glossary of Technologies

As part of the initial market review, a summary was prepared of the different technologies that might form components of an intelligent energy system in London. Many of these are established technologies that have been used for many years, others are technologies that are at the research and development phase or which have yet to be commercialised.

Energy Transport

Technology Type	Capability
District Heating pipe - Transmission	Hot water pipe for transport of heat - 50MW to 10 GW.
District Heating pipe - Distribution	Hot water pipe for local distribution of hot water from generation point to user. Flow temperatures up to 120ºC, return temp down to 50ºC by steel pipes and max. 90ºC by plastic pipes. (500kW-50 MW). Can transport high temperature water or steam across networks and from large heat sources. Available technology for high temperature (steel) and low temperature (plastic).
Dynamic Asset Rating, Dynamic Line Rating	Application of weather and current sensors to allow monitoring of available capacity within electricity network assets. Dynamic Line Rating refers specifically to electricity power lines. Dynamic Line Ratings (DLR) provides a means of identifying the current carrying capability of a section of network in real time. With DLR, network operators can further enhance the capacity available on the grid, allowing greater penetration of distributed generation and avoiding network reinforcement. Overhead lines are expected to provide greatest opportunity.
High Voltage Direct Current (HVDC) Convertor Station Technology	HVDC converter station technology has the potential to reduce losses compared with AC overhead line transmission and contribute to system stability through control of power flows, voltage control and system damping. HVDC also helps prevent fault effects from propagating throughout the network.
High Voltage Power Transmission Systems	High voltage transmission systems can be divided into two main categories, HVDC and HVAC. HVDC can reduce loses in transmission compared to AC and provide greater power per conductor. HVAC is a better fit to existing distribution systems and HVAC is generally cheaper. HVDC is likely to be deployed for use in cross country interconnectors enabling generation and demand to be balanced across wide geographic regions.
Series Compensators	Series Compensators have the ability to increase the power transfer capability of the network by increasing the power transfer capacity of long AC transmission lines without having to construct new overhead line routes. Series compensation can also be used to give greater control over the system such as ensuring balanced power flows to reduce losses.
Smart Transformer Technology	Smart transformers or smart solid-state transformers are engineered to handle high power levels and very fast switching. They can respond to signals from a utility and change voltage and other characteristics of the power they produce. They can handle AC and DC power and can be programmed to redirect the flow of electricity in response to fluctuations in supply and demand. They have processors and communications hardware built in, allowing them to communicate with utility operators, other smart transformers, and consumers.
Super-Conducting Fault Current Limiters	SCFCL potentially provide increased fault level headroom to accommodate distributed generation in super urban environments served by networks with high fault levels where future low carbon commercial development is likely to include CCHP.

Energy Storage

Technology Type	Capability
Batteries	Electrical Energy Storage (EES) technologies which are available for deployment trials are: lead-acid and hybrid lead-acid, lithium-ion and derivatives, sodium-sulphur, nickel-metal-hydride and flow cells. They offer an alternative to network reinforcement by delivering peak power and flattening peaks created by generation or load (e.g. PV in middle of day or EVs at early evening peak). Most types of EES can be expanded in a modular manner. They can discharge energy over a range of time frames from a fraction of a second to slightly under a day.
Compressed Air Energy Storage (CAES)	Compressed-air energy storage plants are tackling the problem of holding captured wind energy so it can be available on demand and is not in excess at peak generation times. During peak production hours, air is pumped into underground cavities, compressing it so when it is tapped, a large percentage of the stored energy is released.
Cryogenic energy storage	Liquid nitrogen is used to store energy – electricity is used to operate a liquefactor, compressing the gas and passing it through a series of heat exchangers and expansion turbines. To release the energy, the cryogenic fluid is compressed further and then evaporated to drive turbine generators. Waste or ambient heat can be used in process and cold gas is produced which can be stored and used to help liquefy the gas-recharger cycle, making the process more efficient. Alternatively cold gas can be used for cooling.
Electric vehicle to grid (V2G) technology	V2G is a system where plug-in vehicles could feed electricity back into the grid, acting as a form of DG or energy storage. This can offer demand-side response by feeding into/taking electricity from grid at certain times, and could also be used as a back-up during power outages. Not yet available in UK, although planned for trial as part of UKPN's Low Carbon London project.
Embedded Storage (building level)	Can be used to shape the daily power profile of a building. Optimises network utilisation, potentially enabling higher penetrations of intermittent DG; increasing the flexibility of DG such as heat pumps and CHP; reducing the need for conventional reinforcement due to increase in peak load from heat pumps; and improving system losses. Can provide a medium-duration standby energy source in the event of an upstream network outage. Needs to be trialled at different scales.
Flywheels	Mechanical energy storage - kinetic energy is stored in rotors loaded with magnets, using electromagnetic fields. Increasingly used, including for voltage regulation and stabilisation at substations for wind generation, avoiding transmission costs, particularly where power is being delivered over long distances, e.g. from wind or solar farms. Has fast power responses and short recharge times. Short discharge times (over tens of minutes) allows the technology to be used for power quality applications (e.g. for short-term bridging between power sources or through power interruptions), but limits its use in large scale applications.
Pumped Hydro	Energy is stored in the form of pumped water. Best suited for large-scale bulk electrical energy storage - applies at transmission network level.
Solar Thermal Electric Steam	This technology allows heat to be stored prior to conversion to electricity, allowing electricity production by a steam turbine generator day and night. Concentrated Solar Power (CSP) is used to increase the temperature of the solar heat source making conversion to electricity more efficient. Thermal storage media can include pressurized steam, phase change materials, and molten salts such as sodium and potassium nitrate. Storage times: steam around 1 hour; molten salts can be longer - up to 1 week.

