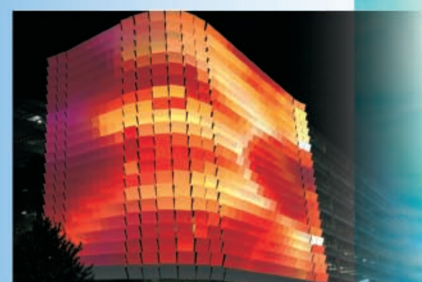
International Energy Agency

CITIES, TOWNS & RENEWABLE ENERGY



Yes In My Front Yard

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive programme of energy co-operation among 28 advanced economies, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Foreword

A major transition of the energy sector is needed if the global issues of energy security, energy access, sustainable development and climate change are all to be adequately addressed this century. Whereas many of the policy initiatives and negotiations relating to energy and climate change are being undertaken at the national and international levels, in parallel many leading cities and towns are taking their own decisions concerning their energy destiny – and their actions are beginning to have an impact. Their collective voice is starting to be heard at meetings of the United Nations Framework Convention for Climate Change (UNFCCC), including at the most recent climate talks which are aiming to reach a new framework agreement. The IEA analysis outlined in this report supports these more local endeavours, provides an overview of renewable energy resources and technologies and identifies and describes several successful case studies, ranging from mega-cities of several million people to small communities of only a few hundred.

In contrast to the common resistance against new energy project developments by local residents and businesses commonly (known as *NIMBY – "Not In My Back Yard"),* the manner in which many cities, towns and their residents have embraced local renewable energy developments has caused the contrasting term *YIMFY – "Yes In My Front Yard"* to be coined in the title of this report.

This book examines the potential for the greater deployment of renewable technologies in built-up environments, including implications for supporting policy development. It evaluates successful local policies in selected towns and cities that have enabled the cost-effective deployment of renewable energy (including by investing in "green" electricity projects and purchases, distributed heat and power generation and transport biofuels). These initiatives are often developed in association with national policies and in accordance with supportive energy efficiency measures.

This report also includes methods of identifying local renewable energy resources, overcoming barriers to implementation, and a review of state-of-the-art technologies. Technologies evaluated include district heating and cooling; combined heat and power from biomass and geothermal sources; distributed generation mainly from solar, wind, geothermal and biomass; smart metering; intelligent networks; and biofuel production, including 2nd generation. The focus is on technologies and policies that will enable the cost-effective deployment of renewable energy heat, power and transport fuel use in cities, towns and also island communities. The study also addresses various means of investment available to a local municipality and identifies the co-benefits involved, including social benefits for the local community members.

This project was supported through a voluntary contribution to the IEA from Japan following the G8 Hokkaido Tokayo Summit meeting in July 2008. Previous IEA analysis for G8 countries concerning renewable energy technologies and deployment has mostly focused on policies for electricity. Within post-Hokkaido G8 activities, special attention is given to measures promoting the use of all renewable technologies in cities and built environments. As an increasing portion of the global population inhabits urban areas, such measures will become increasingly important in the future as we seek to achieve energy policy goals.

Nobuo Tanaka
Executive Director
International Energy Agency

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Executive summary

It is within the powers of local governments to influence the energy choices of their citizens. Several leading and progressive cities and towns[1] have already taken innovative decisions to enhance the deployment and use of renewable energy resources within their geographic boundaries. Since the beginning of this decade, and for the first time ever, over 50% of the world's population now live in urban environments. This proportion will continue to grow over the next few decades. The energy infrastructure that every city and town depends on will therefore need to be continually adapted and upgraded if it is to meet the ever-increasing demands for energy services. This provides the opportunity for local government leaders to encourage increased deployment of renewable energy systems and hence gain the multi-benefits they offer.

In OECD countries, many cities have already taken initiatives to reduce their energy demand through improved efficiency and conservation in an endeavour to reduce their dependence on imported energy and reduce their carbon footprints. Analysis confirms that, in many cases, the increased uptake of renewable energy technologies can also be an economically viable solution to energy security and climate change mitigation, especially when all the other co-benefits are taken into account. Several cities with strong leadership in both OECD and non-OECD countries have developed policies to encourage renewable energy use. For cities in developing countries, this has been encouraged by the additional drivers of reducing local air pollution and moving towards sustainable development and growth. Overall however, only a small proportion of local governments worldwide have developed policies and projects specifically to better utilise their local renewable energy resources and capture the benefits.

Therefore this report aims to:

- inspire the target readership of city mayors, councillors, local captains of industry, managers of small and medium enterprises, and indeed, all members of an urban community, to gain a greater understanding of the potential for renewable energy and to comprehend how its enhanced deployment could benefit local citizens and businesses;
- provide guidance to national, state and regional government policy-makers as to how to best incentivise their local communities in order to help meet national and international objectives relating to energy use; and
- enable policy-makers to appreciate the roles that local municipalities might play in increasing the deployment of renewable energy and moving further towards the desired transition from a fossil fuel future to a sustainable energy future.

The wide range of renewable energy technologies continues to evolve as improved performance, efficiency and reliability, at lower costs, are sought by researchers and manufacturers. The potential offered by distributed energy systems, that usually involve a significant share of renewable energy, is becoming clearer as smart meters and intelligent grids are deployed. This report analyses such technology developments, with emphasis on their application in urban environments.

Policies already instigated by leading local governments around the world, with large and small populations, are reviewed. The policies of cities that have successfully achieved a significant uptake of renewable energy could be easily adopted by other local governments wishing to achieve a similar goal. Case studies from cities and towns, with populations ranging from 12.4 million to 1 500, are presented to illustrate how policy development can impact on the deployment of renewable energy within territorial boundaries.

1. In this report the term "city" refers to urban conglomerations, administered by local municipalities and ranging from small towns (urban settlements of several thousand people), up to mega-cities (each with populations of several millions).

Key findings

- Leaders and officials of local governments have started to become more involved in climate change policy-making by undertaking strategic planning; formulating, approving and implementing appropriate policies; evaluating their effectiveness; and disseminating successful actions that might be replicated elsewhere. National governments in some countries have encouraged this trend, for example by returning the revenue from the sale of carbon credits to the local municipality that invested in an accredited renewable energy project.
- Many cities already utilise their local renewable energy resources cost-effectively. Some smaller towns have even become fossil fuel free; although it is usually easier for a small community, located in rural surroundings, to achieve a high renewable energy contribution than it is for a mega-city trying to meet a similar objective. Cities located near the coast, or on islands, may be able to benefit from off-shore wind and also, in future, from ocean energy technologies currently under development.
- Cities tend to target a specific renewable energy resource that best suits their conditions. For example, solar PV systems suit cities in lower-latitude, high sunshine regions; geothermal power suits cities located near the tectonic plates; and bioenergy is most common in areas with a forest industry nearby. Cities with such a prime resource often try and develop, or attract, business ventures and investments relating directly to it.
- District heating schemes based on geothermal or bioenergy sources, have proven to be efficient and cost-effective in many cities. District cooling schemes are also maturing and good practical examples exist in several locations, including those using new solar sorption technologies.
- In larger cities, only a portion of the total energy demand is likely to be met by renewable energy projects located within the city boundary. These commonly include waste-to-energy combined heat and power (CHP) plants, geothermal heat systems, solar thermal collectors on roofs and building-integrated solar PV systems. Other forms of renewable energy carriers such as wind power, hydro power, concentrating solar power, solid biomass and liquid biofuels, usually need to be purchased from outside of the city and brought in by transmission lines, pipelines, road, rail or boats.
- Renewable energy could become a significant component of the total energy mix of a distributed energy system by employing new and improved small-scale technologies together with smart meters and intelligent grids. Such systems can be very complex but are developing rapidly. A sustainable energy future for many communities could depend on a wise combination of both centralised and distributed energy systems that utilise technological advances throughout the supply chain.
- Many local governments tend to follow early innovators rather than lead. The advantages for cities that lead in the design, investment and monitoring of renewable energy demonstration projects that can be easily replicated, include pride and the creation of a strong national and international interest. Training centres and industrial parks based around a demonstration project can help to educate citizens, attract outside interest, and provide a critical mass of skilled personnel.
- Local authorities can serve as a vehicle to implement top-down policies from national governments, deliver meaningful results, and ensure national mandates are carried out. They can design solutions to climate change that are adapted to the needs of local constituents and are consistent with local policy priorities. This process can help build resilience to climate change in the urban infrastructure. Experimentation on new forms of policy at the local level can provide learning and experience and, when successful and where appropriate, can lead to bottom-up diffusion of approaches between cities, as well as at the national and international levels.
- The local approach to renewable energy project deployment can help to demonstrate what is possible, at what costs and who the winners and losers might be. Social experimentation relating to

renewable energy deployment and climate change mitigation and adaptation can also be undertaken at the local level and, where successful, adopted nationally. National governments therefore need to stimulate action at the local government level in order to fully integrate renewable energy and climate considerations into urban development strategies.

Policy recommendations for local governments

- Development of renewable energy deployment policies should be undertaken in association with energy efficiency measures. In most countries, leading cities have attempted to reduce their energy demand through improved efficiency and energy management incentives, and this has been recognised as a key policy priority. Putting parallel policies in place to support the use of renewable energy by the local community usually makes good sense.
- An assessment of available energy resources, together with analyses of future energy demands and costs of alternative supplies to meet heating, cooling, electricity and transport demands, should be undertaken prior to promoting the use of renewable energy. The assessment should include the potential for renewable energy projects based around water supply, wastes, and land managed by the local authority.
- The evolution of decentralised energy systems will vary with the location, existing energy infrastructure, renewable energy resources available, and energy business ownership status. Local governments could take a lead role by developing policies that will help support the transition of the conventional energy sector to a less centralised system.
- A wide range of policies is already evident for councils to select from that will lead to greater renewable energy deployment. None of these would suit all cities and towns, so careful evaluation is required to determine those most appropriate to local conditions.
- Regardless of size, a city should undertake policy development to support renewable energy deployment in association with other policies, including national policies linked to sustainability goals and climate change, and local policies relating to energy security, energy access, health, employment, equity and reducing energy demands. Policies that are not directly energy-related, but could influence renewable energy uptake, can have direct or indirect impacts.
- Cities with relatively few policies in place to support and encourage the use of their renewable energy resources should evaluate the policies of leading municipalities and determine whether similar benefits could accrue. Any constraints set by their own specific set of circumstances would need to be identified.
- Support from citizens and local businesses for the greater deployment of renewable energy technologies is essential, based on a good understanding of the issues. The personal benefits that would result for individuals and businesses need to be identified and disseminated. Leaders can motivate residents, offer them enhanced pride in their community as a result of being an early adoptor, as well as provide them with greater energy independence, energy security, employment and social cohesion. Strong leadership based on clear objectives is essential.

While there are many examples of cities that have already acted upon climate change and energy security issues by developing support policies to stimulate renewable energy activities, there are many more that have not yet appreciated the serious need for urgent action. The overall goal of this report is to help speed up the necessary transition to a sustainable energy future.

If each of the many successful renewable energy demonstration projects and innovative policies undertaken by leading cities as identified in this study, could be replicated one hundredfold during the coming decade, then cities could become facilitators of change in the energy sector.

1. Rationale

The cities of our Western Hemisphere are growing rapidly. How these cities develop will determine the carbon footprint for the region for generations to come.

Dr Steven Chu, United States Energy Secretary, 16 June 2009 on launching the "Low Carbon Communities of the Americas" programme in Lima, Peru.

Cities, towns and urban neighbourhoods all over the world are pledging to reduce their carbon footprint by decreasing their volumes of greenhouse gas emissions in various ways. Many are actively committing to undertaking environmental initiatives "in their own front yards" as are their local businesses and industries. Overcoming the NIMBY (not-in-my-back-yard) syndrome, whereby energy project proposals are commonly objected to by those living and working nearby, is a problem for national, regional and local governments all around the world. Local governments, whose leaders and staff are closer to the issues raised by their constituents, can have an active role to play in the development of local renewable energy projects by ensuring all stakeholders have a full understanding of the benefits and disbenefits.

Local authorities have the power to reduce greenhouse gas emissions through their responsibilities for regulating land and buildings; maintaining infrastructure for water supply, waste treatment and road transport; investing in public transport systems; and their ability to form partnerships with private organisations and companies. Carefully thought-through policies can enable a local authority council to achieve a reduction in greenhouse gases as well as enhanced energy security and an improved quality of life for the local community. Encouraging the deployment of renewable energy projects at the local level is one role that municipalities can play to help meet these objectives. Using the expertise of raising awareness, providing services, maintaining infrastructure, urban planning, managing assets and buildings, and informing citizens, local governments can become the drivers of the changes in thinking that will be needed if the rapid transition to a low carbon energy system is to eventuate.

There is a growing sense of urgency and enthusiasm towards the goal of achieving a decarbonised world by citizens and businesses. However, in practice, many of the leaders and officials who develop policies and manage a city on a daily basis (including mayors, councillors, executives, officials, administrators, engineers and resource planners) are often unfamiliar with methods and measures for actually implementing renewable energy projects and sustainable energy practices. Such measures may interact with national and state policies as they are developed, or at times be more advanced and ambitious. They include:

- assessing the local renewable energy resources and then encouraging deployment of related renewable energy-based projects[2];
- encouraging energy efficiency and conservation actions by local residents and businesses as well as in commercial buildings, schools, hospitals and other public buildings;
- investing less in roads and car parks and more in public transport systems and infrastructure and plans to encourage walking and cycling;
- identifying, monitoring and regularly evaluating a number of environmental performance indicators;
- producing planning regulations that allow for future adaptation requirements due to climate change impacts that now appear to be inevitable in many urban conglomerations;

2. Assessing comparative energy use between cities requires agreement on how to handle energy supplied from outside, such as power generation or natural gas, and vehicles passing through. Currently there are no standard methods of reporting, although several organisations are working towards standardising methods of data collection.

- developing whole-system thinking rather than trying to solve issues individually; and
- putting a municipal authority's own "house" in order, thereby demonstrating good leadership and governance.

It is appreciated that there are major differences between the administration of towns and cities in OCED countries, transition economies, and other non-OECD countries. Most of the initiatives to date have been taken by municipalities in OECD countries that have the physical, social and financial means to support renewable energy deployment, more so than in many non-OECD countries. However there are some good examples of what can be achieved by motivated local authorities that show strong leadership in developing countries. Several of the case studies (Section 8) were chosen to reflect this.

External expert advice is usually sought to provide direction and confidence to city officials who liaise with residents since some of the issues can appear daunting and a potential threat. Although all the measures listed above have a key role to play in moving towards a more sustainable future, this report aims to provide a technological background and policy advice mainly relating to the first bullet point above on renewable energy. The information is partly based on actual experiences and therefore should have practical implications for the reader. Suggestions and recommendations for strategic solutions are offered to community leaders responsible for the necessary transition towards sustainability and climate change mitigation by developing renewable energy deployment initiatives. Topics covered include the use of renewable energy resources to provide energy services for:

- the built environment;
- small/medium enterprises and industries located within the city boundary; and
- methods of transport to move people and goods around the city.

A further aim of the report is to build the local knowledge capacity of personnel working in urban environments in both developed and developing countries so that community leaders, municipal authority employees, members of local non-governmental organisations, and citizens can together develop achievable targets and plans.

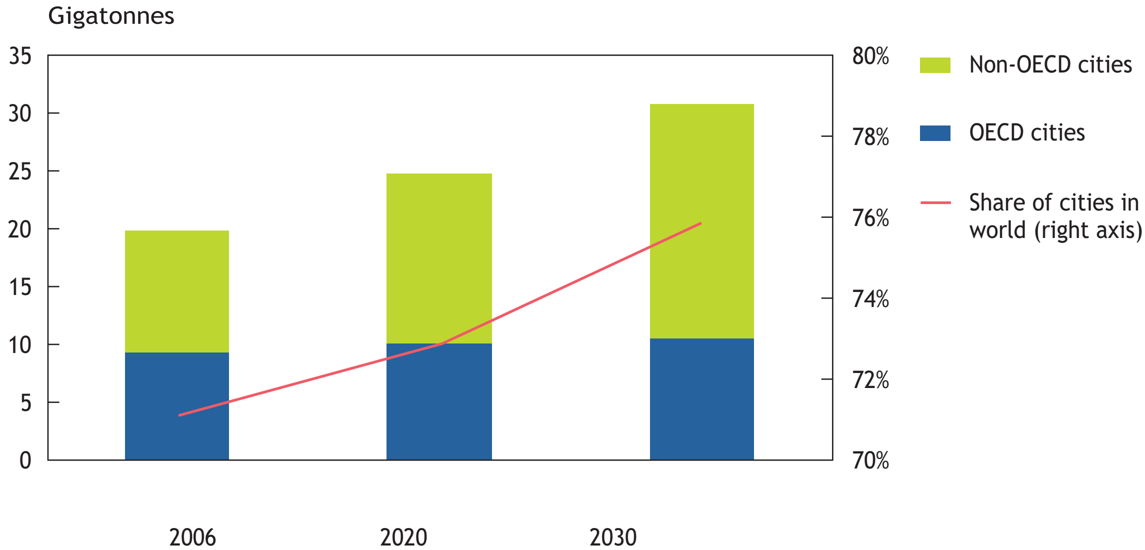
Historic context and future projections

When agriculture began to develop around 10 000 years ago, the first food surpluses that were produced enabled towns to develop, the food being brought in to markets by local producers. Today, about half the world's population still till the soil, three quarters using manual labour. The other half live in urban areas, consuming two-thirds of total primary energy, of which around 60% is consumed in buildings. Cities and towns also produce over 70% of global energy-related CO_2 emissions. This share continues to increase as people living in developing countries shift from the use of traditional biomass (much of which is carbon neutral) to fossil fuel combustion (IEA, 2008a) as governments endeavour to provide energy access for the two billion people still without basic energy services.

Worldwide, the urban population is increasing by around one million people per week. This includes people driven in from the rural areas by an increasing frequency of droughts and floods and other probable consequences of climate change. The challenge to provide basic energy services for the larger number of city-dwellers in future, in order to provide an acceptable quality of life for everyone whilst also reducing greenhouse gas emissions, is daunting (not to mention providing clean water, food, sanitation and mobility). Increasing the contribution from local renewable energy sources, together with using energy more wisely and efficiently than we do now, will become a major part of the solution.

Regardless of the endeavours already made by administrators of leading cities to improve energy efficiency, in most cases, energy demands by their citizens continue to grow. This leads to future concerns for energy insecurity and increased greenhouse gas emissions. By 2030 it is thought that cities and towns will house around 60% of the world's projected 8.2 billion people as the trend to increased urbanisation continues (UNPD, 2007). Residents who live, travel and work within a city will then consume around three-quarters of the world's annual energy demand. By 2030 over 80% of the projected increase in demand above 2006 levels will come from cities in non-OECD countries. If most of this demand continues to be met by fossil fuels, then cities and towns continuing under a business-as-usual future will result in large increases in CO_2 emissions, particularly those located in non-OECD countries (Fig. 1).

Figure 1 • *Carbon dioxide emissions from energy use in cities grows by 1.8% per year (versus 1.6% globally) under business-as-usual scenarios between 2006 and 2030, with the share of global CO_2 from cities rising from 71% to 76%*



Source: IEA, 2008a

Revenue needed for the public administration of cities partly flows from central governments returning some of the taxation paid by cities and businesses and partly from direct payments made by residents, often as a rate levied on the capital value of their property. Some cities also operate businesses related to their operations to provide some extra revenue and many have interest-bearing investments. City councils allocate this revenue as annual budgets in order to provide services for their inhabitants such as water supplies, waste collection and treatment, education and recreational facilities. The funding is also used to build and maintain local infrastructure. Hence expenditure on capital investments relating to renewable energy projects is usually contestable, as is funding sought for financial incentives to support renewable energy technology deployment within the city boundaries. Where appropriate, securing local funding can be linked with any regional and national support measures also in place.

To achieve their overall sustainability objectives, communities must involve energy efficiency measures which are a key element of future energy security and climate change mitigation. However since these are well documented in many other publications, including several from the IEA (see for example, IEA, 2008h), they are not discussed in detail in this report. Suffice to say that because obtaining data and information relating to producing such policies is a challenge for many cities, producing an international database of cities and their energy policies is difficult. The IEA Energy Efficiency Division is considering undertaking a detailed survey of cities to glean such information.

International initiatives already exist that focus mainly on energy efficiency to assist towns and cities with their greenhouse gas (GHG) emissions reduction and sustainability goals. Those well established include the ICLEI[3] "Cities for Climate Change protection campaign"; the European Commission's Covenant of Mayors[4]; Architecture 2030[5]; the Clinton Foundation's C-40 Climate Change Initiative[6]; The European Green Capital competition[7] (with Stockholm being the winner for 2009 and Hamburg for 2010); the Low Carbon Communities of the Americas[8] that includes encouraging light coloured roofs and pavements to reflect back sunlight; and the Carbon Neutral Network[9] established by the United Nations Environment Programme (UNEP) to encourage countries, cities and businesses to reduce their GHG emissions and set varying targets with the long term aim to become carbon neutral. For example Vancouver, Canada, is aiming to become carbon neutral by 2012; Sydney, Australia, for a 70% reduction by 2050; and Slough, England, for 20% reduction by 2028. Other examples of cities that have also signed up to the UNEP network and set carbon reduction goals include Copenhagen, Denmark; Brisbane, Australia; Rizhao, China; and Waitakere, New Zealand, thereby demonstrating the geographic spread.

International initiatives focusing on renewable energy are less common. They include the CONCERTO[10] initiative that was launched by the European Commission to support local communities develop projects based on demonstrating the environmental, economic and social benefits of integrating energy efficiency techniques together with renewable energy sources through a sustainable energy-management system operated on a community level. Also the ICLEI "Local Renewables Initiative" actively supports the deployment of renewable energy use in cities for the following reasons.

- renewable energy sources are mature, available and ready for use today.
- using local resources to produce energy locally establishes a solid foundation for decentralised, secure energy supply — thereby making communities more resilient.
- financial benefits are inherent for many renewable energy programmes — both in terms of saving money and generating an income over the short to long term.
- a steady transition from fossil fuels to local renewables will normally reduce CO_2 emissions and contribute to climate protection.
- switching to local renewables supports local job creation and stimulates the economy.
- local renewables give an impulse to sustainable urban development, and encourage technical and social innovation.
- local action for renewable energy deployment is critical in order to achieve national and international targets on sustainable energy and climate protection.
- the uptake of renewables implies the involvement of local stakeholders using synergies to create change.

Within the UNFCCC climate change negotiation process between governments, there is little mention of cities or the mitigation role they could possibly play. Some of the organisations listed above are attempting to redress this situation by encouraging their city members to integrate greenhouse gas

3. Originally founded in 1990 as the International Council for Local Environmental Initiatives, *ICLEI — Local Governments for Sustainability* is an international association of over 1000 local governments from 68 countries, as well as national and regional local government organisations that have made a commitment to sustainable development — see www.iclei.org.
4. www.eumayors.eu
5. www.Architecture2030.org
6. www.C40cities.org
7. http://ec.europa.eu/environment/europeangreencapital/green_cities.html
8. http://www.nrel.gov/applying_technologies/climate_initiatives.html
9. http://www.unep.org/climateneutral/
10. http://concertoplus.eu/CMS/component/option,com_frontpage/Itemid,239/

emission reductions into their policies. ICLEI is producing a Local Government Climate Roadmap for presentation during the UNFCCC 15th Conference of Parties in Copenhagen at the end of 2009[11]. The aim is for post-Kyoto negotiators to better recognise the potential role for cities by mobilising national governments to support the various local initiatives that are occurring worldwide.

In essence, a city can influence the use of renewable energy by its citizens, by local businesses, or for its own consumption when managing the city by:

- encouraging the purchase of "green" electricity or biofuels for transport that are produced outside the city and then imported for use within the boundary;
- investing in local renewable energy projects that relate to its current core business activities, such as waste management, for example by production and use, or sale of, landfill gas and sewage biogas;
- supporting and investing in new, privately owned, renewable energy projects (such as wind farms, small hydro schemes, geothermal projects, biomass district heating schemes, or combined heat and power (CHP) systems) located either inside or outside the city boundaries, with the heat or electricity then sold to city-based consumers;
- incentivising the uptake of small-scale, building-integrated, renewable energy systems such as solar hot water heating, ground-source heat pumps or solar photovoltaic power generation systems; and
- encouraging the development of a renewable energy manufacturing industry within the city by the attraction of new businesses.

In addition, when designing and planning new suburbs or entire cities on green field sites, incorporating renewable energy systems into the overall design should be given due consideration.

This report endeavours to incorporate each of these aspects into a framework that will enable all stakeholders involved in providing energy services for use in cities to better understand how best to utilise renewable energy for the benefit of the citizens, both now and in the future. It should also be a valuable information source for the actual and potential users of renewable energy services, whether businesses or residents so that they might better comprehend the benefits and constraints of developing renewable energy projects whether small or large-scale. The overall aim is to identify policies that have resulted in the successful deployment of renewable energy technologies. These are presented in a format that will help potential users learn from the experiences of others in order to stimulate the replication of similar projects worldwide. This in turn should lead to lower costs as the technologies involved track downwards along their specific experience/learning curves.

After this *introductory section* the report aims to:

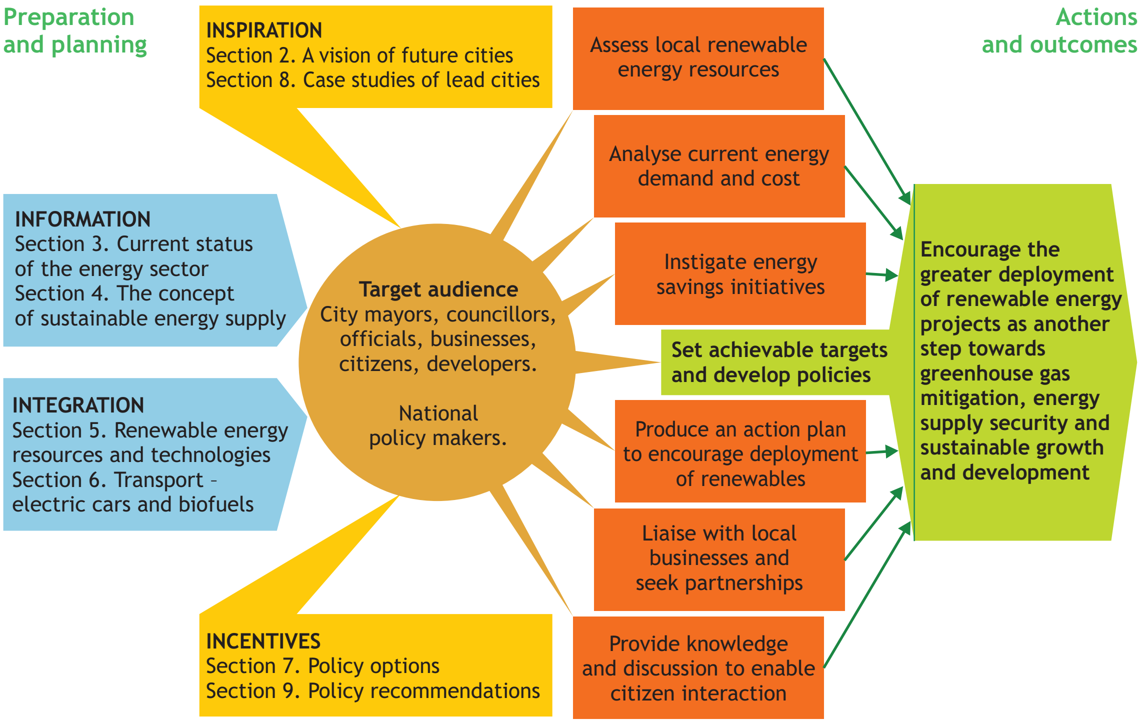
- *inform* readers by outlining the current status of the energy supply sector (Section 3); and describing the concepts behind sustainable cities of the future including distributed energy systems and intelligent grids (Section 4);
- *integrate* more local renewable energy resources into the energy supply system necessary to maintain the life and growth of a community by assessing the potential for increased deployment of existing and emerging renewable energy technologies including their markets and costs (Section 5) in order to provide desirable energy services derived from heating, cooling, lighting, electronic entertainment, driving electric motors, and mobility (Section 6);

11. See http://www.roteirolocalclimaticas.org/EN/downloads/COP-Decision_small.pdf where the draft Roadmap includes the statement: *Drawing on lessons from the success of the implementation of the Rio Agenda's Local Agenda 21 and the successful measures that are being implemented by cities around the world on sustainable energy economy through energy savings and the application of new and existing renewable and high efficiency technologies, to reduce dependence on fossil and nuclear fuels and aim for lowest carbon options.*

- *inspire* municipal councillors, officers and citizens, whatever the size of their community, to increase the deployment of renewable energy alongside their sustainability and energy efficiency goals by offering visionary scenarios (Section 2) and by illustrating what other selected towns and cities have already achieved in an endeavour to improve the quality of life of those who live and work there whilst also reducing their carbon footprints (Section 8); and to
- *incentivise* mayors, decision-makers, politicians and officials to provide leadership by understanding the full range of policy options available (Section 7) and then selecting and developing the most effective policies for encouraging renewable energy uptake in their own communities at minimal cost, in association with energy efficiency measures, and gaining from the numerous co-benefits available such as water conservation, municipal waste reduction and treatment, reduced local air pollution, improved health, employment creation, social cohesion, and lower greenhouse gas emissions (Section 9).

It is anticipated that the information and analysis presented will be useful to members of both large and small communities worldwide that are contemplating undertaking a range of initiatives and developing policies to encourage the local deployment of renewable energy projects (Fig. 2).

Figure 2 • *The various sections of the report have been structured to provide information and inspiration to members of the target audience who may wish to encourage the greater deployment of renewable energy technologies for the provision of energy services within their local community*



The target audience is very broad as are the definitions for “city” and “town”. When compiling the report it was anticipated that potential readers will have a diverse range of backgrounds and widely differing levels of knowledge, experience and understanding of the topic. This was borne in mind, particularly when selecting the case studies (Section 8) that range from mega-cities to small towns covering a wide geographic spread in an attempt to ensure that there is some useful knowledge to be gained for every reader of the report.

The structure of the report consists of the following eight sections that aim to:

- provide a vision for cities of the future from the perspectives of the contrasting lives of two fictitious residents with the differing outcomes dependent on the future pathway as chosen by policy makers today (Section 2);
- review the current status of typical energy systems that supply cities whether in OECD or non-OECD countries and whether the energy sector is privatised or not (Section 3);
- describe the new and emerging concepts of supplying affordable, reliable and sustainable energy for meeting the energy demands of large and small communities to enable them to function, including centralised and decentralised energy systems, based in part around renewable energy technologies (Section 4);
- broadly cover the renewable energy technologies currently available or close-to-market that can provide electricity, heating, cooling and mobility, leaving the interested reader to obtain the technical details from the various IEA Implementing Agreements and other organisations, web sites and literature as listed in the references (Sections 5 and 6);
- discuss what policies and measures are available at the national, regional and municipal levels and how the most appropriate ones may best be selected and employed in order to support renewable energy deployment within a city and hence gain the optimum benefits offered for the economic, environmental and social well-being of the community (Section 7);
- identify some key case study examples to show how several selected towns and cities have already successfully encouraged the local uptake of renewable energy inputs and, in some instances, become the model for national policy developments with replications also occurring in other countries (Section 8); and
- present recommendations for actions (Section 9) that could be agreed and acted upon by leaders, businesses and citizens of a town or city, in relation to:
  - setting targets for renewable energy and greenhouse gas reductions;
  - developing policy plans designed to meet the targets;
  - deciding upon the introduction of relevant regulations and incentives; and
  - providing education, training and information.

The notion that consumers alone decide on what energy sources they will use in future is largely theoretical. In reality, cities determine what infrastructure is required and are certainly a more powerful intermediary with large energy companies than the individual energy consumer could be. The challenge will be for municipal urban authorities to provide a sense of opportunity, excitement and hope for their residents looking towards the future. This could be achieved by combining community-based innovation, the use of new technologies, and innovative planning design, hence moving towards having a city better suited to a future carbon-constrained world.

If each of the many successful renewable energy demonstration projects and innovative policies undertaken by leading cities as identified throughout this report could be replicated twentyfold or thirtyfold, or even one hundredfold, during the coming decade, then cities could become facilitators of change in the energy sector.

2. The vision

Most of the rewarding enrichments of human life — be it personal freedoms and artistic opportunities, or pastimes of a physical or mental nature — do not claim large amounts of additional fuels or electricity.

Vaclav Smil, 2003.

Please note: this section represents two fictional but contrasting possible future worlds. They are largely based on imagination rather than on the outcomes of scenario modelling or technical analysis. Readers familiar with the potential for climate change mitigation technologies, including decentralised energy systems, may wish to move on to Section 3.

This section presents *A Tale of Two Cities*[12]: two possible visions of contrasting future worlds leading out to 2050 and beyond. *Bleak House,* the fossil fuel future, is based on a business-as-usual scenario where climate change mitigation has been given little attention by national or local governments and hence appears to be daunting. This contrasts with *Great Expectations,* in which new technologies have been rapidly adopted by most urban residents to provide them with safe and secure energy services at all times and at a relatively cheap price. In addition, greenhouse gas emissions have declined annually and climate change mitigation appears feasible.

In reality, the world in 40 years time might end up being somewhere between these two somewhat extreme scenarios. Certainly technologies not even dreamt of today will be in common use by then (just as mobile phones, laptop computers, the internet, *wifi*, global positioning systems, roller blades, hybrid vehicles, off-shore wind turbines, thin film PV, and many other commonly used technologies had not even been thought of 40 years ago).

"A Tale of Two Cities"

"Bleak House"

A centralised, carbon-based, business-as-usual energy world: "*It was the worst of times*"

The setting: Most "business-as-usual" scenarios, including the IEA *World Energy Outlook* Reference Scenario based on current energy policies (IEA, 2008c), predict continued worldwide growth in energy demand with fossil fuels remaining dominant. The latest scientific evidence as presented by the Intergovernmental Panel on Climate Change (IPCC, 2007) clearly shows this would lead to a bleak future for the planet.

2015

On yet another day with a record high temperature, Jay was not too surprised to hear his office air conditioner being turned off automatically by the power utility at just after 5 o'clock in the evening to avoid exceeding the peak load capacity of the supply system. Even though this was a brand new office building, without being able to operate the electric cooling and heating systems when needed the building soon became too hot to work in during summer — and also too cold in winter. It had been designed and built by the well-established consulting engineering company that now used the building

12. *A Tale of Two Cities, Bleak House* and *Great Expectations* are classic novels written by English author Charles Dickens in the late 19th century.

as their headquarters. Jay had worked for them since graduating last year with the same *Bachelor of Engineering* degree that his father had received 30 years earlier.

So he left work to drive the seven kilometres home through the city suburbs, in spite of knowing that the roads would be congested all the way at this time of the evening. However, crawling along in the traffic did give him time to read the many advertising signs, especially those posted everywhere from the government saying: "A bright future is assured for the next generations – our coal resources will last for decades so support your national coal industry."

However, the government didn't mention that the world price of coal had soared in recent months due to the rapidly growing demand after the end of the global financial crisis in 2011. Although in the past few years a small hydro project and more large-scale wind farms had been constructed (in spite of continuing objections by the local people), existing and new coal-fired power stations remained the dominant source of electricity. With the local natural gas fields nearing depletion, an LNG terminal was under-construction on the coast 300 kms to the south, but the demand for imported LNG was so high around the world that there was now concern that supplies would not always be secure. In addition, a recent explosion of an LNG tanker had led to other public concerns. These risks had constrained the planned expansion of the LNG network in several cities and led to the national electricity demand increasing even faster than anticipated, now reaching over 4% per year.

Jay knew there was growing evidence that climate change was causing these extreme summer temperatures and the flooding in the city was now becoming routine (now expected one-in-five years whereas it used to be one-in-twenty five years). As a result city ratepayers were being levied 20% on top of their normal annual property value rate payments in order to fund the construction of five metre high levees all along the river flowing through the town. Where construction had already begun, those living nearby had vehemently complained about the loss of their garden area running down to the riverside, not to mention the loss of their view of the meandering river now replaced by a wall of mud and rocks. However, the City Council had accepted that a loss in value for these expensive riverside properties would be necessary in order to better protect the rest of the city. The national government had recently stated that adapting to climate change at whatever cost was the responsibility of all citizens – so, with there being no objection from the opposition benches, the city council had been obliged to incorporate it into its local policies.

Jay's current engineering position involved analysing national policies that could impact on the firm's core business of building power stations, for example the government's plans to construct a new pebble reactor design of nuclear power plant that had been debated publicly for over four years. Suddenly however the decision to proceed, that was finally getting close to being approved, was now put on hold again. The state-owned power utility company had surprisingly only just realised that there was a world shortage of both some key alloy components needed to build a reactor as well as trained nuclear engineers. In addition, discussions on jointly developing a shared storage site in Russia for all the world's high level nuclear waste had failed to reach agreement once again. So a further delay of 15 to 20 years before the new nuclear plant construction began was now anticipated, leaving room for the company to build more coal-fired integrated gasification plants in the mean time whilst other long-awaited technologies, including the designs of Generation IV nuclear plant breeder reactors, were needing yet more time to be designed and evaluated.

The government's hopes that carbon dioxide capture and storage (CCS) technologies would be added to the new coal-fired plants in the region had been dashed when it was found that the closest storage site identified was adjacent to an earthquake fault line and leakage was highly likely since many exploratory wells had been drilled around the area when seeking more oil. Hence, the risks were deemed too high to proceed. An alternative site being investigated was 480 km away which made transport costs prohibitive, and even then it only had storage capacity for around 30 years of the CO_2 being produced. So, although regulations were in place to ensure that all new plants were designed for easy CCS retrofitting, it was considered by the utility that CCS would be unlikely to occur for some years yet, thus avoiding the additional cost on generation. Therefore business-as-usual was the obvious way to proceed, which more than suited Jay's traditional engineering company.

Using his cell phone feature, Jay turned on the air-conditioning in his apartment by remote control when he was still 20 minutes away. He was hopeful it would run long enough to take some of the heat away before the power company automatically turned off the system here also for a few hours, and the water heating too, as part of their rolling black-out strategy brought in to reduce peak loads. Recent demand growth had led to the peak capacity of the distribution lines in the area being exceeded, resulting in inevitable black-outs. Upgrading the local power lines to carry more current was planned, but, given the limited funding available, (and this area of the city having lower priority than several other areas), it would probably take some years before this was accomplished.

On arriving at the studio apartment, a quick check of his E-mail inbox showed one message he didn't want — his power bill was due — and reading the additional comment on it gave him little cause to celebrate: "The company values you as a customer but is sorry to inform you that once again electricity prices will have to be increased due to rising coal-prices." "Maybe now is the time to think again about investing in a solar water heater", Jay contemplated.

2030

Jay took his two near-teenage boys down to the local rainwater drainage channel running through their suburb to build a dam from sticks and mud. The water was fairly murky but he thought they would be all right just paddling in it. It was good to get them away from their virtual electronic world of games using technologies that had not even been thought of when Jay was their age. The boys had recently done a study of hydro-power dams at school and learnt about the increasing competition for water use because much of the upstream water in some catchment regions was now needed for increased irrigation during the frequently dry summers. Jay thought that helping them make their own dam and diversion channel would help them better understand the rising concerns over drinking water shortages around the world.

The hot, dry conditions had also affected the power output from the thermal power stations his company had built a decade ago, since the water used for cooling the plant had become a degree or so warmer on average than anticipated when the plant was designed by Jay's staff in his division. As a result, all the coal-fired stations were running at considerably lower efficiencies than had been expected. In addition, as a result of the increased cooling demands needed, the river water temperature had risen to be above the legal limit imposed by the resource constraint and the fish were struggling to survive. But, since keeping the lights on was their main priority, the government had turned a blind eye to this breach of environmental regulations by the utility.

A small carbon charge on CO_2 emissions that was first imposed by the government in 2020, (after the rest of the world had agreed to a universal approach to climate change mitigation policies), was paid by the thermal generators, but the government paid directly for most climate change obligations relating to the greenhouse gas emission cap as agreed internationally. So the state-owned utility was still able to show a handsome profit at the end of each quarter and business-as-usual was the main aim of the Treasury Minister who chaired the board.

When Jay and the boys returned home to their apartment, he gave them some imported bottled water from the fridge before returning to work on his company's latest CCS design project. This was for a new integrated gasification, combined cycle, coal-fired power plant being built in the region by the Chinese company that now had a near global monopoly on the technology. Considerable public and private RD&D investment, both here and overseas, had gone into testing the various ways of capturing the CO_2

emissions and pumping them underground at low cost. Jay's job was to see which would be the most cost-effective method for this specific site. The current international carbon price of around USD 70/t for emitting CO_2 had helped to drive the project forward, but critics said it was still too costly, or it would not work, or even if it did, it should have been started some 20 years ago. Jay was confident that now was the right time to proceed, given a reasonably lower risk of failure, the technical problems having all been largely resolved elsewhere in the past few years. However, he still had to convince those living nearby that there were no risks involved from CO_2 leakages.

Some fifteen years after initial considerations had begun, building a version of the latest advanced nuclear power plant system had again been considered by the state utility, but the media coverage of a perceived threat of uranium supply deficits as a result of increasing global demand had made the decision too large a risk to bear for the politicians seeking energy supply security as their main vote winner. The LNG terminal down south had proved to be a good investment over the past 15 years, that is when LNG was available in a tight global market. When imports allowed, it was used successfully to a greater degree than ever before, mainly for direct heating applications in both the building and industry sectors. However, after several countries had secured their own strategic LNG supplies over the long term, there were insufficient reserves left available to supply the world market, hence giving little confidence to build any combined-cycle gas turbine power generation plants.

Jay had previously done some analysis for the two regional councils in the areas of the country which had good remaining coal reserves. They had accepted his advice then that open-cast mining was the most economic option to keep the coal resource flowing, even though the scars on the landscape would be clearly seen for many kilometres. Now the world demand for coal was growing, the open-cast mining company was keen to increase the land area of both mines by around 65 000 ha of land that was currently under arable or covered by native forests. Jay was not so sure whether or not this was a good thing. The greenhouse gas emissions from the deforestation, added to the carbon dioxide that would be released by burning the additional mined coal, he realised, would significantly increase the total carbon burden of the nation. In addition, he had calculated that the lost fertile arable land, if cultivated and properly managed, could have sustainably grown around half a million tonnes of dry biomass every year — equivalent to approximately 15 PJ of primary energy. However, since the government had backed the mining company, and his own company stood to benefit from further involvement, he decided to keep this analysis to himself. After all, the rest of the world was producing far more greenhouse gases than this project would, so it would make little difference in the long run, he rationalised.

2050

Jay admired the new roof of his apartment block. The building was over 70 years old and the leaks had been getting worse in the past year or two. In spite of the best budget intentions by local and central governments, all possible funding was being diverted to pay for critical adaptation measures within the city, such as renewing the building foundations that were collapsing due to the underlying clay sub-soil drying out and cracking in the hotter summers; increasing the capacity of the storm water channels, which now often caused local flooding during the more frequent intensive rainfalls; and increasing the height of the 35-year-old levee as the rising sea levels increased the river depth up-stream, giving greater risks of floods, particularly during storms and high tides. Finally the government grant sought for the roof renovation by the building owners had been approved, also enabling them to retrofit the structure and bring it up to the minimum standards that had long been in force for improved energy efficiency (including "smart glass" windows). Solar PV cells and heating systems had been integrated into the roofing tiles.

His grandchildren had visited recently but he knew they did not really enjoy coming to this part of the city where many of the older buildings were in need of repair and there was little for them to do.

However, during this visit, what had kept them amused for a while was playing with the controls of the new light-radiating, electro-chromatic window glass recently installed to give optimum comfort and daylight for the inhabitants. The eldest grandchild of 15 years was already planning her future career as a carbon trader and was working hard at her on-line projects with the aim to eventually get accepted into the internet degree programme. However, she knew there was much competition for places given the few well-paid positions available for new graduates, so her second choice as a climate change risk assessor seemed more likely. She had thought about becoming an electric power line planner, but did not like the idea of being given the authority to displace people from their homes and farms to ensure the power got to where it was needed at all costs. Jay had advised all his grandchildren to consider training as sustainable energy advisors because this he thought was where the future now lay.

On planning his retirement, Jay and his wife had contemplated moving to one of the thriving new cities being built in some of the more wealthy countries of Africa. As the United States President had predicted some 40 years previously, the countries with good renewable energy resources and the ability to best use the newly developing technologies at the time, (then in their infancy), would become the future world leaders. Those African countries with long shore lines had gained the most, partly as a result of the revolutionary ocean energy device designed by the team from Dongtan University that had earned them the 2050 Nobel Prize for physics. Of course it was easier for an African country starting from scratch to build a new city designed to combat the common extreme weather events rather than to attempt to adapt an existing one (as the old OECD countries were being forced to do) by modifying the building stock little by little.

Looking back on his engineering career to date, Jay was still proud of the highways he had helped design, even though there was now much controversy over whether these had been a good investment by the government of the time, since most long distance travel was by efficient, high speed, low-friction trains running along monorails that could also carry goods and vehicles, as well as people, to any part of the city. He realised that, although not particularly well paid in the last few years when his company had been struggling to gain contracts, overall he had been better off than many people mining coal and operating thermal power stations who had been made redundant long before reaching retirement age. Only the power plants suitable for adding CCS retrofits had been allowed to continue operating and, due to lack of foresight in planning for CCS retrofits when most plants were first built, these were relatively few in number.

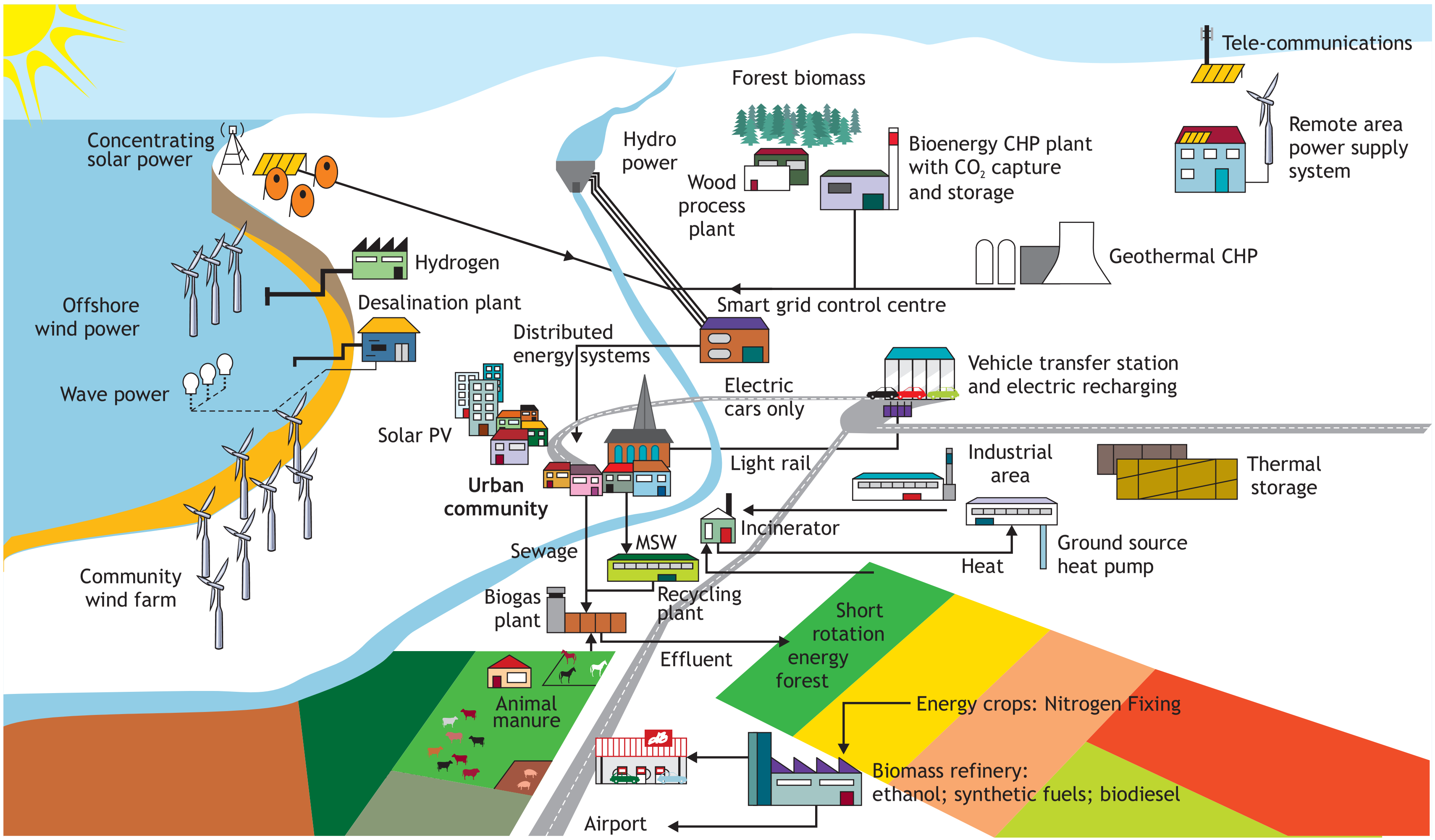
But what caused Jay to reflect the most was why, when the threat of climate change had been understood for so long, had decision-makers not taken some drastic steps to combat it earlier in history. There was still hope for his grandchildrens' future, in spite of the growing concerns at the inability of the world's food and water supplies being able to meet the ever growing demand. But he felt their future lives would have been happier and more secure if early action had prevented the need for the high-cost burden on the present society of adapting to this new, warmer and more volatile world.

"Great Expectations"

The transition to a new, decentralised, decarbonised energy world: "*It was the best of times*"

The setting: The energy supply of some urban communities in the future could have a far higher dependence on renewable energy than today, even reaching 100% in some cases. It would necessitate the greater use of many technologies, distributed and decentralised energy, embedded energy storage, demand side management, electric vehicles and modern communication technologies (Fig. 3). It could also include importing green electricity and biofuels. The role of local governments to help achieve this transition will be significant.

Figure 3 • *Producing significant shares of heat, power and biofuels from locally available resources including solar, wind, ocean, geothermal, energy crops and biomass from wastes, could be a future option for a municipality*



2015

Joy sat comfortably in her sunny new office. Having recently graduated with the new degree *Bachelor in Sustainable Energy and Building Design,* she was less in awe than some of her older colleagues that the building remained comfortable all year round whilst using only a third as much electricity compared with the similarly sized, 1980s tinted glass building across the road.

The District Plan approved by the City Council in 2012 had ensured that all new commercial buildings would have solar water heaters installed unless there was good reason not to do so. Hence, the architects had integrated solar collector panels into the roof and followed the stringent design and orientation guidelines to enable the building to capture solar heat in winter, gain shade in summer, and benefit from natural ventilation and natural light. Although this had added approximately 7% to the capital cost of the building, the ever-rising power prices had meant this would soon be paid off by the electricity savings made. Joy's new job involved explaining to other building owners where the benefits of energy efficiency lay. She first made a walk-through audit of their premises to identify the potential energy savings, and then developed a three-stage strategic plan, starting with those opportunities that gave payback in periods of less than one year.

At 7 o'clock that evening, her message device told her the next electric bus with spare seats available would be travelling down the dedicated lane outside her office building at 19:09 hours. Being the last to leave, she pushed the "sleep" button by the door to automatically turn off all the appliances, and went home. At one point on route she always enjoyed catching a glimpse of the wind turbines on the hills a few kilometres away. She had not only been an early customer for the green electricity provided by the local eco-power retail company, but she had also invested in a small ownership share of the wind turbines, as had many others living in the vicinity. Seeing the machines turning was therefore a double benefit since the green electricity tariff she paid was now less than the standard domestic tariff for coal-fired power charged by the state-owned generator/retailer and she also received a share of the profits. The early problems of noise had long been solved by better design of the blades and gearboxes (where these had not been removed from the designs altogether). Concerns over their variable power output had been largely overcome, (as had been predicted some years before by the IEA, 2008b) in part by more accurate weather forecasting; integration of demand-side management control based on several large cool stores; and the construction of a back-up bioenergy combined heat and power (CHP) plant that was usually operated in winter to provide district heat in some suburbs, but was also available for power generation during anticipated periods of low wind speeds in summer when forecast. In addition, the operators of the local network had been trained to run a more flexible system giving priority access to local wind, bioenergy and solar generation before importing any power from the national grid.

Joy vividly remembered the adventure she and her friends had a few months before when climbing the 379 steps up to the top of the "Tourist Turbine" at the wind farm, with its 150 m rotor diameter. Once up in the nacelle, the operator had braked the rotor and helped strap each of them into the pods between the three blades before releasing the brake to give them a more thrilling ride even than when they had tried bungy jumping from the older turbine set up for this purpose further along the hills.

