Managing water-related energy in future cities – a research and policy roadmap
S. Kenway, J. McMahon, V. Elmer, S. Conrad and J. Rosenblum

ABSTRACT

Water-related energy accounts for around one-quarter of California’s energy use. Most of the influence is within cities. This project aimed to identify research and policy needs associated with managing energy related to urban water. A workshop was convened with diverse representation from water and energy sectors in federal (US), state (California) and municipal governments, research and regulatory agencies, universities, utilities, not-for profit and private sectors. The workshop established a vision of future cities, including elements of success, research needs and barriers. A subsequent on-line survey was used to estimate the potential, effort and ‘potential-to-effort’ ratio of each suggested element. First suggested steps in the roadmap include: development of educational programmes, combined standards, guidelines, funding and planning for water and energy efficiency, improved understanding and management of factors motivating consumers, and improved methods to quantify and track targets of ‘water-related energy and related greenhouse gas emissions’. The ‘roadmap’ could help streamline future effort and sequencing action. The authors note and reflect on the importance of representation at such a workshop, and an effort is made to understand sources of variability in viewpoints. The semi-quantitative method used could have relevance to wider resource management issues and complex problem resolution.

Key words | energy, future cities, greenhouse gas emissions, urban metabolism, water

INTRODUCTION

Somewhere in the future lies a perfect storm for cities: water shortages, carbon caps and struggling economies. This paper describes a research effort aimed at planning for these challenges. The paper focuses on California, an area with a long history in this issue, but it has also relevance elsewhere. Managing ‘water-related energy’ in cities is perceived by these authors to be an important component of solutions because it helps to deal with the challenges of water and energy simultaneously, rather than moving the problem around.

In 2005, the California Energy Commission demonstrated that 19% of the state’s electricity use, and 32% of its non-power station natural gas use was ‘water-related’ (Klein et al. 2005). This includes the energy demand of treating and transporting water and wastewater for cities and agriculture as well as heating and using water in homes and businesses. The analysis clearly established the significance of water-related energy demands. Unfortunately, the work is repeatedly misquoted along the lines that ‘one-quarter of California’s energy consumption is to provide water to cities’. In fact, most of the water-related electricity and natural gas use is associated with the use of water, mostly heating and cooling water for residential, industrial and commercial purposes. The majority of water-related energy use occurs within cities (Table 1), and is mostly related to the end use of water. The urban water system in California consumed 5% of the state’s electricity for water supply in 2001. This is high by international standards and reflects the large distances and elevations for water transport in California.

Wolff & Wilkinson (2011) confirmed the overall magnitude of the connection in California for the year 2000. However, they highlighted large differences in method and
scope boundaries. A similar pattern of linkages has also been demonstrated in Australian cities where 13% of electricity and 18% of natural gas is estimated to be water-related (Kenway et al. 2014 a).

Several literature reviews (e.g. Marsh 2008; Retamal et al. 2009; Kenway et al. 2011 b) attest to the strong Californian contribution to the international analysis and publication record of water–energy links. Recent legislation has strengthened water and energy-conservation targets and provides further impetus for combined solutions. For example, SBx7–7 (2009) sets a 20% water-use reduction goal by 2020, reducing total urban water consumption from 192 to 154 gallons per capita per day (726–583 L/capita per day).

In 2000, residential water use in California was approximately 370 L/capita per day. Of this, the majority was for indoor use (229 L/capita per day) (Klein et al. 2005). In contrast, water use in Australia, averaged across capital cities, was approximately 230 L/capita per day, of which 170 L/capita per day was for indoor use.

Assembly Bill 32 (State of California 2006) requires reducing greenhouse gas emissions to 1990 levels by 2020, and a Governor’s Executive Order calls for 80% below 1990 levels (427 MMT) by 2050. The active water–energy research and tight coupling of water and energy makes it a good location to explore perspectives on this issue.

Motivated by the significance of the results of the Californian Energy Commission, the Californian Public Utilities Commission (CPUC) undertook, in 2009, a programme of work to better understand water-related energy. This included instigation and evaluation of nine collaborative pilot projects involving both energy and water utilities. Detailed analysis and modelling was undertaken of the energy embedded in water services. Results of highest relevance include an upwards revision of the water-related energy demands of supplying water and wastewater services. This increased from 5.1 to 7.7% in 2010. The increase was largely due to the omission of groundwater pumping energy in the earlier analysis (GEI & Navigant 2010 a), and other omissions are possible, meaning that the value could be higher. However, as the CPUC investigations were not scoped to measure or estimate changes in end-user (consumer) energy consumption, relatively little new information on the quantity of this is currently available (EcoNorthwest 2011; GEI & Navigant 2010 b).

The policy, economic and governance relevance of the connections between water and energy continue to emerge. In a statement to the US Congress House Science and Technology Subcommittee on Energy and Environment, Richard Stanley, Vice President Engineering at General Electric indicated that ‘our economy runs on water’ and ‘the nexus between power generation and water usage is one of the world’s most complex and critical public policy challenges’ (R. L. Stanley, 2009, Personal Communication, Presentation to US Congress Hearing.