Thermal Storage	By using a thermal store the heat consumption can be balanced and so increase the efficiency of heat/power production or shift the period of demand. Thermal storage typically includes hot water storage linked to combined heat and power systems but diurnal and seasonal thermal storage has also been considered in homes including use of underground labyrinths, thermal mass and phase change materials to shift heating and cooling demand profiles.
Super-capacitors	Electrochemical capacitors store energy electrostatically. They consist of two carbon fabric electrodes, a separator, electrolyte (typically potassium hydroxide or sulphuric acid), and two current collectors. Hundreds are series-connected together to provide high voltage utility scale applications (600-800V). They have high charge and discharge rates. They provide good operating performance over a wide range of temperatures (-55 to 85°C) but lifetime decreases and self-discharge rates increase at higher temperatures. While commercial applications, such as energy smoothing and backup power during brief outages, have already been established, in general electrochemical capacitors for energy storage are in the developmental and demonstration phase - the small system power rating excludes the technology for large scale energy storage.
Super-conducting Magnetic Energy Storage (SMES)	A superconducting coil stores energy in the magnetic field generated by a circulating current. Superconductors carry substantial currents in high magnetic fields and have short-term discharge over seconds to minutes. SMES was originally proposed for large-scale, load levelling, but, because of its rapid discharge capabilities, it has been implemented on electric power systems for pulsed-power and system stability applications. Currently only applied in small scale system stability applications, though there are several design and development programs for large-scale SMES.
Underground Thermal Energy Storage	The two main methods are Aquifer Thermal Energy Storage and Borehole Thermal Energy Storage, to balance energy demand between summer and winter (or day and night). Heat and/or cold is stored in underground reservoirs and extracted when there is demand for the thermal energy.

Local Generation Technologies

Technology Type	Capability
Biomass CHP	Converts wood to heat and power. Wood is fired in a boiler to produce steam for use in a Rankin cycle. Steam Rankin cycle 4MWe to 300MWe. Suitable for Organic Rankin Cycle at smaller scale. In steam cycle the power/heat ratio can be varied according to requirements, rapidly despatching steam from power gen to heat network or store or vice versa with no change in fuel input. Wood can also be gasified and the gas burnt directly in gas engines, an operational example being Güssing in Austria.
Electric Immersion Heater	Converts electricity to hot water. The immersion heater could be placed in a heat accumulator at any scale and used as a power sink, when the grid or distribution network is overloaded. Heaters would be sized to add heat to thermal stores at same rate possible from conventional hot water charging.
Energy from waste power CHP	Convert waste to heat and power. Can deliver a lot of low carbon, low cost heat. 10's of MW of power, 100's of MW of heat. Typically around 5 units of heat for 1 of power. Plants will be capable of running turbines to send heat to store or to a network. In steam cycle the power/heat ratio can be varied according to requirements, rapidly despatching steam from power gen to heat network or store or vice versa with no change in fuel input.

