World Energy Council

Perspective input into the World Energy Council Scenarios: "Innovating Urban Energy"

Project Partner – Arup

October 2016

Preface

It is estimated that 66% of the world population will live in urban areas by 2050, increasing to 70% by 2060. Bearing in mind this urbanisation, the manner in which energy is provided, managed and consumed in the urban setting is becoming an increasingly important and influential element of the broader energy picture.

This Perspective Paper selects five emerging urban energy innovations which hold the potential to substantially steer transition of the energy agenda in our cities, towns and smaller conurbations. It explores the importance of local government, new digital platforms, hydrogen, city morphology and financial tools in securing a clean, resilient and affordable future for energy, transport and other city systems.

The paper was prepared by Arup (authors Alan Thomson and Stephen Cook) on behalf of the World Energy Council to provide both insight and creative input to the authors of the Scenarios and Resources reports.

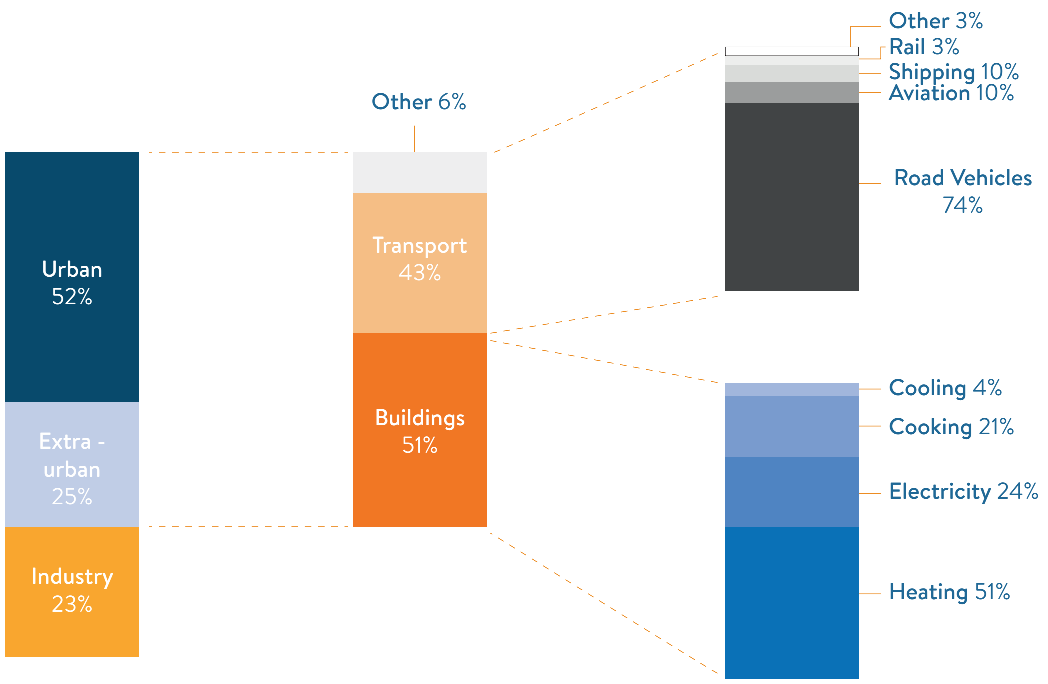
Contents

Section 1.
Introduction

This paper takes a closer look at energy in cities.

Why focus on cities? First of all, more than half the global population lives in cities, and cities account for over half of global energy consumption and forty percent of greenhouse gas emissions, with the largest shares going to road transport, building heating and building electricity (see Figure 1).

Figure 1 Global energy consumption from urban and other uses[7]



(source: Arup analysis based on IEA, UN Habitat, EIA, WEF sources)

As global population increases and the urbanisation trend continues, cities will become ever more dominant consumers of energy and other global resources, and their impacts will spread ever wider. The UN estimates that 66% of the world's population will live in cities by 2050,[1] while another study estimates that the global urban footprint (i.e. its physical extent) will triple over the 30 years to 2030, comprising an additional area of 1.2 million square kilometres.[2] Reducing the impact of urbanisation through increasing urban energy efficiency and switching to clean, low carbon resources is clearly critical for cities to continue to thrive as engines of economic growth and human creativity.

1 United Nations 2015. World Urbanization Prospects: The 2014 Revision. New York.

2 Seto KC, Güneralp B, Hutyra LR 2012. "Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools." Proc Natl Acad Sci USA 109(40): 16083–16088. Cited in Creutzig et al. 2015. "Global typology of urban energy use and potentials for an urbanization mitigation wedge." Proc Natl Acad Sci USA 112(20): 6283–6288.

1.1 Common and distinct city challenges and opportunities

Beyond these headline figures, the physical, economic, social and political complexity of these dense communities creates distinct challenges and opportunities, compared with peri-urban, rural and industrial settings, that merit investigation into urban energy. Firstly, dense, mixed use urban forms can reduce the unit cost of transport and energy infrastructure and enable adoption of efficient transit systems and low carbon heating and cooling networks, but density can also lead to adverse effects such as urban heat island and reduce the availability of renewable resources such as solar and wind.

Secondly, cities face dynamic challenges including rapid urbanisation, demographic change and economic change. Many city governments and utility providers struggle to keep up with the pace of growth, while others in contracting economies struggle to remain viable while providing even basic services.

Thirdly, the legacies of existing urban form, buildings and infrastructure tend to "lock-in" energy consumption patterns and available sources and vectors of energy. This legacy includes complex tenancy and land ownership arrangements as well as physical patterns of development. Rapid change can only occur through highly context-sensitive initiatives.

Finally, the governance of cities – many of which have considerable authority, influence and budgetary powers – can be critical to the design and delivery of locally appropriate, effective solutions for energy systems which also deliver other city drivers – such as air quality, economy and resilience.[3]

Given these features, energy solutions for cities need to be highly sensitive to context, highly granular in application, and be developed as integrated technical, commercial and social packages.

1.2 Five innovations for urban energy

The challenges and opportunities briefly noted above are probably familiar to every major city in the world, and many of these were highlighted in WEC's 2010 report on energy and cities[4]. However, new solutions and opportunities are emerging which can enable cities – and energy actors in cities – to address these challenges in new and potentially more effective ways. In this brief chapter we consider a selection of emerging and potential innovations for urban energy. The innovations we consider are:

- Transactive energy
- City action networks
- Integrated energy planning
- Hydrogen economy
- Financing energy action

Reflecting the above diagnosis that integrated solutions are needed to deliver change in how and how much cities use energy, the innovations we survey are not all about technology: although technological change is an enabler for each, the core innovations span matters of governance, market, finance and society.

3 See for example Arup and C40 Climate Leadership Group 2015. Powering Climate Action: Cities as Global Changemakers. Available at: http://publications.arup.com/publications/p/powering_climate_action_cities_as_global_changemakers

4 World Energy Council 2010. Energy and Urban Innovation. London.

Section 2. Transactive energy

2.1 The transformation of power systems and electricity markets

Power systems today are undergoing a profound transformation, driven by the diversification and decentralization of power generation, coupled with the emergence of advanced power electronics which are capable of managing the increasing complexity and size of modern power systems. The technological changes are in turn driving changes in the ways energy is bought and sold: the twentieth century model of centralized energy production and distribution by a limited number of actors is evolving into a data-driven, multi-directional, market-based platform where divisions between roles – producer, distributor, consumer – are becoming blurred and overlapping.

This convergence of actors participating in a dynamic energy market is referred to as transactive energy (TE). TE is formally defined by the GridWise Architecture Council[5] as:

> *A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.*

Although the idea of a market operating in a dynamic balance in response to supply and demand signals may appear unremarkable in the context of many other industries, the implications for our energy systems are profound. Today, most grids are kept stable through explicit control by a central grid operator, which controls supply to meet continuously changing demand through the dispatch of generation assets in accordance with a pre-defined ranking of priority. An energy market does operate, but the market transactions are mostly undertaken well before or well after the generation-consumption event. In the short term, demand is generally uncontrollable and unresponsive to the cost of supply.

