National Infrastructure Commission call for evidence: 'Electricity interconnection and storage'

Evidence submitted by the iBUILD Infrastructure Research Centre, January 2016

Introduction

The iBUILD (**I**nfrastructure **BU**siness models, valuation and **I**nnovation for **L**ocal **D**elivery) Infrastructure Research Centre brings together a multi-disciplinary team from Newcastle, Birmingham and Leeds Universities to improve the delivery of local and urban infrastructure. iBUILD is developing and demonstrating alternative infrastructure business models that: take a whole life cycle view of infrastructure systems; exploit technical and market opportunities from modern interconnected infrastructure; leverage economic, social, environmental, aesthetic and other values from infrastructure; identify changes in governance, regulation and policy to unlock improvements; and, use innovative financing and funding mechanisms.

iBUILD promotes a service and system-wide approach to local and urban infrastructure, believing that there are significant advantages to be gained from planning, investing and managing infrastructure on an interdependent basis. As the recent floods in Cumbria, Northumberland and elsewhere in the north of England demonstrated, long-term resilience has to be built into the UK's infrastructure sectors and systems. Otherwise, the potential economic and social benefits that can be derived from infrastructure investment will be marginal compared to the economic, social and environmental costs of repairing infrastructure that is damaged or destroyed by adverse (but increasingly regular) weather-related events.

The emergence of the National Infrastructure Commission (NIC) reflects the recent emphasis towards national scale infrastructure planning in the UK, and provides an important strategic context for the planning, development and operation of infrastructure. However, it is also important to consider the distinct role of local and urban infrastructure in driving local, regional and national economies. It is at the local and urban scales where infrastructure services are most dense and where the majority of people use infrastructure services in their everyday lives. Balancing growth across different geographical scales – from the local to the city/city-region – is vital to the long-term success of the national economy, as infrastructure drives local economic growth and job creation, as a consequence of construction and management activities as well as the enhancement and facilitation of other economic activities.

The response below first summarises key findings from our research programme that are relevant to all infrastructure delivery, before specifically responding to the consultation questions. Our response draws predominantly on new research identified during the iBUILD project, but also decades of research and experience in the iBUILD team. This includes engineering expertise in the Centre for

Earth Systems Engineering Research (CESER)[1] and the Institute for Resilient Infrastructure (IRI)[2], and the long-standing track record in local and regional development by the Centre for Urban and Regional Development Studies (CURDS)[3].

iBUILD focuses on all infrastructure sectors, not just transport, but our work has also drawn lessons from non-infrastructure sectors. Where our research is undergoing external peer review we cite working papers which, amongst other work, can be found at www.ibuild.ac.uk.

iBUILD Mid-Term Review and Policy Manifesto

In March 2015, iBUILD published a mid-term review and manifesto setting out thirteen evidence-based policy recommendations on how local and urban infrastructure business models could be strengthened in both design and in application. The key recommendations are elaborated in the full manifesto document which is available online.[4]

Research from across the iBUILD Centre has identified five priority action areas for government and industry. If applied to all infrastructure planning and decision-making, these action areas will help to challenge the "timid, uncoordinated, incremental, wasteful"[5] way the UK currently builds and manages its infrastructure, and help to develop a new approach to delivering infrastructure systems and their services that will enhance the health, wealth and security of UK citizens.

Priority Action Area #1: Have a broader, integrated appreciation of infrastructure

Infrastructure is not just tracks, tubes and trunk roads. Failure to consider the resources that flow along these, the services they provide and the people and businesses that depend on them, will lead to investments that don't deliver effectively. At the same time, it is crucial to understand how all these systems are interconnected; infrastructure depends on other infrastructure to work, not just technically, but also economically and socially. The UK's infrastructure is amongst the most mature and interconnected in the world and therefore has a pressing need to adopt a broad, integrated and sophisticated approach to infrastructure planning.

Recommendation 1: Infrastructure planners, financers, engineers and other stakeholders need to use a broad, but appropriately specified, definition of infrastructure if they are to identify the full range of opportunities from alternative business models.

Recommendation 2: Housing and 'hidden infrastructure', such as efficiency measures, should be considered alongside the large-scale capital investments with which they interconnect, within infrastructure and spatial planning processes

[1] www.ncl.ac.uk/ceser
[2] www.engineering.leeds.ac.uk/resilience/
[3] www.ncl.ac.uk/curds
[4] iBUILD (2015) Are you being served? Alternative infrastructure business models to support economic growth and well-being, iBUILD Manifesto and Mid-term Report, Newcastle University: Newcastle upon Tyne. The full manifesto can be downloaded from http://research.ncl.ac.uk/ibuild/outputs/
[5] Infrastructure UK (2010) *National Infrastructure Plan 2010*, First NIP: October 2010, HM Treasury.

