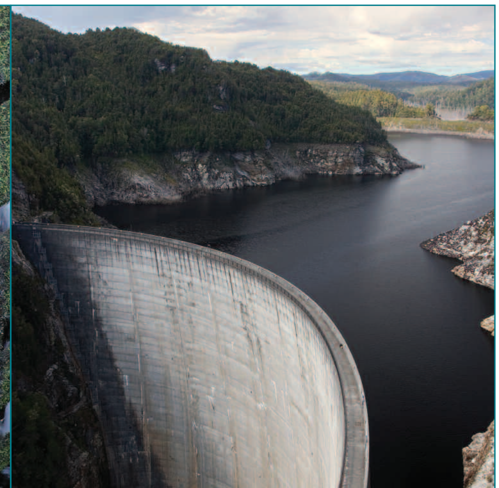
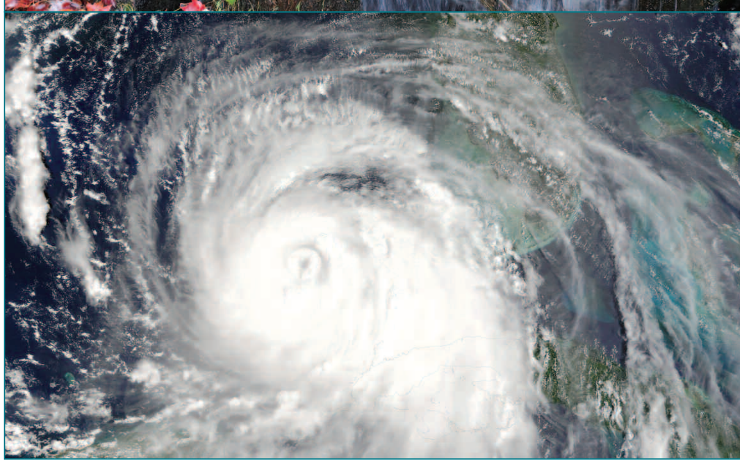
COMMITTED TO
IMPROVING THE STATE
OF THE WORLD





ENERGY VISION UPDATE 2009

Thirsty Energy: Water and Energy in the 21st Century

World Economic Forum
in partnership with
Cambridge Energy Research Associates

Message from the Energy Community Leader 2008
Energy and Water – Sustaining the Flow

By James E. Rogers, Chairman, President and Chief Executive Officer, Duke Energy Corporation, USA

In the last century, global consumption of our planet's finite freshwater supply has grown at more than twice the rate of world population growth, leaving an increasing number of regions chronically short of water, according to the United Nations. By 2025, nearly 2 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be living under stressed water conditions.

Water is critical to energy production and for reducing air emissions from producing energy. Yet, the water/energy nexus is often overlooked. At the World Economic Forum Annual Meeting 2008 last January, I recall UN Secretary-General Ban Ki-Moon warning that what most businesses are doing to address the water issue amounts to "a drop in the bucket."

But for many electric utilities around the world, that is not the case. With changing weather patterns causing more frequent weather extremes in some areas, the availability of water is frequently receiving more attention. In fact, in the United States, utility companies recognize that water quantity is becoming a significant permitting issue.

In the United States, electric utilities are one of the larger consumers of water, although agricultural irrigation is by far the greatest water consumer. But unlike irrigation, and depending on the type of power generation, cooling system and pollution control systems used, power plants return a significant amount of the water withdrawn to the source. As advances in power production efficiency are made, water use efficiency typically increases as well.

A thermal power plant's need for water is due to the fundamental physical law that water can absorb 4,000 times as much heat as air for a given rise in temperature. Environmental controls have also increased water consumption by power plants. For example, requiring cooling towers on new thermal plants causes additional water consumption from evaporation compared with once-through cooling. The use of scrubbers also causes greater water consumption. But electricity is also needed to satisfy regional water needs. In the United States and other developed nations, on average, about 4% of total power generation is used to supply, purify, distribute and treat fresh water and wastewater.

As with carbon emissions, utilities around the world are turning in part to renewable energy and new technologies to explore ways to decrease water consumption. We also are continuously looking for ways to more effectively use existing water sources and to create supplemental water storage.

One promising technology is integrated gasification combined-cycle (IGCC) advanced power systems. IGCC is a technology that efficiently converts coal to a synthetic gas that can be used in a gas turbine for power production. Roughly two-thirds of the power generated in an IGCC system is from the gas turbine. The excess heat from the turbine is used to produce steam in a heat recovery steam generator that produces the remaining one-third of the power. Since the gas turbine doesn't require condenser cooling water, IGCC plants require appreciably less water – up to 40% less – on a gallons per kilowatt-hour output basis.

Duke Energy is building a 630 megawatt (MW) commercial-scale IGCC power plant in Indiana in the US heartland. Not only will this coal plant be cleaner and use water more efficiently, we also hope to demonstrate a successful carbon capture and storage initiative at the site. In West Virginia, another utility is building a coal-fired power plant that will pull its water from pools in the same mine that it is tapping for coal. This project also serves as a test bed for using mine pools found throughout the coal-rich Appalachian region.

Still, the greatest potential for reducing water and air emissions for electricity generation is through greater energy efficiency. We believe that the most environmentally responsible power plant we can build is the one that we don't build. We have filed with our regulators to make energy efficiency part of our standard product offering. Our save-a-watt plan would let us earn a return on a portion of the cost we avoid of having to build new power plants through greater use of energy efficiency, which will save our customers money. We believe this is a key bridge to a future where electricity is generated with significantly less carbon emissions and by using significantly less water.

Water is life, so we need to connect the dots on this critical issue for global policy-makers and leaders. As one of the largest operators of fossil, nuclear and hydroelectric power plants in the United States, we know that a debate on balancing our energy, economic and environmental needs at the policy level is vital. It is one of the best ways to build global support for significant increases in productivity and sustainability in the use of water and for our planet's other natural resources.

Contents

Thirsty Energy: Water and Energy in the 21st Century

EXECUTIVE SUMMARY

How can we ensure that fresh water – fundamental to all life forms and the economy – is available for a growing global population? Although water covers nearly three-fourths of the earth's surface, less than 3% of this water is fresh; the rest is undrinkable seawater. And only a small fraction of that 3% is available for human use. The rest is locked away in glaciers and ice caps.

Pressure on limited fresh water resources is mounting, driven by increasing population, economic growth and pollution. Current trends point to a future of increasing competition for more scarce fresh water resources. However – unlike climate change – water is a local issue and water stress effects will play out locally. Moreover, two key factors – technology and markets – as well as policy will affect the severity of stresses on water resources.

The intersection of energy and water is ancient – water wheels have been used since the Middle Ages to provide mechanical energy as an alternative to human or animal power, and the first oil wells in the United States used drilling technology that was developed to drill for water. However, the relationship between water and energy has taken on new urgency as concerns have grown about the competing pressures for multiple uses of water.

The primary use for this limited amount of fresh water is the agricultural sector, which uses 70% of fresh water withdrawn worldwide, or 2.6 trillion cubic metres in 2001. As the world's population grows – estimated to reach more than 8 billion by 2030 – the pressure to ensure the wise and efficient use of this critical resource will grow considerably.

A second fundamental use for water is industrial, including producing energy for economic development and improving living standards. Today, energy uses about 8% of all fresh water withdrawn worldwide, or 310 billion cubic metres in 2001, and as much as 40% of fresh water withdrawn in developed countries. Energy is also a key input to the water value chain, used to power water movement and treatment.

When discussing how various parts of the economy use water, the distinction between the volume of water ***withdrawn*** and the volume ***consumed*** is very important. Water withdrawn is the total volume removed from the water source. Water consumed is the amount removed for use and not returned to its source. Water withdrawal for energy is much larger than water consumption, by as much as 25 times in the United States, primarily because many power plants use water for cooling and then return it to the water body. However, water amounts withdrawn are also important because energy production relies on water availability for smooth operation and because the water withdrawn is not always returned to the ecosystem in the same state in which it was withdrawn. In many countries, the quality of returned water is highly regulated, although not everywhere.

Gaining an Understanding of the Energy/Water Nexus

Water is used to produce nearly all forms of energy, including generating electric power and providing fuel for transportation. Energy is also used to deliver water, from basic mechanical systems that bring groundwater to the surface so it can be conveyed to homes and businesses to more complex desalination systems designed to convert seawater into potable water. And water is cleaned and recycled again and again by nature through evaporation and rainfall, and through sophisticated waste treatment facilities.

For the energy industry's oil, gas and power sectors, water has always played a significant role in operations. Power plants need water for cooling whether the fuel is coal, nuclear, natural gas or oil. The oil and gas industry uses water or steam pumped underground to force oil to producing wells and to crack open rock formations to unlock resources. Many of the promising, large remaining reserves of fossil fuels are water-intensive to produce, including oil sands and unconventional natural gas. The introduction and scale up of carbon capture and storage will also increase the water exposure of the energy sector.

Energy production does not just use water, it can also contribute to water pollution if resources are not managed properly. In older oil fields, more water is produced than oil, because of the complex geological formations that hold deposits of oil, gas and water. This water is frequently too contaminated to release without proper treatment. Acid drainage from coal mines and fertilizer runoff from crop production for biofuels also have the potential to harm freshwater resources.

Thirsty Energy: Water and Energy in the 21st Century

For the energy industry, pressure on freshwater resources will translate into the need to use water much more efficiently in the extraction, transformation and delivery of energy. Although water worries are global – especially with rising concerns about the impact of climate change – water solutions are local. Translating global water worries into local solutions will not only require increasing awareness of the water challenge but also a better understanding within the energy industry of the complex relationship between water and energy.

Moving Up the Ladder – From Operations to Strategy

Water is increasingly moving from an operations issue to one of strategic significance. Access to water is a growing risk for the electric power industry as it plans to invest in new plants. Particularly in water-stressed regions, a battle over water rights adds an element of risk to any proposed new power plant. Water is also of growing concern for oil and gas companies. As the oil industry focuses on advanced and enhanced oil recovery (EOR), companies need to find sources of water to use in production and solve disposal problems related to produced water.

When the availability and consumption of water are combined with pressures to reduce the use of carbon-intensive fuels, the risks to energy companies become even greater. Although biofuels are water intensive, particularly when produced using irrigated crops, other renewable energy resources are less so, including wind and solar. The energy industry – already under pressure to reduce greenhouse gas emissions – faces a potential challenge from new arguments about moving to alternative fuels and reducing demands on finite fresh water resources.

Searching for Common Principles to Optimize the Water/Energy Nexus

The energy industry accounts for 8% of the world's freshwater withdrawals, an already important share that may further increase depending on the future energy mix. Yet, water is so integral to its operations that the industry must understand the potential risks and partner with policy-makers and other stakeholders in managing the world's water resources. In water-stressed areas, electricity providers are already changing how water is used. They are tackling water efficiency with the same diligence that they approach energy efficiency. The oil and gas industry is also developing new water measurement systems and setting goals to reduce water consumption in its operations.

Many of the concerns about energy use – how to ensure easy availability to growing populations around the world – apply equally to water use. In fact, access to potable water is a widely recognized fundamental human right. Finding ways to optimize the use of water in generating energy – and the use of energy to deliver water – will not be easy. It will take a concerted effort on the part of all stakeholders, including energy producers, water companies, policy-makers and consumers.

What is the role of markets? Although markets may be useful in water-stressed areas, access to clean water is such a basic human right and so vital to ecosystems that markets are limited in their ability to optimize its use. What is the role of regulatory policy? Although water is an issue of global concern, the solutions and policies need to be tailored to local conditions. No energy technology or solution is inherently good or bad from a water perspective; it all depends on the local context. Are there examples of successful optimization of water use by multiple stakeholders in one region that can be applied to problems in another region? What is the role of measuring and reporting water use? What is the role of measuring energy use for water purification and delivery? Are common measurement standards helpful? Or is the relationship so complex and intertwined with climate change, energy security and social issues that another approach to encourage water and energy efficiency is more appropriate?

The relationship of water and energy is ageless and continues to evolve. Understanding how best to optimize the use of water and energy will be critical for business leaders and policy-makers. The energy industry cannot single-handedly solve the growing global water crisis. However, the risks for the industry are too great to stay out of the policy debate and to disregard water in strategic planning. The industry's ability to contribute to a better understanding of the difficult choices ahead argues for joining the dialogue about this important relationship. The World Economic Forum is undertaking a major cross-industry initiative on water from 2008 to

2010 that brings together a multistakeholder group to raise awareness and to find collaborative approaches to address the global water challenge.

Daniel Yergin, *Chairman,*
Cambridge Energy
Research Associates

Christoph Frei,
Senior Director,
Head of Energy Industries,
World Economic Forum

ENERGY ISSUES SURVEY 2008/2009

Setting the Agenda – Key Issues for the Energy Industry

The agenda of the Energy Industry Partnership is shaped by the Industry Partners themselves. The focus issues are identified and selected based on an annual survey conducted with CEOs and senior executives of the Partner companies, all leading global energy companies. Thirty-one CEOs out of 40 partner company CEOs (78%) responded to the Issues Survey 2008/2009, and similar response rates were obtained in previous years. The responders were asked to rank issues according to the degree of their impact on the industry, their uncertainty and their urgency.

The Issue Map Explained

Issues are positioned according to three parameters:

- The horizontal axis indicates the expected impact of the issue on the energy sector.
- The vertical axis indicates the degree of uncertainty surrounding the impact of an issue.
- The size of the bubble indicates distance in time to when the issue becomes pressing.

Immediate concerns are shown by larger bubbles, while small bubbles indicate issues that will become important only in the longer term.

How to Read the Issue Map

- Issues are separated into four categories: macroeconomic risks, energy geopolitics, energy business environment and energy vision.
- High impact/low uncertainty issues require immediate action by stakeholders – including industry, policy-makers, etc.
- High impact/high uncertainty issues would benefit from multistakeholder dialogue to improve understanding and design strategies to tackle them.
- Low impact issues are either considered unimportant or they have not yet registered on CEOs' radar screens. Where the survey reveals sharp differences over the impact of an issue, the second interpretation is more likely, in which case the World Economic Forum may seek to raise awareness.
- Setting the Agenda: Generally, the Energy Industry Partnership focuses on issues that lie on the upper-right corner of the Issue Map (high impact, high uncertainty). The agenda is balanced with respect to short-term and long-term issues. Issues with high discrepancy in opinions are also explored.

Key Topics Emerging from the Issues Survey

Figures 1 and 2 show the Issue Maps 2008/2009 as well as 2007/2008 for comparison. The latest Issue Survey was conducted before the financial crisis worsened in autumn 2008. The crisis is likely to have shifted the picture slightly compared to the Issue Map 2008/2009.

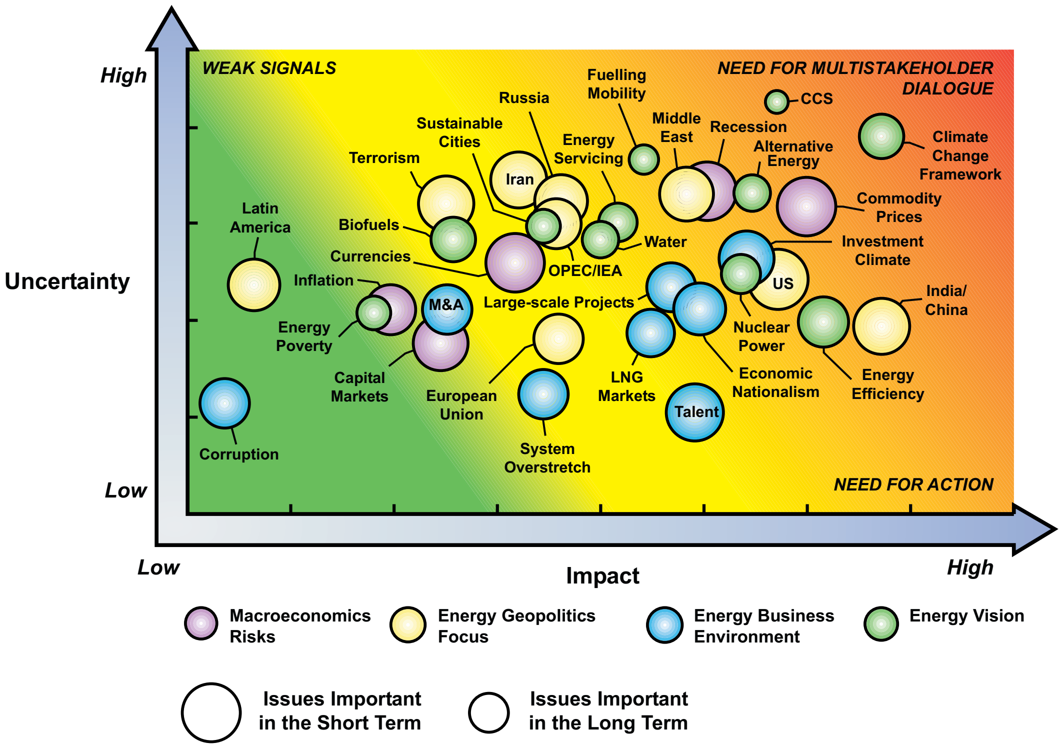
However, the Issue Maps indicate that even before the full extent and impact of the financial crisis became apparent, macroeconomic issues including recession risks and commodity prices ranked high on CEOs' radar screens as short-term issues. It would be natural to assume that the financial crisis has increased the importance of capital market and economic recession risks to the industry.

Climate change framework stands out as the single issue that ranks highest in terms of perceived impact and uncertainty in the Issue Maps of the two last years. This confirms a historic trend from previous years' surveys where climate change has been steadily rising in terms of importance. It demonstrates that the future international climate change architecture is likely to have considerable impact on the energy future and that the current uncertainty around the architecture is a challenge.

Alternative or renewable energy slightly outranks nuclear power in the two last surveys as illustrated by the maps even though both issues come out as important. Interestingly – however – these results inverse the tendency from previous years' surveys where nuclear energy was perceived as more important than alternative/renewable energies. Carbon capture and storage (CCS) stands out as the single issue associated with the highest level of uncertainty, with expected impact to materialize in the longer run.

