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THE WATER-ENERGY NEXUS

Adding Water to the Energy Agenda

A World Policy Paper
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EXECUTIVE SUMMARY

The competition between water and energy needs represents a critical business, security, and environmental issue, but has not yet received the attention that it merits. Energy production consumes significant amounts of water; providing water, in turn, consumes energy. In a world where water scarcity is a major and growing challenge, meeting future energy needs depends on water availability –and meeting water needs depends on wise energy policy decisions.

Competition for water among municipalities, farmers, industrial and power suppliers is already evident in a range of locations, particularly in the Southwest United States but also around the world. As water tables decline, the Organization for Economic Cooperation and Development estimates that 2.8 billion people—nearly half of the world's population– live in areas of high water stress, rising to 3.9 billion by 2030 if present trends continue. As cities grow, municipal water demands will increase. As populations rise and increase their consumption of meat, agricultural competition for water will intensify.

In the United States, generating energy consumes 20% of the water not used by agriculture. Rising demand for energy—both conventional and alternative– has the potential to significantly increase water consumption. As energy producers and consumers seek to reduce carbon emissions, water consumption frequently rises because many cleaner forms of conventional and alternative energy are potentially more water-intensive. Both traditional and renewable energy production are evolving toward potentially more water-intensive technologies, which risks adding to demands on water resources. New energy technologies are being developed to reduce water consumption. However, they are generally expensive, can reduce energy efficiency, and will need time before they can be commercially available at scale.

Now—as new energy policies are emerging– is the window of opportunity to add water to the agenda.

Nations around the world are evaluating their energy options and developing policies that apply appropriate financial carrots and sticks to various technologies to encourage sustainable energy production, including cost, carbon, and security considerations. Water needs to be part of this debate, particularly how communities will manage the trade-offs between water and energy at the local, national, and cross-border levels. These decisions will impact businesses, investors, security, environment, justice, development, and sustainability. Policy makers, business leaders, investors, nongovernmental organizations, and the public at large need sound, non-partisan information to make the right choices. However, information about the water-energy nexus is often fragmented, weak and incomplete, difficult to compare, and filled with jargon. Inaccuracies in media reports are common because of gaps in understanding of the dynamics of the interaction between water and energy. Muddling the debate further, proponents on all sides of energy debates sometimes selectively choose (or even mischaracterize) data to their advantage.

To enhance the quality of discussion and decision-making on the water-energy nexus, this policy paper provides the context needed to evaluate key tradeoffs. We present a comprehensive, user-friendly guide to the most credible available data about water consumption per unit of energy produced across a spectrum of traditional and alternative energy technologies. We identify data holes and important issues that merit further attention. We also have created a glossary to help non-experts decipher energy jargon.

Based on existing data, the most startling finding is that (with some notable exceptions) both traditional and existing alternative energy technologies are evolving toward higher water consumption per unit of energy produced.

Both emerging petroleum and alternative transportation fuels consume more water than conventional petroleum-based fuels:

- Petroleum from the Canadian oil sands extracted via surface mining techniques can consume 20 times more water than conventional oil drilling. As a specific example of an underlying data weakness, this figure excludes the increasingly important steam-assisted gravity drainage technique (SAGD) method. We encourage future researchers to fill this hole.

- Irrigated first-generation soy- and corn-based biofuels can consume thousands of times more water than traditional oil drilling, primarily through irrigation. More research is needed to evaluate second and third generation biofuels.

The picture on electricity generation is mixed:

- Among conventional power plants, gas-fired plants consume the least amount of water per unit of energy produced. Coal- and oil-fired plants consume roughly twice as much water as gas-fired plants. Nuclear consumes approximately three times as much. The nuclear figure may seem surprisingly low in light of the public debate around nuclear water; this reflects frequent confusion between water withdrawal (which tends to be much higher) and water consumption. More research is needed on contemplated future projects including modular nuclear energy.