The move to a real time market-based model of electricity supply and demand means that system can no longer be "controlled" by a central grid operator. Instead, the network will migrate to an energy ecosystem which is kept in a state of dynamic equilibrium through the balancing effect of price signals established by millions of participants. The dichotomy of producers and consumers will evolve into a spectrum of roles which includes "prosumers" which act on both sides of the market, along with additional roles for ancillary grid services providers such as ramping and balancing.

New York's Reforming the Energy Vision and Distribution System Platform[6]

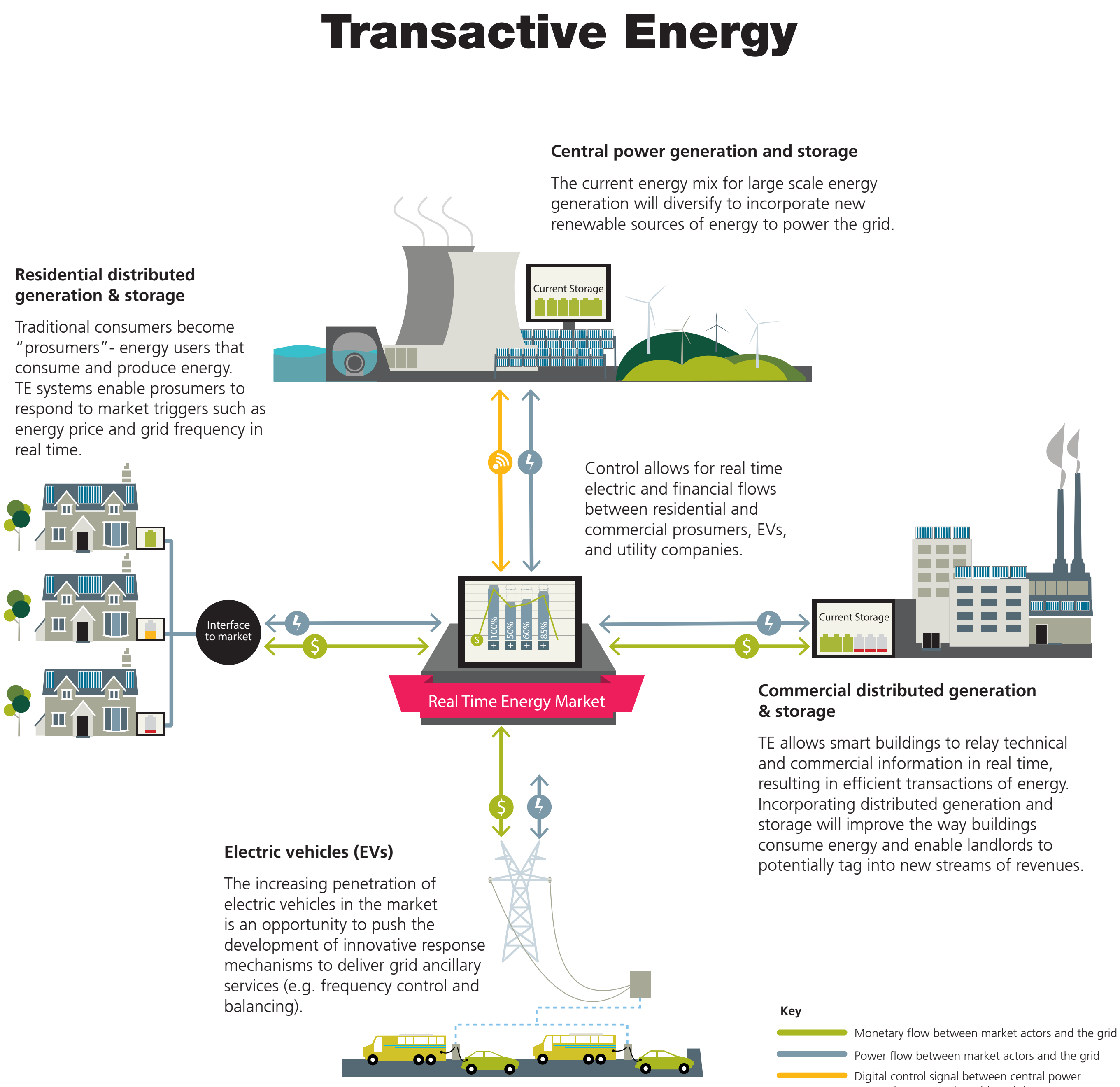
New York State's 'Reforming the Energy Vision (REV)' strategy is an ambitious effort to shift away from large generation systems and deliver infrastructure to empower prosumers to have more control over their energy consumption and production. This approach aims to increase the overall system efficiency while reducing grid expansion costs.

Furthermore, to promote the uptake of DES, New York has also formulated and issued a policy around a platform known as the Distribution System Platform (DSP) provider. The DSP is a basket of market functions intended to enable customer interaction around energy ancillary services.

5 The GridWise Architecture Council "was formed by the U.S. Department of Energy to promote and enable interoperability among the many entities that interact with the nation's electric power system." For further information see http://www.gridwiseac.org/ (Accessed 1 June 2016).

6 New York Government Press Releases, "Reforming the Energy Vision", available at https://www.ny.gov/sites/ny.gov/files/atoms/files/WhitePaperREVMarch2016.pdf. See also New York State Public Service Commission Market Design and Platform Technology Working Group (MDPTWG), 2015. "Report of the Market Design and Platform Technology Working Group." Available at https://newyorkrev-workinggroups.com/.

Figure 2 Transactive energy diagram



The infographic illustrates the transactive energy system. (Image ©Arup)

2.2 The role of Transactive Energy in cities

The complexity, density and diversity of energy consumption in cities makes them potentially key drivers and major beneficiaries of the transactive energy model. This is discussed below in relation to different types of city.

2.2.1 Accommodating growth

In many **rapidly growing cities**, grid capacity and reliability is a major challenge, with grid constraints and supply outages a frequent occurrence. Landlords, businesses and residents either incur losses (e.g. from lower productivity or damage to goods and assets) or higher costs to provide on-site resilience such as running diesel generators. Such local and ad hoc solutions can have other adverse impacts such as worsening air quality, odour and streetscape clutter.

These same cities have potentially the strongest value case for "leapfrogging" to a TE model. A transactive energy system could improve system reliability and efficiency and unlock new investment to meet growing demand of connected areas and to extend access to those who have no electricity grid connections at all. Such investments would focus on distributed energy systems (DES), such as renewable energy, energy storage, microgrids and demand management technologies. These systems can deliver value both locally – through cost savings and local resilience – and to the wider grid – through balancing and load control.

Recent research by Arup and Siemens, for example, indicates that the value to end users of DES investment is significant. Based on a series of modelled case studies around the world, operational cost reductions ranging between 8% and 28% and a return on investment (ROI) between 3-7 years were observed, compared to a business as usual scenario.[7]

2.2.2 Delivering efficient buildings

In **developed cities**, TE offers a significant prize of a step change in building energy efficiency. Buildings in the United States of America, for example, consume around 40% of all energy and 70% of grid electricity[8]; reducing this load is critical to the achievement of carbon reduction targets and is a potential major contributor to economic productivity, as businesses reduce operational costs and homeowners increase disposable income. Applying distributed energy systems within a transactive energy model allows urban building owners to have better information on energy consumption, the tools to control and reduce energy and the access to a market which translates the energy savings and control investments to financial returns.

2.2.3 Electrification of urban heat

In **all cities**, the transactive energy model could enable integration of the electric grid with heating to deliver even greater environmental benefits, lower carbon emissions and improved energy resilience.

In temperate countries such as the UK, energy for heating amounts to almost half of final energy consumed, and peak heating demand (i.e. on a cold winter evening) is as much five times the peak demand of electricity.[9] This heating demand is today met in many cities almost entirely by natural gas supplied directly to buildings, although centralised urban heat networks have high penetration in some cities in northern Europe and North America. Transitioning away from fossil fuel heating to renewable and low carbon sources will inevitably involve a transition towards electricity as the main input energy for heating systems, especially in cities, where alternatives such as biomass and solar thermal are less suitable, due respectively to air quality impacts and the density of energy demand compared with available roofspace for solar generation.