Figure 1

Issue Map 2008/2009: Energy Industry Issues – Results



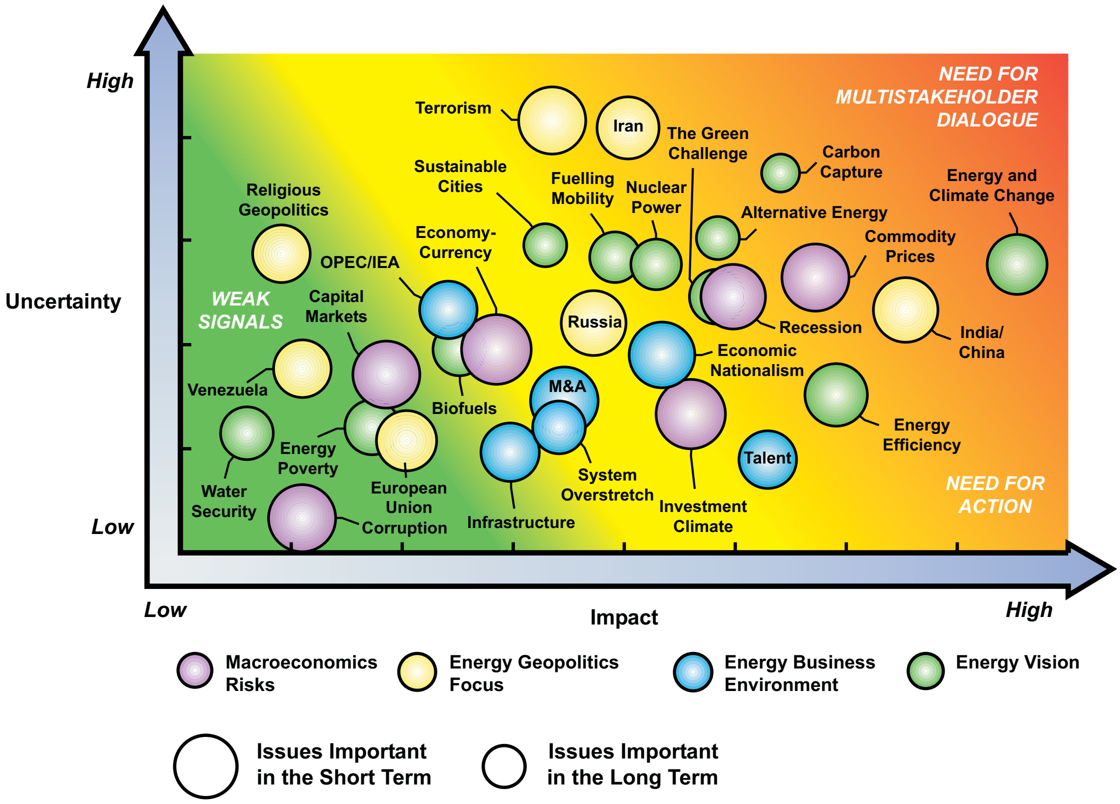
Source: World Economic Forum Energy Industry Issue Map 2008/2009.
81017-8

Sustainable cities come out as mid-range on both impact and uncertainty dimensions which is probably a recognition that cities will play an increasingly important role as centres for future energy demand and for new and innovative energy solutions.

Biofuels rose sharply in the map from a very low starting point in 2005/2006 to mid range in the two last years. Also a related issue – fuelling future mobility needs – is deemed to be of high uncertainty in the longer run.

Energy geopolitics are also associated with considerable uncertainty and large potential impact on the energy industry. The expected impact of India and China on global energy markets stands out as particularly significant. Moreover, political developments in the United States and Middle East also hold the potential to have major impact in the short run, although CEOs deem the associated uncertainty level to be higher for the Middle East. Other geopolitical hotspots such as Iran and Russia score slightly lower on potential impact, although the uncertainty level is seen as fairly high. To be noted, however, most responses were received before the Georgia crisis in Autumn 2008, so Russia may have scored higher in the map if the survey had been conducted post-crisis. On the other hand, terrorism ranks much lower in last two polls, compared to 2005/2006 for instance.

Figure 2
Issue Map 2007/2008:
Energy Industry Issues—Results



Source: World Economic Forum Energy Industry Issue Map 2007/2008.
71103-7_0812

Energy business environment issues like attracting talent, prospects for liquefied natural gas (LNG) markets and economic nationalism are perceived as fairly important in the midterm, although the uncertainly level is quite low as shown in the maps. It is worth noting, however, that another business environment issue – corruption – is expected to have very low impact on the energy industry according to the surveys of the two last years.

Last, but not least, it is interesting to observe how the water issue has moved over the years. Two years ago, the issue of risks related to water/energy interlinkages scored very low in the matrix, indicating that it was not on CEOs' radar screens. In the 2007/2008 poll, water risks scored higher but still fairly low compared to other issues. However, in last year's poll, the water/energy interlinkage made a significant bounce in the map, indicating rising awareness of and expectation that water can impact the energy future. Thus, this report is timely. The aim is to raise awareness of water/energy interlinkages as well as potential impacts, risks and strategies to tackle the challenges.

Thirsty Energy: Water and Energy in the 21st Century

Below is a detailed overview of the questions that were included in the Issues Survey 2008/2009.

Marcroeconomic Risks

Capital markets .... Influence of private equity and sovereign wealth funds on capital flows
Commodity prices .... Still large profits constraint by increasing costs
Economy/currency .... Continued weak dollar … losing primacy as global currency?
Recession.......... Global downturn (bringing down commodity prices) or "global decoupling"?
Inflation.......... Risk for Dutch disease in producing countries

Energy – Geopolitics

European Union.......... New supply policies
India/China.......... Impact on global energy systems
Iran .... Risks for energy markets
Latin America .... Political uncertainty affecting investment opportunities
Middle East .... Political uncertainty affecting supply security
OPEC/IEA .... Decommercialization of natural gas: Russia and Iran driving the "natural gas OPEC"
Russia.......... Political uncertainty affecting investment opportunities
Terrorism .... Risks for energy markets
United States .... Change in priorities of new US administration: Middle East, climate change, interventionism

Energy Business Environment

Corruption.......... Affecting leadership culture
Economic nationalism .... Protectionism and re-nationalization in the energy sector
Investment climate .... Market reform/frameworks that promote investments and innovation
Large-scale projects .... Varying public acceptability in different regions
Mergers and acquisitions .... New wave and new features
System overstretch.......... Diminishing security margins
Talent .... Attracting and retaining talent
LNG markets.......... Tight LNG markets after 2012

Energy Vision

Alternative energy .... From venture to scale
Biofuels.......... Mixed blessings
Carbon capture and storage .... Time requirement from pilot to scale
Climate change framework.......... Route to Copenhagen and international convergence on future architecture
Energy efficiency .... Scaling up and implementing solutions
Energy poverty .... Extending markets to unlikely areas
Energy servicing .... Smartgrid, decentralized solutions, consumerism
Fuelling mobility .... Fuelling future mobility needs
Nuclear power.......... Old dogmas and new horizons
Sustainable cities.......... Localization of energy policy
Water.......... Energy and water interlinkages as future risks

CHAPTER 1: THE GLOBAL WATER PICTURE AND HOW IT LINKS TO ENERGY

Introduction

Energy and water have always been inextricably linked. Water wheels have been used since the middle ages to provide mechanical energy – as an alternative to human or animal power – primarily to grind grain into flour. The first oil wells were drilled using technology designed to drill for water. In fact, in the mid-1800s in the United States, wells drilled for water that found oil instead were considered a nuisance and abandoned. In modern societies where water comes from a faucet and energy from a pump or plug, many people have lost their sense of the critical relationship between energy and water. However, that relationship is stronger than ever and is becoming more strained as human usage of both energy and water increases.

The energy sector's use of water has not been at the centre of recent water resources concern. Instead, much of that concern today is focused on two issues: the water and sanitation needs of growing populations and water use due to agriculture. Both of these issues are vital to humankind. Energy's use of water is not as emotional an issue as domestic use or as large as agricultural use. However, as water resources become more strained around the world, energy companies need to become more aware of their water use and more involved in decisions about water resources policy.

The purpose of this report is to explore the interconnections between modern energy and water systems as well as their potential implications in light of increasing demand – and constrained supplies – for both energy and water. The report also suggests principles to guide better management of the energy-water nexus. Even in the current global economic downturn, the issue of water availability has moved up in the world's agenda alongside climate change. Recent droughts and water shortages in various parts of the world, including Spain, the south-eastern United States and China, have highlighted water's vital role in life and the economy. Water is an essential component of all human life and the systems that support it. Water is also a crucial input to the energy needed to fuel economic growth. The quantity and quality of water available to support energy production, and all other human activity, will become an increasingly crucial issue in many parts of the world as growing populations demand a higher standard of living.

Previously held assumptions about the availability of water may change as competition for water from various users increases.

This report is organized into four chapters:

- The first chapter briefly describes the fundamental role of water, global water resource availability and water's role in the energy sector. It also discusses potential risks and challenges to the energy sector resulting from water resource availability.
- The second chapter provides information about how various energy and water provision technologies use resources.
- The third chapter provides case studies that illustrate water challenges that energy companies have faced and how they have addressed them. This chapter also includes case studies describing the challenge of reducing the amount of energy required to deliver water to consumers.
- The fourth chapter brings together the lessons from the case studies to offer principles for optimizing both water and energy use in sustainable ways.

Water Is Fundamental to Life and the Economy

Water is a life-giving resource, fundamental to human existence as well as economic activity. Water is also a vital part of the biosphere, and all ecological processes rely on adequate water. Management of water for human use can sometimes be at odds with management of water to preserve ecological systems. This tension is an ongoing challenge in many parts of the world, from the Columbia River Basin in the United States where hydropower dams have pushed certain runs of salmon to the brink of extinction, to the Aral Sea in Kazakhstan and Uzbekistan. Irrigation canals built in the Soviet era to divert two rivers that naturally drained into the Aral Sea have reduced the sea's size by more than 60% and more than doubled its salinity, decimating fish populations.[1] Integrating and balancing human and ecological water needs are likely to become more challenging as the human population grows.

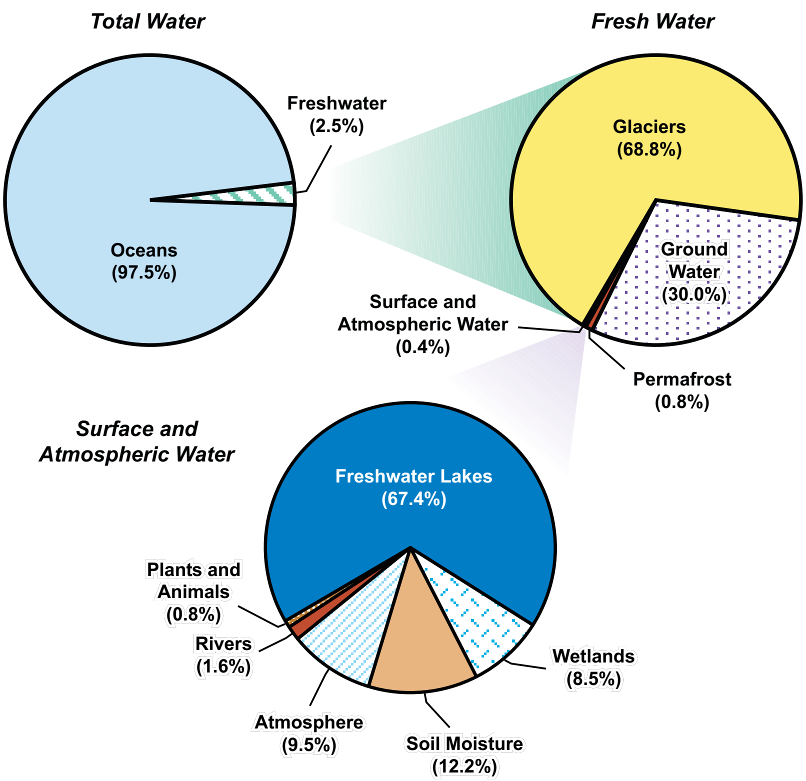
1. Micklin, P.; Nikolay V. Aladin "Reclaiming the Aral Sea," *Scientific American,* March 2008.

Water, Water Everywhere ... but Not Necessarily Available for Use

Although water covers 70% of the earth's surface, less than 3% of the world's water is fresh – the rest is undrinkable seawater (see Figure 3). Nearly 70% of that fresh water is locked away in glaciers and ice caps, leaving a very small portion of the world's water available for human use. Fresh water accessible to humans as rainfall and runoff is very unevenly distributed. The rain gauge in Arica, Chile, in the Atacama Desert, routinely records zero annual precipitation. At the other extreme, Mount Waialeale on the Island of Kauai, Hawaii, has recorded more than 11.5 metres (37.7 feet) of rainfall in a single year.[2]

The world is not running out of fresh water. The amount of fresh water available in the world is, in fact, roughly constant, as water that flows into the ocean evaporates and falls back onto the land as rainfall. However, as James Rogers notes in his preface, *Energy and Water – Sustaining the Flow*, "In the last century, global consumption of our planet's finite freshwater supply has grown at more than twice the rate of world population

Figure 3
Global Distribution of Water



Source: United Nations Educational, Scientific, and Cultural Organization (UNESCO), Cambridge Energy Research Associates.
81017-1

2. Gleick, Peter H., editor. *Water in Crisis: A Guide to the World's Fresh Water Resources.* Oxford University Press, 1993.

growth, leaving an increasing number of regions chronically short of water." This pattern of growth is not sustainable in many areas of the world.

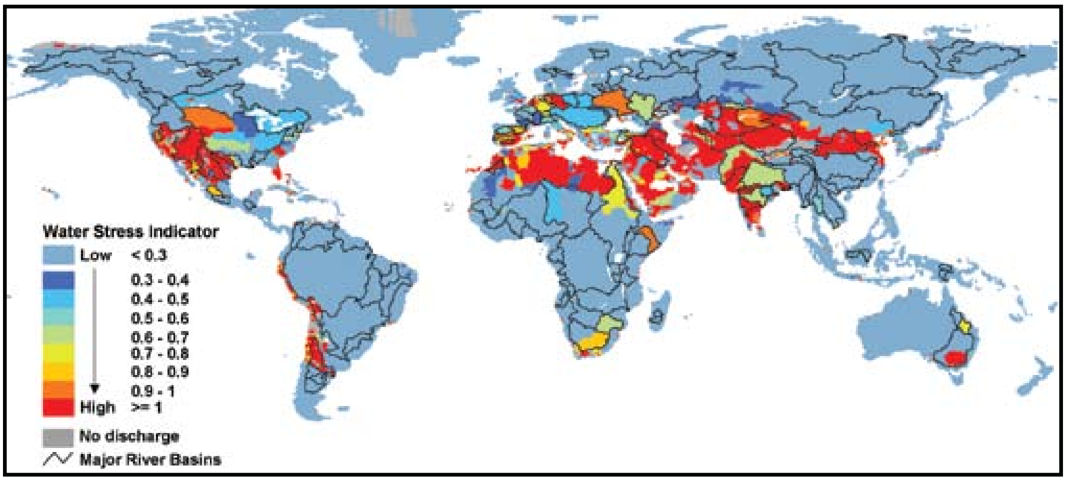
Fresh water is not always available where and when people need it – a concept often described as "water stress." The level of water stress in a location can be evaluated by comparing total water use to the available volume of renewable water resources, defined as streams, rivers and shallow groundwater. *The Second United Nations World Water Development Report* defines a ratio of use to availability greater than or equal to 0.4 as water stressed.[3] The World Resources Institute has produced a map showing the world's major river basins and their levels of water stress (see Figure 4). This map vividly depicts the local nature of water stress and the need for local solutions, a situation that is sometimes masked by studies that only consider water availability at the country level.

Water Resource Management – Inherently Local

Because of fresh water's uneven distribution, water resource management is inherently local. As Margaret Catley-Carlson describes in her perspective, *Energy and Water – Linked and Looming Challenges*, "Water can and should be discussed globally, but can be truly understood and acted upon only locally." Global discussions about best practices in water management can be useful, but policy- and decision-making must be appropriate to the local water resource.

Water is very heavy related to its economic value, meaning that long distance transport of water is generally not economically feasible. For example, a barrel of oil weighs about 125 kilograms (275 pounds) and has recently been worth between US $50 and US $147 on the world market. The same volume of water weighs about 159 kilograms (350 pounds), and in one (rather

Figure 4
Water Scarcity Index by Basin



Source: IUCN-The World Conservation Union, the International Water Management Institute (IWMI), the Ramsar Convention Bureau, and the World Resources Institute (WR I). 2003. Watersheds of the World CD. World Resources Institute: Washington, DC. Copyright 2003, IUCN, IWMI, Ramsar, and the World Resources Institute. 81017-7

3. United Nations World Water Assessment Programme, *Water, A Shared Responsibility: The United Nations World Water Development Report 2, 2006,* page 116.

expensive) US municipality is sold to households for about US $0.14.[4] In addition, global markets for water do not exist, unlike other commodities such as oil or metals. Therefore, optimization of water resources must take place on a local level. The local nature of water resources makes their management very different from the management of greenhouse gas emissions. A reduction in greenhouse gas emissions in Brazil can offset increasing emissions in China, but the abundance of fresh water in the Brazilian Amazon is not helpful for areas of northern China where water is scarce.

Climate change is likely to have a destabilizing effect on the world's water systems. The world's energy and water infrastructure was built based on historically observed hydrological conditions. However, climate change challenges the assumption that future hydrological conditions will resemble those seen in the past. The changes that might occur are difficult to predict at the local level. Increasing precipitation intensity and variability are projected to intensify the risks at both extremes – flooding in some areas and drought in others. In general, water availability is expected to increase in high latitude and wet tropical areas and decrease in mid-latitude dry regions and in the dry tropics.[5] The risk of changing water availability due to climate change is particularly important for long-lived assets, including many energy facilities, that rely on a steady supply of water.

In many places, climate change is likely to add additional strain to areas that already struggle to meet their need for fresh water. Sean Cleary brings together the energy, water and climate challenges in his perspective, *Energy, Water and Climate: Unravelling the Conundrum.* "The tripling of the global population in the 20th century led to a six-fold increase in water usage. The inhabitants of the new cities will consume more water than their forebears and will need secure sources of electricity, while their economic activities will greatly increase global carbon emissions. These pressures on the ecosystem may produce a climate inflection point, with unpredictable outcomes."

Fresh Water Use – What Role Does Energy Play?

When discussing how various parts of the economy use water, distinguishing between the volume *withdrawn* and the volume *consumed* is very important.

- Water withdrawn is the total volume removed from a water source. Often, a portion of this water is returned to the source and is available to be used again.
- Water consumed is the amount of water removed for use and not returned to its source.

Agriculture accounts for the majority of fresh water withdrawal in much of the world. The exceptions to this rule are North America and Europe, where industry comprises a larger share than agriculture. Data that subdivide the industrial sector into its energy component are difficult to find for countries other than the United States, where water withdrawals for energy are approximately equal to those for agriculture, each making up approximately 40% of freshwater withdrawals.[6]

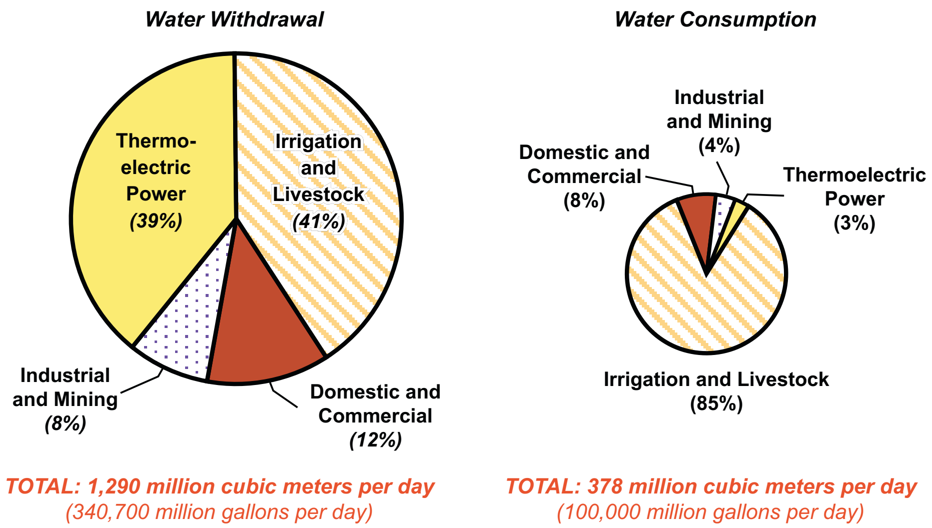
The energy industry's share of freshwater consumption is much smaller than its share of freshwater withdrawal. This difference arises because some energy processes return nearly all of the water they withdraw back to the source. In the United States in 1995, agriculture accounted for 85% of total freshwater consumption, whereas all industrial (including manufacturing, mining and other industrial uses) and thermoelectric power uses *combined* made up only 7% of consumption (see Figure 5).[7] More recent data have not been tabulated, and data for other countries are very difficult to find.