- One of the “cleaner” coal technologies, the integrated gasification combined cycle process, reduces a coal plant’s water consumption by half, while also reducing carbon emissions and other pollutants. However, contemplated carbon capture technologies could increase a coal plant’s water consumption by 30%-100%[1].

- Wind and solar photovoltaic electricity consume minimal water and are the most water-efficient forms of conventional or alternative electricity production.

- The installed base of the solar thermal form of electricity generation (as opposed to photovoltaic) consumes twice as much water as coal and five times as much as gas-fired power plants.

- Natural gas produced by a technique called hydraulic fracturing is a game-changer that could alter the entire energy mix of transportation fuels and electricity generation. The main water issue here involves pollution, which is beyond the scope of this paper; however, additional research is needed on consumption, particularly in order to reflect substantial changes in the technology and its application to oil. Current data indicate that natural gas produced by hydraulic fracturing consumes seven times more water than conventional gas extraction but roughly the same amount of water as conventional oil drilling.

After an extensive review of available data, we chose as our primary data source a report jointly produced by 12 National Laboratories and presented to the U.S. Congress in 2008. Although somewhat dated, the report is relatively comprehensive, widely cited, and appears to be impartial and the most credible data that currently exist. Our methodology is discussed further in Appendix I. Our data sources are transparent and available in Appendix VI below.

We hope this paper serves as an objective, non-partisan information source that motivates policy makers, business leaders, investors, NGOs, and the general public to ask further water-related questions – and to probe critically into the responses they receive. We also seek to increase visibility of water-energy nexus implications on business (opportunities, supply chain costs/inefficiencies, and risks), security (food, military, and energy), and the environment (agriculture, forest, and climate). These are made more complicated by issues of justice (ownership, pricing, and equity) and sustainable development (poverty, sanitation, health, and gender).

The water-energy nexus, along with its wide-ranging impact and the challenging questions that result, has earned a rightful place on the global policy agenda.

INTRODUCTION

The policy debate over energy already reflects a widespread understanding that policy choices will impact cost and availability, national security, and carbon emissions. It is time—indeed past time– to add water to that list of considerations.

Creating energy consumes enormous quantities of water, which is increasingly scarce in many parts of the world. For the purposes of making sound energy policy decisions, it is useful to think of water along three critical dimensions: consumption, withdrawal, and quality.

Consumption refers to water that disappears or is diverted from its source, for example by evaporation, incorporation into crops or industrial processes, drinking water, etc. The source may or may not eventually be replenished. If replenished, the process could potentially take many years—decades, centuries, or longer.

Withdrawal refers to water that is essentially "sucked up" for a given use, but then returned to its source. The quality of the returned water may or may not be the same as it was prior to removal.

Quality is an umbrella term that can refer to pollutants that enter the water; changes to oxygen content, salinity, and acidity; temperature changes; destruction of organisms that live in the water; and so on.

Energy production impacts water along all three dimensions. Different energy technologies have different impacts. The key water issue in the nuclear debate, for example, is the impact of large withdrawals (and the return of water that is warmer) on marine organisms. The hydraulic fracturing debate focuses on drinking water quality. By contrast, the solar-thermal discussion (ought to) focus on consumption in arid environments. The dynamics of the interaction between water and energy are often misstated. A recent *New York Times* article,[2] for example, misstated the environmental impact of a nuclear plant because it confused the key concepts of consumption (water that is used up and not released back into the environment) and withdrawal (water that is taken in but then released). This is an essential concept in nuclear energy, where "closed-loop" systems withdraw less but consume more water.

Because of declining water tables, many consider consumption to be the most important near-term dimension. Once water from a given source is consumed, it is gone. Therefore, while acknowledging the importance of withdrawal and quality, we focus here on the critical issue of consumption.

Data are sparse, but what does exist confirms that the United States is a heavy consumer of water. While agriculture takes up the lion's share of water consumption, at over 80% of the total, electricity is 20% of the rest. Traditional gas, coal, and nuclear power plants consume enormous amounts of water—an estimated 20% of non-agricultural water.