### Table 1 | Water-related energy in California in 2001

<table>
<thead>
<tr>
<th></th>
<th>Electricity GWh</th>
<th>% of total*</th>
<th>Natural gas Million therms</th>
<th>GWheq*</th>
<th>% of state useb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban – supply and treatment</td>
<td>7,554</td>
<td>3.0</td>
<td>19</td>
<td>557</td>
<td>0.1</td>
</tr>
<tr>
<td>Urban – wastewater treatment</td>
<td>2,012</td>
<td>0.8</td>
<td>27</td>
<td>791</td>
<td>0.2</td>
</tr>
<tr>
<td>Residential – water end use</td>
<td>13,528</td>
<td>5.4</td>
<td>2,055</td>
<td>60,226</td>
<td>15.1</td>
</tr>
<tr>
<td>Commercial – water end use</td>
<td>8,341</td>
<td>3.3</td>
<td>250</td>
<td>7,527</td>
<td>1.8</td>
</tr>
<tr>
<td>Industrial – water end use</td>
<td>6,017</td>
<td>2.4</td>
<td>1,914</td>
<td>56,094</td>
<td>14.1</td>
</tr>
<tr>
<td>Subtotal ‘Urban water end use’</td>
<td></td>
<td></td>
<td>4,219</td>
<td>123,647</td>
<td>31.0</td>
</tr>
<tr>
<td>Subtotal ‘City’ component</td>
<td>37,452</td>
<td>15.0</td>
<td>4,265</td>
<td>124,995</td>
<td>31.4</td>
</tr>
<tr>
<td>Agriculture – supply and treatment</td>
<td>3,188</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture – end use</td>
<td>7,372</td>
<td>2.9</td>
<td>18</td>
<td>528</td>
<td>0.1</td>
</tr>
<tr>
<td>Total water-related</td>
<td>48,012</td>
<td>19.2</td>
<td>4,285</td>
<td>125,523</td>
<td>32</td>
</tr>
<tr>
<td>Total Californian use</td>
<td>250,494</td>
<td></td>
<td>13,571</td>
<td>397,728</td>
<td></td>
</tr>
</tbody>
</table>

*1 million therms = 29.30 GWh equivalent; source: derived from Klein et al. (2005).

bTotal Californian use.
Washington, 9 July 2009). Recently, a number of existing and planned power stations, including some renewable energy generation options, have had to be either scaled back or halted due to lack of water (e.g. Adee & Moore 2010). Likewise, many ‘climate resilient’ supply options, such as desalination or high-quality reuse, are highly energy intensive.

Despite the significance of the issue, the research effort bridging the water–energy divide is minor and at best uncoordinated. There is a lack of shared resources, knowledge and approaches. Most efforts address sub-components of the problem, rather than the consequences and opportunities of interaction. This is particularly the case within cities that are less studied than other areas such as the water needs of power plants.

Understanding connections between water and energy within cities helps to find solutions that address the drivers of consumption. Cities currently house the majority of the world’s population. They will be home to an increasing number of people in the future. Because urban growth dictates major investment decisions, reconfiguration of cities offers substantial opportunity for change. Understanding water–energy interconnections will help break the positive and self-reinforcing feedback cycles, leading to increased direct and indirect use of both water and energy.

Other authors have articulated the need to simultaneously address water, energy and public funding in decision making since 1965 (Wolman 1965). The concept of urban metabolism has been shown to have relevance to the water, energy and material balance of cities (Sahely et al. 2003; Kennedy et al. 2007). In an assessment of material and energy flows in megacities, Decker et al. (2000) conclude that understanding the energy and material processes of urban systems is both grossly understudied and imperative when facing the social, environment and energy challenges of the next century. They indicate that analysis of urban metabolism will provide critical information about energy efficiency, material cycling, waste management and infrastructure architecture in urban systems. They support Wolman’s observation that water is the dominant material flux through cities and consequently should be a priority for urban research.

Understanding how to design cities, buildings and technologies that simultaneously draw less on water and energy will help societies compete in a future where water and carbon are simultaneously constrained and when full externalities are valued. However, cities change slowly. Their infrastructure is complex. So too are their institutional frameworks, business structures, systems and opinions. Moving to modes of higher efficiency is not a small task. It demands a systematic and concerted approach, with a clear end goal in mind.

When this research commenced, policy and management needs associated with water-related energy were poorly documented – either within or beyond California. Klein et al. (2005) had identified the need to ‘invest in research that develops more water and energy-efficient appliances, processes, designs, demand-side management methods and technologies, and treatment systems’ and that ‘water and energy agencies and utilities need to work together to identify mutually beneficial research and develop opportunities that the state can pursue to improve both systems, followed with market transformation strategies to accelerate adoption of resource efficient behaviour’. Wolff & Wilkinson (2011) listed significant research and data compilation necessary to improve characterisation of water-related energy. They stressed the need for methodological considerations, for example, how to deal with the potential for double accounting of energy used to generate electricity (e.g. natural gas), as well as the resultant electricity consumption.