On reaching her small, terraced house through the front garden, she could just hear the low hum of the ground source heat pump which had been extracting heat from inside the house intermittently during the day as the ambient temperature rose. The meter on the wall in the entrance way showed at a glance that the house had experienced a steady temperature of 20°C all day long; the hot water temperature had risen to 62°C with no need for any electric back-up to the solar heating system at any time; and the payment being made to the local power company was currently USD 0.08 for the past hour of power that had been needed mainly to maintain the temperature of the refrigerator. Even at this low cost, Joy still toyed with the idea of generating some of her own power on site. So that evening she set herself the task of examining the various systems available and checking out the costs and benefits by using the user-friendly computer models made freely available on the internet.

2030

The shares that Joy owned in the three local wind-farm co-operatives had paid sufficiently high dividends recently for her to spend a few days travelling overseas. Air fares had increased due to the international carbon charge now added to all air travel, but this had been partly offset by many airlines blending cheaper 2nd-generation biofuels in the form of synthetic kerosene, with the more expensive aviation fuel. She had just returned from visiting several African countries which had developed rapidly after realising the full benefits of producing biomass on a sustainable basis for their own production and consumption of electricity, process heat and liquid fuels. Adequate food and fibre production had been maintained by their agricultural industries to meet national demands, with even some surpluses available for exports. This was partly due to improved farm management, including a significant reduction in the wastage of water, fertilisers and chemicals by applying new precision farming methods. It had taken some time to educate the farmers in these more modern production methods, but the additional revenue, including from incorporating carbon into their soils in the form of bio-char, had proven a good incentive for them to want to learn more.

The "new green revolution" in Africa and South America, which encompassed precision farming, genetically improved crops (now well accepted by the public following two decades of testing, scrutiny and field experience), water management techniques, soil nutrient monitoring etc., had been a surprise to many of the early critics who now largely accepted that improved land management and plant breeding had made possible the dream of true integrated production of food, fibre and animal feedstocks along with biomass grown for CHP feedstock and biofuels, and without any further deforestation occurring.

Where good renewable energy resources existed on land close to the centres of demand, electricity generated from wind turbines, small run-of-river hydro schemes, and concentrating solar power systems was being sold into the nearby cities. This extra revenue was welcomed by the landowners who were also pleased to welcome eco-tourists such as Joy coming to learn about these new techniques and to observe first hand the resulting societal benefits to the local communities.

On returning from her vacation, she was pleased to recall having taken the initiative 10 years ago to have encouraged the company's Board of Directors to agree to diversify into renewable energy technologies as a new worldwide business division. She had explained then how being able to give professional advice on their selection and integration into buildings and existing energy systems would fit neatly into their information package, *Managing Energy Services Sustainably*, that was being presented to their many clients. Now that almost all homes and buildings had "smart meters" installed, (enabling the owner to save money by avoiding peak power charges and earn revenue by selling any power generated in excess to the local demand at any moment in time), sales of solar PV panels, Stirling engines, micro-turbines, CHP systems and horizontal wind turbines fixed along the roof ridge, had rocketed.

She had established her own home as a demonstration house in association with the local power distribution company, which owned the lines and from which she was leasing her solar equipment. All the detailed cost calculations she had made were available for public perusal on line, as were the details of the dwelling's varying power demand and supply variations, given on a one minute averaging basis. What most people were interested in was to learn how to manage the system to avoid high demand loads when necessary (from boiling the kettle, ironing, using the power drill etc.) but without impacting on their convenience or lifestyle. Having observed from Joy's experience how easy it was to manage, and noting the resulting cost benefits, many people who had visited her demonstration home had since taken up the concept, much to Joy's satisfaction.

2050

Joy's niece arrived driving her electric pod (with "artificial photosynthesis" organic solar collector coatings integrated into the paintwork). She had covered most of the 400 km journey by driving the short distance from her home to connect with the automatic "super-conductor highway" which had immediately taken over control of her vehicle, enabling her to relax and read the latest report on the large wave-power station that her aunt had helped design before retiring after 35 years working for the same progressive sustainable energy company. Travelling north between cities, she still found it hard to believe what Joy had told her when she was a child, that cows and sheep used to graze this countryside, now covered in grapefruits, grapevines and greenhouses, interspersed with concentrating solar power and energy storage systems to provide all the required heating, cooling, ventilation, water desalination and lighting needs for the vegetable crop plants to grow well and enabling three crops per year to be harvested.

Nutrients were largely recycled via the "Energy and Treatment Facilities" located in most cities, often on the old landfill sites. All unused organic material was collected for anaerobic digestion by newly discovered thermophilic super-bacteria. After the hydrogen produced had been collected and distributed through the reticulation network, the remaining solids and their nutrients were returned to the land. On the edge of many cities, biomass refinery plants were now a common site. These plants converted crop residues into a range of bio-products, including liquid biofuels and the solid carbon residue known as "bio-char", which was pulverised and then incorporated into cropping soils as a conditioner. This technique had been used worldwide for the past two decades to enhance the water holding capacity of many soils and resulted in higher crop productivity without the need for further chemical or irrigation inputs. As a result, the bio-char production process efficiently removed carbon from the atmosphere via photosynthesis of woody energy crops produced as biomass feedstock.

The government had recently reported that a reduction of 2.7 Gt of atmospheric carbon had resulted from bio-char applications in this small country alone, leading to the hope that negative global carbon emissions could actually be achieved within the next decade. This was some 30 years sooner than the IPCC and IEA had estimated it to happen back in the first decade of the century. It was understood even in those days that the only way to stabilise atmospheric greenhouse gases below a target of 450 ppm CO_2-equivalent was by severely reducing emissions further each year after peaking around 2015, with the aim of reaching negative emissions as soon as practical.

On the way to see Aunt Joy, her niece kept an eye open for the last coal-fired power station that had not been suitable for CCS retrofitting and that had therefore been closed down a decade ago. Joy was able to explain that throughout her working life, she had watched the CCS technology for capturing coal and gas-related carbon dioxide emissions develop after a slow start, but that today, when linked with biomass conversion technologies, it was also helping to actually reduce carbon dioxide atmospheric concentrations. She and Joy had also discussed the few old-fashioned, ugly transmission line pylons near the now decommissioned power plant. They could both understand why people in the old days did not want them built close to where they lived, and how public opposition had led to the integration of superconductor electricity grids into the new electric highways that she had been travelling on. It took only a few minutes to drive to Joy's house after leaving the electric highway giving only a two hour journey time overall.

Joy helped her niece to super-connect her electric pod vehicle with the dwelling's energy system in order to get a rapid recharge of the digital storage system, but also, when necessary at times of peak load, to help the system by adding to the total storage on-line that could be called upon and that earned some useful revenue. The meter installed in the vehicle recorded all the charging, discharging and back-up that the vehicle storage supplied, along with the specific times when the time-of-use tariff varied. The aim was to avoid peak loads. The total amount to be paid by the utility was then calculated from all these various transactions at the end of each month.

Joy's new house incorporated all of the very latest energy and communication technologies and she knew why people like her niece were always keen to come and visit. The national Building Code now ensured that all buildings were designed to maximise the use of solar energy, both for heating in winter and cooling in summer. Although in a region that had several frosts each year and with maximum ambient temperatures usually reaching over 30ºC for several days on end, Joy's house used virtually no external energy for heating or cooling. On rare occasions when the solar roof did not collect enough energy to heat, cool or top up the latest energy storage device based on scandium/molybdenum/silicon gels, Joy could import electrons from the national grid using the innovative, high frequency, laser-tronic radiation beams. Surplus power, when generated, also was exported in a similar manner. The new "ultra-smart" meter in the hallway recorded time-of-use, time-of export, time-of-import and calculated the costs and revenue earned based on the relevant time-of-use tariffs that were in place at those particular times.

Based on her years of experience working with the electricity industry, Joy understood how thousands of micro-generators – some similar to her own, others using different technologies – were operating together and controlled as a virtual power station in her neighbourhood. Large hydropower plants, (and in some regions, nuclear and thermal CCS plants) continued to remain in operation here and throughout the world to give base load stability. However, over the past two decades or so, the predicted growing power demands had been partly offset by improved energy efficiency measures and the uptake of more solar water heaters and ground source heat pumps. Demand was also partly met by the increased total capacity of distributed energy systems. She had explained on many occasions at community seminars how the central internet-based control system owned by the line company continually monitored the power frequency and voltage at numerous locations along the underground distribution lines (using remote *wifi* signals). She also showed how it controls the varying demand load at any given moment by turning on or off numerous pre-selected appliances, cool stores, resistance heaters for water and space, etc. She knew that most of her neighbours had now become connected to this intelligent network and as a result, the power supply was reliable, the cost savings were substantial – even after allowing for the capital investment of the cheap, mass produced technologies – and the entire power sector was now fully decarbonised.

In summary

These two visions are presented simply to stimulate the reader to contemplate the question of what sort of world people may want to inherit. Both are based on empirical information related to choosing between futures. They are somewhat extreme examples of a possible future with very different but plausible outcomes based on the social and political choices being made today. Both are based around the deployment of technological developments and market realities that could, at least in theory, occur in many countries. Either scenario could conceivably occur during the next few decades. Whether people in general would be happier with their lifestyles under one scenario more than the other is difficult to assess. Certainly it seems today that ready access to abundant supplies of energy for many people, mainly in OECD countries, does not appear to increase their "happiness rating" above those with access only to basic energy services (assuming they have sufficient food and clean water supplies).

Some key questions arise from the high versus low greenhouse gas emission future pathways depicted in this section.

- What do the pathways imply for future impacts and risks of energy security and climate change?
- More generally, what do the pathways imply for energy security vulnerability and sustainable development, particularly for non-OECD countries?
- What are the differences in vulnerabilities and impacts between different geographical locations (whether Jay and Joy live in a city located in Chile or China or Austria or Australia, for example)?
- What is the dependency of each pathway from the perspective of the urban energy system?

- Could delay in decision-making relating to investment in urban infrastructure lead to a systems lock-in of conventional technologies that would then prohibit emerging technologies to gain a market share even if they prove to be economically viable and competitive on their own? Examples of the sort of technologies that might be affected are distributed energy, electric vehicles, fuel cells, and public transport choices.

No attempt has been made to directly answer these questions in this report, so further analysis could be valuable in this regard. One key message, however, is that significant investment in appropriate RD&D today is essential if the desired transition to a new energy future is to be achieved. Accepting the strong likelihood that there will be technological developments by 2050 that have not even been thought of today, there remains the opportunity for us, the current generation, to influence the sort of world we would like the future generations — our grandchildren as a start — to inherit.

The next section of the report returns closer to reality by covering the current status of the global energy sector, with a review of the state-of-the-art of the wide range of renewable energy technologies commercially available and the technological developments currently in progress.

3. Current status

The significant level of problems we face cannot be solved at the same level of thinking we were at when we created them.

Albert Einstein

The three major global challenges relating to energy supply security, investment credit and climate change are interlinked. They are currently attracting the attention of virtually everyone on the planet who has access to information since nobody is exempt from their consequences. To maintain the current quality of life enjoyed by one billion residents in OECD countries, and to improve it for many others, especially the two billion living in the least developed countries with only very basic energy services, society may need to accept a new economic and technical approach that can cause civilisation to move along the lines of a new paradigm. Making the necessary transition for the global energy sector from the fossil fuel era to a "post-carbon" era will not be an easy task, especially since sustainable development is a parallel objective that should include the more sustainable use and more equitable share of our limited resources, including energy, for all humankind.

If deployment of renewable energy technologies is to gain any significant traction at forthcoming international energy debates and climate change negotiations (where most countries usually seek to maximise any gains for their own advantage), the topic will need a greater awareness created of economic growth potential, commercial opportunities, and hope for the future. Various models show that large potential increases in renewable energy will need to occur, such as:

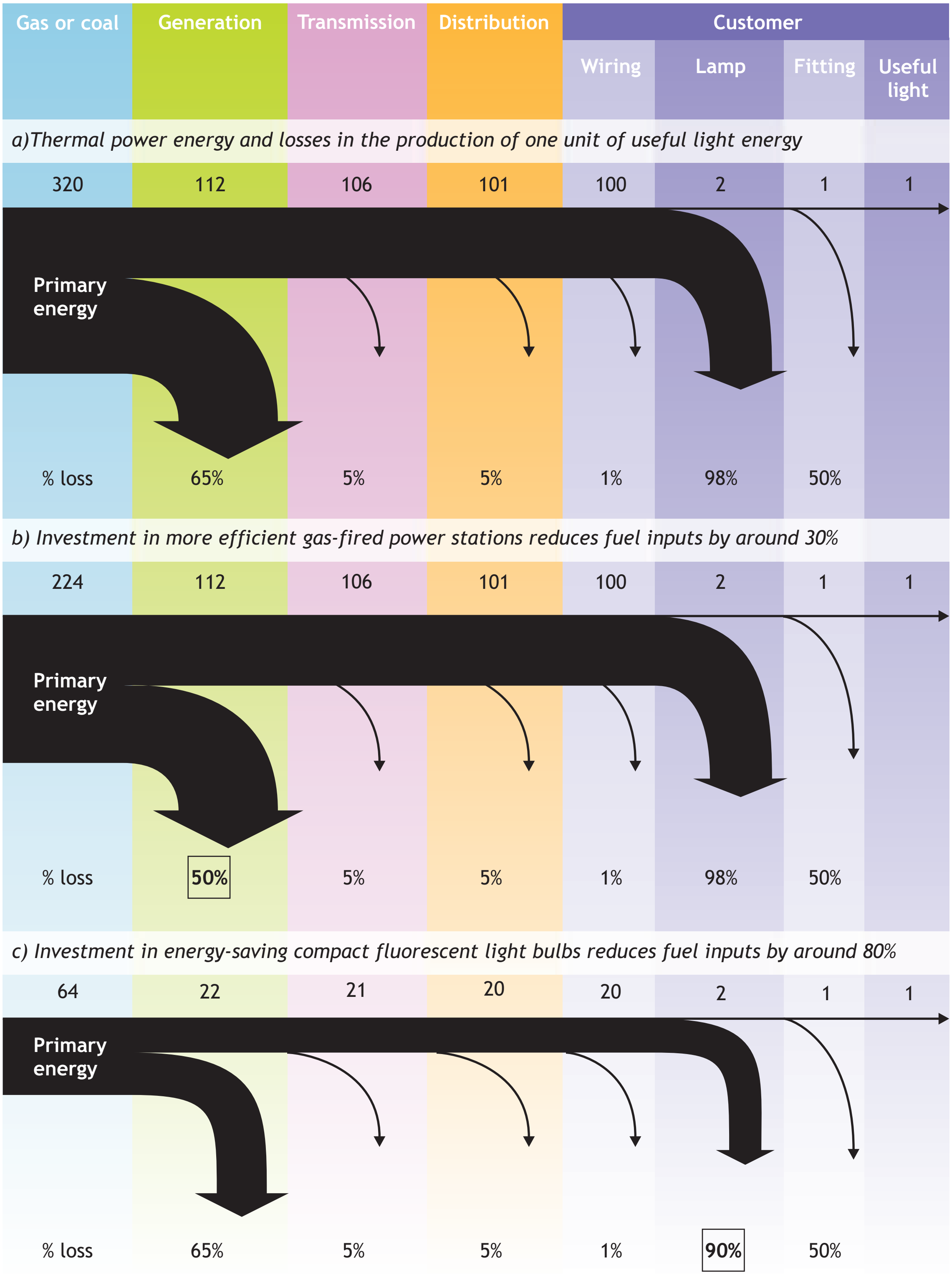
- the IEA *World Energy Outlook* 450 ppm Policy Scenario (IEA, 2009a) that projected 19% of total electricity will come from hydro in 2030, 18% from other renewables, and 278 Mtoe of biofuels, mainly 2nd-generation, will supply 9% of total liquid transport fuels (IEA, 2008d);
- the IPCC 4th Assessment Report (IPCC, 2007) that identified 33% of electricity and 10% of biofuels will come from renewables in 2030;
- the IEA *Energy Technology Perspectives* BLUE scenario analysis (that roughly equated to the WEO 450 policy scenario) that showed 46% of electricity and 23% of liquid transport fuels in 2050 will have to be met by renewable energy; and
- Krewitt *et al.,* 2007 who projected 70% of electricity and 65% of global heat supply will come from renewables in 2050.

In 2007, around 340 EJ (8 100 Mtoe) of primary energy was consumed directly in towns and cities by residents who used considerably more coal, gas and electricity per capita than rural dwellers, but less oil (IEA, 2008a). A large proportion of the total energy was consumed in commercial buildings and by small- to medium-scale industries, which tend to be located mostly in urban locations. The overall efficiency of the systems that currently provide energy services to city residents, mainly from the extraction, conversion, distribution and utilisation of coal, oil and gas, has been assessed to be below 10%[13]. Therefore, there is good potential to improve the process throughout the supply chain. Electricity is one energy carrier that can help provide city consumers with greater and more diverse energy access in the future, but ideally it needs to become a more efficient system than it is at present (Fig. 4).

The entire urban energy system comprises all the various components relating to the provision and use of energy services. Regardless of where the energy resource is extracted or conversion technologies are located, energy flows provide *direct* energy inputs including electricity from distant power plants

13. Draft of forthcoming *Global Energy Assessment* to be published 2010; www.iiasa.ac.at/Research/ENE/GEA/

Figure 4 • *The conversion from primary energy to energy carriers and end-uses is an inefficient process exemplified here by electric lighting (a), even where more efficient power generation plants are employed(b) and energy efficient light bulbs have been installed (c)*



Source: Cleland, 2005

and natural gas in pipelines transmitted long distances for consumption by city dwellers, as well as transport fuels used for moving people and goods locally and internationally to and from the city. In addition, but often not accounted for, is the *embodied* energy in goods and services imported to an urban system and also exported from it in the form of manufactured goods etc. The share of energy flows that stem from the use of renewable energy sources within a city boundary can range from 0% to 100%.

Assessing the energy flows through a city is complex and available data tends to be very limited. One coarse way to estimate urban energy use would be to use national energy consumption data divided by the share of the national population living in the city. However, since urban and rural energy demands per capita differ significantly in some countries, this approach would have limited value. Since actual city energy use data is not readily available, then in some way weighting the coarse energy use per capita numbers (such as by using coefficients based on wealth and saturation levels), could be one method to gain greater differentiation. Taking into account the embodied energy in all imported and exported goods and services is also relevant. This adds to the complexity and highlights data inadequacy even more. Further discussion is found below in Section 7 relating to climate change policies.

There are regional differences in energy use. European cities consume less energy per capita and per year than those in North America or Australasia due to higher population density, extensive urban public transport systems such as subways, and efficient district heating of buildings in some countries. In these regions, differences in consumption of electricity, heat and transport fuels occur between rural and urban dwellers, even though access to energy services is similar wherever someone lives. A rural resident, however, tends to consume more direct energy than an urban resident, mainly due to the higher personal transport demands of those living in more remote areas where relative distances are large and public transport is less available. Conversely in non-OECD countries such as China for example, as average incomes increase in urban areas and access to modern energy services improves, energy consumption per capita has increased to be double that of rural dwellers. While this gap may narrow over time, continuing urbanisation will increase the share of energy used in cities and towns. Conversely, urban incomes tend to be higher than rural incomes. So even if the direct energy use per capita in urban areas is less, the combined energy use when including the embodied energy in products and services consumed, would be greater.

Electricity is a unique energy carrier in that it can use virtually all primary energy sources to provide a wide range of useful goods and services irrespective of scale. For inhabitants of a modern city, perhaps even more so than for those living in rural areas, electricity is essential to enable the further development of technological innovation, communication, safety, supply of water, treatment of wastes, improved health and economic growth.

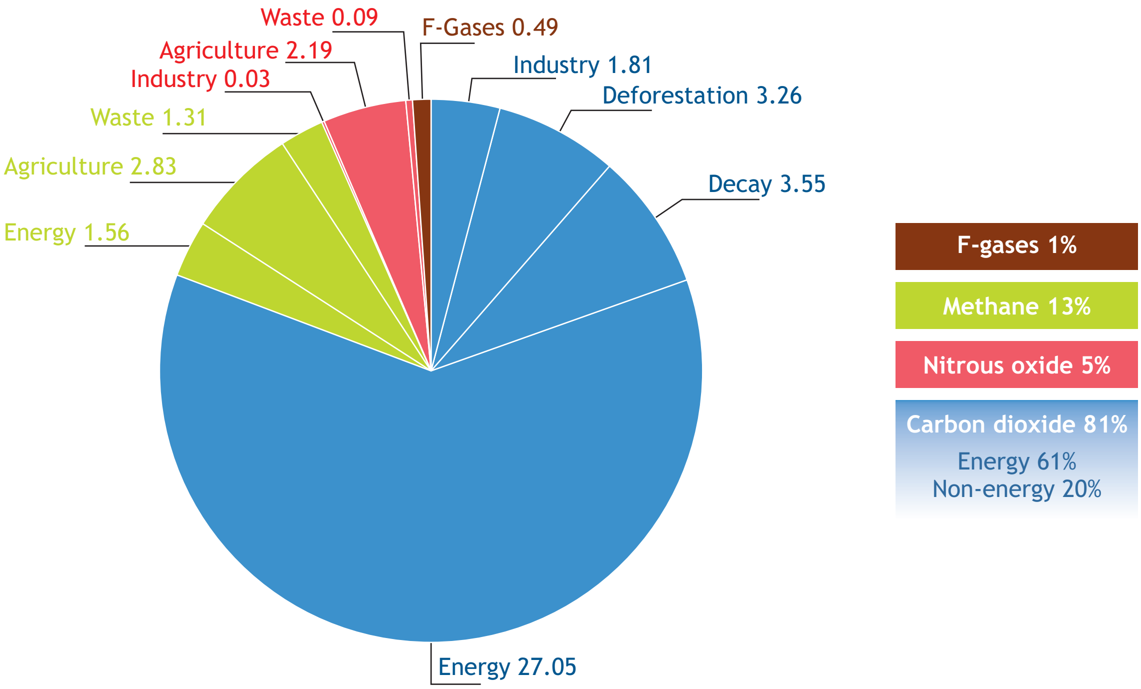
Governments continue to place priority on supplying electricity to meet the growing demand due to the positive impact it can have on quality of life and economic development, whether in OECD or non-OECD countries. Consumption of electricity per capita currently ranges from zero (for the 1.6 billion people without access to it) to over 10 000 kilowatt hours per year in the United States. The global electrification gap effectively excludes a significant proportion of the world population from the potential benefits of a global economy. However, there may be opportunities for developing countries to leapfrog the inefficient generation and energy intensive use of electricity in OECD countries by the uptake of distributed energy systems based mainly on their locally available renewable energy sources (see Section 4).

In its business-as-usual Reference Scenario analysis of future primary energy fuel demands based on government policies currently in place, the IEA *World Energy Outlook* 2008 showed annual growth rate in cities out to 2030 increasing by 1.2% a year for oil and nuclear, 2.0% for gas, 2.2% for coal and large hydro, 2.6% for biomass and wastes, and 7.4% for "other renewables" that include wind, solar and geothermal. Fossil fuels continued to dominate in 2006 by providing 86.4% of the urban total energy demand, and the IEA projection was that a similar share will occur in 2015, dropping only slightly to 85.1% by 2030. However, the expectation that the remaining stocks of oil, gas and coal will have to be used more efficiently and that much of the carbon dioxide released during their combustion must be captured and sequestered wherever feasible, in spite of the additional costs, has to be taken into account.

Overall renewable energy demand in cities based on existing policies and plants, including from large hydro and biomass, was projected in the *WEO* Reference Scenario to only rise from a 6.6% share of primary energy in 2006 to 7.3% in 2015, reaching 9.0% in 2030. Far higher levels could be achieved in reality given appropriate policies, continuing cost reductions with increased experience and strong leadership at all levels of government. Currently, although cities account for just over 50% of the world's population, they consume 82% of total annual natural gas use, 76% of nuclear, 76% of coal, 75% of hydro, 72% of the other renewables and 63% of oil (since a high proportion of transport is outside of cities). Conversely, only 24% of biomass is consumed in cities since this resource is mainly used for traditional cooking and heating in rural areas. Around 76% of total electricity generation is consumed by city dwellers. By 2030, each of these shares will have risen by between 3-5 percentage points as urban growth continues, the exception being biomass and waste, which is projected to rise by seven percentage points as additional modern bioenergy projects in industry and power are developed and more biofuels are consumed.

Greater efficiencies in the combustion of fossil fuels and increased deployment of low-carbon technologies over time, together will not be enough to combat the future advent of peak oil and

Figure 5 • *World anthropogenic greenhouse gas emissions in 2005 by source, amounting to 44.2 Gt CO_2-equivalent with cities accounting for around half of total emissions*



Notes: F-gases include HFCs, PFCs and SF6 from several sectors mainly industry.
Industry CO_2 includes non-energy uses of fossil fuels, gas flaring and process emissions.
Energy methane includes coal mines, gas leakages and fugitive emissions.
Land use emissions are very uncertain.
Source: IPCC, 2007; IEA, 2008a, OECD, 2008 and EPA data provided to IEA.

gas[14] nor the threat of climate change. Agreement was reached by the G8 nations at the L'Aquila Summit in July 2009 that global annual emissions of greenhouse gases will need to be cut by at least 50% by 2050 with industrialised nations aiming for 80% reductions in order to try to meet the target of avoiding more than a 2°C rise in the global mean annual temperature (currently already around 0.7°C above the 14.0°C pre-industrial level). However, international climate change negotiations regarding policies and co-operation needed to meet this target are proceeding only slowly. Energy continues to dominate current total world greenhouse gas emissions (Fig. 5). Although decarbonising this sector alone cannot totally solve the problem, significant mitigation measures would help reach the overall objective (IPCC, 2007). This will need leadership from cities in OECD countries that produce the majority of greenhouse gases, but many cities in other economies are also significant contributors. Therefore, all countries and their cities will need to participate.

Spatial energy densities

The spatial density of energy demand within city urban areas typically ranges between 10 and 100 W/m^2 of land area. It is influenced by population density and average income such that a wealthy suburb of large detached houses with gardens may have a similar energy density (around 10-50 W/m^2) to a poorer suburb of apartment buildings that accommodate more people per km^2 but who use less energy for heating and cooling and own fewer appliances. High-rise building areas might reach energy densities between 500 and 1 000 W/m^2, industry between 200 and 700 W/m^2, with energy intensive industries such as steel mills and refineries being above 1 000 W/m^2.

The overall energy density range per square metre of land for small towns or mega-cities is typically less than the range for fossil fuel extraction infrastructures and thermal energy conversion plants that have energy densities usually well above 1 000 W/m^2 (Smil, 2006). This energy concentration becomes more diluted as it is distributed to end users living in a city. Nevertheless, the highly concentrated energy density range of fossil fuels at oil, coal and gas fields is usually much higher than the energy density range resulting from the collection and end use of many renewable energy flows. These are typically between 0.5 and 1 W/m^2 for wind and biomass and 10 to 30 W/m^2 for solar. Hydropower can have a relatively high energy density (50 to 100 W/m^2) depending if a dammed or run-of-river scheme is in place. However, as for fossil fuels, the location is often outside of a city and the energy needs to be brought in for distribution and sale to the end-users.

Therefore, it can be argued that the high energy densities of some urban areas would require large areas of "catchment" land outside of the city boundary if renewable energy is to be used to increasingly supply the energy needs within the boundaries of a large city. Hence a renewable energy-based society would have to concentrate diffuse energy flows to bridge power density gaps of 2-3 orders of magnitude (Smil, 2003) due to the mismatch between the inherently low power densities of renewable energy flows and relatively high power densities of modern final energy uses.

Conversely it should be understood that only around 5% of a wind farm area is actually used for the turbine foundations and roads. The rest can be used for pasture or cropping. For tar sands and open cast coal mines, the spatial energy density is lower than for oil fields and underground coal mines. For biomass, where the crop and forest residues by-products are utilised as feedstocks, the inefficient process of photosynthesis giving gross yields of less than 1 W/m^2 is less relevant Also solar installations are often located on roofs of existing buildings. Studies in Osnabruck using an aerial laser scanning method to quickly and cheaply assess the suitability of roofs in terms of orientation and inclination

14. Around 40% of the Earth's total oil endowment and 13% of the gas resource has been extracted to date according to IEA analysis outlined in the *World Energy Outlook*, 2008.

for solar collectors to be installed have shown that around 70% of the total energy demand of the city could be provided from solar energy should PV collectors be installed on all of the most suitable roofs[15], although storage and/or back-up would be needed for meeting demand at night-times and during cloudy periods.

Therefore even though energy densities of renewable energy resources can be relatively low, and the variability of some resources adds to the problem, the resources available within a city boundary, with other collectors located on adjacent land, can usually be sufficient to make a significant contribution to the total energy demand.

In summary

The conventional energy supply system based largely on combustion of fossil fuels is fairly inefficient and has high environmental costs. The contribution from renewable energy to the primary energy mix of cities will increase in the future but there are constraints to be overcome for some technologies including their higher costs and the relatively low spatial energy density compared with conventional energy supplies.

15. www.dw-world.de/dw/article/0,2144,3475182,00.html

4. The concept of sustainable energy supply

A mix of options to lower the energy per unit of GDP and carbon intensity of energy systems (as well as lowering the energy intensity of end uses) will be needed to achieve a truly sustainable energy future in a decarbonised world.
IPCC 4th Assessment Report: Mitigation, Chapter 4, Energy Supply, 2007.

The broad concept of sustainability is gaining traction worldwide and consequently leading to changes in the governance of cities and towns. The provision of a supply of sustainable energy is but one component. It is recognised that officials of cities do not have the ability to focus on energy or greenhouse gas objectives alone but have far broader policy objectives to manage in aiming towards a more sustainable future. Creating benefits for the citizens of today should help to provide an acceptable sustainable legacy for all future citizens. Instigation of sustainability drivers by a municipality therefore should help to:

- increase the life-style satisfaction of residents and employees;
- create a healthier environment with less local air and water pollution;
- reduce future risks relating to climate change impacts and energy supply security;
- reduce consumption and waste of limited resources including water and energy;
- create local wealth and reduce the amount of revenue collection needed from rates and local taxes;
- plan for changes due to adaptation from climate change;
- result in a more enjoyable, comfortable and "easy living" urban environment;
- reduce volumes of solid and liquid wastes; and
- enhance its national and international standing.

The Vienna Institute for Urban Sustainability defines the sustainability of a city as "a local, informed, participatory, balance-seeking process, operating within a budget, exporting no harmful imbalances beyond the territory or into the future, thus opening the spaces of future opportunity and possibility"[16]. Several independent organisations agree that implementation of sustainability requires collaboration among all the professions involved with operating municipal services (water, sewage, roading, street lighting, health, education etc.) as well as active participation by informed citizens. The Center for Sustainable Cities based at Kentucky University, United States[17] focuses on buildings and architecture for the implementation of sustainability, but notes that this is only one part of the overall sustainability process. The others relate to the ecology, economy and sociology of a city. The Center web site states that "stakeholders should understand that a city-system is an intricate web of interconnected relationships that can be manipulated in a multitude of ways to achieve balanced and sustainable development". Energy inputs, including from renewables, are part of this web.

The Rocky Mountain Institute (RMI)[18] in Colorado has worked closely with several cities in the United States for many years to aid their goals towards greater sustainability. Where above average solar, wind, hydro, biomass and geothermal resources exist, the technical potential to develop a sustainable urban area powered exclusively by renewable energy could be a feasible option. With this aim in mind, the RMI has developed interactive partnerships with city leaders and officials over many years to:

- establish critical success factors;

16. www.oikodrom.org
17. www.cscdesignstudio.com
18. www.rmi.org

- identify strategies and outcomes for planning officials;
- gain mutual-learning relationships;
- convene broad stakeholder meetings; and
- provide whole-system analysis that identifies tangible economic and environmental benefits for the whole community as a result of implementing energy efficiency measures.

Within cities, the capture and conversion of renewable energy to provide useful energy services can occur by integration into the local land use and the built environment. Hence it can become a major element of the urban economy such as has occurred in the German city of Freiburg im Breisgau (see Case study 6).

Increased renewable energy uptake enables a city to reduce its dependence on fossil energy and lower its carbon footprint as a result. In addition, biofuels, locally produced in a sustainable manner, could become part of a city's sustainable transport policy. So rather than simply be large consumers of energy and producers of greenhouse gases, cities could become the stimulus needed for developing a more sustainable energy future. As a result of policy development, renewable energy in a city can be delivered to residents, visitors and workers by:

- investing in infrastructure to enable "green energy" to be imported from nearby renewable energy generation schemes to provide heating, cooling, transport or electricity services for purchase by residents;
- investing in city-owned generation schemes including from wind farms, hydropower stations and waste treatment systems; and
- enabling the integration of technologies into the roof and façade of a building to capture the renewable energy directly for internal use and possible export any surplus.

Many practical opportunities exist to integrate renewable energy systems into buildings. However barriers to their uptake still need to be overcome in many cities. For example the cost and effort simply to obtain a permit to install a solar water heater on an existing building can be a disincentive to many householders. Urban planning developments and local policy support measures are often necessary to create the infrastructure needed to support solar, wind, geothermal, hydro and bioenergy deployment at the scale necessary to help meet a city's energy demands for electricity, heating and cooling (Newman *et al.*, 2009).

There are several key elements essential to developing a sustainable energy system of the future. The following section introduces the complex interactions involving renewable energy, distributed energy and digital energy. The conventional central generation of heat and power then distribution of the energy carriers throughout a city to the consumers is well understood. However, the overall system can be inefficient with high losses along the supply chain, particularly for electricity (Fig. 4). The option to introduce smart meters, distributed generation technologies and digital energy control as a condition for developing an alternative "intelligent grid" is outlined, together with the ambitions to integrate energy storage, demand-side management and electric vehicles with the aim of achieving a complete and sustainable energy system. The related potential for independent micro-grids in rural areas and the necessary restructuring of utilities are also addressed.

Distribution of energy through carriers

To meet the demand for energy services, the delivery to the end user via energy carriers such as coal, biomass, oil, gas, heat, hydrogen or electricity depends on a complex infrastructure built around roads, trains, boats, pipelines, or wires (overhead and underground). Electricity lines are usually run between poles and buildings as electrification of a city develops, but over time as funding allows, burying the cables beneath the ground both for amenity and safety reasons, is common practice. Pipelines to carry water and gas are commonly placed underground in cities too, although this is more costly for both installation and maintenance. Using natural gas lines to also carry landfill gas and biogas is technically feasible if the gas is first cleaned and scrubbed to suit the pipeline standards.

District heating and cooling systems also depend on a piping network, usually underground, which adds to the insulation to reduce heat losses, or for cooling, heat gains. These systems allow multiple energy sources to be connected to numerous energy consumers by pumping hot or cold water as the energy carrier. Such technologies facilitate the use of renewables and are most economically viable where there is a dense cluster of urban, commercial and industrial users to minimise the capital investment costs per connection. After the oil crises of the 1970s, several countries with cold winters developed district heating systems in combination with combined heat and power (CHP) generation to increase overall energy efficiency (IEA, 2009b). Some Scandinavian cities have reached more than 50% market penetration from district heating using biomass and in Iceland, the share of district heating using geothermal resources has reached 96%. (In both instances the renewable energy resources, biomass and geothermal heat, were readily available and project development therefore cost-effective. Regions without such good natural resources cannot expect to achieve such high shares of the energy mix). In lower latitude countries district cooling is increasingly being used, either through the distribution of chilled water or by using the district heating network to deliver heat for heat-driven sorption chillers (see Section 5).

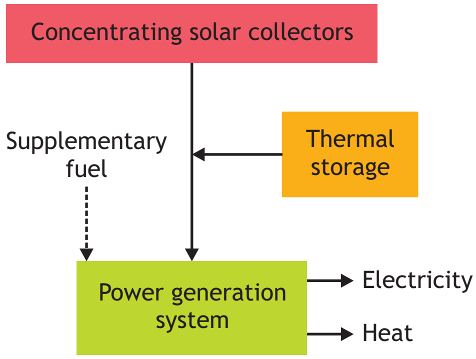
Storage

Storage of energy enables the decoupling of supply from demand. Solid, liquid and gaseous energy carriers can also act as stores of chemical energy. Gas and oil can be stored in tanks and coal can be delivered and stock-piled near to a heat or power plant. Biomass is also a store of chemical energy but it has a shorter storage life without degradation occurring naturally. Uranium can be stored after processing from the ore, but at a high cost, and water can be held as potential energy storage in hydro lakes. Low enthalpy heat and cold used for maintaining comfortable temperatures in buildings can be stored relatively cheaply and efficiently for periods of months with minimal temperature change. However, storage of heat at higher temperatures, and cold at lower temperatures, are subject to greater losses. Storage of electricity is more complex. In theory, it can improve the economic efficiency and utilisation of an electricity system, but it is usually costly and there is often little flexibility in managing the production and delivery of electricity from storage. However, recent research investment has been relatively high into batteries and other energy storage technologies and there are hopes that low cost storage systems will evolve quite rapidly as a result.

The economic performance of an electricity storage system depends on the conditions under which it is operated. Costs depend upon the mix of the power plants in the system, power tariffs and prices, fossil fuel prices, line charges for transmission services, regional inter-connections, etc. The technical and economic characteristics of storage systems are well understood, but where there are high shares of renewable energy technologies, there is a need to model the trade-offs between load management, grid management, transmission and storage systems (Krewitt, 2008).

Intermittent renewable energy resources such as solar, wave and wind have limited inherent storage capabilities so ideally they need priority access to the electricity grid (IEA, 2008b). Battery storage is feasible on a small scale, but at a relatively high cost. Concentrating solar power is an exception since some system designs can store the collected radiation energy as heat for later use when needed (Fig. 6).

Figure 6 • *A concentrating solar thermal power plant with heat storage (e.g. brine) to enable power and heat generation to continue after sunset*



A number of electricity storage devices are available differing in their capacity, duty cycles, time of response to reach full power output, and their load following capability (Table 1). Battery designs are continually being developed and improved. Lithium-ion batteries have greater than 90% efficiency and their gravimetric energy density is superior to other rechargeable systems in the small capacity range (kilowatts). At the larger scale for applications up to several megawatts, redox-flow batteries have around 70% efficiency with the electrolyte stored in large tanks allow. New developments include adiabatic compressed air which gives around 70% efficiency since it differs from conventional compressed air systems by incorporating the compression heat into the expansion process and therefore avoiding the need for additional fuel.

Table 1 • *Summary of energy storage technologies for electricity generation showing applications and response times*

Storage technology	Applications	Scale	Response time	Discharge time	Current capacity (MW)
Batteries (Lead acid; Li-ion; Ni-Cd)	Stand-alone systems; remote dwellings; tele-communications	Small	Seconds	Minutes to hours	120
High temperature batteries	Peak shaving; load levelling; primary reserve	Medium	Seconds	Minutes to hours	Small
Zinc-bromine batteries	Peak shaving; load levelling; primary reserve	Medium	Seconds	Minutes to hours	Small
Sodium-sulphur batteries	Grid energy storage	Medium to large	Minutes	Minutes to hours	300
Redox-flow batteries	Peak shaving; load levelling; primary reserve	Medium to large	Seconds	Minutes to hours	100
Flywheels	Peak shaving; load levelling	Small to medium	Seconds	Minutes	25
Pumped hydro	Secondary reserve; minute reserve; load levelling; peak shaving	Large	< 15 minutes	Hours to days	100 000
Compressed air	Secondary reserve; minute reserve; load levelling	Large	< 15 minutes	Hours to days	500
Hydrogen systems	Secondary reserve; minute reserve; load levelling; reserve power compensation e.g. for wind unavailability	Large to extra large	> 15 minutes	Hours to weeks	Small

Source: Based on Krewitt, 2008

Other higher capacity storage technologies include flywheels, super-capacitors, and super-conducting systems. If energy storage can become cost effective, it could make a significant impact on today's electricity markets where the supply constantly has to meet the ever-changing demand. Being able to store energy could provide more flexibility of the market in both operational and financial terms. The additional cost of a storage system depends on the fuel prices, electricity price, power plant mix, grid design and conditions under which it is operated.

The role of hydrogen as a form of energy storage is under debate. If produced locally from low-cost, greenhouse gas free electricity generation powering an electrolyser, then stored and delivered as required for power generation, heat, industrial processes, or transport, the need to build a new distribution infrastructure will not be required. Conversely if it is to be produced in large centralised coal or gas plants that would produce carbon emissions and also require new infrastructure, then, if poorly designed, the overall efficiency of the entire system may be no better than the current electricity model. (Hydrogen is also discussed in Section 5). More RD&D investment would help better understand energy storage and accelerate the development and deployment of more cost-effective storage systems for both small- and large-scale systems.

Electricity supply systems

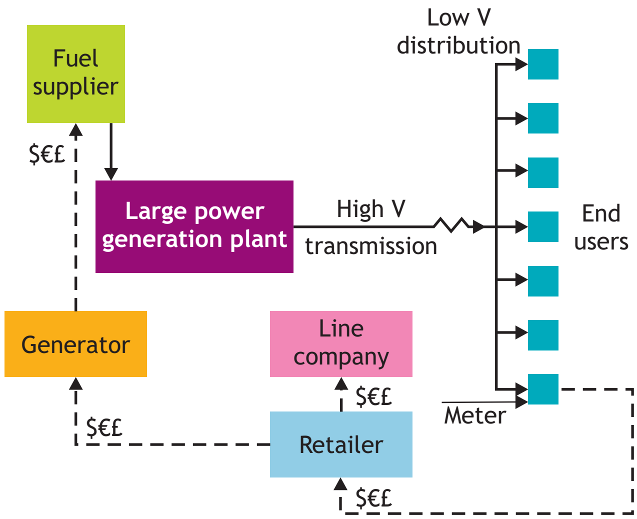
Centralised electricity supply systems are the common means of providing electricity services, whether to a small home in a city or to an energy-intensive industry. Large-scale generating plants continue to be constructed in order to feed high voltages into the grid. They are mostly fuelled by relatively low-cost coal as well as by natural gas and nuclear and gain economies of scale. In addition, hydropower currently accounts for around 16% of the total annual generation (around 19 000 TWh in 2007), with nuclear power providing slightly less. Other non-hydro renewable energy generation accounted for around 2% of the total, mainly from wind and bioenergy with some geothermal and a little solar power.

A typical system is where electrical current from a few major sources of generation is delivered to numerous electrical loads initially via high voltage, long distance transmission lines that minimise power losses and that, in turn, are connected to lower voltage local distribution systems through transformers (Fig. 7). In OECD countries, much of the electricity distribution infrastructure that delivers the electricity was built several decades ago. Upgrading the line capacities and transformers to meet growing power demands and to overcome problems of circuit congestion at times of peak loads is continually underway. However, upgrading entails more than simply adding to or replacing existing wires and poles with those having more current-conducting copper, since the old electro-mechanical analogue control systems cannot provide the precise requirements needed by digital appliances and computers as used extensively by modern society. Nor can the conventional systems continue to provide the security and reliability expected by customers.

In non-OECD countries, some cities have a complex web of dangerous overhead power lines running along the roads and between the buildings. This is a common sight as rapidly growing electricity demands can be cheaply and crudely met by simply adding more wires to those already functioning. Power outages are common, as is the theft of electricity by unregulated tapping of the circuits, thereby adding to the complexity and safety aspects of the system design. The cost of putting this infrastructure underground is often prohibitive.

A grid operator now has the choice to simply replace the old grid with more of the same or rethink the whole concept of network architecture to better address the issues of energy security, climate change and costs to the consumer. Where the grid is still owned by the utility that also owns the large power generation plants, the traditional model of the electricity sector is more likely, the incumbent being unable to contemplate a solution other than simply replacing the old grid is a barrier to developing a new network structure.

Figure 7 • *A simplified representation of the conventional electricity system with electrons flowing in one direction (solid lines) and revenue in the other (dashed lines)*



The vision for the electricity grids of the future in sustainable cities is for them to integrate significant shares of renewable energy generation. Deployment and incorporation of more renewable energy systems in the grids of today is a key step forward. This section attempts to provide a brief overview of this complex topic. Much more detailed analysis is being undertaken by the new IEA Implementing Agreement (IA) on Electricity Networks Analysis, Research and Development (ENARD[19]). They recently released six briefing sheets on the power system of the future[20] and are working in collaboration with the IEA PV Power Systems IA[21] on grid integration of PV (Fechner, 2008). Moreover, the Smart Grids Platform of the European Union (2008) and the United States Department of Energy (US DOE, 2009) are closely monitoring the potential for intelligent or "smart" grids, as are progressive utilities and electrical meter and equipment manufacturers.

In the future, the reliability of the supply of electricity carried along an existing power corridor could be increased using new conductors with carbon-fibre cores that not only have higher capacity, but are also lighter weight, so they sag less at the higher line temperatures associated with high power-flow rates. New designs of super-conducting cables can operate at lower temperatures and carry three times the amount of electricity of similar size conventional copper conductors that can have high losses of around 10% from heat production due to the resistance of the copper. Such innovative technologies could become components of an "intelligent" grid whereby digital electronic systems can be used to control electricity delivery integrated with more efficient use (see below).

Excess reserve capacity is usually built into the system in order to only be brought on line for short periods to meet peak daily and seasonal demands. It is therefore a relatively expensive option in terms of the total cost per MWh generated. The intelligent grids of the future (see below) will in theory be able to communicate with customers so that such peak demands can be managed by grid-operators in real time, thereby reducing the strain on the system, the cost of infrastructure and the need for surplus generating capacity.

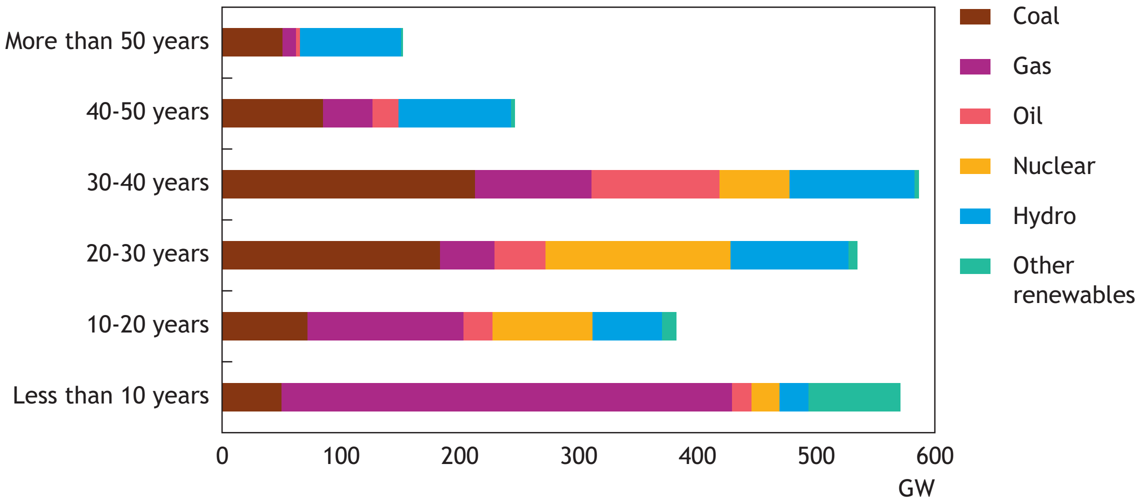
The challenge to continually match supply with demand has been met by having base load, middle load and peak load power stations, with the latter two groups coming on and off stream to meet the

19. www.iea-enard.org
20. http://www.iea-enard.org/content/Publications/WorkshopProfiles.aspx
21. www.iea-pvps.org

continually varying demand. With a greater share of variable renewable energy supply in the systems, this concept is less relevant as the challenge becomes one of guaranteeing firm capacity when depending on a range of energy sources and generation technologies. Innovative concepts to integrate renewable energy systems in a reliable power supply system include pooling various decentralised renewable energy sources, transmitting power over long distances between clusters of supply and demand, and using load management and energy storage systems to a greater degree (Krewitt, 2008). These all help to increase the flexibility of the system and thus accommodate a greater share of renewables (IEA, 2008b).

The common aim of governments and utilities over past decades has been to keep generation costs down in the short term for the benefit of consumers. It can be argued that this has restricted the uptake of innovative technologies that could have improved the efficiency, security and environmental performance of the existing fleet of centralised generating plants. In developed countries, over half of the existing coal-fired power plant capacity is over 30 years old (Fig. 8) and so many plants will need replacing in the short to medium term. Several nuclear reactors are also reaching the end of their operational lives and some have already been shut down. Coupled with the rising demand for new power capacity in non-OECD countries, this means that many investment decisions will need to be made in the next few years. These decisions will greatly affect greenhouse gas emissions for several decades to come.

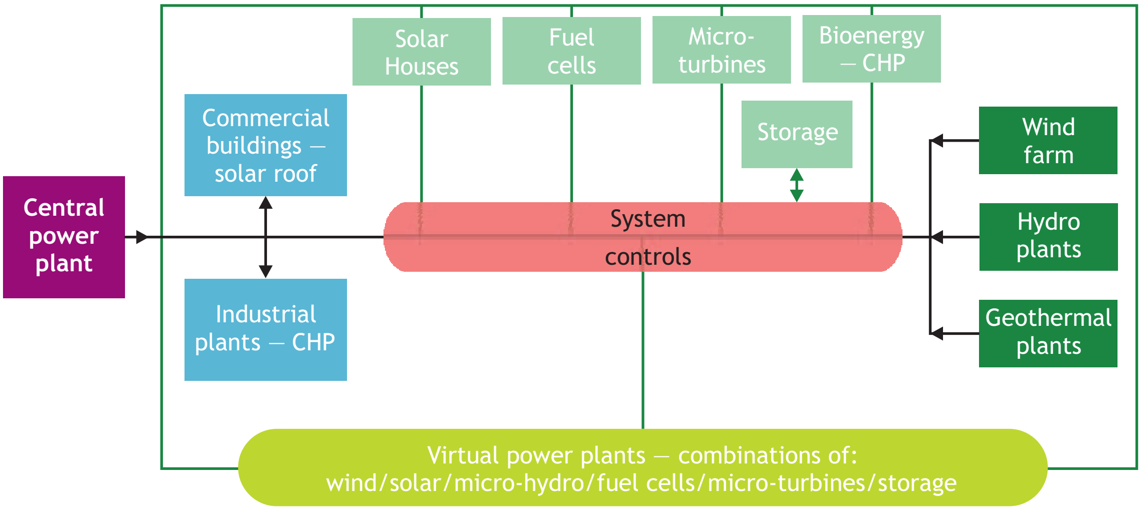
Figure 8 • *Capacity and age of the fleet of power generating plants in developed countries in 2006*



Source: IEA, 2008a

Any improvements to the current status of the electricity generation sector will be difficult to achieve even though new technologies are available. As is the case for advanced coal gasification with CCS, and also “Generation IV” nuclear, there could be significant capital investment costs involved compared with business-as-usual generation using pulverised coal and steam turbines or natural gas and combined-cycle gas turbines. The industry incumbents are not always willing to concede that there might be “a better way” to provide a reliable power supply, especially in regions that presently have no electricity services at all. Reduced comparative costs will be the main driver without which new grid concepts are unlikely to occur unless supported by government incentives. Therefore the transition to intelligent grids, virtual power plants and distributed generation systems (Fig. 9 and section below) will be a challenge, given that the traditional centralised system is well established. Any cultural or institutional inertia in the industry will need to be overcome if the rapidly growing demand for improved energy quantity and quality is to be met, as well as greenhouse gas emissions reductions.

Figure 9 • *Vision for the electricity system of the future*



Source: Based on European Union, 2008

Conventional high-voltage AC transmission systems are limited to distances of around 500 km without significant losses. However, high-voltage DC technology is now well established up to 3 000 MW carrying capacity over 1 000 km, including under water, and can provide low cost transmission for around EUR 0.01/kWh (Asplund, 2007), with losses below 5%. The long distance transmission of renewable electricity, even across continents, is the antithesis of local distributed generation, but provides another means of grouping renewable generation plants. It can link regions with a high renewable energy resource, such as solar radiation in North Africa, with cities of high electricity demand, such as those in southern Europe. In this example, high radiation levels in summer match the high demand for air-conditioning.

Smart metering

When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge of it is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced it to the stage of science.
Sir William Thompson, Lord Kelvin (1824-1907)

Although the uptake of greater energy efficiency technologies in many cities has, in part, reduced the continuing rapid rate of growth in electricity demand, little has yet been done by utilities to update the infrastructure or to introduce new business incentives that offer efficiency of service and quality of supply to the customers. The traditional electricity meter is a good example that, in many buildings, has not been changed for decades. The electricity supplier usually owns the meter and, being a monopoly, has often discouraged most consumers (except perhaps very large customers) from having any market leverage. However, new metering technology is now available at acceptable prices to transform this historic model and, in addition, the internet has enabled society to benefit from a new service-based market business model, including pay-as-you-go systems that can help reduce power being wasted (Chambers, 2006).