Recommendation 3: National reforms in policy and regulation are required to enable an integrated approach to local infrastructure planning that can identify, and has the capacity to exploit, synergies across infrastructure sectors.

Priority Action Area #2: Enable action at the local scale that connects with the national

Too much infrastructure planning is top-down, yet every piece of infrastructure has to go somewhere; it is inherently local. Top-down approaches to infrastructure development and management stop locally-led and innovative business models from flourishing and discourage innovation. It also risks the wrong infrastructure being put in the wrong place at the wrong time because of a lack of local knowledge, engagement and ownership. These issues prevent the UK from maximising returns from infrastructure investment. The UK must devolve an appropriate and sensible proportion of infrastructure investment and responsibility to local institutions so they can deliver infrastructure that better reflects the values and needs of the communities it serves, yet remain mindful of the national strategy.

Recommendation 4: National and local policy frameworks should be realigned to focus on delivering wider societal benefits and to enable local infrastructure business models to emerge that can provide local solutions that are complementary with mainstream systems.

Recommendation 5: Effective operation of local alternative infrastructure business models requires greater fiscal decentralisation, complemented by a stronger and statutory devolved role for cities and localities in the planning, development and delivery of infrastructure.

Recommendation 6: Provide support for a wider range of innovative local infrastructure financing mechanisms, including tax increment financing, municipal bonds, social impact bonds and crowd source funding approaches.

Priority Action Area #3: Capture long-term value of every kind

Infrastructure is not only about cash returns. Investment in infrastructure provides wider health, economic and environmental benefits for society; infrastructure converts financial value to social value. A new economic valuation system that recognises these long-term, whole-life benefits is essential to maximise the benefits. Infrastructure must also be built for minimum whole-life costs. This might mean paying a bit more upfront for something that will last – and serve– for longer without the need for frequent maintenance; a resilient and sustainable infrastructure.

Recommendation 7: Incorporate measures of social and environment benefit (and cost) into infrastructure appraisal frameworks to recognise the wider societal and environmental outcomes and ascertain the widest possible set of mechanisms to capture revenue and other values.

Recommendation 8: Implement a quantitative framework within the infrastructure appraisal process to assess the value of flexibility and resilience across the whole system over the long-term.

Recommendation 9: Local authorities and infrastructure owners should apply resource assessments as a matter of course to identify the potential of land and infrastructure assets to generate long-term, stable revenue streams and not just one-off, short-term windfalls from selling-off assets.

Recommendation 10: Employ a new approach to infrastructure economics that recognises the long-term and system-wide value of infrastructure provision.

Priority Action Area #4: Deliver more efficient planning, procurement and delivery

Approaches to project financing, funding and delivery should not be chosen for political reasons. Mechanisms must be adopted that can best deliver the desired economic, social and environmental values, regardless of their political flavour. Many of methods and tools to enable this already exist: the Project Initiation Routemap, Building Information Modelling (BIM) systems, life-cycle assessment, so they must be used. These approaches support more efficient planning and procurement, minimise costs and human effort, preserve the environment, and maximise the potential to reuse and recycle materials and components in the future.

Recommendation 11: Implementation of the Project Initiation Routemap has been shown to have many cost reduction benefits and should be made standard practise for all public funded projects.

Recommendation 12: Planning and design of infrastructure should consider the material and resource demands of infrastructure pipelines to identify opportunities for reducing waste in the construction and operation phases, whilst designing for end of life material recovery or repurposing of infrastructure.

Priority Action Area #5: Accelerate the uptake of innovations through practical action and demonstration

Action often speaks louder than words. Alternative approaches to infrastructure business models are emerging. However, to quickly identify the most successful approaches and encourage their wide uptake locally, nationally and internationally, a number of ambitious demonstrator sites should be established for integrated infrastructure planning and testing of innovative infrastructure business models.

Recommendation 13: Establish full-scale urban demonstrator sites for integrated infrastructure planning and testing of innovative infrastructure business models.

Improving how electricity demand and supply are balanced: Electricity interconnection and storage

1. What changes may need to be made to the electricity market to ensure that supply and demand are balanced, whilst minimising cost to consumers, over the long-term?
   - What role can changes to the market framework play to incentivise this outcome:
   - Is there a need for an independent system operator (SO)? How could the incentives faced by the SO be set to minimise long-run balancing costs?
   - Is there a need to further reform the "balancing market" and which market participants are responsible for imbalances?
   - To what extent can demand-side management measures and embedded generation be used to increase the flexibility of the electricity system?
2. Related to barriers to energy storage capacity
3. Related to interconnectivity
4. International best practise in relation to planning and balancing supply and demand

The nature of our evidence means that we contribute primarily to Q1, but our international review has identified lessons for Q4.