The aim of this project was to improve understanding of the necessary actions and research associated with management of water-related energy in cities. It sought to work collaboratively with both the water and energy sectors: a long-articulated challenge. Focussing research leads to higher-quality outcomes. Shared knowledge leads to effective resource management. While substantial previous research has been conducted, much has been undertaken from a particular perspective; for example, considering the impacts of water on energy, or energy on water. This has led to a diversity of studies with many important individual outcomes, yet no clear overall picture of either the magnitude of the problem developing, the need for progress, or the research necessary to support management and policy (Kenway et al. 2012b). This paper draws on a workshop and survey undertaken by the authors to partially fill this gap.
METHOD

The principle methodology involved convening a workshop to systematically extract converging themes from senior professionals actively working on water–energy–carbon intersections with a focus on cities. California was selected as the location because it has a strong physical connection between water and energy. This has led to a high level of published information on the water–energy nexus, indicating an active research community. More recently, a progressive legislative and institutional framework for conservation of both energy and water has also been developed. This has included conducting co-management trials involving water and energy utilities collaborating to understand the energy consequences of various water conservation measures (GEI & Navigant 2014a, b).

The workshop included representation from a deliberately diverse stakeholder group. State, federal, local, utility, research and not-for-profit interests across both the water and energy sectors (Table 2). A series of short presentations was invited from particularly active participants. Presentations were arranged to address the following major themes.

Table 2 | Focus and perspective of participating organisations

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Major focus</th>
<th>Institutional perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop Waste</td>
<td>Water/energy/waste</td>
<td>✓</td>
</tr>
<tr>
<td>Pacific Institute</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>California Energy Commission</td>
<td>Energy</td>
<td>✓</td>
</tr>
<tr>
<td>Alliance to Save Energy</td>
<td>Energy</td>
<td>✓</td>
</tr>
<tr>
<td>University of California Berkeley</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>Electric Power Research Institute</td>
<td>Energy</td>
<td>✓</td>
</tr>
<tr>
<td>California Water and Energy Coalition</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>East Bay Municipal Utility District</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>University of Queensland, Australia</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>Lawrence Berkeley National Laboratory</td>
<td>Energy/water</td>
<td>✓</td>
</tr>
<tr>
<td>University of Oregon</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>Southern California Edison</td>
<td>Energy</td>
<td>✓</td>
</tr>
<tr>
<td>California Public Utilities Commission</td>
<td>Energy/water</td>
<td>✓</td>
</tr>
<tr>
<td>Water Research Foundation</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>California Urban Water Conservation Council</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>Australian National University</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>University of Texas, Austin</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>Simon Fraser University, Vancouver</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>American Water</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>San Francisco Public Utilities Commission</td>
<td>Water</td>
<td>✓</td>
</tr>
<tr>
<td>Colorado University</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>Brookhaven National Laboratory and Uppsala University</td>
<td>Energy</td>
<td>✓</td>
</tr>
<tr>
<td>Rosenblum Environmental Engineering</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
<tr>
<td>University of California Berkeley/University of California, Los Angeles Schools of Law</td>
<td>Water/energy</td>
<td>✓</td>
</tr>
</tbody>
</table>

*Lawrence Berkeley National Laboratory and University of California Berkeley were strongly represented with three to four representatives each due to proximity and participation in planning. Most other organisations had only a single representative.
• What are the elements of success in the water-energy-efficient city of the future? What are the major opportunities for cost-effective energy efficiency via water management in cities? (Session 1).

• What are the major needs and barriers to progress in the most important element? (Session 2).

After the presentations, an interactive component was convened generally following the World Café method outlined by Dunn (2004). The 35 workshop participants were self-arranged into ‘café-style’ tables of five or six people. A ‘host’ and ‘scribe’ were identified for each table. All tables worked on the same question (above). After a relatively short period of discussions, all people at the table, with the exception of the ‘host’, were required to move to other tables of their choice. Here, the role of the host is important – they have to briefly explain the main points already made at the table and facilitate input from the newcomers on major points that they had heard at their previous table. After two or three rounds, presentations from each table were then made to the entire group, on the most important points. These were recorded on flip charts and discussed among the entire group. Group discussion was used to identify the issues with the highest priority on which to focus for Session 2.

An on-line survey was developed after the workshop in order to explore the benefit received from participation in the workshop and to better clarify the individual and cumulative view of the initiatives and issues identified. For example, participants were asked to rate the initiatives as follows.

• On a scale of 1–5, to what extent do you believe the following initiatives have POTENTIAL to support progress toward water and energy-efficient cities of the future. (1 equals no potential, 5 equals significant potential.)