Volumes of water consumed will be the primary focus for the remainder of this paper. Consumption is a better measure of an activity's impact on water resources, since it measures the amount of water that is no longer available for other uses. However, the figure above demonstrates that the energy industry is very dependent on water, even though energy accounts for a relatively small fraction of total water consumption. The large quantity of water withdrawn for electric power

4. Calculated using water rates for the City of San Diego, California.
5. Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: *Climate Change and Water.* Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, page 3.
6. United States Department of Energy, *Report to Congress on the Interdependency of Energy and Water,* December 2006, page 9.
7. Solley, W., Robert R. Pierce and Howard A. Perlman, *Estimated Use of Water in the United States in 1995,* United States Geological Survey, Circular 1200, 1998.

Figure 5

Water Withdrawal versus Consumption in the United States



Source: United States Geological Survey, Cambridge Energy Research Associates.
81017-2

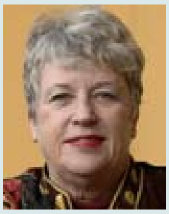
generation is vital, even though the contribution to water consumption is much smaller. The risks that this dependence poses to the energy industry are very location-dependent. Water availability and water stress are local issues, and the possible impact of water scarcity on the energy industry is similarly local. In areas of high water stress, regulatory and public pressure on the energy industry to reduce water use is likely. Increased competition between energy and other water uses, particularly agriculture, is likely in water-stressed areas, and physical scarcity of water may impact operations. Examples of how these risks can play out are described in the case studies in Chapter 3.

Perspectives on the Global Water Picture and How It Links to Energy

The chapter includes the perspectives of two individuals who have described the global interconnection between water and energy resources. These perspectives appear at the end of the chapter.

- **Margaret Catley-Carlson,** Chair, World Economic Forum Advisory Council on Water; Patron, Global Water Partnership; International Water Management Institute Board; United Nations Secretary-General's Advisory Board on Water and Sanitation, Canada

- **Sean Cleary,** Chairman, Strategic Concepts, South Africa



Energy and Water – Linked and Looming Challenges

By Margaret Catley-Carlson, Chair, World Economic Forum Global Advisory Council on Water; Patron, Global Water Partnership; International Water Management Institute Board; United Nations Secretary-General's Advisory Board on Water and Sanitation, Canada

Energy and water are inextricably linked. Most forms of energy are produced using large volumes of water. Additionally, large amounts of energy are used in modern drinking and wastewater treatment systems, totalling 3% of the US energy bill, for example.[8] In poor communities, both energy and water are likely to be lacking.

Globally, our human pattern of water usage is unsustainable. Why? Population, prosperity and pollution.

Population. We have the same amount of water today as the Earth of the dinosaurs or Julius Caesar. But we have grown from Caesar's world population of about 400,000 to almost 6.5 billion people today, heading for 9.2 billion by 2050.

Prosperity. With increasing prosperity, people in many places use upwards of 2,500 litres of water a day.[9] How do we use it? To drink and to wash – yes – but the food we eat accounts for about 75% of the water we abstract globally. Water from the soil, rain or irrigation, through the evapotranspiration of plants, creates food, and the water involved is "lost" to the water cycle. Foods differ in their water impact: a kilo of wheat uses about 1 ton of water; rice, about twice that amount; and chicken, up to five times more.[10] The increase in energy use that comes with prosperity also results in additional water demand. Producing a litre of oil uses three litres of water. From an energy point of view, water provision in wealthy societies can be very energy intensive. For example, the oil used in the production, transportation and disposal of a bottle of water is, on average, equal to filling that bottle one-fourth of the way with oil, and about 3.24 watt-hours of power is used to produce a litre of desalinated water.[11]

Pollution. Pollution makes water unusable and increases the pressure on the resource everywhere.

In a world where more people want and can afford more food and energy, we need to give a lot of thought to our current habits. Water cannot be created and has no substitute (unlike energy forms), but it can be managed better. In particular, we need to be able to grow more food with less water. The science is available, but too often the incentives for water use run backwards – to increase the demand for water and not to foster change. Our trade policies do not encourage optimal water use.[12] We need as vibrant a market for used water as there is for used cars – extracting the nutrients for crops (in a world of skyrocketing fertilizer prices), using lightly treated water for appropriate industrial and agricultural purposes and even contributing to energy via anaerobic methane production from wastewater.

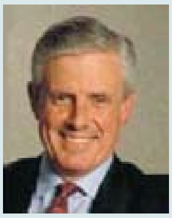
Water can and should be discussed globally, but can be truly understood and acted upon only locally. Water is intensely political – who gets it, who can use it, whether they pay or not and whether polluters are regulated and apprehended. All of this is the stuff and substance of local politics. Good industrial and agricultural use patterns depend on stable policy climates – water improvement does not come about unless public policies change. So perhaps the most important task for the business community is to help create the climate in which governments can make better decisions about protecting water and making water use more productive. There are several ways for companies to join the effort. Support the CEO Water Mandate and work towards a common understanding of responsible water use via sensible international voluntary standards – the Stewardship Initiative and others going in the same direction should be brought together to coordinate their work.

What is the chief problem? We don't value water – it is as simple as that. Because we don't value it, we don't consider whether we are using it as wisely as possible: planting the right crop in the right place (or buying the crop on the global market if local production is inappropriate); fixing municipal leaks, which often average as much as 50% to 60% of the water going into the system; avoiding water-costly sewage systems in water-short areas; considering water availability in city planning. Not valuing water makes it very difficult to get reasonable pricing systems in place – systems that will serve the poor (with subsidies if needed), fix leaks and work to the benefit of a greater part of the population.

There are answers – and circles of people joining together to support them. Business can lead in valuing water. Turn off the tap; better still, have taps turn themselves off. Install water-efficient technologies, such as continuous loop and self-cleaning. More important, check up on how subsidiaries and subcontractors are using water. Stop polluting and support pollution regulation. Energy producers have a key role in deciding on their production processes and the water impact they will have. And that brings us full circle.

---

8. See http://www.epa.gov/waterinfrastructure/bettermanagement_energy.html.
9. See http://maps.grida.no/go/graphic/water_consumption_top_countries.
10. See http://www.siwi.org/sa/node.asp?node=25 on Tony Allan and Virtual Water; see also, IWMI, Comprehensive Assessment.
11. See http://urila.tripod.com/desalination.htm.
12. See http://www.worldwatercouncil.org/fileadmin/wwc/Programs/Virtual_Water/virtual_water_final_synthesis.pdf.



Energy, Water and Climate: Unravelling the Conundrum

By Sean Cleary, Chairman, Strategic Concepts, South Africa

The unbridled enthusiasm for markets – efficient ways to allocate economic goods if information is near-perfect – in the past three decades has made us forget that our survival depends on respect for the global ecosystem. Translating this insight into sound policy is complicated, however. The global ecosystem is a complex and significantly (but not entirely) adaptive system whose components we do not fully understand and whose workings seem mysterious.

One part of the challenge is grasping the relationships among energy, water and climate. We have begun to understand some of the relationships between climate and energy. We know that large-scale changes in the climate are probably due to the emission of more greenhouse gases, a result of increases in population and economic output. The use of fossil fuels for electricity, heating and transport is the biggest contributor to higher greenhouse gas emissions, and we may be dangerously close to a climatic inflection point.

The problem is more complex when we introduce water into the equation. The most obvious aspects of the relationships may be these:

- Social and economic progress depends on access to water and energy.
- Climate and water systems are linked, and changes in one system induce important, non-linear changes in the other.
- Most energy production uses water: we convert water's kinetic energy to electricity in hydro generation; use water to drive turbines and cool exhaust streams in thermal generation; and need water to extract, produce and refine liquid hydrocarbons and to produce organic products for biofuels.

We need more energy for development, but current energy technologies put pressure on the supply of available water. Water usage and availability and energy production have an impact on climate; climate changes affect the availability of water; and the availability of water, in turn, has an effect on energy production.

The Intergovernmental Panel on Climate Change (IPCC) reports that global warming poses major challenges to water resource management, and the US Department of Energy indicates that energy production will be affected by the rising demand for water, notably from agriculture and urbanization, and by climate change.

But the relationships among energy, water and climate are not linear and cannot be generalized. The availability, quality and usage patterns of water are local in character.

Many countries and communities are experiencing acute water scarcity. If present climatic trends continue – a linear assumption – about 1 billion people in snow-fed river basins will have less water. There will also be more extreme weather events – frequent and violent floods and harsher droughts – but these will occur in specific, perhaps more widespread, locations. The IPCC warns that yields on rain-fed lands in Africa may be halved. This threatens community survival, risks state collapse and impels migration. Many regions may also experience changes in the periods in which water is available. This will complicate energy production planning.

The rising demand for water from agriculture and from fast-growing cities in Asia, Africa and Latin America sharpens the challenge. The global population in 2050 will be about 9.2 billion, up from 6.5 billion in 2006, and greater wealth in many emerging markets is resulting in new and growing cities and higher, more diversified consumption. The tripling of the global population in the 20th century led to a sixfold increase in water usage. The inhabitants of the new cities will consume more water than their forebears and will need secure sources of electricity, while their economic activities will greatly increase global carbon emissions. These pressures on the ecosystem may produce a climate inflection point, with unpredictable outcomes.

These linkages mean that we must consider water use and energy production in planning mitigation and adaptation strategies. To take one example: if we are to be dependent on hydrocarbons for a large share of our energy for several decades, we need clean coal technologies and effective carbon capture and storage mechanisms. But current technological solutions for both are water intensive, and the water needed may not be available where it is required.

We are at the start of a difficult and steep learning curve. Considering the water requirements of different energy solutions, as well as their carbon footprints, is a good beginning. Each company should assess the value of water in each locality and in each business it operates, to set internal and external prices. Each business must understand its water footprint by plant and by location. Water balances should be determined using hydrological modelling.
Exploring diverse technological solutions to energy generation and consumption to address different requirements for water use may be a key to securing the necessary global agreement on adaptation, reduced emissions and adoption of climate-friendly technologies by 2013. The principles will be global, but much of the solution will lie in addressing local specificities. Like agricultural terroir and the weather, water is local, and we can only ignore that fact at our peril.

CHAPTER 2: ENERGY AND WATER – INTEGRATED ALONG THE VALUE CHAIN

Introduction

Energy and water are linked in two primary ways – water is used in the production of nearly all types of energy, and energy is used in the provision of water and the treatment of wastewater. This chapter describes how the various energy technologies use water and the amount of water they use. Additionally, it explains the importance of energy in modern water and wastewater movement and treatment. Greater understanding about the total water use of different energy technologies can help policy-makers and industry better understand their current water use and help them choose technologies that are appropriate for the local water environment.

Water's role in the energy value chain varies depending on the type of energy in question. In each case, the value chain is divided into three components: production of energy raw materials, transformation of the raw materials into a form usable by consumers, and delivery to the final consumer. In some cases, the primary use of water is in production of the energy raw material, while in others transformation to a usable form is the primary water use. However, in each case, delivery of the final energy product to the consumer uses minimal water. The following sections provide more detail about the water use of each process and also describe the water pollution issues associated with some technologies.

Water in the Natural Gas and Liquid Fuels Value Chain

Figure 6 depicts the natural gas and liquid fuels value chain, including liquid transportation fuels. This figure describes the amount of water consumed at each stage of the value chain: production of energy raw materials; transformation of the raw materials into a form usable by consumers; and delivery to the final consumer, which uses a minimal amount of water. For most processes in this value chain, the majority of water use occurs at the raw materials stage.

As an example of how to read the figure, compare the water used to produce gasoline from different raw materials. Producing traditional oil uses 3 to 7 litres of water per gigajoule (GJ) and refining that oil uses an additional 25 to 65 litres of water, for a total of 28 to 82 litres of water per GJ of finished gasoline. Since one litre of gasoline contains 0.034 GJ of energy, production of each litre of gasoline from traditional oil uses approximately 1 to 3 litres of water. A similar calculation for gasoline made from oil sands results in water usage of around 3 to 55 litres of water per litre of gasoline.

Production of Raw Materials

Oil and gas. Minimal water is used in the production of traditional oil and gas resources. In fact, the more important issue is water that is *produced* from the underground formation along with the oil and gas. The quality of this water ranges widely. Although some produced water is nearly fresh, the vast majority is at least as salty as seawater.[13] Some wells produce very little water, particularly when they are young. However, as wells mature, the amount of water produced along with the oil often increases, reaching as much as 40 times the amount of oil produced as the well reaches the end of its useful life. In 1999 worldwide, an estimated 210 million barrels of water were produced along with oil. As much as 75% of this produced water was re-injected into the oil reservoirs to enhance oil recovery, as described below.[14] Disposal of water not reused can be a problem, however, particularly when this water is salty or contains metals or other contaminants.

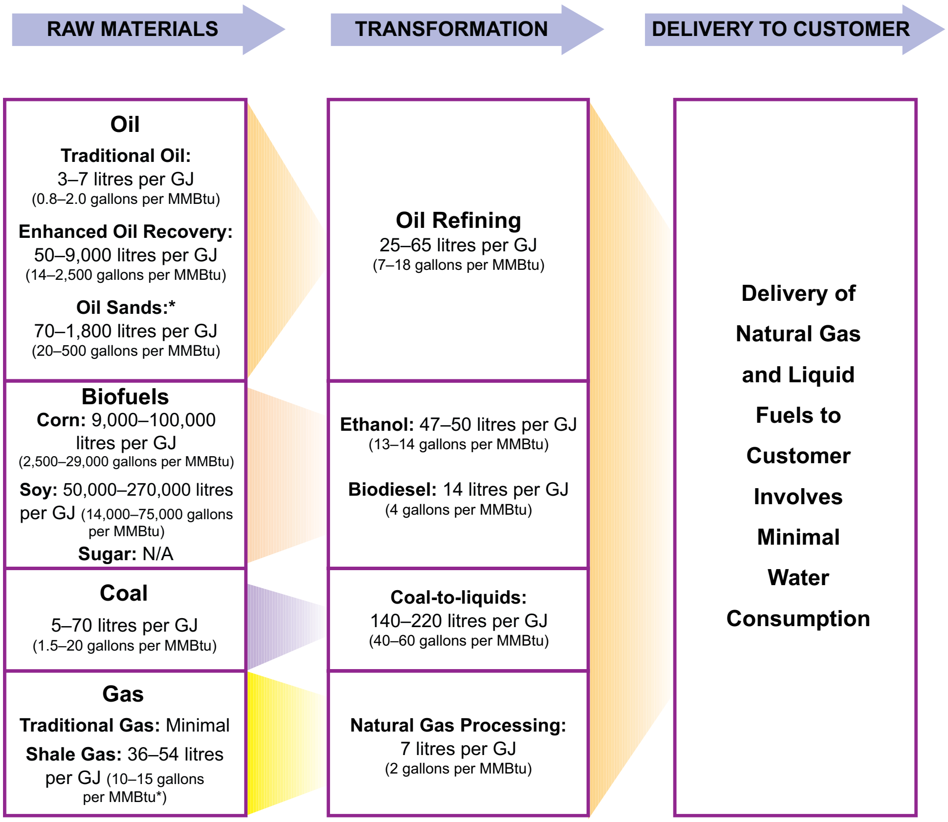
EOR techniques and unconventional oil resources are often net users of water, sometimes large quantities of water. EOR involves injecting water or gas into a reservoir to maintain pressure in the reservoir and ultimately recover more of the underground oil. Often, water recovered along with the produced oil is reinjected to enhance recovery. At other locations, the produced water is not of sufficient quality, and another water source must be found, particularly for steam injection methods of oil recovery.

Oil sands are another resource that involves use of large amounts of water. When the oil sands are mined and oil is removed at the surface, steam is used to strip the bitumen from the surrounding clay and sand. When oil sands are produced in situ, steam is pumped underground to strip the bitumen and allow it to be

13. United States Department of Energy, *Report to Congress on the Interdependency of Energy and Water,* December 2006, page 21.
14. United States Department of Energy, National Energy Technology Laboratory, *Addressing the Critical Link between Fossil Energy and Water,* October 2005, page 19.

Figure 6

Gas and Liquid Fuels Value Chain – Water Consumption



Source: Adapted from US Department of Energy, *Energy Demand on Water Resources. Report to Congress on the Interdependence of Energy and Water, December 2006* (except where noted).
*CERA estimate.
Note: MMBtu = million British thermal units; GJ = gigajoules.
81017-4

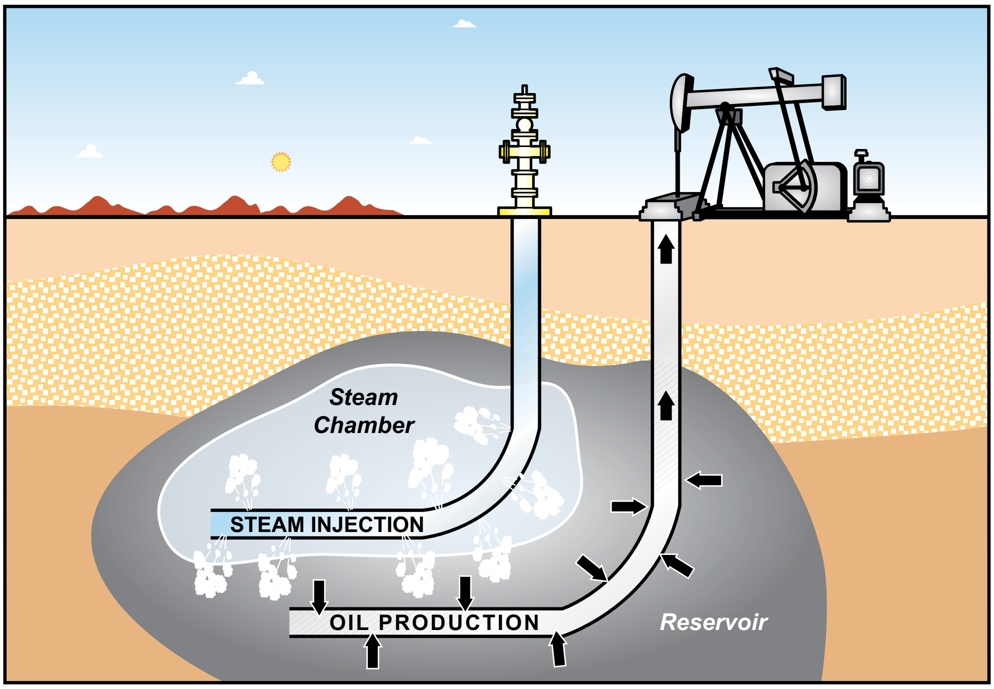
moved to the surface in a process known as steam assisted gravity drainage (see Figure 7). Either way, a high quality water source is necessary to make the steam.