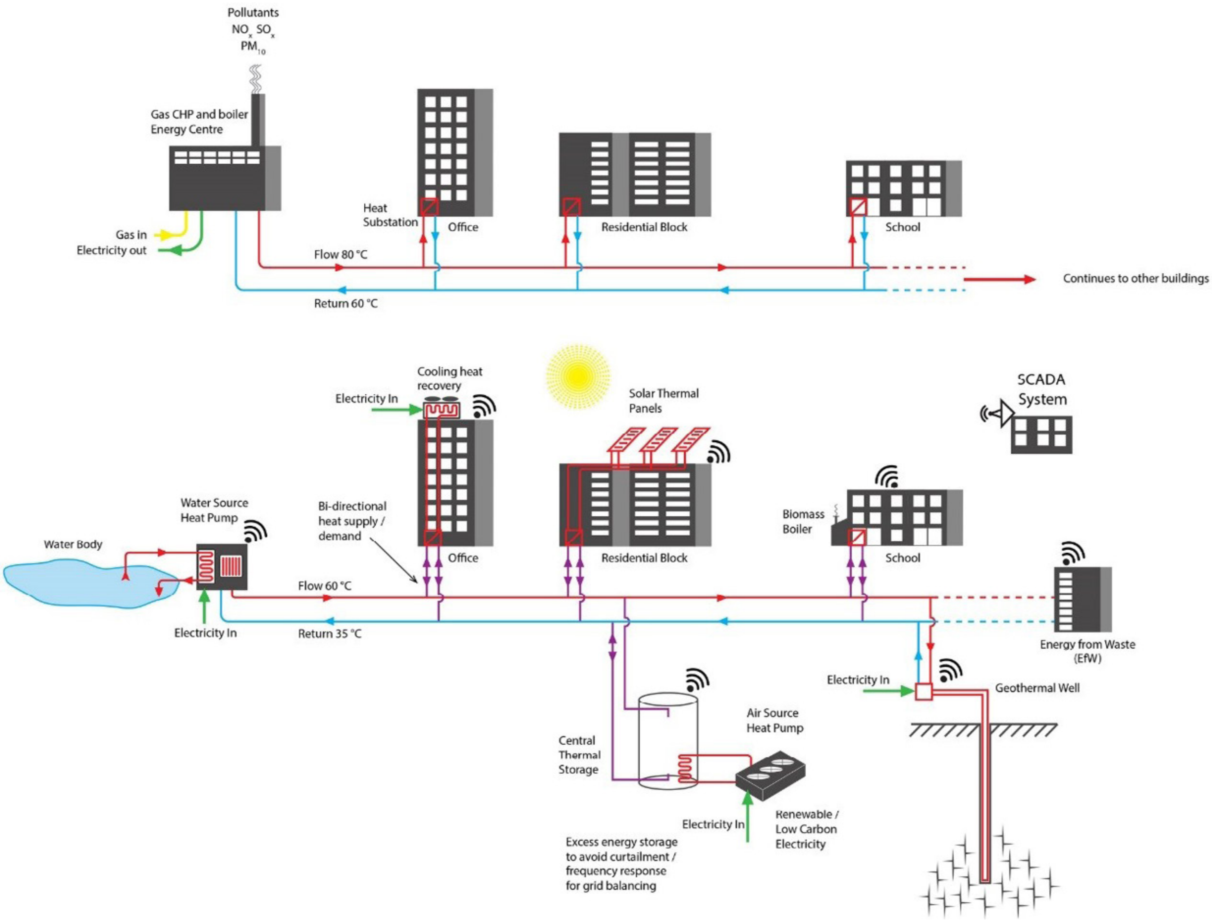
7 Arup and Siemens, 2016. "Distributed Energy Systems: Flexible and Efficient Power for the New Energy Era." http://w3.siemens.com/topics/global/en/intelligent-infrastructure/pages/intelligent-infrastructure.aspx.

8 US Energy Information Administration, 2014. Annual Energy Outlook 2014, Report No. DOE/EIA-0383(2014). Available at http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

9 UK Department of Energy and Climate Change, 2012. The Future of Heating: A strategic framework for low carbon heat in the UK. London. Available at: https://www.gov.uk/government/publications/the-future-of-heating-a-strategic-framework-for-low-carbon-heat

Cities can enable the electrification of heat in a way which limits pressure on grid networks by capturing available heat sources from within cities – from ground, air and water but also from sewers, tunnels and other urban infrastructure – and carrying the heat via hot water heat networks to where it is needed.

Figure 3 Integrated heat networks using multiple heat sources



(Image ©Arup)

In the most cases, with a warm heat source and low temperature receiving system, heat networks could deliver four to six units of heat output for each unit of electricity (although multipliers[10] of around three are more typical as average performances across the year[11]). Heat storage, meanwhile, can be used to smooth peak electric loads and avoid times when grid capacity is constrained. Through these means urban heat networks can effectively enable a low carbon transition while contributing to grid balancing through a transactive energy market mechanism.

10 Also referred to as coefficients of power, or COPs.
11 Greater London Authority, 2013. London's Zero Carbon Energy Resource: Secondary Heat Report Phase 2. Available at: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/031250%20(final)%20GLA%20Low%20Carbon%20Heat%20Study%20Report%20Phase%202_0.pdf

2.2.4 Electrification of urban transport

Like heat, the transportation sector appears to be on a rapid trajectory towards electrification, especially in cities. Although today's stock of road vehicles is almost entirely made of liquid fuel-powered vehicles, electric vehicle (EV) penetration is rising rapidly. This is due to a mix of pull factors, including improving vehicle design, battery performance and falling prices, and push factors, including policy support for EVs and restrictions on other fuel types to improve air quality. Currently, EVs represent less than 0.1% of total passengers cars in the world, but recent research by Bloomberg New Energy Finance forecasts that "continuing reductions in battery prices will bring the total cost of ownership of EVs below that for conventional-fuel vehicles by 2025." By 2040, Bloomberg projects that EVs will represent 35% of global light duty vehicle sales. Such a volume equates to an 11% share of the global electricity demand in 2015.[12]

Such a rate of transition from petroleum- to electricity-based transport will have a profound impact on the grid. The impact will however be greatest on urban energy systems, given that EV penetration will inevitably be most concentrated in urban areas, because:

- cost and environmental benefits over conventional gasoline and diesel engines are greatest in cities;
- EV range limitations are less of an issue in cities, where most trips are only a few miles. The shorter range also makes EVs more viable for city-based medium-duty vehicles (e.g. delivery trucks and tradesman vans); and
- Urban densities mean that deployment of EV charging infrastructure is more viable in cities.

Transactive energy can provide a critical means to ensure generation and distribution infrastructure investment in cities keeps pace with the rising marginal demand of energy. TE can also provide price signals to secure premium payments from those whose need for recharging may be urgent, while rewarding those willing to postpone or spread out their recharge. Vehicle fleets may also be able to capture excess generation in low demand periods (e.g. overnight) and so increase utilisation of wind as renewables take an ever larger share of the generation mix.

12 Bloomberg New Energy Finance 2016. "Electric vehicles to be 35% of global new car sales by 2040", available at http://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/

Section 3. Mayors and city action networks

The Paris climate conference (CoP21) in December 2015 marked a pivotal moment when non-state actors – in particular cities – were formally recognised as having a fundamental part to play in delivering a low carbon future for the planet.[13] Cities have the ability to take direct local action and in many places mayors have a political mandate for climate and environmental action even when support and leadership at a national level are more equivocal.

Cities are also taking action together, across geographical and political boundaries. For example, the Climate Summit for Local Leaders, held during CoP21, was a meeting of over one thousand mayors to discuss how cities are tackling climate change. The summit built on the previous efforts of the Compact of Mayors, which is a global coalition of mayors and city officials pledging to reduce greenhouse gas emissions and track progress in a transparent and uniform way.