Fuel Cells	A device capable of generating an electrical current by converting the chemical energy of a fuel (e.g. hydrogen) directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside. It does not contain an intermediate heat cycle, as do most other electrical generation techniques. A limited number of fuel cells are now installed in office developments in London and companies are developing products for the domestic market.
Gas Fired CHP – Turbine (Large)	Converts gas to heat and power - 50-600 MW. CCGTs (Gas turbine(s) with a heat recovery boiler and a Rankin steam cycle for power generation) will operate according to half hourly power price already. Large plants can justify staff and controls to respond to power market signals, modulation is normal.
Gas Fired CHP – Turbine (Medium)	Converts gas to heat and power - 5MWe, 10 MWth. A smaller gas turbine unit around 5MWe can be fired in open cycle with a heat recovery boiler to produce heat for a district heating network. (This is intermediate scale district heating).
Gas Fired CHP – Engine (Small)	Converts gas to heat and power - 50kW to 2500kW, usually fractionally more heat available than power. Gas engine will only operate economically at near highest engine output. The heat output is from the cooling jacket, it is waste heat, but must be fully utilised, either through heat rejection to the environment or heat use to a network or thermal store. Typically run when heat loads reach the thermal output. When combined with thermal stores they can run significantly more hours/year.
Organic Rankin Cycle	Will use organic fluid instead of water with single pressure step process. Typically a fixed power output and excess heat can modulate or be rejected - so operated more like gas engine CHP than Rankin steam cycle with turbine pass-out. While power can be delivered from DH hot water, e.g. from a store, the efficiency is very low (+- 6%) and would require very significantly raised electrical price to make economic on a part time basis.
Solar PV	Solar photovoltaic panels producing electricity from sunlight and daylight.
Solar – Concentrated Solar Power (CSP)	Sun to steam to heat and power. Solar energy is harnessed using concentrating mirrors to raise steam, CHP as per normal thermal cycle.
Solar Thermal	Solar panels provide hot water for space heating or domestic use.
Trigeneration	Gas engine CHP with heat used to power absorption chillers to provide cooling as well as heating.
Waste Water Heat Pump	Waste water heat pump - uses a heat pump to extract heat from waste water in sewers. Can utilise excess power in the grid to generate heat more efficiently than immersion heaters.

Information Communication Technologies and Controls

Technology Type	Capability
Active Network Monitoring/Management technologies	Similar to Distributed Intelligence and Enhanced remote control. Power flow substation monitoring at selected distributed substation sites, to provide ability to capture HH time-stamped values from distribution substations using SCADA; give an insight into real-time power flows & voltage regulation, hence capacity for DG/additional demand; and monitor power quality providing insight into power quality trends (important with DG and ULCV charging systems). Condition monitoring technologies could provide early indications of potential failure and enable pre-emptive action.