Unconventional natural gas resources are also generally net users of water. Most natural gas resources considered "unconventional" today involve gas trapped in tight formations underground, including shale or tight sandstone. Producing gas from these reservoirs requires fracturing the underground formation with water to allow gas to flow to the production well. The estimates in Figure 6 are for the initial phase of production. Water use is likely to decrease as the well matures, and some older wells will produce water rather than consume it.

Biofuel feedstocks. The water intensity of biofuel feedstocks depends on the feedstock used and where and how it is grown. Irrigated crops are much more water intensive than non-irrigated ones. The higher numbers shown in Figure 6 represent crops that are irrigated, while the lower numbers represent non-irrigated crops. Grain and oilseed crops grown for biofuels are much more water intensive than the petroleum

Figure 7

The Steam Assisted Gravity Drainage Production Technique



Source: Cambridge Energy Research Associates.
80420-1

feedstocks used to produce transportation fuels. Sugar cane is an exception to this rule, since it is generally not irrigated. In fact, a period of drought during its growing phase is needed to concentrate the sugar.[15] Feedstocks that could be used for second generation biofuel production, including grasses and crop wastes, are likely to use less water than today's feedstocks. However, good information is not available on the water use per unit of energy for these crops, because they are not yet in commercial production.

As with many energy raw materials, water pollution is as important an issue as water use. Fertilizers used on crops, including those grown for biofuels, run off into surface water bodies. The excessive levels of nutrients that result have caused algae blooms, anoxic conditions in surface water and even contributed to a "dead zone" in the Gulf of Mexico of approximately 22,800 square kilometres (8,800 square miles), where there is inadequate oxygen to support aquatic life.[16] Nitrates from fertilizer runoff can also cause human health problems, especially in rural agricultural areas where nitrates are most often found in drinking water. "Blue

15. Martinelli, Luiz A. and Solange Filoso. "Expansion of Sugarcane Ethanol Production in Brazil: Environmental and Social Challenges," *Ecological Applications* 18(4), 2008, page 886.

16. National Oceanic and Atmospheric Administration (NOAA), United States Department of Commerce, "NOAA and Louisiana Scientists Predict Largest Gulf of Mexico 'Dead Zone' on Record this Summer," http://www.noaanews.noaa.gov/stories2008/20080715_deadzone.html, July 15, 2008.

baby syndrome" can occur in infants fed formula made with water high in nitrates because the nitrates limit the blood's ability to carry oxygen to the body.[17]

Coal. Water use in coal mining depends on the method of mining. For example, underground coal mines use water for cooling the cutting surfaces of mining machinery and inhibiting friction-induced ignition of coal dust or gas. Surface mines often use water to suppress dust from the mining process and on roads entering the mines.[18] The majority of bituminous coal in most parts of the world is cleaned before it is burned to reduce the ash and sulphur content and increase the coal's heating value, using more water.[19]

However, water contamination, rather than use, is the primary issue in coal mining. Drainage from mines and from piles of mining waste can become acidic when sulphur-containing minerals are exposed to water and oxygen. The acidic water dissolves some metals that may be present in the rock and soil, frequently including lead, zinc, copper, arsenic and selenium. These metals are then carried with the water throughout the affected watershed and can be absorbed by plant and animal life in the food chain.[20] Water contamination is an issue in many areas where coal is mined, from the United States and Canada to China and Australia.

Transformation of the Raw Materials into a Form Usable by Consumers

Petroleum refining. The amount of water used in a petroleum refinery varies significantly depending on the complexity and the types of processes used in the facility. Refineries use water mostly for process cooling, and some refinery processes also generate water contaminated with a variety of substances, including oil, suspended solids, ammonia, sulphides and chromium. This water is usually treated at wastewater facilities at the refinery and then discharged to public sewer systems or directly to surface waters, depending on the degree of treatment.[21]

Biofuels. Ethanol is produced by a biological fermentation process involving a slurry of ground grain and water. Future technologies for cellulosic ethanol production will involve the same water-phase fermentation process, with application of enzymes to break cellulose into sugars preceding the fermentation. Thus, at the transformation phase, second generation biofuels are unlikely to use less water than current technologies. Biodiesel production is much less water intensive, since the chemical reactions that create biodiesel do not take place in a water phase. Vegetable oils are reacted with an alcohol, usually methanol, to produce alkyl esters or biodiesel.

Coal-to-liquids. Coal-to-liquids (CTL) plants use water in three primary ways. The largest need is for water to cool process streams. Water is also used to feed steam-producing boilers and in the liquefaction process itself. The amount of water used in liquefaction depends on the design of the plant. In some plants, water reacts with carbon in the coal to form carbon monoxide and hydrogen. Water can also be used in scrubbers to remove ammonia and hydrogen chloride from intermediate gas streams.[22]

Delivery to the Final Customer

As noted in Figure 6, almost no water is consumed in this segment of the value chain.

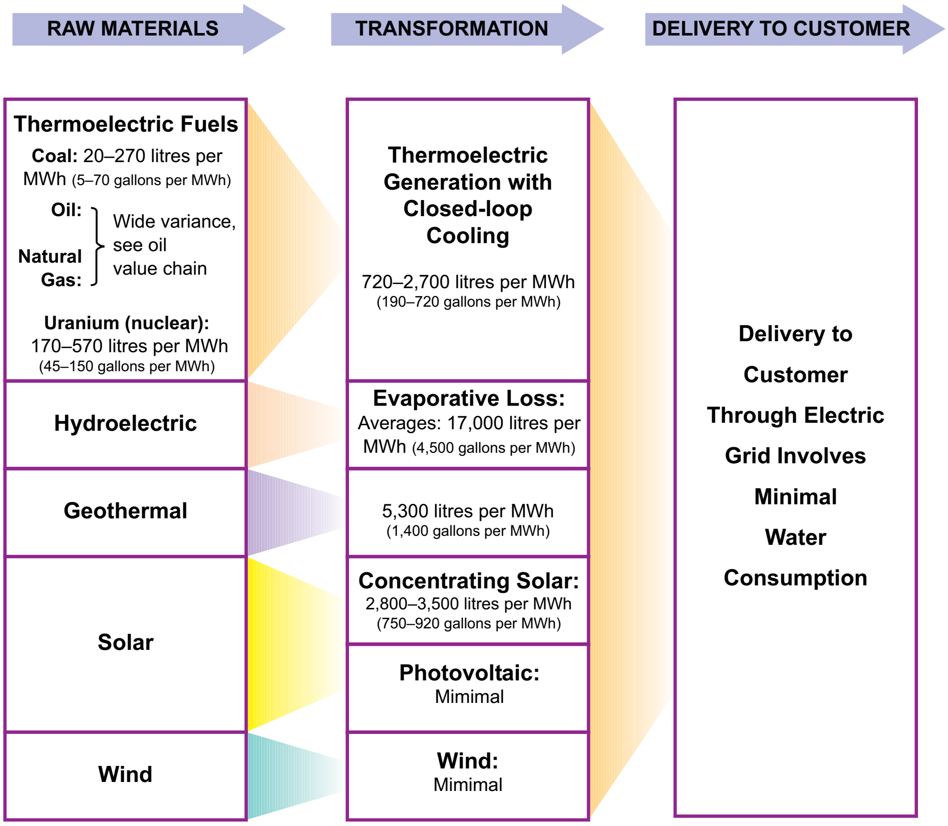
Water in the Electricity Value Chain

Figure 8 depicts the value chain for electricity provision. Unlike liquid and gaseous fuels, the majority of water use in electricity occurs at the transformation stage. As in the previous figure, the data describe the amount of water consumed, not withdrawn.

17. World Health Organization, Water Sanitation and Health, "Water-related Diseases: Methaemoglobinemia," http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/.
18. *Industrial Water Management: A Systems Approach, Second Edition,* prepared by CH2MHill for the Center for Waste Reduction Technologies, American Institute of Chemical Engineers.
19. United States Department of Energy, National Energy Technology Laboratory, *Addressing the Critical Link between Fossil Energy and Water,* October 2005, page 14.
20. Environmental Mining Council of British Columbia, *Acid Mine Drainage: Mining and Water Pollution Issues in BC,* 2000.
21. Energetics, Inc. *Energy and Environmental Profile of the U.S. Petroleum Refining Industry,* prepared for the US Department of Energy, Industrial Technologies Program, 2007, page 31.
22. United States National Energy Technology Laboratory, *Emerging Issues for Fossil Energy and Water: Investigation of Water Issues Related to Coal Mining, Coal-to-liquids, Oil Shale, and Carbon Capture and Sequestration.* DOE/NETL-2006/1233, June 2006.

Figure 8

Electricity Industry Value Chain – Water Consumption



Source: Adapted from US Department of Energy, Energy Demand on Water Resources. Report to Congress on the Interdependence of Energy and Water, December 2006.
Note: MWh = megawatt-hours.
81017-5

To illuminate the data in the table, compare the water use of different forms of electricity generation. A megawatt-hour (MWh) of electricity from coal uses 20 to 270 litres of water at the coal mining stage and an additional 1,200 to 2,000 litres (see Table 1, below) when the energy in the coal is converted to electricity, totalling 1,220 to 2,270 litres of water consumed per MWh. In comparison, nuclear energy uses 170 to 570 litres of water per MWh during the mining of uranium and production of the reactor fuel and an additional 2,700 litres per MWh as the energy from nuclear fission is converted to electricity, for a total of 2,870 to 3,270 litres of water consumed per MWh.

Production of Raw Materials

The hydrocarbon-based forms of raw materials for electricity generation – coal, oil and natural gas – are described in the previous section. Renewable forms of raw material, including hydroelectricity, geothermal, solar and wind, require little or no water at the raw materials stage. Uranium is the only raw material not already discussed that uses a significant amount of water at this stage.

Uranium. The amount of water used in uranium mining is similar to that used in coal mining, and the problems of water pollution are also similar. However, uranium requires much more processing than coal to become a usable fuel for electricity production. The process of converting uranium ore to finished reactor fuel involves several steps that use water, including milling, enrichment and fuel fabrication. These additional processing steps make uranium a much more water intensive fuel than coal, per unit of electricity produced.

Transformation of the Raw Materials into a Form Usable by Consumers

Thermoelectric electricity generation. Thermoelectric forms of electricity generation, including coal, natural gas, oil and nuclear, constitute 78% of world electricity generation capacity.[23] All thermal electric plants that use steam turbines require cooling to condense the steam when it exits the turbine, and water is by far the most common source of cooling. Cooling uses 80% to 90% of the water consumed in thermal power plants, regardless of the fuel source. Additional water is used primarily in control of environmental emissions.[24]

Two types of water cooling technology as well as a dry cooling system are used in thermal electric power plants.

- Once-through cooling systems withdraw large quantities of water, but return the majority of this water to the source, generally at a higher temperature, after one trip through the condensers. The mechanism used to withdraw the large quantity of water needed and the higher temperature water returned to the source have the potential to harm aquatic life near the plant.
- Closed-loop systems recirculate cooling water and reject excess heat through a cooling tower or pond. These plants withdraw only enough water from the source during steady state operation to make up for water lost due to evaporation. Although closed-loop systems withdraw 95% less water than once-through systems, closed-loop systems actually consume more water, since the water withdrawn is all lost to evaporation.[25] Closed-loop systems are less dependent than once-through systems on the availability of a large supply of water at all times.
- Dry cooling systems that rely on air rather than water for cooling are also possible. However, since air is a less efficient heat sink than water, dry cooling systems tend to be larger and less efficient. Dry cooling systems are also much more dependent on weather conditions than water cooling, becoming less efficient in hot weather.

Table 1 shows the wide range of water use for thermoelectric cooling in plants with closed-loop cooling systems. The amount of water needed for cooling depends on the type and efficiency of the power plant. Natural gas combined-cycle plants use the least water per unit of power produced, whereas nuclear plants use the most.[26]

Hydroelectric power generation. Hydroelectric power makes up 20% of world electricity generation capacity.[27] Water passing through the turbines to produce electricity is returned directly to the river. However, water consumption through evaporation occurs because more water evaporates from reservoirs than from a naturally flowing river system. Estimating consumption for hydroelectric generation is thus particularly difficult because it relies on modelling rather than measurement. Water consumption of hydroelectric systems varies widely based on the surface area of the reservoir and the local climate. Run-of-the-river projects without storage result in much less water consumption than reservoirs with large surface areas.

Renewable electricity. Renewable electric power generation technologies include wind, solar and geothermal. Unlike thermoelectric and hydroelectric systems, wind and solar power generation use virtually

23. United States Energy Information Administration, *Annual Energy Review 2007,* Table 11.17, June 2008.
24. Cambridge Energy Research Associates, *The Power of Water,* 2007, page 2.
25. *Ibid,* page 2.
26. *Water Requirements for Existing and Emerging Thermoelectric Plant Technologies.* US Department of Energy, National Energy Technology Laboratory, August 2008.
27. United States Energy Information Administration, *Annual Energy Review 2007,* Table 11.17, June 2008.

Table 1

Water Consumption in Thermoelectric Power Plants per unit of Net Power Produced
Closed-loop Cooling

	Litres per MWh	Gallons per MWh
Nuclear	2,700	720
Subcritical Pulverized Coal	2,000	520
Supercritical Pulverized Coal	1,700	450
Integrated Gasification Combined-cycle, slurry fed	1,200	310
Natural Gas Combined-cycle	700	190

Source: *Water Requirements for Existing and Emerging Thermoelectric Plant Technologies*. US Department of Energy, National Energy Technology Laboratory, August 2008.

no water during the production of power, except for minimal and occasional use for washing turbine blades or solar cells.[28]

Geothermal power plants use the heat of the earth to produce steam or hot water, which is then used to produce electricity. Cooled water can then be reinjected into the geothermal wells, but in most cases some water is lost to evaporation in the cooling system, resulting in water consumption.

Energy in the Water Value Chain

In addition to the use of water in energy production, energy is a significant input to modern water provision and wastewater treatment systems. As shown in Figure 9, energy is used to move water from its source, treat it, pump it to end users and treat it after its use. Electricity accounts for approximately 80% of municipal water processing and distribution costs.[29] Municipal and industrial water supply and wastewater treatment systems in the United States consumed an estimated 138 terawatt-hours (TWh) of electricity in 2005, just over 3.5% of the total consumed.[30] This amount of electricity is similar to the total amount used to run refrigerators in the United States.[31]

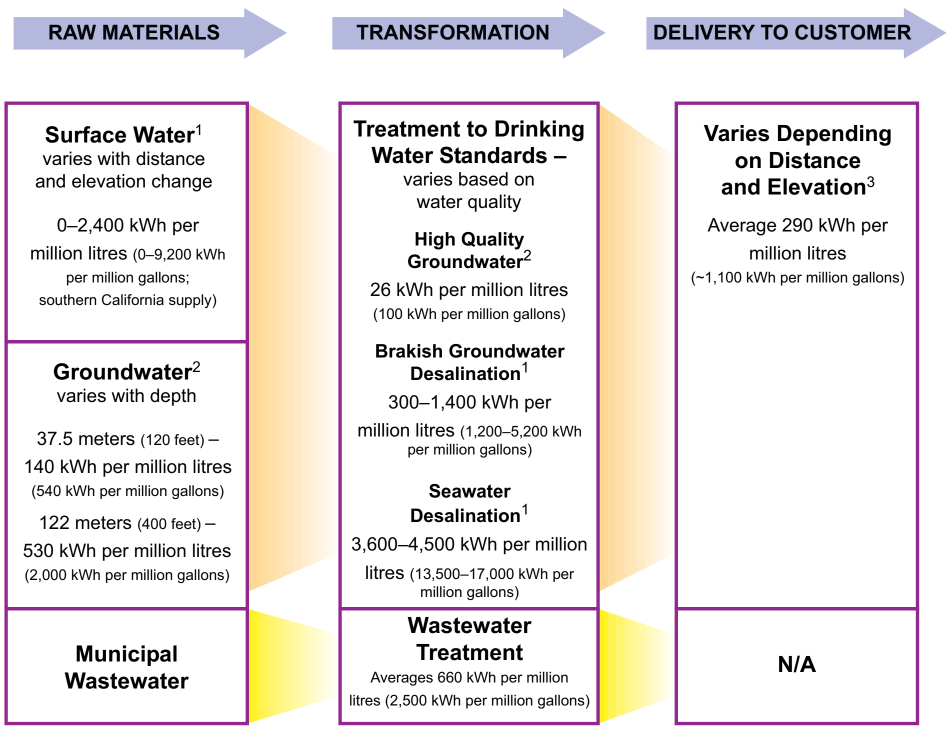
These rolled-up numbers hide the differences in energy use for drinking-water provision based on the water source. On average, groundwater supply requires about 30% more electricity on a unit basis than surface water, because of the expense of raw water pumping.[32] However, very high quality groundwater requires little energy for treatment.

Pumping water over long distances or great elevations is very energy intensive. For example, water supplied to Southern California from the State Water Project travels 610 metres (2,000 feet) over the Tehachapi Mountains, the largest lift of any water system in the world, and requires about 2,400 kilowatt-hours (kWh) per million litres (9,200 kWh per million gallons). The electricity used to deliver water to customers in Southern California is equal to one-third of total average household electricity use.[33] Water travels long distances not just for residential use, but for agricultural use as well.

28. United States Department of Energy, *Report to Congress on the Interdependency of Energy and Water,* December 2006.
29. *Water and Sustainability: US Electricity Consumption for Water Supply and Treatment – the Next Half Century.* EPRI, Palo Alto, CA: 2000. page 1-2.
30. *Ibid,* page 1-5.
31. United States Energy Information Administration, U.S. Household Electricity Report, http://www.eia.doe.gov/emeu/reps/enduse/er01_us.html.
32. *Ibid.,* pages 1-2.
33. *Energy Down the Drain: The Hidden Costs of California's Water Supply.* Natural Resources Defense Council and Pacific Institute. August 2004, page 2.