Carbon reduction technologies have vastly different water impacts. Wind turbines and solar photovoltaic panels consume minimal amounts of water, primarily when they are cleaned. One of the “cleaner” coal technologies, the integrated gasification combined cycle process, reduces a coal plant’s water consumption by half, while also reducing carbon emissions and other pollutants.

Some carbon-reduction technologies substantially increase water consumption. First-generation biofuels from irrigated soy and corn can consume thousands of times more water than petroleum, primarily due to irrigation when grown.

Carbon capture technologies could increase a coal plant’s water consumption by 30%-100%.[3] The solar thermal form of solar electricity generation can consume twice as much water as coal-fired and five times as much as gas-fired power plants.

Oil and natural gas are also becoming more water consumptive. As conventional oil and natural gas become more difficult to access, alternatives such as petroleum derived from the Canadian oil sands are emerging. This particular alternative, however, can consume approximately twenty times as much as traditional oil.

Production of on-shore natural gas has increased at a breathtaking pace in the last five years due to improvements in “unconventional” hydraulic fracturing techniques (see glossary). Dramatic supply increases have reduced natural gas prices and renewed the promise of domestic, lower-carbon energy. However, debate rages over the water impact of hydraulic fracturing. Although anecdotes and theories abound, there is not enough high-quality data to support the claims of either side of the debate. Because unconventional natural gas extraction will play an increasingly important role in our energy future, its water impact needs to be thoroughly understood.

Selecting sites for energy production, whether conventional or alternative, must depend on local water availability, particularly keeping in mind the consequences of declining water tables in many parts of the world. On-shore natural gas production may be less of an issue in rural areas but more challenging in New York City’s watershed. Water-hungry technologies might make sense where water is abundant but concerns about building solar thermal plants in arid Southwestern deserts deserve further probing.

Energy decisions represent a series of complex tradeoffs balancing water, national security, cost, and carbon emissions concerns. Biofuels consume a full third of the US corn crop, inextricably linking energy with agriculture. This leads to unresolved issues involving the relationship between increased demand for energy crops, and to what extent this drives conversion of forests into agricultural land. When forests are removed, many important functions are lost. For example, at the level of the local ecosystem, forests mitigate floods and droughts, while acting as natural water filters. As a result, policy makers also must consider national security, cost, and carbon consequences of energy’s impact on agriculture and forests.

Below we have summarized the water requirements of fuels for transportation and for electricity generation. Energy experts generally separate transportation from electricity generation because most modes of transportation rely on liquids derived from petroleum including gasoline, diesel, and kerosene to power up automobiles, trucks, and airplanes, respectively. With the exception of vehicles, electricity—which can be generated from a number of different sources– largely powers everything else. Hence, we analyze transportation fuels separately from electricity generation.

FINDINGS I: TRANSPORTATION FUELS

At least for the moment, the world depends on petroleum-based liquid fuels and established transportation infrastructure. Due to historic petroleum supply shocks, energy security, and increasing climate change concerns, significant research and funding have gone toward commercializing a range of alternative vehicular fuels.

With the exception of natural gas, all emerging alternatives —whether from fossil or other sources– consume significantly more water for a given unit of energy. While nuances abound, the key takeaway is that most emerging alternatives increase water intensity relative to conventional petroleum. Some would increase it substantially.

Producing “synthetic crude” from the Canadian oil sands consumes 20 times more water for a given unit of energy than conventional petroleum such as from the Mideast or Nigeria.[4] Biofuels from crops such as soy and corn, when irrigated, can consume thousands of times more water than conventional petroleum. From a purely consumption-based perspective, natural gas is the most efficient in water terms. Available data suggest that even the controversial gas extraction technique of hydraulic fracturing consumes roughly the same amount of water as conventional petroleum per unit of energy produced.