Key messages

- Distributed generation and energy efficiency measures (including those within buildings) should be considered as an integral part of energy infrastructure planning, equal to increased centralised supply (i.e. new power stations), as they can increase flexibility, resilience and security, and reduce demand and carbon emissions.
- The magnitude of demand reduction and the value of changes to the supply system as perceived by the consumer – two things inter-related by behavioural change – will depend on whether such changes are implemented via private, public or civic provision and financing.
- It is critical to consider these provision systems or value allocation options, when considering the options for the *physical implementation* of demand reduction and/or distributed generation. Local re-investment of the short-term profits generated from cost-effective EER measures into measure that promote long-term values and goals (e.g. achieving CO_2 emission targets, alleviating fuel poverty, increasing energy security), rather than allowing these profits to be appropriated by external financial entities, will increase the value and efficiency of the overall system for consumers, communities and UK plc alike.

Market frameworks - Business models for local electricity supply

At the city-regional to neighbourhood level inappropriate regulatory frameworks too inflexible to open up all opportunities for balancing supply and demand. What is needed is a supportive policy and regulatory environment to allow local balancing within distribution networks. This can be achieved by making space for business model innovation at the retail or 'supply' end of the market that integrates demand reduction and energy efficiency as key parts of the overall supply system. Government may wish to support a local supply market because it offers four key opportunities that national utility

business models are unable or unwilling to capture or pursue owing to commercial and financial pressures:

- Better routes to market for local generation: the market for small scale power purchase agreements is constrained; support for local supply business models is needed.
- Fulfilling the potential of the demand side: the benefits of demand side management in the UK are being missed.
- Real energy efficiency gains: national utilities are not best suited to delivering energy efficiency programmes because they disrupt their business model. Local supply archetypes could be better suited.
- Re-localising energy value: energy value is 'leaking' out of local regions and the UK due to increasing international financialisation of supply utilities, or limited focus on delivering social value (e.g. alleviating fuel poverty).

The emergence of smart technologies and distributed generation create additional value propositions that may be best captured by local supply enterprises; such as demand response, and smart loads.[6,7,8,9] Increasing diversity of local generation and consumption patterns suggests local balancing could more efficiently optimise supply and demand within regions[10,11,12,13] and could complement/run in parallel to national balancing.[14] However, the UK electricity system is based on 'top down' control, directing energy from centralised generation to meet demand at any point.[15] Regulation and trading systems follow this centralised model which encourages increased sale of cheap units of energy, rather than increased efficiency of services provided – heat, light etc. – to reduce demand.[16] Energy trading arrangements assume organisations manage their physical position and achieve contracted balance nationally.[14]

---

[6] Pudjianto, D., Djapic, P., Auinedi, M., Kim Gan, C., Strbac, G., Huang, S. and Infield, D. (2013) 'Smart control for minimizing distribution network reinforcement cost due to electrification' *Energy Policy*

[7] Ceseña, E. A. M., Good, N., Mancarella, P. (2015). Electrical network capacity support from demand side response: Techno-economic assessment of potential business cases for small commercial and residential end-users. *Energy Policy*, *82*, 222-232.

[8] Oren,S.S., 2013. A historical perspective and business model for load response aggregation based on priority service .In: Proceedings of the Hawaii International Conference on System Sciences. IEEE,pp. 2206–2214.

[9] Palensky, P., & Dietrich, D. (2011). Demand side management: Demand response, intelligent energy systems, and smart loads. *Industrial Informatics, IEEE Transactions on*, *7*(3), 381-388.

[10] Foxon, T.J. (2013) Transition pathways for a UK low carbon electricity future, *Energy Policy*, 52, pp.10-24. doi: 10.1016/j.enpol.2012.04.001

[11] Cornwall Energy (2014) *Creating Local Electricity Markets: A Manifesto for Change*. Cornwall Energy

[12] Cornwall Energy (2014a), Local tariffs and the BSC, July 2014 Nigel Cornwall. Evidence submitted to the Local Supply Working Group 2014.

[13] Cornwall Energy (2014b) Cornwall Energy information note [domestic supply market] (Figures up to 31.7.2014). Cornwall Energy

[14] Elexon (2014) Encouraging local energy supply through a local balancing unit. www.elexon.co.uk/wp-content/uploads/2014/08/Encouraging_local_energy_supply_through_a_local_balancing-unit.pdf

[15] Lockwood, M., (2014) Energy networks and distributed energy resources in Great Britain, IGov EPG Working Paper: 1406.