Advanced Metering Infrastructure (AMI)	Advanced metering infrastructure is a term denoting electricity meters that measure and record usage data and provide usage data to both consumers and energy companies at least once daily. AMI has the potential to offer significant savings to DNOs in areas such as automatic meter reading, reduction of disputed accounts, improved network control.
Data Collectors/ Concentrators	Interface between individual meters and the data warehouse. A variety of communications options available.
Demand Side Management Technologies	Technologies to adjust/reduce customer electrical demand profiles to match economic availability of generation, providing the potential to offset/delay network reinforcement. These include a range of applications within the customer’s installation to allow enhanced control/improved lifestyle, for example through remote control of appliances and heating, security monitoring, lighting control etc. *See also ‘Smart Meters’ and ‘Smart Devices’ and ‘Remote Smart Controls’ in ‘Smart Products’ section below.*
Distributed intelligence	A combination of sensors and distributed processing which can enable real-time decisions based on inputs from the network, and apply corrective action creating "self healing" networks. Allows real time monitoring of power flow across the network, and targeted investment.
Dynamic Line Ratings (DLR)	Application of weather and current sensors to allow DNOs to operate networks to maximum capacity without reducing asset life or infringing statutory requirements. Allows improved utilisation of assets and deferral of reinforcement costs, and identification of network reconfiguration/reinforcement opportunities.
Enhanced Automatic Voltage Control (EAVC)	An EAVC system consists of a range of devices that can help a DNO to keep network voltages within certain limits in the context of increased voltage-control challenges thrown up by new network developments (ie increased distributed generation), over and above existing AVC controls at the grid and primary transformers. It may be a cost-effective alternative to conventional network reinforcement. Examples of EAVC solutions include: modified control solutions to the conventional AVC relay at primary transformers, taking additional voltage sensing input from points on the network; in-line voltage regulators for HV circuits; HV switched capacitor banks; on-load tap-changers and/or LV regulators for distribution transformers; three-phase or single-phase voltage regulators for LV circuits.
Enhanced monitoring and control schemes	Application of greater granularity to the voltage/reactive power monitoring and control to reduce losses/improve network stability. Solid state devices are used to dynamically adjust network characteristics.
Enhanced remote control	Extension of existing SCADA (Supervisory Control and Data Acquisition) facilities deeper into the network, e.g. normally open points, key switching points, critical customers/services. Can lead to improved response times, reduction in network downtime and improved customer restoration times in the event of faults.
Low Voltage Network Monitoring and Control	Status data for the low voltage distribution network is currently virtually non-existent. Enhanced measurement leads to a better understanding of network load profiles and in combination with advanced metering infrastructure can be used to detect non-technical loss, reducing disruption to customers, and to improve use of assets through better understanding of network loading, voltage profile, harmonics etc. It can be used to identify "spare" network capacity to support EV charging, storage solutions etc. LV networks are generally controlled by "single shot" fuses meaning transient faults result in sustained non supply. Smart fuses with an "auto-reclose" capability are now entering the market.

Outage Management/ Supply Restoration		A range of technologies designed to minimise the impact of network "faults" and restore supply to as many customers as possible in the shortest time. At its simplest it may be a change in business processes; at its most sophisticated a combination of distributed intelligence, algorithms and auto-controlled switchgear.
Preventative Maintenance/ Asset Monitoring Technologies		Application of sensors and comparison of data gathered to the device design specification can be used to detect early indications of failure mechanisms, reducing costs, safety risks and unplanned outages. This includes pressure alarms, winding temperature, dissolved gas analysis, DLR etc.
Voltage and Volt-Ampere-Reactive Optimisation (VVO)		Active voltage control, which involves fine-tuning of the substation source voltage according to the output of the generators, can prevent voltage-rise issues. This enables the connection of intermittent renewables to the MV network by improving responsiveness to load changes.
Communication Technologies	**Asymmetric digital subscriber line (ADSL)**	ADSL is a type of broadband communications technology used for connecting to the internet. It allows more data to be sent over existing copper telephone lines. ADSL network has widespread coverage and is reliable, although capacity could be an issue.
	Fibre	Fibre optical cables are installed in the ground to provide point-to-point communications. The cables are rugged, do not corrode and are immune to electromagnetic and radio frequency interference. Fibre has high capacity and reliability. London has an above average penetration of fibre including FTTH (Fibre to the Home). UKPN may also have good fibre coverage in this area.
	GPRS/GSM	General Packet Radio Service, a standard for wireless communications which runs at speeds up to 115 kilobits per second / Global System for Mobile Communications – systems run at 9.6 kilobits per second. High density coverage available, 98% available in London area.
	Home Area Network / Home energy monitoring packages	Home energy monitoring packages consist of a range of technologies and are likely to include an in home display, an online interface, and a meter as well as communication technology and potentially domestic appliance controls.
	Microware Technology	Microwave technology can provide a high bandwidth point-to-point wireless communications network.
	Power Line Carrier (PLC)	PLC is a system for carrying data on a powerline conductor for wireless area network applications. Opportunities exist to use both LV and MV PLC to capitalise on existing DNO electrical infrastructure, at comparatively low capital cost, with potential connection to every electricity customer and minimum disruption. However PLC is susceptible to radio frequency noise, performance degrades with distance, and MV PLC technology is not yet mature.
	SCADA	Supervisory control and data acquisition, a system used by power utilities to send and collect supervisory control signals and monitor data through power lines.
	Wide Area Network (WAN)	A computer network connecting all the buildings in a building complex to each other or all the homes and businesses in a neighbourhood, town or city to the internet.
	WiFi	A mechanism that allows an electronic device to exchange data wirelessly over a computer network. Unlicensed spectrum with high user base, comparatively low cost, easy to install. Coverage and channel interference may be an issue due to building construction/density and high usage levels.
	WiMax	WIMAX is essentially a broadband communications technology used to provide connectivity over large geographic areas. Available within London with comparatively low implementation cost and minimum disruption. Signal quality in densely built up areas is an issue which could be mitigated if using data concentrators on roof of large buildings.