Figure 9

Domestic Water Industry Value Chain – Energy Consumption



Source: Cambridge Energy Research Associates.
1. *Energy Down the Drain: The Hidden Costs of California's Water Supply.* Natural Resourse Defense Council and Pacific Institute, August 2004.
2. *Energy Demand on Water Resources: Report to Congress on the Interdependence of Energy and Water.* US Department of Energy, December 2006.
3. Electric Power Research Institute: *Water and Sustainability (Volume 4): US Electricity Consumption for Water Supply and Treatment – The Next Half Century, 2000.*
Note: kWh= kilowatt-hour.
81017-3

Desalination is one of the most energy-intensive water provision mechanisms. The amount of energy used depends on the salinity of the source water. Desalting brackish groundwater is less energy intensive than turning seawater into fresh drinking water. Disposal of brine created during the desalination process is an additional problem for desalination plants. Brine is typically twice as salty as the intake water for the plant and also contains higher concentrations of unwanted constituents found in the intake water, including manganese, lead and iodine. Ocean disposal is the most common and least expensive option but can have significant impacts on the marine environment. Evaporation ponds and deep well injection are other options.[34]

Bottled water is a final energy-intensive way of providing water. As Margaret Catley-Carlson points out in her perspective, "Producing, transporting and disposing

34. Gleick, Peter et al. *The World's Water 2006-2007: The Biennial Report on Freshwater Resources,* Island Press, 2006, pages 77–79.

of a bottle of water is, on average, equal to filling that bottle one-fourth of the way with oil." In wealthy countries, consumers buy bottled water because of fear about the quality of their water, convenience and taste preferences. However, in other parts of the world, failure of governments to provide potable water service forces consumers to rely on bottled water for drinking, at a cost that can be a thousand times higher than a municipal water supply.[35] World bottled water consumption in 2007 totalled approximately 190 billion litres (50 billion gallons).[36]

Conclusions

The data in this chapter demonstrate that not all energy and water provision technologies are created equal. Products that seem identical on the surface, such as a litre of gasoline or a unit of electricity, can have very different levels of water consumption embedded within them. The same is true for water provision technologies – vast differences exist in the energy required to deliver a unit of water to a customer's tap. However, the case studies in Chapter 3 demonstrate that one must consider the circumstances of the energy or water use. Technologies that are appropriate in areas of water abundance are problematic in areas of water stress, and severe fresh water scarcity may make very energy-intensive water technologies attractive. Context is everything.

35. *Ibid.,* page 170.
36. International Bottled Water Association, http://www.bottledwater.org/public/Stats_2007.doc.

CHAPTER 3: UNDERSTANDING THE RISKS AND OPPORTUNITIES IN THE WATER-ENERGY RELATIONSHIP

Introduction

The water-energy relationship is critical all along the value chain – from extracting raw materials and transforming those raw materials into usable forms of energy, to delivering that energy to consumers. As noted in Chapter 2, some segments of the energy chain are more water intensive – in terms of both water consumption and water treatment and disposal.

In Chapter 3, the focus is on 10 case studies that analyse how companies have addressed the risks and opportunities in the water-energy relationship. The local availability of both water and energy resources is a critical component of each case study, and each challenge requires a local solution.

These case studies explore four categories:

- **Water Security, Energy Security and Climate Change.** These three issues are not always aligned. Three case studies illustrate the difficulty – and creative solutions – in balancing these three concerns.
- **Balancing Multiple Uses of Water.** Multiple stakeholders often want access to the same freshwater supplies. These two case studies illustrate ways these challenges have been addressed.
- **Treatment, Reuse and Conservation of Water Associated with Energy Production.** These three case studies illustrate how companies have creatively reduced their water use and reused wastewater streams.
- **Conservation of Energy in Water Provision.** Freshwater supplies are not always located close to major population centres. These two case studies demonstrate the challenge of improving energy efficiency in providing fresh water to areas where it is scarce.

Water Security, Energy Security and Climate Change

Energy security and climate change are near the top of every country's agenda. The recent extreme volatility in energy prices has world leaders concerned about where their future energy supply will come from and what price they will have to pay. With the expiration of the Kyoto Protocol in 2012 and the planned negotiations for a successor in Copenhagen in 2009, climate change planning has become more urgent.

However, concerns about energy security and climate change are not always aligned with water security and conservation. The following case studies provide examples where energy sources and technologies designed to increase energy security or mitigate climate change cause concerns about water security. In each case, the local conditions determine how to balance the competing priorities.

Case Study 1: Water Tradeoffs in Carbon Capture and Storage Technology

Continuing worldwide concern about climate change has brought the need for low-carbon electricity to the forefront. CCS is being promoted as a partial solution to the problem. CCS is particularly attractive in countries with large coal reserves and a heavy reliance on coal for power generation. Other countries want a stake in providing future CCS technologies. Australia, Canada, Germany, Japan, Norway, the United Kingdom and the United States have all launched programmes to promote CCS. However, there are currently no commercial-scale power plants operating with CCS, and significant technology, policy and infrastructure barriers stand in the way of large-scale CCS implementation.

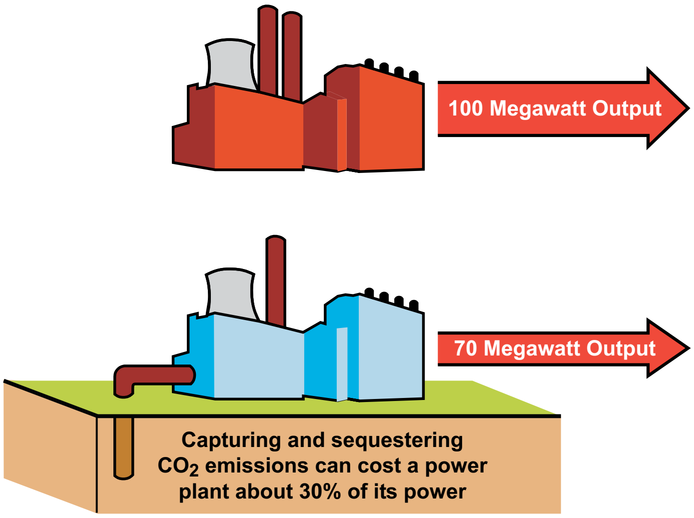
Adding CCS to a power plant increases its water consumption. Two technical reasons are behind this increase. First, capturing and compressing carbon dioxide (CO_2) requires energy, reducing the efficiency of the plant and thus increasing the amount of water consumed per unit of output (see Figure 10).

Second, the technologies used to capture CO_2 consume water. CO_2 can be captured at two points in the electricity generation process, either before or after the fuel is burned.

Pre-combustion CO_2 removal can be used in integrated gasification combined-cycle (IGCC) power plants. Heating coal under pressure in the presence of steam converts it to "syngas," consisting mostly of hydrogen and carbon monoxide. The syngas is then processed in a water-gas-shift reactor, where the carbon monoxide is converted to CO_2 and hydrogen. Finally, absorbents

Figure 10

Efficiency Loss Due to Carbon Capture and Storage at Typical Power Plant



Source: Cambridge Energy Research Associates.
70610-5

are used to remove CO_2 from the syngas, which is then burned to produce electricity. The primary water uses in this process are steam used in the production of syngas and water used in the water-gas-shift reactor.[37] Power plants of this type are not yet in common use, although several are in various stages of planning and construction. In his preface, James Rogers describes two plants of this type that are under construction in the United States.

Post-combustion CO_2 removal can be used in pulverized coal and natural gas combined-cycle plants. Absorbers are used to remove CO_2 from the flue gas exiting the plant. However, this task is more challenging than removing CO_2 from syngas because flue gas is at a lower pressure and contains a lower concentration of CO_2. Additionally, compressing the removed CO_2 to a pressure that can be transported or injected requires a large amount of energy, decreasing the overall efficiency of the plant.[38] Both of these power plant types are common today, but none currently operates with CCS.

Plants with pre-combustion CO_2 removal require less additional water per unit of electricity generated than those with post-combustion removal. Water use in IGCC power plants with CCS would increase by approximately 46% over a similar plant without CCS. Water use in pulverized coal and natural gas combined-cycle plants with CCS would increase by 90% and 76%, respectively, over similar plants without CCS.[39]

37. United States National Energy Technology Laboratory, "Carbon Sequestration: CO2 Capture", http://www.netl.doe.gov/technologies/carbon_seq/core_rd/co2capture.html.

38. *Ibid.*

39. National Energy Technology Laboratory, United States Department of Energy, *Water Requirements for Existing and Emerging Thermoelectric Plant Technologies,* DOE/NETL-402/080108, August 2008, page 13.

The storage portion of the CCS value chain could actually produce water, depending on the nature of the storage site. Injecting recovered CO_2 to increase oil or natural gas production is a frequently cited win-win option from an energy standpoint, but both of these options have the potential to produce contaminated water. Injecting CO_2 into oil reservoirs for EOR or for recovery of coal-bed methane (CBM) could produce up to 3.8 litres (one gallon) of water per kWh of power produced. Other sites recommended for CO_2 storage include saline aquifers and depleted oil and gas reservoirs. These injection sites can produce up to 1.9 litres (0.5 gallons) of water per kWh of power produced. The economics of CCS depend greatly on whether water is produced at the injection site and its quality, since this water is likely to be saline or contaminated and require extensive treatment to make it usable for agriculture or acceptable for disposal to surface water bodies.[40]

The water impact of CCS and its economic feasibility is thus very dependent on the power plant technology employed and the characteristics of the sequestration site. Sufficient water is necessary at the power plant to support CO_2 removal, meaning that CCS may be difficult to implement in dry climates. The characteristics of the CO_2 injection site determine whether contaminated water is produced, posing potential disposal or treatment issues.

Case Study 2: Coal-to-liquids Strains Water Supply

Several countries with large coal reserves are considering CTL technologies to produce transportation fuels. CTL is attractive from an energy-security standpoint because it allows the use of coal to produce a diverse range of liquid fuels, including diesel, gasoline, liquid petroleum gases, methanol and dimethyl ether. However, CTL fuels are both carbon and water intensive. The manufacture and use of CTL fuels emits approximately twice the amount of greenhouse gases as conventionally produced gasoline and diesel. CTL manufacture also uses approximately 5 to 7.5 litres of water per litre of liquid fuel produced.[41] CCS could make carbon emissions of CTL fuels similar to those of petroleum-derived fuels, but at the cost of even greater water use.

Until recently, CTL fuels were expected to help meet China's rapidly growing demand for transportation fuels. The Shenhua Group, China's largest coal producer, has announced plans to construct as many as eight CTL projects with the potential to produce 600,000 barrels per day of liquid products by 2020.[42] However, on 4 September 2008, China's National Development and Reform Commission announced a halt to CTL projects due to environmental concerns. The only exceptions are two Shenhua projects, including one that is already operational and produces about 20,000 barrels per day. The main problem in China is that the coal reserves are located primarily in the north, a region suffering from long-term drought. Transporting the coal from its source to areas where water is more plentiful is economically unfeasible, meaning that the projects cannot go forward without causing severe stress on the local environment near the mines.[43]

Similar problems with CTL access to water occur in South Africa. As in China, CTL plants are located near sources of coal. As described in Pat Davies' perspective, *Business and Water in Southern Africa*, water transfer and storage facilities from the Vaal River supply Sasol's CTL plants. To further ensure water reliability, Sasol has a 40% stake in a ZAR 3 billion (US$ 305 million) pipeline to provide additional water from the Vaal River to the Secunda CTL facility as well as to power stations belonging to Eskom, the local electric utility. As Pat Davies explains, water supply is an ongoing issue. "The water supply challenge remains under the microscope as a number of new industrial sites, including power stations and CTL facilities, are considered in South Africa. This new demand further stretches the total supply capability of the existing water supply infrastructure."

40. Bennett, Barbara, Massood Ramezan and Sean Plasynski, "Impact of Carbon Capture and Sequestration on Water Demand for Existing and Future Power Plants," Presented at the Sixth Annual Conference on Carbon Capture and Sequestration, May 2007, http://www.netl.doe.gov/publications/proceedings/pro_toc.html.

41. United States Department of Energy, *Report to Congress on the Interdependency of Energy and Water,* December 2006, page 60.

42. Cambridge Energy Research Associates, *The Potential of Coal-to-Liquids: Can It Be a Game-changer This Time?* July 2008, page 14.

43. Zhang Qi, "Is it the end of the line for coal-to-oil in China?" *China Daily,* 9 October 2008.

Case Study 3: Water Use in Biofuels Production

Biofuels are another technology frequently cited as increasing energy security and decreasing greenhouse gas emissions. In the United States, the primary biofuel in use today is ethanol produced from corn. The water use of US corn ethanol production varies, depending primarily on where and how the corn is cultivated. For example, in most US corn-producing states, approximately 6.5 litres of water are consumed per litre of ethanol produced. However, in Nebraska, North Dakota, South Dakota and Kansas, cultivation of corn uses approximately 320 litres of water per litre of ethanol produced because the dry climate requires irrigation.[44] Except for North Dakota, these states overlie the Ogallala Aquifer, a vast underground water resource beneath the US Great Plains. This aquifer is a crucial source of water in the region, providing 30% of the total water used for irrigation in the United States and 82% of drinking water for the population living within its boundary. However, the aquifer recharges slowly and has lost nearly 10% of its total water volume since intense use for irrigation began in the 1940s.[45]

Concern about water use is beginning to become a factor in siting ethanol plants. As described by Environmental Defense, the American environmental organization, in a recent report, "Water demands associated with individual ethanol plants – due both to ethanol processing and growing corn feedstock – are not exceptionally higher than demands from other industrial or agricultural users, but the construction of new ethanol plants in areas of existing water stress will exacerbate conflicts if water is already scarce."[46] Ethanol production is increasing rapidly in areas where the Ogallala Aquifer is most under stress (see Figure 11). Areas of high aquifer depletion currently contain five corn ethanol plants with combined production of 270 million litres (71.5 million gallons) per year. However, an additional nine plants with capacity of 2.4 billion litres (639 million gallons) per year of capacity are currently under construction in these areas. Even if the corn to feed the plants is not grown locally, water use for ethanol processing will increase groundwater withdrawals in these water-stressed areas by a total of 9.8 billion litres (2.6 billion gallons) per year.[47]

Several options exist for reducing or better managing ethanol's water consumption, particularly in areas where water is scarce. Ethanol plants can be located adjacent to municipal wastewater facilities and use their effluent as feed water. Modern ethanol plants have facilities to treat water coming into the process and do not need potable water as a feedstock. Alternatively, ethanol plants can be sited near livestock facilities to provide water recycling opportunities. If the livestock facility is nearby, distillers' grain, a by-product of ethanol production, can be fed directly to cattle in its wet form instead of being dried and transported, reducing the amount of water needed by cattle and saving the energy that would have been used in the drying process. Ethanol plants sited in the Ogallala Aquifer are frequently near dairy and feedlot operations to take advantage of this synergy and somewhat reduce the additional water stress these plants could cause. Finally, strong regulatory oversight by state and local governments on the siting of ethanol plants is needed, with an emphasis on water availability. For example, an ethanol plant in Nebraska was recently approved only after the water needed was offset by reducing water use in a nearby agricultural area.[48]

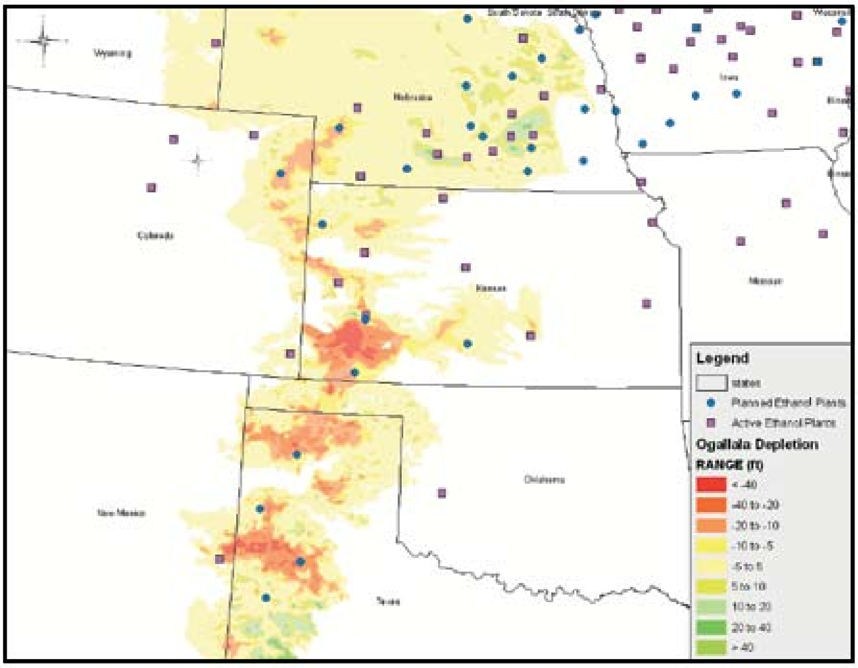
Balancing Multiple Uses of Water

Energy must share available water resources with other users, including households, agriculture, recreation and other industrial users. Additionally, availability of adequate water is crucial to ecosystems. Balancing the needs and interests of various water users is often a challenge, particularly when there are many different users of a water system or when water is in short supply. The following case studies demonstrate the benefits of consulting with multiple stakeholders when planning water use.

44. May Wu, Presentation at Argonne National Lab Biomass 2008 Conference, April 17, 2008.
45. United States Geological Survey, *Changes in Water Levels and Storage in the High Plains Aquifer, Predevelopment to 2005,* Fact Sheet 2007–3029.
46. Environmental Defense, *Potential Impacts of Biofuels Expansion on Natural Resources: A Case Study of the Ogallala Aquifer Region,* 2007, page i.
47. *Ibid.*
48. Institute for Agriculture and Trade Policy, *Water Use by Ethanol Plants: Potential Challenges,* 2006, page 5.

Figure 11

Aquifer Depletion and Ethanol Plant Locations in the Ogallala Region



Source: Environmental Defense Fund.
81017-6

Case Study 4: Water Management for Electric Power during Drought Conditions

Power plants are second only to agriculture in the volume of fresh water withdrawals in the United States, and a similar proportion of use occurs in other industrialized countries. Water use by power plants in the United States is strictly regulated at the federal or state level, both in quantity and quality. Although power plants are not generally charged for water, their permits designate the amount of water they are allowed to remove and consume from a water body and the quality of the water that must be returned to the water body, including a maximum temperature. The amount of water the power plant is allowed to withdraw or consume is based on providing enough water for all uses, including maintaining the environmental and ecological quality of the water source.

A recent drought in the United States provides an example of how power producers can respond to a water crisis. The summer of 2007 brought the most severe drought the US Southeast had seen in more than a century. The extremely dry conditions affected all water users – some cities even banned certain nonessential uses of water. During the drought, the US Federal Energy Regulatory Commission convened a group of experts to understand the implications of the drought on grid reliability and to make plans to mitigate the negative effects. On a company level, Southern Company, a large power generator based in Atlanta, Georgia, helped forge a dialogue among the stakeholders in its communities, including power plant operators, community leaders and those who live near plants or reservoirs, to discuss how best to balance the water resources available. Elevated temperatures and reduced flow rates in power plant intake waters made compliance with outlet water temperature limits particularly difficult. To comply with the temperature limits on its permits, Southern Company ultimately produced less power at some units and took other units offline at times while ultimately managing its pool of generation resources to ensure continued reliability. The lessons of the drought of 2007 have been well learned, however. Although 2008 was another dry year in the US Southeast, the drought did not have nearly as large an impact on power generation. The 2007 drought brought a new sense of urgency around water management, bringing about changes in water storage during the winter and making 2008's dry summer much easier to manage.