The growth of climate-related city coalitions and networks – such as the Compact of Mayors, the C40 Cities Climate Leadership Group, the Covenant of Mayors, ICLEI Local Governments for Sustainability and 100 Resilient Cities (100RC) – is a reflection of the value that cities place on sharing and learning through peer-to-peer mechanisms. Their collective influence is formidable, and represents a significant proportion of the world's population. For example:

- The Compact of Mayors has 450 signatory cities representing almost 400 million people. According to the Compact, commitments already made (before CoP21) by its members can deliver half of the global urban potential greenhouse gas (GHG) emissions reductions available by 2020, and 25% of reductions by 2030.[14]
- Over 150 cities and regions – representing 150 million people – signed The Paris Pledge, a pledge from non-state actors to act on the Paris commitment and to 'ensure that the level of ambition set by the agreement is met or exceeded.'[15]
- Similarly, The Mayors' Declaration on Renewable Energy was signed by 700 city mayors in Paris 2015. The Declaration supports a municipal transition to 100% renewable energy supply by 2050, or alternatively to reduce greenhouse gas emissions by 2050.[16]

> *"CoP21 is the first time that cities will have their voices fully recognized at a global U. N. conference on climate change — and the first time mayors are gathering in great numbers to demand bold action."*
>
> **Michael Bloomberg, the former mayor of New York City and current U. N. Special Envoy for Cities and Climate Change.[17]**

Tokyo Cap-and-trade Program

In April 2010, the Tokyo Metropolitan Government implemented a cap-and-trade program, which was the first urban carbon trading program focused on urban industries. In the first 5-year period carbon emissions were set to reduce by 6% for factories and 8% for offices from the base year. In the second five-year period, these are set to increase to 15% and 17% respectively.

The highly successful program has achieved overall emissions reductions of 25% from the 2002-2007 baseline by its fifth year.[18]

13 "The Conference of the Parties... Welcomes the efforts of all non-Party stakeholders to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other subnational authorities." UNFCCC, 2015. "Adoption of the Paris Agreement". Available at: https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
14 Compact of Mayors 2015. "Climate Leadership at the Local Level: Global Impact of the Compact of Mayors."
15 Paris Pledge for Action. Available at: http://www.parispledgeforaction.org/
16 Barbière, C. in Euractiv 2015. "700 cities promise renewable energy transition by 2050". Available at: http://www.euractiv.com/section/climate-environment/news/700-cities-promise-renewable-energy-transition-by-2050/
17 Michael R. Bloomberg, 2015. "Climate Summit for Local Leaders". Available at: http://climatesummitlocalleaders.paris/content/uploads/sites/16/2015/12/Anne-Hidalgo-and-Michael-Bloomberg.pdf
18 Tokyo Metropolitan Government 2016. "Tokyo cap-and-trade program achieves 25% reduction after 5th year."

3.1 City powers

Notwithstanding the power of city networks to stimulate action and foster peer-to-peer knowledge exchange, nearly all cities work within national and state legislative and policy frameworks. Formal power derives from the higher tier of government, as well as at least a proportion of capital and operational budgets. National governments' may increasingly devolve more budgetary and policy-making responsibility to local governments or they may maintain a more centralised, top-down approach. Both of these scenarios create a different landscape for responding to energy demand drivers, and may have different outcomes.

For example, several of England's largest cities have recently secured "devolution deals" with the United Kingdom central government. These deals give each city extended powers and fiscal control. In spite of these deals, the cities have recently called for greater fiscal control to enable them to deliver projects that meet the specific requirements of their city. Currently 95% of taxes raised in a city are sent back to the national government and redistributed to cities with certain stipulations.[19]

A key argument in support of the devolution agenda is that city governments will generally have a much clearer understanding of the challenges they face and therefore should have the power to deliver projects to address these. A recent study Powering Climate Action: Cities as Global Changemakers shows that cities have also been able to deliver projects without having significant amounts of power.[20] Cities can deliver projects through a broader approach to governance and partnership with other stakeholders, without requiring direct control of assets or influence over policy.

This could suggest that if national governments fail to establish climate change and energy policies for cities to take action, cities can still succeed in doing so through horizontal integration and coordination with other city stakeholders.

3.2 Municipal energy companies

A related emerging trend is the renewal of interest in municipal energy companies (MECs). Municipal energy companies date back to the early 20th development of grid networks in North America and Europe. Although many were privatised, some notable exceptions, such as Cleveland, St. Paul, Munich and Copenhagen have endured and have established new models for investing in energy infrastructure while delivering public benefits. A recent survey of MECs reports that around 25% of the electricity customers in the USA are supplied by municipal energy companies and energy co-operatives, while around 80% of distribution networks are owned and operated by public regional and municipal energy companies, or Stadtwerke. In Germany, the recent growth of Stadtwerke in recent years can be attributed to a "commitment to developing renewables, strengthening local democratic control, and strengthening the local economies."[21]

In the United Kingdom, where MECs are being actively explored in London and several other core cities, high levels of public trust in local governments and their access to low-cost capital are key drivers of renewed interest in the municipal energy model.

For those without the benefit of a legacy energy entity, making the transition can be challenging, especially where regulatory frameworks are built around limited markets with high barriers to entry. Nevertheless many cities around the world are exploring the potential for taking control of their city's energy destiny, thereby boosting the local economy and aligning energy investment decisions with public policy on energy, climate change and social welfare. Where such explorations and supported by the public and stimulate investment in resilient, low carbon energy infrastructure, such developments are anticipated to thrive.

19 London and England's largest cities join to call for greater devolution to drive economic growth. (n.d.). Retrieved April 18, 2016, from http://www.corecities.com/news-events/london-and-englands-largest-cities-join-call-greater-devolution-drive-economic-growth

20 Arup, 2015. Available at: http://publications.arup.com/publications/p/powering_climate_action_cities_as_global_changemakers

21 Hall 2016. "Public ownership of the UK energy system – benefits, costs and processes," University of Greenwich Public Services International Research Unit. Available at http://www.world-psi.org/sites/default/files/documents/research/2016-04-e-uk-public.pdf

Munich Municipal Energy Company[22]

Stadtwerke München (SWM), which is 100% owned by the city council, generates electricity and supplies electricity and gas to the great majority of households in the city.

In 2008, the city council decided that SWM should plan to generate enough renewable energy in its own plants to supply all of Munich's private households, subways and trams combined by 2015, and by 2025 enough to supply the entire municipality, including business and commerce. The 2015 target has already been achieved. SWM works with local welfare organisations to provide free energy advice to low-income households. SWM also provides public transport, water, district heating, telecoms and cable services to the whole city.

Today, energy supply is characterized by oligopolies of private energy suppliers. There is practically no competition on price. The transition to renewable energies is made rather reluctantly. By 2025, our utility company aims to produce so much green energy, that the entire demand of the city can be met. That requires enormous investments around 9 billion euros by 2025 and can only be successful if the long-term goal is sustainable economic success rather than short-term profit maximization ….German cities and towns are currently trying to correct the mistakes made in their privatization policies of the past. There are many examples of newly established or revived municipal utility companies, especially for energy and water supply, or of the repurchase of municipal transport services.

Dieter Reiter, Mayor of Munich: Welcome address to Munich Economic Summit May 2011.

District Energy St. Paul[23]

In the district energy field, District Energy St. Paul is considered the most notable in the United States for its use of renewable energy sources and implementation of energy conservation measures.

Launched as a demonstration project in 1983, District Energy was Saint Paul's response to the energy crises of the 1970s. The venture was a public-private partnership between the City of Saint Paul, State of Minnesota, U.S. Department of Energy, and the downtown business community, all of whom believed in the viability of a hot water district heating system to alleviate the pinch of the energy crisis.

District Energy St. Paul was built from the vision of Saint Paul Mayor George Latimer. Led by Mayor Latimer, the City lobbied state and federal governments for assistance in adopting a technology, developed in Europe, that could solve the heating problems of the city. Using the expertise of Hans Nyman, District Energy's first president, the system was successfully designed to be energy efficient, fuel flexible, and result in stable rates for its customers.

Today the municipal energy company delivers heating and cooling to most of the city's downtown. Customer's benefit from stable prices and low carbon energy from the utility's mix of gas and waste wood combined heat and power (CHP) facility which delivers 65MW of electrical power alongside the heat supply, and from the 1.2 MW solar thermal energy array located on the top of the adjacent conference centre.

22 From Hall 2016. Public ownership of the UK energy system – benefits, costs and processes." University of Greenwich Public Services International Research Unit (PSIRU). Quoted in http://www.cesifo-group.de/DocDL/Forum-3-2011.pdf ; https://www.swm.de/english/company/about/annual-report.html

23 District Energy St. Paul 2016. "District Energy St. Paul – History." Available at http://www.districtenergy.com/inside-district-energy/history/ . See also UNEP 2015. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy. Available at http://www.unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf

Section 4.
Integrated energy planning

The relationship between density and the viability of public transit – with consequential benefits for transport energy consumption – has long been recognised,[24] while the wider relationship between urban form and energy has been less clear. However new data is emerging which demonstrates a complex but significant relationship between urban form and energy consumption.