Electric cars are powered either by a hybrid combination of fossil fuels and electricity, or are fully electric. It is important to recognize that batteries merely store energy, and are not the sources of the electricity. Therefore evaluating an electric vehicle’s water consumption requires tracing back to the way the electricity was originally produced, which in turn requires making numerous assumptions, such as whether the electricity was generated from a solar photovoltaic plant or a hydroelectric plant or a gas-fired thermoelectric plant? Because so little data are available, no estimates are included here.

Conventional oil and natural gas

Relative to every other transportation fuel, oil and gas consume the least water per unit of energy produced. Natural gas is the least water intensive, consuming approximately two gallons per million BTU of energy content. Petroleum consumes approximately 14 gallons for the same amount of energy. To put these figures in context (Box 1), more than 30 gallons of water are consumed to produce the gasoline to drive roundtrip from New York City to Washington, D.C., whereas approximately 5 gallons of water would be needed to produce the same amount of energy from conventional natural gas. (Process and potential water quality impact are critical as well, but they are not the focus of this paper.)

Box 1. The World Policy Institute-EBG Capital Transportation Chart—Making Sense of Energy Jargon

Gallons of water consumed to produce the energy required to drive round-trip from New York City to Washington, D.C. (approximately 2 million BTUs)

Natural gas (as on land)	5 gallons
Unconventional natural gas (shale)	33 gallons
Oil (traditional)	32 gallons
Oil sands (mining)	616 gallons
Biofuels (irrigated corn)	35,616 gallons
Biofuels (irrigated soy)	100,591 gallons

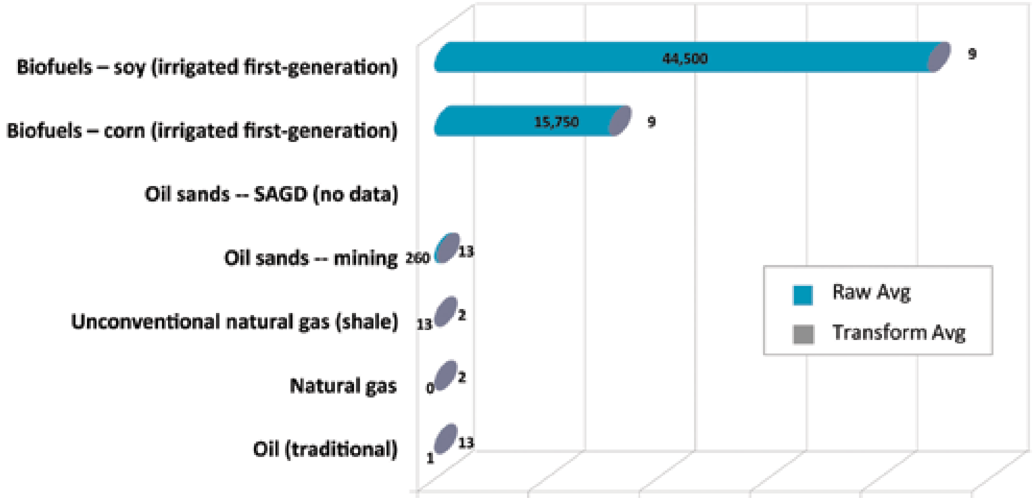
Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009. See Appendix V, Table 1 for additional information.

Oil sands

Canada is the single largest supplier of imported oil to the United States—even larger, despite popular conceptions, than Saudi Arabia, Venezuela, or Nigeria. There are two primary methods of oil sands recovery. The strip-mining technique is known best. However, the more recent steam-assisted gravity drainage technique (SAGD) is better suited to deeper deposits. Much of the future growth of production in the Canadian oil sands will be from SAGD.