[16] Roelich, K., Knoeri, C., Steinberger, J.K., Varga, L., Blythe, P.T., Butler, D., Gupta, R., Harrison, G.P., Martin, C. and Purnell, P., 2015. Towards resource-efficient and service-oriented integrated infrastructure operation. *Technological Forecasting and Social Change*, *92*, pp.40-52.

iBUILD research[17,18] identified nine business model archetypes for local electricity supply. Each of these business models incentivises demand response and balancing of local generation differently. Table 1 shows each of these business models and how they variously incentivise: better routes to market for distributed generation, local balancing and demand response, energy efficiency and energy value retention.

Table 1: Archetypes of energy business models. Scale +++ = strong positive effect to --- + strong negative effect -/+ = neutral

Archetypes	Enabling Mechanisms	Opportunities/value propositions of local supply			
		Better routes to market for local generation	Fulfilling the potential of the demand side	Real energy efficiency gains	Re-localising energy value
Current Archetype	Full Supply License	--	-	--	---
Local White Labelling	Third Party Licensed Supplier Partnership (TPLSP)	+	-	-	-/+
Local Aggregator	TPLSP	++	+++	+	+
Local 'Pool and Sleeve'	License Lite with TPLSP	+	-/+	-	+
Municipal Utility	Full Supply License	+++	+	---	++
Municipal ESCo	Full Supply License	+++	++	+++	+++
MUSCo	Full Supply License	+++	++	+++	+
Peer to Peer	TPLSP	+++	-/+	-/+	+
Peer to Peer with Local Balancing Unit	TPLSP With local settlement unit	++	++	-/+	++

Source: Hall and Roelich 2016

[17] Hall, S., Roelich, K., (2015) *Local Electricity Supply: Opportunities, archetypes and outcomes.* Ibuild/RTP Independent Report. March 2015, Available online at: https://research.ncl.ac.uk/ibuild/outputs/local_electricity_supply_report_WEB.pdf
[18] Hall, S., Roelich, K., (2016) Business model innovation in electricity supply markets: the role of complex value in the United Kingdom, *Energy Policy*, Forthcoming.

Each of these business models has different challenges in market proliferation. Some of these archetypes are constrained by the regulatory environment, a lack of capacity/experience in a new sector, a lack of understanding of replicable models, and unclear risk frameworks. In response to these barriers[18] propose a set of short, medium and long term strategic activities that could be carried out at the national scale that would foster this sector and help to realise as yet untapped opportunities in the energy market. Each of these recommendations is evidenced more fully in [17] and [18]. However we call attention to medium term proposal 3, as this would create a geographic unit in settlement that would enable suppliers to optimise balancing within regions, making best use of distributed generation and geographically aggregated demand response. This is both the most market and technically efficient approach but is currently impossible within the national market structure. These proposals are:

- **Short Term Proposal 1: Local supply innovation fund**
  A substantial but time-limited fund of comparable size to the urban and rural community energy funds, explicitly aimed at testing local supply archetypes in the market
- **Short Term Proposal 2: A 'portal of power'**
  An online platform with clear policy and regulatory advice specifically generated by and tailored for local supply stakeholders
- **Short Term Proposal 3: Resource the Local Supply Working Group or similar forum**
  Continued resource to support the Local Supply Working Group which has progressed the understanding of local supply in the UK and will be needed to guide its future development

- **Medium Term Proposal 1: Clarify the requirement for national supply**
  New fully licensed suppliers are looking to exploit the benefits of focussing on particular geographies, but regulation is not suited to this. New frameworks and customer protections for geographic supply are needed.
- **Medium Term Proposal 2: Amend the requirement for fully licensed suppliers to offer only four tariffs for those areas operating local supply archetypes.**
  Fully licensed suppliers looking to partner with 'intermediary archetypes' that rely on this relationship are being penalised by the requirement to offer only four main tariffs. This has been facilitated by a temporary arrangement for the 'local white labelling' sector, but will need to be addressed as new local supply archetypes and intermediary relationships proliferate.
- **Medium Term Proposal 3: Allow for a 'local balancing unit' [Balancing unit allowable within a single grid supply point region].**
  This would allow new local business models such as aggregators and junior suppliers to maximise the benefits of local supply and demand management, offering benefits to suppliers, network managers and system operators.

- **Long Term Proposal 1: Investigate the opportunity to allow local ESCo or multi utility models which incentivise substantive efficiency gains to be exempt from supplier switching legislation.**
  As a longer term activity, the requirements on suppliers to ensure the domestic consumers' right to switch supplier need reviewing to make space for domestic energy performance contracting that

can be delivered where it is relevant. i.e. by being recouped through the household energy bill. This would unlock new opportunities for energy efficiency in deep retrofit, micro generation and appliance efficiency.