France provides an additional example of how drought conditions can impact electric power production. The summer of 2003 in Europe was the warmest on record, with temperatures 20% to 30% higher than average over a large part of the continent. The high temperatures were particularly hard on France's nuclear reactors, which generate approximately 75% of the country's electricity. In some regions, river levels were too low for the plants to operate at all. Six nuclear plants were granted exceptions from the normal temperature limits on their discharge water to allow them to continue to operate. Demand for electricity soared as the population used more air conditioning because of the heat, but total electricity generation was down due to the lack of water. France cut its power exports in half to make up for the difference.[49]

Case Study 5: Stakeholder Involvement and Multiuse Management in Hydropower

The Joint Multipurpose Program (JMP) is a coordinated set of investments to ensure the sustainable development and management of the Eastern Nile River, developed by the Eastern Nile Subsidiary Action Program and the World Bank's Nile Coordination Team. The JMP approaches the Eastern Nile and its tributaries as one river system shared by three countries: Egypt, Ethiopia and Sudan. The guiding principles of the project specify that the projects should take into account the social, political and geographic context of the Eastern Nile Basin and that they address the extreme hydrological variability, serious watershed degradation and the key role of agriculture in the region. Water storage is central to the JMP's plans. Water storage increases flow during drought periods and decreases peak flows during floods, provides for more irrigation and allows the generation of hydropower. An electric grid to distribute the hydropower will link the three countries, provide funds needed for debt service, as well as provide power for households and for industrial development. Cooperation among the three countries is also necessary to increase water conservation and improve environmental management, including controlling river bank erosion and restoring riparian ecosystems. The project is just beginning and has a 25- to 30-year time horizon, but the coordinated approach shows promise in balancing the use and management of water with the needs of stakeholders in the three countries.

British Columbia's extensive hydroelectric system provides an additional example of cooperation among stakeholders in a river system. In 1998, BC Hydro launched a programme to develop water use plans for each of its hydroelectric plants over a five-year period. The objective of the process was to clarify how rights to water resources in British Columbia should be exercised, taking into consideration environmental (e.g. fish habitat and wildlife) and social (e.g. recreational) uses as well as power generation. BC Hydro established the water use plans in a collaborative process with government agencies and local community stakeholders at each location. They developed a discovery process to determine the key issues at each plant and then established consultative committees that included representatives from each stakeholder. The outcome of the process is a set of detailed operating conditions that are embedded into BC Hydro's operating licenses and thus serve as a comprehensive definition of regulatory compliance. Each water use plan identified constraints or boundaries for operating the dams, including specifying flow rates, methods for ramping water flow up and down and seasonal reservoir levels.

As a result of the consultative planning process, nearly all of the water use plans were created with a high degree of agreement among the stakeholders. All parties understand the boundaries within which the power plans must operate. Thus, disagreements about plant operations are much less frequent, and conflicts

49. United Nations Environment Programme, *Environment Alert Bulletin: Impacts of Summer 2003 Heat Wave in Europe,* March 2004.

Aswan Dam on the Nile River, Egypt

that do arise are easier to resolve, due to the working relationships established with the stakeholders during the consultative process.

Treatment, Reuse and Conservation of Water Associated with Energy Production

Like many industries, the energy industry has the potential to cause water pollution through water used or produced in its processes. As described in Chapter 2, many energy processes generate contaminated water, and properly disposing of that water or treating it for beneficial reuse is imperative to management of the world's limited water resources. Conserving and recycling water also conserves vital water resources. The following case studies illustrate improvements in water pollution management and creative reuse of water.

Case Study 6: Management of Water Produced along with Oil

Water produced along with oil frequently poses a disposal or pollution challenge. The volume of such water is increasing at about 10% per year. The ratio of water to oil produced varies from less than one to as large as 40, depending on the maturity of the oil field.[50] Recent high oil prices led to a renewed interest in extending the life of existing oil fields, frequently using processes involving injecting water into oil reservoirs, including reservoir pressure support and waterflooding.

50. Khatib, Zara. "Produced Water Management: Is It a Future Legacy or a Business Opportunity for Field Development" Presented at the International Petroleum Technology Conference, Dubai, December 2007, page 1.

The water injected during these processes then contributes to increasing volumes of water recovered along with oil at the surface.

Shell's management of produced water in Oman is an example of pollution prevention and creative water reuse. Shell and Petroleum Development Oman (PDO) committed to phase out disposal of produced water into aquifers with salinity lower than seawater, to avoid contaminating such aquifers and to preserve them for other uses. Shell and PDO used two methods to dispose of the produced water. First, they constructed disposal wells to inject the produced water into deep aquifers that contain water unsuitable for human use. The second approach is the Greening the Desert initiative – a project to explore technologies that reuse produced water in agriculture or forestry near the oil field. One reuse method is to use the produced water to irrigate reed beds. The reeds grow well in brackish water, and natural processes in the reed beds degrade residual oil and cleanse the water of heavy metals. Effluent from the reed beds can then be used grow other crops. However, such crops would not be appropriate for human or animal food, so the focus is on producing fibres for construction material.[51] This creative water reuse example both reduces pollution and promotes economic development near the oil field.

A second example of reusing produced water comes from Chevron's Kern River oil field in California. Steam is used in the field to lower the viscosity of the oil and allow it to flow to producing wells. About nine barrels of water are produced for every barrel of oil. Chevron uses about half of this water to generate new steam to enhance oil production. However, the remaining water must be disposed of in some way. Produced water from the Kern River oil field is unusual in that it contains minimal dissolved solids and metals, and can be used for agriculture with minimal treatment. The excess produced water is treated with an oil-water separator and then processed through large filters filled with walnut shells, a common medium for filtering oily water. At this point, the water can be sent through canals for use in irrigation of local crops, including grapes, citrus, almonds and pistachios. The only contaminant remaining in the water that must be reduced is boron – blending with another fresh water source is needed to cut the boron concentration in half to prevent damage to the plants.[52]

Geothermal power production is another potential reuse opportunity for water produced along with oil. At an oil field near Casper, Wyoming, the US Department of Energy and Ormat Technologies are conducting a year-long test using water produced from oil wells for geothermal power generation. Hot water from an oil well is moved to a heat exchanger where it vaporizes another liquid with a lower boiling point. The vapour from that liquid turns a turbine, which is connected to a generator. The electricity from the generator is used to power the oil field's electrical system. Once the water from the well is cooled, it can be re-injected into the well to enhance oil recovery or released. This process has been producing 150-200 gross kW of electricity.[53]

Case Study 7: Minimizing Power Plant Water Use

As described in the previous chapter, the options for cooling at thermal electric plants require varying degrees of water usage. Once-through systems withdraw the most water, but closed-loop systems consume more water. Another option, dry cooling, relies on air rather than water for cooling.

Pacific Gas & Electric's proposed Humboldt Bay Repower Project in Eureka, California, would replace the existing power plant with a new facility that uses much less water. The current Humboldt Bay Power Plant uses a once-through cooling system that draws water from the ocean. The proposed plant would use an air radiator cooling system on a closed loop – similar to an automobile radiator. Cooling water circulates through tube bundles with fins that are cooled by fans. Because it is a dry cooling system, water is not lost through evaporation in a cooling tower. The water is continually recycled and there is virtually no wastewater discharge. Once the old facility is fully decommissioned, the Humboldt Bay Power Plant will no longer withdraw ocean water. The current plant's water demand is approximately 197,000 litres (52,000 gallons) per minute, while the proposed facility would require only 6.3 litres (1.67

51. Al-Masfry, Rashid, et al, "Technology Reaches Water Disposal," *E&P Magazine,* July 2007.

52. Waldron, Jim. "Produced Water Reuse at the Kern River Oil Field", *Southwest Hydrology,* November/December 2005, pages 26-27.

53. *Oil & Gas Journal,* 27 October 2008.

The Kern River Oil Fields near Bakersfield, California

gallons) per minute of water. The Humboldt Bay Repower Project was recently granted regulatory approval.[54] Although the old design of the Humboldt Bay Plant used seawater instead of fresh, the change reduces the impact of the plant's very high water withdrawal on surrounding marine life.

PNM, an electricity and natural gas utility in New Mexico, operates the San Juan Generating Station, an 1,800 MW coal-fired power plant. Fresh water is very scarce in the Four Corners area where the plant is located – the intersection of Colorado, Utah, New Mexico and Arizona. The plant is equipped with cooling towers that condense the steam used in the generating turbines so it can be used again at least 10 times, and as many as 50 to 100 times before it evaporates, greatly decreasing the plant's water requirements. Additionally, one of the four units at the plant has a hybrid cooling tower that

54. Application for Certification: Humboldt Bay Repowering Project.

can operate in both wet and dry modes. However, the plant is about 10% less efficient when operated in its dry cooling mode. The plant operators have turned to federal government agencies, other local industrial water users, and local Native American tribes that own water rights to negotiate additional water rights for the plant in times of drought, rather than incur the cost and efficiency penalty of converting the plant to dry cooling.[55]

Case Study 8: Water Reuse and Conservation in Liquid Fuels Production

Two facilities located in very dry areas are pushing the envelope of water conservation and reuse. The Reliance Jamnagar refinery will be the world's largest refining complex when an expansion currently under way is completed at the end of 2008. The facility is in the state of Gujarat on India's dry west coast. All of the water used at the plant is produced from a desalination system with a capacity of 62,400 cubic metres (16.5 million gallons) per day. Various schemes are employed at the complex to conserve and reuse water, including using air instead of water for cooling some systems, recovering steam condensate and segregating wastewater streams to allow more efficient reuse. This integrated water management approach reduces the water requirement of the facility by about 60%, thus reducing the size and energy requirement of the desalination facility. Nearly all of the treated effluent from the plant is reused on site for horticulture – about 2,200 acres of the site is covered with a tree plantation, served by a drip irrigation system to minimize water use. The only discharge from the complex consists of streams high in dissolved solids that cannot be reused, and are disposed in the Gulf of Kutch. The refinery has also used its desalination system to provide drinking water to surrounding communities during times of water scarcity.[56]

The Pearl Gas-to-liquids (GTL) plant in Qatar provides an example of a plant that neither takes in nor discharges water during steady-state operation. Jeroen Van der Veer describes the operation of the plant in his perspective, *Water – A Critical Enabler to Produce Energy*. The plant uses approximately 1,300 cubic metres (340,000 gallons) of water per hour, but the Fisher-Tropsch reaction on which the plant is based produces about 1,400 cubic metres (370,000 gallons) of water per hour. Shell designed a fully integrated water management scheme for the plant, based on the reuse of all wastewater. Van der Veer further describes the plant's environmental attributes: "Over the full lifecycle of Pearl GTL, we will achieve a neutral or better balance between the freshwater intake and the water produced in the plant itself, so that local water sources will not be depleted or affected. The water management solutions we found for Pearl GTL place it in a different class of sophistication from anything seen before in our industry."

Conservation of Energy in Water Provision

Many water provision activities are energy intensive. As a result, operators of water provisioning activities continuously strive to find ways to become more energy efficient, thereby reducing their costs. The three case studies presented here illustrate the challenges of reducing energy use in the finding, transformation and delivery of critical water resources.

Case Study 9: Energy Use for Desalination

Desalination is one of the most energy-intensive and expensive ways to produce fresh water, but in areas where fresh water supply is insufficient to meet demand, desalination is an option. Half of all desalination capacity in place today is in the Middle East and North Africa. Additionally, many small island communities rely on desalination for a large fraction of their total water need.[57]

Two primary technologies can separate salts from water: thermal distillation or reverse osmosis. Thermal distillation is often used in energy-rich areas and can produce water with a much lower salt content than reverse osmosis. Reverse osmosis often uses less energy and can remove other contaminants from the source water. However, the energy required for reverse osmosis treatment increases along with the source water's salinity.[58]

55. Water Management: San Juan Generating Station," http://www.pnm.com/environment/sj_water.htm.
56. Personal communication, K. G. Ramanathan, Reliance Industries, India.
57. Gleick, Peter, et al., *The World's Water 2006-2007: The Biennial Report on Fresh water Resources,* Island Press, 2006, page 57-58.
58. *Ibid.,* page 54.

In his perspective, *The Optimal Combination: Integrated Power and Water Desalination Plants*, Gérard Mestrallet describes the state of the art in desalination. Building thermal desalination and power plants together saves energy, because the heat rejected from the power plant turbines can be used to heat water for desalination. This configuration is common in the Middle East. GDF Suez has also built a reverse osmosis desalination plant in Perth, Australia, that uses electricity from a wind farm for its operation, avoiding 30 tons of CO_2 emissions per year.

Case Study 10: Long Distance Transport of Fresh Water

Over 50 years ago, Mao Zedong observed: "Water is abundant in the south and scarce in the north. If it is possible, we can borrow some from south to north." With the South-to-North Water Transfer Project, that is exactly what China aims to do. The project – the largest of its kind in the world – consists of three sections that will divert water from the Yangtze River to the Yellow River. Upon completion, over 44 billion cubic metres of water will be transferred annually to northern China.

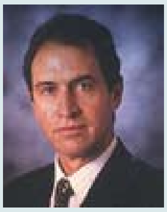
The energy needs of this massive project are also enormous. The eastern route will divert 14.8 billion cubic metres of water per year from the lower part of the Yangtze to the city of Tianjin. Water from the Yangtze will travel 646 kilometres while being conveyed upwards to the higher-elevated Yellow River. This will be done by a series of pumping stations that will lift the water 65 metres, using approximately 3.4 billion kWh of electricity per year. The middle route will send 9.4 billion cubic metres of water annually from the Danjiangkou Reservoir on the Han River, a tributary of the Yangtze, to Beijing. A portion of the middle route was completed before the Beijing Olympics to ensure adequate water supply for the city. In this portion of the project, the water is primarily conveyed by gravity. The plan for the western route, which is not yet under construction, is to divert 20 billion cubic metres of water per year from the upper reaches of the Yangtze to the Yellow River. This would be done in three sections and would require building large dams and lengthy tunnels. The pumping stations use 7.1 billion kWh of power per year.[59]

Perspectives on Understanding the Risks and Opportunities in the Water-Energy Relationship

The chapter includes the perspectives of three individuals who have shared examples of the risks and opportunities in the water-energy relationship. These perspectives appear at the end of the chapter.

- **Pat Davies,** Chief Executive, Sasol, South Africa
- **Gérard Mestrallet,** Chief Executive Officer, GDF Suez, France
- **Jeroen Van der Veer,** Chief Executive, Royal Dutch Shell, Netherlands

59. http://www.nsbd.gov.cn/zx/english/20081118/.



Business and Water in Southern Africa

By Pat Davies, Chief Executive, Sasol, South Africa

Water is a key enabler for sustaining livelihoods and supporting development imperatives in Southern Africa. The condition of water resources and their management in this region are highly varied. South Africa is primarily an arid country and also one where the most abundant water resources are located at some distance from the major concentrations of urban domestic and industrial demands. This gives rise to a complex interrelationship among competing water users that has to be carefully managed to advance the interests of the whole. Managed correctly, water can be a renewable resource.

Sasol places a very high demand on water, particularly at its existing CTL plant in Secunda, South Africa. Although the CTL process is water intensive, it is also essential for energy security, particularly that of transport fuels, in South Africa and will be for other coal-rich countries in future.

Sasol's operations are primarily located for ease of coal access. There are several water storage and transfer schemes along the Vaal River to supply water to Sasol's sites at the required level of assurance. Sasol is continuously undertaking initiatives to improve water efficiency and ensure greater water security. In partnership with Eskom, the electricity utility, and the Department of Water Affairs and Forestry we have a 40% stake in the ZAR 3 billion Vaal pipeline project, an investment aimed at ensuring a sustainable supply of water to Eskom power stations and the Sasol Secunda complex. As part of a recent expansion of the Secunda complex, a series of integrated water treatment processes have been installed to recover and upgrade a cooling water blowdown stream to produce high-quality condensate water. This has resulted in a saving of approximately 5% on the total raw water intake to the complex.

The water supply challenge remains under the microscope as a number of new industrial sites, including power stations and CTL facilities, are considered in South Africa. This new demand further stretches the total supply capability of the existing water supply infrastructure. Several studies have been undertaken to re-examine the total potential of the South African water situation. Initial findings indicate there is scope for improvement in water use efficiency within municipal water supply infrastructure, through eradicating the illicit use of water and embarking on a greater drive to reuse treated sewage effluents.

Sasol has a keen interest in the successful resolution of these dilemmas and is engaged with authorities and other stakeholders to seek sustainable solutions. Through necessity, Sasol has become a leader in many aspects of water use and recycling, and has made significant progress in this area. An extensive programme is under way to reduce the water intensity of Sasol's CTL and gas-to-liquids (GTL) alternative energy offerings. In a noteworthy achievement, we designed, piloted and implemented an integrated water treatment system for the Oryx GTL facility, recently commissioned in Qatar. Effluent generated in this process is upgraded for reuse as a process cooling medium. Future designs are building on the Oryx experience, and we envisage being able to further improve beneficial reuse and recycling of water generated at new facilities. This will improve efficiency of water use significantly, compared to existing operations.

We consider the sustainable management of water as part of our responsibility to uplift the lives of all South Africans, subject to the constraints that nature has imposed upon us and, of course, the gifts that it has bestowed.

The Optimal Combination: Integrated Power and Water Desalination Plants

By Gérard Mestrallet, Chief Executive Officer, GDF Suez, France

All economies, whether advanced or developing, are striving to be more competitive in the continual quest to optimize resources to meet growing demand. Challenges abound. Fossil fuel reserves are not endless and fresh water resources are limited in many regions. We are also concerned about the environmental footprint of human activities and their consequences on climate change. We want cheaper energy, cleaner water and air and sustainable economic and social development.

Only 3% of the world's available water is fresh. Of that fresh water supply, 70% is consumed in agriculture, 22% by the industrial sector and 8% for drinking water. The United Nations forecasts that the world's population will reach 9.2 billion by 2050. There are grave concerns that, at that time, 40% of the population – 3.6 billion people – may suffer from food shortages, economic deprivation and poor health because of water stress. Therefore, providing reliable and affordable access to water and energy are vital challenges for governments, industries and civil society.

Desalination is an unconventional method to produce fresh water that has shown promise in responding to demand from water stressed areas in coastal cities. This is an especially apt solution because 42 of the 70 cities with more than 1 million inhabitants that do not have direct access to additional fresh water resources are located on the coast. In fact, 39% of the world's population lives within 100 kilometres of the coast. Proximity to the sea is advantageous because fresh water cannot be transported over long distances. Countries in the Gulf and the Mediterranean, as well as Australia, historically have been the most important desalination markets in the world and are expected to remain so.

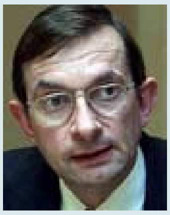
Desalination is an energy-intensive process, but in the past decade the water treatment industry, membrane and equipment manufacturers and power producers have made significant improvements to the process that reduce freshwater production costs. Desalination by reverse osmosis technology is the most recent advance and is already one of the leading methods of freshwater production.

Reverse osmosis is a membrane-based separation process that captures more than 99.9% of salt content in seawater. Reverse osmosis facilities can improve their energy efficiency by around 25% by using pressure exchangers instead of conventional turbines. Not only is reverse osmosis less energy intensive and less expensive, it also is more environmentally friendly than other methods of desalination. Desalination by reverse osmosis costs 0.40 to 0.80 euros per cubic metre compared with a cost of 0.65 to 1.80 euros per cubic metre when using thermal distillation. The price of desalination in the future will depend on energy costs and advances in technology. The industry is expected to grow from current revenues of US$ 9.2 billion to US$ 21.1 billion by 2015. By that time, the annual fuel and electricity bill for the industry will amount to US$ 5.8 billion. There is indeed room for improvement.