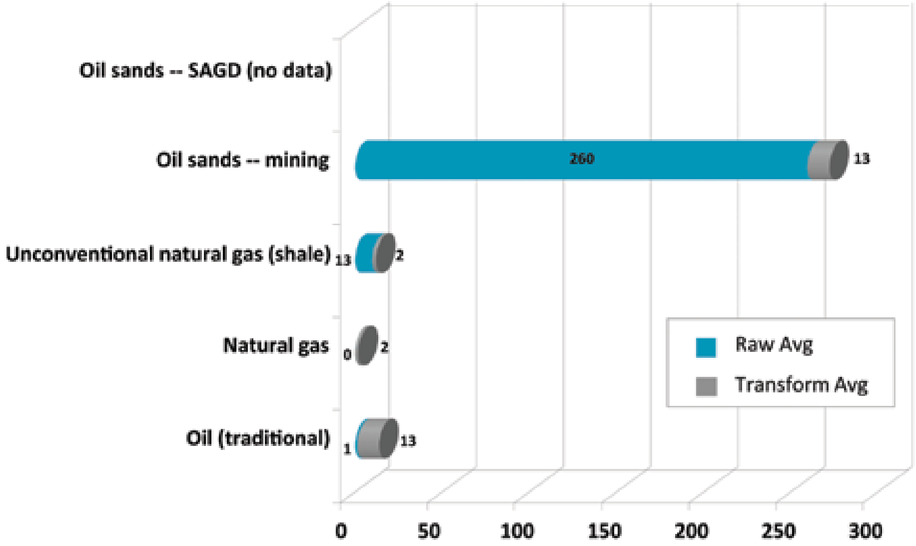
Canadian oil sands production consumes 20 times as much water as traditional oil. The impact of more recent SAGD developments could benefit from further evaluation.

Graph 1. Average Gallons of Water Consumed to Produce 1 million BTUs (roughly the energy required to drive from New York City to Washington, D.C.)



Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009. See Appendix V, Table 1 for more information.

Graph 2. Average Number of Gallons of Water Consumed to Produce 1 million BTUs (roughly the energy required to drive from New York City to Washington, D.C.),



Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009. See Appendix V, Table 1 for more information.

“Unconventional” natural gas via hydraulic fracturing

Natural gas produced by a technique called hydraulic fracturing is a game-changer that could alter the entire energy mix of transportation fuels and electricity generation. Some consider natural gas to be a domestic energy source that could make coal obsolete. Others see it acting as a bridge until lower carbon technologies are developed even as it threatens wind and solar. The primary concern, which is strong enough that it has the potential to halt drilling, involves water pollution. Questions about radioactivity also are emerging. Though water pollution is beyond the scope of this report, we suggest that water consumption—which impacts drilling location, cost, and growth potential– be added to the energy evaluation criteria.

Massive domestic production of low-cost “unconventional” natural gas in the last five years is the most important North American energy development in decades. It has resulted from improvements in hydraulic fracturing (variously known as “frac’ing or “fracking”), a technique that pumps liquids under high pressure to create fractures in rocks that previously could not release their natural gas. Natural gas produced by this method is called “unconventional” but the end product is the same as natural gas produced by “conventional” methods. Natural gas can be processed into a transportation fuel, burned in gas-fired electric power plants, or burned in the Canadian oil sands to generate steam in the SAGD extraction method.

Because of its sheer volume, on-shore production, jobs creation, energy security, and “cleaner” energy benefits, natural gas will undoubtedly play a large role in the energy future. However, there are concerns about the impact of hydraulic fracturing on water. A prominent example is the debate about drilling for natural gas in the Marcellus Shale, a rock formation underneath parts of New York and Pennsylvania, which provides New York City’s drinking water.

Although the most credible consumption data we identified are dated, they indicate that hydraulic fracturing consumes seven times more water than conventional gas but only slightly more than conventional oil consumes. Consumption data on all sides of the debate can vary by political persuasion and tend to be anecdotal and/or not statistically valid. Substantial changes in hydraulic fracturing over the last few years make it difficult to compare data among locations and over time. Now that hydraulic fracturing is beginning to be used in oil extraction—with similar game-changing opportunities and risks– the need for better information is even more compelling.