Meters that display and record real-time energy consumption data are becoming more commonly installed. Known as advanced metering infrastructure (AMI), a typical system that incorporates advanced smart-meters and software can measure, collect and analyse electricity demand patterns and provide information through some form of communication on request or to a pre-determined schedule. The network between the measurement devices and utility business systems enables customers, suppliers, utility companies and service providers to gain information collected and distributed by the system. These businesses can then participate in the market or provide demand response solutions, products and services. The system encourages a change in energy usage from normal consumption patterns by providing greater information to customers than they had access to previously. They can now respond to price changes or to other incentives designed to encourage lower energy usage use at times of peak-demand periods, or during periods of low operational system reliability. Real time smart meters can therefore add value to electricity markets for all stakeholders, compared with the conventional business model of simply maximising the quantity of electricity sold for the benefit of the utility.

A good design of smart meter should also be able to control and verify a number of separate circuits, typically those dedicated to large load devices such as air conditioners, refrigeration stores, motor drives, water pumps, electric vehicle charging and water heaters. The energy user can then select the optimum time-of-use based on varying tariffs and thus enable utilities to undertake load demand response actions and compensate customers for doing so. In addition, intelligent thermostats can communicate to allow utilities and/or customers to automatically adjust heating/cooling systems based on a balance between comfort, cost and power system requirements including peak load shaving.

Information from smart meters can be made available to the energy company or the consumer at the meter itself or at a short distance from it. The information is continually exchanged with an intelligent grid operation control centre that gives the utility control over the web of electricity generation technologies to meet the ever-changing demand. In turn, the utilities can share information across the entire system, thereby enabling suitable actions to result in order to maintain system stability.[22]

Smart metering can be used for both electricity and natural gas. The fact that data is provided directly to the utility obviates the need for manual meter reading. With smart meters, the consumer can pay differentiated rates depending on the time of day or the season. Smart meters also allow accurate monitoring of excess electricity from micro-generation that is sold to the grid (net metering) and can facilitate pre-payment or pay-as-you-go plans. Studies have shown that smart meters can produce overall energy savings of 5 to 15% (Darby, 2006).

While smart meters already exist in the market, there is nevertheless, on-going development. For example, at the United States Pacific Northwest National Laboratory,[23] a wireless system for electricity end-use metering permits near real-time measurement, tracking, and reporting for hundreds of different appliances and heavy electrical equipment (IEA, 2008e). Easy to install and use, the system provides cost-effective solutions for facility managers interested in proactive energy consumption management.

Existing standard electricity meters have a long lifespan and it is often not cost-effective to replace them early, given their initial cost. In some countries, where deregulation allows for fairly quick switching between energy companies by customers, the ownership and replacement of company-specific meters can cause major problems. Continual development means that to date, there has been poor standardisation of the technology and the lack of any regulatory requirement for smart meters is a concern in many cities. The barriers to greater deployment can be overcome by regulations, certification and subsidies for installation. This is the case in the Netherlands, where the government has amended the Electricity Act 1998 to improve the operation of the market by installing smart meters in each of the 7 million households and small businesses by 2014 (unless a householder rejects having the meter installed on privacy grounds) (Spencer-Jones, 2007). While the four grid operators own the meters and are responsible

22. www.gridpoint.com
23. http://gridwise.pnl.gov/

for their installation, the energy suppliers are responsible for managing the data. The meters can remotely read energy consumption and any export to the grid; can be remotely connected and disconnected; can detect and meter power quality; have the ability for on-line interaction between customers and suppliers; and have the ability to give a real time response to controllers of the electricity systems.

Smart metering will provide a communications channel to energy consumers that will break down the traditional monopoly status of electricity suppliers and improve delivery of services. To explain the benefits of smart metering, the energy saving opportunities, and their interaction with intelligent grids of the future, information and awareness campaigns will be important. Successful outcomes will largely depend on the attitudes of the customers to energy usage.

Distributed generation

Just as the distributed information technology and internet communication revolutions dramatically changed the social context as well as the economic parameters of doing business, a distributed renewable energy revolution will have a similar impact on the world.
Jeremy Rifkin *et al.*, 2008.

The move to a "Third Industrial Revolution" incorporating a social vision with an economic vision is considered by some world leaders to be essential if the future challenges of energy security and climate change mitigation are to be met. Major changes to the energy supply sector tend to only occur when a new energy regime happens to converge with a new communication regime (Rifkin *et al.*, 2008). For example, in the 18th century the deployment of the coal-powered steam engine was aided by the printing press to disseminate its benefits and hence enable the rapid pace of the "first industrial revolution" to occur. In the late 19th and early-to-mid 20th centuries, the "second industrial revolution" occurred when first-generation electrical forms of communication, including the telegraph, radio, and telephone, enabled the necessary infrastructure development, organisation and marketing of millions of small vehicles powered by internal combustion engines and fuelled by oil products. Today, the technologies that made possible distributed global communication networks, including personal computers and the internet, can be applied to "distributed energy systems", whereby millions of privately-owned heat and power generation systems can produce energy for meeting local demand as well as sharing, in a similar manner to how electronic information is shared.

The electricity grid in place today was designed and developed historically when energy was cheap, pollution was free, and information dissemination was constrained. Today energy is relatively expensive, pollution needs to be paid for and information is abundant. In addition, the expectations for security of supply in terms of reliability and power quality have also changed. It is therefore appropriate to review the role of the electricity grid supply system with which we have all become familiar and to consider a paradigm shift to a new model based on increasing contributions from distributed resources, including renewables and CHP systems.

To achieve a rapid growth in renewable energy supply in a region, one effective mechanism could be the greater deployment of more locally distributed power generation within an intelligent grid. Other objectives that could be simultaneously addressed by the deployment of distributed electricity generation include minimising the need for new, large-scale thermal generation linked with transmission and distribution infrastructure. In addition, end-use efficiency could be encouraged, including the incorporation of combined heat, power and cooling systems. Innovative electricity pricing and business structures will be needed in many cases, to ensure that any incentives such as cost reductions in bulk electricity sales can be countered. These could be replaced with incentives that encourage investments in distributed generation and achieve societal benefits and reduce carbon emissions.

A decentralised form of energy use will need a major reconfiguration of the electricity grid and an acceptance by the incumbent utilities that future commercial opportunities will result. Energy storage will be an essential component as will demand-side management by remote control, smart meters and intelligent grids. Earlier evaluations of distributed energy systems by the IEA include *Distributed Generation in Liberalised Electricity Markets, 2002* and *Grid Integration of Renewable Energy, 2008.*[24] The World Alliance for Decentralized Energy (WADE) also provides regular news and information on distributed energy technologies to members. The following section in part builds on these publications.

Most electricity used in the world today is generated by large central power plants. In simple terms, electrons flow in one direction and the user pays the retailer who reimburses the generation and transmission/line companies (Fig. 7).[25] Distribution is through somewhat inefficient and costly networks, using long power lines at varying voltages and often with significant line losses up to around 10% of the total power actually generated. During peak periods, utilities tend to deploy their more costly and less efficient power plants. This system has evolved from the very early generation systems that consisted of small, widely distributed, individual power generation plants using local energy sources and usually located fairly close to the customer load so that only short lengths of distribution lines were needed. Over time, cheap coal, oil and gas fuels were able to be transported over longer distances. Moreover, the investment and operating costs of larger generation plants became more competitive; large power plants were designed for easier control to match fluctuating demand; and many governments were willing to invest in national transmission and distribution infrastructure for the social good.

Today, however, the power sector in some countries is experiencing a renaissance with the advent of *distributed energy*. There are as yet no universally accepted terms for electricity that comes elsewhere than from large generating units exporting electricity into a high voltage network. Those used in this report are as follows.

a) *Distributed generation (DG)* is electricity generated in small plants to serve a user on-site or to provide support to a local distribution network by connection to a grid operating at a low level distribution voltage.

b) *Distributed heating and cooling* is where local systems reduce the demand for importing electricity or fossil fuels into a district to provide these end-use services.

c) *Distributed energy systems* include distributed power generation plus distributed heat, demand-side measures and, where appropriate, storage.

A distributed energy system is decentralised and, if well-designed, should, where necessary, be able to meet increasing local energy demands, incorporate demand side management as a critical first step, provide security of supply, reduce greenhouse gas emissions compared with thermal power plants, and provide many social benefits, including local employment, sustainable development, pride, independence, and social cohesion of communities. Although the emphasis can be on renewable energy sources for local production of heat and power, this does not have to be exclusive of other forms of primary energy, particularly natural gas (for direct combustion for heat, CHP, or as a fuel for gas engines or, after reforming, for fuel cells), and also gasoline or diesel (used in generating sets operated to meet peak load demand or as back-up systems).

The demand for distributed generation technologies that can give back-up to grid power outages and hence higher reliability has grown in recent years, particularly for safety reasons in hospitals, as well as

24. http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=2040

25. In fact, a typical wholesale electricity market usually has several generators bidding into a merit order every 30 minutes at varying prices and is very complex. In addition the system operator, transmission, distribution, metering, and customer relationship management are part of the system for which separate charges are embedded in the various tariffs paid by the customers.

security for credit card, trading, finance, defence, computing and information technology companies etc. Worldwide DG capacity orders for internal combustion engines and gas turbines below 30 MW for stand-by, peaking as well as continuous applications, have been around 10% of annual global electricity generation orders (over 20 000 MW in 2000; IEA, 2002) and somewhat greater when renewable energy generation is included.

Renewable energy projects such as hydro dams, geothermal field developments, or off-shore wind farms usually require large capital investments. Hence future developments could be constrained if credit is not widely available. Private or public investors with access to limited credit will therefore need to have confidence in the technologies and their ability to provide enhanced energy security if they are to choose renewable energy over other potential investments.

Key economic advantages possible from distributed generation, especially for on-site power production, include avoidance of transmission and distribution costs which can amount to around 30% of the delivered electricity costs; waste heat available for use on site as combined heat and power; delaying the need to upgrade a congested transmission system; and the opportunity to use relatively cheap local fuels such as landfill gas and crop or wood processing residues. Conversely smaller plants tend to be less efficient with a lower fuel economy (unless used in CHP mode) and have higher capital costs per kW.

Another key barrier to the deployment of distributed generation systems is a lack of incentive for the system operator. DG is often seen as a complexity that carries additional costs. Grid operators also often maintain a passive system rather than treat the DG as an active control element in the operation and planning of the network (Krewitt, 2008). Market access can also be a hindrance to deployment where entry barriers have not been removed by regulations (Scheepers, 2007).

Many new small-scale heat and power generating technologies are commercially available, often using renewable energy sources (as well as natural gas). Technologies include bioenergy or natural gas CHP systems; wind, solar, small-hydro and micro-hydro generators; geothermal heat pumps; solar thermal systems; Stirling engines (see Box A); steam turbines and fuel cells. As generation becomes more widely distributed and the number of generating plants increases, the direction of flow of electrons along a power line must then be in both directions. The owners of the local distribution lines then become service providers.

Large central power stations will continue to exist to provide base loads for industry and cities, but large numbers of smaller systems will be added to the system. System operation will then need to be co-ordinated and facilitated by information and communication technologies (DISPOWER, 2006). Renewable energy heating and cooling applications can become part of the overall energy system in order to reduce the demand for electricity otherwise used for this purpose.

The costs of small generation technologies continue to decline through greater mass production. Taking into account the reduced investments needed for new transmission infrastructure and for network upgrading to meet higher load capacities, an economically viable solution for small CHP plants can often be found. In the many regions of the world currently without access to electricity, this could be in the form of a small local-grid. This is analogous to a similar "leapfrog" technology — the mobile cell phone that has given millions of people hi-tech communication without having to wait decades for investment in the alternative conventional development of costly infrastructure. The mobile phone enables a person to easily communicate with another person directly wherever he or she may be, rather than the old process of telephoning a building with the hope that there might be someone there to respond.

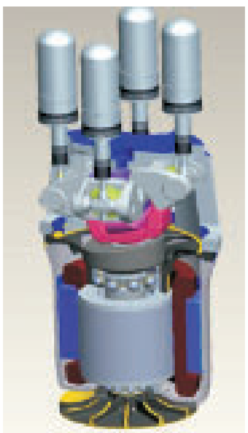
Mobile phones were rapidly embraced by the general public, giving a rate of market growth in OECD countries somewhere around 40% to 50% per year. In many developing regions such as Africa, the technology has leap-frogged the need to build costly poles and wires to bring telephone connections to the more remote communities. The rapid rate of deployment of mobile phones over the past decade, now coupled

Box A • *Whispergen domestic CHP technology*

This novel device can serve as a substitute for a hot water boiler and also generate power. It is described here to illustrate how new and unexpected technologies can enter a market and develop rapid change in a system, as was the case with mobile phones and laptop computers. The Whispergen domestic scale, combined heat and power system, developed in New Zealand, is based on the Stirling engine and a novel yoke coupling. In essence four cylinder nodes (Fig. 10), housed within a sealed hood (not shown), are heated by any source of fuel (biogas, natural gas, LPG or even concentrating solar heat). This starts a process of gas expansion and contraction inside the cylinders that gives linear motion. The wobble yoke mechanism converts this into rotary motion of the alternator to generate electricity. The operation is clean, quiet and needs only low maintenance, thereby making it suitable for applications in small boats and domestic situations.

The on-grid, heat demand-led domestic model produces 1kW_e and 13 kW_{th} and substitutes for a hot water boiler, with AC electricity being generated as the co-product to supplement the grid supply or to export when in surplus to demand. It can be mass produced and installed and maintained like any other domestic appliance.

Figure 10 • *Cutaway diagram of the Whispergen micro-CHP generation technology showing yoke coupling between the Stirling engine and alternator and example of the domestic installation of the appliance*



Source: www.whispergen.com

A typical product development cycle has been undertaken and the device is now finally reaching the fully commercial stage after eight years of field trialling and seven years of iterations. Low volumes of the product were manufactured for undertaking technology trials and detailed testing in around 30 homes in the United Kingdom. Demonstrations of its potential in the northern European market resulted in modifications and further testing before market testing began in around 400 homes. Mass manufacturing by selected partner Mondragon (of the Spanish MCC industrial group of whiteware and gas boiler manufacturers) began with prototypes being produced in 2007. A joint venture company (EHE: Efficient Home Energy) was incorporated in early 2008 and a factory then established with the capacity to produce 30 000 units per year on a single shift. Wider marketing and deployment are now being pursued in Germany, Belgium and the Netherlands, with Italy, Spain, United Kingdom and France under evaluation.

with the added convenient E-mail and internet access from almost anywhere in the world, illustrates what is possible when a new technology enters the market. The costs involved to access these communication services do not seem to be a deterrent for many people whose monthly phone bills greatly exceed their electricity accounts. Whether a similar acceptance of decentralised energy systems by society, with all their potential benefits, will occur in the future in a similar manner remains to be seen.

Where existing power is provided by large nuclear, thermal or hydro plants to provide base-load, these would remain the heart of the system. New decentralised plants would be added and managed, possibly under the control of the line companies.[26] Policy-makers, as well as the more conservative members of the power industry, need to be aware of the growing transition towards distributed energy systems.

- Decentralised systems and their integral technologies, including smart meters, intelligent control systems, and small-scale generation technologies, are reaching the commercial stage of development.
- The overall costs of a DG system, compared with traditional power generation, are declining and include costs saved from avoiding new infrastructure and deferred line upgrades.
- Existing demonstration and early commercial-stage projects illustrate the reliability, quality and benefits of an integrated system.
- Decentralised systems in both OECD and non-OECD countries could be designed as either stand-alone systems, local mini- or micro-grids, or linked with major power supply systems via low-voltage distribution networks.
- Since the potential for distributed energy deployment has not always been adequately included in the past due to lack of data, evaluations of future trends, barriers, benefits and implications for decentralised systems are being developed for use by scenario modellers.
- Recommendations for policy-makers and utility companies are already being developed by some national and state governments in order to advance the transition to distributed energy systems with a high share of clean energy technologies.

Social issues of DG and demand side management (DSM) that relate to consumer behaviour and change are yet to be fully evaluated. Careful tariff price setting will be needed to ensure that consumers maximise the benefits that the technology offers. Innovative business models for the utility and line companies need to be developed which could include such factors as ownership and leasing of the small-scale generation technologies or enabling third parties to invest in the equipment.

Intelligent grids

Combining evolving information technology with the proven technology of the existing power grid infrastructure leads to a paradigm shift. To enable distributed energy to become prominent and provide multi-benefits, as many electrical engineers consider is technically feasible, the thousands of small generation components of a system would need to be linked together using intelligent controls that, through internet and *wifi* technologies, would be used to produce a balanced system at all times. Integrating energy storage and load management control into the system to manage peak periods can also be a crucial part of the design in order to give high quality and reliable power.[27] Siemens list five building blocks that will assist in developing the current power grid into an intelligent grid (Julliard, 2009): improved management of critical grid conditions with the control system giving 'self-healing'; condition monitoring with real time on-line maintenance; better control of load flows; smart metering;

26. A good analogy is the main-frame computer that remains a vital part of modern IT operations, along with millions of small personal computers, all individually linked into the system by wires or *wifi*.
27. See for example www.weforum.org/pdf/slimcity/SlimCity%20Knowledge%20Cards%20-%20Smart%20Energy.pdf

and integration of distributed energy resources into the power grid. Storage of energy tends to remain a costly option at present (see above), but it would bring increased value to an intelligent grid if the storage costs /kW could be brought down.

For many cities in non-OECD countries, the rapid rate of urbanisation involves building networks from poles and wires to provide electricity to a growing population, usually with little consideration or support for developing intelligent grids. International aid programmes and public/private partnerships could be the means of demonstrating the pathway needed and hence avoid missing the opportunity to leapfrog the construction of conventional electricity infrastructure.

Where infrastructure already exists, the "intelligent grid revolution" involves an innovative electronic communications and control system being superimposed over the entire electricity delivery system. With minimal intervention, an advanced metering infrastructure could result and lead to energy saving benefits. Also known as the "Smart Grid", it is in essence the optimisation of the network using detailed data flows between all key stakeholders. The present electricity system and transmission and distribution grid infrastructure in many OECD countries is old and vulnerable to outages in many places. Many existing power lines will need upgrading in the future to meet the ever growing demand for electricity under the present grid system. This, coupled with growing climate change concerns, has resulted in some grid operators and line owners already seeking alternative technologies and new business models. Other incumbent generators / retailers do not view the business implications so positively, especially where large investments would be required to scrap assets before the end of their useful life.

A smart grid is more than meters and automatic controls. The main added-value is how data collected from various sources such as weather forecasting, energy demand and appliance use, can be used to provide customers with information leading to cost savings, climate change mitigation and other social benefits. The poor experience of sudden loss of wind power to the system by the Electricity Reliability Council of Texas[28] exemplifies how better forecasts, grid flexibility, storage and demand control options all need to be part of the integrated smart grid system.

At present, most residential and small business customers receive a monthly payment account containing limited information that sometimes simply estimates how much electricity has been consumed since the last payment. Many customers do not understand even this limited amount of information provided, other than the amount to pay. What is not yet clear for smart grid investors and operators is what information customers actually value and how they may or may not be interested in having a new system installed, possibly with some inconvenience, limited cost-saving benefits and the risk of privacy data being released. "Who will own the data?" and "Will it be secure?" are questions receiving considerable attention from those developing the intelligent grid concept, since a negative public reaction at the early concept stage could become a major barrier to market deployment.

When technological innovations in power equipment are combined with information and communication technologies, a more efficient use of distribution network capacities should theoretically be possible. A new "Digital Energy" initiative (NEF, 2009) aims to not just narrowly focus on the physical flow of electricity and network optimisation but to create value from the direct involvement of consumers and small generators by providing data relating to pricing, carbon content, asset tracking, security of supply, etc. This could help add value to the business, finance and economic implications of the shift to a digital energy infrastructure. In several cities preliminary smart grids are already in place following the installation of smart meters in buildings and transformers located at distribution nodes.

For utilities, load and generation characteristics need to be taken into account for network operation and planning. In an intelligent grid, all the components of the system would be in continual communication

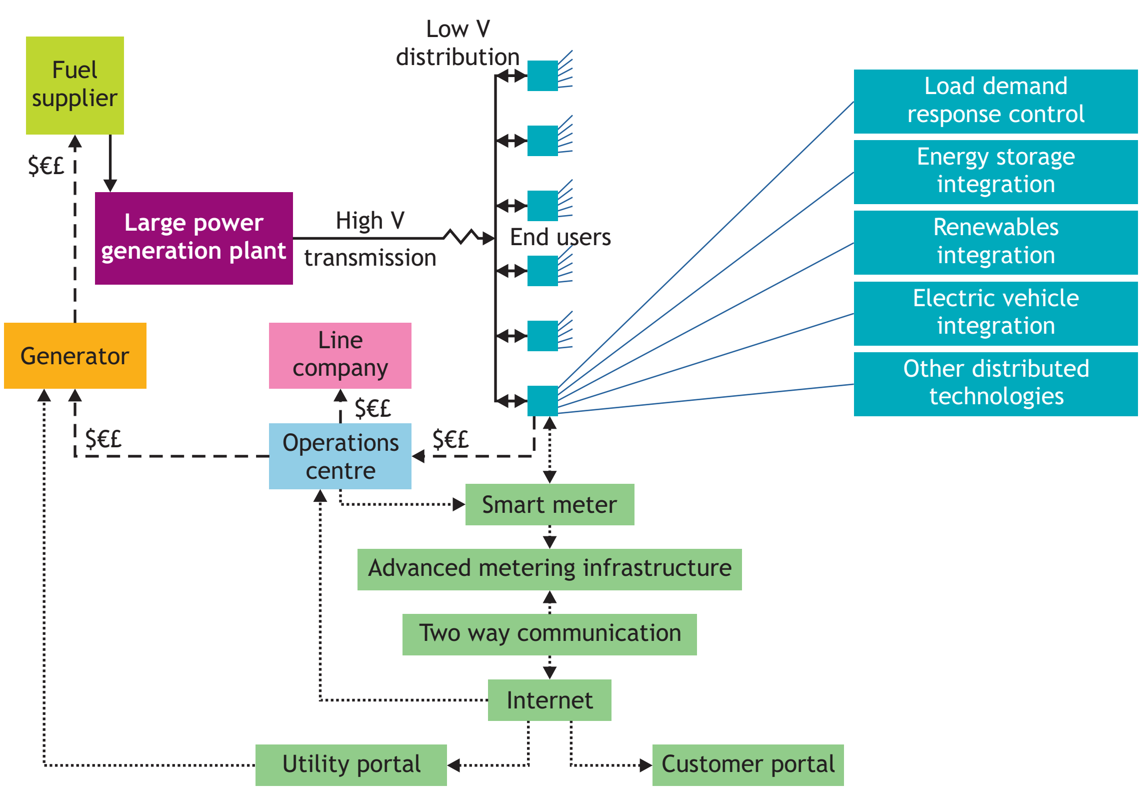
28. www.smartgridnews.com/artman/publish/article_420.html

so that performance is optimised. This would enable relevant, real time, information data to be sent to transmission and distribution controls, end-use devices, and consumers to enable appropriate action to be taken instantly at any given moment to keep the grid functioning reliably, to minimise costs, and to reduce resulting greenhouse gas emissions. The system would use sensors and meters to optimise the balance of the power generation supply and delivery with the ever-changing demand. This would minimise losses, be self-correcting and enable energy efficiency and demand-side responses to be integrated and encouraged.

An intelligent grid would transform the electricity distribution system from the common radial design of feeder with electrons moving from the central generation plant in one direction along out-going distribution lines (Fig. 7, page 7) to a network with two-way electron flows that ensure all generation sources, whether large or small, can be connected to end-use appliances (Fig. 11). This will require conversion from the present electro-mechanical system to a digitally monitored and controlled network. Having instantaneous two-way communication between electricity consumers and electricity suppliers will enable all stakeholders to participate actively in the market place. For small-scale generation plants, such as from building-integrated solar PV, roof-mounted vertical axis wind turbines, or small CHP plants, many consumers will also be suppliers.

One attribute of an intelligent electricity system would be the ability to practically use a significant share of variable renewable energy (particularly from wind, solar and wave). The present electro-mechanical controls that many electricity delivery systems rely on cannot reliably transport more than small percentages of variable sources of renewable energy without requiring costly back-up capacity of electricity generation that can rapidly be brought on-line as the wind drops or clouds appear. Making

Figure 11 • *Representation of a distributed generation system with two-way flows of electrons (solid lines), revenue (dashed lines) and information (dotted lines) through smart meters and intelligent grids*



the system more flexible by adding storage, introducing cross boundary connections, and using demand side management would enable a larger share of variable renewables to be accommodated (IEA, 2008b). The opportunities for transformative innovation to support distributed generation systems (see below) could be greater on the demand side than on the centralised supply side and an intelligent grid could help realise these. However, a future "green" electricity system incorporating variable renewables will need to be based around an intelligent digital grid.

Small-scale CHP systems using local resources (such as natural gas, biogas, biomass etc.) could also be incorporated. Ground source heat pumps, air-to-air heat pumps, air-to-water heat pumps and solar thermal space and water heating/cooling systems could be added to reduce the heating and cooling demands currently provided by electricity or other energy carriers. Overall, it should be possible to design an intelligent grid (or local mini-grid) with high performance efficiency, acceptable reliability and the potential to integrate a relatively high proportion of variable renewable energy sources.

The Department of Energy of the United States (US DOE, 2009) claims that intelligent grids could be 99.97% reliable with two-way digital communications and "plug-and-play" capabilities for adding small generation systems. It is expected that intelligent grid enhancements could enable 50% to 300% more electricity to be sent through existing corridors by easing congestion at peak times and increasing the full utilisation of installed capacity. The investment cost involved in replacing and upgrading the United States grid alone could reach USD 1.5 trillion by 2030 (Fox-Penner *et al, 2008)*. Hence there is a window of opportunity during these upgrades for wise investment in future intelligent grid systems to gain the benefits.

The US DOE (2009) lists the five fundamental technical concepts that will drive the intelligent grid:

1. integrated communications that connect components to open architecture for real-time information and control, allowing every part of the grid to both "talk" and "listen";
2. sensors and measurement technologies to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management;
3. advanced components that apply the latest knowledge of superconductivity, energy storage, power electronics and diagnostics;
4. advanced control methods to monitor essential components, thus enabling rapid diagnosis and precise solutions appropriate to any event; and
5. improved interfaces and decision support systems to assist decision-making by grid operators and managers and transform them into visionaries.

Most of these technologies are commercially available and intelligent grids are beginning to emerge. For example, the Canadian Province of Ontario's Independent Electricity System Operator[29] is rolling out smart meters and offering time-of-use pricing for all customers. In New Zealand, Orion Energy,[30] an electricity distribution company owned by the City of Christchurch, is also installing smart meters, even though no national regulations are anticipated. The company has been a strong advocate of demand side management for larger customers and for several years has developed guidelines for distributed generation connections. Other examples of smart grid demonstrations exist in the United States cities of Boulder, Colorado; New York, New York; and Charlotte, North Carolina. In this latter example, the utility Duke Energy is collaborating with electricity equipment manufacturer Cisco Systems to design and deploy the smart grid infrastructure using internet protocol standards. Cisco is also working with IBM to assist the utility Nuon undertake a pilot study using 500 households in the city of Amsterdam to enable consumers to make more informed decisions about their energy consumption through the use of smart meters[31].

29. http://www.ieso.ca/imoweb/infoCentre/ic_index.asp
30. www.oriongroup.co.nz
31. http://newsroom.cisco.com/dlls/2009/prod_071409e.html

Social issues yet to be resolved include ownership of the metered data, consumer privacy aspects, and security of the system against virus infiltration and sabotage activities. While a number of international standards are under discussion, consensus as to how to best proceed has not yet been reached. It is likely that due to the variations in existing power supply systems in terms of voltage and frequency, regional standards will be required rather than worldwide standards for intelligent grids being implemented. A key initiative is through the Institute of Electrical and Electronic Engineers (IEEE) that, in association with Intel, announced in June 2009 a groundbreaking smart grid initiative for the power engineering, communications and information technology industries. This was the project as approved by the IEEE *Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS) and End-Use Applications and Loads.*[32]

Micro-grids, building integration and electric vehicles

The building sector is typically the largest user of electricity and often accounts for a significant portion of national greenhouse gas emissions. An intelligent micro-grid can incorporate buildings into the system as both electricity suppliers and energy consumers. This would enable a smooth interconnection of supply with demand and the integration of the diverse range of energy services (heating, cooling, lighting, electronics, motor drives etc.) that have traditionally been operated separately. The ability to embed intelligence into the building structure enables all appliances and energy sources associated with the building to communicate and thereby automatically coordinate actions to give higher overall efficiency and lower costs. Hence, zero net-energy buildings, and buildings generating more power then the inhabitants need, have become an achievable and realistic design goal in most regions of the world.

Encouraging electrification in developing countries at the village and small township scale can be achieved through the technological development of renewable energy-powered micro-grids. Local co-operatives could be established to own and operate the micro-system and hence provide market transparency and direct consumer access that conventional centralised electricity supply systems generally do not provide. The micro-grids could incorporate various intelligent grid technologies so as to maximise the benefits for individual business and domestic consumers and the community as a whole. Local micro-grids could also provide the opportunity for future system expansion in a sustainable manner, assuming they are managed in response to the needs of the user whilst increasing the reliability, efficiency and value of the energy services provided (GEA, 2009).

Micro-grids are usually developed and installed by local entrepreneurs. Where feasible, they are operated in co-operation with a centralised bulk electricity supplier to resolve rising peak power demands where economic storage is unavailable. When carefully designed, micro-grid technologies can produce a power supply system that is reliable and can provide economic and political incentives for all stakeholders.

As well as intelligent interconnected buildings with distributed generation, electricity storage can be incorporated as a key element of micro-grid design in the form of plug-in electric vehicles (see Section 5). A strategy for delivering electricity is where these electric vehicles can become an efficient energy supply source during high cost, peak demand periods. Energy management of the vehicles can enable charging/discharging to be controlled to suit the needs of the drivers and the grid (Gridpoint, 2009). For example, vehicles connected to the grid will be automatically detected and identified by the utility and managed in accordance with the owners' wishes. When undertaken at off-peak times, vehicle charging can commence, but at a timing and rate to avoid creating a peak load. When the system is operated during peak periods and as agreed by the driver based on any imminent need for use of the vehicle, the utility can discharge any remaining power from the batteries to the grid and then recharge later during off-peak times.

32. http://standards.ieee.org/announcements/intel_p2030.html

The key policy to enable the full benefits of micro-grids, distributed generation, and electric vehicles to be realised is time-of-use electricity pricing for both purchase and sale of electrons from and to the grid. This will encourage consumers to be more energy efficient, to take advantage of the resulting energy savings, to benefit from revenue opportunities, and to seek low carbon emission options.

Utility restructuring

Even though there is limited penetration of distributed energy in today's electricity markets, an evolution to a more decentralised power system with potential benefits of security and reliability is anticipated (see, for example NEF, 2009). How a decentralised system will emerge from the current centralised system is difficult to comprehend due to the complexities involved. Within many existing network systems, DG is being accommodated at relatively small shares and the system is being adapted slightly to handle the limited amount of variable renewable energy technologies involved. The next stage could be the creation of a decentralised network system that works in tandem with the centralised system. This in turn, could eventually lead to a dispersed system where most power is generated by decentralised power generation technologies and a limited amount from central generation (IEA, 2002). Exactly how this will be achieved and under what timeframe will vary with different networks and whether they are under private or public ownership.

To be integrated into DG systems, renewable energy technologies will need to be:

- granted market access without having additional costs and complexities from dealing with the market;
- appropriately priced to incorporate all the benefits and costs of distributed power; and
- operating under market conditions that adjust prices to varying power demands and do not disadvantage small generators.

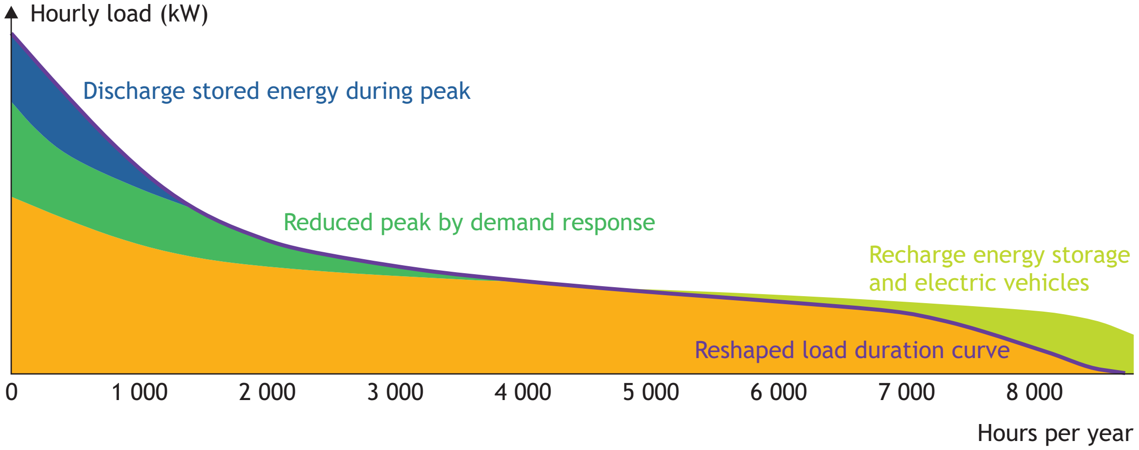
The deployment of DG systems will also depend on when relatively cheap energy storage, other than pumped-hydro, becomes feasible as an integrated part of the system.

Connecting DG to an existing distribution system can impair the network performance and reliability unless standard rules are put in place. The costs of connecting DG to a grid can be substantial especially if the system needs to be reinforced as a result. These costs will need to be recovered. Since large-scale generators, (that compete with DG producers), do not usually pay for the transmission system or its upgrades, it would be a disadvantage if DG producers had to pay these costs. The solution is for DG producers to pay the connection costs but for any other costs to be recovered from all consumers on the grid through imposing an operating charge.

Every consumer of a utility has a load duration curve that identifies the hourly demand load over a year and identifies the peaks and the seasonal periods (Fig. 12). A utility investing in an intelligent grid linked with smart meters and energy storage would provide the opportunity for its consumers to reshape the load curve by reducing peak loads and transferring some demand to low use periods. This is particularly attractive to consumers where payments are based on peak load periods. When aggregated across a region, this system in its entirety could result in avoiding the need to build new plant capacity.

Present designs of electricity distribution grids do not enable flows of electrical current from numerous generation sources to be fed into the system simultaneously through numerous connection nodes. To enable this to occur, utilities can implement technical solutions that are under development or already commercially available. These include converter technologies that can also provide ancillary services and control schemes that enable a high penetration of distributed generation in local grids.

Figure 12 • *Example of electricity load duration curve reshaped by peak load reductions (blue) using discharged energy storage and demand response techniques and by lower load increases (green) as a result of recharging energy storage including electric vehicles*



Technical barriers relate to the reliability of the supply, power quality, grid stability, grid control, safety and protection. To give better integration of DG into an existing system with intelligent networks in place (Scheepers *et al.*, 2007), a utility could use active management (such as fault level control through network switching in urban areas) to increase the proportion of DG that can be handled. Since central generation plants are presently used to give system control, installing large numbers of small generators could pose problems in this regard. However, this can be overcome by grouping many small generators to form a virtual large power plant (Fig. 9, page 52) in order to both trade the electricity generated as well as to provide system support services.

In summary

Distributed energy systems have the potential to benefit both suppliers and consumers. Having large numbers of new small generators connecting to a network could reduce the need for a utility to construct high voltage transmission lines or to replace those working up to capacity. Individual micro-grids can be designed to operate on their own in places presently without access to electricity and hence avoid the need to install a grid infrastructure in regions currently without main power. Even where grid-connected, micro-grids could possibly operate in isolation during extreme situations to provide emergency power, for example when there is loss of supply from the high voltage transmission networks.

In the future, renewable energy systems could provide a larger component of the supply portfolio for many utilities. The systems can be measured, controlled and managed with the advent of a smart grid software platform.[33] Being able to control and manage this supply will be necessary to avoid any impact on grid operation and power quality, as well as on the frequency and period of power outages. Load management, energy storage integration and electric vehicle management could all be used as a resource to balance supply with demand. Renewable energy sources can be optimised by better matching of generation capacity with demand and the inherent variability of wind, solar and wave power can be managed to minimise spill or the need for back-up systems. Customers will be able to manage their energy use on-line by accessing data directly from the utility operating centre. In addition, such software systems could be used to verify generation levels from renewables in order to assess whether a utility has met renewable energy portfolio standards, regulatory mandates or renewable energy credits.

33. See for example www.gridpoint.com.

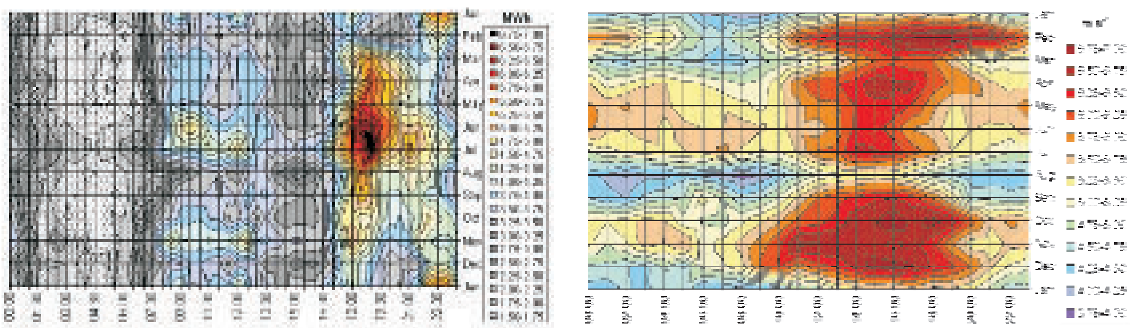
5. Renewable energy resources and technologies

Renewable energy, with its low carbon footprint, the relative speed with which it can be deployed into developed and developing communities alike, and its ability to generate new kinds of businesses and green jobs, is a key element of the transition to a "Green Economy".

Achim Steiner, UN Under-Secretary General
and UN Environment Programme Executive Director (UNEP, 2009).

Assessing the renewable energy sources available in or near to a city is a crucial step before developing policies that support the deployment of renewable energy technologies. The variability of some renewable energy sources such as wind and solar can be problematic when attempting to continually match electricity supply with demand (Fig. 13). Electricity demand by season on the left (depicted as MWh per half hour intervals over 24 hour periods) shows a higher demand in winter (June/July), peaks in the evenings and troughs at night and mid-afternoons. This partly matches the local wind resource (shown on the right as mean annual wind speeds over half hour intervals) with peaks in the afternoons in spring and autumn and in evenings in late summer.

Figure 13 • *The measured electricity demand of a small New Zealand community was compared with the local wind resource to attempt to match supply with demand*



Source: Murray, 2005

Various technical options exist to help make the grid more flexible (IEA, 2008b). Obtaining high quality historic data showing the availability of renewable energy sources and their degree of fluctuations in space and time is required in order to apply these options most efficiently (Krewitt, 2008) and to determine the optimum mix of technologies. This includes reliable short-term weather forecasting so that the dispatching of power can be scheduled initially a day, or even just a few hours, ahead. Meteorological tools and remote sensing have been developed to aid this process so that, for example, 24-hour forecasts of wind can now have a 95% accuracy.

Long-term historic time series data indicating the average availability of renewable energy sources in a given region are useful when assessing the potential for future renewable energy project developments. For example, solar irradiation resource assessments based on satellite data can give an indication of the potential annual contribution to water heating from solar energy or the seasonal variations in power generation output from a solar PV panel. Greater shares of renewable energy generation in the supply system tend to lead to greater decentralisation. Hydro plants can be thousands of megawatts capacity each and wind, solar, bioenergy, geothermal and ocean generation can be up to hundreds of megawatts, but these technologies can also be installed at the micro-level scale of just a few kilowatts each.

This section briefly introduces the range of technologies used for generating electricity as well as for providing heating and cooling that are currently available or close to market and that might well contribute to the renewable energy supply of a city of the future (Fig. 3). For each technology discussed, there is much information in the literature and more details can also be found at the web sites of the relevant IEA Implementing Agreements. These are referenced below since most sites contain good overviews of the latest technologies based on continuing international collaboration by the members and extensive literature reviews.

Electricity generation

Renewable energy sources (with the exception of large hydro) are widely dispersed compared with fossil fuels which are concentrated at individual locations and require distribution. Hence, renewable energy must either be used in a distributed manner or concentrated to meet the higher energy demands of cities and industries.

IPCC 4th Assessment Report: Mitigation, Chapter 4, Energy Supply, 2007.

Solar

Integrating solar photovoltaic (PV) panels into roofs and facades of buildings at the design-and-build stage is a growing development in many cities. Buildings integrated with PV are not yet main-stream, but where supported by favourable policies, market implementation is now underway. PV systems can be used virtually anywhere and buildings offer large areas with which to capture solar radiation to produce electricity that can be either used in the building or fed into the electricity grid.[34] Significant shares of around 10-30% of the total electricity demand of a city could be met by PV systems on buildings providing electricity at the point of use. The IEA PV Power Systems Implementing Agreement has one task specifically dealing with "Urban-scale PV Applications" and much relevant information is contained on their web site,[35] including a database of current urban PV projects. The objectives are to:

- define the global solar market through economic and other market drivers;
- develop guidelines to integrate PV into standard building design models, tools, practices and community energy infrastructure planning;
- identify technical and infrastructure challenges related to building integrated PV and demonstrate best practices to overcome such barriers; and
- disseminate relevant information (including market research) targeted to a variety of stakeholders.

Overall, the PV market is growing at a rate of 30 to 40% annually and shipments in 2008 totalled more than 5 GW_{peak}. PV installations consist of either modular solar panels bolted externally on to an existing building or integrated systems within the building design that replace external wall or roof cladding. The development of roofing tiles incorporating PV cells has enabled traditional roofing designs and functions to be maintained. In off-grid remote areas the technology can be competitive with other systems, such as diesel generation sets. However, more development is needed to reduce costs even further than in the past few years to make the systems more competitive.

34. See *Potential for Building Integrated Photovoltaics* http://www.iea-pvps.org/products/rep7_04.htm
35. http://www.iea-pvps-task10.org/

Policies to support PV installations (such as the German feed-in-tariff currently around EUR 0.43 to 0.32/kWh depending on project scale and over a 20 year contract, or the French feed-in-tariff which varies whether the PV system is building-integrated or not, or is located on the mainland or in overseas territories) are normally essential for deployment to occur in cities. The cost of solar power even when competing with retail electricity tariffs rather than wholesale, remains relatively high, although parity with retail power prices from the grid is expected within the next decade in high sunshine areas where retail prices are relatively high.

In a liberalised power market, cooling requirements in some urban areas can possibly be met economically with PV-powered air-conditioners at times of peak power prices, since the solar PV outputs tend to be highest at the same time that cooling is required. Other than for use on buildings, city authorities have used PV panels and battery storage for street lights, parking meter ticket machines (Fig. 14), illuminated advertising signs and tele-communication applications.

Figure 14 • *In Berlin, the old gas lamps still function next to the new solar-powered parking meters (left) and the advertisement lighting at the bus stop (right) is solar-powered with battery storage under the seat*

Photo credit: Ralph Sims

Solar PV cells vary in efficiency, performance and price and their annual output depends on the local mean annual solar radiation levels. Typically amorphous silicon cells are cheaper than mono-crystalline, but due to their lower efficiency, they generate around only 0.5 kWh/m^2/day in peak summer at 35 degrees latitude (with approximately 1 800-2 000 sunshine hours a year) compared with mono-crystalline cells that produce around double that output. Thin film cells are commercially available in many countries, including China, and due to their flexibility, many applications other than integration into buildings or panels can result. They are lighter and more flexible than the rigid and bulky conventional cells, but less efficient and robust.

Solar PV generation in mid winter is around half that in summer, so overall, and depending on location, an energy efficient, passive house design consuming around 4 500 kWh/yr of electricity to supply all the power needed for the appliances, lighting, heating/cooling, and hot water back-up for the solar heating system would require 20 – 30 m^2 of solar PV module area plus an inverter and battery storage. A British study of micro-generation confirmed this by finding that a system of 2 kW$_{peak}$ could provide between 40% and 50% of a typical domestic household's total annual electricity needs (DTI, 2005).

Barriers to greater market penetration vary with location and application but often include the initial capital cost, length of payback period, security risk from theft, access to the grid for selling surplus electricity, lack of distributors and installers willing to provide on-going service and maintain warranties. Local government planning regulations are not always well formulated and officials often lack experience in approving such systems, including following architectural preservation orders that can prevent PV systems being attached to some historic buildings and districts. There are also concerns about quality and standardisation because manufacturers and installers are small and have been in the business for only a short time. Feed-in-tariffs, subsidies and improved regulatory framework can serve as market introduction programmes to help reduce the initial costs of deploying PV technologies and help overcome barriers. Regulations, standards and labelling are useful and more certified installers should be trained in order to anticipate market developments.

Current fundamental RD&D focuses on developing or improving PV solar cells and modules.[36] On-going applied RD&D is oriented more towards improving manufacturing and systems with the aim of finding ways to reduce costs and materials. Research is also underway to:

- maximise the value of PV in grid support;
- improve access to new products;
- foster synergies and partnerships; and
- provide consumer information.

Further technical R&D efforts are being directed towards:

- developing new concepts of wafer, cell or module production;
- identifying new materials and processes;
- evaluating new thin-film technologies;
- manufacturing higher performance multi-layer and concentrating cells;
- improving efficiencies and reducing costs of crystalline silicon cells;
- achieving better measurement and characterisation; and
- undertaking generic research into photon and materials interaction.

New multi-layer cells at the R&D stage offer higher efficiencies and integration into architectural glass, perhaps with automatic shading incorporated. Also at the research stage are arrays of tiny silicon solar cells that have higher efficiencies than thin-film but are flexible and could be incorporated into window tinting, for example to power the air conditioner or GPS of a vehicle.[37]

In Osnabrück, Germany, the recent development of a laser scanner system used from the air to measure the orientation and inclination of city roofs, and also to calculate the potential shadow from trees, chimneys etc. that could reduce the output of a solar panel, has enabled the whole city to be quickly assessed for its total solar potential. Known as *SUN-AREA*[38], this project can be used by any city to identify the building roofs that have the greatest potential for PV installation. In the Osnabrück example sufficient suitable roof area exists to provide 70% of the total electricity demand of the city.[39] Freiburg has used the same tool to provide similar information for all its building owners (see Case Study 6).

Small-scale concentrating solar power systems are being considered for power generation in hot countries, possibly linked with Stirling engines (see Box A), but they remain at the R&D stage at present. It is difficult to predict whether such technologies could be used in urban areas.

36. See www.iea-PVPS.org for more details.
37. http://technologyreview.com/read_article.aspx?ch=specialsections&sc=solar&id=21467
38. http://www.al.fh-osnabrueck.de/21325.html
39. www.dw-world.de/dw/article/0,2144,3475182,00.html

Wind

The local wind resource varies considerably with terrain and natural and physical obstructions. This is particularly the case in a built up area where shelter, funnelling between buildings, and turbulence are high. Where the terrain and mean annual wind speeds are suitable, wind turbines can be located on the boundaries of a city or located off-shore for a city near the water. Both options can lead to planning constraints due to visual impairment of the landscape and a lack of public acceptance. Social acceptance is one of the tasks[40] of the IEA Wind Implementing Agreement.[41]

Wind resource data for a specific location can be obtained from nearby weather stations by installing anemometers on the site, or for some regions, by commercial databases such as 3TIER.[42] Ideally measurement of the resource needs to continue over long periods, but correlating the on-site data with weather station data could provide a rough historic analysis of the site to be made within a few weeks of starting the measuring in relation to wind speed distribution, mean wind speeds, peak wind speeds, calm periods, and the prevailing wind direction. As a rule of thumb, given that the power output is a function of the cube of the wind speed, investments made in wind farm developments on sites with a mean annual wind speed of less than 7 m/s at hub height are less likely to be profitable for either large or small scale wind power generation without some form of financial support being available. Support schemes will have to respect market deployment expectations, cost of technologies and profitability expectations by the investors. The French feed-in tariff is a good example; it mixes a fixed tariff for all wind power installations with a variable one depending on each plant's electricity generation output.

For wind farms being planned to supply green power in a region, if the city intends to be the project investor, then the cost of building the transmission lines to bring the power to the city should be included in the total cost assessment. Where the intention is to purchase "green power", the physical location of the wind farm is of no importance since the actual electrons flowing from the wind farms into the grid will not necessarily be those that reach the users. Independent auditing of how much green power is actually produced determines how much can be sold, so the consumer does not need to be connected directly to the generator.

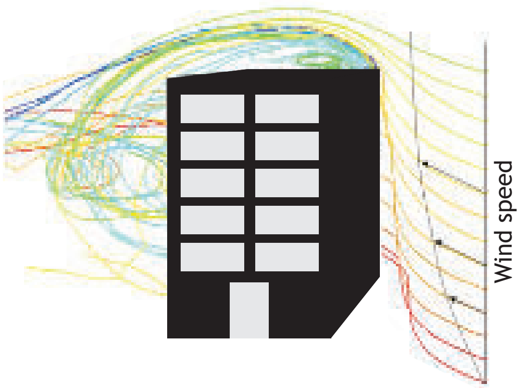
Small wind energy systems (<100 kW) are usually designed to provide power to remote locations and micro-turbines (<2 kW) are often used on boats or caravans, but they are also increasingly being used as independent and low-carbon alternatives to utility-generated electricity. Micro-wind turbines can power a single dwelling, whereas small systems are more suited for an apartment block, a business or a whole community. There are many examples of stand-alone turbines for schools, sports centres, business parks and rural homes, but few are built in densely populated urban areas due to perceived noise issues, visual effects on neighbouring properties (possibly including flicker at certain times of the day if poorly located) and planning constraints from maximum height regulations. There is no evidence to support the concern sometimes raised that the existence of a residential wind turbine will lower property values on adjacent or near-by properties.

Usually consisting of two or three wooden or composite blades on a horizontal axis, the rotor drives a generator either by way of a gearbox or directly, which helps to reduce the noise and maintenance levels. The electricity can either be fed directly into the grid or used to charge batteries. Small wind turbines produce alternating current (AC) current, which can be converted to direct current (DC) through a system controller for battery storage. The DC is then converted to normal AC (240V 50Hz in Europe) current by inverters to power appliances or for export to the grid.

40. www.socialacceptance.ch
41. www.ieawind.org In addition, the American Wind Energy Association provides useful information on small wind systems at www.awea.org/smallwind
42. http://firstlook.3tiergroup.com

Small wind turbines mounted on buildings can give vibration problems and can also be affected by local turbulence. On particularly turbulent sites on buildings it is recommended to mount the turbine on higher towers, at least 10 metres above the structure (Fig. 15), as severe turbulence can reduce the life of the turbine blades due to fatigue. Towers give an advantage of higher wind speeds, which increase with height. If connected to the grid through an inverter that can detect a main supply power outage, in the event of such an event, small turbines (and also solar PV panels) can be shut down automatically for safety reasons. Testing of small wind turbines to ensure they have good reliability, together with the instigation of quality labelling to ensure that power output claims by manufacturers are correct, are the subjects of a new task of the IEA Wind Implementing Agreement led by the Spanish research centre CIEMAT[43].

Figure 15 • *Illustrative representation of wind flows around a building showing increasing speed with height and resulting turbulent air movements around the top and sheltered parts of the building.(Not to scale)*



Source: Based on www.turby.nl

A wide range of small wind turbines are commercially available from almost fifty manufacturers who market around 50 000 units per year, mainly for boat and caravan owners and remote dwellings that often also use some solar PV[44]. Some designs are more suited for roof mounting in cities than others due to their lower noise levels. There is growing interest in hybrid systems of micro-wind turbines with solar PV. For example, the Scottish Swift turbine (Fig. 16) is being investigated by distribution line companies as a possible new business venture[45] and Turby, a Dutch company, has undertaken extensive design testing of a turbine that is claimed to be suited more for tall buildings and apartment blocks than for houses[46].

Micro-wind turbines are commercially available, although the market is under-developed and there are few companies in the world providing the full range of services for design, installation and maintenance. It is difficult to find retail suppliers with trained and certified installers who will maintain warranties and service contracts. Most small-scale turbines remain relatively expensive at around USD 3 000-6 000/kW installed, giving 10- to 15-year payback periods depending on wind speeds and competing retail power prices. To avoid the continuing reliance on grants or subsidies that encourage greater deployment, investment costs need to be reduced through a combination of further technical development, simpler

43. http://hannevind.com/web/SWTTask_proposal_6th_VP.pdf
44. www.windenergy.com
45. www.vector.co.nz/sites/default/files/pdf/microwind-faq.pdf
46. www.turby.nl/99-downloads/Turby-EN-Application-V3.0.pdf

installation methods, mass production and greater market deployment. There are research efforts underway to reduce both the overall cost of energy produced and the cost of installation. Capital costs and the length of payback time are present barriers as well as the difficulty in many locations of selling surplus electricity produced to the local grid.