• Given the same initiatives, on a scale of 1–5, how significant a LEVEL OF EFFORT do you think will be needed for the initiative to influence progress toward water and energy-efficient cities of the future. (1 equals minor effort needed, 5 equals significant effort would be needed.)

• To what extent do you feel the workshop will help you create collaborations across multiple stakeholders?

These questions enabled the production of a roadmap covering the identified issues. It also enabled semi-quantification of the overall potential-to-effort ratio for each initiative. The intention of such analysis is that, generally, work would begin more strategically with work of higher potential and requiring less effort. That said, the general view was that all elements identified are important. Many elements perceived as less critical were ignored or glossed over. Consequently, uptake of most of the elements identified was encouraged.

A four-point contact method (Dillman 2007) was used to gather responses, and 26 workshop participants (of 35 workshop participants) completed the on-line survey. Of these, 16 described themselves as from the energy sector and 10 from the water sector. Participants identified themselves as either from federal government (1), state or provincial government (4), municipal/local government (1), not-for-profit organisations (4), university or research (13) and consultant (1) or utility (2). Some overlap is likely in all these categories (see Table 2). For example, some researchers work for federal entities (such as the US Department of Energy’s Lawrence Berkeley National Laboratory, administered by the University of California), and consequently could be viewed as from either the research or federal government groups. The group completing the on-line survey was generally considered representative of the overall workshop, with perhaps a small bias towards the university sector.

THE VISION OF A SUCCESSFUL AND EFFICIENT CITY

For this workshop, cities were discussed in the context of large populations (1 million people or more) living in close proximity: major urban centres. The authors acknowledge this is a relatively broad definition and focussed somewhat on the developed world. Consequently, the results of the workshop may or may not be applicable to other configurations or interpretations of the term ‘city’.

The workshop participants narrated a vision of a city successfully managing the water–energy nexus:

In future, successful cities will be liveable, fun and locally self-sustaining. They will meet regulated standards, and optimise diverse energy and water supply portfolios in an affordable manner. The cities will achieve or strive towards zero net energy (carbon) use and water
The city would be self-reliant and not draw on the surrounding environment for input resources or for waste assimilation, noting that the degree of self-reliance is likely to depend on local conditions. What is critical is that the city operates within its local water and energy (carbon) budget. This efficiency paradigm is fully embraced at a ‘whole system’ level. It fosters creativity, design innovation, business and economic success.

**MAJOR AREAS OF ACTION AND POLICY TO ENABLE THE VISION**

Ten major areas were identified that would help achieve this vision, with sub-areas identified for some:

(A) Integrated standards, guidelines, and cross-institutional funding and planning:
   - (A1) funding across two or more utilities or government levels
   - (A2) combined standards/guidelines
   - (A3) integrated policy
   - (A4) a framework for operation
   - (A5) integrated planning processes.

(B) Education:
   - (B1) in schools
   - (B2) the public
   - (B3) college level.

(C) Rates reflect full costs.

(D) Urban metabolism management:
   - (D1) full urban water, energy and material balances are developed
   - (D2) data-warehouse to capture full performance metrics
   - (D3) understand urban processes (e.g. consumption) and its effect
   - (D4) use ‘metabolic performance data’ to guide policy and action.

(E) Align technology development and adoption with needs.

(F) Water-related energy is defined and tracked:
   - (F1) targets set and tracked over time
   - (F2) a clear method for determining water-related energy exists.

(G) Human motivation for water and energy consumption is understood and managed:
   - (G1) a high level of understanding of what motivates people
   - (G2) behavioural understanding is used to influence consumption.

(H) Wider integration also occurs with:
   - (H1) waste
   - (H2) transport.

(I) Adaptive management and feedback is implemented.

(J) Blueprints for urban architectural development are prepared.

The on-line survey enabled these elements to be positioned with regard to both their potential and effort (Figure 1). Based on the potential-to-effort ratio, initiatives were loosely grouped into three areas. Initiatives with the highest potential-to-effort ratio are left of, and above, the left-most black dashed line. Those with a lower potential-to-effort ratio, are right of the right-most dashed line. Definitive positioning is not possible due to the variability in viewpoints captured in the survey. Nevertheless, the results give an impression of overall priorities. This information gives some insight regarding the possible staging of a coordinated research and management effort. For such an analysis, the relative position is more important than the absolute score.

While the workshop participants were clear that all themes identified require strong research and management action, in overview, four areas appear to have a stronger case for more immediate attention. The areas with the highest potential-to-effort ratio include the following:

- (A) Integrated standards, guidelines, and cross-institutional funding and planning.
- (B) Education.
- (F) Water-related energy is defined and tracked.
- (G) Human motivation for water and energy consumption is understood and managed.