- **Long Term Proposal 2: Investigate the opportunities for demand reduction-centred business models and their treatment in regulation and policy.**
  Much more work is required to investigate how energy demand reduction can be incorporated into markets and incentives. The opportunities of demand reduction can be delivered by new aggregator business models. However to date demand reduction has been undervalued in favour of policy mechanisms aiming to reduce unit prices as opposed to final bills. Local supply options can deliver demand side services that reduce final bills, deliver benefits to distribution and transmission system operators and reduce the need for centralised generation investments across the system.

The Department for Energy and Climate Change has already used [17] to inform the update to the Community Energy Strategy.[19] This work has also fed into the Ofgem consultation on Non Traditional Business Models. However the NIC will find this work of particular interest as innovation in energy retail markets has the potential to deeply affect the need for new transmission and distribution grid re-enforcement, the need for interconnection and the capacity and utilisation of the existing thermal generation fleet. By optimising for balancing at the local level significant savings could be made on critical infrastructures. If this is a managed process these critical infrastructures have much less chance of becoming stranded assets.

Revolving fund financing and governance structures

The research assumes that the provision of demand reduction measures can offer systematic benefits by lessening the requirement for generation infrastructure and improving system flexibility and reliability.[20,21,22] We focus upon a particular class of demand reduction, namely that of the energy efficiency retrofit (EER) of UK buildings. The technical potential of such measures is well known, thus we consider instead how different modes of governance and financing arrangements may influence the extent to which such technical potential is achieved. Research results suggest that overall levels of EER provision, are highly dependent on the source of its financing and the contexts and conditions under which it is deployed and governed.

Different financing and governance arrangements are analysed with respect to various private, public and civic modes. Here these modes are considered in the context of a revolving investment fund for EER. A revolving fund recycles direct financial returns, (in the case of EER, fuel cost savings) from previous investments, to further funding in a specific investment area – thus helping to capture and retaining local value. Revolving fund structures are used currently to finance investment in EER in a

[19] Department of Energy and Climate Change (2015) Community Energy Strategy Update, DECC, Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/414446/CESU_FINAL.pdf
[20] Washan, P, Stenning, J and Goodman, M. 2014. Building the Future: the economic and fiscal impacts of making homes more energy efficient. 2014.
[21] Mount, A and Benton, D. 2015. Getting more from less: realising the potential of negawatts in the UK electricity market. 2015.
[22] ADE. 2014. Invisible Energy: Hidden Benefits of the Demand Side. 2014.

variety of sectors, for example, the SALIX fund for public sector buildings and the HEFCE fund for Higher Education. The ring-fenced nature of returns are intended to act as a driving force for the achievement of ambitious targets for levels of provision, while drastically lowering initial investment requirements - a point of significant benefit in an era of austerity (see Gouldson et al 2015 for more on revolving funds). Our modelling assesses the potential of private, public and a civic revolving funds and suggests that the impacts – in terms of investment achieved, measures deployed, and energy saved – can vary dramatically depending on how EER provision is financed and operated.

Demand reduction (for both electricity and heat) via EER has much potential, with carbon emission reduction targets foreseeing a carbon neutral housing stock by 2050.[23] The achievement of this target will offer inherent benefits to system resilience, but will require the implementation of a wide variety of privately cost-effective and privately non-cost-effective EER measures. Policy mechanisms in the UK in the last 10 years have mainly targeted the most privately cost-effective measures. The Carbon Emission Reduction Target scheme (2008-2012), for example, was effective at provision of the most cost-effective measures. Measures that are equally necessary (for the achievement of long term targets) but not necessarily cost-effective in the short term, were largely ignored. The focus on the most cost-effective first allows the greatest bang for a limited buck, but creates a scenario where unlocking the remaining long-term, high-value potential becomes increasingly expensive.

Publicly funded schemes, such as the Green Deal Home Improvement Fund (2012 – present day) which have some focus on less privately cost-effective measures, have limited capacity in an era of fiscal austerity and limited public money. Alongside the CERT scheme they also have the drawback of offering a piecemeal approach to an issue which will require multiple measures in single properties in the long term. The support for individual measures, as opposed to overall energy saving attainment or a "whole house" approach, leads to inefficient implementation of a costly process and will only exacerbate issues with household disruption and lack of consumer buy-in.