Figure 16 • *Examples of roof-mounted micro-turbines include the Swift 2m diameter, horizontal axis, rated at 1.5 kW at 14 m/s wind speed with a ring that reduces noise levels down to 35 decibels (left); the Turby 2.5 kW (at 14 m/s) vertical axis design (centre); and the Aerotecture 1 kW modular system based on a combination of Darrieus and Savonious designs that can be operated horizontally (right) or vertically*

Sources: left www.swiftwindturbine.com; centre www.turby.nl; right www.luciddreamproduction.net

Small hydro and water supply systems

Hydro power is one of the oldest renewable energy systems with the first water wheels applied for irrigation purposes over 2 000 years ago and then for milling grain in the past few centuries. Smaller and faster turbines used for power generation were developed in the late 19^{th} century. At the large scale, hydropower generation is usually based on dams that store large volumes of water on rivers some distance from cities, with the potential energy of the water passing through turbines used to generate the electricity that is then transmitted over long distances. Many small (<10 MW) and mini (<2 MW) run-of-river hydro systems exist often closer to the load in stand-alone or grid-connected systems. Many of those built directly as run-of-river systems within city boundaries in past decades are still operating. Micro-hydro systems (<500 kW) using Pelton turbine designs require a high head to be efficient so are largely inappropriate for city streams and rivers. However pico-scale (<10 kW) low-head systems (less than 2 – 3 m height difference in a run-of-river situation) are being developed[47] so that in an urban area, wherever a water wheel has been operated in the past to power a grain mill or pump water, electricity could be generated instead.

The IEA Hydropower Implementing Agreement[48] concentrates on large hydro but also covers small systems in detail, though there is little work to date on micro- or pico- systems. The points covered on planning issues and public acceptance of a project are relevant at all scales. Having secure, all-year-round water supplies is essential, particularly for stand-alone systems where back-up generation is less likely to be available. The opportunity to combine wind and hydro to conserve water and add reliability to the system can be considered where conditions are appropriate.

47. See for example www.reuk.co.uk/Low-Head-Waterwheel-Invention.htm and www.tvenergy.org/pdfs/Final%20Hydro%20 Report%2022April04.pdf
48. www.ieahydro.org/annex2.htm

All cities have a water storage supply and this can often be behind a dam close to the city boundary. If the water already flows through an outlet pipe, normally on its way to the treatment plant before entering the water distribution system, and there is sufficient head created by the dam, then installing a mini hydro-power system in the outlet pipes could be technically and economically feasible, if only to provide sufficient electricity to supply the water treatment plant (Fig. 17). The system design needs to avoid oil, grease and wear of component contaminating the water supply.

Figure 17 • *In the outlet pipe of the 80 year old city water supply dammed reservoir 5 km from the city centre of Palmerston North, New Zealand, four Pelton wheel turbines installed recently generate almost 1 MW of power for use at the nearby water treatment plant*

Photo credit: Ralph Sims

City wastewater treatment systems could also have the potential for some power generation. In the city of Amman, Jordan for example, at the Samra wastewater treatment plant, two 830 kW Pelton units are powered by the raw water entering upstream of the wastewater treatment plant under a head of 104 m, and two 807 kW vertical axis Francis units have been installed to operate in the treated water with a 42 m head (ESHA, 2009). Wear on the turbines from particles carried in the wastewater can be reduced by screening and the design of pipework needs to avoid build-up of solids.

Geothermal

Conventional geothermal electricity generation requires relatively high temperature fields and hence is restricted to cities and towns located along plate boundaries and on hot spots such as in Hawaii. Around 15% of the world's population lives within accessible distances to plate tectonic boundaries, including Indonesia, the Philippines, Iceland, New Zealand and several countries in East Africa and Central and South America. So the opportunity for some cities to invest in geothermal power station developments is good. In addition, the exploitation of deep fractured, sedimentary formations and the development of new designs of generators that use lower temperatures give increased potential. For example, at Landau[49], Germany, wells 3.3 km deep were drilled to extract water at 160°C for use in underground

49. http://www.dw-world.de/dw/article/0,2144,3255490,00.html

heat exchangers to heat pentane gas that drives the 3 MW_e turbine for power generation, with the used water then providing 7 MW_{th} heat to the local district heating scheme (Fig. 18) (Sanner, 2008). In France the Soultz-sous-Forêts demonstration project is now producing electricity from the pre-commercial plant with on-going research occurring in parallel. At Chena Hot Springs, Alaska, two 200 kW organic Rankine cycle systems have been operating since 2007 on the heat from water extracted at only 73°C (Holdman, 2008). Since steam cannot be produced, a secondary binary fluid with a lower boiling point flashes to the vapour phase which then drives the turbine. The generation costs are claimed to be less than USD 0.05/kWh.

Figure 18 • *A binary geothermal facility commissioned in late 2007 at Landau, Germany, showing heat exchanger pipework (centre) and fan cooling platform (top left), and with the turbine in the white building generating 3 MWe and providing 28 MWth to the local district heating scheme*

Photo credit: geox GmbH provided by the IEA Geothermal Implementing Agreement.

Bioenergy

Biomass, including municipal solid waste, landfill gas, forest residues, biogas from organic wastes, etc., is commonly used as feedstock for bioenergy plants. Normally these generate heat for direct applications for use by industry, space heating of buildings etc., but also in combined heat and power (CHP) plants. Stand-alone bioenergy power generation plants are less common, so the bioenergy technologies are therefore covered in detail below in the heat section.

Heat resources and technologies

Growing food, materials and fuel for heating and cooking in the immediate surrounds of an urban area was historically the only option due to transport limitations. This is still the case in many rural areas in developing countries. Only with the advent of road transport links did bringing food and fuel from further afield become possible. Today food is also shipped long distances by rail, ship and air leading to some concerns about "food miles". Solid, liquid and gaseous fossil fuels are also transported cheaply all around the world in various forms, a significant portion being used to meet the ever growing heat energy demand by cities. However, the green infrastructure of a modern urban area that provides a range of ecological and recreational services could also provide some food, fibre, feed and fuel from biomass for use by the community.

Several methods of heating buildings and water rely on bioenergy as well as solar or geothermal resources. Waste industrial heat can also beused. Using heat from electrical resistance heaters, convection heaters, microwave cookers, and kettles, (or for cooling using electric fans, heat pumps, refrigeration systems etc.) is common practice. When using renewable energy generation, these can be considered to be a renewable heating/cooling application. However, in this section and the section on cooling below, only direct heating and cooling applications are considered.

To be most effective, a building would need good design, high levels of insulation and sun screening facilities to minimise the capacity of a heating or cooling installation designed to maintain comfort throughout the year. This would help minimise the overall cost of providing the energy services. A full analysis of renewable energy heating and cooling technologies, their relative costs, and the related policies in 12 OECD countries is given in a recent, readily available, 200 page report (IEA, 2007a) so the details will not be repeated here.

Bioenergy

Solid biomass as a fuel for heating within a city can be collected in the form of municipal solid wastes (MSW), produced from crop and forest residues, or grown as forest and vegetative grass energy crops. Gaseous fuels produced from sewage and other organic wastes as landfill gas or biogas could also be used to provide heat (and possibly power too as a combined heat and power (CHP) system – see below). Liquid biofuels are normally reserved for use in the transport sector due to their higher energy density and compatability with liquid petroleum products and infrastructure.

MSW waste-to-energy

Organic wastes of a city arising from food processing, food waste, sewage, packaging, paper, textiles, etc. can typically reach around 1t/person/yr in OECD countries. The large volumes involved, after collection, can be treated and linked to heat production and application in a variety of ways including separation and production of refuse derived fuels (RDF); combustion of the dry waste fraction; and anaerobic digestion of the wet wastes. Many examples exist of waste-to-energy projects in cities including MSW incineration (as in Vienna, where the architecturally designed, locally accepted, 270 000 t/yr plant at Spittelau in the centre of the city provides heat for the district heating scheme and publishes flue gas emission information on its web site daily[50]). Full details of the technologies (including incineration of sewage sludge) and related issues such as emissions to air can be found from the IEA Bioenergy task "Integrating energy recovery into solid waste management".[51]

The concept of minimising organic waste production by reducing, reusing and recycling helps a city save on the costs of collection and treatment of refuse. Future societal and technical changes in the production of waste and its conversion to energy need to be anticipated by a city when planning and designing future waste-to-energy projects, since the present volumes incinerated or sent to landfills may decline over time.

Landfill gas, sewage gas and biogas

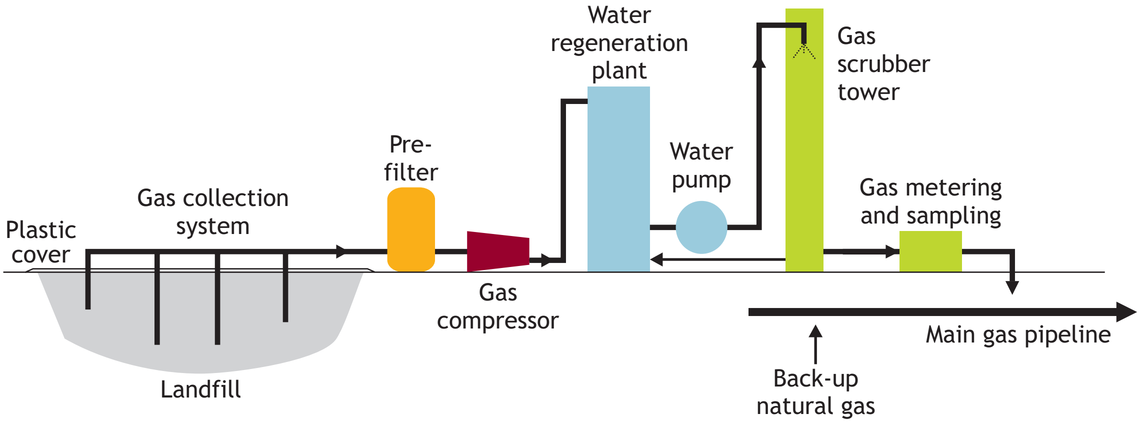
Thousands of landfill gas sites exist worldwide, the concept of collecting the methane gas produced from the decaying rubbish and using it for practical application having first been developed in the 1980s. The gas can be combusted directly for useful heat generation on-site or combusted in a gas engine driving a power generator. If injected into a gas pipeline, it first needs to be scrubbed to reach acceptable quality standards (Fig. 19). An example of a successful project is the Keele Valley Landfill in Toronto

50. A detailed presentation is available at www.authorstream.com/Presentation/Rachele-50188-GRECH-Presentation-140405-animation-Waste-Energy-Austrian-Experience-presentat-Education-ppt-powerpoint/

51. www.ieabioenergytask36.org

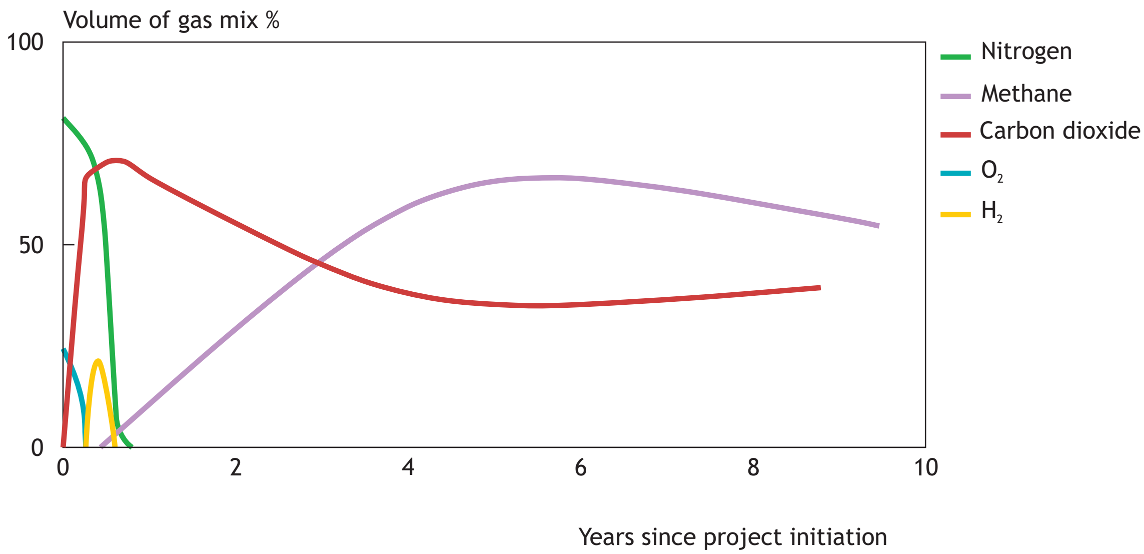
that has provided revenue to the city of around USD 3-4 million annually through the sale of electricity to around 24 000 houses[52]. Typically for landfill gas projects, methane production increases over the first few years (Fig. 20) then peaks before declining over another decade or two before becoming uneconomic. A reduction of installed power generation capacity over time after reaching the peak is the usual compromise. Beneficial greenhouse gas mitigation also results since, rather than release the methane produced during natural bacterial waste decomposition to the atmosphere, collection and combustion to provide heat converts it to CO_2, a much less potent greenhouse gas.

Figure 19 • *Pipes inserted vertically into a landfill before sealing collect the gas mixture which, if not to be used directly on-site, can be compressed and scrubbed clean of CO_2 and other contaminants before being injected into a natural gas pipeline for distribution*



Source: Sims, 2002

Figure 20 • *The gas mix changes over time from the commencement of a landfill gas site, with methane reaching a peak before going into slow decline over two to three decades to be taken into consideration when planning for the use of the gas and calculating the overall economics*



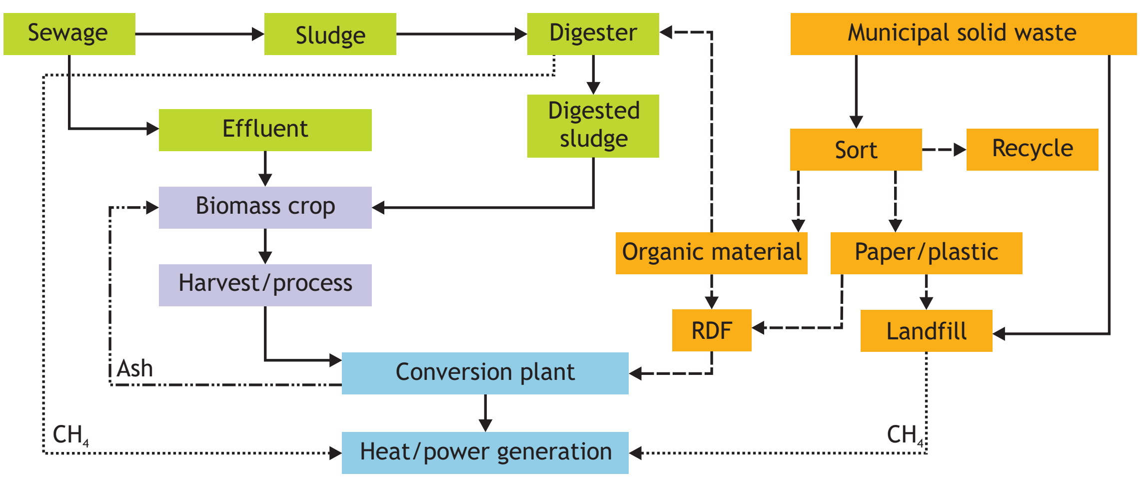
Source: Sims, 2002

52. The Toronto landfill site is described at www.c40cities.org/bestpractices/waste/toronto_organic.jsp

Many cities already produce biogas through anaerobic digestion of the sewage effluent and sludge as well as other organic feedstocks from farm animals and food processing plants. Some biogas plants are at the community scale where food and farm wastes are brought in for treatment. Electricity and heat are usually both produced and the farmers take away the non-odorous solid residues for use as soil conditioning and nutrient replenishment. The amount of gas produced in a landfill or anaerobic digester varies with the composition of the feedstock, carbon/nitrogen ratio and ambient temperature (some gas being using to maintain the digester temperature around 35°C for optimum bacterial activity). Matching the heating plant or gas engines to varying biogas outputs has to be incorporated into the design. Full details can be obtained through the IEA Bioenergy task "Energy from biogas and landfill gas"[53].

Selecting the most suitable technologies for waste-to-energy conversion for a city in part tends to be based on what treatment plants already exist. Various interactions occur between the treatment processes (Fig. 21). So, for example, in a small city of 150 000 inhabitants, around 8 000 t of municipal green waste (excluding plastics) produced annually could be digested to produce around 1 Mm^3 of biogas per year, or, if put into landfill, could produce sufficient gas to power two or three 1 MW gas engines to generate around 5 000 MWh of electricity. In addition, anaerobic digestion of the city's sewage sludge could produce around 10 Mm^3 of biogas. The choice a city makes between landfill or incineration of MSW, digestion or incineration of sewage sludge, recycling for materials or separation for energy (Fig. 22) is largely site-specific and cost related. Additional biomass could be imported to increase the economy of scale of the waste-to-energy projects and obtain improved energy performance from the overall city waste system.

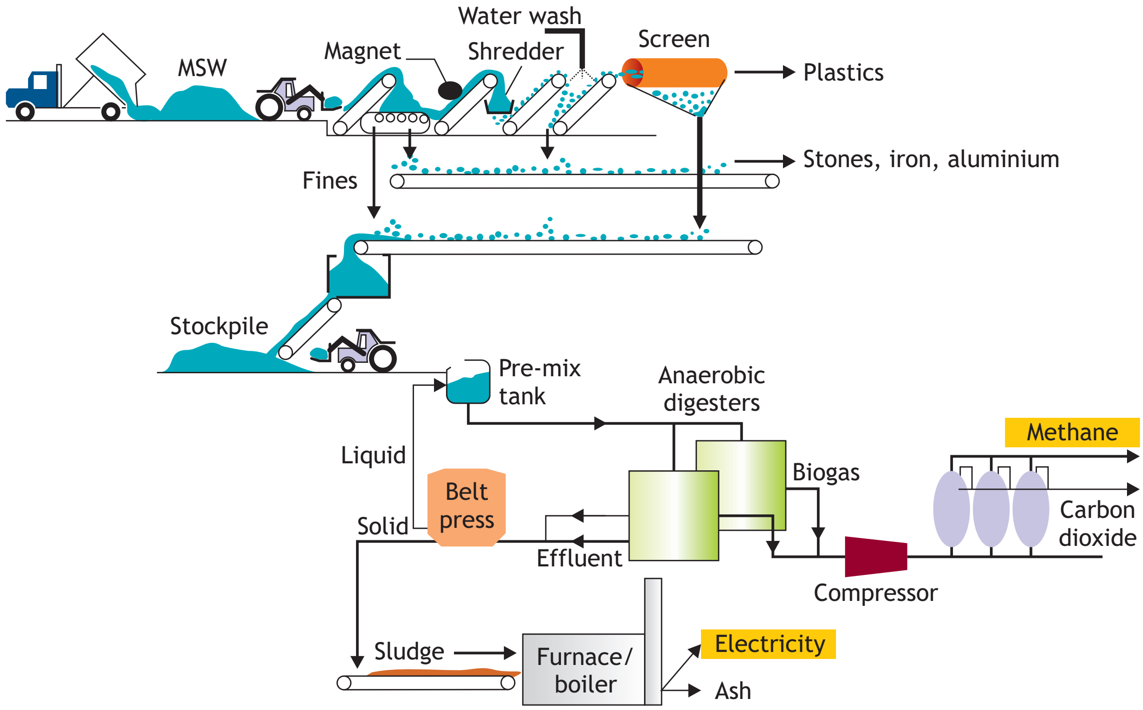
Figure 21 • *Combining waste resources from sewage treatment and MSW in a city for conversion to energy can be linked to nearby energy crop production in order to gain nutrient cycling benefits as well as economies of scale*



Source: Riddell-Black, 1996

53. http://www.iea-biogas.net

Figure 22 • *Separating the organic fraction of MSW for anaerobic digestion of it to produce biogas with the dried solid residues combusted for heat and power (Sims, 2002)*



Source: Sims, 2002

Solid biomass

Heating of buildings by solid biomass in small, domestic, double burning enclosed stoves using firewood logs or pellets is common practice in urban dwellings, as is the use of larger biomass boilers in industry. Ensuring that a sufficient locally-produced biomass resource will be available in the long term, that it is produced on a sustainable basis, and that its planned use meets the local and national planning and air pollution regulations, are key issues a developer or investor needs to consider in advance of installing a biomass-burning appliance. A set of bioenergy guidelines was therefore produced by the IEA to assist with this process (IEA, 2007b). Biomass is also widely imported for use in cities, for example wood chips and pellets are imported into Europe from as far away as Western Canada. Full discussions on "sustainable international bioenergy trade" are given by the IEA Bioenergy task of this name.[54]

Algal biomass

An innovative way of producing biomass within some cities in the future could be by converting flat rooftops into facilities for blue-green algae production. (This may require having to strengthen the structure to carry the added weight, which would likely result in prohibitive costs). Algae growth can be far more rapid than other forms of biomass, given the right temperature and nutrient availability. Hence, it can be continually cropped to produce biofuels or to fuel small scale CHP plants. So in addition to providing shelter from the weather for the inhabitants of buildings, roofs could be designed to also harvest water, collect solar energy and grow algal biomass.

54. http://www.bioenergytrade.org

Solar thermal

Space heating

With good design, careful planning, and common sense, a building can be designed to be comfortable for people to live and work in, under almost any climate by using natural sunlight, shading, ventilation and daylighting together with good design, suitable materials, thermal mass, earth sheltering, and adequate insulation. Passive solar building designs, the orientation of buildings to the daily sunpath and to maintain a natural breeze, and the avoidance of potential shading of a building by new buildings or nearby growing trees can become key issues involving the planning regulations of a city. National and state building code standards also have an impact. While existing apartment buildings, commercial buildings and dwellings cannot be easily modified to improve the solar gain in cold climates (or reduce it in hot climates), new building developments should be designed with these factors in mind. The principles of passive solar design can also be applied, at least in part, when retrofitting existing buildings.

Architectural design in this regard is usually an iterative process including:

- conducting a site analysis of shadows on the shortest and longest days;
- orientating the building within the site boundaries;
- considering the windows and their positions based on sun access between 9 a.m. and 3 p.m. for both heating/cooling as well as daylighting;
- developing a suitable building design with interior space corresponding with the solar gain and living patterns;
- calculating the insulation R-values for walls, glass, roof and walls;
- assessing the heat gain or heat loss of the building throughout the year; and
- then reassessing to try and improve the design in a cost effective manner.

Several tasks of the IEA Solar Heating and Cooling Implementing Agreement discuss these technologies in detail.[55]

Air-to-air heat pumps have become widely accepted as cost-effective heating and cooling systems for buildings as their costs have declined over recent years due to mass production. The better designs are quieter and have a higher coefficient of performance. They therefore use less electricity to achieve the same results. Although they concentrate heat from the air that, in effect, is heated by the sun (or they discharge heat to the air when cooling), they are usually considered to be an energy efficiency device since they reduce the electricity or gas demand of traditional building heating (or cooling) systems. As such, they are not included in this report on renewable energy.

Hot water

Heating water using solar collectors or air-to-water heat pumps can be a viable source of energy that can reduce gas or electricity consumption for heating water by around 50 to 70%, depending on the latitude as well as the behaviour of the hot water users. Using most hot water in the evening with an electric or natural gas back-up system installed to raise the temperature over night prevents the solar system from making a significant contribution compared with using the water in the morning. Most systems are installed on dwellings, but hotels, motels and small businesses can also benefit.

At the end of 2007, global installed solar thermal capacity was nearly 150 GW from over 200 Mm^2 of collector area (including around 10% of unglazed systems used for swimming pools, commercial

55. www.iea-shc.org

building ventilation, heating air and agricultural drying) (IEA, 2007a). Evacuated tube collectors tend to have a superior performance to simple glazed collectors and therefore require a smaller collector area for the same level of heat output. The potential for freezing conditions and hail in a region need to be considered when selecting a system. A gas or electric back-up system is required in most locations to ensure hot water is available at all times, though some systems rely on a wood-burning stove with water pipes passing through the hearth to also heat the water in winter. Integrating a system including the hot water storage cylinder into a new building design is usually cheaper than retrofitting an existing building, especially if the roof orientation and angle of tilt is not ideal for the location. Integrating collectors into the design of a building as a component (such as integration into a balcony structure) is gaining interest amongst architects (SHC, 2009).

Codes of practice exist in some countries to ensure that:

- installations are sized to give a minimum share of the normal annual hot water requirement;
- the cylinder capacity matches around 1.5-2 times the daily use;
- the ratio of cylinder volume to collector area is designed to give a balance between energy savings and rate of heat recovery after hot water use; and
- systems are tested to ensure they meet minimum standards.

Within Europe, the leading city Vienna had around 13 000 m^2 of solar collectors installed in 2007, Barcelona had 4 300 m^2 (Box B) and Lyon 3 500 m^2 (Ambiente Italia, 2007). Combi-solar systems are also available that can heat both water and space, although the total costs and payback periods for an installation need to be carefully analysed. Devices that combine power generation through PV panels as well as hot water collectors are under development. (Full details of all these technologies can be found on the IEA Solar Heating and Cooling web site www.iea-shc.org).

Geothermal

Several towns and cities around the world have the ability to extract hot water or steam from near the surface of the Earth's crust to directly heat buildings or for use by industry. In 2005, around 70 000 TJ of direct heat was provided in cities (including those as diverse as Beijing, Paris and Reykjavik). It was used for industry process heat, swimming pool and space heating applications, mostly through district heating schemes. In France, district heating has been in operation for some 35 years, and now serves some 200 000 apartments, mostly located in Paris suburbs. The total heat delivered from geothermal heat pumps (GHPs) in 2005 was around four times that utilized for district heating (Lund, 2005), but elsewhere this would vary depending on the available resources.

Enhanced geothermal system, deep fractured formations, and CHP

Research and demonstration of enhanced geothermal systems (EGS, hot dry rocks) whereby 4-5 km deep bores are drilled, the deep layers fractured, cold water injected, and hot water and steam extracted, could enable many cities to obtain heat (and electricity) in this manner in the future. However, the drilling and technology costs remain high and seismic impacts need further clarification, with one project having been suspended in Basel, Switzerland whilst awaiting further geological analysis (Bromley and Mongillo, 2008). The EGS technique is not yet at the full commercial level although considerable R&D investments have been made, particularly in the United States and Australia. One demonstration plant has begun operating at Soultz-sous-Forêts in France and another is near-operational at Cooper Basin, Australia. CHP schemes have also recently been developed using hot water from deep fractured sedimentary formations at Landau as "partial EGS" (see electricity section above) and Unterhaching, Germany. The Austrian CHP plants at Altheim and Blumau are also deep-fractured formations. The IEA Geothermal Implementing Agreement has an Annex dedicated to this growing technology.[56]

Box B • *The Barcelona Solar Ordinance*

The aim of this ordinance is to regulate, through local legislation, the implementation of systems for collecting and using active solar energy for the production of hot water for buildings. All new and renovated, private and public, commercial and residential buildings are required to supply at least 60% of the hot water demand through solar thermal collectors using the 2 350 annual hours of sunshine received. Other approved renewable energy heating technologies can be substituted by the building developer if desired. This ordinance first took effect in August 2000. It initially targeted buildings with a hot water heating demand of more than around 30 MJ/day, such as residential buildings with more than 16 apartments. Owners of buildings too small to comply were offered a subsidy to voluntarily install a solar system but since the minimum requirement was removed in 2006, all buildings now have to comply regardless of size or use. It applies to all residential and commercial buildings, to industry where hot water is needed for the process or for staff facilities, and to buildings where there are kitchens or collective laundries such as in hospitals, sports centres and schools. In addition, all heating of swimming pools has to come from solar sources.

The Barcelona Energy Agency (BEA), a consortium of organisations with energy and environment interests, was established to evaluate the planned installations provided when a building developer seeks a planning permit or licence. Once approval has been granted, building inspectors ensure that construction meets the detailed design criteria and fines can be imposed for non-compliance. Buildings with cogeneration systems installed or with roofs that are shaded from the sun can seek exemptions. The area of collectors per 1 000 population has increased twentyfold since the ordinance was introduced. The target of 96 300 m^2 total collector area installed by 2010, as in the Barcelona Energy Improvement Plan, is likely to be exceeded by around 10%.

A crucial reason for the success of the policy was the support obtained from the citizens. A programme to communicate information on the use, costs and maintenance of solar water heating systems was conducted by the BEA in parallel with the ordinance first being introduced. The city published an explanatory guide to the ordinance in several languages; held regular meetings with stakeholders such as building contractors' associations, engineers, architects, and environmental organisations; promoted the ordinance to neighbouring cities; implemented demonstration projects; and organised a "Solar Day". This programme was carried out alongside neighbourhood associations and body corporates of buildings to ensure that members of the public and tenants of buildings also fully understood the benefits of solar water heating and would keep the systems operating efficiently. Monitoring existing systems was also undertaken.

The success of the Barcelona ordinance led to the Spanish government developing a national policy that, depending on the level of hot water consumption, the climate zone of the building location, and the availability of back-up heating fuels, requires 30 - 70% of the energy demand for heating water in new buildings and those being renovated to come from solar systems. Many other municipalities throughout Spain are now considering or have developed a similar ordinance. Burgos, Seville, Madrid, Pamplona and other cities have followed Barcelona's lead and adopted regulations more stringent than those of the federal government.

56. www.iea-gia.org/annex3.asp

The city of Southampton, United Kingdom, uses a variation of this concept in that an aquifer of hot water runs under the city centre. This Wessex basin was drilled into by Southampton City Council in 1987 to a depth of 1 800 m, and brine with a temperature of 76°C rose to within 100 m of the surface of the well. A heat station, a combined-heat-and-power generator, and absorption heat pumps were constructed soon after. Twenty years later the system still supplies around 60 TJ of heat a year to one of the United Kingdom's few district heating schemes, amounting to 18% of the total heating requirement of the city.

Geothermal waste heat

Waste heat from geothermal power stations can also be utilised, but often the location of the resource is too remote from the heat demand. In Iceland, heat is carried in hot water over 60 km to Reykjavik and elsewhere industrial enterprises such as greenhouses, fish farming and timber drying have been established near to the heat source. Where convenient heat loads exist, the high initial temperature at around 120°C or above is ideal for cascading heat demands for such descending temperature applications as binary power generation, industrial process heat, kiln drying of timber, district heating, swimming pools, greenhouse heating and fish farming.

Ground source heat pumps

Annex 8 of the IEA Geothermal Implementing Agreement[57] reports on geothermal (ground source) heat pumps (GHPs) in detail, linked with other issues relating to the direct use of geothermal heat. Small- to medium-scale GHPs can be used virtually anywhere for both heat supply in winter and cooling in summer (Box C) as well as to provide hot water. They use the heat storage capacity of the ground as an earth-heat sink since the temperature at depths between 15 and 200 m remains fairly constant all year round at around 12 to 14°C. Vertical bores enable heat to be drawn out in the winter and brought to the necessary temperature by a heat pump. The ground normally cools to below 10°C as a result. Circulating water in summer is initially sufficient to provide the desired cooling with the heat pump being operated in reverse if more cooling is later required. The ground stores the extracted heat, rising to an average temperature of around 20°C. The cost of drilling bores remains a high proportion of the total so shallow horizontal pipes around 1-2 m depth can be an alternative system but with lower efficiencies.

A large-scale GHP project is at the Pfizer GmbH factory in Freiburg where 19 double-U geothermic probes have been installed at 6 m intervals over an area of 0.12 ha in 15 cm diameter boreholes drilled to around 130 m depth. After the pipe probes were inserted, the holes were refilled with a bentonite mortar solution to prevent connection of the probes with any water-conducting fissures. The total heating capacity is 135 kW and cooling, 100 kW, with the compressor having a coefficient of performance (COP) of well over 4. After one season, and following extensive energy efficiency measures, it is claimed that cost savings were around USD 440 000 per year compared with conventional heating and cooling systems (gas and electricity) and 1 200 tonnes of CO_2 emissions were avoided.[58]

Other examples include a large project at Zurich Airport, with 58 000 m^2 of floor area heated (2 120 MWh/yr heating load) and cooled (1 240 MWh/yr) using 300 geothermal energy piles drilled to 30 m depth, and the renovated Hotel Dolder in Zurich, which uses 72 borehole heat exchangers installed beneath the spa at 150 m depth for heating, cooling and domestic hot water (1000 MWh/yr). The largest GHP district heating scheme is being developed in Milan, Italy that will provide heating for some 250 000 inhabitants (Sparacino, *et al.*, 2007).

57. www.iea-gia.org/annex8.asp

58. www.pfizer.com/responsibility/ehs/case_studies_freiburg.jsp

Box C • *Ground Source Heat Pump, Three Rivers District Council, Rickmansworth, England*

Three Rivers Council, servicing a population of 180 000, has its offices located in Rickmansworth, Hertfordshire to the north west of London just inside the M25 motorway. The three-storey council building constructed in 1990 has public meeting rooms on the top floor with the main room where council meetings are held accommodating up to 150 people. This room is served by a mechanical ventilation system comprising an air handling system to provide cooling, tempered air heating, and humidification. Energy saving measures are provided by a plate heat exchanger and motorised recirculation dampers. Air quality is constantly monitored to maintain optimum air supply into the room space.

Due to the age and reliability of the air condensing units, and the R22 refrigerant used (which is to be banned by the European Union by 2010), replacement of the units was investigated. After rejecting maintaining the current system or replacing it with a similar new system, advice was sought from the Ground Source Heat Pump Association and various heat pump manufacturers whether to install a cooling-only ground source heat pump (GHP) or a reverse cycle GHP system to provide both cooling and heating to the public room. The latter was chosen and installed, thereby integrating a new renewable energy technology with the existing engineering installation in the building.

Since the small garden area in front of the council offices was in need of an upgrade, the opportunity was taken to use this area to install the ground heat energy transfer system. The heat loss and heat gain required for the meeting room were calculated and gave the basis for the design of a horizontal, closed loop pipe acting as the heat exchanger. A 300 m snaking trench, 2 m deep and 1.6 m wide was dug to accommodate the polyethylene pipe that was then connected to an inverter-controlled circulation pump. The pipe was filled with a water glycol solution and a Mitsubishi WR2 (25 kW heating and 22 kW cooling capacity) heat pump was connected between the ground source and the existing air handling unit supply duct. To achieve optimum performance from the unit, the pressure and extractor fan motors were replaced with inverter-driven units to match the supply air with the air conditioning requirements. The GHP system was integrated into the building management system for optimum control and monitoring is to be conducted on-line to measure the energy consumption. Since commissioning in early summer 2009, the cooling objectives have been successfully met, but the cost effectiveness has not been analysed to date.

Millions of domestic scale GHPs have been installed (IEA, 2007a). Sweden leads the way with almost half a million, as well as around 600 large-scale installations for district heating schemes.[59] Around 70% of new houses in Sweden and 30% in Switzerland have a GHP installed.

Hydrogen

Production of this energy carrier can be achieved via a large number of processes based on renewable and non-renewable energy sources including chemical reforming of methane from natural gas or biogas; gasification of solid fuels including coal or woody biomass; electrolysis of water using electricity including that generated from renewable energy sources; high temperature thermal using concentrating solar power; bacterial fermentation of algae and other forms of organic biomass; and photo-electrochemical solar cells. The IEA Hydrogen Implementing Agreement provides detailed information of the status of hydrogen production and use in stationary and vehicle fuel cells, as well as a list of selected demonstration

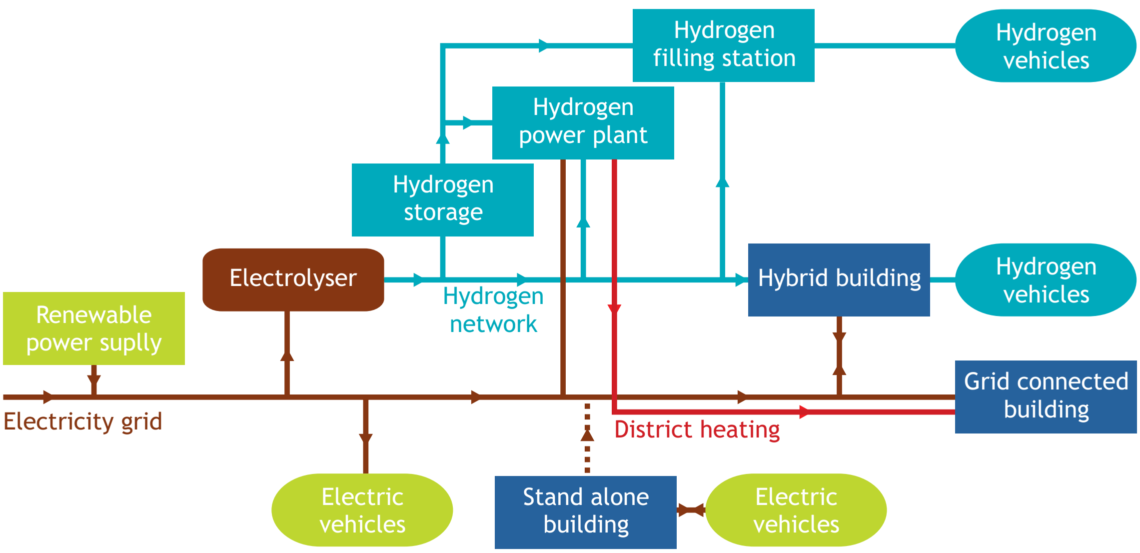
59. www.geothermal-energy.org/geoworld/geoworld.php?sub=duses&country=sweden based on 2004 data.

case studies[60] . There are now many examples from around the world; others are described in Task 18 on Integrated Systems Evaluation[61] and in a recent European Commission report (Owen, 2009).

Knowledge of the installation, operation and maintenance of stationary fuel cells to provide heat and power in commercial and residential buildings is growing as a result of the data analysis being widely reported from the many projects being monitored. Stationary fuel cells, particularly polymer electrolyte membrane (PEM) designs, are being commonly used as back-up power supply systems, especially for IT companies and critical computer networks. Remaining barriers include cost, hydrogen storage, matching the variable needs of the building users for heat and power with the energy system outputs; reliability of balance-of-plant components and of the fuel cell itself; operating life of the system prior to needing replacement; safety issues; and development of planning consent guidelines by the local authorities.

In 2006, a group of Danish companies released a vision for a hydrogen city named "H2PIA" which has created interest,[62] although the site and date of building construction (possibly Ringkøbing, starting in 2010), has not yet been confirmed. The concept involves the hydrogen being produced from non-fossil fuels to ensure it is carbon-free and includes a hydrogen-fuelled CHP plant based around fuel cells, a vehicle refilling station, individual fuel cells located in futuristic buildings, and a district heating scheme (Fig. 23). However the costs and energy balances for this future city concept are yet to be determined.

Figure 23 • *The concept of a hydrogen-based city of the future*



Source: Based on RE-THINK CITY 2008[63]

The European Commission's "ROADS2HYCOM" project evaluated the potential for hydrogen use in buildings in detail (Owen, 2009). Following detailed analysis and extensive surveys, a database of existing and potential public technology demonstrations was established. The early adopters for both city power generation applications and high profile transportation were mainly municipalities and regional authorities. These were characterised in terms of the drivers and system capacities. Key success factors were also identified. A set of three handbooks for community and municipal stakeholders was developed to give guidance on identifying whether or not fuel cells and hydrogen are of interest, and, if so, to give an overview of the technologies; assistance with financing, exploitation, planning, and

60. http://www.ieahia.org/page.php?s=d&p=casestudies
61. http://www.ieahia.org/pages/static/task18.htm
62. http://www.h2pia.dk/com/h2pia/
63. http://www.biner.hu/fileadmin/templates/image/hidrogen/H2PIA_Description.pdf

establishing a project; running it and monitoring its success. The project found that political will is a dominating success factor amongst early adopters, although this is linked to local public perceptions, the local legacy of innovation and technology development, energy resources and social needs. The future challenge is to ensure that policies for transport, energy supply, energy efficiency, taxation, carbon trading and regional development, support a hydrogen future where appropriate.

Building codes at present rarely contain any guidance on hydrogen for use in fuel cells or for direct combustion for heating and cooking using modified gas stoves, gas heaters and spark ignition engines used for power generation. Although there are only a few hydrogen-fuelled appliances on the market, retail sites are beginning to appear on the internet. The system performance and energy balance for the direct combustion of hydrogen to provide heat is more favourable than if hydrogen is first converted to electricity through a fuel cell and then that electricity is subsequently consumed for heating applications. In buildings of the future, distribution and direct combustion of hydrogen could become a common use in a similar way that natural gas has in recent decades.

Development of the infrastructure and urban planning needed for a "hydrogen city" (Fig. 23) is under evaluation (Box D) and there has been considerable public and private investment in RD&D for the future production, storage and distribution of hydrogen. Injection into natural gas pipelines and safety issues that can influence building codes are being considered by Task 19 of the IEA Hydrogen Implementing Agreement.

Box D • *Fukuoka hydrogen town, Maebaru, Japan*

The "Fukuoka Hydrogen Town" project has begun in the housing communities of Minakazedai and Misakigaoka in Maebaru City, Fukuoka Prefecture, southern Japan. The two neighbouring communities were chosen as demonstration sites to promote the use of hydrogen energy. The first fuel cell system was installed at the end of 2008 and 150 more houses will have systems installed to make it the world's largest demonstration project of this kind. The evaluation will continue for about four years in order to examine the reliability of the technologies, their overall energy benefits, and any limitations observed from operating the systems. Funded by the New Energy and Industrial Technology Development Organization (NEDO), the companies Nippon Oil Corporation and Seibu Gas Energy jointly installed the 150 1 kW Ene-Farm fuel cell co-generation system units. They utilise hydrogen extracted from liquefied petroleum gas (LPG). Each system can cover about 60% of the power consumption of a typical household and about 80% of the hot water supply. There is also the potential to reduce energy consumption by about 30% over conventional systems it is claimed. Hence, carbon dioxide emissions will also be cut.

The project is being promoted by the Fukuoka Hydrogen Strategy (Hy-Life Project), which is run by Fukuoka Prefecture and the Fukuoka Strategy Conference for Hydrogen Energy. This consortium is Japan's largest between industry, academia and local government and is designed to undertake joint RD&D in the areas of hydrogen production, distribution, storage and applications.

In April 2009, Fukuoka Prefecture and Kitakyushu "Eco-town", an industrial city with a population exceeding 1 million people, became the first local governments in Kyushu to have cars powered by hydrogen fuel cells in their vehicle fleet. The longer-term objective is to enable fuel-cell and hydrogen-powered vehicles to operate freely by establishing an infrastructure or a "hydrogen highway." The Fukuoka consortium is also planning to build hydrogen refilling stations in the Higashida area of Kitakyushu city and at Kyushu University Ito campus, where solar energy is to be used to drive an electrolyser to produce the hydrogen. Currently hydrogen is delivered by pipeline from a local steel mill.

District heating and combined heat and power (CHP)

District heating schemes can provide opportunities for integration of renewable energy sources at a relatively large scale. The schemes involve piped distribution in densely populated urban areas and can suit bioenergy, geothermal and solar energy sources. The integration of biomass into a district heating system allows the operation of larger facilities which have lower specific investment costs than having numerous small-scale boilers and would enable emission abatement technologies to be incorporated at viable costs. Smaller boilers would need to use a more costly, higher quality source of biomass with consistent moisture content in order to comply with local emission standards. However, bringing the biomass to a large central site can produce logistical problems of transport requiring good planning. For example, a 10 MW_e CHP plant would require around 10 truck deliveries a day to supply the 60 000 t/yr of biomass (IEA, 2007a).

As for all CHP plants, there is higher efficiency from combining the heat and power generation compared with having separate plants but it requires an adequate heat demand nearby to be viable (IEA, 2009b). Pooling individual heat consumers into a district heating scheme can achieve this aim. In Scandinavian countries biomass CHP plants have been successfully operated for many years, particularly in Sweden, where they have largely displaced oil-fired plants over time (IEA, 2008c).

District heating has similar benefits when using geothermal heat systems which tend to be large scale. The low thermal efficiency of geothermal power plants (around 10%) means there is considerable waste heat available, but this normally needs large consumers to be located nearby, (including district heating schemes) for it to have a value.

District heating could also be the catalyst for large solar thermal systems with seasonal storage as part of the system. This is usually by water held in large underground tanks warming up in the summer from solar collectors on the roofs and then circulated to the radiators in the buildings in the winter. Gaining a solar fraction around 50% should be feasible with gas or biomass used as the back-up when needed. Hot water storage is flexible as it is independent of geological conditions and can be stored for days in a steel reinforced concrete tank submerged in the ground. Alternatively, a pit filled with small gravel stones and water and lined with a waterproof material such as butynol or heavy plastic sheet would require no support structure. The water can be circulated and the gravel holds the heat with good heat transfer contact. Ducted storage systems have U-tubes inserted into bore holes of 10-20 cm diameter and up to 100 m deep. Solar heat is conducted to and from the saturated soil, although this is a slow transfer process that constrains the capacity of the system. Where geologically available, naturally enclosed groundwater aquifers can have the water extracted through bore holes, heated by a solar thermal system, then returned for storage. Each of these storage systems has reached the demonstration stage but the costs tend to be prohibitive.

Cooling technologies

The design of buildings in hot countries has for centuries provided cooling through thermal mass, shading by trees, reflection from white surfaces of the building, and natural ventilation. For example, the Romans used the principle of the sun warming the outside of a tall external "solar chimney" painted black to encourage the more rapid upward convection of hot air and thereby drawing cooler air into the building. Variations of this passive solar cooling concept are often used in modern building designs. Another traditional passive cooling concept is the evaporative cooling technique originally used in Mali, whereby water at the top of a tower attached to a building evaporates and hence cools the incoming air, causing a downdraft of the denser air inside the tower that then cools the associated building space.

In the past decades, thermal insulation of modern buildings to give a lower heating demand can also reduce the cooling demand in summer. Cooling demands have grown in recent years because of increased internal heat loads from computers and other appliances, demand for more rigorous personal comfort levels, more glazed areas that increase the in-coming heat. In some regions, cooling demands have grown due to a change in the ratio of building surface to volume. The overall effect is that modern building designs have tended to increase the demand for cooling whilst reducing the demand for heating. This trend has been amplified by recent warmer summers in many areas, increased demand for comfort particularly by those living in developing countries and economies in transition, and the recent availability of low-cost, air-conditioning systems. The reduction of cooling loads should be encouraged as a positive aspect, but the increased application of conventional cooling equipment using air conditioners that create peak electrical loads can be avoided in other ways. In order to decrease the cooling load, building design should focus more on the use of passive cooling options and active renewable energy solutions. The peak electricity load experienced in summer could then be reduced.

To use renewable cooling most efficiently from a quality perspective it is possible to set up the following merit order of preferred cooling technologies (IEA, 2007a), although from an economic point of view, the order may differ with location:

- energy efficiency and conservation options in buildings and industry sectors;
- passive cooling options *e.g.* passive building design measures, summer night ventilation without the need for auxiliary energy;
- passive cooling options using auxiliary energy, *e.g.* cooling towers, desiccant cooling, aquifers;
- solar-assisted, concentrating solar power or shallow geothermal active cooling systems;
- biomass-integrated systems to produce cold (possibly as trigeneration — see below); and
- active cooling and compression refrigeration powered by renewable electricity.

Active cooling systems involve a range of technologies including the production of cold through sorption cooling driven by a renewable source such as solar energy, but they tend to be relatively costly at this early stage of their commercialisation (IEA, 2007a). Solar-assisted cooling for air-conditioning and refrigeration systems is gaining interest as it reaches the near-market stage of development. This thermally-driven process is complex, being based on a thermo-chemical sorption process. A liquid or gas can either be attached to a solid, porous material (adsorption) or absorbed by another liquid or solid material (absorption) (Box E). The technology has not been widely applied and needs more RD&D efforts to give reliability and to reduce costs that can compete with conventional cooling technologies. One advantage of solar-assisted cooling technologies is that peak cooling demands often correlate with peak solar radiation and hence offset peak electricity loads for conventional air conditioners.

The cost of solar-assisted cooling (SAC) is declining with experience in system design. The interest from refrigeration companies, solar thermal system manufacturers, policy makers and utilities has grown as peak power demands increase during periods of hot weather.

Trigeneration (combined cooling, heating and power generation or CCHP) can be powered using a single heat source from the combustion of synthesis gas, liquid biofuels or natural gas, or from solar energy. The surplus heat from the thermal power generation is utilised for heating in the winter or cooling in the summer, so high efficiencies result.[64] The Swedish city of Växjö has already begun to use some excess heat from the biomass CHP plant in a demonstration plant for absorption cooling[65] in the summer, and a larger 2 MW plant is planned (see Case Study 8).

64. See for example www.trigeneration.com

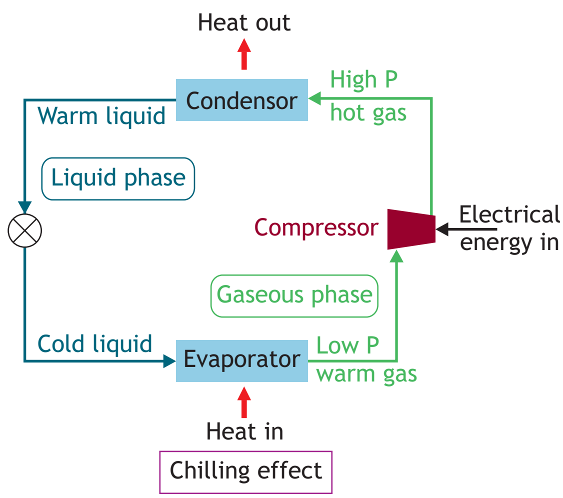
65. www.vaxjo.se/upload/29082/absorption%20cooling.pdf

Box E • *Sorption chillers*

A sorption chiller is basically a type of refrigeration system used mainly for central air-conditioning with decentralised fan coils or cooled ceilings. It is based on a chemical heat-driven process rather than an electrical drive and has a lower coefficient of performance typically around 1 (whereas mechanical refrigeration can be >3). Closed loop systems include both absorption and adsorption chillers that can be used for central or decentralised conditioning of air or water. Applications include food storage in recreational vehicles and boats. Open cooling cycles use desiccant and evaporative cooling systems that directly condition air.

A refrigerator is basically a mechanical vapour recompression unit that uses an electrically-powered compressor to increase the pressure of the gaseous refrigerant (typically an HCFC), and then condenses this hot, high pressure gas back to a liquid by heat exchange using air as a coolant (Fig. 24). The cooled high pressure gas then passes through a pressure release valve which drops the temperature to below that needed for air or water cooling. In contrast, a sorption refrigerator changes the refrigerant gas back into the liquid phase using a method that potentially needs only heat and has no moving parts. The technology is most commonly being used in places where electricity to drive a compressor refrigerator is unavailable, unreliable, costly or the compressor noise is an issue.

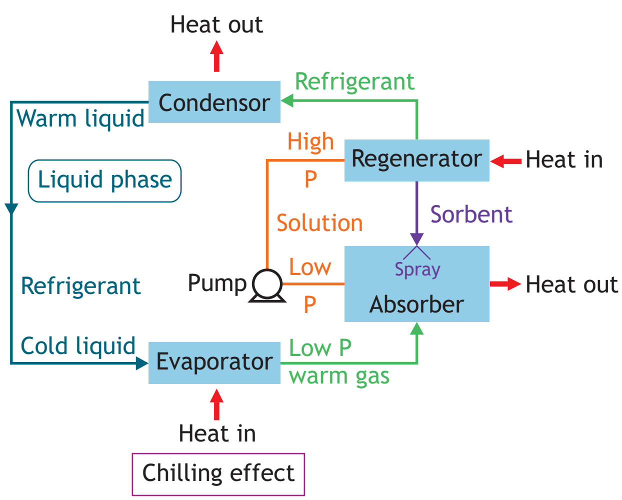
Figure 24 • *Standard refrigeration cycle based on the phase change of the refrigerant from liquid to gas and driven by electrical energy*



Absorption[66] cooling uses a liquid sorbent (water or lithium bromide) to absorb the refrigerant (ammonia or water, respectively) (Fig. 25). The high affinity of the sorbent for the refrigerant causes the refrigerant to change to the gas phase at a lower pressure and temperature than it normally would, thus transferring heat from one place to another. Using heat from any source including geothermal, bioenergy or waste process heat to create a temperature of at least 80°C in the regenerator, the refrigerant is desorbed from the solution. The separated liquid sorbent is then sprayed back into the absorber and the high pressure refrigerant vapour produced is condensed so that the refrigeration cycle continues.

66. A detailed comparison between absorption and adsorption systems is given at www.wasteheat.com/Library_files/WHS%20Adsorption%20vs%20Absorption.pdf

Figure 25 • *Absorption chilling principle driven by heat input to separate the sorbent from the refrigerant and enable the refrigeration cycle to continue*



Variations of absorption chillers exist with different coefficients of performance and energy input requirements. For example, whereas the absorption refrigerator requires a small solution pump (Fig. 24), other systems need no electricity input at all. In small-scale refrigerators for use when camping, liquid ammonia refrigerant evaporates in the presence of hydrogen gas, providing the cooling. The evaporated ammonia (now gaseous) is then passed into a container holding water, which absorbs the ammonia. The water-ammonia solution is then directed to a heater (regenerator), which boils ammonia gas out of the water-ammonia solution. Next the ammonia gas is condensed into a liquid which is then sent back through the hydrogen gas, completing the cycle. The use of hydrogen as a carrier avoids the need for a pump.