Today, there are 12,500 desalination plants in 120 countries. To optimize energy and water outputs while reducing CO_2 emissions, we build combined desalination and power production facilities whenever possible. GDF Suez has projects operating and under construction totalling 2 million cubic metres per day of water production capacity and more than 13,000 MW of electricity generation. For example, the Al Taweelah A1 independent power and water plant in Abu Dhabi supplies 30% of the emirate's power capacity and 28% of its water supply. At the same time, we have been able to significantly reduce the plant's CO_2 and nitrogen oxide emissions. GDF Suez is, by far, the world leader in developing and operating combined facilities for desalination and electricity production.

In the coming decades, countries that are rich in fossil fuels can afford to invest considerable amounts in desalination infrastructure. In many cases, integration and better use of renewable and alternative resources can improve the energy balance of water treatment facilities and reduce their impact on climate change. For example, our seawater desalination plant in Perth, Australia, uses reverse osmosis to produce 143,000 cubic metres of water per day. A new pressure exchange energy recovery process at the plant has improved conventional performance by 15% to 20%. A wind farm was installed nearby to supply green energy. Combining the desalination plant and wind farm reduces CO_2 emissions by 30 tons per year.

We believe that, in fast-growing emerging economies, coupling water and nuclear power generation facilities will allow for affordable access to energy and water with much less environmental impact. It is important to stress, however, that for water, as with energy, there is no single solution. A mix of different approaches is the best way to meet country-specific demand issues and environmental concerns.



Water – A Critical Enabler to Produce Energy

By Jeroen Van der Veer, Chief Executive, Royal Dutch Shell, the Netherlands

Availability and access to fresh water have emerged as critical issues, perceived by many as a challenge as pressing as climate change. Analysts estimate that, by 2025, two-thirds of the world's population could be living in conditions of "water stress," with a major impact on farming (using 70% of the world's fresh water), industry (using 22%) and day-to-day living (using 8%).

The global demand for energy and water is intensifying as a consequence of a growing world population, better standards of living in developing countries and significant industrial growth in countries such as China and India. New developments (industrial, agricultural, domestic) will exacerbate environmental issues such as groundwater depletion, wetland degradation and receding river levels. Climate change adaptation will start to play a role, bringing with it high levels of uncertainty and risk, with some regions affected more than others.

Water and energy are intrinsically linked. Energy generation uses water in a variety of ways, and likewise, energy is consumed in water processes, e.g. extraction, distribution and treatment. Supply and access to water and water pollution caused through hydrocarbon extraction and refining are key issues for the oil and gas industry. With the emergence of biofuels and the development of unconventional resources, the energy industry's water footprint is expanding into new arenas.

In the face of growing public concerns about water availability, regulatory pressures will become intense, especially at the local level. It is imperative for our industry to improve handling of water-related issues through schemes that reduce freshwater use and maximize treatment and reuse of produced water in our operations. Water reuse is quickly becoming an important business and economic factor since disposal and forced clean-up options are very expensive.

Additionally, constraints on water extraction limit the ability of businesses to grow or operate. Water-stressed areas, such as the Middle East, North Africa, Australia and China, need integrated water and energy solutions to cope with water scarcity issues given the rapidly increasing energy footprint. However, more energy intensive solutions to water problems can also result in increasing greenhouse gas emissions. It is therefore important to take a holistic approach to facility design and to optimize water, energy and emissions control simultaneously and value water properly when calculating project economics.

Water already plays an important role in Shell operations. Key issues upstream are increasing production and disposal of water and water availability for injection and EOR. Where possible, Shell looks for innovative technologies to minimize our operational water footprint. In Schoonebeek, for example, large quantities of municipal wastewater, not natural sources, will be treated to generate steam for EOR. In the Middle East, we are investigating the use of biofilters (reed bed technology) to clean up produced water and potentially make it available for reuse.

In our downstream operations, we have decades of water management experience in upgrading water sources to a quality for industrial use in cooling systems, steam and hydrocarbon process applications. In Australia, the Shell Clyde refinery in New South Wales has become a partner in Sydney Water's Every Drop Counts programme, working to reduce water consumption and achieve cost savings. At our manufacturing sites, process effluents have to be disposed against ever-tightening legislation globally and a continuous reduction of water intensity, with zero liquid discharge (ZLD) as the ultimate limit.

ZLD is being applied in the Pearl GTL project in Qatar. Like any large project, Pearl GTL needs a lot of water, approximately 1,300 cubic metres per hour, and desalination of seawater is energy intensive. The good news is that a GTL plant – by virtue of the chemistry of the Fisher-Tropsch reaction on which it is based – also produces a lot of water, at Pearl GTL around 1,400 cubic metres per hour. That has enabled us to design an integrated water management scheme based on the full reuse of wastewater. Over the full lifecycle of Pearl GTL, we will achieve a neutral or better balance between the fresh water intake and the water produced in the plant itself, so that local water sources will not be depleted or affected. The water management solutions we found for Pearl GTL place it in a different class of sophistication than anything seen before in our industry.

This type of innovation and application of new technology is required globally to reduce the water intensity and operations footprint in the energy industry. Although water is often considered a local issue, stakeholders will also consider the global impact of companies like Shell. Maximizing our water recycling and improving our water efficiency will ensure that Shell continues to have adequate access to water for its operations and will help support the availability of water resources for other societal uses.

CHAPTER 4: IN SEARCH OF COMMON PRINCIPLES FOR OPTIMIZING THE WATER AND ENERGY NEXUS

Introduction

Water is essential to life, yet its availability is often taken for granted by societies that have easy access to fresh water. The same can be said for energy. It is the lifeblood of the global economy, yet its low cost and availability on demand are also often taken for granted. As the world population grows and becomes more prosperous, water stress in many parts of the world is also likely to grow. The easy availability of water and energy will no longer be a given.

This report has highlighted the interconnection between water and energy on many fronts, including how the sources for each are identified, transformed into usable forms and delivered to consumers. The report has also provided examples of the creative optimization of both of these vital resources through case studies from around the world. The case studies demonstrate that solutions to water and energy problems are as varied as the countries from which the case studies are taken.

Improving energy efficiency and access to energy for the world's poor is on the agenda of both governments and corporate leaders. Ensuring that societies have potable water is a centuries-old right that is widely recognized. However, finding ways to optimize the use of water in generating energy – and the use of energy in delivering water – increases the complexity of business and policy decisions. There is no one simple roadmap for managing a relationship as complex as that between energy and water, but four overarching principles can guide decision-making:

- **Water issues are local.** The first step in optimizing the energy and water relationship is to define the problem at the local level. Local availability of resources is an essential factor in any potential solution.
- **Water issues cannot be viewed in isolation.** Issues of water resources and energy are inextricably linked with energy security and climate change, among other concerns. However, as with energy efficiency, water efficiency can be a winning strategy on all fronts.
- **Markets can be helpful in allocating water resources, for the most part.** Local markets for water can help allocate water to its best use and provide incentive for water conservation. However, access to clean water is a human right, and water is vital to the health of ecosystems. Therefore, any plan to use markets to allocate water must take basic human and ecological needs into consideration.
- **Consider not only water use, but also opportunities for reuse.** Many energy technologies produce large amounts of water, including today's oil and gas production and the potential CCS technology of the future. Beneficial reuse of this water when possible, and proper treatment and disposal when reuse is not possible, are crucial to protect water resources.

Water Issues Are Local

Water is a local good. Global markets for water do not exist. Because water is very heavy for its economic value, it is very expensive to transport. Water is transported over long distances only in circumstances of extreme necessity or at great cost. Thus, water resource planning must occur at the local level. As Sean Cleary says in his perspective, "The principles will be global, but much of the solution will lie in addressing local specificities. Like agricultural *terroir* and the weather, water is local, and we can only ignore that fact at our peril."

Despite water's local nature, water resources are often shared across political boundaries. Samir Brikho, in his perspective, *Watersheds Do Not Recognize Political Boundaries*, emphasizes the importance of integrated management of water resources: "Integrated watershed management plans for all major (and often minor) watersheds should address present and future requirements for all sectors including energy, agriculture and environment. Watershed planners and energy planners need to work together to develop management plans and instil a cooperative atmosphere. Since watersheds do not recognize political boundaries, international cooperation is necessary, and each nation needs to be committed to understanding the relationship of these two commodities."

Nations and other political entities that share water resources must work together to manage these resources collaboratively. The Nile River basin example described in Chapter 3 is a good example of collaborative use of water resources.

Nuclear Power Plant

No Technology Is Inherently Good or Bad

A corollary to the principle that water issues are local is that no technology is inherently good or bad. Even technologies that are very energy or water intensive have their place. The appropriateness of a technology depends on the local situation and the resources available. For example, desalination is an energy-intensive way to provide drinking water, but in the Middle East where freshwater resources are scarce and energy resources are plentiful, desalination is likely the most sustainable way to provide drinking water. As described in the case studies, desalination plants are becoming more efficient, through co-production of electricity or use of renewable energy resources. Similarly, water-intensive technologies such as nuclear power and biofuels may be appropriate in areas where sufficient water exists to support them.

Water "Footprints" Only Tell Part of the Story

A water footprint is a summation of the water used in providing a product or service. Such footprints have become very popular in the measurement of greenhouse gas emissions, and the idea is gaining traction to measure water use as well. However, as described in the first chapter, different areas are endowed with very different levels of fresh water resources. Thus, the economic and social value of water differs greatly from place to place, depending on its scarcity or abundance. Any water footprint that does not take into account the local conditions where the water was used does not give a full picture of the water impact of the product or service being evaluated.

In this vein, water management and greenhouse gas management are very different problems, although they are often related. Greenhouse gas emissions are a truly global problem, and greenhouse gasses have the same impact no matter where they are emitted. Water issues are the precise opposite. Good water management in one place has no impact on the availability of water in distant locations.

Finding the right metric to measure the water intensity of a business or product is a challenge due to water's local nature. Comparison of similar processes across locations or companies can help businesses understand if they are operating in the most water-efficient manner possible. However, both the hydrological and political environment in a place will determine the optimal level of water use. The most high-tech water-saving technologies may not be necessary or cost-effective everywhere. Regional water use metrics are likely to be necessary, rather than ones designed for global use.

Water and Energy Issues Cannot Be Viewed in Isolation

Water and energy are inextricably linked with other global issues, including climate change and energy security. A holistic approach to energy and water management considers all of these issues and looks for creative solutions that optimize all of these parameters. Some energy technologies with low CO_2 emissions are large users of water, and technologies that may enhance energy security may be harmful from a water security standpoint. Thus, an optimized solution may involve tradeoffs among the various factors. In his perspective, *Water and Energy: New Thinking,* Peter Gleick sums up the energy water relationship in this way, "Decision-makers and corporations should better integrate energy issues into water policy *and* water issues into energy policy. Failure to link these issues will *inevitably* lead to disruptions in the supply of both water and power, while thoughtful, integrated policies will provide important advantages."

Geothermal Power Plant and Pipelines

As Jeroen Van der Veer states: "Additionally, constraints on water extraction limit the ability of businesses to grow or operate. Water stressed areas, like the Middle East, North Africa, Australia and China, need integrated water and energy solutions to cope with water scarcity issues given the rapidly increasing energy footprint. However, more energy-intensive solutions to water problems can also result in increasing greenhouse gas emissions. It is therefore important to take a holistic approach to facility design and optimize water, energy and emissions control simultaneously, and value water properly when calculating project economics."

Cost-effective applications of water and energy efficiency are winning strategies on all fronts. Using less energy reduces water use and water pollution, while increasing energy security and decreasing the greenhouse gas emissions that contribute to climate change. Using less water has a similar effect, decreasing the energy needed to treat and transport that water. Thus, increasing energy and water efficiency is the one globally relevant strategy. Efficiency should be at the top of the list for every energy and water planner and a focus for policy-makers everywhere.

Water Markets Can Be Helpful, for the Most Part

Because of water's local nature and differing value in different areas, no global price or pricing mechanism exists for water. However, local water markets exist in many areas, particularly those that already experience water stress. An important prerequisite to the development of these markets is a system that allocates water ownership. In many water-stressed areas, systems for water rights have emerged through custom or through law. However, in areas where water rights are unclear, the ownership issue must be solved before water trading or markets can emerge. In the western United States, water rights have provoked battles for more than 200 years. The writer Mark Twain once said, "Whiskey is for drinking; water is for fighting over." This proverb is likely to prove true in more parts of the world in the future.

Even in areas where water rights are clear and water is bought and sold, its market value is often not reflective of its economic value. As Stephen Hoffman, a water resource economist, describes it, "The asset's market value is often capped and varies based more on political will than scarcity. If water were a true commodity, like oil, the price of water in a given consumptive use would equate more with the marginal cost of providing it, including scarcity and ecological considerations."[60] Water prices that reflect the marginal cost of provision are important to encourage efficient water use. In his perspective, *The Interface of Energy and Water – A View from China*, C. S. Kiang describes several ways to make water management more efficient, including revealing all costs of water resources to users and valuing water in ways that reflect local scarcity.

However, the notion of pricing water at its "true cost" runs headlong into an important truth: access to water is a fundamental human right. The United Nations describes the issue this way: "Water is fundamental for life and health. The human right to water is indispensable for leading a healthy life in human dignity. It is a prerequisite to the realization of all other human rights."[61]

Water is a very emotional issue, and many people hold a negative view of water markets and private sector involvement in water provision. Efforts to privatize municipal water systems and charge prices reflective of costs have run into fierce opposition in many parts of the world, including Bolivia, the Philippines and Indonesia. A frequent problem with these agreements is that they have neglected to provide subsidized water to poor residents who cannot afford to pay the full cost. The South African constitution guarantees access to water for people and ecosystems, and this right was recently reinforced in the courts. In the past, pre-paid water meters were installed in some poor households in Johannesburg. If the residents did not have money to pay the meter, they did not have access to clean water. The Johannesburg High Court recently declared such meters unconstitutional and ordered Johannesburg water to provide residents with 50 litres per person per

60. Hubbard Preston, Holly, "Mysteries of Water and the Future of a Scarce Resource" *International Herald Tribune,* 26 April 2008.
61. United Nations Economic and Social Council, Committee on Economic, Social and Cultural Rights. General Comment No. 15. *Substantive issues arising in the implementation of the International Covenant on Economic, Social and Cultural Rights. The Right to Water.* E/C.12/2002/11 Twenty-ninth session, Geneva, 26 November 2002.

day for free. The judge in the case stated that it was the obligation of the city "to ensure that every person had both physical and economic access to water."[62]

The concept of "virtual water" is another way of thinking about using markets to allocate water resources. Instead of transporting water over long distances, water-intensive goods are transported instead, particularly agricultural products. Transmitting electric power to dry areas where power plant cooling is difficult is another example of trade in virtual water. Trade in water-intensive goods is not typically thought about as an alternative to water markets, but it does provide water-rich areas with opportunities to monetize their resource, and water stressed areas a way to efficiently meet the needs of their people. Saudi Arabian grain production provides an excellent example. In the 1970s, the Saudi government wanted to diversify its economy away from oil and become more self-sufficient in food production. It offered a large subsidy to wheat farmers, who relied entirely on groundwater to produce 2.5 million tonnes a year of wheat. However, the level of groundwater use required was not sustainable, and at the beginning of 2008, the Saudi government announced it was reducing wheat purchases from local farmers and planning to rely entirely on imports by 2016. The Saudi government decided to rely on imported "virtual water" in the form of wheat, rather than imprudently and unsustainably using its own water resources.[63] Importing virtual water could allow for more appropriate use of the local water in water-stressed areas for all uses, including energy.

Amid all of the questions about how to best allocate and price water, what guiding principles result in a functional, efficient market?

- Water markets must be based on a fair allocation of water rights, including allocating water for ecosystem preservation. Ecosystem preservation is vital, and water must be set aside, even if there is no one to "buy" this water.
- Water markets must charge individual users at the marginal cost of providing the water, with exceptions. This principle does not mean that all users of water are charged the same price. Potable water provided to households requires much more treatment than water used in agriculture and will thus be more expensive. Providing water to the poor is an exception to the marginal cost rule, and other exceptions may be appropriate due to local conditions.
- Water markets must take local stakeholders and conditions into account. The type and number of participants in a water market and the level of water stress in the location will result in different arrangements for water rights and markets. Cookie-cutter solutions are not possible.

More widespread pricing and trading of water has the potential to be advantageous to energy companies, giving them a clearer understanding of the value of the water they use. Where water markets are developing and taking root, the cost of water consumption will give users clear incentives to reduce their water use. In this case decisions about water use can be made based on the economic value of the water used or saved, which will vary greatly in different locations.

Consider Not Just Water Use, but Opportunities for Reuse

Most discussions of water and energy focus on the amount of water used in energy systems, but energy production can be a source of water as well. The case studies in Chapter 2 provided several examples of beneficial reuse of water produced or contaminated in energy production. As shown in these case studies, opportunities exist for linking energy production facilities with wastewater treatment facilities, agricultural facilities for crops or livestock, or other industrial water users to reuse water. Margaret Catley-Carlson describes the need for water recycling in her perspective: "We need as vibrant a market for used water as there is for used cars – extracting the nutrients for crops (in a world of skyrocketing fertilizer prices), using lightly treated water for appropriate industrial and agricultural purposes, and even contributing to energy via anaerobic methane production from wastewater."

Municipalities in dry areas have begun using reclaimed waste water to supplement the water supply. A treatment plant in Singapore recycles waste water into water that is pure enough to drink, although it is used by local semiconductor manufacturers instead. In Windhoek, Namibia, a wastewater recycling plant supplies about

62. Isaacson, Maureen, "City Council's Township Water Meter Plans Get Flushed by High Court Judge," *The Sunday Independent,* 4 May 2008, page 3.
63. "Saudi Scraps Wheat Growing to Save Water," *Middle East Online,* http://www.middle-east-online.com/english/business/?id=23803.

250,000 residents with drinking water. Using recycled waste water for drinking may not be acceptable to consumers, but using such water for industrial and agricultural purposes can free other sources of high quality water for domestic use, reducing water stress. Andrew N. Liveris focuses on water reuse in his perspective, *Addressing the Nexus of Water, Energy … and Food. NOW*. He describes a partnership among Dow and the local government and water provider in Terneuzen, Netherlands. Dow reuses the city's wastewater in its chemical plants, enabling the local utility to cut energy use for water purification by 65%.

These examples demonstrate the potential of water reuse and of linking facilities together, where the output of one facility becomes the input for the next. Integrated design of multiple industrial facilities, including those for energy production, has the potential to conserve both water and energy resources.

Conclusion

Although energy consumes a small fraction of the world's fresh water, water is a critical part of the energy value chain. Energy's share of water is likely to be squeezed in the future. Agriculture is by far the world's largest water consumer, and the stress of feeding an ever-growing population means that agriculture's share of water use will grow in many areas, even as technology decreases the amount of water needed for the world's food supply. Economic and population growth will also increase demand for finite fresh water resources. As a consequence, energy companies may face greater competition for their share of water and must be aware of their water use and its sustainability given local conditions. Growing population and economic growth will also increase the demand for energy and clean water, putting additional stress on water resources.