	Wireless Mesh	A network technology where each node or end-device can communicate with any nearby devices to create 'smart' data routing that finds the most efficient path or data and can change the path when a node stops working. Communications technologies and protocols exist on the linking of short-range wireless devices to each other to expand range and provide resilience and contingency through alternate communications pathways. In densely populated areas a comprehensive mesh can be established quickly.
	3G	3G technology includes wide-area wireless voice telephone, video calls, and wireless data, all in a mobile environment.

Smart Products

Technology Type	Capability
Building Management Systems (BMS)	BMS can provide access to data which is currently not available and which will identify when energy is consumed and which operational process or facility is consuming energy. Access to this granular and specific data then allows organisations to modify processes and operations which could reduce energy consumption whilst maintaining business operations.
Electric vehicles	Electric vehicles include pure-electric, parallel- and series-hybrids, which can displace higher carbon alternatives. They may be charged at residential properties or at car parks. Charging of EVs can be accomplished from standard 240V sockets at 10A or via a dedicated circuit from a consumer unit at higher rates. They have potential to be used as embedded storage to manage peaks in load (see storage above). But this will also cause issues such as increase in load, impacts on voltage levels (reduction when charging, increase if feeding into grid), and impacts on power quality.
In Home Display (IHD)	A display which allows domestic customers to view their energy use and potentially other information on their consumption patterns. Provision of an IHD is expected to be one of the mandatory elements of the Government’s Smart Meter roll out programme.
Smart Controls	Smart controls are currently on the market including 'smart buttons' which can be used to turn off appliances in homes when occupiers are out, if they are connected to 'smart plugs' which also can monitor how much energy an individual appliance is using.
Smart Domestic Appliances	Smart appliances are appliances with a built-in capability to respond to signals from smart meters. The following loads could potentially be managed through smart appliances: wet appliances;- refrigeration; convenience loads such as home computing products and consumer electronics. The maximum demand available for demand response at the time of the system peak is likely to be around 155W per household of a total daily peak load of between 1 and 1.5kW. For commercial and or industrial customers the amount of demand response available varies. DSR can reduce peak loads and reduce network reinforcement costs, but this may only be possible within a limited window due to customer expectations. Ofgem also suggests the level of payments to customers could be low.
Smart Meters	A utility meter for electricity, natural gas or water, usually, that always includes two-way communications technology. Alone they can make electricity consumption significantly more observable, controllable and automated than it currently is. Aggregated data can be used to improve network planning/operation and reduce DNO overheads. They will affect incremental costs and benefits of smart grid technologies by providing data; functionality allowing DSR; functionality allowing more active network management. Combined with DSR they could shift peak load to avoid reinforcement costs for network assets such as transformers, circuits, circuit terminations and switchgear. There is uncertainty over the extent to which DSR can be used to avoid network reinforcement costs, e.g. how responsive customers will be to signals, and the issue of competing uses of DSR (peak-shaving to avoid reinforcement costs for DNOs vs. demand-shifting by suppliers to reduce wholesale electricity costs in production).

Appendix C: Technology Relevance Matrix

The table below provides a high level assessment of the relevance of the various smart energy technologies for London. This assessment was used early in the study to help inform the choice of areas that the study would focus on. In general the study has not looked in any detail at transmission level technologies and considerations up stream of the bulk supply points that serve London. Technologies that require substantial land areas were also considered to be unlikely to be deployed in London.