One study which drew upon data from 274 cities found the "economic activity, transport costs, geographic factors, and urban form explain 37% of urban direct energy use and 88% of urban transport energy use." Applying these results to projected growth in urbanisation, the study found that there was a potential greenhouse gas savings "wedge" available from the application of appropriate urban planning and transport policies. The wedge represented a reduction of around 26% of greenhouse gas emissions compared with a business as usual scenario. The greatest majority of the opportunity was linked to the projected rapid urbanisation in Africa and Asia, while the "lock-in" effect of established mature cities in Europe and North America limited the potential to employ changes in urban form to drive down energy consumption and associated GHG emissions.[25]

Another recent study of ten cities in the USA found that per capita energy consumption, when measured on a life-cycle basis, ranged from 90 GJ/year/capita in higher density cities up to 140 GJ/year/capita in lower density cities, which equates to a 35% per capita energy savings from differences in urban form.[26]

These studies help to demonstrate a truth which has long been understood from experience on the ground, i.e. that spatial planning is an essential ingredient to a well-functioning city. Spatial planning involves the allocation or zoning of uses for different sites or districts, setting policies and codes for new developments, and providing for the provision of infrastructure to service new and existing developments and populations. Without effective planning, cities can experience slum development, sprawl, congestion and pollution, all of which lead over time to worsening health outcomes for the population and loss of competitiveness for the city.

Integrated spatial planning takes a holistic approach to city development based on a clear set of objectives to achieve sustainable development. Integrated planning can yield tremendous benefits for cities, making them both more liveable and more efficient. Integrated energy planning, in turn, builds on those same principles, but adds a layer of focus on the use, distribution and generation of energy within the city. Integrated energy planning can help cities make the most use of available energy sources and implement the most efficient energy distribution solutions.

The infographic overleaf provides two contrasting pictures of energy use in cities, with and without integrated planning.

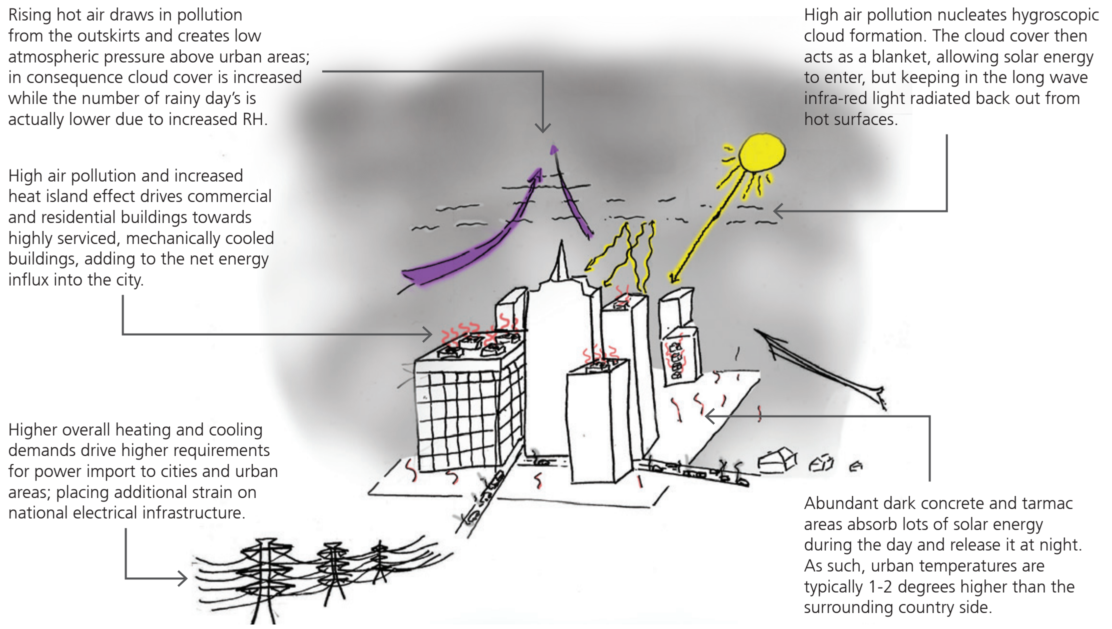
24 See for example Newman, P. and Kenworthy, J. R. 1989. Cities and automobile dependence: a sourcebook. Aldershot: Gower.

25 Creutzig et al. 2015. "Global typology of urban energy use and potentials for an urbanization mitigation wedge." Proc Natl Acad Sci USA 112(20): 6283–6288.

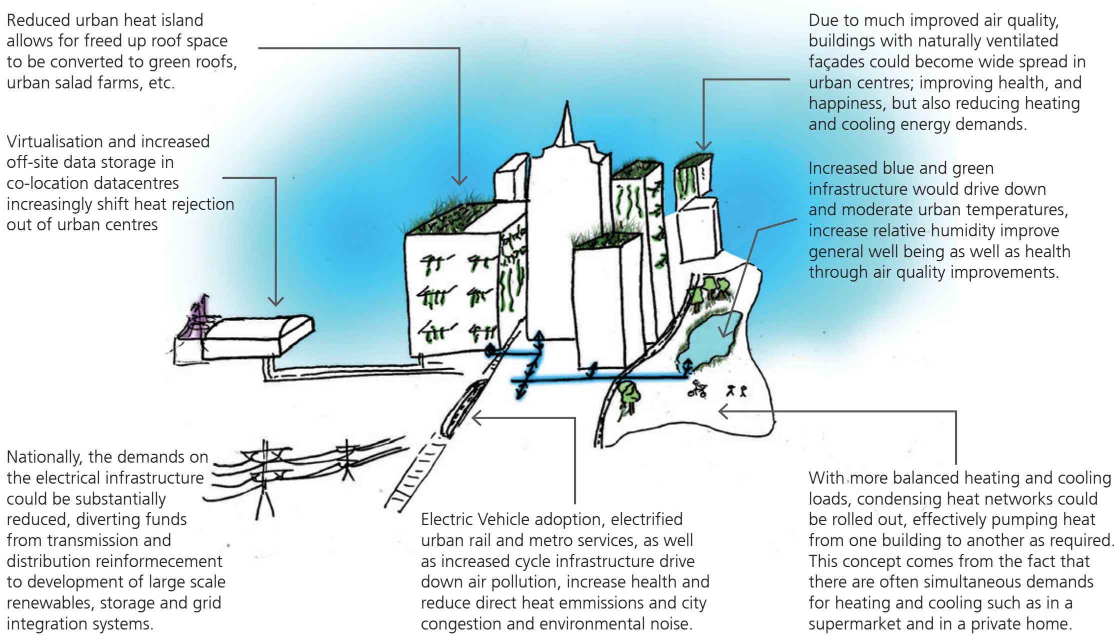
26 Nichols and Kockelman 2015. "Urban Form and Life-Cycle Energy Consumption: Case Studies at The City Scale," Journal of Transportation and Land Use, 8 (3): 1-15.

Figure 4 Cities with and without integrated urban planning (Image ©Arup)

An illustration of urban development without integrated energy planning



An illustration of urban development with integrated energy planning



(Image ©Arup)

New Songdo City, South Korea

The Songdo International Business District (IBD) is a master-planned city, built on 1,500 acres (6 km^2) of land reclaimed from the Yellow Sea. Songdo was designed around the principles of 'smart and sustainable', using an integrated urban development project to create a new city comprising residential, cultural, business, retail, and recreational sites. To maximise energy efficiency and asset utilisation, and lower environmental impacts, buildings have been designed to meet LEED standards while connected sensors allow residents to monitor and adjust temperature, heating, lighting and energy use, and compare their usage with neighbours. By focusing on connectivity and technology, Songdo has achieved 40% lower per capita energy use than similar sized cities.