Our modelling considers the impacts to overall provision of different hypothetical frameworks for provision. The private mode delivers significant investment and carbon savings in the short-term, focussing upon exploiting financially cost-effective opportunities. However, this often precludes the ability to implement more socially-minded modes of delivery e.g. using the savings from these cost-effective opportunities to deliver measures with low financial benefit-cost ratios that are nonetheless essential for delivering long-term goals such as meeting carbon reduction targets or alleviating fuel poverty. The public mode could achieve deep levels of EER deployment even when restricting investment to the cost-effective measures; provided that the potential public co-benefits of such investments (healthcare savings, improved tax revenues from net employment gains, etc.) are incorporated into the economic decision making process and the public benefit of EER is credited via subsidy. The civic mode, despite being assumed to have access to relatively limited levels of upfront investment, achieves high levels of EER deployment in the longer-term, on a par with that achieved by the public scheme. It does this by recirculating capital from early cost-savings into the measures with lower benefit-cost ratios, much more efficiently than a public subsidy scheme) via a number of

[23] CCC. 2015. Meeting Carbon Budgets - Progress in reducing the UK's emissions. 2015 Report to Parliament. 2015.

beneficial social and institutional arrangements that are characteristic of civic decentralised energy movements funding cost-ineffective measures with the returns from cost-effective measures and lower stipulated interest rates. The retention of local value by the civic fund is envisaged to encourage a more coherent approach to EER uptake, potentially limiting household disruption with a more multi-measure or "whole house" approach.

In summary, the private mode we consider requires little public investment, is fast (with respect to implementation), but is limited in scope and thus potentially very costly in the long-term (as privately cost-ineffective measures may be left requiring large subsidies). Comparatively, the public mode requires substantial public investment, but is also fast and foreseen to be both profitable in the longer-term (via increased tax returns and healthcare savings) and thorough in scope. The civic mode requires little (although not insignificant) public investment, is profitable in the long-term and thorough in scope, its benefits, however, are achieved more slowly.

Beyond the energy system: Alternative and integrated infrastructure business models

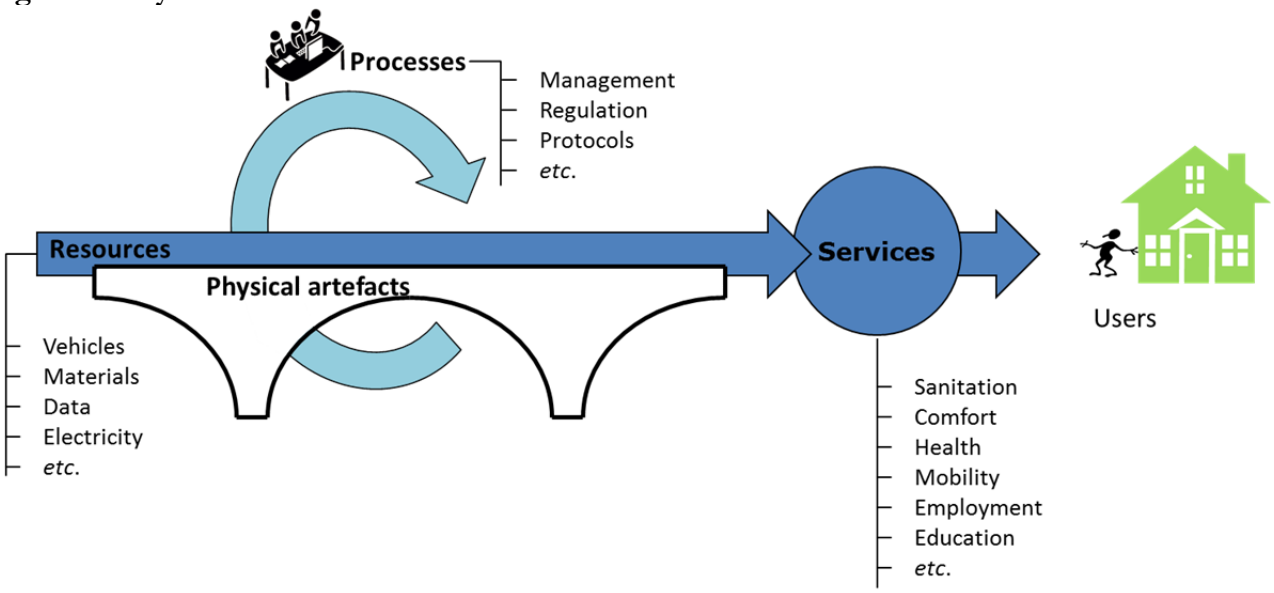
Business models take into consideration different governance, but must also consider the wider infrastructure system that comprises (Figure 1):

- *physical artefacts* – includes the physical links, nodes and components of infrastructure systems such as roads, bridges, pipes and cables;
- *processes* – includes actors, institutions, management, regulation, protocols and procedures that govern the infrastructure over its lifecycle;
- *resources* – includes people, vehicles, water, electricity and data that are conveyed by the physical artefacts and the materials used in the construction of the artefacts; and,
- *services* – such as warmth, mobility, sanitation, transportation, welfare services and communication that benefit a wide range of users.