Given this growth in water demand, the energy industry may face a more challenging regulatory environment and more public attention around its water use in the future. Climate change may reduce water availability in some areas. Recent droughts in Europe and the United States have demonstrated the industry's vulnerability to water shortages. In areas where water stress is an issue, the energy industry must understand its water use profile and strive to use water as efficiently as possible. Policy-makers also must consider water availability when setting energy priorities.

Energy companies will be increasingly called upon to be partners in managing the world's water resources, along with agriculture and other large users. The industry's goal must be to use water resources wisely while taking into account climate change and energy security concerns. Finding solutions that optimize along all three parameters will be a challenge for energy companies for decades to come. This challenge raises a set of questions for the industry:

- How will the energy sector's share of water use change in the future? How can energy companies measure and monitor their water use, given the local nature of water resources and the differing value of water from place to place?
- What role will water markets play in allocating future resources? How might water markets change the economics of various energy technologies?
- How can the industry best engage with the other stakeholders, including agriculture, other industries and government to shape future water policy?
- What technologies can improve the water efficiency of the energy industry? How can the energy industry become better integrated with other industries, agriculture and municipal water and wastewater operations to optimize water use and re-use?

The World Economic Forum and Cambridge Energy Research Associates will be exploring this critical set of questions in the months ahead.

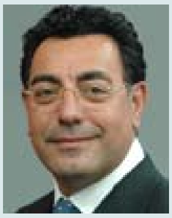
The World Economic Forum is undertaking a major initiative on water from 2008 to 2010. This initiative is not specific to the energy industry, but brings together multiple stakeholders with goals to:

- *Raise awareness* among the world's leading political, macroeconomic and corporate decision-makers about the structural water challenges that our world system will face in coming decades;
- Find ways *to leverage the competencies of international business* to help political and civil society leaders address the water challenge; and
- *Catalyse new multistakeholder platforms* to convene breakthrough discussions about the water challenge at the global and regional levels and to stimulate tangible activities at the highest level to help avert a crisis.

Perspectives on Common Principles

The chapter includes the perspectives of three individuals who have analysed common principles for optimizing water management in the energy sector. These perspectives appear at the end of the chapter.

- **Samir Brikho,** Chief Executive, AMEC plc, United Kingdom
- **Peter Gleick,** Co-Founder and President, Pacific Institute for Studies in Development, Environment and Security, USA
- **C. S. Kiang,** Chairman, Peking University Environment Fund, China
- **Andrew N. Liveris,** Chief Executive Officer and Chairman, The Dow Chemical Company, USA



Watersheds Do Not Recognize Political Boundaries

By Samir Brikho, Chief Executive, AMEC, United Kingdom

Since the beginning of time, the world has consumed water for a variety of uses and at the same time consistently sought ways to improve upon and expand the production of energy. At its simplest level, the global economy is dramatically influenced by the efficient use of water and energy. The world's thirst for economic growth has put tremendous demands on both resources at increasingly accelerating rates.

Tensions are developing between these two resources; limited water supplies are restricting our capability to generate more energy, and limited supplies of energy are affecting our capability to supply more water. As a result, an increasing client base is looking for innovative solutions to water resources management as well as for alternative energy sources. As the world evolves into one global market, we will see a shift towards unprecedented cooperation in water supply management and a push for alternative energy sources that break or minimize the energy-water link. The continued economic growth of China, India and other emerging markets will increase the challenges between water supply and energy production and increase the world's need to be sustainable.

Integrated watershed management plans for all major (and often minor) watersheds should address present and future requirements for all sectors including energy, agriculture and environment. Watershed planners and energy planners need to work together to develop management plans and instil a cooperative atmosphere. Since watersheds do not recognize political boundaries, international cooperation is necessary, and each nation needs to be committed to understanding the relationship of these two commodities.

To reduce risks to energy development projects, both primary and secondary sources of water supply should be investigated. Planners need to understand the intrinsic variability of hydrologic cycles and provide adaptive measures to accommodate these anomalies. Contingency plans should consider the reuse of produced water and wastewater, and provide alternatives to increase water supplies and reduce water requirements.

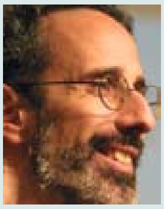
Climate change adds another layer of complexity. Climate change is closely tied to the interrelationship of water consumption and energy production. In fact, AMEC is conducting several watershed studies that include climate change estimates. Plans for both supply and consumption of energy and water must take into consideration not only present uses, but forecasted future demands.

These plans must lead to actions. Guiding principles for water management related to energy production should include the following:

- Water for people and food is a priority.
- Energy production needs to be maintained along with growth projections.
- Conservation and water use efficiency are implicit practices.
- Sufficient water must be available for aquatic life and protection/enhancement of the environment.
- Focus on research and technology is necessary to achieve efficient use and production of energy, including optimized energy production and reduced water use.
- Regulatory certainty is needed to ensure sustainability and to eliminate risk of administratively losing supply sources.

Some examples of water supply alternatives are already in front of us: air cooling rather than water cooling, recycling process water and wastewater, more efficient irrigation systems, forecasting and operational improvements, on-stream and off-stream water storage, pricing that correctly values water, and many others that need to be seriously addressed and researched with new technologies applied. Multipurpose hydropower and run-of-the-river hydro developments need to be addressed. Hydro developments, while they may have negative impacts on the environment, could provide water for multiple uses including drinking water for municipalities, irrigation for food production, industrial use and in-stream flow to protect the environment. Alternative energy supplies should include solar, wind and tidal/wave energy, among others. We must focus and act on sustainable water/energy developments that have accounted for the risks associated with shortfalls in both sectors and that do not trade off energy security by sacrificing the environment. Well formulated plans and actions can provide both. Governments need to be part of this development by enacting policies, providing funding and facilitating implementation of the options.

The global community must manage these issues, but as champions of industry we must shoulder some responsibility and leadership, and assist the market in being good stewards of our resources for generations to come. Although these issues may appear daunting and enormous, I believe as industry leaders we are not only well positioned, but also willing to lead the global market in providing the sustainable solutions the world needs.



Water and Energy: New Thinking

Peter Gleick, Co-Founder and President, Pacific Institute for Studies in Development, Environment and Security, USA

Water use and energy use are closely linked. Moving, treating and using water require substantial amounts of energy. Producing energy takes substantial amounts of water, especially with traditional fossil and nuclear systems. Yet rarely are these energy connections adequately evaluated. And they are even more infrequently addressed by policy-makers, or energy and water managers.

Limits to energy are beginning to affect water systems, and limits to water are beginning to affect energy systems. Considering these two resources together offers substantial economic and environmental benefits. Additionally, a new problem that must be addressed is the challenge of global climate change, which affects policies in both areas.

The Energy Cycle

The entire energy cycle requires water, from mining to generation to distribution of energy. Energy end use and waste disposal also use and contaminate water resources.

For example, the largest withdrawal of water in the United States and most other industrialized countries is for power plant cooling. Most cooling water is not "consumed" but is returned to a river or lake after a rise in temperature. Yet in arid and semi-arid regions, power plant water demand can be substantial compared with the water resource available, causing problems for other users and natural ecosystems. Nuclear and fossil-fuel energy systems require far more water per unit of energy produced than most renewables, depending on cooling system type. As water resources become increasingly scarce due to human demands and changes in supplies, we have begun to see examples of energy production constrained by lack of water. Nuclear and fossil fuel plants have been either de-rated or temporarily shut down when water is short. New cooling technologies have been required to reduce water demands that threaten fisheries or other aquatic ecosystems. And finding additional water to cool new power plants is increasingly difficult in some regions where water supplies are constrained. More such problems are likely to develop in coming years.

Water Supply, Use and Treatment All Require Energy

Our water systems all require substantial energy, from collecting water at a source, to conveyance, treatment, distribution, end use and waste treatment. The energy intensity of water provided depends on the source of water and how it is used. For example, Southern California relies on a wide range of water sources. The energy intensity of providing that water ranges from less than 500 kilowatt hours (kWh) per acre-foot for local sources and reclaimed wastewater to more than 4,000 kWh per acre-foot for desalinated seawater from reverse osmosis systems. (An acre-foot of water is equal to 1,233 cubic meters, or 326,000 gallons.) Different choices about the source of water thus have different implications for energy requirements and hence greenhouse gas emissions. The California Energy Commission recently estimated that as much as 20 percent of California's energy use went to some aspect of water supply or use.

Water efficiency efforts can save substantial water (and energy) at lower cost, often faster than new "supply." Water efficiency should be given a higher priority by resource planners, and water-efficiency programs at all levels should be designed to capture multiple benefits. More science and analysis are needed, but some suggestions include:

- Phase out irrigation, energy and crop subsidies that promote wasteful use of water and energy.
- Pursue new standards and smart labeling of water-efficient appliances that also save energy.

Climate – Water – Energy Links

Water and energy are also linked to climate change through the emission of greenhouse gases. Some climate change – perhaps significant climate change – is already unavoidable. We must both move to avoid those consequences we cannot manage and learn to manage those impacts we cannot avoid. A key element to any climate strategy will thus be to reduce the greenhouse gas emissions associated with our water systems by developing non-carbon energy sources for water and to figure out how to adapt to unavoidable impacts on water availability and infrastructure.

Conclusions

Water and energy are tightly linked, but these links are poorly understood and rarely used in policy. Decision makers and corporations should better integrate energy issues into water policy and water issues into energy policy. Failure to link these issues will inevitably lead to disruptions in the supply of both water and power, while thoughtful, integrated policies will provide important advantages.

The Interface of Energy and Water – A View from China

By C. S. Kiang, Chairman, Peking University Environment Fund, People's Republic of China; Xiaoliu Yang, Peking University, People's Republic of China; and Feng Chaolin, Tsinghua University, People's Republic of China

Water and energy are the most basic infrastructure services needed to sustain modern life. Efficient use of these limited resources requires improved management and a new mindset about their essential nature. This consciousness parallels the lessons of the current financial crisis, which we finally recognize as interdependent and international in scope and scale. These related critical issues must be addressed simultaneously and holistically. Global leaders coming together to solve the financial crisis should apply the same resolve to the climate and energy crisis before there is a meltdown. Rebuilding should incorporate the most energy-efficient solutions reflecting the concerns of the 21st century and can only be accomplished through international cooperation.

China's economy is starving for energy. Hydroelectricity is commercially attractive and technologically mature, and could play a more important role in meeting China's energy demand. Three Gorges Dam is connected to the national electricity grid and substitutes for high-emission coal power, diminishing climate change effects. Small hydropower projects account for the biggest portion of China's projects under the Clean Development Mechanism – an international cooperation mechanism between developing countries and developed countries against climate change. To further exploit the value of water resources as an energy source, in China's National Eleventh Five Year Plan, the Mid- to Long-term Plan for Renewable Energy Development has set an ambitious goal to develop an installed capacity of 80 gigawatts (GW) of small hydropower projects by 2020. Hydropower in China provides energy, reduces global warming, and indirectly helps to stabilize the planet's water circulation. Policies and financial channels should be available to encourage small-scale hydropower production to supplement local energy needs.

However, other forms of energy, either nonrenewable or renewable, may adversely affect the sustainability of water resources. Geothermal energy is an example. China is the world's largest producer of geothermal energy, based on one facility. Yangbajin is located in Tibet, where water is scarce for agricultural, irrigation and household usage.[64] While geothermal development in this site provides energy to the local population, the wastewater from the geothermal plant is polluting local water at levels greater than the national water standard. Despite a massive effort in freshwater reinjection, this energy project still causes severe local water pollution that cannot be eliminated.[65]

Though China's water efficiency per unit of GDP has been improving in the past years, China's water consumption per GDP is still five times the world average and eight times the American level. However, potential win-win solutions exist to improve efficiency. These include strengthening water market management, especially in the South-to-North Water Transfer Programme, and ensuring that those who demand more pay more. This principle may press local administrations to push industries to improve water utilization efficiency. Competitive cross-district allocation of water rights and appropriately revealing all costs of water resources in city water provisions may propel the market players themselves to reduce water usage. Water valuation should reveal local water scarcity and thus propel companies to apply water conserving operations.

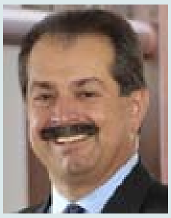
Further reforms in China's water and energy sectors are necessary to increase private sector participation and improvement of social development. In pursuit of a stable macroeconomic framework, policy reforms will be consolidated and poverty alleviation accelerated. This can improve the supply of power, water, and sanitation systems and increase the operational and end-user efficiency of infrastructure sectors. Renewable energy sources and sound management of water resources should be developed. For the energy sector, such improvements include:

- Separating transmission systems and making them common carriers to enable freer trade
- Setting prices to reflect cost of supply and ensuring the financial viability of the supply entities
- Improving operational efficiencies in such areas as system loss reduction, theft reduction, metering, billing and collections
- Enabling increased private sector investments in energy

In the water sector, irrigation efficiencies must be improved substantially. Extensive rehabilitation of the irrigation facilities should be undertaken to reduce losses. Programmes such as lining canals, adopting more efficient forms of irrigation, introducing a volumetric charge for water use and constructing tamper-proof volumetric measuring structures deserve priority.

Climate change and sustainable economic recovery and development are two sides of the same coin. We must have both sides of this metaphoric coin to forge a holistic path to the financial and environmental future. We cannot be tentative and we must not procrastinate in this highly volatile climate. Restructuring the financial systems of the world brings about the opportunity to integrate solutions – addressing climate change and energy, including water, food, health and other essential issues as part of the financial recovery of the world.

64. Zeng Yi et al. *The Present Status of Utilization of Geothermal Energy and Resources Research by the Aid of Japanese Government in Yangbajing Geothermal Field, Tibet, People's Republic of China,* Proceedings World Geothermal Congress 2005.
65. Now the reinjection rate is 37%, and experts are trying to gradually increase this level to 100%.



Addressing the Nexus of Water, Energy … and Food. NOW.

By Andrew N. Liveris, Chief Executive Officer and Chairman, The Dow Chemical Company, USA

As the world's population grows, so does the need to accelerate our ability to address the associated challenges in an integrated manner – NOW. Central to solving these challenges is looking at the interactions among the major environmental concerns. Traditionally, this debate focuses on the interaction between energy and water from both a supply and a demand perspective. Developing truly effective solutions depends, however, on adding a third dimension to that debate: the challenges to food production. Not only are many food crops today also being used as feedstock for energy production, but regardless of the end use, food production requires enormous amounts of water. Each potential solution to address the nexus of these three challenges should be evaluated on its impact on the three dimensions. At Dow, we are using our innovation skills to address the challenges related to water, energy and food.

Our Dow Water Solutions business is dedicated to providing innovative, technology-based solutions to a broad spectrum of water issues – from treating seawater to make it fit for human consumption, to contaminant removal in municipal water supplies, to industrial and residential water purification systems and to reducing and reclaiming water used in industrial processing. As part of our 2015 Sustainability goals, this business is working towards reducing the cost of desalination and water reuse by 35%. The key success factor in achieving this goal is reducing the overall energy consumption of desalination. Reverse osmosis technologies have made great strides in this area, and more improvements are in the future.

Dow Agro Sciences is another business contributing to the solutions by developing drought resistant crops that produce "more crop per drop," bringing more value to local farmers and potentially increasing local food supplies.

One final example is Dow's joint venture with Crystalsev in Brazil for the manufacture of polyethylene from sugar cane. The new facility will use ethanol derived from sugar cane – an annually renewable resource – to produce ethylene. Ethylene is traditionally produced using either naphtha or natural gas liquids, both hydrocarbon products for which extraction results in high CO_2 emissions. It is estimated that the new process will produce significantly less CO_2 compared with the traditional hydrocarbon-based process. A significant determinant in our decision to move forward with this project is that use of the sugar cane does not have a negative impact on the food supplies in Brazil, and there is no impact on the rain forest.

Private and Public Sectors Simply Have to Work Together

Today, sustainability joins availability, quality and security as critical challenges to water, energy and food supply. The issues are admittedly complex and diverse. But we believe these challenges are all solvable. The fundamental technologies already exist. The primary driver for success in dealing with these challenges is the willingness of the private and public sectors to work together using an integrated approach that goes beyond technology to include the will and commitments of all stakeholders.

- Government must have the will to drive pragmatic, integrated policies that ensure affordable water.
- Society must have the will to conserve and reuse existing supplies.
- Businesses must have the will to create technology solutions that solve problems and make economic sense.

One example of how business and government commitment can translate into tangible results is a project in Terneuzen, Netherlands, where Dow partnered with the government and a local water provider to reuse the city's wastewater in our plants. As a result, every litre of water is used three times instead of once. This enabled the local utility to cut energy use for water purification by 65% – which equals 5,000 tons of CO_2 reduction annually.

Please Join Us

At the World Economic Forum Annual Meeting 2008, I joined UN Secretary-General Ban Ki-Moon and the leaders of 11 other large multinationals and influential organizations to launch the Water Call to Action. A year has passed and, although progress has been made, the urgency with which we need to address these issues has only increased. Therefore I would like to repeat the invitation to all leaders from business and leaders from the research, development, international non-governmental organizations and government communities to come together and help shape a concrete and detailed action plan.

LIST OF KEY CONTRIBUTORS

The World Economic Forum thanks those who actively contributed to this report:

Samir Brikho
Chief Executive
AMEC, United Kingdom

Margaret Catley-Carlson
Chair, World Economic Forum Advisory Council on Water
Patron, Global Water Partnership
International Water Management Institute Board
United Nations Secretary-General's Advisory Board on Water and Sanitation, Canada

Feng Chaolin
Tsinghua University, People's Republic of China

Sean Cleary
Chairman
Strategic Concepts, South Africa

Pat Davies
Chief Executive
Sasol, South Africa

Christoph Frei
Senior Director, Head of Energy Industries
World Economic Forum

Peter Gleick
Co-Founder and President
Pacific Institute for Studies in Development, Environment and Security, USA

Samantha Gross
Associate Director, Global Oil
Cambridge Energy Research Associates (CERA), USA

C. S. Kiang
Chairman
Peking University Environment Fund, People's Republic of China

Andrew N. Liveris
Chief Executive Officer and Chairman
The Dow Chemical Company, USA

Espen Mehlum
Associate Director, Head of Electricity Industry
World Economic Forum

Gérard Mestrallet
Chief Executive Officer
GDF Suez, France

James E. Rogers
Chairman, President and Chief Executive Officer
Duke Energy Corporation, USA

Susan Ruth
Senior Director, Global Energy and Global Oil
Cambridge Energy Research Associates (CERA), USA

Jeroen Van der Veer
Chief Executive
Royal Dutch Shell, Netherlands

Xiaoliu Yang
Peking University, People's Republic of China

Daniel Yergin
Chairman
Cambridge Energy Research Associates (CERA), USA
Executive Vice-President
IHS, USA

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum is an independent international organization committed to improving the state of the world by engaging leaders in partnerships to shape global, regional and industry agendas.

Incorporated as a foundation in 1971, and based in Geneva, Switzerland, the World Economic Forum is impartial and not-for-profit; it is tied to no political, partisan or national interests. (www.weforum.org)