London Infrastructure Plan[27]

The London Plan is the Mayor's strategic plan for the UK capital. It includes an integrated economic, environmental, transport and social framework for the development of London over the next 20 years. The London Infrastructure Plan (LIP) 2050 is a component of the Plan. LIP adopts an integrated approach to identify, prioritise and cost future infrastructure in a growing city, mapping out the city's future needs for transport, green, digital, energy, water and waste infrastructure. The London Energy Plan is a spatial strategy that forms part of LIP and is designed to map energy demand, supply and infrastructure to 2050.

27 Greater London Authority 2011. The London Plan. Available at: https://www.london.gov.uk/what-we-do/planning/london-plan. See also Greater London Authority 2015. The London Infrastructure Plan. Available at: https://www.london.gov.uk/what-we-do/business-and-economy/better-infrastructure/london-infrastructure-plan-2050

Section 5.
The hydrogen economy

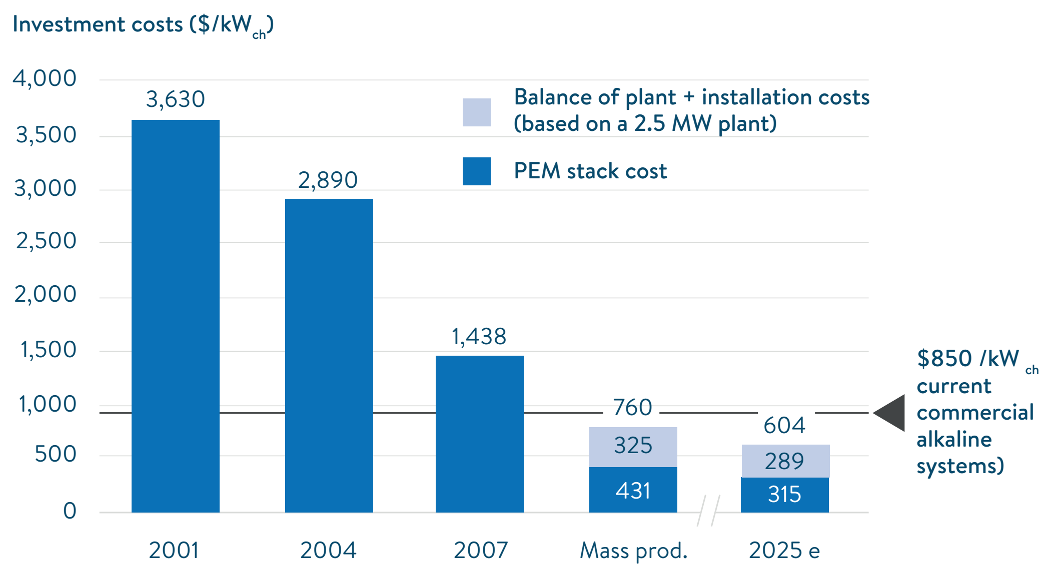
Hydrogen has long been recognised for its potential to act as a flexible low carbon energy carrier that could displace fossil fuels for both stationary and transport energy. Fuel cells – the main technology class which uses hydrogen – are attractive for urban applications because they are silent and emissions-free at point of use. They also offer rapid refuelling and potentially greater range than current generation batteries. Thus, the hydrogen economy vision comprises a variety of urban applications including:

- Electricity storage for seasonal and long-term grid balancing
- Electricity storage for back-up supply and off-grid applications
- Combined heat and power (CHP, or cogeneration) for buildings or heat networks.
- Domestic scale micro-CHP
- Transport fuel for buses and light duty vehicles
- Injection into the gas grid to displace natural gas

Despite its attractions, realising hydrogen's potential has proven challenging due to low round trip efficiencies and high production, isolating and storing costs.[28] The overall efficiency of hydrogen-based storage ranges from 30-35%[29], compared with efficiencies of 70-90% for many other competing energy storage technologies.[30]

Although efficiencies are not expected to increase significantly, hydrogen production costs are expected to fall to half their current levels (see Figure 3).

Figure 5. Historic and predicted future Proton Exchange Membrane (PEM) electrolysis costs[31]



28 In the region of $850/kW for hydrogen production and $1400/kWe for fuel cell power generation.

29 With commercial electrolysis, hydrogen production efficiencies currently range up to 80% and fuel cell power generation efficiencies range up to 40%, hence 0.80 x 0.40 = 0.32

30 Arup. Five minute guide to hydrogen. Available at: http://publications.arup.com/publications/f/five_minute_guide_hydrogen [Insert citation for Arup 5-minute guide / underlying references]

31 SBC Energy Institute 2014. *Leading the Energy Transition: Hydrogen-Based Energy Conversion.*

5.1 Emerging applications

Fuel cell deployment has accelerated in recent years, including a 30% annual growth rate for stationary generation, back-up power and materials handling equipment.[32] Although most applications are based on natural gas as their input fuel, "green hydrogen" applications using renewable electricity are gaining traction. The following examples highlight recent developments:

- **Residential fuel cells:** The Japanese government launched a commercial residential fuel cell support programme, call the Ene-Farm scheme, in 2009. Its aim was to stimulate the market and then to withdraw support as innovation and economies of scale enable the products to be deployed on a commercial basis. A total of 120,000 units were deployed over the six-year programme; the government's longer term target is for 1.4 million units by 2020 and 5.3 million by 2030.[33]
- **Remote stationary energy supplies:** Fuel cell developer Intelligent Energy and Indian telecom company GTL Limited signed a ten-year deal in 2015 to install and manage modular fuel cells to provide back-up power to more than 27,000 telecom towers in India. By early 2016 over 10MWh of energy had been deployed.[34]
- **Fuel cell buses:** Aberdeen in Scotland is the site of the UK's first hydrogen production and bus refuelling station, which opened in March 2015. The European, UK and Scottish Government funded demonstration project involves the operation of ten city buses serving the city and surrounding areas.[35]
- **Hydrogen from surplus renewable generation:** The Clean Energy Partnership is a German programme led by several major energy and transport companies involving the deployment of fuel cell vehicle charging stations across the country. This is part of a wider hydrogen production infrastructure, which includes a number of power-to-gas facilities which are located in regions that have plenty of wind-generating capacity. The largest of these is a plant near Werlte which opened in 2013, and which will produce around 1,000 tonnes of hydrogen fuel per year.[36]

32 IPHE 2014. "2014 Hydrogen and Fuel Cell Global Commercialization & Development Update."

33 See also Fuel Cell Works 2013. "ENE-FARM installed 120,000 residential fuel cell units." Available at: https://fuelcellsworks.com/archives/2015/09/23/ene-farm-installed-120000-residential-fuel-cell-units/

34 Intelligent Energy 2015. "Intelligent Energy announces milestone £1.2 billion deal to provide efficient, economical and clean power to over 27,400 telecom towers in India." 1 October 2015. See also Intelligent Energy 2016. "Breakthrough clean energy achieves 10MWh milestone of fuel cell power delivered to Indian telecom sites." 1 February 2016.

35 Aberdeen city Council 2015. "UK's largest hydrogen production and bus refuelling station opens in Aberdeen." Available at: http://www.aberdeencity.gov.uk/CouncilNews/ci_cns/pr_hydrogenfuel_110315.asp

36 E&E 2015. "Clean Energy: After years of theorizing, the hydrogen economy is emerging from excess wind power in Germany." Available at: http://www.eenews.net/stories/1060024908 See also European Power to Gas 2013. "Audi opens renewable energy E-gas plant in Germany." Available at http://www.europeanpowertogas.com/blog/623

5.2 Assessing hydrogen's real potential as an urban energy solution

With cities increasingly under pressure to decrease carbon intensities and improve air quality, the real potential of hydrogen as an urban energy solution will be determined by its ability to compete with electricity. Both energy carriers deliver zero emissions at the tailpipe and offer the promise of decarbonising transport and heating in particular when linked to a renewable and low carbon source of energy. It may, therefore, be relatively simple economics that determines a technology leader or shared solution.

5.2.1 Hydrogen transport

As discussed earlier in this chapter, the electrification of transport is already well under way, with modern, battery electric vehicles (BEVs) expected to achieve parity with gasoline and diesel cars by the early 2020s. Hydrogen fuel cell electric vehicles currently offer very limited competition to BEVs in the passenger vehicle market; as BEV sales accelerate and investments are made in the BEV charging infrastructure, hydrogen's window of opportunity in this sector appears to be closing.