A version used in many larger industrial-scale plants uses evaporation of water under low pressure to provide chilling. The water vapour is absorbed by the lithium bromide to give a solution, then the water is subsequently driven off using heat so that the cycle can continue. Another open cycle occasionally used in space cooling passes warm moist air from a building through a spray of salt solution (lithium bromide refrigerant) to lower its humidity (Fig. 26). The warm, dry air is then passed through an evaporative cooler where it is cooled and also rehumidified with a water (sorbent) spray. The resulting cool moist air has its humidity reduced again with a second spray of salt solution. The now diluted salt solution is returned to the regenerator under low pressure, where external heat causes the water to evaporate. This is condensed and eventually rerouted back to the evaporative cooler.

For *adsorption* chillers the refrigerant water is adsorbed on a solid sorbent such as silica gel, giving release of latent heat on the surface (Fig. 27). The amount of latent heat that can be released decreases to zero with increasing addition of water molecules, so the evaporation heat has to be dissipated. The desorption of the stored water and the refrigerant pressure generation for the condensation (regenerator) can be achieved at relatively low temperatures of 55 to 70°C, so that this technology is more appropriate to the application of solar energy to obtain hot water than is absorption. Closed adsorption chillers generate cold water at 5 to 6°C through the periodical cycle.

Both solar adsorption and solar absorption designs have reached the commercial stage with several companies offering products from 15 kW to several MW scale. Plants are operating for example at Munich airport (3.6 MW), Cologne airport (2 MW) down to 60 kW at the library in Hornsby, New South Wales, Australia.

Figure 26 • *Simplified illustration of the absorption chilling process for cooling air*

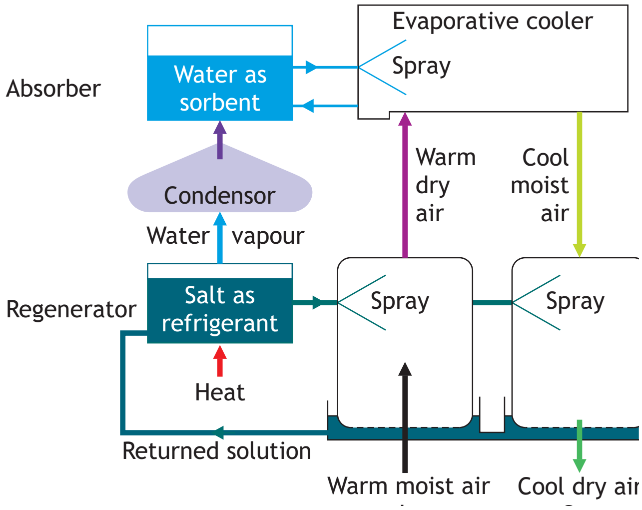
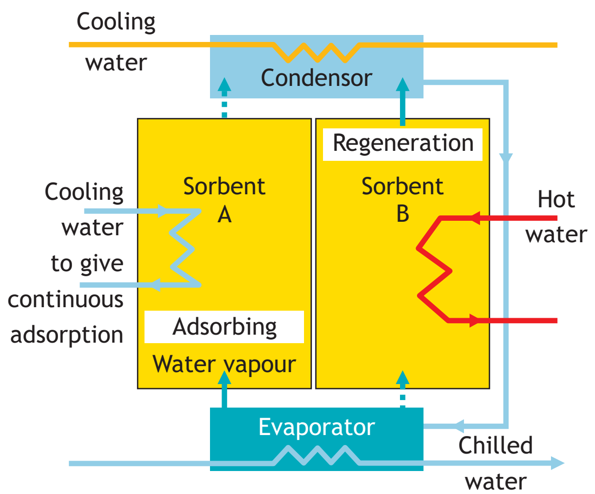


Figure 27 • *Simplified illustration of the adsorption process for chilling water*



While the sorbent in chamber A adsorbs the water vapour entering from the evaporator, the sorbent in chamber B is being regenerated using hot water. When the sorbent in A becomes saturated with water vapour, the chambers A and B are switched to provide the alternative function. The low pressure conditions in the evaporator cause the refrigerant to transfer into the gas phase by taking up the heat from the water loop and thereby producing the useful "cold" to chill the water.

District cooling systems have been operating successfully for some years in cities near a reliable cold water supply. Where natural aquifers or waterways are utilised as the source of cold, then this could conceivably be classed as a form of renewable energy. Seasonal storage of cold during winter for use in summer is possible through aquifer storage, snow or ice storage, cold water taken from the sea or deep lakes. Similar to district heating systems, a network of pipes carries cold water from the supply to a series of buildings where it is passed through simple heat exchange systems. Sea water can be used but is more corrosive than fresh water. District cooling systems from 5 to 300 MW are used in several cities (including Paris, Amsterdam, Lisbon, Stockholm, and Barcelona) using either absorption chillers, compression chillers or a cold water distribution network. Solar energy is not currently utilised at this scale. For example, in a USD 58M scheme, Cornell University in the United States extracts water from the bottom of a nearby lake at around 4 – 5°C and passes it through a heat exchanger before storing it in a 20 000 m^3 stratified thermal storage tank used to cool the incoming air from 75 campus buildings. In Uppsala, Sweden two absorption heat pumps used for upgrading heat from a solid waste biomass CHP plant in winter are used in summer for absorption cooling. The cooling capacity of 10 MW is used in a district cooling network, with the only additional costs being for cooling towers and some piping.[67]

In summary

A wide range of renewable energy technologies to provide heat and power is available in the market and new and improved systems continue to be demonstrated. Costs continue to decline and can be competitive with conventional energy supply in many locations. A lack of appropriate energy conversion technology is rarely a barrier to the increased uptake of renewable energy resources if desired within a city or town.

67. http://zae.uni-wuerzburg.de/files/westermark_zae-symposium06.pdf

6. Transport resources and technologies

Fossil fuels have been essential in the development of our modern technological society. Now we must use the wisdom and wealth that have made it possible to begin to move beyond them.

"Energy for Tomorrow: repowering the planet", National Geographic, Collector's Item, 2009

There are many good examples of recent city planning and design to encourage walking, cycling and public transport by giving improved access, more rapid transit and safer routes. Urban planning initiatives mainly aim to reduce traffic congestion, local air pollution and greenhouse gas emissions. This is evident in some green field cities as well as existing urban developments such as in Kuritiba, Brazil with its busways[68] successfully introduced a decade ago. However, the mobility of city residents still mainly relies upon imported and refined petroleum fuels for powering road vehicles.

The current problems of climate change, oil security, local air pollution and traffic congestion have served to focus the problems of designing cities around the ever-growing dependence on the motor vehicle. Moving away from the gasoline or diesel-powered internal combustion engine for road vehicles to other drive-train technologies may help to overcome the first three problems listed above, but heavy traffic congestion on a daily basis, as well as the time wasted by the drivers waiting in a queue, require solutions other than just building more roads or changing the energy source.

Only technologies directly related to renewable energy use in transport are discussed in this section.

- Electricity purchased from renewable energy generators can be used for public transport modes including metro, trams and light rail systems as well as for a growing number of electric light duty vehicles and electric motorbikes.
- Hydrogen fuel cell buses and light vehicles are being demonstrated widely, but they are not yet fully commercial. As is the case for stationary fuel cells (see above), the hydrogen can be produced using renewable energy sources.
- Bioethanol and biodiesel account for around 1.5% of global road transport fuel demand (IEA, 2008d). Popular concerns relate to the use of food crops and sustainability issues. Use in cities as blends at the retail service stations is widespread. In addition, production of biodiesel using waste cooking oil from fried food outlets is collected, refined, then chemically converted at the micro- scale into methyl esters by many individual enthusiasts and small companies. Second-generation biofuels from ligno-cellulosic feedstocks have future potential and are also discussed.

Electric rail

Modern electric rail systems can help solve many of the problems resulting from road congestion, pollution and emissions. Many examples of electric-powered light rail or underground metro schemes exist globally, are under construction in both OECD and non-OECD countries, or are being expanded. Some use renewable electricity (Box F). Beijing, for example, now boasts the largest metro in the world and still aims to build 120 000 km of new rail by 2020, employing around six million people for an investment of around USD 140 billion/yr (Newman *et al.*, 2009). Delhi is building a 250 km rail network with the aim that 60% of its inhabitants will be within a 15-minute walk of a station. Perth, Western Australia has developed its 170 km network over the past two decades and has successfully attracted people living in the suburbs away from their cars by offering a faster journey time. For any form of

68. http://www.treehugger.com/files/2009/03/curitiba-brazil-bus-rapid-transit-video.php

electric propulsion the source of electricity has to be considered (Box F). Improved efficiency of the vehicle fleet is also high priority[69] but is not discussed further in this report.

In Europe, Japan and elsewhere, high-speed trains are gaining in popularity and competing with short haul flights. Taking a convenient train between two city centres has a breakeven time of up to around four to five hours travel time when compared with using an airport when access, queuing and waiting times are included. In addition according to the Union Internationale de Chemin de Fer[70], the greenhouse gas emissions in Europe per passenger kilometre by train at 47 gCO_2 /km are claimed to be typically around 25% that of car travel (with one person in the car) and 30% that of the equivalent air travel, including transport to and from the airport. Freight can be as low as 25 gCO_2/t km. However, this comparison depends on the source of electricity to power the trains and whether the seats are full. A car with 5 people in could compete well with an electric train running only half full of passengers. The train company Eurostar[71] claims to be carbon neutral and its trains in France run mainly on electricity generated by nuclear power. Therefore, each passenger travelling between London and Paris on a round trip is responsible for just 11 kg of CO_2 emissions if making the trip by train, whereas flying the same route would generate over 120 kg per person.

Box F • *Electric light rail powered by wind*

The City of Calgary's light rail transit system, the C-train, with electric drive motors powered by overhead electric wires, transports around 200 000 passengers daily. Annual power demand to operate the network is over 21 GWh. Most of the power generated in the state of Alberta is from coal-fired power stations. The light rail system running on coal-fired power is responsible for emissions of around 20 000 tCO_2/yr. If all the rail passengers drove cars with only one person in each instead of taking the train, the total carbon emissions would be around 150 000 tCO_2/yr higher, illustrating the environmental benefits of public transport even when powered by fossil-fuel generated electricity.

Strong westerly winds coming from the Rocky Mountains led to the development of a twelve 650 kW turbine wind farm to the south of Calgary. Changes in the regulations that govern the sale of electricity in Alberta now allow anyone to buy electricity from companies producing wind power. A partnership between the city, the local energy supply company ENMAX Power Corporation and Vision Quest Windelectric Inc. resulted in the City of Calgary announcing the *Ride the Wind!*™ programme in September 2001. The council took the decision to buy commercial wind power as the primary source of the C-train's electricity at an additional cost of around CAN 0.005 per passenger trip. The greenhouse gas emissions from operating the train are now effectively zero. This was the first light rail system in North America to, in effect, run on wind power. A high speed train between Calgary and Edmonton is now under evaluation and could theoretically also be powered by renewable electricity.

Electric vehicles

Produced originally in the 1890s and holding the land speed record in 1901 at 91 km/h, electric cars are not new, but because of concerns of possible high future oil prices and climate change mitigation, they are gaining a resurgence. The cost of the electricity to run an electric car in the United States equates to around USD 0.20 /litre gasoline. Battery technologies have improved, recharging points are appearing in city centres (Fig. 28) and electric bicycles and scooters are gaining in popularity. All electric and plug-in hybrid vehicles can have their batteries recharged by plugging into an electric power socket

69. For examples see Chapter 7 of IPCC, 2007; and Chapter 15 of IEA, 2008e.
70. http://www.uic.org/homepage/FactandFig%2011-08.pdf
71. http://www.eurostar.com/UK/uk/leisure/about_eurostar/environment/faq.jsp

(240 or 110 V usually), enabling the on-board charger to function. Where the electricity is sourced from coal-fired power plants, environmental benefits are limited to reduced local pollution in the city. Where the power used is generated by renewable energy systems or nuclear, then climate change benefits are also gained. Electric vehicles can also provide an energy storage mechanism, making larger shares of intermittent renewable electricity possible (see Section 4 on Distributed Energy). However, further improvements in storage systems are needed to improve performance efficiency, increase the vehicle range between charges (currently up to 150 km at open road speeds), and lower costs. Even the best lithium-ion batteries used today in vehicles are far from ideal and the need for more rapid recharging and investment in related infrastructure remain barriers. Ultra-capacitors that store the energy in charged electrodes rather than in an electrolyte, are increasingly being seen as an option, storing less energy per unit weight than batteries at this stage but able to deliver it more quickly. Research investment is good and technical breakthroughs can be hoped for.

Figure 28 • *Electric vehicle charging points have been installed in Paris for several years and more recently by Camden Council, City of London to provide free parking for registered owners whilst recharging the vehicle batteries for up to three hours at no charge*

Photo credit: Ralph Sims

Electric power produced from hydrogen fuel cells is an alternative route. Many demonstration cars and buses are in operation, but their cost remains too high to be competitive in the market. The source of hydrogen is critical if the life-cycle carbon footprint per kilometre travelled is to be reduced (see Section 5). Storage, energy balance, fuel cell reliability and system costs are barriers yet to be overcome. Development of a hydrogen distribution infrastructure may also be a technical and economic constraint for where the hydrogen carrier is not produced at the point of use. How rapidly electric, plug-in hybrids or fuel cell vehicles become widely available is hard to predict, though recent developments and political support could make some IEA predictions (IEA, 2008e) seem pessimistic.

Biofuel production

Currently, liquid biofuels mainly originate from food crops, particularly sugarcane, corn (maize), oil palm and oilseed rape crops. Their sustainability is under question. Analysis at the IEA (Sims *et al.*, 2008) and elsewhere has considered the impacts on total greenhouse gas emissions from direct and indirect use of land, noting that some biofuel crops have a larger impact than others. This debate continues internationally and is one reason why the interest in 2nd-generation biofuels, produced from ligno-cellulosic feedstocks, has grown. The IEA 2008 report *From 1st to 2nd generation biofuel technologies*[72] concluded that it will probably take several years for 2nd-generation biofuels to be produced commercially via either the biochemical or thermo-chemical routes. This is in part due to the immature nature of the technologies even after 35 years or more of development, with various demonstration plants commencing operation or being designed mainly in Europe and the United States, but also due to the need to scale up commercial production plants to gain economies of scale. However, this then leads to supply chain problems of delivering sufficient quantities of feedstock all year round. Where the feedstock originates as residues from agricultural or forestry processes, then perhaps it can be deemed to be more sustainably produced than if from purpose-grown energy crops when land use competition issues once again arise.

Currently several cities have supported the use of biofuels in their municipal bus fleets and own vehicle fleet (*e.g.* Ballarat, Australia; Calgary, Canada; Curitiba, Brazil; Markam, Canada); by subsidising public-access biofuel refilling stations (*e.g.* Ann Arbor, United States; Stockholm, Sweden); establishing mandates for a biofuel blend in taxi fleets, buses etc (*e.g.* Betim, Brazil); or establishing a biofuel belend mandate for all transport fuels sold within the city boundary (*e.g.* Portland, United States) (Martinot *et al.*, 2008).

Some cities such as Güssing, Austria (see Case Study 12) have extensive experience producing and utilising their own biofuels, such as biodiesel from locally grown oilseed rape. Others have used imported palm oil or even waste cooking oils collected from local restaurants and fast-food outlets. Economic advantages that exist in the cost of cheaper feedstocks, however, may be outweighed by higher production costs from a plant producing at the small scale. Other cities such as Växjö, Sweden are closely involved with R&D developments of 2nd generation biofuels, including DME (di-methyl ethers), but at present the scale of plant likely to be needed to achieve competitive fuel costs (Sims *et al.*, 2008) could be a future deterrent for all but large cities.

There is also opportunity for cities in non-OECD countries to produce their own biofuels from sugarcane and other crops for local use where land and water are readily available nearby. The Brazilian example could well be replicated elsewhere, but care is needed to ensure that negative impacts from land use change do not occur. Biofuels from algae have long been researched, but without commercial success to date. However, further recent investments in R&D, including by Exxon in partnership with Synthetic Genomics Incorporated (SGI), searching for new strains of algae, [73] may enable some progress to be made. Since less land is required for algal production than growing energy crops to supply the same energy value of liquid fuels, once the technology has been proven at the commercial scale, either using reactors, seawater, flat roof tops, or sewage ponds[74] for the growing medium, then cities could well have a real interest in undertaking local investments. Nevertheless, commercial production is unlikely to be the case for some years yet.

In summary

The historic dependence on oil imports for road transport within a city remains the norm. Cities with light rail or metro systems can purchase green electricity to reduce the carbon footprint. The uptake of biofuels and electric vehicles are both likely to increase in future years, but in both instances, having a sustainable energy supply (of biomass feedstocks or renewable energy power) is critical. It is very uncertain whether biofuels, hydrogen fuel cells, or plug-in electric vehicles will be the market leaders for light duty road vehicles in future decades. The use of liquid biofuels may be more valuable in the aviation and marine industries, where other alternatives are limited (IEA, 2008e).

72. http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=2079
73. http://www.guardian.co.uk/environment/2009/jul/14/green-algae-exxon-mobil
74. See for example http://www.oilgae.com/blog/2007/01/algal-sludge-turns-to-fuel-in.html

7. Policy options

While cities are beginning to include renewable energy in urban planning, there are still relatively few explicit local renewable energy policies. Rather, renewable energy is often addressed indirectly within other themes such as sustainability, climate change, clean transportation and "green" or "eco" programmes. Often energy savings and energy efficiency are the main priorities, which makes sense due to the enormous opportunities for reducing energy demand. Reduced demand also enables renewables to meet a larger share of the remaining demand. However, it is also true that the potential for renewable energy is often overlooked, short-changed, or needlessly postponed within these broader themes and programmes.

Eric Martinot *et al.*, 2009.

At present there are few cities or towns currently powered entirely by renewable energy, though some smaller towns, urban areas and islands have made good progress towards this goal and many others have various projects and policies underway or planned. Such progress towards a renewable energy future requires a high level of commitment from local governments, whether large or small. Most cities and towns have one or more good sources of renewable energy available for capturing and converting to provide useful energy services to the community. Many have legislative powers that can be used to implement policies relating to change, including the greater deployment of renewable energy technologies within their boundaries. Since developers tend to respond to incentives that stimulate investments, city policy makers have to determine how to best encourage renewable energy uptake giving their local resources and the specific conditions relating to the development, growth and wealth of their city. In all cases the approach taken should revolve around long-term planning, setting targets and developing policies to help meet the targets.

A national/regional enabling framework is essential for policy making at the local level and is discussed in more detail below. In many situations, the public administration of an urban settlement relies on the central government returning some of the taxation paid by its citizens, although where local corruption exists, central governments are more reticent to provide such funding. Other revenue can be generated in some countries by local governments being able to raise funds through a property-rating scheme in order to provide local services (water, waste collection and treatment, street lighting, roading, recreational amenities, etc.). Whether a city is funded by central or local taxation, or both, capital for investment in the central provision of services and urban networks is often constrained. Thus projects relating to energy services, including those using renewable energy, will have to compete with many other costs as identified in a municipality's annual budget. In cities prone to sea level rise, extreme weather events, river floods etc., the cost of adaptation to combat future climate change impacts is already beginning to occur in long-term investment frameworks. Thus strategies relating to climate change mitigation, including the greater uptake of renewable energy, have to compete for limited funding.

Understanding the energy demand trends of a city is useful before attempting to implement such policies that could make a significant impact on the uptake of renewable energy. For most cities it would be relatively straight forward to obtain historical energy use data and break down the demand trends by sectors (commercial, industrial, residential, transport) or possibly even further by end use where the data exists (*e.g.* for residential lighting, hot water, refrigeration, space heating and cooling, drying, cooking, washing, electronic appliances). This can also be a useful start to producing a greenhouse gas emission inventory. Daily and seasonal variations in demand for electricity, natural gas, coal and oil products can usually be obtained and peak energy demand loads identified. Making accurate assumptions to determine the potential shares of renewable energy in the electricity, heating, cooling and transport sectors that could be achieved cost-effectively in the future, especially when accounting for all their co-benefits, would be more challenging.

The opportunities to both reduce the total energy demand, and shave off the peaks, by improved energy efficiency and better energy management should first be instigated by city officials in association with the local utilities. This might be more easily achieved if the utility were owned, or part-owned, by the municipality than if it were privately or state-owned. In the United Kingdom, for example, the Carbon Trust has established the Local Authority Carbon Management Programme[75] that provides local authorities with technical information, change management guidance and mentoring in order for their staff to better identify practical ways of reducing costs and carbon emissions from buildings, vehicle fleets, street lighting and waste under their control. Interestingly, renewable energy does not feature highly in the programme at this stage.

Work is continuing at the IEA on promoting energy efficiency. This includes giving best practice advice to local governments (IEA, 2008h), where, previously, there had been a lack of a rigorous and transparent approach to defining best practice. Further work is planned to identify, analyse and communicate innovative policies, mechanisms and other arrangements between national, regional and local governments that have been shown to be effective in improving energy efficiency. Since the scarcity of data under a common management format was identified as one output of the initial study (IEA, 2008h), undertaking a survey of selected cities is one approach being considered. A similar project covering multi-government arrangements for renewable energy could be a useful topic for future work programmes given that this report does not go into this area in any depth due to lack of available data.

When considering policy development, ideally, the best investment returns (in terms of cost per tonne of CO_2 avoided) should be identified, but also considered alongside other economic, environmental and social drivers (such as savings of imported energy, reduced local air pollution, local employment opportunities, lifestyle, tourism, poverty, health and sustainable development). The overall return on investment in a "sustainable energy package" is usually higher than if investing in renewable energy technologies alone with the aim to simply displace existing fossil fuel demand. This is usually the case for buildings too, whether for individual dwellings, apartments, institutions, or commercial office blocks. This was the rationale behind development of the "Merton Rule" (Box G).

The types of policy deployment instruments that could be employed by cities have been classified here into a combination of categories partly based on the various means of local governance (Bulkeley and Kern, 2006), partly on the Stick (regulatory), Carrot (incentives) and Guidance (information) policies[76] as described in the IEA report *Renewables for Heating and Cooling* (IEA, 2007a), and partly on the more recent detailed classification used specifically for cities by Martinot *et al.*, (2009) produced in association with the Institute for Sustainable Energy Polices, Tokyo, REN21 (Renewable Energy Policy Network for the 21st Century) and ICLEI – Local Governments for Sustainability. This latter analysis includes setting local targets, voluntary actions, the operation of the municipal infrastructure, and acting as a role model for local businesses and citizens to follow. Each category of policy can be designed to support the same goal of renewable energy uptake, but they each address the barriers in different ways.

75. www.carbontrust.co.uk/carbon/PublicSector/la/

76. This grouping structure was originally based upon "*Carrots, Sticks, and Sermons: Policy Instruments*", Vedung *et al.*, 1998.

Box G • *The Merton Borough initiative*[77]

Known as the "Merton Rule" after being first introduced by the London Borough of Merton in 2003, it is a prescriptive planning policy regulation that requires developers of all new buildings in the district to plan to generate at least 10% of their predicted future total annual energy demand (for heating, cooling and electrical appliances) using renewable energy equipment integrated into the building design or located on-site. Acceptable systems include solar PV panels, solar water heaters, ground source heat pumps (for heating and cooling space and heating water), and biomass from residues and energy crops. Energy arising from direct combustion or fermentation of domestic or industrial organic wastes is not permitted due to the possible problems of local pollution, odours etc.

The concept was deemed to be successful and has since been taken up by the Greater London Council and many other municipalities across the United Kingdom. Each municipality can vary the details and thresholds outlined in the regulations to suit their local conditions. For example variations in the original 10% demand level have ranged between 5% and 20%. The most commonly accepted threshold for implementation of the regulation is a development of more than 10 dwellings or 1 000 m^2 floor area of non-residential development but other thresholds exist. The regulation also serves to encourage the energy efficient design of buildings, and to give consideration to their layout and orientation on site, since having to provide 10% of a low energy demand coming from renewables is more cost effective than having to provide 10% of a high energy demand. In cases where the incorporation of renewable energy equipment could make a new building development unviable, where, for example, it is not possible to mount solar panels or wind turbines on a roof due to shading or for other technical reasons, a specified departure can be sought by the developer. When given sufficient grounds, the regulation may not be enforced. The energy use of the buildings is subsequently monitored to ensure that the target is being met. (See Case study 5 below for more details.)

An overview of the policies that have been utilised by cities to promote an increased use of renewable resource for heating, cooling, electricity and transport is given in Table 2 to help readers identify potential options. The different coloured fonts enable the reader to more easily track the type of policy as described in the case studies (Section 8). It should be noted however that policies are often developed as part of a portfolio and there may not always be such distinct boundaries between polices as in the classification below. While they often overlap, the policies are listed individually here for convenience.

- **Governing by leadership.** *Targets* can be set by local authorities for having a specified level of renewable energy deployment (such as x m^2 of solar collectors installed by 2015) or broader targets (such as y % reduction in greenhouse gases by 2020, towards which renewable energy deployment would make a contribution). Normally the targets are not binding and act as a signal to residents and local businesses to consider how they might help achieve the target. Setting the target at the right level can be difficult: too high and a loss of enthusiasm and momentum can occur when it becomes clear it cannot be met; too low and complacency may then set in once it has easily been met. Ideally the target level needs to be achievable but at a stretch, so this first requires some good analysis of the available renewable energy resources and comparative costs of the technologies.
- **Governing by authority.** *Sticks* are schemes generally implemented by cities by means of governing through regulatory authority depending on the legal powers devolved. Local (or

77. www.merton.gov.uk/living/planning/planningpolicy/mertonrule.htm

central) governments can intervene in the market by placing requirements on specified sectors such as from issuing rules that limit greenhouse gas emissions in the built environment or from transport. This type of instrument can force renewable energy deployment by directly requiring the development of specified technologies. The legal and administrative costs of political incentives are often kept to a minimum, although monitoring and enforcement may be required at the local or regional level. Where value added tax (VAT) or carbon charges are in place, these can affect the cost-competitiveness of renewable energy technologies. For example, there can be a disincentive for heating and cooling technologies (REHC) when the VAT rates are reduced for electricity and gas but a full rate is applied to REHC technologies (IEA, 2007a). Under such circumstances, government regulations for VAT reductions should be adjusted to include REHC technologies. It is more difficult to compensate at the local level.

- **Governing by provision.** *Carrots* are typically financial incentive schemes that encourage and facilitate businesses and citizens to go beyond what is legally required of them at the national level by taking additional actions. This can entice the utilisation of renewable energy technologies to meet local energy services by addressing the cost gap between them and conventional technologies. In order to be effective, these incentive schemes need to be designed so that sufficient levels of funding are allocated to bridge any conceivable gap between the market price of energy and the costs for equivalent renewable energy supply. The incentives should be predictable and consistent over the period when the policy is in effect to provide investment confidence. Local governments could add additional incentives to any incentives offered by central governments, where the legislation allows. Tax incentives, including tax credits, tax reductions and accelerated depreciation, may be based on investment costs or energy production. A wide array of tax incentives exist and these can increase the competitiveness of renewable energy. Fiscal incentives typically present a lower financial burden to cover administration and transaction costs and are thus an attractive option for governments, but the overall level of incentives needs to be carefully established if a successful outcome is to be achieved.

- **Governing through enabling.** *Guidance* measures include education schemes, promotion of technologies, demonstration of new technologies with industry to help provide "market push", creating improved awareness by stakeholders, and also support for RD&D (IEA, 2006).

- **Self-governing.** *Voluntary actions* (other than setting voluntary targets) that are often business-led have already been widely employed by cities as illustrated in several of the case studies (Section 8). They include:

  - *Municipal operations* whereby, in order to help meet its voluntary targets and/or reduce its operational costs, a local authority can purchase "green energy" from a local utility to meet its own demands or choose to invest directly in demonstration or proven renewable energy projects (possibly including the utilisation of some of its publicly-owned land), with the resulting energy products and services used in its own buildings, facilities, businesses and vehicles; and

  - *Voluntary agreements* established between the municipality and companies in the private sector, leading to informal agreements to invest in renewable energy for mutual benefits. These agreements can involve the authority investing in a demonstration project jointly with an entrepreneur or the purchase and/or development of renewable energy technology installations as commercial investments by the local authority in partnership with a private company.

Table 2 • *Types of policy instruments available for use by local governments to encourage deployment of renewable energy technologies within their boundaries. (Framework reproduced from Table 1 of Martinot et al., 2009, courtesy of REN21, ISEP, and ICLEI, with modifications and additional examples based on IEA, 2007a)*

Type	Options	Description and examples
Target setting	***Overall target***	Most cities promoting renewable energy at the local level have set voluntary targets for renewable energy or CO_2 emission reductions that often aim for energy savings and improved efficiency, but can also include renewable energy. Typical targets are in the region of a 10-20% reduction of 1990 CO_2 emissions by around 2012 or 20-40% by 2020 or reducing the carbon footprint per capita to a stated level. The targets are usually based on analysis of projected energy demands and the assumed potentials for the reduction and substitution of fossil fuels. Becoming “100% renewable” or “carbon neutral” are longer-term goals.
	Sector specific	Targets set by a municipality in terms of “% share from renewables by a given date” can be exclusively for electricity, buildings, or their own operations. A target could also determine a specified increase in capacity by a certain date such as the total solar water heater collector area, increase in installed MW of wind power installations, or the number of efficient wood burning stoves replacing open fires.
“Sticks” Regulatory schemes based on legal responsibility and jurisdiction	***Urban planning***	Renewable energy issues can be incorporated into a planning strategy for future development of a city, town or suburb by local regulations. Examples include orientating all new buildings for maximum solar gain in winter; determining the minimum proximity of wind turbines to neighbouring properties based on their height; ensuring that ground access for geothermal heat pumps does not extend across surface boundaries and restricting the maximum building height to avoid shading. For example, in Boulder, Colorado a “no-shade” building ordinance ensures that all structures get access to adequate sunshine needed to supply installed solar collectors. A district plan to provide this and other effects could be made for any period between 5 years and 50 years. It often involves developing instruments, policies and activities to meet a pre-set target. Many plans involve sustainable transport initiatives, including running the public transport buses on biofuels or introducing cycling lanes and park-and-ride schemes. Transport policies are only considered in this report if they relate to electric vehicles (cars, trams, light rail) powered by renewable electricity, the uptake of biofuels, or the use of hydrogen if sourced from renewable energy (Section 6).
	Building regulations and Building codes	These typically apply to energy efficiency measures but can equally be applied to a specific renewable technology. Usually for the latter, standards are set relating to the energy performance of buildings that can be met using on-site renewable generation or CHP plants. Regulations can assist the further uptake of renewable energy systems by seeking replication of some element, for example, in the overall planning of heating either as district heat or at the building-scale. Regulations are easily understood and often enable developers to choose the most suitable and cost-effective option, therefore allowing flexibility to reflect local circumstances.

Type	Options	Description and examples
		Regulations requiring solar thermal systems for hot water in new or renovated buildings have become increasingly common following the success of the Barcelona Ordinance in 2000 that has since been taken up by 70 other Spanish municipalities (IEA, 2007a and Box B, Section 5). Regulations could also be used to require home owners to connect to a district heating grid fuelled by biomass (as in Växjö, Sweden) or geothermal (as in Reyjakvik, Iceland). Building permission could be withheld if building design plans, when reviewed, are found not to incorporate the necessary installations or at least have the capability to retrofit. Such regulations can be justified where renewable technologies are more cost-effective, if installed during construction rather than retro-fitted. The impact on the total building cost is therefore relatively low. An obligation placed on developers of new buildings can, in turn, create a minimum critical mass within the market, thus leading to lower costs and, as a result, a higher uptake of renewable technologies. Supplying a portion of hot water demand in a building using solar thermal technologies is relatively straightforward to implement and monitor compared with regulating for the supply of heat for space heating. Supplying heat for both water and space is more cost effective for geothermal or biomass heating systems. Building regulations may be criticised in that they could encourage individual heating systems for buildings or even for separate apartments, rather than support district heating which, in a densely populated built-up area, could be a better option.
	Taxes	Taxes levied on fossil fuel use made at the local level (for example, as an increased rate paid to the municipality for a building using oil or coal for heating purposes) are not yet common. A carbon charge levy has been introduced in some countries by the state or national governments, but no examples exist to date of local governments taking such an initiative.
	Standards and mandates	Performance standards for renewable energy equipment are usually established by national or state governments to prevent less efficient technology designs from entering the market. This has been successfully achieved with various domestic appliances and electric motors. Greater confidence in the reliability and performance of the technology is thereby created, thus reducing investment risks. Cities could establish "standards" or guidelines relating to issues such as the siting of small wind turbines in relation to neighbours' boundaries; protection of the solar envelope of a building from future shading by nearby trees or new building developments; noise limits; the use of biofuel blends, etc. For example, Portland, Oregon mandated that all transport fuels within its boundary must be blended with 5% biodiesel or 10% bioethanol and Betim, Brazil mandated that all taxis and public transport use biofuels.
"Carrots" Financial incentive schemes ***a) Investment incentives***	***Capital grants and rebates***	Renewable energy installations such as solar thermal and geothermal heating are usually capital intensive, but with relatively low running costs. Capital grants are a straightforward incentive to reduce the up-front investment costs for the purchaser. This is a very common type of support used by central governments as it is relatively easy to administer, and can also be employed by municipalities. Grants or subsidies may be offered either to the owners or developers of the renewable installations,

Type	Options	Description and examples
		or directly to the manufacturers of the renewable energy technologies. It is more usual that grants are offered in support of the demand-side market (owners and developers) as grants for selected manufacturers may interfere with competition. For large renewable energy plant owners, grants may be offered in terms of: • USD x/MW capacity installed, thereby directly targeting the capital investment costs for plant and installation; • subsidies set as a percentage of total investment; • a fixed payment incentive per installation; • rebates in the form of the refund of a specific percentage of the cost of installation; or • the refund of a fixed amount per unit of capacity once installed. Where a budget limit is imposed by the municipality, grants may be awarded on a first come, first served basis or auctioned. A risk lies in providing grant funding for the installation, as this does not guarantee how much renewable energy, if any, will actually be generated. Moreover, if only limited funding is made available per grant, it may provide a disincentive for investments in higher quality technologies.
	Operating grants	These incentives provide cash payments based on the amount of energy generated, typically on a USD/kWh basis for the production of renewable electricity, or USD/GJ for heat. Payments based on energy generation and hence plant performance, rather than on capital investment, may place more emphasis on choosing better quality installations. Moreover, funding energy generation ensures that renewable power or heat is actually produced. The distributed nature of heat supply at the small- to medium-scale, including from renewables, complicates the implementation of operation grants due to a lack of cost-effective metering and monitoring procedures that are often only practical for larger systems. As an example the new French Heat Fund of EUR 1 billion for the 2009-2011 period supports the operation of renewable energy heating installations based on the real heat production during the two first running years. Additional funds are already secured for the next period.
	Investments in private energy-related activities	A municipality could invest in an energy project or activity simply as a means of revenue generation but also to encourage the development of a renewable energy project in the region. Options include city-financed investment as a third party funder, issuing of bonds, and trading of green certificates.
	Soft loans and loan guarantees	Financial assistance in the form of low or zero-interest loans over a long term, and/or loan guarantees, effectively lowers the cost of capital. Since the high up-front cost is often a deterrent for potential renewable investors, lowering it can effectively bring down the average cost per unit and hence reduce the investment risk. Loans offered at subsidised interest rates, lower than the market rates (defined as soft loans), may also incorporate long repayment periods and/or payment deferments. This type of incentive is easily implemented by banking institutions that normally provide investment support to developers, and it could also be actioned by municipalities.

Type	Options	Description and examples
		Banks often hesitate to provide loans for equipment which is still developing a market presence, but when it becomes "bankable", it may pave the way for project developers to accrue additional funding sponsorship. Very little risk for the administrative body is associated with soft loans and loan guarantees, but they do not necessarily encourage investors to purchase the most reliable systems or maintain them adequately and produce as much energy as possible.
b) Fiscal incentives	*Tax credits and planning cost reductions*	Under the definition of a tax deduction support scheme, renewable energy installations represent an expense to a taxpayer. Credits or deductions may be a percentage of the total investment or a pre-defined, fixed sum per installation. Only parties with an income or property tax can usually benefit, which therefore provides no incentive to potential investors without such tax liabilities (unless, as in France, they receive a tax credit from the Government that then, one year after the expenditure, pays about half of the eligible amount within a fixed limit). *Investment tax credits* cover either a percentage or the full costs of installation. These are especially good for the early diffusion of early market technologies whose costs are relatively high. P*roduction tax credits* can provide tax benefits for the amount of renewable energy actually produced, therefore increasing the rate of return or decreasing the payback period. In general, production incentives are preferable to investment incentives because they promote the desired outcome of increased renewable energy generation. However, they are normally administered by central government rather than by local government. Exemptions against local property taxes, where applicable, or abatements for taxes on residential renewable energy installations, could become feasible. The cost of seeking a planning consent to install a solar water heater on a property can be prohibitive in some cities and could actively discourage installations. Although not strictly a tax credit, some level of reduction or easement could be made possible by the local authority.
	Tax reductions and accelerated depreciation	A tax reduction or tax exemption system reduces the amount of tax that must be paid in total, thus reducing the total cost of investment in a renewable energy project. The incentive option usually has a relatively low burden for administrative and transaction costs, but the overall level of fiscal incentive needs to be carefully established to achieve successful outcomes. Tax reduction systems could include relief from taxes on sales and property and exemptions of paying value-added-tax on renewable energy equipment and services. While these are normally central government policies, similar approaches could be adapted for local government interventions. External benefits provided to support renewables could occur in the form of exemptions from eco-taxes and carbon charges, lower car parking charges, or local energy taxes imposed on conventional fuels. This type of policy instrument has been notably successful in Sweden, where the exemption of biomass from the energy tax in the 1990s levelled the playing field with oil so that today, the majority of heat today is generated from biomass.

Type	Options	Description and examples
"Guidance" Knowledge and education schemes	***Information and promotion***	A lack of information regarding renewable energy resource availability, technology development, and product availability may inhibit investment in applications simply due to a lack of awareness. Education to promote renewable energy aims to enhance the awareness of the general public, specific stakeholders, or private businesses by undertaking information campaigns and promotional activities, such as project demonstrations. This type of support may take the form of technical assistance, financial advice, labelling of appliances, or information distribution. Information on resource availability (and analysis, where needed), the benefits and potential of renewable energy, preferred type of plant, capacity and energy production statistics, and assistance with applying for available central government incentives, can be made available in a variety of forms. For example, Canada's Office of Energy Efficiency has produced the free download web-based RETScreen tool[78] and numerous free publications on renewable energy. Several cities have established market facilitation agencies to give ratepayers advice, such as the *Renewable Energy and Energy Efficiency Resource Centre* in Nagpur, India (Case study 3).
	Training	Cities could help provide training and education to increase the knowledge of local people, including those considering employment as installers of renewable energy technologies. Training programmes may be established in schools, universities, or amongst key professional groups so they consist of well-informed, skilled individuals and networks. Skilled professionals are needed within the supply chain for renewable energy; including equipment installers, engineers, building auditors, and architects, who should be encouraged to incorporate renewable energy systems into their designs. Providing information and knowledge-based promotion need to work in conjunction with other political tools, including geographic information system databases (GIS) and media campaigns.
Voluntary actions by an authority for operating its municipal infrastructure	***Procurement/ purchase***	Purchasing renewable electricity ("green power") by cities for use in municipal buildings as well as schools, recreational facilities, hospitals and other public facilities is becoming fairly common, as is the use of biofuel blends or biogas in municipal vehicle fleets and public transport vehicles. A municipality choosing to purchase locally manufactured renewable energy products for its own use can act as a stimulus for local businesses in addition to helping meet any targets in place. Procurement of solar water heaters for use on city buildings is a prime example of where leadership can encourage other businesses to also invest.
	Investment	Several cities have already invested in their own biomass district heating and CHP plants, district cooling facilities, wind farms, biofuel processing refineries, community biogas plants using a range of organic feedstocks and landfill gas sites with the energy products and services utilised for their own operations. Any heat or power surplus to their requirements can be offered for sale to the residents and local businesses. joint-ownership of a private project such as a wind farm.

78. www.retscreen.net/ang/home.php

Type	Options	Description and examples
	Utility	Where a municipality fully owns, or is a major shareholder in a local utility, as, for example, Toronto City is the major shareholder in Toronto Hydro, it may be possible for the city to impose controls or impose regulations to encourage renewable energy generation by that utility for its own use. However, this is not always possible depending on the type of ownership, how the national electricity sector functions, and whether there are any over-riding national regulations in the legislation.
Voluntary actions by authority as role model	*Demonstrations and land use*	Many examples exist of cities investing in new renewable energy technologies in order to help facilitate the market by demonstrating the concept and raising the awareness of potential investors. Use of public land for renewable energy activities (such as developing a wind farm in the water catchment area of Palmerston North, New Zealand — see Case study 7) can provide co-benefits such as improved public access, recreational activities such as mountain bike trails, and enhanced biodiversity.
	Voluntary agreements	In some countries environmental regulations enacted by the national government can be viewed as the minimum and can be exceeded at the regional or local level should the circumstances warrant. In other countries such as the Netherlands, national regulations (such as building regulations) cannot legally be exceeded by local governments setting increased demands. In this case local authorities may get around the legal constraint by seeking voluntary agreements with the local private sector. Voluntary agreements could be designed between the municipality and a building developer to encourage energy efficiency and other sustainability initiatives. They could also be instigated to encourage renewable energy options. If, for example, national regulations were in place for installing solar water heaters on all new buildings of a minimum size, the voluntary agreement by a municipality, (perhaps in a specific region of the country with relatively high solar radiation levels), could also encourage the developers to install solar water heaters on smaller buildings and also as retrofits.

Influence of national policies

The overlapping interests of national governments, regional authorities, and local governments relating to climate change mitigation and adaptation, greater energy security, and wider energy access, imply that partnerships between policy-makers at all levels is warranted. National policy-makers can empower their cities and towns to become more effective in implementing policies that mitigate and adapt to climate change. An OECD study (Kamal-Chaoui and Corfee-Morlot, 2009) is aimed to help national policymakers answer the questions: "What role can and should city authorities play in the design and delivery of cost-effective and timely climate policies?" and "How can central governments assist and encourage local governments to fulfil their potential to become effective players?"

The thesis is that climate strategies cannot be effectively implemented without national governments working closely with local governments, but that the latter's authority to act is often constrained by national legal and institutional frameworks. The position of city authorities to engage with local stakeholders to effect change, including the greater deployment of renewables, needs to be better utilised.

As an example the City of Toronto owns the local electricity distributor Toronto Hydro, but its renewable energy policy options are constrained by the regulators from the provincial government of Ontario. This exemplifies the reality that cities only have a certain ability to act and influence at a national scale, are constrained within the limits of their powers, and also are constrained by their limited resources (Siemens, 2007).

A city government cannot be a single or dominant player but can serve a very useful role when interacting with other stakeholders. National governments hold the broad perspective such as on the national power grid or vehicle regulations; businesses add innovation through R&D investment and the agility to respond quickly to change; whereas cities, through the large number of individuals that they influence on their lifestyle choices, can help to bring about large-scale change. Cities can lead change through demonstration and education. Toronto, for example, through its "Climate Change, Clean Air and Sustainable Energy Action Plan" began with the city doing what it could of its own volition and then engaged the community as well as local businesses to meet the targets outlined in the plan. Mary MacDonald, Climate Change Advisor to the mayor, stated that desirable and dramatic changes often come from a combination of bold moves by the city, together with thousands of individual choices made by the citizens (Siemens, 2007).

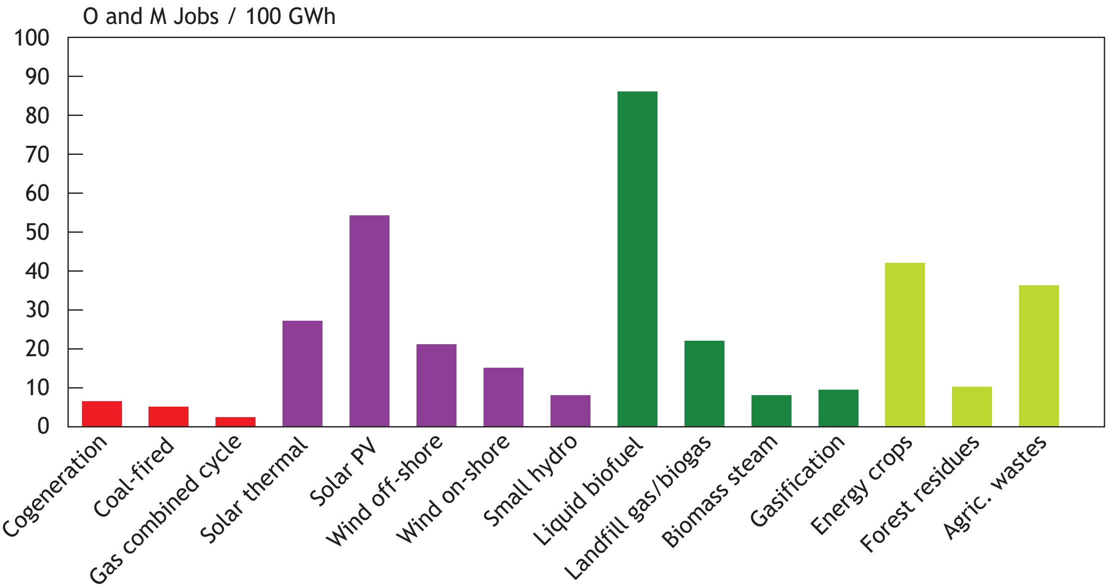
A growing number of local government leaders and officials in cities and towns have taken initiatives to reduce their energy use and to develop projects and policies to better utilise their renewable energy resources in an endeavour to reduce their carbon footprint and gain other benefits. A series of steps is usually taken as the best approach (Kamal-Chaoui and Corfee-Morlot, 2009):

- Strategic planning, with support from local businesses and the community, can help link carbon mitigation from renewable energy deployment with other local benefits, such as the potential for creating "green" jobs (Box H) or reducing local air pollution.
- Formulating policy in association with all local stakeholders should aim to produce priorities and action plans that then need to meet with full approval and broad support from the community if they are to succeed.
- The ability of cities to implement policies relating to climate change and renewable energy depends on the policy of the national government on local governance and devolution of power and on the willingness of the local authority to fully exploit its powers. Other barriers to implementation can include lack of co-ordination across departments within the municipality; insufficient technical expertise and knowledge within the organisation in order to recognise and develop opportunities; inability to raise the necessary funding to support implementation or project developments; and a shortage of support from the national government in the form of a strong regulatory framework.
- Evaluating the effectiveness of local policies by measuring their outcomes on the uptake of renewable energy has rarely been undertaken at the local government level. Developing performance benchmarks and appropriate indicators in order to monitor progress and provide feedback should not be difficult at the local level. The approach taken by Merton Borough council (Case study 5) illustrates what is possible at zero or low cost to the local government. Other ideas can be gleaned from the IEA report *Deploying Renewables: Principles for Effective Policies,* (IEA, 2008g) that analyses the effects of national policies.
- Disseminating the approach made to achieve successful policies and actions, based on actual experiences and identification of the best practices, can assist in gaining replication elsewhere. This could be informally through national associations and networks of local governments, at the international level through attending workshops and making presentations, or by hosting visits for other local governments to be able to evaluate the projects undertaken first hand.

Box H • *Employment opportunities*

Renewable energy project deployment creates useful employment for both skilled and unskilled workers, more so than for operating the equivalent energy output capacity of plants in the fossil fuel industry (Fig. 29). Designing and building of electricity, heat, CHP and biofuel plants as well as their operation and maintenance, requires relatively high labour input compared to fossil fuel plants of similar capacity. Installations of small-scale systems, including solar water heaters, ground source heat pumps, biomass boilers, solar PV panels, small wind turbines, and mini-hydro, are particularly labour intensive. Although employment creation is usually viewed as a benefit of renewables, the additional costs involved with these "green jobs" add to the total cost of the renewable energy generation.

Figure 29 • *Employment requirements for operation and maintenance jobs for various renewable electricity projects per 100 GWh of energy output, with bioenergy projects requiring additional labour inputs to produce and deliver the biomass to the plant from various sources (IEA, 2007b)*



Source: IEA, 2007b

Installing renewable energy technologies and integrating them into buildings needs certification and accreditation schemes to be developed for the installers at the city or national level. For example, the European Union's Renewables Directive, Article 14, focuses on training installers of small-scale building-integrated renewable energy systems. The European project QualiCert[79] (Common Quality Certification and Accreditation for installers of small-scale renewable energy systems) proposes having a required certification scheme in each European member state that obeys a set of similar criteria and recognises the certification process used in the other member states. To guarantee good support by the whole industry, QualiCert relies on a multi-stakeholder approach involving builders, training providers, accrediting bodies, the European renewables industry, installers, and a number of national energy agencies. This approach addresses the need for a comprehensive system to guarantee quality installations by certified tradesmen which, in turn, will spur further market deployment.

79. http://ieea.erba.hu/ieea/page/Page.jsp?op=project_detail&prid=1828

A detailed analysis of the effectiveness and efficiency of national market deployment policies aimed at the diffusion of renewable energy technologies in the electricity, heat and transport sectors was undertaken by the IEA for OECD countries plus the large emerging economies (IEA, 2008g). The innovative methodology used to assess the potential for a given renewable resource technology and the cost-effectiveness of policies, together with the lessons learned, could well be adapted to similar policies after being introduced at the local government level.

The two concurrent national goals of exploiting the most abundant renewable energy resources in a given location by 1) encouraging deployment of those technologies that are closest to market competitiveness and 2) implementing a long-term strategic vision to provide cost-effective options, also hold good for the renewable energy goals of cities. An integrated approach of policy design to achieve a smooth transition towards the market by deploying renewable energy technologies on a fully competitive basis at the local level can be based on the same five fundamental principles as defined for national policies (IEA, 2008g):

- Non-economic barriers, including administrative hurdles, obstacles to grid access, poor design of electricity and heat markets, lack of information and training, and social acceptance issues all need to be overcome by suitable policies in order to improve the market functioning adequately.
- To attract investments, a clear and predictable support framework with commitments over the long term needs to be established.
- Depending on the maturity of a technology and its replicability, appropriate incentives that guarantee a specific level of support for different technologies should be developed and implemented.
- Financial incentives introduced to encourage deployment should be decreased over time in order to foster technological innovation, gain from learning experience, and move less mature technologies towards market competitiveness.
- The impacts of gaining successful penetration of technologies on a large scale within an overall existing energy system should be assessed in advance and any resulting social, economic or environmental changes anticipated.

In many instances local policies can be introduced on top of national policies where there is a particular benefit from so-doing. Where national policies do not exist, then a well designed and implemented local policy could become a model for other municipalities and possibly be the catalyst for a national policy in the longer term. For example, Barcelona's "Solar Thermal Ordinance" (Box B, Section 5) was later adopted in the national building codes of Spain, though as a less stringent regulation. In many such examples, there is no reason why local governments could not exceed the national regulations — for example, by a region of high solar radiation aiming for 70% of hot water from solar rather than maybe the 50% stated in a national policy covering all regions.

Although the responsibility of monitoring and reducing greenhouse gas emissions falls on national governments under the UN Framework Convention on Climate Change (UNFCCC), cities are beginning to address the challenges posed by climate change and several have already set climate targets (Martinot *et al.*, 2009). Local government policies can have a major role to play in helping countries meet their national climate change obligations. Local governments can influence energy use by their community, both directly and indirectly, and often have policy instruments at their disposal which differ from those of national governments and therefore give significant policy influence. Other than transport and energy efficiency policies, cities could encourage the use of integrated renewable energy-production technology, such as the introduction for industry of trigeneration (combined cooling, heating and power generation).

The density of demand for energy services in many cities provides opportunity for economies of scale (*e.g.* less infrastructure unit cost per capita), as well as greater energy efficiency, due to relatively low transmission and distribution losses. In addition to international city networks, a number of national networks have been formed or have re-orientated their work towards climate change. These include the Nottingham Declaration Partnership in the United Kingdom; the United States Conference of Mayors; Canada's Partners for Climate Protection; the Spanish Network of Cities for Climate; the Kyoto Club in Italy; and the Coalition of Local Governments for Environment Initiative (COLGEI) Group in Japan. The activity of these networks has encouraged some cities and towns to adopt specific greenhouse gas (GHG) abatement targets. However, only a relatively few throughout the world have actively pursued CO_2 mitigation policies to date. Significant obstacles include competing demands for financial and staff resources; the challenges resulting from two to three year re-election periods; the lock-in of 30-60 year investments in infrastructure and the lack of co-operation with neighbouring authorities beyond their borders. There are some notable exceptions, (such as London, United Kingdom with a target to reduce GHG emissions by 60% below 1990 levels by 2025 under the *Mayor's Climate Change Action Plan* and Seoul, South Korea aiming for a 25% reduction below 1990 levels by 2020), but the present rate of development of climate change policies by municipalities is too slow to really help meet national and global targets. Therefore, national governments of most countries have a continuing role to play in providing incentives and financial support to encourage their towns and cities to undertake and monitor CO_2 abatement activities, including energy efficiency and the deployment of renewables. Conversely, where national governments are being tardy in implementing climate change policies, some local governments are leading the way (Section 9).