Infrastructure is therefore the artefacts and processes of the inter-related systems that enable the movement of resources in order to provide the services that mediate (and ideally enhance) security, health, economic growth and quality of life at a range of scales.[24] Moving beyond a narrow or solely economic view and distinct from the world of more conventional goods and services, an infrastructure business model therefore describes how infrastructure systems create, deliver and capture economic, social and environmental values over the whole infrastructure life cycle.[25]

[24] Dawson RJ (2013) *Bridges n'that: An infrastructure definition for iBUILD*, iBUILD Briefing Note 1.
[25] Bryson JR, Pike A, Walsh CL, Foxon T, Bouch C & Dawson RJ (2014) *Infrastructure Business Models*, iBUILD Briefing Note 2.

Figure 1: A systems view of infrastructure.

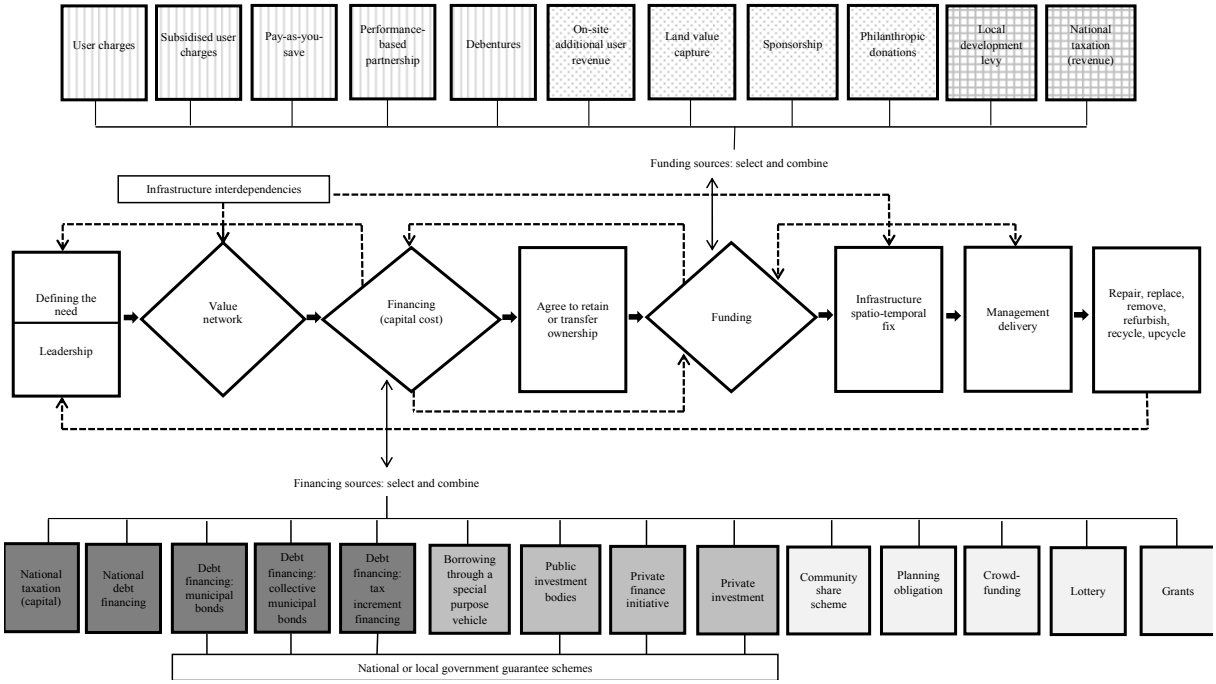


Source: iBUILD (2015: p5).

iBUILD has undertaken a review of over hundred UK and international local infrastructure business models, both traditional and non-traditional, across all infrastructure asset classes.[26] The business models are diverse. Value creation includes social, economic and urban regeneration outcomes as well as direct outputs in terms of service supply. International comparison has illustrated how the development of business models from niche to established mainstream models reflects the regulatory, political and socio-economic context.[27] For example, the success of municipal decentralised energy supply in Denmark and subsidy-supported business models for local energy supply in the UK.

[26] Currently online here: http://ceg-research.ncl.ac.uk/ibuildDemo/ (URL subject to change when site goes fully live)
[27] Bryson, Mulhall, Song, Loo, Dawson (in review) Conceptualising Local Infrastructure Business Models: The Spatio-Temporal Fix, *Research Policy*.

Figure 2: Conceptual Framework of Local Infrastructure Business Models



Source: Bryson et al. (in review).