For buses and heavy good vehicles, weight and space impose less of a constraint to design, while battery power and range are further away from being competitive with liquid fuels. Here hydrogen's greater range and rapid refuelling capability offer advantages in the urban and intra-urban context.

Hydrogen buses capable of travelling over 200km on a single tank and with the ability to re-fill rapidly are already traversing cities in increasing numbers. If current high costs can be reduced sufficiently quickly, hydrogen has the potential to become the HGV fuel of choice.

5.2.2 Hydrogen heat

While heat pump technologies can deliver efficient, low-carbon heat from electricity, widespread electrification of heating (in cold cities in particular) is made challenging due to significant additional investment required to upgrade network infrastructure sufficiently to meet the extra demand. In the UK, for example, peak heat power currently delivered by natural gas can be up to five times greater than the installed electrical grid[37].

For heating, therefore, the future of hydrogen will be determined by its ability to offer a least-cost alternative to electrical grid upgrading, either through re-use of existing assets or lower-cost rollout.

For heating or transport, hydrogen's potential role will depend on its ability to decarbonise, shifting from the current reliance on fossil fuels (gas reformation or electrolysis) for its production.

37 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf

Section 6. Financing energy action

Unlocking financing for projects that will enable a step change in how, and how much, energy they use is a recurring challenge for cities. While some cities have very limited powers to raise finance and determine spending priorities, even those with access to finance may struggle to demonstrate a clear business case for investment in their projects and programs. Payback periods can be lengthy, and upfront project development and transaction costs can limit the scale at which cities can act. Cities also have limited powers, and may struggle to secure the necessary willing partners in the face of program risks and uncertainties.

Recognising these manifold challenges, the Cities Climate Finance Leadership Alliance's recent report The State of City Climate Finance Report[38] makes five recommendations to help encourage investment in low-carbon urban projects:

1. **National Governments:** National government to create an enabling framework that encourages cities to invest in low carbon projects.
2. **Climate externalities:** Support for cities to put a price on climate externalities.
3. **Investment worthy:** Help cities make the business case for climate related projects.
4. **IFI finance:** International financial institutions to channel funding for projects through local financial institutions to help cities deliver climate projects.
5. **Innovation:** Create an environment that encourages the development of new financial instruments and funding models.

Despite these challenges and uncertainties, research shows that cities are committing significant amounts of their own city budgets and savings to fund low carbon projects. The C40 and Arup Climate Action in Megacities report[39] shows that 70% of city-wide scale actions have been funded by the cities' own budget or savings. Meanwhile at CoP21, twenty-two mayors from the Rockefeller Foundation's 100 Resilient Cities programme pledged to allocate 10% of their budgets to fund infrastructure projects, community planning, or governance initiatives that would contribute directly to the resilience of their cities. This shows that cities are willing to commit streams of funding for specific types of city projects to address energy and climate change challenges.

Most of the recommendations listed above are mutually reinforcing, leading to the identification of a number of opportunities for various stakeholders in the energy sector. For example, a national government framework could be created to leverage private sector funding from international financial institutions (IFI).

The opportunities are significant, especially in the energy sector; the finance industry has also been developing incremental innovations that can support low carbon transitions in cites. A selection of financing mechanisms are described below.

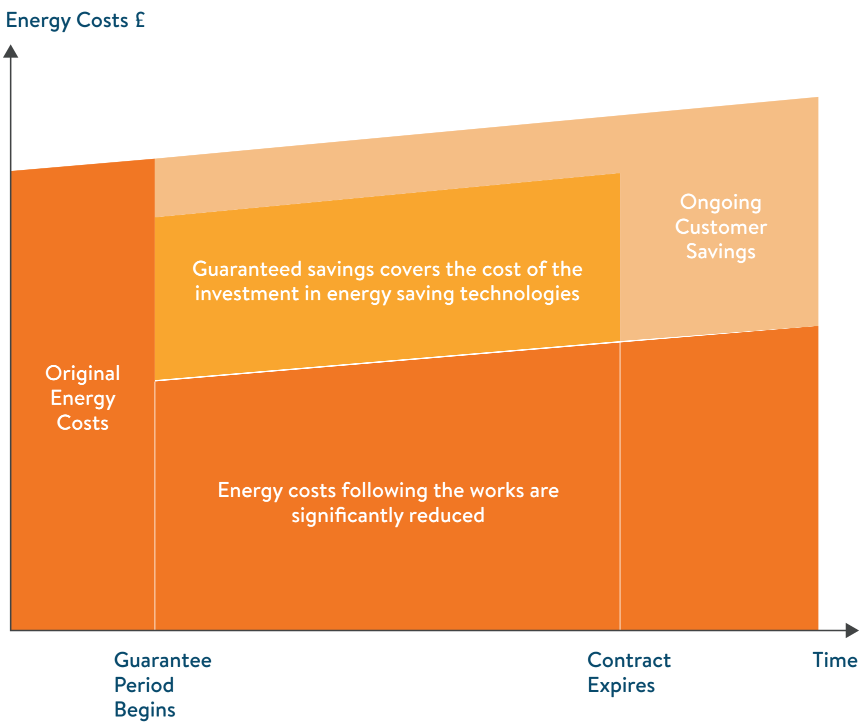
38 Cities Climate Finance Leadership Alliance 2015. The State of City Climate Finance Report. http://www.citiesclimatefinance.org/2015/12/the-state-of-city-climate-finance-2015-2/

39 C40 and Arup 2015. Climate Action in Megacities 3.0. Available at http://cam3.c40.org/#/main/home.

6.1 Energy Performance Contracting

Energy Performance contracting (EPC) is a form of packaged financing and capital works where financial savings from energy conservation measures are used to fund the cost of the measures. The attraction of EPCs is that it allows end users to secure energy savings investments without drawing upon limited capital or balance sheet payments. To be successful for all parties, the EPC contract implies that the funder has a stake in the energy savings for the client and hence leading to real and accountable carbon and energy savings. If the savings do not materialize as expected, the EPC contractor may be required to absorb some of the lost savings.

Figure 6 Working of the EPC model



RE:Fit London, paving the way for EPC[40]

RE:FIT London is jointly funded by the Mayor of London and the European Union European Regional Development Fund, and is aimed at helping to make London's non-domestic public buildings and assets more energy efficient.

RE:FIT targets a range of organisations, such as London boroughs, NHS bodies, central government departments, schools and other educational establishments and cultural and heritage organisations to implement retrofit projects.

RE:Fit has leveraged £93m in capital investment cumulatively saved 119,000 tonnes of CO_2 and £7.1m/year in utility bills from 619 buildings.

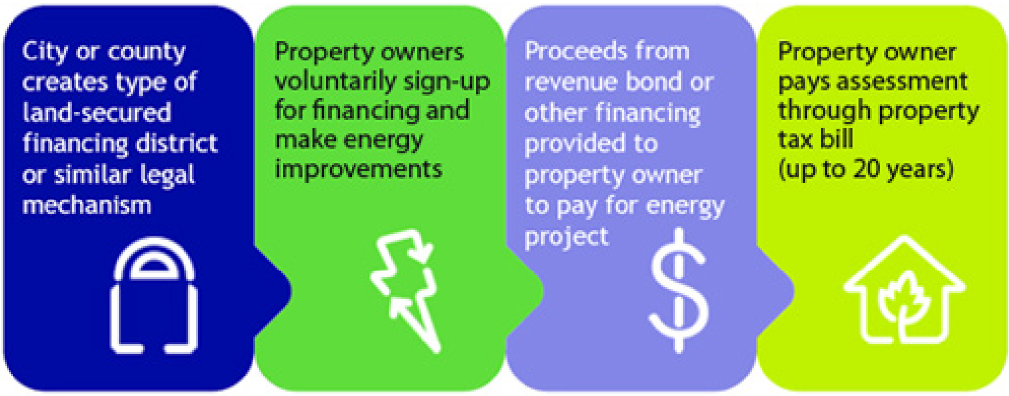
40 Ashden 2016. "Winner case study: Greater London Authority - RE:FIT." Available at https://www.ashden.org/files/case_studies/GLA%20REFIT%20Ashden%20UK%202016%20case%20study.pdf

6.2 Property tax approaches

An innovative program developed in the United States known as the property-assessed clean energy (PACE) program helps residential and commercial property owners to finance energy efficiency measures through property tax repayments.[41] PACE was built on an existing structure known as "land-secured financing district" or "assessment district". This structure enables local and state governments to issue bonds to fund projects that serve a public purpose. PACE extended this model to energy efficiency and provides property owners an opportunity to implement improvements without facing large upfront capital costs.