Climate change policies and measuring emissions

There is a growing range of policy measures designed to address the challenge of climate change at the local government level. Carbon taxation has been successful in supporting CHP and DHC developments in Sweden and elsewhere. Cap-and-trade emissions trading schemes (ETS) are becoming increasingly popular, the principle being that allowances to emit GHGs have limits imposed and thus a market price for them is produced to minimise the mitigation cost by developing the cheapest options. Hybrid schemes at the national level are also being considered (IEA, 2008a). Normally national or state governments are responsible for establishing policies as a possible means of meeting their international GHG emission obligations. However, cities are now becoming involved, such as Tokyo mandating a cap-and-trade system on all large businesses and office buildings within its boundary starting in April 2010 (Case Study 1).

The land area of an urban community can impact on the per capita energy demand and hence its carbon efficiency. Based on an analysis of 100 cities in the United States (Sarzynski, 2008), densely populated urban areas tend to have a lower carbon footprint per capita than more rural ones due to the concentration of building developments and use of more public and electric rail transport. However, the fuel mix used to generate the electricity consumed has a high impact, as does the supply of pipeline gas that is more common to a major city than to a rural town in the United States. Communities dependent mainly on coal-fired power plants and natural gas are at a disadvantage when striving to achieve a low carbon footprint per capita than those with greater reliance on hydropower and other renewables. This "energy supply perspective" is only a small part of the overall picture. There is growing support when measuring urban energy for using the "energy consumer perspective" that also includes the embodied energy in all the goods and services consumed by the community's residents and businesses. So it can be argued that the energy analysis for a city should deduct the energy embodied in goods locally manufactured and exported but include the embodied energy in imported goods and services. A further complexity is to separate out energy used for transport within the city boundary from the energy consumption of road vehicles, trains, boats and planes just passing through. In theory, local governments should address their energy and GHG emissions on a total input/output basis. However, there is usually insufficient data available to do so at present — particularly for the transport and industry sectors and also for smaller towns.

Other anomalies can arise. When operating a new CHP plant that has replaced an old heat plant for example, on-site emissions can increase, even though the total system emissions can decrease. This is because the emissions avoided when displacing some electricity generation from an alternative thermal power plant with the CHP plant can exceed the additional on-site emissions produced when the heat plant was replaced (IEA, 2009b). Consequently, CHP plant owners could be penalised through having to buy more allowances than would otherwise be needed for a heat-only boiler and grid-supplied electricity. ETS designs need to take account of such anomalies. In addition, if the sector to which the CHP plant is deemed to belong has stringently capped allowances, this could discourage a developer of new CHP plants. There could also be a discrepancy if owners of buildings with individual domestic boilers that are efficient but not currently included in ETS schemes because they are too small, are forced by new regulations to convert to a large urban CHP/DHC scheme that is included in the ETS. This would possibly discourage investment in the emission reduction option.

Voluntary carbon markets

Recently, voluntary carbon markets and carbon offset programmes have developed alongside the international regulated markets. Businesses or individuals wishing to neutralise their carbon footprint can buy credits from others in the community with no aspirations to become carbon neutral but willing to invest in low carbon technologies and sell the carbon credits (Fig. 30). Trades mainly through "over-the-counter" or the Chicago Climate Exchange provide an opportunity for consumer action by citizens; an alternative source of carbon finance; an incubator for carbon market innovation; and the chance to buy locally produced carbon credits (Hamilton *et al,* 2009).

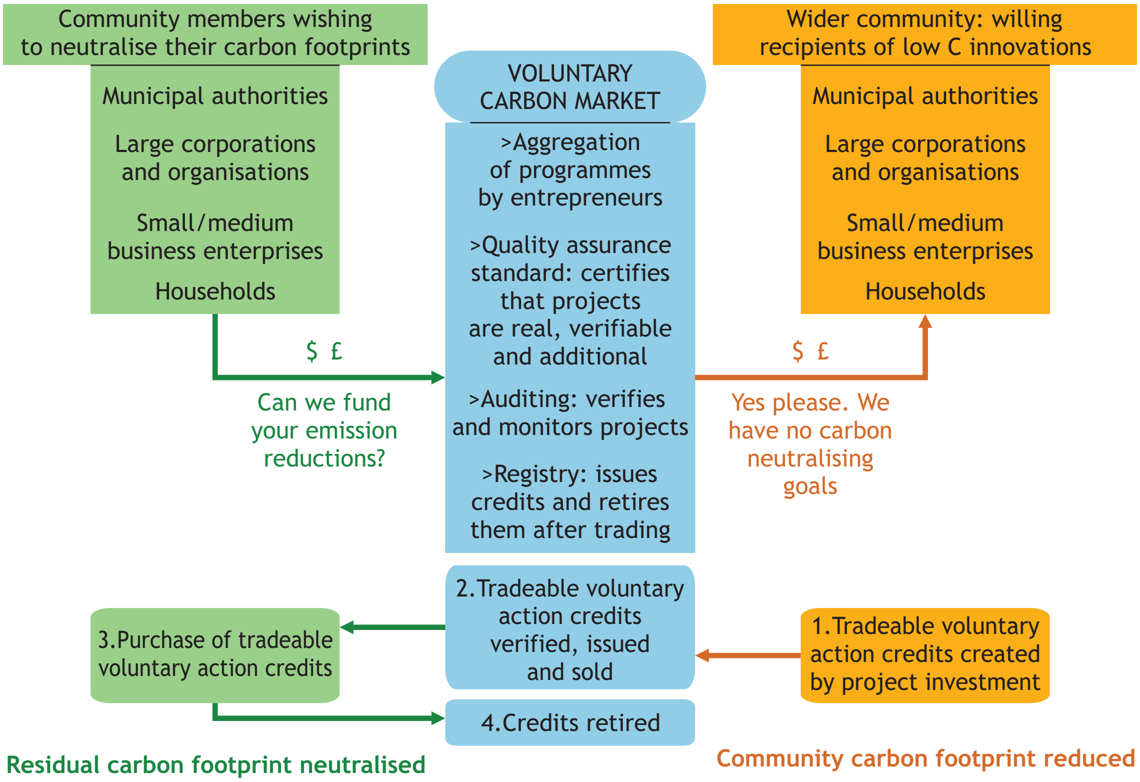
In the United States in 2008, San Francisco announced plans to produce "locally grown" offset credits. At the same time in Colorado, a Carbon Fund was launched as a funding source for community-based clean energy and climate mitigation projects[80]. This initiative aimed to develop a funding source for local community-based clean energy and climate mitigation projects such as energy efficiency in schools, buildings and transport, and renewable energy initiatives, including on-farm biogas plants. The fund provides high quality carbon offsets to consumers as a means of encouraging new energy efficiency and renewable energy projects, supporting Colorado's climate change mitigation objectives, and providing high quality, credible offsets for individuals, businesses and government agencies interested in mitigating their carbon footprint. These carbon offsets enable local consumers to:

- engage in a more sustainable energy lifestyle by measuring their emissions from energy use and travel;
- reduce their emissions through energy efficiency and renewable energy; and
- offset unavoidable emissions.

The fund only supports new, verifiable, GHG reduction projects developed in Colorado. The state Energy Office has partnered with communities interested in supporting local clean energy and climate mitigation projects; individuals and organisations interested in offsetting their environmental impacts; developers of emissions-reducing projects needing financial or community support and the non-profit organisation, Climate Trust to manage the programme. Any donations to the fund are tax deductible.

80. www.coloradocarbonfund.org/why.html

Figure 30 • *A voluntary carbon market within a community works by those members investing in carbon emission reduction projects such as renewable energy with the ability to sell the "tradeable voluntary action credits" to those wishing to reduce their carbon footprint but unable to do so directly*



Based on: www.gtriplec.co.nz/assets/Uploads/papers/Paper_2_Scaling_Up-Voluntary_Mitigation_Actions_Final.pdf

Many of the investments in voluntary markets are thought to be driven by corporate social responsibility and branding to gain good public relations and also by expectations of pending national regulations. Such pre-compliance projects include mainly landfill gas and forest developments, with credits gained from afforestation / reforestation and improved forest management. Proving project legitimacy of these carbon offsets remains a market issue resulting in establishment of voluntary offset standards, market transparency, and the forming of collations for self-regulation to increase the quality of the carbon offsets. In 2008 the market had exceeded 120 $MtCO_{2\text{-eq}}$ (Hamilton *et al.*, 2009) with average trades around USD 7.30 /$tCO_{2\text{-eq}}$ giving a market value around USD 700M. Many suppliers prefer the Voluntary Carbon Standard[81] to other standards but others use the CDM (clean development mechanism of the UNFCCC). Credits backed by standards traded higher in 2008 and renewable energy projects were favoured, trading on average for around USD 22 /$tCO_{2\text{-eq.}}$ for solar, USD 18 /$tCO_{2\text{-eq.}}$ for geothermal, and USD 17 /$tCO_{2\text{-eq.}}$ for bioenergy projects. Carbon sequestration projects through geological or soil carbon capture and storage were at the other end of the scale at around USD 3/$tCO_{2\text{-eq}}$, possibly due to the higher risk of non-delivery at this stage of development.

There remain some concerns about double counting by the voluntary carbon market[82] (Ward and Weaver, 2009). The question is to what extent is it acceptable for voluntary carbon market transactions

81. www.v-c-s.org

82. When GHG emission reductions or removals from an activity are claimed by two separate entities for the purpose of demonstrating emission reductions or are sold by a single entity to multiple buyers.

to occur inside sectors already covered by obligatory, compliance accounting? Still under discussion is whether there is a difference in credibility between voluntary mitigation actions undertaken without a voluntary trading facility and those actions that take place through a trading facility. Also not yet determined is whether the atmosphere is better off, unaffected, or worse off as a result of trade in voluntary mitigation actions by means of tradable voluntary action credits that are non-fungible with compliance units. One proposed solution is for compliance carbon units to be cancelled. This means that the cap of a cap-and-trade scheme would then be lowered by any actions that might create voluntary units that could be traded in the voluntary market. The cancellation requirement also has the effect of preventing the ability of the voluntary market to incentivise domestic mitigation actions (such as community energy efficiency or renewable energy programmes) in countries that have signed the Kyoto Protocol. There appears to be no similar concern about other voluntary actions that serve to help a local government meet its compliance obligations but do not involve voluntary credits.

Distributed energy policies

A supporting regulatory environment is critical for the deployment of distributed energy including heat and power generation based on renewable energy. It helps overcome any existing biases by incumbents against the introduction of active network management. In addition, it can help reduce any additional costs of operation that the introduction of distributed generation (DG) might bring on the system, at least initially.

In practice, depending on the level of privatisation reached, there are major differences in the association between a city authority, the utilities serving the city, and the gas, heat and electricity distribution networks. Larger cities may own or part-own the utility as well as the distribution companies. In this instance seeking benefits for their residents from improved energy efficiency, load management measures, and distributed energy is relatively easy compared with dealing with state or privately-owned companies where profit is the major driver. This issue is not dealt with in detail here, but analyses of the complexities can be found elsewhere, such as in the IEA publication *Distributed Generation in Liberalised Electricity Markets* (IEA, 2002).

Heating and cooling policies

Historically, renewable heating has not received as much policy support as renewable electricity or biofuels for transport. This disparity is, at least in part, due to a lack of legislative tools and policies designed to support the market development of specific heating and cooling technologies. Here cities can play an active role, since renewable energy heating and cooling (REHC) services are usually provided by locally based businesses because the heat/cool generated cannot easily be fed back into an extensive distribution grid, as is common practice with renewable electricity. Renewable energy technologies available for meeting heating and cooling demands in many locations currently lack cost competitiveness with conventional systems that are based on relatively cheap electricity, gas or coal (IEA, 2007a). Public support is therefore necessary to ensure growth in deployment.

Policies that support REHC may be inherently different from those which address renewable electricity generation or the uptake of biofuels, reflecting the somewhat different characteristics of these markets. Electricity markets are clearly assigned to one or more centralised grid operators whereas, with the exception of district heating systems, heat is often the responsibility of individual producers. Therefore, policy instruments need to be specifically addressed in order to meet the unique, local characteristics of REHC resources, the small-scale technologies often involved, and the widely distributed demand.

Experience has shown that the status of the market greatly influences the levels of required support and degree of successful product deployment (IEA, 2008g). For technologies that have reached a critical mass, comparative intensities of support lead to higher levels of deployment. Therefore, in a supportive policy environment, a cycle of technology and market development becomes self-enforcing in terms of economies of scale, falling costs and public awareness. Markets that have not yet reached a critical mass (or are in decline) are not subject to such benefits and so will require stronger policy support to gain more rapid diffusion. Cycles function differently depending on the stage of maturity of a technology and how far its market has progressed (IEA, 2008g). Careful policy design is necessary to incorporate these factors.

Providing district heating and cooling (DHC) schemes requires cities to become involved with local infrastructure in order to create the necessary linkages and planning that combines facilitating measures with regulations. Combined heat and power (CHP) is a versatile energy supply technology that can meet demand for both heat and power efficiently when carefully designed. If using biomass, solar or geothermal resources, a low carbon footprint can result. A rational framework can provide heating, cooling and electricity efficiently by identifying and linking demand and supply whilst supporting the best energy sources available (IEA, 2009b). Municipal governments in Denmark, for example, first assessed heat demand and supply options (including using straw and biogas as fuel), then introduced restrictions on electric heating and on power generation without heat recovery. At the same time, they supported R&D in emerging renewable CHP technologies to stimulate a transition to a low-carbon heat and power system.

Local energy planning at a municipal or building level can result in development of CHP or DHC in a number of situations by co-ordinating heating, cooling and energy supply. Good planning can create stable heating and cooling loads through DHC networks. Local governments have the spatial planning tools to facilitate this process and to address the regulatory challenges of construction, installation and energy sales. While DHC networks have a high up-front capital cost, they are a valuable long-term asset for optimising energy supply and creating a bridge to low-carbon systems for a city. Where capital investment is not economically viable under private-sector criteria, local governments can support DHC network investment through loans and guarantees, or by investing directly, as is the case for other long-term infrastructure. Setting standards for environmental building performance is normally not achieved through market incentives. Therefore, accelerated uptake of small-scale CHP and other low-energy technology solutions in buildings may require a critical mass of customer demand to bring down the costs per unit of product. Building regulation standards, applied to thousands of new buildings, could create such a demand in a relatively short period.

In summary

Many types of policy have been used successfully by local governments to increase the deployment of renewable energy in their regions. There is good opportunity for others to copy these policies but their effectiveness has not been analysed to date. The carbon trading markets are rapidly evolving and opportunities exist for even small cities to benefit (see for example Case study 8). Various decisions taken by city councillors can impact on GHG emissions, sometimes in perverse and unpredictable ways. The rate of development of carbon markets and related trading rules is rapid as they evolve both nationally and globally. Large cities could employ specialists to keep abreast of this topic and identify possible benefits and pitfalls. Smaller towns that cannot afford this option could consider employing the services of specialist carbon market consultants.

8. Case studies of cities

City government efforts, at whatever level, need to address not only what they can do directly to reduce carbon emissions, but also how they can promote greater adoption of these technologies by consumers. Depending on the technology, this can come through changes in regulation, taxes, subsidies, access to capital and provision of trusted information, as well as marketing and campaigning to raise the awareness and encourage citizens to make choices that are both economically and environmentally sound. Cities could also help bring together different stakeholders that need to act jointly to make change happen.

Siemens, 2007.

The towns and cities listed below exemplify what is being achieved around the world by several leading municipalities. They were selected to include examples ranging from mega-cities to small towns and to provide a geographic representation. A list of the activities and policies in other cities is presented in the *Global Status Report on Local Renewable Energy Policies* (Martinot *et al.*, 2009). That analysis identified relevant policies for 160 cities and towns, with further analyses in progress. It is not the intention to duplicate this work here, but rather to build on it using similar methodology and characterisation of the policies.

For each of the thirteen case studies, the policies that are in force have been identified according to the classification used in Section 7 based on the definitions as listed in Table 2. A summary of the chosen case study cities and communities, as characterised by their populations and policies, is provided in Table 3. This provides a means for the reader to select examples which relate most closely to their specific community situation and hence to identify some concepts and policies that may be worthwhile considering to ascertain whether they might be transferrable.

Some of the case studies are very ambitious, and have started with new building constructions on green field sites. Some are island communities with specific problems to deal with (Box I). Others are small towns or suburbs that have succeeded in making a major impact by developing several renewable energy projects and introducing a number of policies in parallel. It is not anticipated that readers representing a local authority that wishes to encourage the greater uptake of renewables within their boundary would attempt to copy exactly the policies of a case study city, even if it models their own situation.

Rather it is intended that the individual policies highlighted as being successful will enable other cities and towns to learn from those experiences and then consider taking similar initiatives, but, of course, first taking into account their own specific set of circumstances. Examples of individual policies that would be easy to replicate by other municipalities are abundant in the case studies. Many of the cities also have instigated energy efficiency and transport policies and targets, but these are not discussed here in detail because other IEA analyses have concentrated on these policy aspects (see for example IEA, 2008h).

No attempt has been made to evaluate the effectiveness of the policies that cities have put in place. This has been undertaken by the IEA for national renewable energy policies in OECD countries plus Brazil, Russia, China, India and South Africa (IEA, 2008g). A similar analysis of the effectiveness of local policies would be a useful future study. At this stage, however, many of the projects put in place by cities are demonstrations of technologies and educational guidance, so their effectiveness is difficult to measure.

Box I • *Funafuti, Tuvalu, South Pacific*

The four-island nation of Tuvalu, with most of its 25 km^2 of land below 1 m above sea level and the highest point at 4.5 m, is very concerned about the impacts of sea level rise on its groundwater supplies and indeed, its whole future after a 3 000-year history. It is already experiencing increased flooding. Therefore, the government of the 12 000 population is aiming to make the transition from using fossil fuels towards renewable energy systems in order to demonstrate to larger countries what needs to be achieved to reduce the potential impacts of climate change. Using external funding through e8, a non-profit organisation consisting of 10 leading power utilities from the G8 countries including the Kanzai Electric Power Company and the Tokyo Electric Power Company that jointly funded the USD 410 000 project, a 40 kW solar PV system has been installed on the roof of the largest football stadium to provide 5% of Funafuti city's power demand. With assistance from the donors, the installation is managed, maintained and monitored by the state-owned Tuvalu Electricity Corporation. After one year of operation, the diesel fuel imported from New Zealand to run the diesel generators has declined by around 17 000 litres, with carbon emissions consequently reduced by around 50 tCO_2. Although only three to four percent reductions of the total diesel fuel consumption and GHG emissions, the government aims to expand the scheme to 60 kW and also to build similar installations on its other islands. With support from the Italian government, it is commissioning a USD 800 000, 46 kW solar PV system for Motufoua secondary school on Vaitupu island. The longer-term goal is to reach a 100% renewable energy system on the islands, mainly from sun and wind. Foreign aid, the main source of revenue for the islanders, would have to be found to support the USD 20 million required in total. Their concerns are similar for other low-lying island nations such as the Maldives, and also Carteret, Papua New Guinea from where the islanders have already been relocated. The transfer of the Tuvalu residents to other countries once the islands become inhabitable will cost much more than investing in renewable energy.

The Tuvalu government has no power over its destiny. Based on present scientific knowledge, its future will depend on how quickly climate change mitigation actions will be undertaken by the major greenhouse gas emitting nations in order to restrict sea level rise to an acceptable level. Tuvalu realises that its efforts alone will make little difference to reducing total global greenhouse gas emissions and climate change impacts, though every contribution helps. However, it will demonstrate to larger nations at international climate negotiations what could be achievable on a larger scale, and how renewables can help solve this huge global problem.

Table 3 • *Case study cities and towns listed by population showing summary of the relevant policies currently in place as outlined in detail below*

City or town	Population	Policy classification																			Comments
		Target		Stick				Carrot						Guidance		Voluntary -municipal operation			Voluntary -role model		
		Overall target	Sector specific target	Urban planning	Building codes regulations/	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement / purchase	Investment	Utility	Demonstration / land use	Voluntary agreements	
1) Tokyo	12 400 000	X	X		X		X							X		X	X				Wealthy mega-city
2) Capetown, S. Africa	3 400 000	X	X	X				X						X	X	X					Poor mega-city
3) Nagpur, India	2 100 000	X	X		X							X	X	X	X		X		X	X	Poor large city
4) Adelaide, Australia	1 160 000	X	X					X						X		X	X		X		Wealthy large city
5) Merton, London, UK	200 000	X	X	X	X		X							X							Mega-city leading district
6) Freiburg, Germany	200 000	X	X	X	X		X	X			X			X	X	X	X	X	X	X	Medium town
7) Växjo, Sweden	78 000	X	X		X			X						X		X		X	X	X	Small town
8) Palmerston North,NZ	75 000	X	X														X	X	X	X	Small town
9) Masdar City, UAE	40 000		X											X		X	X	X	X		Urban planning from new
10) El Hierro, Spain	10 000		X					X			X			X	X		X	X	X	X	One of Canary Islands
11) Samsø, Denmark	4 400		X					X			X			X	X		X		X		Island for comparison
12) Güssing, Austria	3 800		X				X							X	X	X	X	X	X		Small community -rural
13) Greensburg, USA	1 600		X	X	X					X			X	X				X	X		Rebuilding after tornado

Case study 1

Tokyo, Japan

Population: 12.4 million

Rationale for selection: Mega-city funding its long-term vision for renewable energy potential

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement / purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X		X		X							X		X	X			

Description

Renewable energy supplies around 2.7% of the total energy demand of Tokyo, the remainder coming mainly from imported oil, coal and natural gas, as well as 14% from nuclear energy. The main sources of renewable energy are power and heat from waste incineration plants, as well as solar PV and solar thermal installations. Since the city faces a continual earthquake risk, the city Bureau of Environment views renewable energy as a link between energy policies and disaster preparedness policies.

In Tokyo 37% of electricity is used for lighting and electronics, 43% for hot water and 20% for space heating and cooling. The electricity market in Japan was partly liberalised in 2005. As a result, large power customers were able to choose their electricity supplier. Reduction through energy efficiency measures is being sought and solar PV systems will enhance grid supply (Fig. 31).

The Tokyo Metropolitan Government (TMG) adopted the Tokyo Renewable Energy Strategy in April 2006, setting the opportunity for discussions around a target of 20% from renewable energy supply for the city by 2020. This target level was chosen to be in line with other targets in OECD countries, and also to stimulate new opportunities for businesses. It was felt that the purchasing power resulting from implementing the target would help boost renewable energy deployment throughout the whole country.

In order to achieve the target, the TMG requires all energy companies operating in the city to regularly publish the amount of carbon dioxide they are emitting from their range of activities, as well as to publicise their plans to use more renewable energy in the future. By showing the power consumers how much "green electricity" each company produces, the city is driving greater competition for renewable energy since customers seek to purchase the "green electricity". This is part of the public education goal. Power companies are also improving the generation efficiency of existing power plants and switching to cleaner fuels (*e.g.* from coal to natural gas). The programme has already resulted in emissions reductions of over 680 000 tCO_2/yr, compared with 2004 levels.

Figure 31 • *The hazy Tokyo city skyline shows a number of large PV installations, many now more than 10 years old*

Photo credit: Ralph Sims

The TMG determined that citizens use energy to make their lives more comfortable. They then asked: "What services are needed for this objective? How much energy is required to provide such services? Where should that energy come from?" The overall goal of the TMG outlined in the policy document "Tokyo's Big Change: the 10-year plan" is to reduce the city's greenhouse gas emissions by 25% from 2000 levels by 2020. In the longer term, the goal is to reach a "Carbon-minus Tokyo" by changing the structure of society. A "Strategic Joint Committee for an Environment-Friendly City" was established in January 2007 involving several internal departments to ensure that all stakeholders can help bring about the desired structural change. A fund of around USD 4.3 billion was then agreed by the city leaders for fiscal year 2008 to promote measures against climate change. A defining document, the *Tokyo Climate Change Strategy* (TMG, 2007) was released in June 2007. The aims are to create a mechanism to utilise Japan's environmental technologies; to encourage large and small businesses and households to take responsibility to reduce their CO_2 emissions; to implement intensive, strategic measures during the initial period when shifting to a low-carbon society; and to use private and public funds, tax incentives and bold investments to achieve the desired CO_2 reductions. It has even been suggested by the city governor that officials who cannot develop ideas and implement them in order to meet the target should leave their positions.

A three-year action plan out to 2010 has been formulated to speed up progress. It comprises 39 policies, 334 projects (254 being new) and a budget of USD 18 billion (which includes the USD 4.3 billion for 2008). A series of pilot projects is planned to ascertain the links between renewable energy and the policies. One aim is to enhance green power purchasing to help promote renewable energy use among businesses and to gain corporate sponsorship for renewable energy projects. The Bureau of Environment is also studying how best to use solar heating and other sources of renewable energy in low energy house designs.

National government initiatives that have assisted the aims of the TMG include the 2003 Electricity Law which enabled new generators to sell to a broad array of customers, and the 2003 Renewable Portfolio Standard that aims to stimulate renewable energy so as to provide 1.35% of the nation's electricity supply by 2010. New national goals and subsidies have more recently been introduced by the central government with the objective to double renewable electricity by 2020 from biomass, hydro and geothermal, with the main emphasis on increasing the current 5 000 MW of solar PV capacity twentyfold. The national subsidy for solar PV installations, introduced at up to around USD 2 500 per household, can be used in combination with local government subsidies. In addition, electric power companies will have to purchase any surplus renewable power generated and exported for around USD 0.50 /kWh, double the current price.

Renewable energy technologies

Electricity

- The Tokyo Metropolitan Government has invested in two 2.5 MW wind turbines located on reclaimed land by the central breakwater at Tokyo Bay.
- The city water treatment plant uses electricity from one of Japan's largest solar PV generators.
- A project to expand the use of solar energy was launched in March 2007 with the aim to achieve the greater use of solar thermal and solar PV for lighting in the Tokyo metropolitan area, up to around 1 000 MW total capacity.

Heating

- The greater use of solar thermal systems for heating water and space in houses is to be encouraged by the TMG as one of its objectives, but it is not yet clear exactly how this will be accomplished. If successful it will offset electricity and natural gas currently used for heating purposes.

Transport

- A project for the practical application of 2nd-generation biodiesel fuel was launched in February 2007.

Current policies relating to renewable energy project deployment

Sticks

- All power producers and suppliers, including Tokyo Electric Power, are required to release reports detailing the CO_2 emissions per kilowatt hour of electricity generated, their target for reduced emissions, the amount of renewable energy generated, and future schedules to achieve more generation from bioenergy, hydro, wind, solar, etc. If a company fails to provide a report after a further reminder request, the TMA will publicly announce it as a non-participant in the scheme.
- An amendment to the Tokyo Metropolitan Environmental Security Ordinance, which includes measures to reinforce the Green Building programme, was approved in June 2008 by the TMG. It aims to establish a system for evaluating defined environmentally-friendly features of houses that could enhance their value in the market. Owners of mid-size or larger dwellings will be mandated to submit plans on energy conservation for any new construction or planned extensions. Apartment owners will need to indicate the energy performance of their buildings in any advertisements for sale or rental. A process for encouraging all building owners to consider introducing renewable energy technologies is under discussion by the TMG.
- Tokyo's cap-and-trade scheme[83] was established because the GHG emissions from commercial buildings grew by over 30% since 1990 to reach over 20.6 Mt CO_2 in 2006, whereas industry reduced

83. www.kankyo.metro.tokyo.jp

its emissions by 47% to 5.2 Mt CO_2. Consequently, the Tokyo Metropolitan Government mandated a cap-and-trade scheme in June 2008 that will be the first urban scheme to give an emissions limit to office buildings. Any organisation that consumes over 60 TJ of heat, electricity and transport fuels per year is to be included, such as large commercial buildings, 1 100 businesses and 300 factories also covered. Large businesses are encouraged to engage in emission trading with small businesses. The first five-year compliance period will be 2010 to 2014, with the second 2015 to 2019. Base-year emissions are to be calculated from the average of the past three years with the cap for the first compliance period set at 6% below this average. Calculation of the allowance allocation has a variable compliance factor incorporated for the five-year period. In order to meet the target of 25% reduction of emissions below 2000 levels by 2030, the cap for the second period will need to be around 17%. Obligated businesses will be able to trade green renewable electricity certificates as well as green heat certificates derived from solar hot water. Fines will be imposed for non-compliance.

Carrots

- To introduce solar power systems at public facilities within the city, donations and investments are being sought from citizens, local businesses and corporates.
- The Green Power Purchasing Forum was established in March 2009 to try and change the structure of energy supply and demand by taking advantage of the city's purchasing power as a major electricity consumer. Over 80 organisations had joined within three months.

Guidance

- Public seminars have been held to encourage citizens and businesses to select the energy supplier they prefer, taking into account the amount of renewable energy investment being made and planned by the utility.

Innovative policies and replication potential

Encouraging electricity companies to disclose their CO_2 emissions data to stimulate customers to choose greener electricity can be replicated by any other city working within a liberalised energy market. The generous budget to support climate change mitigation measures cannot be easily replicated by many cities with smaller populations or lower revenues.

Helpful websites

- www.c40cities.org/bestpractices/energy/tokyo_companies.jsp
- www.ens-newswire.com/ens/apr2006/2006-04-06-05.asp
- www.kanyo.metro.tokyo.jp

Case study 2

Cape Town, Western Cape, South Africa

Population: 3.4 million

Rationale for selection: city in Africa exemplifying the difficulties involved with renewables

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X	X				X						X	X	X				

Description

The city of Cape Town has a wealth of untapped renewable energy resources. Yet the city's 10 200 GWh/year of electricity consumption relies heavily on thermal generation using coal and gas. Over 95% of electricity is purchased from Eskom (established in 1923 as the Electricity Supply Commission) that owns and operates 17 thermal generation plants, the Koeberg 1800 MW nuclear plant (the only one in Africa) and four hydro power plants totalling around 2000 MW capacity. Two hydro-power plants, totalling 1400 MW capacity, have pumped storage with two more planned at around 1500 MW each. Eskom controls the national grid and local distribution. It is planning a 100-200 MW wind farm. After the South African government attempted its privatisation in the late 1990s, funding for investing in more generation was denied. The problem was exacerbated by restrictions in coal supplies, lack of plant maintenance and failure to encourage energy-saving initiatives. Consequently, for several months during early 2008, Eskom conducted rolling black-outs across the country to minimise their problem of having to meet increasing peak load demand.

In response to the calls for climate change mitigation, Cape Town became the first city in Africa to implement a ground-breaking Integrated Metropolitan Environmental Policy (IMEP), which established the Energy and Climate Change Strategy (ECCS) that integrates renewable energy. Both the IMEP and ECCS have mission statements, sectoral campaigns, targets/goals and timeframes. The renewable energy focus for Cape Town is on wind generation and solar water heaters. The largest issue faced in implementing these environmental strategies is the financial challenge, since almost 40% of households in the city are living below the poverty line. Communication and increasing awareness are paramount for the success and further development of renewable energy sources in Cape Town.

Renewable energy technologies

Electricity

- A pumped storage plant consisting of two 200 MW turbine units located at the Steenbras Dam, two kilometres upstream of the Kogelberg Dam on the Palmiet River near Cape Town, pumps water to the dam and generates electricity from running the water down again in peak periods. At night, excess power on the grid generated by the conventional coal and nuclear plants is used to pump water to the upper reservoir. The project was regarded as a forerunner in environmental engineering and the whole site is a conservation area that in December 1998 was declared a Biosphere Reserve by UNESCO. The plant, operated by Eskom, is capable of responding to a surge in peak power demand in minutes. It has reduced the number of black-out incidents in Capetown and saved the city approximately USD 320 000 /month.
- The Darling wind farm, 70 km from Capetown, is the first commercial utility-scale, renewable energy project in South Africa (other than hydro). As a national demonstration project opened in May 2008 after two years of construction, four 1.3 MW turbines generate a total output of 13.2 GWh/yr. The city of Cape Town has contracted to purchase the electricity from the independent power producer for 20 years, apparently for around 20% above the Eskom electricity price, in order to make it a viable project. To make up the shortfall, consumers in the voluntary green market can purchase green electricity certificates from this source at a cost of USD 0.03 /kWh, in addition to the normal electricity costs. The demonstration wind project includes a visitor and education centre.

Heating

- To meet the city's goal of having 10% of all households and 10% of all city-owned housing equipped with solar water heaters by 2010, the Solar Water Heater Advancement Programme was developed. It calls for solar water heater installations to be undertaken on all new buildings, a subsidisation scheme, and a project to install solar water heaters on the facilities of the city's nature reserve.
- The Kuyasa project aims to install 6 300 solar water heaters in this low-income housing settlement, along with insulated ceilings and energy efficient lamps. It is supported as a clean development mechanism (CDM) project under the UN Framework Convention on Climate Change. The project, initiated by the city, will cost an estimated USD 1.5 million and over 2 300 solar water heaters have already been installed in less than a year. Each system with a capacity of 110 litres, helps to reduce annual GHG emissions by 1.29 tCO_2/household/yr, compared with heating by coal-fired electricity. Residents pay a portion of the installation costs but overall will save approximately USD 100/yr. The city will train local plumbers and electricians to install and maintain the systems and keep residents informed about renewable energy propects.

Transport

- A little more than half the total energy in Cape Town is used by the transport sector. The city has created a goal of a fully operational 'non-motorised' transport strategy by 2015. To meet this goal, the city is promoting bicycle and pedestrian transport with increased bicycle lanes and walkways; creating pilot projects for suitable cleaner transport fuels and options, including biofuels; and providing information to the public on feasible alternative transport energy sources.

Current policies relating to renewable energy project deployment

Targets

- These aim to result in the following outcomes:
  - 10% renewable energy supply by 2020;

- 10% of all households with solar water heaters by 2010;
- 10% of city-owned housing to have solar water heaters by 2010; and
- non-motorised transport to be in place by 2015.

Sticks

- Legislation is in progress for all new dwellings, extensions, and city-owned housing to install solar water heaters. Originally drafted in 2007, the proposed regulation is currently stalled.

Carrots

- The Renewable Energy Finance and Subsidy Office (REFSO) was created to give a one-off capital grant for renewable energy project developers (fiscal years 2005/06 – 2007/08).
  - Subsidies were placed at USD 32/kW capacity for electricity; USD 35/kl/yr capacity for biodiesel; USD 21.5/kl/yr for bioethanol or equivalent for other renewable energy technologies.
  - The subsidy was not to exceed approximately USD 32 000 per project.

Guidance

- Dissemination of renewable technology information by direct mail campaigns has been achieved.
- Green Building Guidelines are available both on-line and in hard copy format to explain how buildings and homes can become energy efficient, including the use of renewable energy.
- An Energy Committee was established to advise the Mayor and Mayoral Committee.
- Commerce and industry have been given information on options for generating renewable energy along with facilitation of grid-connection for such systems.

Innovative policies and replication potential

Cape Town has the potential to be a model city for other large African cities. However, financial issues and lack of information stifle the spread of renewable energy. The city has commissioned further research on the feasibility of waste-to-energy, waste-to-methane, co-generation, and sewage bio-digestors. The development of a "green tariff" is under consideration. Although wave energy development is in its infancy, it is being monitored as it holds much promise. Overall, there has been steady progress made, a lot of the potential to use renewable energy has not been realised due to severe funding constraints.

Helpful websites

- www.capetown.gov.za/
- www.capetowngreenmap.co.za/
- www.capegateway.gov.za/

Case study 3

Nagpur, Maharashtra, India

Population: 2.1 million (2001 census)

Rationale for selection: a large city in a non-OECD country with several different policies in place

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X		X		X					X	X	X	X		X		X	X

Description

The move towards renewable energy sources in Indian cities has been motivated by different objectives than other cities of the world. Concerns over the stability and security of the supply of energy, as well as sustainable development, are the key issues, more so than climate change. In addition, since major cities such as Nagpur often experience daily black-outs for several hours, the general public and politicians would be particularly interested in renewable energy systems if this could help solve these problems. India receives solar energy exceeding 5 000 TWh/yr and the national government is committed to 50 MW_p of solar power being installed by 2012. It also has the fourth highest wind potential in the world, which makes it an excellent candidate for renewable energy use.

Nagpur is located in an area that makes it a natural hub for industry, with two national highways and rail connections to all of India's other major cities. The soils of the region are rich for agriculture and there are huge deposits of coal and other minerals. Despite the high level of industry, Nagpur carries the distinction of being the second greenest city in India and is relatively pollution-free. As an important political and industrial centre, Nagpur is a model city for implementing renewable energy projects. It is a member of the ICLEI Local Renewables Model Communities Network project, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and GTZ. Membership began in 2006 and is on-going, with continuous support from the Nagpur municipal corporation and city stakeholders. Numerous pilot projects have been instigated and awareness campaigns undertaken, most targeting women, teachers and students (Kumar, 2009). This has led Nagpur to adopt a "Renewable Energy and Energy Efficiency" policy. Objectives outlined include to promote renewable energy sources such as solar water heating systems in all commercial/domestic activities; adopt new and renewable energy sources for all city applications such as its parks, campus lighting and traffic signals; and establish waste-to-energy projects. Nagpur is the first "solar city" in India and is planning to become the future host of the world's largest renewable energy park.

City carbon emissions were analysed for 2007/08 with the residential (35%), commercial (31%) and transport (27%) sectors each emitted around one third of the total and industry (6%) and waste (1%)

the remainder. Carbon emissions stemming directly from municipal operations from water supply and sewage treatment were around 50% of the total, with 40% from street lighting and the remainder from energy used by municipal vehicles and buildings.

Renewable energy technologies

Electricity

- In 2008 Nagpur was designated as India's first "Solar City" in its Solar Cities Programme. The total cost of the Nagpur Solar City programme is USD 3.8 M, with USD 1.9 M coming from the national ministry and the remainder paid by the municipal corporation. Nagpur's transformation into a model solar city will be complete by 2012. In addition, energy efficient green buildings will also be promoted on a large scale in the city. Instead of utility-scale solar plants, Nagpur will invest in small-scale solar power generation for street lights, garden lights, traffic lights, advertisement hoardings and solar water heaters.
- A solar power pack system was installed at the Renewable Energy Resource Centre on the Nagpur Municipal Corporation's property.
- For the new waste-to-energy demonstration plant, the Nagpur Municipal Corporation leased four hectares of land and entered into a build-own-operate agreement with two companies in 1998. The bio-methanation plant, with an estimated cost of USD 9.7 M, uses dry anaerobic composting to produce biogas. The facility was designed to process 520 t/day of municipal solid waste, generating 5.4 MWh of energy and 150 t of organic compost for sale. The current status of the project is unknown since investing partners backed out of the project in 2001.
- The Unique Waste Plastic Management and Research Company Pvt. Ltd. in Nagpur manages a waste-to-energy demonstration plant that converts plastic waste into diesel fuel equivalent.
- The multi-modal international hub airport special economic zone (MIHAN-SEZ) is government land set aside for industrial development. Manufacturers of renewable energy equipment and components have been encouraged to the location including a 2 000 MW/yr mono-crystalline photovoltaic production plant, a 240 MW/yr thin film plant, an exclusive float glass plant for application in solar collectors, and a 2 000 MW thermal power plant. These are to be located on 400 hectares of the MIHAN-SEZ using investments from Russian plane maker Sukhoi and a Malaysian-based firm, SKS Ventures.
- The world's first renewable energy park is being created on 3 000 hectares of land purchased by the Nagpur Municipal Corporation. Once fully operational, it aims to produce almost 50% of the current global production of renewable energy components, according to Mr Muttemwar, the Minister of New and Renewable Energy. It will include:
  - a 10 MW solar thermal energy plant which will be Asia's largest;
  - production of a range of renewable energy devices and systems;
  - nearly 500 companies establishing production units with American, Australian, and Japanese companies already showing interest;
  - investment of USD 2 billion initially with the potential to attract USD 5 billion within five years; and
  - an estimated 20 000 direct jobs together with 150 000 indirect ones.

Heating and cooling

- A 500 litre/day solar water heating system has been installed in Nagpur Municipal Corporation's hospital.
- A solar thermal system has been installed in Hotel Pride, Nagpur.

Current policies relating to renewable energy project deployment

Targets

- a 20% reduction of conventional energy consumed by municipal buildings and services to below 2005 levels by 2012;
- a minimum 3% reduction in overall city conventional energy consumption by 2012; and
- 10% of primary energy consumption to be met by renewable energy sources.

Sticks

- It has been mandated that all new residential buildings with greater than 1 500m^2 floor area must install solar water heaters. A 10% property tax rebate is offered to gain compliance.
- An energy audit of the water supply system will be undertaken to reduce waste and losses and hence reduce pump energy demand.

Guidance

- The Renewable Energy Resource Centre was established in 2006 to facilitate dialogue with the local community and to produce newsletters and brochures which further educate and promote renewable energies. The centre is strategically located in a high traffic area that is frequently visited by citizens.
- Several awareness campaigns have been undertaken using a mobile van, establishing more than 20 school energy clubs, and providing training for students and teachers.
- For *Akshay Urja Diwas*, (national renewable energy day), Nagpur organized a rally and school children participated in competitions. Banners, posters, a cultural programme and stalls raised awareness and served to educate the public about products related to renewable energy use.
- The Nagpur Municipal Corporation hosted a round-table discussion on city-level renewable energy policies. An International Workshop for the “Local Renewables Model Communities” network was also hosted by Nagpur. It aimed to provide a common platform to share and learn from experiences of other cities about renewable energy and to discuss the financing of renewable energy projects.

Innovative policies and replication potential

The Nagpur council has set the policy goal of becoming a model city in renewable energy and energy efficiency. All of the pilot projects and demonstration plants are designed to be replicated elsewhere. Nagpur was chosen by the national government to set an example for other Indian cities to also become “solar cities”. Funding support for up to 60 cities to develop roadmaps on how to reduce their energy demand, oversee the implementation stage, and create awareness campaigns in order to also become “solar cities” has been made available by the national government for up to around USD 0.5 M per city.

Helpful websites

- http://www.iclei.org/uploads/media/LR_Nagpur_policy_bali.pdf
- http://www.iclei.org/index.php?id=4995
- http://mnes.nic.in/ India’s Ministry of New and Renewable Energy
- http://59.90.39.15:8081/NMCEIP/index.jsp Nagpur Municipal Corporation website

Case study 4

Adelaide, South Australia

Population: 1.16 million (with 20 000 living in the Adelaide City Council administered area)

Rationale for selection: a large OECD city with a good solar resource and several policies to exploit it

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building regulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X					X						X		X	X		X	

Description

Adelaide, the coastal capital of South Australia, is the fifth largest city in the country (although the centre of the city, administered by the Adelaide City Council, is only around 3 km^2). The city currently ranks in the Top 10 in the Economist's "World's Most Liveable Cities", with the economy mainly based in manufacturing, particularly defence and automotive. The median individual income is relatively low at around AUS 19 000/yr but Adelaide's housing and living costs are substantially lower than in other Australian cities. In recent years, there has been a substantial increase in the population which in turn has increased the demand for energy and the resulting greenhouse gas emissions have increased significantly since 1994. In addition Adelaide has greater peak electricity supply problems and higher average domestic electricity prices than other major Australian cities.

There is overlap in the policies and programmes between the State of South Australia (with around 75% of the 1.6 million population living in Adelaide), the greater metropolitan Adelaide, and the smaller City of Adelaide. For the latter, the Capital City Committee established the "Adelaide Green City Programme" in 2002 aiming to create a better, more sustainable and environmentally friendly city and to be recognised internationally as a green city by 2010. In 2003, urban ecologist Herbert Girardet was commissioned to give policy advice on achieving these goals and all 33 of his recommendations have now been implemented.

The City Council's "Carbon Neutral Action Plan 2008-2012" set a goal of reaching zero net greenhouse gas emissions in buildings by 2012 and in transport by 2020. Projects initiated in the first year of implementation resulted in 6 000 tCO_2 emission reductions. A CHP plant is to be installed at the Aquatic Centre which will halve current GHG emissions. Other community projects include encouraging cycling, providing assistance to improve the environmental sustainability of businesses, and providing incentives to city residents to install solar systems. Energy efficiency audits for homes and businesses have been conducted and smart meters are being installed in homes that wish to participate.

Several policies and initiatives of the South Australian state government complement the goals set by the city. These include the State Strategic Plan target to support "the development of renewable energy so that it comprises 33% of the state's electricity production and consumption by 2020", currently at 14.7% of production and 16.3% of total consumption (due to imports of electricity from other states). Over half the national total capacity of wind power is located in the state with 740 MW installed and a further 128 MW under construction. A feed-in tariff for small scale solar PV introduced in 2008 has resulted in the number of systems expanding from 1 500 to 8 000 by mid-2009. Under the new Building Innovation Fund, five projects have been funded for 2009/2010 that implement innovative renewable energy and energy efficient technologies for commercial buildings. Rebates for solar water heaters and energy efficiency measures are also offered.

In June 2009 the Premier of South Australia announced the establishment of "Renewables SA" along with an AUS 20M fund to accelerate investment in the sector by fostering innovation and creating green jobs. The first project funded was the establishment of a Centre for Geothermal Research because South Australia has attracted over 90% of the national R&D investment in geothermal systems, drilling techniques and exploration since 2002. Hoping to help make Adelaide the global centre for renewable energy policy and research, University College, London, opened an overseas campus in 2009 with a focus on urban energy and resources.

Other initiatives involve improved pedestrian routes and access; more bus stops to better suit people of limited mobility; adding the newest environmentally friendly, hybrid automobiles to the government fleet; establishing an Office of Cycling and Walking; installing more than 10 km of on-road bicycle lanes and more than 6 km off-road bicycle paths; and doubling the number of bicycle lockers provided at railway stations and transport interchanges. These are not directly involved with renewable energy so will not be discussed further here.

Renewable energy technologies

Electricity

- Mini-wind turbines

  The state government is continuing a trial of mini-wind turbines with several different models purchased and installed on metropolitan buildings. For example several Swift 1.5 kW mini-wind turbines of 2 m diameter have been installed on the roofs of prominent buildings (Fig. 32), including the State Administration Centre, Wakefield House and the Adelaide Central Markets. Each turbine produces around 4 000 to 5 000 kWh of electricity per year and avoids 1.4 tonnes of greenhouse gases entering the atmosphere by displacing coal-fired power generation. Another 20 have been ordered.

Figure 32 • *1.5kW mini-wind turbine above Wakefield House*

Photo credit: John Mercer

- Solar PV

The City of Adelaide (plus the three nearby suburbs of Salisbury, Tea Tree Gulley and Playford) received recognition from the Australian government as one of six solar cities under its Solar City Programme launched in October, 2007 with AUS 1.2 M granted to implement various solar projects. This is in addition to the Adelaide Green City Programme and state government support, so together several iconic solar PV projects have been developed to demonstrate the potential for this technology.

- The South Australian government funded a 160 kW solar array on Adelaide airport.
- A 1 MW array, the largest in Australia, has been constructed on the roof of the Goyder Pavilion at the Adelaide Showgrounds (which also incorporates a storm water collection system harvesting 6-7 million litres per year).
- At Adelaide Central bus station a 50 kW grid connected, solar power system of 320 panels was installed in March 2008 by BP Solar. It generated more than 99 MWh of electricity in its first 12 months of operation.
- Adelaide Central Market is to have a 50 kW solar PV project installed in 2010 as part of the Adelaide Solar City initiative. It has been designed not to detract from this popular historic tourist site.
- A 4 kW solar PV system installed at the Golden Grove Arts and Recreation Centre generates about 5.6 MWh /year of electricity.
- A 50 kW solar PV system, the Keylink Solar Project, installed at Detroit Diesel Australia, produces 20% of the building's electricity needs. It is a joint project between the city and the largest industrial property group on the Australian stock exchange. It will showcase the power of solar energy, educate the local community, and demonstrate the commercial applications of solar energy.
- In the North Terrace Solar Precinct, the South Australian Museum, Art Gallery, State Library, and Parliament House buildings each have solar PV systems installed, generating a total of around 130 MWh/yr.
- Approximately AUS 2M has been invested in a 50 kW solar PV system that will produce more than enough electricity to power the City Council's Rundle Lantern. It is made up of 748 square panels (Fig. 33) that can be programmed to display numbers, letters, geometric shapes as well as artistic displays of lighting patterns.

Figure 33 • *Adelaide's popular public digital art display, Rundle Lantern (left), is powered by a solar photovoltaic system as are the solar "Mallee trees" (right) on the Adelaide Festival Plaza*

Photo credit: Adelaide City Council (left); Dee Muzzi (right).

- Decorative “solar mallee trees” (named after the native eucalyptus tree species, Fig. 33) harness solar energy via their laminated oval solar cell canopy to provide a source of light at night. Each tree can produce 860 kWh annually but only consumes 125 kWh, so the excess of over 2 000 kWh/yr is exported to the power grid during the day once the batteries have been recharged. Overall this avoids around 2 tCO_2/yr of emissions which equate to planting around six real trees each year.
- On Victoria Square 12 solar PV lights will be designed to produce electricity during the day and export it to the grid at peak times, whereas at night the lights will be powered from the grid at off-peak times. As part of the “Green City” programme some of the support funding also came from the state.
- The roofs of five new tram stops comprise 40 transparent solar panels that also can provide shade by removing 90% of the heat and 98.5% of the UV light. Each of the 1 m^2 panels gives 1.76 kW_{peak} and will generate around 7 kWh of electricity daily on average. Lighting demand for each shelter is only 1-2 kWh per day so excess power will be exported to the grid. Power output from the five shelters will avoid around 13 tCO_2/year of emissions.
- The South Australian government introduced a Solar Schools Programme and is installing 2 kW solar PV systems on 250 schools. Two inner-city primary schools in the City of Adelaide are funded as part of the federal government’s Solar Cities Programme that provided grants of up to AUS 40 550 for installing solar PV systems.

Heating and desalination

- A solar thermal testing centre will be established to support the research and development of solar hot water, solar heating systems and other solar technologies.
- The Spanish engineering firm Acciona announced plans in mid-2009 to double the size of Adelaide’s new desalination plant.[84] The deal will make the plant the largest renewable energy-powered project of its type in the world.
- Biomass for energy has limited applications in the city but a “Three million trees” programme aims for volunteers to plant native tree seedlings and associated under-storey on around 2 000 ha of parks, reserves, other municipality-owned land, transport corridors, water courses and coastline. Once fully grown the trees will have removed around 900 000 tCO_2 from the atmosphere. It is unlikely any will ever be harvested for biomass use but experience gained in species selection, survival rates, maintenance requirements, etc. could be useful should such an activity be proposed around the city in the future.

Transport

- The Tindo bus (named after the Kaurna Aboriginal word for sun) is the world’s first solar-powered bus using 100% solar electricity (Fig 34). It uses sodium/nickel chloride batteries with controlled temperature. Recharging power comes from the largest grid-connected solar PV system in South Australia located at the Adelaide Central Bus Station, costing AUS 550 000 and producing 70 MWh/yr. Funding came from the city council and the federal government. Batteries are continually topped up during operation by the on-board solar panels. It also has a regenerative braking system that saves up to 30% of energy consumption, so that overall, the Tindo can travel up to 200 km between re-charging. The system has low-maintenance components, and overall fuel costs are claimed to be 50% lower than for a diesel bus. It is a zero emissions, carbon neutral vehicle with free fares offered to passengers.

84. http://www.abc.net.au/news/stories/2009/06/28/2610554.htm

Figure 34 • *The Tindo bus is the world's first to be fully solar-powered using both roof mounted PV panels and a PV recharging system*

Photo credit: Adelaide City Council

Current policies relating to renewable energy project deployment

Targets

- The state target of 33% renewable electricity by 2020 has a major impact on the policies of Adelaide as a "solar city".

Carrots

- Rebate programmes
  - Photovoltaic programmes give cash rebates of around AUS 800 per system for domestic and small business installations.
  - A solar hot water heater cash rebate of AUS 1284 (if installed after February 3, 2009) or AUS 801 (if installed before February 3, 2009) is available for consumers wishing to replace an existing electric storage hot water system.

Guidance

- An extensive consumer campaign is underway to encourage residents to adopt green energy including installation of solar PV systems on homes and businesses with rebates from the government.
- A Renewable Energy Virtual Display is located in the foyer of the South Australian Museum to demonstrate a range of methods to reduce greenhouse gas emissions, including by the uptake of PV, solar hot water, wind, carbon sequestration through tree planting and biodiesel. Daily data concerning the renewable energy produced in South Australia is provided through the interactive website.
- Developing industry capacity in the renewable energy generation sector is an objective of the city council.
  - A government-facilitated activity aims to encourage private sector exploration of a scheme to remove barriers to the uptake of domestic solar water heating systems.
  - A hydrogen research group has been established to explore several renewable energy/hydrogen demonstration project opportunities.