Developing and implementing alternative approaches provides some benefits, but as noted above, our infrastructures are increasingly interconnected and some of the most promising opportunities are from thinking about delivering what people really require i.e. warmth, light, mobility etc. rather than electricity, gas, roads. This can help identify business models that deliver efficiencies across multiple 'traditional' sector boundaries. A rapidly emerging interdependence is between electricity and transport infrastructure – most notably uptake of electric vehicles (EVs). Coupled analysis of energy and transport systems models, has demonstrated that distribution networks could accommodate higher growth in electric vehicles than previous studies have suggested. Exploiting the geographic spread and different timings of EV charging can limit the impact on power infrastructure. Distribution network operators should collaborate with new market players, such as charging infrastructure operators, to support the roll out of an extensive charging infrastructure to make both networks more robust.[28]

A well-established demonstration of the value of integrated infrastructure thinking applied to an industrial park – now an industrial ecosystem – is the closing of material and energy loops locally with integrated infrastructure in Kalundborg, Denmark. Since 1972, this industrial park has evolved from a single power station into a cluster of companies that exchange materials and energy for mutual benefit as by-products from one business are often inputs for others. For example, treated wastewater from a refinery is used to cool a power station which in turn provides steam for the refinery and a pharmaceutical plant. Surplus heat from the power station is also used for warming nearby homes and businesses. This has led to substantial annual savings of resources and costs – for example, a reduction in water consumption of 3.3million m3/year, savings of $15m from resource sharing and far larger

[28] Neaimeh M, Wardle R, Jenkins A, Hill GA, Lyons P, Yi J, Huebner Y, Blythe PT & Taylor P (in press) A probabilistic approach to combining smart meter and electric vehicle charging data to investigate distribution network impacts, *Applied Energy*.

savings by sharing infrastructure have been reported – highlighting how integrated infrastructure business models can produce substantial savings.[29,30]

There are many potential ways of organising and regulating such interactions to create efficiencies. For example, in 1887 in Indianapolis, local civic leaders established a natural gas company as a Public Trust, with an aim to "create the greatest long-term benefit for customers and communities". Today, the Citizens Energy Group owns and operates a large portfolio of physical infrastructure assets that deliver multiple services including energy, water and wastewater for 800,000 people and thousands of businesses in the Indianapolis area. This has provided community services that are entirely compatible with good financial management. The group was awarded a top rating (MIG 1) by Moody's credit rating agency in 2014, a reflection, in part, of the strength of the company's infrastructure business model.[31] By recognising the opportunities from the interdependencies of modern infrastructure, and explicitly designing this into our energy and other systems, this not only offers opportunity for alternative business models but also can be used to deliver flexible infrastructure systems that can enhance resilience.[32]

[29] Chertow MR & Lombardi DR (2005) Quantifying Economic and Environmental Benefits of Co-Located Firms, *Environmental Science & Technology*, 39(17):6535 -6541.
[30] Chopra SS & Khanna V (2014) Understanding resilience in industrial symbiosis networks: Insights from network analysis, *Journal of Environmental Management*, 141:86-94.
[31] www.moodys.com/research/Moodys-Concludes-Review-and-Confirms-MIG-1-on-Indianapolis-Indiana--PR_302963
[32] Khoury M, Bullock S, Fu G, and Dawson RJ (2015) Improving measures of topological robustness in networks of networks and suggestion of a novel way to counter both failure propagation and isolation, J. *Infrastructure Complexity*, 2(1):1-20.

Contributing authors

The iBUILD Centre involves over 50 researchers who have contributed to the research base that we draw from here. The submissions to the three NIC consultations were coordinated and prepared by:

Peter O'Brien & Andy Pike, Centre for Urban and Regional Development Studies, Newcastle University
Richard Dawson, Centre for Earth Systems Engineering Research, Newcastle University
John Tomaney, Bartlett School of Planning, UCL
Phil Purnell, Institute for Resilient Infrastructure, University of Leeds
Niall Kerr & Stephen Hall, School of Earth and Environment, University of Leeds

For further information about iBUILD please contact:

Centre Director: Professor Richard Dawson
Email: [email address redacted]
Telephone: [phone number redacted]

Centre Manager: Dr Claire Walsh
Email: [email address redacted]
Telephone: [phone number redacted]

Additional contact details

iBUILD Newcastle - Headquarters
Professor Richard Dawson
School of Civil Engineering and Geosciences
Cassie Building
Newcastle University
Newcastle upon Tyne
Tyne & Wear
NE1 7RU

iBUILD Birmingham Professor Chris Rogers School of Civil Engineering University of Birmingham Edgbaston
Birmingham
B15 2TT
United Kingdom
Tel: [phone number redacted]
Fax: [fax number redacted]

iBUILD Leeds Professor Phil Purnell Faculty of Engineering
Woodhouse Lane
University of Leeds
Leeds
LS2 9JT
United Kingdom
Tel: [phone number redacted]