With regards to element (A), the on-line survey indicated that (A2) combined water and energy standards and guidelines, and is likely to have the highest overall potential/effort within this group. This is followed by (A1) and (A5), respectively, combined water and energy funding and planning initiatives. Surprisingly, integrated water and energy policy making (A3) was deemed as having a lower overall potential-to-effort ratio. It is possible that this reflects the drawn out
and politically challenging development of the *Global Warming Solutions Act of 2006* Assembly Bill 32 (AB-32) and the 2009 *Water Conservation Act* (Senate Bill 7 × 7; SB7 × 7). AB-32 establishes California’s goal of cutting greenhouse gas emissions to 1990 levels by 2020. SB7 × 7 establishes California’s goal of reducing water use by 20% by 2020.

More recently, the California Public Utility Commission has undertaken water/energy nexus pilot projects at a time of economic downturn in California. This may warrant further consideration. In any subsequent survey, it could be relevant to see if the influence of ‘government’ versus ‘non-government’ factors played a role in shaping this perception. The survey also suggested less urgency for a combined structure and framework for operation (A4).

Integrated targets and methods (F) were viewed as having similar potential. It would appear prudent to first improve methods (F2), such that water-related energy and associated greenhouse gas emissions are well quantified, and reduction potentials (and costs) are well understood, before targets were established (F1). Similarly, improving the understanding of factors affecting motivation (G1) would perhaps best precede efforts to use behavioural factors to influence changes.

Sequencing of work over a longer period of time requires consideration of more factors than a single ‘potential-to-effort ratio’. For example, some areas may develop faster than others. Alternatively, breakthroughs may be achieved, lowering the necessary effort or increasing the potential of particular measures.

The four component elements of urban metabolism management (D1)–(D4) identified in the workshop fell into an area of lower overall potential-to-effort. It is possible that this relatively new approach and analysis method is not well understood. Alternatively, it may have been viewed as more general and less specific to the immediate needs of managing urban water and energy demands. Either way, many of the steps viewed as having a higher overall potential-to-effort ratio would provide a much more solid foundation for understanding the overall material and energy balances of cities and the influence of their component systems.

Blueprints for the overall urban architecture (J) were viewed as having a lower potential-to-effort ratio. It is possible that this element was perceived as more prescriptive and premature, given the current state of knowledge. Full cost charging and rate making (C) was also surprisingly rated as having a relatively low potential-to-effort ratio. Further partitioning and exploration of this complex area is likely necessary given the wide-spread repercussions that pricing can have. In addition, to date, relatively little research has been conducted on the economic or financial implications of the water–energy nexus (Kenway et al. 2011b).

Sequencing of research and management actions could likely be further improved by more detailed consideration
of the themes and their component elements. It is also likely that significant iteration is necessary between the research in one element and the other elements. Consequently, some form of analysis and development in all themes could commence concurrently.

For the highest priority area (A), integrated standards and cross-institutional funding and planning, the workshop identified key needs as well as barriers to progress. These are discussed below. Brief information on the balance of areas is provided in the supplementary material (available online at http://www.iwaponline.com/jwc/004/063.pdf).

**Integrated standards, guidelines, and cross-institutional funding and planning**

Integrated water and energy standards and guidelines, and cross-institutional funding, planning and policy development were viewed as essential and a high priority for action. Because this area was identified as the highest priority, specific needs and barriers to progress are also discussed.

In order to improve the water and energy efficiency of our urban systems, it is necessary that processes work together to optimise the efficiency of the ‘city system’. Such a view considers the efficiency of the city itself, for example, to maximise the use and value of water and energy, as opposed to considering the efficiency of individual systems such as ‘water’ or ‘energy’. To enable such a view, more cross-sectoral work is required horizontally (e.g. across utilities) and vertically (e.g. state–local–federal collaboration). It is also required analysis and management across the ‘scale of the system’, for example, to enable fair competition between centralised and decentralised developments. A critical challenge will be how a progressive regulatory environment is enabled, including the development of accountability of combined water and energy performance to an independent third party. Decoupling of utility revenues from energy sales could provide a model for ‘decoupling’ of water-related revenue streams from water sales (Lesh 2009). Similar to the scheme adopted for encouraging energy-conservation behaviour among energy utilities (California Energy Commission 1999), a public goods charge could establish a fund for paying for water conservation measures.

The public goods charge enables a component of energy bills to be charged such that a ‘conservation fund’ could be established to support activities that conserve energy. It was intended to stimulate investments in cost-effective, sustainable energy savings not likely to be adequately provided by the competitive or regulated market (California Energy Commission 1999).

The workshop participants concluded that there is a major need for research in this area including: (i) vision, (ii) data needs, (iii) techniques and methods, (iv) technologies, (v) tools, and (vi) development patterns. There is also a major question of what appropriate standards and objectives are.