Innovative policies and replication potential

Adelaide as a "solar city", (in association with the greater metropolitan area of Adelaide and the South Australia state government) has demonstrated the potential for solar energy technologies in a range of applications; supported development of local industry; provided information to citizens; and offered a financial incentive scheme in the form of a rebate to encourage private investments. Successful outcomes have resulted and GHG emissions reductions have resulted. However it will remain to be seen how cost effective this package of policies will be over the longer term and whether significant benefits from the total investment provided by the national, state and city governments will be successfully achieved.

Helpful websites

- http://www.capcity.adelaide.sa.gov.au/html/greencity.html
- http://www.adelaidecitycouncil.com/
- http://www.adelaidesolarcity.com.au/
- http://www.capcity.adelaide.sa.gov.au/pdf/Girardet_final_8Mar.pdf
- http://www.cityofadelaide.com.au/

Case study 5

Merton, London, England

Population: 200 000

Rationale for selection: a successful innovative policy by council that has been replicated widely

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration land use	Voluntary agreements
X	X	X	X		X							X						

Description

The Borough of Merton in the south west of the City of London is one of 33 London boroughs (defined as a self-governing sub-division of a city). It became a leading municipality in the United Kingdom after setting a goal to reduce its CO_2 emissions by 15% by 2015. After considerable analysis as to how this might best be achieved, it developed policies that would give the highest emissions reductions in the shortest time period and at the least cost, but also ensuring that these were related to activities over which the council has direct control.[85] This led to including building design, urban planning, local energy use and waste but excluding transport policies that tend to involve national and regional policies.

As a result, the borough has become known for the "Merton rule" that it developed and first implemented. Following the publication of the national planning policy statement "Planning Guidance on Renewable Energy" issued by the Office of the Deputy Prime Minister in 2004, Merton was the first municipality to formalise the government's renewable energy targets in its adopted district plan. It became a condition of the local planning consent process for renewable energy to play a major role. The original threshold for implementation of the policy was more than 1 000 m^2 of non-residential development or group of 10 or more houses/apartments. In effect the rule has become a directive to building developers that they integrate sufficient renewable energy technologies into their new buildings to produce sufficient energy for use on-site to result in at least 10% CO_2 emissions reductions compared with if the building had been operated without these technologies installed. The basic principle also encompasses energy efficiency, since investing in renewable energy to achieve the 10% reduction when consuming a lot of fossil fuel-based energy would be costly. Reducing the energy demand means a lower investment is needed in renewables.

85. A municipality has little control over local industries or the chosen lifestyles of its residents for example.

The impact of the policy was so effective that it was soon taken up by the Mayor of London as well as by other boroughs and councils across the United Kingdom. It has since become part of the national planning guidance, though there is some current debate that this concept may be amended or withdrawn.

The Greater London Authority (GLA), created in 2000, formed the London Energy Partnership to address climate change initiatives across the wider London region. In 2005 a Climate Change Action Plan was developed and the London Climate Agency was created to deliver the policy. The Mayor of London promoted the use of on-site renewable energy generation and CHP. The GLA set various targets as outlined in several policy documents (Siemens, 2008). For example the 2004 Energy Strategy set a target of 665 GWh of electricity and 280 GWh of heat to be generated by decentralised renewable energy installations by 2010. In addition, the intention for the 2012 Olympic Games is that 20% of the energy consumed during the games will come from new, local, renewable energy sources. For example, an aerobic digestion system is planned with the biogas to be used at the games village.

Renewable energy technologies

As a result of the Merton rule, building developers have invested in such technologies as small wind turbines, solar PV, ground source heat pumps, biomass heating and CHP systems, and solar water heaters. Any additional costs involved have not had to be borne by local taxpayers, but by the developers. Under some circumstances they may be eligible for financial support from the national government. Examples of several successful new building projects within the Merton borough, and in the neighbouring municipality of Croydon that also abides by the policy, are outlined below. Croydon is one of around 150 councils across the United Kingdom also actively implementing or drafting the Merton policy.

Electricity

- King's College, Wimbledon installed a 5 m tall, 3 m diameter vertical axis wind turbine produced by the British company "Quiet Revolution" on a mast adjacent to the new, three-storey, 660 m^2 floor area extension to the science department. Their target was to reduce emissions by over 6 tCO_2 annually. The power generated from the 5kW device is around 6000 - 7000 kWh/yr and is used mainly to meet the lighting demand in the building. The installed cost is relatively high, at around GBP 35 000, but future installations could be eligible for a 50% grant through the British government's "Low Carbon Building Programme" that commenced in July 2009.
- The curved roof of a new self-storage building, owned by the company Big Yellow, has solar PV panels installed. A wind turbine similar to that at King's College was constructed adjacent to the building. Together, these technologies result in 12 tCO_2 reductions/yr.
- A complex of 350 apartments has been built by Fairview Homes in Croydon after being granted planning permission in February 2006. A mixture of solar roof tiles that produce either electricity from PV systems or solar heat for water has been integrated into the roof design.[86] Together with 20 micro-wind turbines and 61 solar water heaters installed on the building roof, they result in a 50 t annual CO_2 reduction. This is in excess of the 10% minimum requirement, since the builder considered the Merton rule as adding value to the apartments which consequently sold quickly after completion in 2007.

Heating and cooling

- The do-it-yourself and garden equipment chain store B&Q, has installed in its New Malden branch a solar thermal system and a ground source heat pump for under-floor heating in the new 10 000 m^2,

86. Since development in 2004, Solarcentury has partnered with Sony UK to manufacture these tiles. www.solarcentury.co.uk/Press/Press-Releases/Solarcentury-partner-with-the-Sony-UK-Technology-Centre-in-the-drive-towards-green-technology.

three-storey store. The aim was to meet the 10% emission reduction local regulation using a vertical axis wind turbine and solar PV panels as well as to provide around 20% of its on-site energy demand.

- Developers of an apartment and office block of 6 000 m^2 installed solar thermal collectors and solar PV panel installations on the roof. Together they provide an annual emissions reduction of 20 tCO_2.
- The 3 000 m^2 Lidl supermarket building in Merton installed horizontal pipes of a ground source heat pump system under the car park. Heat extracted from both the building space in summer, and from pre-cooling of the refrigerated chilling cabinets, is stored in the ground for use in the winter. The consequent reduction in CFC gas used in the refrigerators resulted in a greenhouse gas reduction of 92 tCO_{2eq}/yr, equivalent to 35% saving of total carbon emissions.

Current policies relating to renewable energy project deployment

Sticks

- The regulation in Merton that all new buildings must have at least 10% CO_2 emission reductions through the uptake of renewable energy has led to a range of technologies being used by building designers and developers on all new buildings. Compliance with the policy is required as a condition of the planning consent before the construction of the building can become legal.
- The 10% calculation is based upon the energy consumption of the proposed building multiplied by the floor space of the development. Where the end-user of the building is not known at the time of construction, fittings can not be included in the energy assessment. Since this would have resulted in only the lighting being considered, the Energy Use Benchmarking Guides produced by the Building Research Establishment are used to give the energy consumption per square metre, as based on the type of building. For example, an open plan office with natural ventilation will normally use less energy than having separate offices and forced ventilation. Gas and electricity values can then be estimated by calculating them separately and then combining. Total energy consumption is then converted into carbon emissions to give the total carbon footprint for the building, from which the 10% requirement can be determined. This is the figure that the developer has to satisfy using whatever choice of technologies is deemed most appropriate.
- It is usually cheaper to reduce the energy consumption of a building than to provide renewable energy equipment. If energy efficiency measures are to be incorporated as standard into the building (such as compact fluorescent lighting and increasing the thermal mass) then this will reduce the overall carbon footprint, thereby reducing the 10% requirement. Failure to meet the agreed target results in the developer being fined.

Guidance

- Many presentations have been made by staff of the council at national and international conferences to inform other council about the policy.

Innovative policies and replication potential

Since June 2008 the British government now "expects all authorities" to put in place policies similar to the Merton rule. The Minister for Housing and Planning wrote to all chief planning officers to this effect, urging them to do so and highlighting the successful work of the Merton municipality. It was emphasised that it was essential for all planning authorities to follow this example, and many have now done so. They have usually employed similar principles, but not all have chosen 10% as the minimum CO_2 reduction target level. There are good arguments for some local authrorities to increase this minimum level to 20%, as London did in 2006, but others have preferred to set it at 5%. In part the level depends on local renewable energy resources and the health of the local economy.

Monitoring of each building to ensure that the emission reduction target is being met by the users was originally based on periodically reading the meters within the building. However, that took time and failed to provide certain information, for example, exactly when a failing technology may have stopped working following the last reading. The concept now employed by Merton council of real-time energy monitoring within the building for grid imports, local generation use, and even exports of surplus power to the grid, enables closer monitoring to occur, using continuous automatic updates. The data can be conveniently shown on a digital map of the district with all buildings identified, along with details of the plant, the commissioning date, etc. To achieve this, a planning enforcement is required to ensure the building developer installs suitable monitoring devices that give real-time, energy outputs for each of the installed renewable energy technologies.[87] The data can then be used to automatically calculate the CO_2 avoided to date,[88] confirm compliance with planning and building codes, provide evidence for renewable energy technology performance and policy effectiveness, and give cumulative renewable energy generation data or CO_2 reductions for a region or nation.

Around half the United Kingdom's local authorities have now adopted the Merton rule in one form or another. Should it ever become standard practice for all councils throughout the United Kingdom, then if set at the 10% level, it would result in 160 000 tCO_2 avoidance annually and would also result in around GBP 1 billion of renewable energy industry business being stimulated. This would, in turn, lead to economies of scale for the various renewable energy technologies and hence encourage more people to retrofit their homes, offices and factories.

Helpful websites

- www.merton.gov.uk/living/planning/planningpolicy/mertonrule.htm
- http://www.roteirolocalclimaticas.org/EN/programa.html

87. This is economically possible for electricity generation, but it can prove to be more of a challenge for small heating and/or cooling systems.
88. This concept would also enable energy data from numerous distributed systems to be accumulated, so that its full contribution could be considered in national databases which is not usually the case today.

Case study 6

Freiburg im Breisgau, Baden-Wüerttemberg, Germany

Population: 220 000 with around 6 000 living in the suburb of Vauban.

Rationale for selection: a town with a practical vision for renewable energy supported by its citizens

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X	X	X		X	X			X			X	X	X	X	X	X	X

Description

Freiburg city politics have aimed towards developing a sustainable city since the 1970s when protests were made against a nuclear power plant planned to be built nearby. In 1986 the Freiburg municipal council passed the "Local Energy Supply Concept", with goals for improved energy efficiency, effective generation and the greater use of renewable energy sources. A decade later, under the "Climate Protection Concept", the city resolved to reduce its CO_2 emissions by 25% of the 1992 level by 2010. Since then, the city has become internationally recognised for its environmental approach and, amongst other awards, was a finalist in the 2009 European Union's "Green Capital Award".

Nevertheless, the city is unlikely to meet its 2010 CO_2 reduction target. This is in spite of having doubled the use of public transport and having reduced the average emissions per capita by more than 20%, from 10.6 tCO_2/yr in 1997 to 8.53 tCO_2/yr in 2007. An overall total greenhouse gas reduction of 13.8% was achieved by 2007, transport being the main challenge, having only a 4.8% reduction. Regardless, in 2007, based on detailed analysis, the city council set a more challenging "Climate Protection Action Plan" goal of reducing its CO_2 emission by 40% by 2030 and voted additional budget funds to help meet this goal. To achieve it will need strong political frameworks through bold legislation in national and European Union partnerships; political concepts for reducing vulnerability; an improved transport system with alternatives to the automobile; citizens to support the concept by taking an active part in lifestyle choices; and for renewable energy to provide a larger share of the municipal energy supply.[89]

The focus on renewable energy has attracted solar businesses and research institutes as well as the European office of ICLEI and the head office of the International Solar Energy Society (ISES) to the

89. Dr Dieter Salomon, Lord Mayor, Chairman of FWTM at the International Conference "Local Renewables Freiburg 2009" welcome address, 27-29 April 2009.

city. A large solar trade fair is held annually, in addition to a wide range of energy events, such as the "Local Renewables Freiburg 2009" organised jointly by FWTM (Management and Marketing for the City of Freiburg) and ICLEI. Many visitors come to Freiburg specifically to see the renewable energy projects and to learn from local policy experiences. A target of 10% of electricity coming from renewables by 2010 has been set, with two thirds expected to come from bioenergy CHP plants and the rest split between wind (1.6 percentage points of the target) and solar (1.1 percentage points). Reaching only a 4% share in 2008, the target will probably not be met, but some biogas plants are being planned that should help make a further contribution.

The settlement of Schlierberg in the suburb of Vauban, 3 km south of the city centre, is a major visitor attraction, with its zero-energy houses and other energy efficient buildings using heat from a wood chip cogeneration plant and with many solar PV installations. Once a French military base, the city purchased the site in the early 1990s and then took the responsibility for its planning and development. The overall plan was to develop the district to meet ambitious ecologic, social, economic and cultural requirements in a co-operative manner with the citizens. The buildings were converted to low-energy homes (with maximum 65 kWh/m^2 annual heating demand) starting in the mid 1990s, eventually with around 50 units also having solar PV installed on their roofs. Other buildings were developed by investors as passive houses that consume no more than 15 kWh/m^2 per annum. The purchase price for this "Baugruppen", is currently around EUR 2 300/m^2, tending to be slightly higher than the average. Private cars have to be parked in the community car parks on the periphery for an annual fee and are only allowed near the houses for deliveries.

The energy politics between city administrators, the more conservative state of Baden-Württemberg, Badenova,[90] and the corporate energy company EnBW working in the region, makes it challenging for the city council to progress its sustainability agenda as rapidly as it might wish to. Given this constraint, good progress has been made. For example, a budget of EUR 2 million has recently been agreed for the renovation of the city's old and historical buildings. This has included the non-intrusive, strategic installation of 180 solar PV panels on the tiled roof of the historic City Hall.

Renewable energy technologies

Electricity and CHP

- Around 40 GWh of renewable electricity is generated annually at present. With 1 800 hours of sunshine received annually, the solar resource in the city is one of the best in Germany. The rapid uptake of solar PV has also been supported by the national feed-in-tariff law and under the Renewable Energy Act, power is sold to the grid. Approximately 60 local buildings have significant solar PV systems integrated into their designs. These include the 100 kW_p system installated on the roof of the Badenova football stadium in 1995, since extended to 290 kW_p; 690 kW_p on the Trade Fair Centre roof; 365 kW_p above an expressway tunnel; 240 PV panels on the 19-floor façade of the railway station; as well as various PV panels installed on the City Hall, the Fraunhofer Research Institute for Solar Energy Systems, half of the 70 schools, several churches, a few factories (including 570 kW_e installed on the Solar-Fabrik manufacturing plant), private houses, supermarkets and multi-storey car parks (Fig. 35). By 2009 over 12 MW_p of PV capacity had been installed in total, producing around 10 GWh/yr of electricity. However, this is still only just over 1.1% of the total power demand of the city. Several of the buildings generate more power than is consumed by their residents.

90. Badenova is the largest energy supplying company in the South Baden region, originating from the merger of several local and municipal energy providers, some remaining as principal shareholders.

Figure 35 • *Examples of buildings in the Vauban suburb with solar PV on their roofs include a car park, a supermarket (just across the boundary in Merzhausen), private houses and an apartment block with the tram to the city centre running on grass covered areas*

Photo credits: Ralph Sims

- Five 1.8 MW Enercon wind turbines have been constructed on city land in the nearby Schwartzwald (Black Forest) overlooking the city (Fig. 36). They generate 14 GWh/yr of electricity that meets around 1.3% of total city demand. Since the state council has prohibited wind further developments for aesthetic reasons, targets to increase this share may no longer be achievable.

Figure 36 • *Wind turbines on Freiburg council-owned land in the Black Forest overlooking the city*

Photo credit: Ralph Sims

- The Vauban biomass CHP plant using wood chips from the nearby forest and wood processing industries has 345 kW_e capacity and produces around 1.5% of the total power demand for the city. The heat capacity of 7 MW_{th} has been utilised in a district heating scheme since 2002 to meet around two-thirds of the local heat demand. In addition, a solar PV manufacturing facility has installed a small CHP plant running on vegetable oil. In total, over 50% of the city's power demand is met by around 130 local, small-scale CHP plants, but most of these are burning natural gas. For example, the chemical company Rhodia has operated a CHP plant in partnership with the local utility company Badenova since 1998. It has the capacity for 60 MW_e and 244 MW_{th} of heat used on site, giving a performance efficiency of around 80%.
- A landfill gas site also produces CHP, with a total power generation from biomass sources amounting to around 16.6 GWh/yr, or 2% of total energy demand. The target for biomass CHP electricity is around 6% of the projected total demand by 2010. Badenova is planning five new sites for the production of biogas within the Freiburg region. The gas will be fed into the natural gas network and used as fuel for CHP plants in Freiburg to help meet the targets.
- Freiburg's refuse collection used to be taken to the city's landfill site before 2005. Since then, non-recyclable waste is incinerated at a thermal plant in the Industrial Park, Breisgau 20 km south of Freiburg. This plant supplies electricity to 25 000 households and extraction and use of the surplus heat is planned.
- Small hydro-power plants in local rivers, streams and canals generate around 1.9 GWh/yr.
- An enhanced resource geothermal project near Freiburg has been evaluated with the aim of producing 4 to 10 MW_e electricity and 23-40 MW_{th} heat. The high drilling cost, estimated to exceed EUR 50M, is a disincentive, as are the technical and safety risks. Whether construction will begin within the next two to three years remains uncertain.

Heating and cooling

- Around 15 000 m^2 of solar thermal collectors have been installed on numerous buildings within the city. This includes the University Hospital cafeteria with a 270 m^2 collector to produce hot water for use in the kitchen and dishwasher.
- The "Heliotrope" rotating solar house that tracks the movement of the sun is a novel design of building by local architect Rolf Disch. It is cylindrical, built on a single supporting shaft, with triple-glazed windows on only one side and with solar collectors mounted on the roof.[91] It follows the sun in winter to gain heat, but can rotate away from it in summer to provide cooling.
- A ground source reversible heat pump has been installed by the pharmaceutical company Pfizer in its Freiburg plant to give mechanical heating, mechanical cooling or natural cooling to its office building. The 19 probes drilled to 130 m depth at 6 m spacings in a field of 0.12 ha in 2008 can provide heating up to 135 kW capacity with a cooling capacity to 110 kW. The soil temperature varies between 10°C and 20°C from the end of the heating period to the end of the cooling period. The company also has installed a Quantum high efficient chiller and a biomass boiler and is planning to install a biomass CHP unit.

Transport

- The city trams are powered by electricity with 80% of their total demand generated by local hydro-power plants and the rest from other renewables in the mix.
- Good cycle tracks, and easy access to electric trams and buses for the majority of the city population, have enabled 35% of residents to choose to live without owning a car. In Vauban,

91. http://www.inquirer.net/specialfeatures/theenvironmentreport/view.php?db=1&article=20090314-194059

car-free living is strongly promoted, with easy access to 35 share-cars available for residents to rent when required, by simply booking one over the internet. Residents are encouraged to park their private cars in one of the two multi-storey car parks located a short distance away from the housing areas, for which they pay a substantial annual fee. A regular, free tram service to the Freiburg city centre and elsewhere has been installed since 2006, with buses also providing free travel.

Current policies relating to renewable energy project deployment

Sticks

- A zero-energy housing standard to achieve a maximum of 65 kWh/m^2/yr was established for all new house constructions and house renovations in the city. The districts of Vauban and Rieselfield have all their new buildings meet this standard, although some meet the "plus-energy standard", whereby improved, passive house designs, integrated with solar PV, give greater electricity generation than is needed to meet the demand of the residents.
- After 2009, all new houses built will have to meet a "passive house standard" of maximum energy demand of nearly 15 kWh/m^2/yr.
- Energy issues are taken into account at the early planning stage of new city facilities including passive solar designs and energy efficient building standards.

Carrots

- The regional energy supply company Badenova, with Freiburg city as a joint owner, offers a EUR 300 investment rebate for customers wishing to install PV systems. In addition, the national feed-in-tariff is an incentive.
- An additional budget of EUR 2M has been agreed for the renovation of the city's old and historic buildings, including the non-intrusive, strategic installation of 180 solar PV panels on the tiled roof of the old City Hall.
- The city's Building Society provides loans for, not only insulation of existing buildings, but efficient energy supply solutions in new buildings, including biomass for heating.
- The city has provided subsidies totalling EUR 450 000 per year since 2003 for the energy efficient renovation of old, privately owned buildings that therefore also supports the local crafts people.

Guidance

- A vocational college (Fig. 37) runs a renewable energy training centre for technicians and installers of renewable energy projects.

Innovative policies and potential for replication

The council's 12-point programme for its Climate Protection Policy includes "taking into consideration climate protection, energy efficiency and solar optimisation at an early stage of all urban developments, urban land use plans, and real estate sales contracts".

Badenova finances renewable energy projects through the sale of green electricity at a special tariff, with a EUR 0.15 /kWh premium. A 10% uptake by customers choosing to support renewable projects provides a fund amounting to around EUR 0.5 M/yr. Using this fund to support renewable energy projects at up to around 10% of their capital investment cost has enabled steady development of projects to continue within the city, the latest being the planned biogas plants.

Figure 37 • *Displays of solar, wind and hydro systems are evident in the front of the Freiburg Polytechnic college, where technicians and installers are trained in renewable energy technologies*

Photo credit: Ralph Sims

An internet tool to enable building owners to identify the suitability of their roofs for installing solar collectors has been developed.[92] It is similar to the Osnabrück system described in Section 5. Building roofs and specific sections of them are classified as excellent, good or fair, based on the orientation and pitch of the roof. The website also provides building owners with the size of the potential suitable roof area, indicative costs of investing and installing the solar panels, and possible CO_2 reduction benefits.

To also help foster the development of this low energy city, Freiburg is developing a "heat register" as a planning instrument showing heat demand and supply across the city to increase and optimise existing heat networks and cogeneration plants at all scales.

The renewable energy strategy of the city has not depended solely upon core funding. It has also resulted from the synergy created by the vision for the city's future with many stakeholders, especially those in the solar sector who are collaborating for mutual benefit. Even though this approach could be replicated by early-mover cities in other countries, it could not become common practice once renewable energy becomes main-stream.

Considerable interest in Freiburg's policy approach has been achieved. It is perceived as a "model green city" by many Asian countries with frequent visits from Japanese, South Korean, Indian and Chinese delegations. It has nine partner cities including Padua, Italy with which, through a joint subsidiary company, it will use its experience to help build the largest PV plant in Italy.

92. www.freiburg.de/freesun

Helpful websites

- www.freiburg.de/greencity
- www.local-renewables.org/freiburg2009
- http://www.roheline.ee/files/energia/worner.pdf
- http://www.c40cities.org/bestpractices/energy/freiburg_ecocity.jsp

Case study 7

Palmerston North, Manawatu, New Zealand.

Population: 80 000, of which around 8 000 live in the peri-urban district

Rationale for selection: a town with good resources used for own cost-saving purposes

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building regulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X														X	X	X	X

Description

Palmerston North is a typical small town located within a rural community, which it services. Massey University, the regional hospital and the Linton army camp are located there. Approximately 28 000 dwellings, mostly detached houses with individual gardens, are located within the broader city boundary that covers over 300 km^2. Around 10% of the dwellings are situated outside of the main urban conglomeration in the nearby small townships, on farms, and on "lifestyle" blocks of land, each of around two to three hectares.

The City Council has a goal to "promote sustainable behavioural changes in Palmerston North to ensure we all have a future. This includes town planning, transport, energy, waste, agriculture, water and shopping." As an early part of its focus on sustainable development, the city had been a member of "Energywise Councils" administered by the New Zealand Energy Efficiency and Conservation Authority (EECA) partnership until the programme was disbanded. In 2008, the newly-elected city council agreed for Palmerston North to continue to "become a responsible city by joining the global challenge to reduce the volume of greenhouse gas (GHG) emissions entering into the atmosphere". It recognised that to do this, it needed goals, a strategy to implement actions, and a tool to measure progress. With this ambition in mind, in June 2008 it signed up to the national government-funded programme, Communities for Climate Protection – NZ (CCP-NZ). This was based around the ICLEI organisation, the New Zealand branch having 33 local government members representing 80% of the national population of over four million. Worldwide, approximately 800 local governments participate in this programme, thereby integrating climate change mitigation into their decision-making processes.

CCP-NZ was a voluntary programme aiming to empower local governments to reduce GHG emissions from their operations and through the actions of their communities. It used a strategic milestone framework designed for both municipal authorities and larger regional councils. Palmerston North completed a GHG inventory as the first milestone in early 2009, identifying 475 kt of GHG emissions in 2006, of which 12.2 kt came from council activities, mainly methane from the sewage ponds (41%) and

CO_2 from energy use in buildings (25%), the vehicle fleet (12%), and street lighting (9%). Under business-as-usual, it was projected that community emissions would grow 10% by 2010, mainly from transport (55%), waste (13%), industry (13%) and the growing residential sector (12%), but projected to soon overtake industry. However, in May 2009 the New Zealand Ministry for the Environment announced it was no longer able to fund the CCP-NZ organisation.[93] Regardless, Palmerston North intends to continue to reach the other milestones by setting emission reduction goals; developing a local plan to achieve these goals; implementing and quantifying the benefits of policies and measures in the action plan; and monitoring progress towards the reduction goal. A budget to implement the policies appeaed in the "Long-Term Council Community Plan 2009/19". The focus over the next 10 years is on giving advice to the community, providing incentives for energy efficient and sustainable buildings and for meeting climate change mitigation.

Renewable energy technologies

Electricity and CHP

- Wind farms

  Three large private wind farms exist within and just outside the city boundary (Fig. 38) and others are planned. The 37 MW Phase 1 of the Tararua wind farm, located 12 kms to the west of the city on the plains, was completed in 1999. It has since been extended to over 140 MW as the site on the Tararua Ranges has an exceptional mean annual wind speed of over 10 m/s and a 45% capacity factor is typical for each turbine. No government subsidies are available in New Zealand, but carbon credits, sold to the Dutch government even before the Kyoto Protocol came into force by at least one of these wind farm developers, help the revenue stream. The total electricity demand of Palmerston North city in 2008 (560 GWh /yr), plus the neighbouring districts (240 GWh /yr), was exceeded by all the local wind farms when over 850 GWh was generated in the region that same year. Power from the first Tararua wind farm constructed in 1999 enters directly to the city distribution system, whereas power from the wind farms constructed afterwards is exported to the grid.

Figure 38 • *The 1.5 MW turbines of the 120 MW Te Apiti wind farm under construction (left) and in the foreground (right) are just outside of the Palmerston North city boundary (delineated by the Manawatu Gorge shown by the rising mist). Within the boundary are the original 660 kW turbines of the Tararua wind farm and the 31 recently added 3 MW turbines (seen on the plateau across the gorge). The urban city centre is located 12 km away to the right of the photo, down on the plains*

Photo credits: Ralph Sims (left); Phil Murray (right).

93. http://www.iclei.org/index.php?id=9813

Due to the concentration of wind turbines on the hills overlooking the city, there has been growing resistance to further developments. The City Council, based on local experience, made a submission in 2008 to the government's proposed "National Policy Statement for Renewable Electricity Generation". Of the several points made, those most relevant to the city's policies were as follows.

- The benefits of renewable energy are evident. It is the potential, cumulative and actual effects of the development of renewable projects that causes the most debate at the local level.
- Consideration needs to be given to changing the construction of wind masts to monitor local wind conditions as a permitted activity or keeping it as a restricted discretionary activity to be judged on a case-by-case basis.
- In terms of small-scale wind turbines likely to become more popular in the future, it is very difficult to enable or provide for such activities within local planning documents without having a fundamental understanding of how they might actually eventuate and what their real effects on the surrounding environment might be.

Having gained experience from observations of wind farm developments in the region, the city is now undertaking its own development of a 360 MW wind farm in partnership with the state-owned power generation utility, Mighty River Power. To be constructed partly on city-owned reserve land that is covered with native forest and within the water catchment area, the Turitea wind farm proposal has become somewhat controversial. Some of the proposed 122 turbines, each up to 125 m tall and 3.5 MW capacity, will be clearly visible on the hills just 10 km from the city centre. If the project proceeds, city residents will benefit from the revenue earned from leasing the land and would gain access to the "Ecopark" reserve for recreational purposes that is currently prohibited. Some neighbouring landowners are keen to see the wind farm expanded outside of the reserve land boundaries and others are agreeable to grant access over their land for roads and power lines. If this wind farm is granted approval, then virtually all of the 20 km of plateau land running along the tops of the Tararua ranges that is within the city boundary will have received a wind farm consent.

- Landfill gas

Although the original city landfill site is now closed, it continues to produce methane gas. This has been collected for the past four years for heat and power generation. The site has since been transformed into a track for mountain bikers and an industrial recycling centre (opened by the Prime Minister in 2007) aiming to increase the waste recycling rate from 30% to 50%. At present the Awapuni Landfill Gas-to-Electricity Project has 17 active gas wells drilled to collect the methane, which is then combusted in an engine driving a generating set to power the wastewater treatment plant and the operations of the Awapuni Resource Recovery Centre on the former landfill. Any additional electricity is sold to the national grid. If test wells prove that sufficient methane is present, eight further wells will be drilled and connected to a new gas engine/generator to be co-located alongside the existing 1 MW generator. This should virtually double the present generation capacity. The Council budgeted around USD 80 000 for the generator, well drilling, pipe installation and the electrical work. To achieve a financial return from the second generator, the Council also intends to offer carbon credits for sale.

Currently, when running at full capacity, around 35 000 carbon credits per year are produced (one credit equating to 1 t $CO_{2\ \text{equivalent}}$ emissions avoided). The credits were awarded to the council by the New Zealand Government Climate Control Office following auditing and verification by an internationally certified authority. They can then be sold on national or international markets. As this is outside of a planned national emissions trading scheme, (under review by the new government), initial sales of 149 000 carbon credits were made by the city through the Chicago Climate Exchange to the Austrian Government in 2006 for around EUR 600 000. Around 30% of the total was paid by the Austrian government initially, with the balance to be paid on delivery of the credits during the first commitment period from 2008 until 2012. This agreement was made prior to the ratification of the Kyoto Protocol. A further 5 540 credits have been sold privately to Toyota New Zealand, whose head office is based in the city. Toyota's aim is to offset emissions from their business operations in order to become carbon neutral, with the revenue going towards the benefits of the local community. A carbon credit supply agreement is under negotiation for future years that could see Toyota help fund the landfill site development. The consultants Carbon Market Solutions and TBL Solutions assisted the council with the deal. One thousand credits have also been sold to the airline Virgin Blue and others sold over the internet on "Trade me".

- Wastewater treatment plant biogas

  For several years, the City Council has collected and then flared the methane gas produced from anaerobic digesters that are part of the process treatment at the wastewater treatment plant. In many similar plants the gas is used to generate electricity for use on-site. One proposal was to instead pipe the methane gas to the gas engine/generators at the landfill site nearby and, in return, receive hot water as a by-product to maintain the temperature of the digesters at the optimum 37°C needed for most efficient activity of the bacteria. However, it was finally decided to locate the second gas engine at the treatment plant instead of at the landfill alongside the first engine.

  Gas feeder pipes have been laid to supply this second gas engine that will generate electricity using the biogas produced by the plant's sludge digesters. Since the existing landfill gas plant output will reduce over time as the site depletes, the electricity produced from the sludge feedstock used in the new system will eventually take its place. The gas digesters built at the treatment plant about 40 years ago will be extensively refurbished to maximise the gas production potential and will provide spare capacity to meet further growth of the population.

  Heat from the engine will be recovered to maintain the digesters to an efficient 37°C. The power generated will be used locally with any excess exported to the local network. The total operational output of the two gas plants together will be able to meet about 75% of the council's in-house power demand. When fully operational, the project is expected to generate an initial surplus of around USD 50 000 annually, with a total revenue earned for the council of USD 4 million over a 20 year period. Plans are being made in association with Massey University researchers to significantly expand the biogas plant capacity and import more organic feedstocks from around the locality.

- Hydro power

  The Council's mini hydro station was initially proposed by a local Massey University student who realised the potential for using the twin dams at the city's water supply reservoir to also generate some power. She calculated how much power could be generated by the water passing through the dam outlet pipe. The cheapest design option was to use four pumps, acting in reverse, as motors to drive four 150 kW generators. The project was commissioned in 2002 and has since provided sufficient electricity to operate the nearby water treatment plant with any excess power being sold to the national grid to earn revenue. This has helped reduce the GHG emissions from the water treatment plant from around 95 tCO_2 to 17 tCO_2/yr. It is now proposed to install an additional dedicated turbine for USD 150 000 which will supplement the four existing motors and generate power using the water held behind the upper dam. The four motors will then be used to generate electricity from the excess water that currently spills over the dam in wet weather (Fig. 17, page 72). More effective utilisation of the hydro scheme should result and additional revenue made for the city through the sale of excess power.

Current policies relating to renewable energy project deployment

Self-governance

- The Council has set a general target in relation to greenhouse gas reduction and a more specific policy to generate 100% of its own electricity using local renewable energy resources by 2009. It has made no policies specifically to regulate, encourage or advise the community on renewable energy.

Proposed policies

With more experience in wind farm resource consent applications than any other authority in New Zealand, the City Council has gathered the support of nine other New Zealand councils to encourage the government to create national guidelines for wind farms. It will now ask Local Government New Zealand to put this issue on its agenda and if successful, to lobby the Government for a national policy statement. To simplify the planning process, the Council, in particular, wants to see guidelines stating the minimum distance turbines can be placed from homes, the allowable maximum saturation of an area's skyline, and to identify iconic areas on which turbines cannot be built. If renewable energy project development is to become an on-going issue, the government should avoid the current slow, ad hoc process which deals with applications on a case-by-case basis. Guidelines could help reduce the time and financial costs associated with such resource consent hearings.

Innovative policies and replication potential

This case study exemplifies a city with significant renewable energy resources available but no formal policies to encourage the greater deployment and use of renewable energy within the community. The Council has developed renewable energy projects to support its own business operations, benefit the environment, and enhance the city's finances. It has partnered with a utility to gain investment opportunities, and benefitted from the trading of carbon credits earned from the landfill gas site. Other New Zealand cities such as Christchurch and Waitakere have also employed innovative ideas from their staff and communities to achieve similar renewable energy goals. Many cities in other countries could do the same.

Helpful websites

- www.palmerstonnorth.com/YourCouncil/NewsAndViews/MediaReleases/Detail.aspx?id=15388
- http://www.mfe.govt.nz/rma/call-in-turitea/information-sheet.html

Case study 8

Växjö, Småland, Sweden

Population: 78 000

Rationale for selection: a long history of renewable energy policies aiming for 100% renewables

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes regulations/ codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
X	X		X			X						X		X		X	X	X

Description

In 1996, the council of the southern Swedish city of Växjö, with a municipal annual budget of EUR 400 M, unanimously decided that the city shall become fossil fuel free. On the path to that goal, local greenhouse gas (GHG) emissions per capita should be reduced by 50% by 2010 and by at least 70% by 2025 (compared with 1993 levels). Currently, after a 32% reduction since 1993, they are around 3.5 t CO_2 /capita which is one of the lowest levels in the world. Emissions from transport have now stabilised and are just starting to track down. The overall aim of the city council is to take responsibility to mitigate climate change and to provide business opportunities for local companies. The city has reduced CO_2 emissions by around 32%[94] and now uses over 54% renewable energy to meet the total energy demand across all sectors.

The energy supply coming from renewables is mostly from biomass used in CHP district heating plants, but also from imported renewable electricity, and a little local wind, hydro, biogas, solar PV and geothermal. Växjö has made more major progress in the heating sector, some in the electricity sector and less progress in the transport sector, but advancements are continually being made as a result of vigilant monitoring, measurement, and evaluation. This is supported by the Swedish Local Government Act that encourages strong actions through the power of taxation as well as supporting efficiency actions and environmental projects. The city's environmental policies cover consumption, water, natural resources, energy and transport. Eleven sustainability indicators were developed, and an "ecoBUDGET" procedure was established in order to implement the action plan. Since smart metering was first introduced into apartments in Växjö to give feedback on energy use,[95] customers have reduced their electricity consumption by 24% and their hot water usage by 43%. The system includes a web portal that allows users to see hourly rates of consumption and make comparisons with others in the neighbourhood.

94. All data on emissions reductions are between 1993 to 2005.

95. www.weforum.org/pdf/slimcity/SlimCity%20Knowledge%20Cards%20-%20Smart%20Energy.pdf

The municipality-owned company, Växjö Energi AB (VEAB), was formed in 1969 to supply and retail heat and power to the community. Grant funding for various projects, totalling approximately USD 25.2 M, has been received, in part from several national government agencies. Växjö has also received funding from the European Commission' CONCERTO programme under the "Sustainable Energy Systems in Advanced Cities" (SESAC) programme as a result of being one of the first cities to work towards realising such lofty renewable energy goals.

Renewable energy technologies

Electricity

- Växjö has reduced CO_2 emissions in the electricity sector by 24% from the greater uptake of biomass CHP power generation. The plant used 90.5% wood waste, 6% peat and 3.5% oil in 2006, with plans in place to increase the wood fraction to 96%.
- The Teleborg School project demonstrates to the public the benefits of solar PV and the school uses the project for six different education modules across varying subjects. Approximately 58 000 kWh/year of power is generated from the PV solar panels installed on the school roof. A solar PV system has also been discussed for the city swimming hall.
- Energy efficiency measures are in place that decrease the amount of electricity used, thereby offsetting the increased costs of using green electricity. Smart meters are being installed.

Heating and cooling

- Since 1980 Växjö has used biomass for district heating due to the high cost of oil. Since then the distribution network has grown and now biomass has largely displaced the dependence on imported fuel oil whilst creating local jobs and providing additional income to the local forest owners and wood processors. The network has reached local villages as well as older suburbs and enabled conversion from electrical heating to occur. Almost 91% of heating now comes from renewable energy sources, mostly from forest biomass products (Fig. 39), which has reduced CO_2 emissions in the heating sector by 76%.
- Wood pellet burners have been installed in a high school and at the airport and solar water heating has been installed for the showers at the swimming hall.
- A large biomass CHP plant was commissioned in 1997. The plant will supply the local area with hot water for heating and, under the European Union's SESAC programme[96] also provide absorption cooling. A 2 MW plant (Fig. 39) is planned to be used to produce cooling in summer at Växjö University, the hospital and a shopping complex. The cold water is distributed via the district heating pipeline system.

Transport

- Växjö is a logistics centre and experiences heavy traffic which has actually led to a 23% increase in CO_2 emissions in the transport sector since 1993. Biodiesel blends (based on rapeseed oil) are being used in public transport systems. Plans are in place to blend 5% biodiesel in diesel, and 10% of ethanol in gasoline, with encouragement given to purchase flex-fuel vehicles. A Centre for Biomass Gasification has been established at Växjö University which will conduct research on the clean burning fuel DME (dimethyl ether), being evaluated in association with Volvo, and other 2nd-generation biofuels for transport.

96. www.vaxjo.se/upload/29082/SESAC%20in%20V%C3%A4xj%C3%B6.pdf

Figure 39 • *Woodchips from forest residues are used as the renewable energy fuel in the biomass district heating plant (left). A York adsorption cooling unit in the Växjö Energi AB plant converts heat into chilled water for cooling (right)*

Photo credits: Ralph Sims (left); Alex Wilson, www.BuildingGreen.com (right)

- Biogas from sewage sludge will be produced when the new anaerobic digestion plant becomes operational (see below), and will be used as a fuel for public transport buses from 2011. The biogas produced will also be used in around 500 private vehicles to be serviced at a recently opened filling station.
- A "Growing cycling" project is underway with new cycling roads constructed and an information campaign in operation. It also has a goal of increasing its cycle traffic by at least 20% by 2015, compared to 2004.

Co-generation and tri-generation (polygeneration)

- The Sandvik II CHP plant runs solely on biomass fuels, with electricity capacity of 37 MW and heat capacity of 63 MW. A new CHP plant fired by biomass is expected to be constructed in the future. By 2015 a full-scale production plant for the gasification of biomass is also planned.
- An anaerobic digestion plant to supply heat, electricity, and vehicle fuel (tri-generation) from the biogas produced from biological wastes has been constructed by the company Sundet. It is located at the sewage treatment and water purification plant, based on a pre-existing digester. The feedstocks are food wastes and sludge taken from the sewage water purification process. The water treatment plant is self-sufficient in heat, producing more than 60% of its electricity demands and exporting the remainder.

Policies relating to renewable energy project deployment

Sticks

- When building new homes on municipality-owned land, a maximum of 90 kWh/m^2/yr energy demand has to be met. Consideration is being given to having no conventional heating systems installed in the construction of new homes within the city by 2010, with connection to the district heating system compulsory.
- Based on the environmental programme, in 2004 the Växjö council created a policy that all electricity the municipality uses must be renewable.

Carrots

- National subsidies were provided to individual households towards the installation costs of solar systems and small-scale biomass boilers, including wood pellet boilers from 1998 to 2005.
- Municipal subsidies have been provided to purchase an environmental vehicle with free parking made available as an additional incentive.

Guidance

- An Energy Information Centre, "EnergiCentrumEtt" was set up to offer free energy advice to residents (with around 2000 consultations/year registered).
- A web tool "Energy Check" (EU-funded project, SESAC) is available to help residents save energy.
- Eco-driving education for the public is available and round-table discussions to keep local commitment high have been a valuable part of the process.
- Local demonstrations and technical visits have been held and meticulous data collection has helped disseminate the results to educate residents to make improvements.
- A local Climate Commission was created in 2007 to further develop co-operation between business, policies and research by working with Växjö University and local companies, including to produce a toolbox for citizens/businesses wishing to use renewable energy.
- New wooden apartment buildings, up to seven-storeys high, have been constructed to show the energy efficient benefits and advantages from using wood as a building material. They will use 100% renewable energy.

Innovative policies and replication potential

Växjö early succeeded in mobilising large parts of the society for the realisation of the vision by appreciating the engagement of individuals and groups in the identification and realisation of socio-economic benefits.

Bo Hektor, IEA Bioenergy, Task 29 paper.

The local efforts and successes in Växjö can serve as an example to other cities within Sweden and across the world. Their claim is that information, knowledge and dialogue are the best tools for change and that commitment by municipal leaders, employment of competent officials, and the gaining of political consensus on environmental issues, is vital for continued success.

The city has received numerous awards and recognition for its actions. Around 100 foreign delegations visit Växjö each year to examine this model city and its achievements, so the opportunity for replication is high.

Helpful websites

- Fossil Fuel Free Växjö: http://www.vaxjo.se/upload/3880/CO2%20engelska%202007.pdf
- City of Växjö: www.vaxjo.se/english
- BioEnergySmåland – Expo Växjö: http://www.vaxjo.se/upload/3880/Bio_Eng_OK.qxd.pdf
- http://www.c40cities.org/bestpractices/renewables/vaxjo_fossilfuel.jsp
- http://www.energie-cites.org/db/vaxjo_139_en.pdf

Case study 9

Masdar City, Abu Dhabi, United Arab Emirates

Population: 40 000 residents plus 50 000 daily commuters (both projected)

Rationale for selection: ambitious city design with innovative projects on a green-field site

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
	X											X		X	X	X	X	

Note: Since Masdar City is at an early stage of Växjö, Småland, Sweden *n field site, all information quoted is based on projections as found in the literature and is subj*

Description

Our mission is to accelerate innovati ***ble technologies and make these available and affordable on a global***

Dr. Sultan Al Jaber, Chief Executive off

In the heart of the OPEC countries lies Masdar City, located about 30 kilometres east of the United Arab Emirates capital, Abu Dhabi. The carbon-neutral urban development was planned with the aim for it to be supplied entirely by renewable energy; to use systematic recycling techniques so that it is nearly waste-free; and to significantly reduce water consumption per capita. The costs to build the whole city are estimated at USD 22 billion.

The Abu Dhabi leaders launched the Masdar Initiative in 2006. The development of Masdar City is a part, and already renewable energy, through its 10 MW photovoltaic solar power plant, is being produced. Commissioned in June 2009, this solar facility is the largest grid-connected one in the Middle East and North Africa (MENA) region (Fig. 40). It is Abu Dhabi's first source of renewable energy and is currently powering the construction of the city and on-site facilities. A subsidiary of the Mubadala Development Company, Masdar is a multi-facted initiative of the Abu Dhabi government to advance the development, commercialisation and deployment of renewable and alternative energy technologies and solutions and to become a world hub for the research, development and demonstration of future energy technologies. The aim is to drive the commercialisation of sustainable energy, carbon management and water conservation technologies built around key foundations in the areas of human capital, financing, technology and infrastructure so that Abu Dhabi can make the transition from a technology consuming city to a technology producer.

Masdar City is being designed so that the building and urban planning designs will lead the world whilst incorporating traditional Arabic planning principles as much as is feasible. Since the city is located in the

Figure 40 • *The 10 MWpeak solar PV plant, located on the edge of the planned city (right), is already producing power for use during the first construction phase*

Photo credit: Masdar City Corporate Communications (left); www.masdaruae.com and Foster and Partners (right).

world's sunbelt, solar energy is a key focus industry. Building construction began in 2008 and the seven phases of its construction will reach completion over the next decade, with Phase one due for completion in 2013. Throughout its construction and when completed, Masdar will become a clean technology cluster that attracts businesses, government policy-makers, industry experts and researchers. It will thereby create an environment to stimulate innovation and clean technology research and development. In August 2009, Abu Dhabi was selected by the 136 signatory states of the International Renewable Energy Agency (IRENA) as the host for its headquarters that are to be located in Masdar City.

The mandate of Masdar City is to champion renewable energy technologies. It is a city that will be carbon neutral, have zero waste, use 100% renewable energy, and aspire to have the world's greenest commercial buildings. Fossil-fuel vehicles will not be permitted within the city boundaries in order to further reduce greenhouse gas emissions and help achieve the zero carbon objective. Planners have designed an underground transportation system so the streets will be car-free. As a special economic zone, the city will be attractive to both sustainable energy researchers and hi-tech companies by offering zero taxes, zero import tariffs, zero restrictions on capital movement and strong intellectual property protection.

In June 2009, the Fraunhofer Gesellschaft and Masdar, representing the Masdar City Project, signed a cooperative agreement for a strategic partnership aiming to establish close cooperation in sustainable urban development and building planning and to provide an ambitious example. Participating in this cooperation are the Fraunhofer Institute for Industrial Engineering, the Fraunhofer Institute for Building Physics and the Fraunhofer Institute for Solar Energy (ISE). These organisations are exploring the creation of a joint institute for sustainable urban development that will try to work closely with the Masdar Institute of Science and Technology, which is presently being constructed and will be the region's first post-graduate institution dedicated to the study of alternative energy and environmental technologies. At present the ISE is working with Masdar on solar climatisation projects, as well as solar-thermal process heating. This collaboration will help ensure Masdar plays a key role in the development of Abu Dhabi's renewable energy sector by driving continual innovation and the commercialisation of clean and sustainable energy technologies.

The Masdar Initiative has built a portfolio of renewable energy operating assets and begun to encourage investments from high-tech companies and to develop renewable energy projects. Projects to date include:

- the Masdar Clean Tech Fund of USD 250 million venture capital;
- the Torresol Energy project that is a joint venture between Masdar and Sener, a Spanish engineering firm that is building a number of concentrating solar power (CSP) plants in Spain;
- Masdar investing USD 170 million in WinWinD, makers of wind turbines;
- a joint venture with E.ON as an investment in the London Array, off-shore wind farm project;
- *Shams 1,* a flagship project, is a 100 MW CSP plant using parabolic trough technology that feeds green power into the Abu Dhabi grid; and
- the world's largest hydrogen-fired power plant of 500 MW will supply clean energy to meet Abu Dhabi's growing electricity demand with connection to the grid.

Masdar executives aim to make further investments in order to create a portfolio of production assets. For example, Masdar is developing a solar manufacturing cluster to attract companies from the solar industry as well as from gas, glass and other industries. Masdar will provide the infrastructure and kick-start development of the industrial park concept. In addition "Masdar PV" is a wholly-owned thin-film PV company which, as an anchor client, will apply advanced semi-conductor nano-manufacturing technologies to create PV modules with an annual manufacturing capacity of 210 MW.

In addition, Masdar is building a 300 km CCS network in Abu Dhabi to capture and transport approximately 5 Mt CO_2 from three industrial sources. The CO_2 will be used for enhanced oil recovery (EOR) before being stored.

Renewable energy technologies

Electricity

Masdar City, in effect a surburb of Abu Dhabi, is incorporating several sources of renewable energy into its buildings (Fig. 41). Photovoltaic panels and concentrating solar power systems (CSP) will be integrated to power the city with geothermal heat pumps and solar thermal evacuated tube collectors installed as circumstances permit. Grid management and near real-time electricity generation solutions are being examined that will enable customers to reduce energy demand and allow electricity providers to operate more efficiently. The 10 MW_e solar power plant already supplying power will enable Masdar to be built using renewable electricity. However the carbon emissions from the major energy input of liquid fuels used for construction vehicles will be more challenging to offset. As a zero waste city, Masdar will have a "Waste2Energy" programme whereby municipal and human wastes become an energy source through gasification, pyrolysis or plasma arc gasification. Together these clean energy facilities will help Abu Dhabi achieve its seven percent renewable energy target by 2020.

Cooling

The feasibility of a deep geothermal resource borehole is currently being evaluated to provide a heat energy source used to provide 24-hour cooling based on sorption techniques (Box E). Building designs, tree plantings and city infrastructure in general have been strategically designed to minimise the cooling demand by using natural processes wherever possible.

Figure 41 • *In these conceptual pictures of Masdar City, the PV panels are visible on the building roof (left) and the solar-powered LED street lights are illuminated (right)*

Photo credits: www.masdaruae.com and Foster and Partners

Transport

The city area has been designed to be easily walkable. To traverse the city in a vehicle will require the use of the innovative electrical Personal Rapid Transit (PRT) system, a private, automated pod that is powered by renewable electricity. An example was displayed at the first World Future Energy Summit held in Abu Dhabi in January, 2009 (Fig. 42). The PRT journey will take a maximum of seven minutes to anywhere in the city and there will be 85 stations providing close proximity to every building and facility. For transport of the commuters between Masdar and their homes in Abu Dhabi and its other connecting suburbs and communities, a Light Rail Transit (LRT) is planned.

Figure 42 • *The Personal Rapid Transit car, to be powered by renewable energy, will operate non-stop throughout the city subways and eliminate potential traffic congestion if conventional vehicles were to be allowed on the roads*

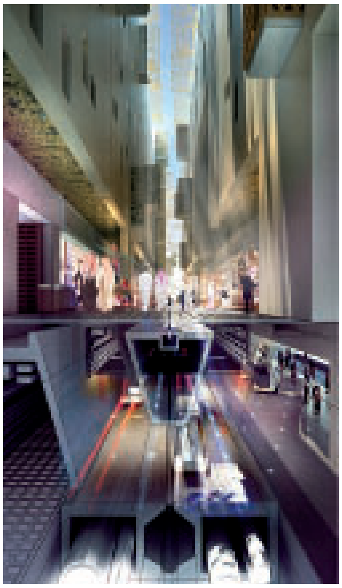


Photo credits: www.masdaruae.com and Foster and Partners (left); www.treehugger.com (right)

Proposed policies relating to renewable energy project deployment

Guidance

- Research and dissemination of knowledge is thought to be important to gain international recognition.
  - The Masdar Institute of Science and Technology (partnering with the Massachusetts Institute of Technology) is a centre of high-calibre renewable energy and sustainability research, to which leading scientists and researchers will be attracted from around the world.
  - Abu Dhabi has hosted the World Future Energy Summit and the European Future Energy Forum and will be the location of the headquarters of IRENA.

Self-governance

- The goal is for buildings and transport systems to be powered by renewable energy.

Innovative policies and replication potential

The technologies and applications that are being used in Masdar City can easily be replicated by other cities. This includes energy efficient building designs that incorporate passive solar heating and cooling systems and innovative technologies to maintain low energy demand. Another example is the personal transit system (Fig. 42), that could be utilised in other cities around the world. The use of intelligent grids and smart metering are technologies that Masdar City will acquire and learn to develop best practices. These technologies will position Masdar City as a veritable "silicon valley for clean, green and alternative energy".

Some interesting novel technologies have been planned to be demonstrated within the new city. Neither the high costs of implementation presumed, nor the behavioural issues and wants of those who might live and work in the new metropolis, do not appear to be constraints to progress.