			Delivery Agent/ Responsibility					Scale		Integration			Technology Readiness	
		Technology Type	National Grid	Major Energy Producer	Energy Distribution	Distributed Energy Generators / ESCOs	Consumers	National	Local	Intregration complications for London	Impossible in London	Relevance Score for London (1-5)	TRL 6 - 8	TRL 9
Energy Transport	Pipes, Cables and Transformers	High Voltage Power Transmission Systems	Y					Y				3		Y
		Series Compensators	Y					Y		Y		3	Y	
		High Voltage Direct Current (HVDC) Convertor Station Technology	Y					Y				3		Y
		Power Cable Technology	Y		Y			Y	Y			1		Y
		Transformer Technology	Y		Y				Y			1	Y	
		Dynamic Line Rating	Y		Y			Y	Y			1		Y
		Super-Conducting Fault Current Limiters			Y				Y			1		Y
		District heating pipe - Transmission		Y					Y			1		Y
		District heating pipe - Distribution			Y	Y			Y			1		Y
Energy Storage		Batteries		Y	Y				Y			2	Y	
		Electric vehicle to grid (V2G) technology			Y		Y		Y			3	Y	
		Pumped Hydro		Y				Y			Y	5		Y
		Solar Thermal Electric Steam		Y		Y		Y			Y	5		Y
		Compressed Air Energy Storage (CAES)		Y				Y				5		Y
		Flywheels		Y		Y			Y	Y		3		Y
		Super-conducting Magnetic Energy Storage (SMES)							Y			3	Y	
		Super-capacitors							Y			3	Y	
		Embedded Storage (building level)					Y		Y			2		Y
		Cryogenic energy storage							Y			3	Y	
		Underground Thermal Energy Storage		Y				Y				3		Y
		Thermal Storage (Buffer Vessels)				Y			Y			1		Y
Energy Generation		Energy from Waste CHP				Y			Y	Y		1		Y
		Gas Fired CHP – Turbine (Large)			Y	Y			Y			1		Y
		Gas Fired CHP – Turbine (Medium)			Y	Y			Y			1		Y
		Gas Fired CHP - Engine				Y			Y			1		Y
		Biomass CHP				Y			Y			3		Y
		Electric Immersion Heater				Y			Y			2		Y
		Solar Thermal				Y	Y		Y			2		Y
		Organic Rankin Cycle				Y			Y			3		Y
		Waste Water Heat Pump				Y			Y	Y		2		Y
		Solar CSP				Y		Y			Y	5		Y
Energy Monitoring and Control	Distribution Automation	Distributed Intelligence			Y				Y			1		Y
		Enhanced remote control			Y				Y			3		Y
		Active Network Monitoring			Y				Y			2		Y
		Dynamic Asset Rating			Y				Y			2		Y
		Outage Management/ Supply Restoration			Y				Y			1		Y
		Preventative Maintenance/ Asset Monitoring			Y				Y			2		Y
		Low Voltage Network Monitoring & Control			Y				Y			2		Y
	Distributed Generation	Voltage and Volt-Ampere-Reactive Optimisation (VVO)			Y				Y			1		Y
		Enhanced monitoring & control schemes			Y				Y			2		Y
		Enhanced Automatic Voltage Control (EAVC)			Y				Y			2		Y
		Data Collectors/ Concentrators			Y				Y			2		Y
		Aggregators (Distributed Energy Sources)			Y	Y			Y			2		Y?
		Demand Side Management			Y		Y		Y			2		Y?
		Fibre	Y		Y				Y			2		Y
		ADSL			Y				Y			1		Y
		Power Line Comms (PLC)	Y		Y				Y			2		Y
		WiFi				Y	Y		Y			1		Y
		Wireless Mesh			Y				Y			2		Y
		GPRS/GSM	Y		Y	Y			Y			1		Y
		WiMax			Y	Y			Y			2		Y
Smart Products	Appliances and Packaged Systems	Electric vehicles					Y		Y			2		Y
		Smart Meters					Y		Y			1		Y
		Smart Asset Management					Y		Y			2		Y
		Smart Domestic Appliances					Y		Y			3	Y	
		Remote smart controls					Y		Y			3	Y	
		Home energy monitoring packages					Y		Y			2	Y	

Key:

Relevance for London

1	Already used extensively in London - likely to continue
2	Could be used in future as part of the Smart City drive
3	Could be used in London but not a key focus for study due to technology scale or technology readiness
4	Could be employed in London but unlikely - significant challenges to overcome
5	Could never be deployed in London