Appropriate metrics and standards for monitoring are needed, including data availability, access and management. Wide public discussion of the metrics could be a useful way to inform the community and test what is actually being proposed. If this forms the basis of setting standards, then the resultant standards are more likely to be established in an open way. A wholistic view of ‘the system’ is needed. The urban metabolism framework may be one approach for this; however, this is not an easy place to start (see Figure 1, element (D)). This suggests that knowledge of urban metabolism needs to be progressively built.

**What is needed to enable progress of integrated standards, guidelines, funding and planning?**

A number of needs were identified that could help accelerate integrated standards and cross-institutional activity. An increase in the number of co-funded water–energy trials, as run in 2008–2011 by the CPUC, would be highly beneficial. This needs to expand into the domain of water end use and include energy savings to consumers associated with water savings, particularly relating to the management of hot water. Wider participation including public involvement would be beneficial. Analysis should include comprehensive information on the costs of doing versus the cost of not doing, including avoided costs. In particular, it is important that funding encourages integrated planning processes.

Tools are necessary to help understand the whole of the system as well as the component parts. For example, this could include tools describing the connections between: (i) water, energy and carbon, (ii) water quality, energy and carbon, and/or (iii) wider connections to costs, economic productivity and potential, life-cycle costs and impacts.
Development of standard metrics and processes would be highly useful. For example, development approvals, reporting arrangements and terminologies used across the water and energy sectors and cycles could be streamlined. Carbon credits and equivalents represent a new and potentially unifying metric of high relevance.

The economics of how water and energy are interconnected is a critical part of the information set that is not currently available. New business and utility models that reward elimination of waste are necessary at levels spanning the whole city as well as its component systems. It would be helpful to identify a mechanism to enable success for diverse stakeholders. Funding for alternative development options including decentralised systems is important to create the diversity from which successful and resilient models could be found.

Relationship building and trust is needed across the myriad of affected organisations. It is particularly critical to have other sectors of government, including health, economic development and external bodies, such as unions and rate-payer groups, involved. This should include increased awareness of the importance of the links between water and energy, and what optimisation of the system will require with regards to workforce development. There is a need to enable learning from mistakes. Opportunities for change include major ‘transitions’ in the system, for example, during drought or economic crisis when policies are often revised.

What are the barriers to progressing integrated standards, guidelines, funding and planning?

Several major challenges create barriers to progress. For example, jurisdictional boundaries are neither aligned nor well coordinated. There is a lack of trust between the public and government, between component institutions, and between regulators and institutions, and existing control is held dearly. The principal agent problem, i.e. 'it's not my problem', has a wide influence. Issues that are not directly relevant to a particular institution or agency are largely ignored. This is a strong part of the current Silo culture and thinking.

There are real physical differences between water and energy. They are very different resources, even though they have similar public-interest aspects. Water is heavy. Water is consumed in the human body and, consequently, water quality is of high importance. Because of variable rainfall, long-term storage in dams is required to smooth variations in rainfall. In contrast, electrical energy has to be stored in hydrodams and, of course, in oil, coal and other fossil fuels.

Due to these differences, water and energy management needs to differ substantially. Similarly, many existing management control systems lack inter-operability and cannot communicate or share information readily. More broadly, the 'language' used in the different sectors is often quite different, leading to challenges sharing information.

A major barrier is the current lack of co-ordination between the different funding sources for water and energy infrastructure (and greenhouse gas mitigation) and action. Much of the current funding is oriented towards supply-side (rather than demand-side) approaches. Greater emphasis is warranted towards reducing demand. It seems highly likely that more cost-effective measures can be found by addressing water and energy consumption simultaneously. There is a need to establish much more clearly the costs and benefits of water and energy conservation, including all the life-cycle implications. For example, in option analysis for urban water strategies, the water and energy savings to consumers of water conservation measures should be included into cost–benefit analysis.

The core business case and model are not well developed or clear for combined water and energy conservation or management. This includes lack of business models for public–private engagement. There is a fear of change, of job loss and of shared control.

Short-term policy making is problematic. Federal pre-emption on standards and codes can either accelerate or hinder local progress in efficiency.

The wider issue of agency entrapment and the need for research in this area are also strongly endorsed by Brown et al. (2011). In a commentary on Total Water Cycle Management in Australia and UK, they note that the urban water sector is ‘locked in’, meaning that the water sector is unable to move beyond the current large-scale, centralised infrastructure model and unable to accommodate new technologies and management approaches beyond niche projects. While factors influencing ‘lock in’ are not explored, integration of water–energy research and management is
argued here as providing one avenue for the water sector to look beyond the boundaries of its current role and management.

**Sources of variability**

Some effort was made to understand sources of variability and sub-trends within the data. Viewpoints of participants labelling themselves from either ‘water’ or ‘energy’ sectors seemed remarkably similar, with perhaps a slightly more optimistic view of the potential from the energy sector (Figure 2). This was particularly the case for a ‘framework for operation’ (A4), where the average view of the ‘energy’ sector rated this more than one standard error unit higher than the view of the ‘water’ sector.