PACE ties debt to the property rather than the property owner and hence supports changes in ownerships structures for those properties. Participating in the PACE program is voluntary. Typically, periodic repayments are spread over 10 to 20 years. Programs such as PACE originated from local governments within cities to support their carbon reduction targets.

Figure 7 Functioning of the PACE program



6.3 Green Bonds & Capital Markets

A bond is a financial instrument used for raising capital through the debt capital markets. When a bond is issued to raise capital for projects or activities that have an environmental benefit (renewable energy, low carbon transport etc.), it is labelled as a "green" bond. The bond issuer (whether private or public sector) raises a fixed amount of capital from investors over a set period, repaying the capital when the bond matures and paying an agreed amount of interest each year.

Johannesburg Green Bond[42]

In June 2014 Johannesburg become the first African city to use a municipal green bond to help finance low carbon projects. The R1.46 billion bond COJGO1 was priced at 185 basis
points (1.85%) above the R2023 Government Bond. The bond was 150% oversubscribed.

"Green bonds have opened a new finance flow that will be essential to confronting climate change."

Rachel Kyte, World Bank Group Vice President and Special Envoy for Climate Change[43]

41 US Department of Energy 2016. "Property-Assessed Clean Energy Programs." Available at http://energy.gov/eere/slsc/property-assessed-clean-energy-programs.

42 City of Johannesburg 2014. "Joburg pioneers green bond." Available at http://www.joburg.org.za/index.php?option=com_content&id=9076:joburg-

43 World Bank 2015. "Green Bonds Attract Private Sector Climate Finance." Available at http://www.worldbank.org/en/topic/climatechange/brief/green-bonds-climate-finance

6.4 Secondary Markets

The primary capital market provides initial project financing, which is usually in the form of debt finance but can also be equity. The resale of these debt or equity shares to new investors creates the secondary market. In the context of energy, especially energy efficiency, this market is expanding thanks to increasingly ambitious energy performance policies and regulations.

According to the IEA, the extent of mandatory global energy efficiency regulations has increased from 14% in 2005 to 27 % in 2014. Such regulations imply an additional investment requirement. Programs such as the US-originated Warehouse for Energy Efficiency Loans (WHEEL) have emerged to help raise the required capital from the secondary capital markets.

The purpose of WHEEL is to provide low cost, large-scale capital for state and local government and utility sponsored residential energy efficiency programs. It achieves this by facilitating secondary market sales by purchasing unsecured residential energy efficiency loans. These loans are then aggregated into diversified pools that support the issuance of rated asset backed notes sold to capital market investors. Proceeds from these note sales are then utilised to recapitalize WHEEL, allowing it to continue purchasing eligible loans from state and local programs. Programs such as WHEEL can be set up with the support of national and local governments to unlock the potential energy efficiency with a city.[44]

6.5 Crowdfunding

Traditionally, a small number of investors including banks and state governments would provide large sums of money to finance energy projects. Crowdfunding subverts this approach and uses the power of the internet to allow a large number of stakeholders to invest small capital sums. Projects seeking funding are displayed via an online portal accessible to the general public. Once a project has reached its funding target, it can be commissioned to provide the promised returns to its investors. As crowdfunding projects are easy to set up, accessible to all investors, and may be financed through debt or equity, the approach has significant and increasing potential for community and city specific projects.

44 NASEO 2016. "Warehouse for Energy Efficiency Loans (WHEEL)." National Association of State Ennergy Officials. Available at http://www.naseo.org/wheel.

6.6 Public Private Partnerships (PPPs)

Although there is no single internationally accepted definition of Public-Private Partnerships (PPPs), the basic concept involves a long term contract between a private party and a government entity with the objective of delivering a public asset or service, such as a large solar plant or residential heating scheme. PPPs pave the way to bring in private sector knowledge to the public through specific government programs.

Some recent examples of energy-related PPPs include the following:

- General Electric agreed a collaboration deal with the Vietnamese government to provide 1,000MW of wind-power capacity in the country by 2025.[45]
- Swindon Council launched its first crowdfunding application for a new solar farm in the UK.[46]
- NYC invested $140 million in the Accelerate Conservation and Efficiency (ACE) program, a competitive funding program for city agencies to identify and implement energy efficiency projects. The city leveraged funding from its own funds and savings and through bond issuance.[47]

45 Vietnam Investment Review, 2016. Vietnam's MoIT and GE to cooperate on 1,000MW wind energy in Vietnam. [Online] Available at: http://www.vir.com.vn/vietnams-moit-and-ge-to-cooperate-on-1000mw-wind-energy-in-vietnam.html

46 Hobey, E., 2016. Abundance & Swindon Borough Council Launch Solar Bond: Following the Sun. [Online] Available at: http://www.crowdfundinsider.com/2016/02/82182-abundance-swindon-borough-council-launch-solar-bond-following-the-sun/

47 NYC: Citywide Administrative Services, 2016. Building Efficiency: Accelerated Conservation and Efficiency (ACE) program. [Online] Available at: http://www.nyc.gov/html/dem/html/municipal/efficiency.shtml

Section 7. End notes

Member committees of the World Energy Council

Algeria
Argentina
Austria
Bahrain
Belgium
Bolivia
Botswana
Brazil
Bulgaria
Cameroon
Canada
Chad
Chile
China
Colombia
Congo (Democratic Republic)
Côte d'Ivoire
Croatia
Cyprus
Czech Republic
Denmark
Ecuador
Egypt (Arab Republic)
Estonia
Ethiopia
Finland
France
Gabon
Germany
Ghana
Greece
Hong Kong, China
Hungary
Iceland
India Indonesia
Iran (Islamic Republic)
Iraq
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea (Republic)
Kuwait
Latvia
Lebanon
Libya
Lithuania
Luxembourg
Mexico
Monaco
Morocco
Namibia
Nepal
Netherlands
New Zealand
Niger
Nigeria
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russian Federation
Saudi Arabia
Senegal
Serbia
Slovakia
Slovenia
South Africa
Spain
Sri Lanka
Swaziland
Sweden
Switzerland
Syria (Arab Republic)
Taiwan, China
Tanzania
Thailand
Trinidad & Tobago
Tunisia
Turkey
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Zimbabwe

Patrons of the World Energy Council

Accenture Strategy

Bloomberg New Energy Finance

Electricité de France

Emirates Nuclear Energy Corporation

ENGIE

GE Power

Hydro-Québec

Korea Electric Power Corp.

Marsh & McLennan Companies

Masdar

Oliver Wyman

PricewaterhouseCoopers

Siemens AG

Swiss Re Corporate Solutions

Tokyo Electric Power Co.

VNG – Verbundnetz Gas AG

About the World Energy Council

The World Energy Council is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all. Formed in 1923, the Council is the UN-accredited global energy body, representing the entire energy spectrum, with more than 3000 member organisations located in over 90 countries and drawn from governments, private and state corporations, academia, NGOs and energy related stakeholders. The World Energy Council informs global, regional and national energy strategies by hosting high-level events, publishing authoritative studies, and working through its extensive member network to facilitate the world's energy policy dialogue.

Further details at www.worldenergy.org and @WECouncil

World Energy Council
62 – 64 Cornhill
London EC3V 3NH
United Kingdom

T: (+44) 20 7734 5996
F: (+44) 20 7734 5926
E: info@worldenergy.org

About Arup

Arup is truly global. From our 92 offices worldwide more than 12,000 planners, designers, engineers and consultants deliver innovative projects around the globe. Arup is working with clients to shape a better world through the efficient, affordable and sustainable sourcing of energy, its dispatch and use.

Further details at www.arup.com/energy and @ArupGroup

Arup
13 Fitzroy Street
London
W1T 4BQ

E: energy@arup.com

ARUP

WORLD
ENERGY
COUNCIL