Helpful websites

- http://www.masdar.ae/home/index.aspx
- http://www.masdarcity.ae/index.aspx

Case study 10

El Hierro, Canary Islands, Spain

Population: 10 000

Rationale for selection: small island community with good resources and opportunities for replication

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
	X					X			X			X	X		X	X	X	X

Description

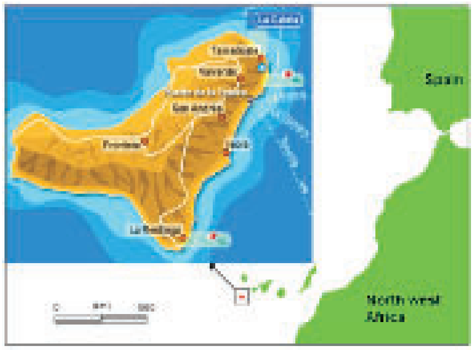
A Spanish island off the east coast of North West Africa and the smallest of the Canary Islands, El Hierro's main industry is tourism. The 276 km^2 island has its own small, independent electricity grid and, until recently, the electricity demand was met mainly by a 10 MW diesel-fired system. Two wind turbines (100 kW and 180 kW) also contributed less than 5% of the electricity demand. The council implemented a 100% renewable energy programme and now, after undertaking a major wind/hydro project, claims El Hierro is the first island in the world to become self-sufficient in electricity using exclusively renewable energy. The entire project was budgeted at USD 76.1 M and is based largely on a system of hydro and wind power, good resources of both being available due to location and rugged terrain[97] (Fig. 43).

The project was led by a consortium of seven partners, including the local El Hierro government and the ITC (*Istituto Tecnológico de Canarias*). It received some funding from DG TREN (Directorate-General for Transport and Energy) of the European Commission (EC), and was selected as an EC demonstration project due to its large renewable energy potential, especially in wind, hydro and solar, and the high replication opportunities possible.

In addition to the target of 100% renewable energy for electricity, the overall project focuses on energy saving and conversion from oil products to lower carbon and demonstrate cleaner systems for transport. Since a high degree of participation by the local population is paramount to the success of the project, extensive awareness campaigns have been arranged.

97. See http://www.flickr.com/photos/nightlyforestelf/265342751/

Figure 43 • *Due to its location, El Hierro has very high renewable energy potential, particularly in wind and hydro due to the rugged terrain and good rainfall, as well as high solar radiation levels*



Renewable energy technologies

Electricity

- Wind/hydro

  Given the island's configuration and terrain, the strategically placed wind farm supplies El Hierro with enough wind resource to meet the island's electricity demand. When in surplus, the wind energy is used to desalinate water and also to pump water from a lower to an upper reservoir. This pumped storage is used to meet peak loads and during extended periods of low wind speeds (Fig. 44).

  When the wind turbine generation output is insufficient to meet the power demand, the water from the upper reservoir is passed through hydro turbines to the lower reservoir, thereby converting the potential energy into electrical energy. An oil-fired thermal power plant is the back-up for long periods of inadequate wind supplies. The desalination plant helps replace water loss due to evaporation, fills the reservoirs, and also produces water for irrigation and domestic use. The wind/hydro power station (WHPS) provides approximately 80% of the electricity demand of the island.

- Solar PV Programme

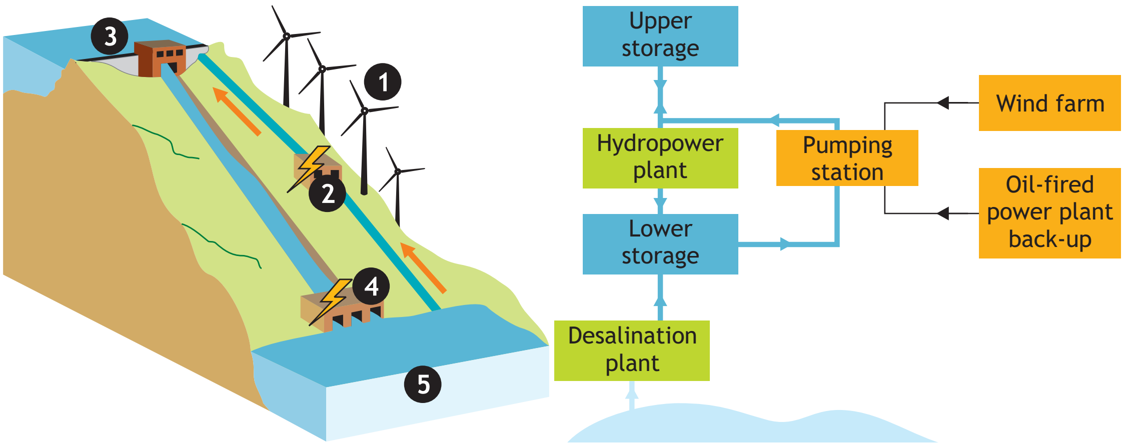
  A local company was established to supply and install the solar systems in the "10 PV roofs" programme. Ten 5 kW systems were installed on public buildings, which increased the percentage of renewable energy exported to the grid.

Heating

- Solar thermal programme (PROCASOL)

  The aim is to reduce grid-energy consumption by substituting electrical heaters with solar thermal systems for hot water. A local company installs the systems and instils confidence for potential purchasers by providing service and maintenance. The programme is mainly for individual households. An estimated 2 500 m^2 of collectors will be necessary to capture the entire market on the island.

Figure 44 • *The wind/hydro system uses wind power when available to meet demand and, when in surplus, to pump water to the upper storage used for peak power demands and calm periods*



1. Wind farm *9.35 MW installed power with maximum penetration rate of wind energy for direct consumption into the grid of 30%.*
2. Pumping station
3. Upper storage reservoir: *700 m above sea level. Its capacity of 200 000 m³ is sufficient to cover the electricity demand during seven consecutive days without wind.*
4. Hydropower station: *Three 3.3 MW Pelton turbines are able to operate from 10% to 100% of their power capacity to follow the load while keeping the same overall efficiency.*
5. Lower storage reservoir: *Capacity of 200 000 m³*
Desalination plant: *Capacity of 5 to 10 m³/day of potable water used to top up the lower reservoir.*

Source: Based on http://img183.imageshack.us/img183/5716/proycenthid11hh2.gif

- Biomass: "El Hierro- zero waste"

  There is good biogas production potential using feedstocks from sewage sludge, animal wastes, the organic part of the municipal solid waste, and organic industrial waste resources. An experimental farm sponsored by the local Island council is using methane digesters for sewage treatment. Solid wastes from local forests and plantations also have the potential to be used as fuel for heat production from direct combustion.

Transport

A hybrid bus, using scrubbed biogas as fuel for the spark ignition engine, has been incorporated into the fleet, along with an electric minibus which recharges its batteries at a solar PV station.

An extensive pedestrian network has also been developed.

Current policies relating to renewable energy project deployment

Carrots

- The local government offers a direct funding subsidy per m² of solar water heating collector panel for each system, combined with zero-interest rate financing. It guarantees the installation and maintenance of the solar collectors and hot water storage systems.
- In order to finance the overall project, a consortium, Gorona del Viento El Hierro, was established made up of the local government, ITC and the power utility UNELCO-ENDESA that owns and administers the wind-hydro power station.

- Every islander has the option of part-ownership of the WHPS by purchasing shares in Gorona del Viento El Hierro, thus increasing their involvement.

Guidance

- To gain acceptance, it was imperative to promote, inform, and explain the concept and benefits to the local institutions and population. Imparting knowledge is recognised as being crucial to the success of the project. Therefore, various means of diffusion were used, including brochures, publications, websites, DVDs, workshops, seminars, technical visits and awareness campaigns.
- Training sessions were instigated in early 2005 to create a local network of professionals who are qualified to install and maintain the new technologies.

Innovative policies and replication potential

If successful, this system could be implemented on other islands on all continents where suitable resources exist, thereby increasing the energy independence and quality of life for thousands of islanders worldwide.

Helpful websites

- http://www.insula-elhierro.com/english.htm
- http://old.insula.org/islandsonline/El%20Hierro-1.pdf
- http://www.insula-elhierro.com/en/pdf/El%20Hierro-sep2005.pdf

Case study 11

Samsø, Denmark

Population: 4 400

Rationale for selection: a small community with public ownership of some renewable energy projects

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/ exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
	X					X			X			X	X		X		X	

Description

Denmark has an impressive, long-term commitment to the use of renewable energy that is widely recognised by the international community. The level of research investment, the regulations in place, the public willingness to participate, and the political will to remain a leader in the field by following through policies with action, have been paramount to its success.

One symbol of Denmark's "greenness" is the 112 km^2 island of Samsø, off the east coast of the Jutland peninsula in the geographic centre of the country. In 1997 the local council won a national contest for Samsø to become a model town and demonstrate how the community's energy demand could be met using renewable energy. This aim, to become energy self-sufficient, is close to being met. Samsø now produces more than 100% of the electricity it needs from renewable sources, mostly wind generation. Since 1997 it has reduced its CO_2 emissions by around 150%. The conversion to using renewable energy, rather than having a power cable from the mainland bringing across coal-fired electricity and using oil-fired boilers to heat the buildings on the island, has cost approximately USD 115 million. Around 45 full-time jobs have been created during this period, along with 30 permanent new jobs in the island's energy sector, while fostering economic growth. Local citizens fully co-operated with the council and are closely involved in the building and funding of all the projects. Around 80% of the capital raised to construct the renewable energy systems comes from local investors, with no direct subsidy from the national government. The wind turbines are owned by individuals, collectives, resident associations, or the Samsø council. About 2 000 people visit this carbon-neutral island each year to view the turbines and other renewable energy demonstration plants and the island has also become a training ground for professionals working with the technologies. Samsø Island has become the model community for renewable energy.

Renewable energy technologies

Electricity

- A total capacity of 11.1 MW of land-based wind turbines and a further ten 2.3 MW off-shore turbines, generate more electricity in total than the island community needs. Total wind power generation offsets the carbon emissions from the oil products used in vehicles on the island, thereby, at least in theory, making Samsø "carbon negative". The 10-turbine, off-shore wind farm to the south of the island generated 77 GWh of electricity in 2008 at a capacity factor of around 38%. This wind farm was developed and funded by the islanders and the excess energy is sold to the mainland grid. The Energy Foundation on the island receives annual donations from the wind turbine owners that are used to fund other local public energy projects.

Heating

- Approximately 75% of the heat demand on Samsø comes from solar thermal and biomass energy. Four district heating plants are powered by either solar thermal systems or the combustion of locally produced straw and wood pellets.
- Solar thermal collectors provide district hot water (Fig. 45). The utility company NRGi was chosen by Samsø to provide the heat, which it supplies using 100% renewables.
- Approximately 20 individual building heating systems use ground source heat pumps. In addition, 75 biomass boilers, ovens and furnaces have been installed and solar thermal heating is used, with around 100 units on private homes and various other buildings. Twenty homes were selected to demonstrate the new concept of combined space and domestic hot water heating from a solar heating plant.

Figure 45 • *An array of solar thermal collectors heats water to 70oC, which is then piped to local houses for heating. A wind turbine is visible in the background*

Photo credit: Nicky Bonne

Transport

- Farm tractors, ferry-boats, and government vehicles are all powered on locally grown and processed biodiesel, while others are powered by renewable electricity. Only private cars still consume oil-based products.
- The target set by the Samsø council aims towards a gradual conversion of the transport sector from petrol and diesel to electrical power. The electrical demand will be met by 75% being produced from wind turbines and the rest by biomass and solar PV systems.

- The next project being planned is to develop a small hydrogen production plant using an electrolyser powered by wind energy (Box J). The aim is to eventually use the hydrogen energy carrier to supply the entire vehicle fleet on the island using renewable energy sources.

Box J • *Hydrogen production, Nakskov, Denmark*

The town of Nakskov, on the Danish island of Lolland to the south east of the Jutland peninsula, has established a full-scale wind/hydrogen energy plant and testing facility. Hydrogen is produced by using excess wind power generated on the island to electrolyse water and produce hydrogen and oxygen. The oxygen is used in the municipal water treatment plant nearby to speed up the biological treatment process.

The hydrogen energy carrier is stored in low-pressure storage tanks at 6 bar pressure and used to fuel two polymer electrolyte membrane (PEM) fuel cells. Acting as micro-CHP stations, they generate 2 kW_e and 6.5 kW_e capacity, respectively. Commissioned in May 2007, it is the European Union's first full-scale hydrogen community demonstration facility using fuel cells. The project, a joint partnership between the municipality of Lolland, IRD Fuel Cells, and Baltic Sea Solutions, has received support funding from the Danish Energy Agency. Lolland produces 50% more energy from wind generation sources than it consumes in total, so the hydrogen project is seeking to produce and store hydrogen for use in local residential and industrial facilities by using the excess wind power.

Current policies relating to renewable energy project deployment

Carrots

- Subsidies for heating systems provide reimbursements to households for up to 50% of the total for any investment that will increase energy conservation or efficiency.
- Necessary bank loans required for capital investment in renewable energy installations are guaranteed by the council.

Guidance

- Research and dissemination of knowledge
  - An Energy Academy with a visitor education centre has been opened in Ballen.
  - Citizen meetings are held regularly.
  - Local workshops have been organised within the district heating scheme areas.
  - A public campaign for the promotion of renewable energy and project installations has been undertaken.
  - Direct mail campaigns to residents have been conducted.

Innovative policies and replication potential

Samsø council is exploring the potential of using methane gas from its small landfill sites that are no longer in use. Gas from one landfill site already generates sufficient electricity to run a 15 kW gas engine generating set. The electricity generated is sold to the NRGi grid. Further exploration of using methane is expected; Samsø Deponigas I/S, a co-operative, was created for this development.

In 1997, Samsø was completely dependent on oil and coal, which was imported from the mainland. Today, it is carbon-neutral and uses 100% renewable energy in all areas other than transport, which is also making significant strides to meet this goal. As one resident simply stated, "Our successes can easily be replicated elsewhere."

Helpful websites

- http://www.energiakademiet.dk/
- http://www.samsoe.dk/

Case study 12

Güssing, Burgenland, Austria

Population: 3 800, plus 27 000 in the surrounding rural district that it services

Rationale for selection: several innovative projects in small community as a result of good leadership

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes codesregulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
	X				X							X	X	X	X	X	X	

Description

A sign reading "*Eco-Energy Land*" welcomes people entering the small Austrian town of Güssing. This is an enormous change from the situation that it found itself in a little less than 20 years ago. Then, its economy was based on agriculture, there was no industry to speak of, and a high rate of unemployment was resulting in an unacceptable rate of migration to other regions. The town, without a single railroad or highway passing through, was one of the poorest in Austria. Barely able to afford its annual USD 8.1 million bill for the energy imported from outside sources, the town needed a major overhaul to save itself. In 1990, the Güssing council enacted a policy which called for the complete abandonment of fossil-fuel based energy. This was also endorsed by the surrounding district.

Güssing is the first community in the European Union to produce its entire energy demand (electricity, heating/cooling, transport fuels) out of renewable resources. All the resources come from within the region, making it self-sufficient. Only one third of the biomass produced locally from crop and forest residues each year is consumed. Overall, Güssing has reduced its carbon dioxide emissions by 93% (from 1995 levels). The energy supply is now independent from oil, gas and their fluctuating prices. Combined with a "special scheme" of stable energy prices, not linked to oil and gas, and guaranteed for 10-15 years, it has attracted 50 new enterprises to Güssing, all producing or using renewable energy and creating more than 1 000 new jobs. It has therefore become an important location for small industries with high energy consumption. For example, Blue Chip Energy, a high-efficiency solar cell production company, built a USD 70.4 M solar manufacturing plant in Güssing because the plant can be powered with clean energy from renewable resources. Eco-tourism is also bringing approximately 400 visitors per week to Güssing, whereas previously the only thing for them to see was the 12^{th} century Hungarian castle.

A biomass CHP plant is a world leading design and the town has also invested in a biomass district heating system, a biodiesel plant and solar PV installations. Annual sales of energy products from Güssing are around USD 18.3 M/year, of which some USD 6.6 M is from the sales of the excess power generated and exported to the national grid. Around USD 700 000 of the annual profit is reinvested into alternative energy projects. The European Centre for Renewable Energy was formed and is based in Güssing, funded jointly by the town, the Austrian government and the EU. This centre, together with the Güssing Technology Centre Focusing on Environment Technologies, has brought much research and development investment to the town, resulting in the production of a number of innovative technologies, solutions and patents. Public acceptance for all of the projects is excellent and in return for its advancements, Güssing has been awarded several honours. Since 1995 CO_2 emissions from heat and power demands have been reduced by over 90%.

Renewable energy technologies

Electricity and CHP

- The main biomass gasification CHP plant constructed in 2001 is a steam biomass gasification plant (Fig. 46) developed by Dr Hofbauer from Vienna University. It has a fuel capacity of 8 MW and an electrical output of 2 MW_e, with 4.5 MW_{th} of heat contributing to the district heating scheme. The plant initially had reliability problems but now runs successfully for around 8 000 hours a year. A local company has licensed the technology. Two other biomass CHP plants are also operating.
- A 29 kW solar PV plant generates around 3 MWh/yr.

Heating

- A 23 MW_{th} district heating system, commissioned in 1998, supplies 95% of the city buildings using biomass wood chips for fuel. Two other small district heating systems were established in 1992 and 1993 in the nearby villages of Glasing and Urbersdorf. Around 60% of the total 42 MW of heat demand is met with renewable energy.

Transport

- A demonstration 1 MW_{SNG} bio-SNG (synthetic natural gas) methanation section is attached to the biomass CHP plant (Fig. 46) that can produce up to 100 m^3/hr of bio-SNG. A biogas plant is also planned.

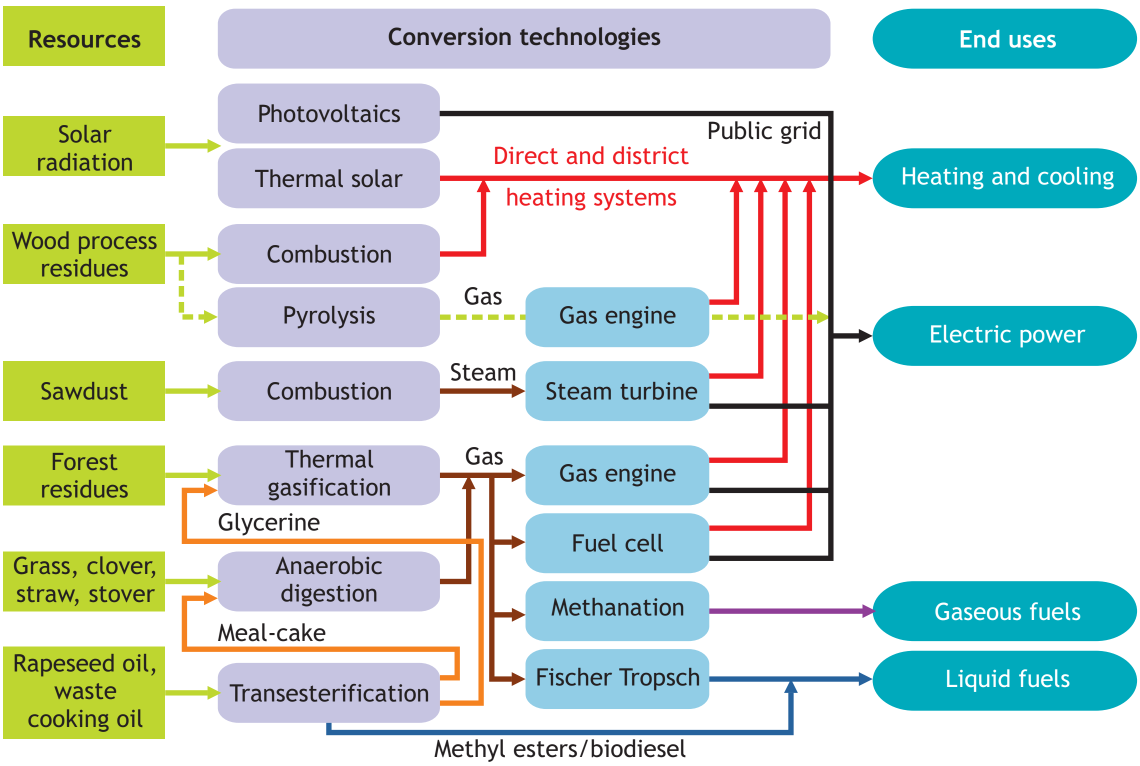
Figure 46 • *Biomass resources, collected from the local district (left), are stored at the fluidised-bed, steam gasification, CHP plant (centre). The methanation pilot plant (right) attached to the CHP plant, produces synthetic natural gas and has been operational since October 2008*

Photo credits: left Ralph Sims; centre www.bioenergy-in-motion.com; right www.ie-leipzig.de/Energetik/Bio-SNG/News.htm

- A biodiesel plant built in 1990 converts locally produced rapeseed oil into esters suitable for vehicle fuel and blending with mineral diesel. Plans are underway to produce 500 t/yr of liquid fuels in 2010.

In order to learn more about a range of energy technologies (termed "polygeneration" by the city council), a number of diverse research projects are being undertaken in association with universities and industry (Fig. 47). Currently in various stages of operation and planning over the five year period, 2007-2013, they include the generation of hydrogen, fuel cell technology, bio-SNG production, and the Fischer-Tropsch synthesis process for biofuels. Along with other technologies, the aim is to develop "total energy centres" in the town.

Figure 47 • *Güssing is implementing the concept of "polygeneration" from the wide range of renewable energy resources locally available*



Source: EEE- Europäisches Zentrum für Erneuerbare Energie Güssing GmbH

Current policies relating to renewable energy project deployment

Targets

- The target of 100% self-sufficiency through renewable energy was established by the town in 2001. To extend the target to the wider region by 2010 will require a series of new policies that are now being put into place.

Sticks

- A mandate was introduced in 1992 that all public buildings in the town must stop using fossil fuels. This resulted in an almost 50% reduction on energy expenditure, with more efficient use of energy also resulting.

Guidance

- Information/promotion
  - The European Centre for Renewable Energy was founded to coordinate all the operational plants, projects, and research, as well as to promote and educate renewable energy.
  - The Biomass-Energy-Network is a network of regional, national and international partners to further educate, promote and train people about renewable bioenergy.
  - Comprehensive programmes, events and seminars have been offered to raise awareness and to ensure continual development and quality assurance in the field of bioenergy plants.
  - Special projects and education programmes have been designed for schools.
  - *Energy Systems of Tomorrow* is a sub-programme aiming to spread the knowledge and experience of Güssing's successes.
- Role model
  - Several innovative demonstration plants have been established by the town in partnership with funders, designers and developers using various technologies. The risk of failure has been high, but success has resulted. The plants are open to visitors at anytime.
- Training
  - Solar-School Güssing (2003), consisting of a demonstration plant which produces solar power for heating/cooling (Fig. 48), eight laboratories, and a trade-school, all offer training for craftsmen, trades people and "train-the-trainer" courses.
  - The European Centre for Renewable Energy provides services for potential customers and manufacturers by offering advice and acting as an agent.

Figure 48 • *Solar-school Güssing uses and demonstrates solar energy systems during training courses that provide information for the craftsmen who consult, design, service, and install renewable energy technologies*

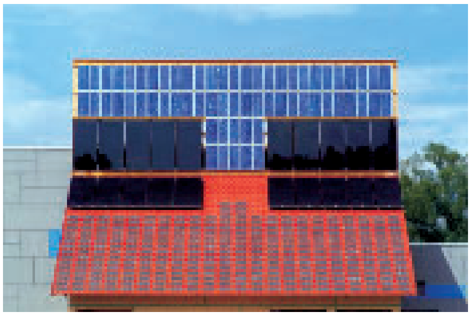


Photo credit: www.bau-docu.at/.../referenzen_en.php

Innovative policies and replication potential

The Güssing model for a small town in a rural environment is designed to be replicated — initially from the town to the wider district (as is planned by 2010), and then more widely nationally and internationally. For a community to replicate a similar model elsewhere, the renewable energy resources readily available must be first ascertained, including whether the land area available to produce biomass resources is sufficient to cover the desired energy demand. Analysis of energy demand and the local renewable energy sources should always be the essential first step. When examining different options, the potential resources and suitable conversion technologies commercially available should be kept in mind. The cost-effectiveness of a renewable energy project will vary with location and available resource, and all the social and environmental benefits and disbenefits to the community need to be considered.

Güssing's extensive experience in analysis, preparation and implementation of the various renewable energy projects is being disseminated to other interested communities around the world through the "Energy Systems of Tomorrow" programme designed around Güssing's successful policies. For example the Irish town of Clonakilty, with a similar population, took a small delegation on a fact-finding visit to Güssing in November, 2008.[98] This town has a similar objective to "enable a strong, sustainable economy for Clonakilty and the surrounding area by 2020, through self sufficiency in renewable energy".[99] It is anticipated that more communities will also endorse such an ambition within the next few years.

Helpful websites

- http://www.ecreag.com
- http://www.ecreag.com/attachments/047_Modell_Guessing_engl.pdf
- http://www.austriantrade.nl/ca/events/Guessing6.pdf (solar school)

98. http://www.sustainableclon.com/wb/wb/media/gussingreport.pdf
99. http://www.sustainableclon.com/wb/wb/pages/sustainable-energy-working-group.php

Case study 13

Greensburg, Kansas, United States

Population: 1 574 (2000 United States census)

Rationale for selection: very small community with 100% renewable target on green field site

Target		Stick				Carrot						Guidance		Municipal operation			Role model	
Overall target	Sector specific target	Urban planning	Building codes regulations/codes	Taxes	Standards and mandates	Capital grants and rebate	Operating grants	Investment	Soft loans and guarantees	Tax credits	Tax reduction/exemption	Information/promotion	Training	Procurement/purchase	Investment	Utility	Demonstration/land use	Voluntary agreements
	X	X	X					X			X	X				X	X	

Description

Greensburg, a small town located in the central state of Kansas, United States, was devastated by a three kilometre wide tornado on May 4, 2007 that destroyed 95% of the buildings (Fig. 49). In the wake of the disaster it became apparent that changes would need to occur to sustain the town for future generations. That provided the unusual opportunity to rebuild the town in a way that could serve as a model for other small town communities to show how they can use renewable energy technologies and innovative design to reduce long-term costs and increase energy efficiency. Greensburg is now garnering national and international attention as the first community in the United States to become "100% green".

Figure 49 • *The devastated town of Greensburg after the tornado struck*

Photo credit:
www.greensburggreentown.org Greg Henshell/FEMA

With the median income of each household only around USD 28 500, the most important elements identified for Greensburg's redevelopment included commitments to:

- maintain the overall quality of life that Greensburg enjoyed before the storm; and
- determine the most cost effective combination of sustainable development concepts to meet the present and future needs of the community.

The rebuilding of Greensburg is based upon a two phase plan, with input from the federal government's Green Building Council[100] and ensuring that the community members play a large role. Phase 1 was to develop a recovery plan led by the United States Federal Emergency Management Agency (FEMA) and Phase 2 was a community master plan led by the local Kansas City planning and architectural firm Berkebile, Nelson, Immenschuh, McDowell Architects (BNIM). In addition, the Department of Energy (DOE), through its National Renewable Energy Laboratory (NREL), has provided USD 2.15 million in funding for technical assistance in redevelopment. NREL also provided a team of experts that conducted studies, developed renewable energy business strategies, and assembled financing and ownership options to produce or procure renewable energy technologies. Funding was also received from corporate sponsorship and commercial investments.

Greensburg is not just retrofitting, reforming, passing new policy, modifying, etc. but involves completely rebuilding the town. The region has an abundant supply of renewable resources including wind, solar, methane gas from the landfill, and land available nearby for the production of biomass crops for biofuels or possibly for bioenergy heat and power generation. The town could potentially become a net exporter of renewable energy, especially biomass, during the coming years.

The Greensburg town council has approved a set of goals, set out in a living document that provides guiding principles for the creation of its master plan and its vision to be a model "eco-community". Greensburg has the energy goal of being 100% renewable, so therefore all city buildings are being rebuilt with the integration of renewable energy systems as a design priority. For example the school facility has been designed by BNIM[101] to support the adopted master plan. The school campus, one of the first public buildings in the town to be reconstructed, is being designed to the platinum standard of the United States Leadership in Energy and Environmental Design (LEED) for Schools. Key sustainable strategies and technologies include the use of geothermal heating, ventilation and cooling (HVAC) systems, two 100 kW wind turbines, daylighting provided in all occupied spaces, proactive indoor air-quality design decisions, acoustic performance, and thermal comfort options. NREL has provided education, training, energy modelling and on-site assistance to help the community understand and establish new standards for new and renovated residential, public, and commercial buildings.

Renewable energy technologies

Electricity and CHP

- Centralised installations will provide power and heat for use in multiple buildings.
  - Kansas has the third highest wind resource potential of all the states, so Greensburg's wind resources have become part of its emerging economy. The local motto has become: "The wind took it away and the wind could bring it back." The Greensburg wind farm, as currently proposed, will consist of ten 1.25 MW turbines. The system will meet the pre-tornado electricity demand of the community, but will be grid-connected to allow for the variability factor of wind power to not disrupt supplies. Funding of the project is a collaborative effort between the town of Greensburg and John Deere Renewables. The local utility Kansas Power Tool, will purchase the electrical output from the wind farm and provide clean power from other sources

100. http://www.usgbc.org/
101. www.schooldesigner.com/Architects/BNIM-Architects/Elements/Greensburg-Schools-Disaster-Relief.asp

when the wind turbines cannot generate sufficient electricity to meet the demand. Commercial operation of the wind farm could occur as early as 2010. Native Energy, Inc. will be the exclusive marketer of renewable energy credits (RECs) from the wind farm, purchasing about two thirds of the expected REC output over 20 years. This will thereby provide critical revenue to enable project financing for this and other rebuilding ventures. Clipper Wind Power, Inc. shared its wind data assessment information with the project developers and that has helped the turbine siting process and enabled the project to move forward more rapidly. The system will include a 1.5 MW biodiesel generator for emergency backup.

- Decentralised systems will be designed for integration with individual buildings and structures as they are constructed.
  - Solar energy applications are planned on various individual buildings including:
    - solar preheating of ventilation air entering a building;
    - solar water heating for domestic, commercial, or swimming pool uses;
    - rooftop solar PV panels for electricity generation and grid-connected for net-metering; and
    - solar lighting for parks, signs, parking lots, etc. (Fig. 50).

Figure 50 • *The 5.4.7 Arts Center, (named after the date of the tornado strike), is the first Leadership in Energy and Environment Design, platinum building in Kansas. It has solar PV panels situated on the ground, eight solar PV panels on the roof and solar lighting installed. The three wind turbines, visible to the rear of the Center, each produce 600 W and are connected to a battery bank*

Source: BNIM

Heat

- Biomass heat from pellet stoves for use in dwellings and small businesses is being encouraged.
- Geothermal heating using ground source heat pumps will also be encouraged.
- NREL is currently working with local business and economic development interests to analyse the feasibility of a new business strategy for pelletising biomass wastes that could then be combusted to provide heat for the buildings.

Transport

- Production of bioethanol and biodiesel will be undertaken commercially. It is expected to grow with demand and be sold to local consumers. Tortsen Energy, LLC. plans to build a biodiesel plant with centralised biodiesel storage on 20 hectares of land in the proposed new green industrial park on the outskirts of Greensburg. The biodiesel plant will employ between 20-30 people and will produce all the electricity needed for the processing from its own wind and solar investments. It is expected to take 5-10 years to build.

Pending policies relating to renewable energy project deployment

Target

- The overall policy objective is to become 100% renewable energy dependent.

Sticks

- City zoning and building codes will be amended to allow for appropriate use of individual solar and wind systems.

Carrots

- A solar access ordinance for new neighbourhood planning has been prepared. It exempts the cost of on-site wind and solar energy projects from sales and property taxes and provides the necessary safety requirements.
- Where possible, adopting net-metering and other policies to encourage on-site renewable energy use by building owners is being encouraged. A draft interconnection agreement and net-metering policy has been prepared with the utility.
- To encourage the use of less gasoline and diesel for transport, a "walkable" community is being planned, with adequate pedestrian links making most of the main facilities easily accessible. Car-share programmes and recharging stations for electric vehicles are being developed.

Guidance

- A non-profit "Greensburg Green Town" business was created to assist in the rebuilding and education process.
- An annual conference on the town's progress has been proposed, to which leaders and interested lay-people from other communities from around the world will be invited.
- The city planning of building projects is transparent in order to educate residents, business owners, and visitors about the sustainable features being used.
- Educational efforts in the community will be made to target the opportunities for renewable energy utilisation and provide information to enable options to be evaluated. Once established, the Sustainable Resource Office will be the vehicle for education, including about how to further reduce emissions and energy use with day-to-day lifestyle choices, including lawn mowers, incandescent light bulbs versus LEDs, water heaters, etc.
- Several television programmes and a reality television show, "Greensburg", are tracking the progress of the town as it rebuilds.

Innovative policies and replication potential:

Since Greensburg's polices were driven by a very unusual situation, it cannot truly be seen as a model green town. The external validity and replication potential is questionable regarding the funding it has received as the result of it being designated a federal natural disaster. Nevertheless, many of the lessons learned from the reconstruction process, and the decisions taken by the community, can be useful information for other towns of similar size wishing to develop renewable energy and efficiency projects.

Helpful websites

- http://www.greensburggreentown.org/
- http://www.greensburgks.org/
- http://www.greensburgks.org/recovery-planning/long-term-community-recovery-plan/GB_LTCR_PLAN_Final_HiRes.070815.pdf

9. Policy recommendations

Municipal governments can work closer together in a very different way from the heavy diplomatic interactions between national governments. It allows them to be the first wave of government to understand when people are concerned about something.

Mary MacDonald, Climate Change Advisor to Toronto's mayor

City councils that have the authority to use their decision-making, legislative, financial, planning, educational and purchasing powers to encourage the greater deployment of energy efficiency and renewable energy systems within their boundaries do not always use these powers. Many successful cities could be highlighted where the leaders have governed and guided their communities to accept the drivers of change leading to the many varied local, national and international benefits that can result from meeting their heating, cooling, electricity and transport demands using renewable energy systems. In contrast, there are many more examples of local governments in the climate and energy policy landscape that have been unable to develop quantifiable climate change mitigation targets or introduce strong policies linked with the deployment of renewable energy systems or the wide-scale application of energy efficiency in buildings and transport.

The roles that local governments might play to encourage the uptake of renewable energy have been described in Section 7. In summary they include:

- identifying all the benefits for those considering investing in renewable energy projects;
- providing planning, financial and advisory support for project development as necessary;
- recognising all local societal and environmental benefits resulting from renewable energy projects as well as the disadvantages; and
- ensuring that all city residents are given the opportunity to learn more about the technologies, as well as their benefits and disbenefits, and the impact they could have on the local environment and their lifestyles.

Supportive policies already in place for renewable energy uptake in cities are very varied with widely different approaches resulting from such factors as specific local conditions, the amount of energy flows, the type of energy sources available, average income of the population, the availability of financing options, local business interests, housing density, age of building stock, transport infrastructure, and the linkages with national government policies. In moves towards greater overall sustainable energy uptake, the potential of renewable energy cannot be overlooked. This is particularly the case where the anticipated future growing trend towards more distributed (decentralised) energy systems, normally using some local renewable energy sources, is becoming evident. The way in which future energy systems evolve will vary with the location, existing energy infrastructure, renewable energy resources and energy business ownership status. It is therefore only possible in this final section of the report to provide broad recommendations on relevant policies for consideration by all local governments.

There is little doubt that local governments can take on a major role by developing local policies that will support the transition of the energy sector (Martinot *et al.*, 2009). Renewable energy is today being included in some innovative urban planning initiatives as illustrated in several of the case studies above. However these are exceptions as most cities and towns in whatever country, have relatively few policies in place to support and encourage the use of their renewable energy resources.

Many leading cities in most countries have attempted to reduce their energy demand through improved efficiency and energy management incentives, and this has been recognised as a key policy priority. The potential for using renewable energy has often been recognised to a lesser degree, sometimes under climate change goals or as part of developing an "eco" image objective. City councils that give a higher emphasis to energy efficiency than to renewables are usually giving sensible priorities since there are many opportunities for a community to avoid wasting its energy. Enabling and encouraging the residents to reduce their carbon footprints and also save money in so doing makes good sense. Putting parallel policies in place to support the use of renewable energy by the local community would also make good sense.

There is a wide range of policies for cities to select from that will lead to greater renewable energy deployment, but none would suit all cities and towns. Other policies that are not directly energy-related, but that could influence renewable energy uptake, include urban planning regulations, land transport options, building codes, employment, health, development and growth, investment stimulus, trade and emissions trading. Therefore, energy policies should not be developed in isolation, since all these other policies can have a direct or indirect impact on them.

The leaders and council members of any city or town have the opportunity to develop visionary policies that will affect the manner in which the community evolves. These policies will be constrained by the current status and culture of the community and the aspirations of its members. Therefore the policy recommendations outlined below will need to be placed within the context of a city's current situation, together with any long-term goals it may already have for sustainable development, energy security, wider distribution of energy services, energy cost reductions and its contribution to climate change mitigation.

Recommendations relating to the suite of available policies

Details of the wide range of renewable energy supporting policies and their descriptions have been provided in Table 2. Examples of how cities and towns have successfully employed these specific policies have been outlined in the selected case studies that are described in more detail in Section 8 and as short descriptions in earlier sections. Classified according to the list given in Table 2, some recommendations for cities and towns contemplating the instigation of such policies are listed below. Examples of cities that have already undertaken such initiatives are given in parentheses.

Renewable energy resource assessment

It would be wise for a local government to initially establish the type and amount of energy resources currently consumed by the whole community. It should also assess the sub-set of those resources used for undertaking the specific work programme when operating the services and facilities as a local authority. Determining the energy available, the energy demand projections, the resulting emissions from energy use, the type and amount of renewable energy resources, and the energy flows and balances should be conducted by and summarised in an energy status report (as has been accomplished by *Nagpur city*)[102]. This is usually required as a first step before encouraging the increased collection and use of local renewable energy sources. Seasonal and daily variations in energy demand need to be considered when evaluating the potential for renewable energy supply. For the renewable resources whose supply varies over the short term, particularly solar, wind and wave power, storage and back-up systems also need to be evaluated if a large share of the energy mix is contemplated.

102. Examples of cities that have already implemented some of the recommendations given here are listed throughout this section. Not all of them were included as case studies in Section 8. The wide range of examples and their geographic spread serves to confirm the important role that leading cities have already initiated.

Targets

- **Broad targets.** Targets for cities aiming towards overall greenhouse gas (GHG) emission reductions *(Hamburg, Kitakyushu)*, reducing GHG emissions per capita *(Daegu, Yokohama)*, becoming carbon neutral *(Austin, Vancouver)*, becoming fossil fuel free *(Växjö, Stockholm)*, or aiming for sustainable development *(Dubai, Freiburg)*, can result in a wide range of policy objectives, such as improved energy efficiency, fuel switching, development of CHP plants, installation of district cooling etc. Renewable energy may or may not be a significant component of these policy options, but can be specified whenever it is desired to enhance its contribution to the energy supply of the city.

- **Sectoral targets.** Setting a target specifically for renewable energy deployment can help focus the community on methods and technologies available for reaching the target. The target could be for a pre-determined share of renewable electricity *(Adelaide, Taipei)*, renewable heating/cooling *(Beijing, Tokyo)*, transport from biofuels *(Betim, Stockholm)* and/or for electric vehicles *(Oslo)* by a specified date. It could be for a specified number or share of dwellings, (Oxford) and/or commercial buildings (*London*), and/or government buildings *(Leicester, Toronto)*. to incorporate some form of renewable energy installation by a specified date. Setting the appropriate size of target is imperative and should be based on an assessment of the resources, available technologies, cost evaluations, co-benefits and links to other policies.

Governance by authority

- **Urban planning.** Regulations imposed by a municipality on its planning *(Linz)*, housing density, zoning, public transport and infrastructure can encourage the local generation and deployment of renewable energy including through distributed energy systems *(New York)* and electric vehicle use *(Yokohama, Adelaide)*. Other factors to be considered include impacts on local air pollution and health *(Mexico City, Ottawa)*, as well as on vehicle congestion *(London)* and travel time reductions. The concept of permitting an increased percentage of total land area for a building on a given plot of land if the building integrates a specified amount of renewable energy generation could also be a consideration.

- **Building codes.** A range of regulatory options is available for a city to promote changes in building design and orientation *(Sǎo Paolo, Kitakyushu)*, and shading issues *(Boulder)*, so long as they concur with national legislative requirements. Successful examples include solar water heating on new buildings *(Lianyangang, Cape Town)*; uptake of zero and low-energy houses *(Beddington, Göteburg)*; and a requirement for x% of total energy for a new building to come from integrated renewable technologies *(Merton)*. The "Merton rule" (Case study 5) is of particular significance as it has been shown to encourage the architects, designers and developers of buildings to consider energy efficiency as a high priority in order to keep the share of renewable energy down to a manageable level.

- **Tax exemptions.** Within the compliance requirements of national tax regimes, there can be opportunities for local governments to create adjustments to local tax payments *(Frederikshavn)* such as a discount on property development fees *(Caledon)*. For example, the annual charges against the rateable value of a property with a ground source heat pump installed could be lowered, or local property sales taxes, fuel taxes or permitting fees could be reduced where renewable energy technologies are involved.

- **Standards and mandates.** An appropriate specialist department within a municipality's administration structure (*e.g.* engineering or environment) could be selected and instructed by the chief executive to take responsibility for meeting energy or climate change targets and to plan for the uptake of renewable energy in the community *(Münster)*. The department could also ensure that all renewable energy projects meet acceptable standards, possibly based on the local climatic and energy resource conditions and constraints. This could be achieved by, for example, mandating for biofuel blending *(Portland)*, using only biofuels with specified characteristics for cold weather use *(Halifax)*, imposing a cap-and-trade system on large businesses *(Tokyo)*, incorporating the trading of green electricity and/or heat certificates within a climate policy, or exceeding the national standards set for solar water heaters in regions of the country more likely to experience freezing conditions or hail damage.

Governance by provision

- **Capital grants and rebates.** Where sufficient funding is available within the community, providing grants or subsidies towards the capital investment by a business or homeowner can incentivise the purchase of renewable energy equipment such as solar PV *(Ann Arbor, Adelaide)* and ground source heat pumps *(Beijing)*. Care is needed to ensure the fixed amount of a grant or percentage of the capital cost will be sufficient to create the desirable volume of increased sales. When such a policy is first introduced, the ability of manufacturers, suppliers, installers and maintenance personnel to meet a possible sudden increase in demand for a technology will need careful assessment to avoid the scheme soon losing support if a long lead time results on delivery or administration.
- **Operating grants.** Payment of some form of support finance after the actual generation of renewable energy in the form of useful heat *(Oslo)*, cold, or electricity, such as a feed-in-tariff scheme *(Gainsville, Los Angeles)*, would encourage the plant owner to operate and maintain the technology to maximise its performance and output. This avoids the risk of a plant being built to gain a capital grant or tax credit, but then being poorly operated and maintained.
- **Private investment.** A municipality can invest in a private renewable energy company to encourage development of a technology *(Bristol, Kunming)*. It can also provide investment opportunities for its citizens in such enterprises as wind farm development *(Samsø)*. The possible investment risks involved can be high unless the revenue from the return on the investment is secured by some form of guarantee. The earlier that the investment is made in the development of the project, then the greater the risk.
- **Soft loans and guarantees.** Loans offered towards private investments by citizens and/or businesses in renewable energy technologies at low interest rates for end-user financing *(Kunming)*, and revolving funds for household credit *(Nelson)*, can be an attraction for both renewable energy project developers and small-scale purchasers. The period of the loan should be less than the perceived operating life of the technology.
- **Tax credits, reductions and exemptions.** Tax adjustments are not usually able to be made by local governments but where it is possible in some manner, then they can be a useful tool to encourage renewable energy equipment manufacturers, consultants, designers and researchers to establish their business centre in a city offering generous benefits. Other examples include property tax credits given by local governments for installation of residential *(Belo Horizonte, Nagpur)* or commercial solar hot water systems.

Governance through enabling

- **Information/promotion.** A wide range of activities can be undertaken by local governments to provide greater understanding of the benefits of renewable energy systems *(Rizhao, Oxford)* and to place the disbenefits into context. Both stick and carrot policies, as well as demonstrations and local government investments relating to renewable energy, will prove more successful if they are undertaken in parallel with some form of guidance policies to make them more acceptable to the local residents. Establishment of information centres to raise public awareness is a common strategy *(Betim, Nagpur)*.

- **Training.** Rapid deployment of some renewable energy technologies in certain regions has been constrained by a lack of skilled people. A city can relatively easily establish community training schemes *(Betim, Hamburg)* in order to enhance the local skill level as well as to encourage local employment opportunities.

Self-governance

- **Procurement and purchases.** The purchasing of renewable electricity, biofuels and renewable energy equipment *(Moreland)*, possibly in bulk and jointly with other municipalities, can save unit costs as well as aid market transformation programmes. Integrating renewable energy into the daily operations of a local government *(Santa Monica, Woking)* can be a good role model for local businesses to follow.

- **Investments.** Local governments can opt to invest in many renewable energy-related activities such as projects linked with waste treatment systems *(Oslo, Christchurch)*; water supplies *(Amman)*; products for use in their own buildings *(Okotoks, Hamburg);* and own fleet vehicles *(Markam);* as well as in public transport *(Güssing, Calgary);* and local schools *(Bristol)*. Many examples exist of community-owned solar PV installations *(Lida, Milagro)*, wind farms *(Samsø)*, biodiesel vehicles *(Ballarat)*, hydrogen vehicles and related infrastructure *(Reykjavik, Fukuoka)*, or biogas-fuelled buses *(Stockholm)*. Selling resulting carbon credits from such investments can generate additional revenue for a city *(Palmerston North)*.

- **Utility.** Where a local government owns part or all of its local power or gas utility company, on behalf of its citizens it can influence such factors as: the uptake of tariff regulations and green power *(Oakville)*; renewable portfolio standards *(Minneapolis, Tokyo)*; inter-connection standards with the grid *(Nelson)*; smart metering systems *(Christchurch)*; and net-metering regulations *(Mexico City, New York)*.

- **Demonstrations and land use.** Many examples exist of a city willing to partner with the private sector in order to show the potential of a new technology to its citizens. Moreover, it can often result in gaining national and international attention *(Freiburg, Melbourne)*. The risks of failure and cost over-runs need to be considered, but often some government or regional funding can also be made available. Where municipalities own suitable land, it can be leased *(Palmerston North)*, sold *(Freiburg)*, or permitted for renewable energy installations undertaken by the private sector. Benefits can result for local citizens, such as improved access for recreation, and the investment risk is relatively low.

- **Voluntary agreements.** Where regulation of renewable energy actions is not feasible due to legislative constraints, then negotiating an agreement with a private building developer, utility company, taxi company *(Betim)*, etc. to voluntarily utilise more renewable energy in their business activities than they might otherwise have done, can be a positive means of encouraging uptake.

Citizen support

It is apparent from several of the case study cities and towns analysed that while community leadership is imperative, support from the “grass roots” level can be just as important. Obtaining support from within the community, including local businesses, is often a wise move for councils to undertake before attempting to introduce any challenging new policies. This is particularly the case when aiming to widely deploy many renewable energy technologies such as wind turbines or biofuel use, where there has been extensive coverage in the media of the more negative attributes. Gaining a more balanced view of the benefits and disbenefits, through education and debate, is often an important early step.

Strong community concerns have even led to local citizens taking charge of their local power supply. For example, soon after the Chernobyl nuclear power plant accident, the citizens of the small German town Schönau had serious concerns about the plans underway to build a nuclear plant in their district. After forming a co-operative (one-person-one vote), they purchased the local distribution grid and then founded their own utility, based mainly on renewable energy with a small amount of gas-fired cogeneration. Today the Schönau power company (EWS) is operating nationwide and supplies around 75 000 customers with green electricity.[103] This independence of action has been an inspiration for other community groups wishing to have a greater input into critical energy decisions being made by others that can deeply affect their local environment. Setting up a private utility may be too ambitious for some, but other approaches such as obtaining shares in the local utility in order to at least have a say on future energy policy directions, may be less daunting.

"Everyone wants electricity but nobody wants power stations!" Whether intending to build a coal-fired power station, a nuclear power plant, a natural gas CHP scheme, a community-scale biogas plant or a wind farm, during the project planning and consenting process, objections from local residents are usual for a variety of reasons. This "not-in-my-backyard" (NIMBY) syndrome is evident worldwide and is partly a negative response to any form of change. People in general do not readily accept change to their lives or usual habitats unless there are obvious positive benefits to be gained. Efforts need to be made to provide information and education on the need for energy infrastructure and, in particular, the benefits from developing renewable energy. Ideally this would result in the "yes-in-my-front-yard" (YIMFY) syndrome.

Local acceptance of many renewable energy projects could be achieved if some financial gains were received by those living and working nearby and who might be affected in some way by the project. Private ownership of a project is one such example. This is not always possible due to the relatively high costs of some systems, PV for example, where these can be a disincentive unless there are government support mechanisms in place. Even where financial returns exist for a user, such as from installing a solar water heater on a house in a sunny region to reduce monthly electricity accounts, the initial capital investment can often be seen as being too high, or the payback period too long, for many potential consumers. Enabling the residents living near to a proposed wind farm site or biogas project to actually invest directly in the project, and hence to gain financially as shareholders, is one method to obtain local support. However in almost all the successful case study cities listed in Section 8, some form of education initiative to provide information about the proposed technology and project to the members of the community is apparent. Developing special projects for schools as a method of education, holding community meetings, establishing energy information centres, running workshops, undertaking awareness campaigns through the media, and setting up representative committees of all stakeholders, including local resident associations and businesses, have all helped lead to successful project developments.

The creation of a support base from within the local community using various guidance and incentive tools, even where strict regulations are proposed, is highly recommended. As was stated in the IEA report on *Renewables for Heating and Cooling* (IEA, 2007a), while the most appropriate stick and carrot policies will vary from city to city and town to town, evidence suggests that a comprehensive policy package that also includes guidance, public information and training can be the most effective.

103. www.ews-schoenau.de/fileadmin/content/documents/Footer_Header/EWS_2008_EN.pdf

In summary

A suite of policy options supporting renewable energy deployment is available for policy-makers in cities and towns to consider. Many have been shown to be successful, judged by the local uptake of renewable energy projects and their embracement by citizens and local businesses. Many of these policies are ripe for replication by the numerous local governments around the world that, at this stage, do not have any policies in place. Leaders of cities and towns can select whichever policies are most appropriate to match their prevailing local conditions and then consult with the local community concerning their implementation. Gaining strong community support is vital if a “yes-in-my-front-yard” (YIMFY) city culture is to be achieved. This will encourage wider renewable energy deployment and contribute to the major energy transition that the world urgently needs to undertake.

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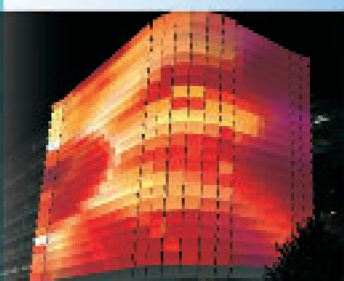

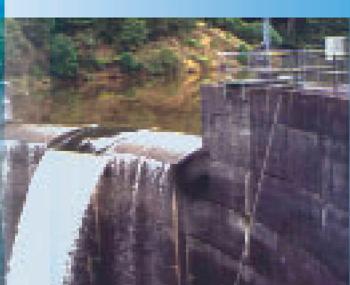

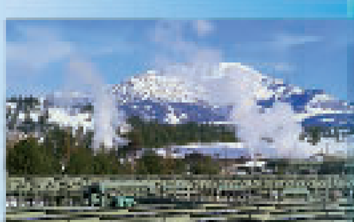

CITIES, TOWNS & RENEWABLE ENERGY

Yes In My Front Yard

Local governments have the power to influence the energy choices of their citizens. Many cities and towns have already encouraged energy efficiency measures. Even so, as demand for energy services continues to grow, the energy infrastructure that every city and town depends on will need to be expanded, upgraded or replaced. This provides the opportunity to increase the deployment of renewable energy technologies and decentralised energy systems, and hence gain the multi-benefits of increased energy security, climate change mitigation and sustainable development, but also the social benefits of reduced air pollution, such as improved health and employment.

Many combinations of policies have been employed to stimulate local renewable energy development. These policies include: local governance by authority; providing resources; enabling private actors; leading by example; allowing self-governance. Mega-city mayors, down to small-town officials, have successfully introduced such policies, although these vary with location, local resources and population. *Cities, Towns and Renewable Energy – "Yes In My Front Yard"* includes several case studies chosen to illustrate how enhanced deployment of renewable energy projects can result, regardless of a community's size or location.

The goals of this report are to inspire city stakeholders by showing how renewable energy systems can benefit citizens and businesses, assist national governments to better appreciate the role that local municipalities might play in meeting national and international objectives, and help accelerate the necessary transition to a sustainable energy future.

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