More difference appeared between the views of different institutional positions (Figure 3). The ‘utilities and consultants’ typically viewed the potential of different measures lower than the views of ‘university and not-for profit’ organisations or those representing ‘federal, state and municipal government’. However, the relatively small population of ‘utility and consultants’ surveyed (N = 3) means results should be treated very cautiously.

Results from Figures 2 and 3 may suggest an indication of sample frame and self-selection bias. That is, individuals may be more likely to favour measures within their organisational domain. However, it is interesting to note that the relative trends of responses are consistent across respondent characteristics analysed here.

**Comparison with other recent publications**

This work has identified a myriad of research and management priorities of high relevance to water-related energy in...
Simultaneous to the effort in this work, two related publications were released in mid-2011. These further articulate the need for coordinated policy, action and research on water–energy connections. While neither of the publications were available prior to our workshop, the documents are highly complementary and are consequently discussed.

The Alliance for Water Efficiency (AWE) and American Council for an Energy Efficient Economy (ACEEE) articulate a blueprint for action and policy agenda for the United States (AWE & ACEEE 2011). Major initiatives suggested include: (i) increased water–energy sector collaboration, (ii) deeper understanding of embedded energy, (iii) replicating best practice, (iv) integrated research, (v) separating utility revenues from unit sales – and considering regulatory structures that provide an incentive for investing in end-use water and energy efficiency, (vi) leveraging existing and upcoming standards, (vii) implementing codes and mandatory standards, and (viii) pursuing education and awareness.

Similarly, the University of California, Berkeley published Drops of Energy (Elkind 2011), a policy paper focussed on the role of conserving urban water to mitigate greenhouse gas emissions. This study identified main barriers to water conservation as: (i) lack of financial incentives to conserve, (ii) insufficient data, (iii) lack of consumer awareness, and (iv) lack of funds for water-efficiency measures. Several short- and long-term solutions were put forward, including: (a) promoting local water districts efforts, (b) monitoring and publishing water consumption data, (c) a coordinated California-wide marketing campaign, and (d) expanding the funding for efficiency programmes.

Several of the highest-priorities areas observed in the current study highly complement the AWE/ACEEE and University of California, Berkeley reports. For example,
pursuing education and awareness as suggested by AWE/ACEE could be broadened into university and school educational programmes. This would also be supportive of a customer-outreach programme as suggested by the University of California, Berkeley report (Elkind 2011). Leveraging standards, as suggested by AWE/ACEEE, could include integrated standards and guidelines. AWE & ACEEE (2011) articulate the need for ‘whole building rating systems (not just energy and water separately) and land-use and planning codes that account for water and energy efficiency’. Such areas would be highly relevant for the development of combined standards. It could also support the ‘whole of government’ funding effort.

This (current) paper differentiates because it has a city focus, but carries a broader content than water conservation alone. Example initiatives here include those of relevance to management and planning systems and processes and related underpinning data and information. Furthermore, the current paper has more of a research than policy or action focus, yet strives for relevance to both. Consequently, it arguably has a tighter agenda than the AWE/ACEEE work, and a broader agenda than the University of California, Berkeley study. Potentially, this helps link the two initiatives.

Major additional areas of research and analysis identified in the current study and omitted in the AWE/ACEEE and University of California, Berkeley work include: (G1) development of a high level of understanding of what motivates people with regard to their consumption patterns of water, (F1) deeper knowledge of methods for quantifying water-related energy and associated emissions, and (F2) development and tracking of targets for the water-related energy and greenhouse gas emission of cities.

We would argue that the complementary nature of the three studies, and the more complete picture they collectively give, reinforces the need for systematic research and action. The timing of the emergence of these two studies, along with the current analysis, is wider evidence of the groundswell of concern on the issue of water–energy issues integration. It also highlights that many organisations are cognisant of the opportunities and benefits of co-management and action. Collaboration across diverse stakeholders including water and energy sectors and all levels of government is highly warranted. Such effort could be expected to achieve far more than by isolated or sector-driven research.

Outside California, the Australian Government has recently published Challenges at Water-Energy-Carbon Intersections (PMSEIC 2010). This takes a wide systems view of all water and energy connections, and discusses, relatively generally, emerging principles, networks, landscapes and the need for enhanced knowledge and learning. Among other things, the report notes that resilient pathways for cities and towns will be found by simultaneously reducing greenhouse gas emissions, lowering overall water demand, maintaining overall environmental quality and allowing living standards to continue to improve.

The benefit of collaborative efforts to address complex environmental issues was also supported by the survey results. Survey respondents noted that the workshop will assist them in: (1) understanding water–energy problems to be addressed, (2) identifying key objectives to clarify what their organisation decisions should achieve, and (3) defining a rich set of alternatives. The survey also suggested that participants felt the workshop created linkages between organisations managing various aspects of water and energy use in cities. These results suggest that achieving the vision of an integrated water–energy-efficient system extends far beyond the capacity of individual organisations. It also suggests that better processes may lead to actions that benefit the environment and have a wider public good.

**REFLECTION ON THE PROCESS AND SUGGESTIONS FOR FUTURE ANALYSIS**

On reflection, it may have been beneficial to have had a stronger representation from regulators, local government and non-government organisations participate in the study. This may have helped focus the results to harder pragmatic solutions. It may also have more clearly identified legislative and political barriers and challenges, of which there are many. However, such involvement could come at a cost to the wide consideration of ‘blue sky’ options and solutions unimpeded by history and agenda.

The workshop participants included a broad multi-disciplinary base. While representation was not formally tracked,
it included engineering, planning, economics, social science, policy, resource management and waste. Emphasis was placed on securing senior (managing director/chief executive level) input from organisations working actively on the water–energy–carbon nexus. It is possible, or even likely, that inclusion of greater representation of one discipline (e.g. planning or engineering), or even one cultural perspective, could shape the overall roadmap. Repeating the exercise, with different groups participating, would be one way to test this. Both the World Café process and the on-line survey were intended to help reach consensus on complex issues, rather than to reinforce the views of individuals.

Shaping an agenda and process that engenders the support of such a wide group would likely be a challenging exercise. However, future action should aspire to include a pragmatic process, acknowledging that different degrees and types of stakeholder involvement are appropriate across varying circumstances. While some bias could have resulted from the membership of the group surveyed, the overall participation was chosen on the basis of a high level of expertise and knowledge with regard to managing water-related energy.

Discussing in adequate detail the complexity of water and energy connections in cities is no small task. Our workshop allowed a single day. A longer period of time could help bring participants to a closer position and help reduce variability in the viewpoints on the relative potential and effort involved in individual measures. Such an effort could realistically take weeks or even months, and ideally should be structured with an intent of reaching as close to consensus as possible. This is particularly the case as some measures and suggestions could be considered as relatively new.

The on-line survey was of high value. It could readily be extended to capture the perceptions and views of a wider group of participants, including stakeholders who did not participate in the workshop. To enable this, it would be necessary to improve documentation of the suggested measures. Such documentation, together with a larger sample size – and improved descriptions and detail for the ‘effort’ and ‘potential’ categories surveyed, could help further tease apart priorities. Improved survey design to help unpack sources of variability would be valuable.

In order to adequately define a detailed research, policy or action agenda, it would be necessary to go several steps beyond the general areas and issues identified in this document. For research, it would be necessary to articulate key questions at several layers within each of the elements identified here.

While this paper focussed on individual cities, with a metabolic approach to consider imports and exports of resources, future research could consider the linkages between cities and regions.

In overview, our learning was that there is a much greater and deeper body of analysis and management necessary in order to significantly improve the management of water-related energy in cities. Increased collaboration between the water and energy sectors, across levels of government, research and wider stakeholders is also strongly warranted. A multi-stakeholder consortium approach could well be a useful way of advancing the status quo.

CONCLUSIONS

This paper has outlined a vision for cities seeking greater efficiency in water and energy. It is clear that there is significant action, research and policy development necessary to achieve this vision. Those areas having the highest priority included education programmes – at multiple levels – and development of combined water and energy standards, guidelines and planning processes. A clear methodology for determining water-related energy is needed, as are targets. Improved understanding of what motivates people and their consumption of water and energy will be necessary. Many more exist.

Further effort is required to translate the priority areas identified into structured research questions and projects. Collaboration across the water and energy sectors, research, industry, government, not-for-profit and private sectors is necessary. Formation of a research ‘consortium’ or alliance across the various affected parties, organisations and research bodies could be a highly effective way of progressing. To achieve this, a research agenda with wide endorsement would be required. Such an effort could help unite the many component pieces of information and
enable a collective picture to progressively emerge. Special effort should be given to include political representation.

The research and action roadmap developed in this study used a mixture of workshops and semi-quantitative surveys to better elucidate priorities. This has given some insight into a potential sequencing of work and actions. While the overall result is likely to have been influenced by the membership of the workshops and the survey, and is California-centric, it could be argued that the assembled group represented cutting-edge knowledge of the water–energy nexus, its implications and the necessary research and management in cities. Much more work is required to establish the finer details, as well as specific applicability to a particular city or alternative region or country.

The method used in this study could have more general applicability for similar complex problems. However, it could also be improved with regard to understanding sources of variability in perspectives, description of options and quantification of effort and potential necessary to progress particular initiatives.

A detailed research and action roadmap, supported by policy, and progressively implemented and periodically redefined, is needed to help move progressively towards solutions. Should a longer term water–carbon economic crisis emerge, such a road map would arguably facilitate a faster and more effective response.

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REFERENCES


of Engineering and Information Technology, University of Technology, Sydney, Australia.

PMSEIC 2010 Challenges at Energy-Water-Carbon Intersections. Prime Minister’s Science, Engineering and Innovation Council, Canberra, Australia.


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