Although beyond the scope of this analysis, water withdrawal and water pollution data related to hydraulic fracturing suffer from the same problems. Anecdotally, frac engineers report concerns about water availability. Because of its importance, hydraulic fracturing is one area in particular that requires more robust, current data and improved methodologies.

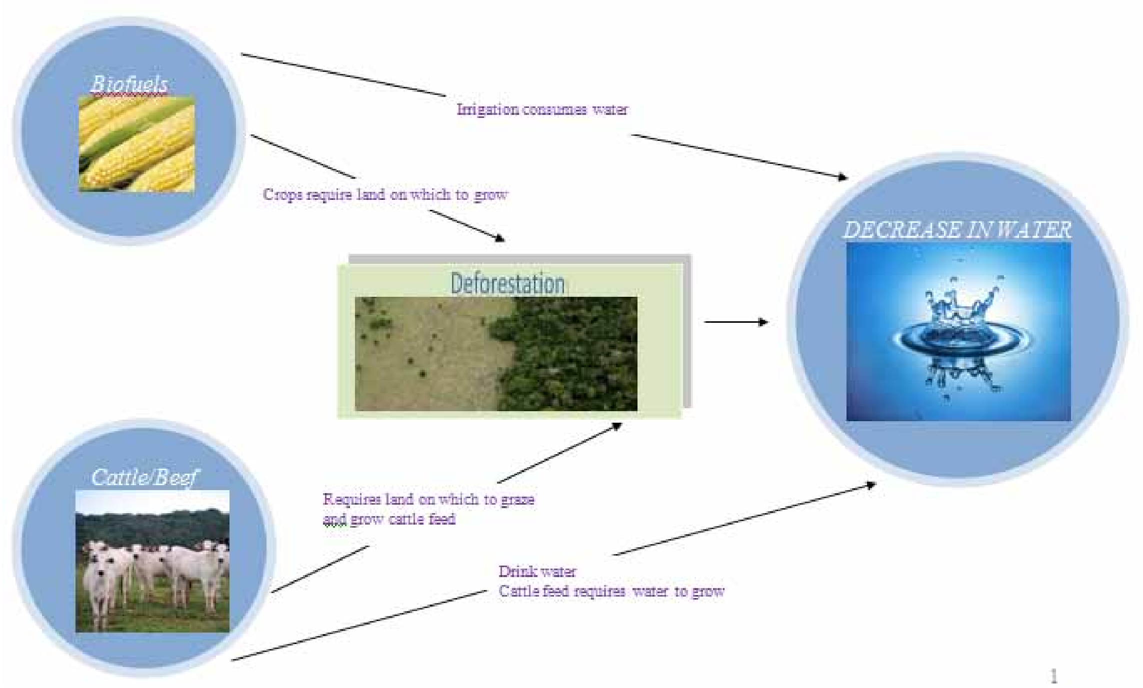
Biofuels

When irrigated, first generation soy and corn based biofuels are off-the-chart water consumers, especially during their growing phase (as much as 1,000 to 3,000 times more than oil). In 2008, roughly 35% of the U.S. corn crop was converted to ethanol.[5] U.S. government mandates, financial incentives such as tax credits, and tariffs on imported ethanol support the market. In 2008, more than 10% of the U.S. soy crop was converted to diesel, almost 60% of Brazil’s sugar crop was converted to ethanol, and 60% of Europe’s rapeseed (canola) crop was converted to diesel.[6]

Overall sustainability criteria for biofuels are under development. "Second" and "third" generation algae and cellulosic based biofuels are not expected to compete with food, and reduce land-use impact. Alternative biofuels sources are also in development and address water, such as residues, perennial grasses, no/low irrigation crops, etc. Municipal solid waste is often categorized alongside biofuels as another potential transportation fuel source. Its water consumption depends on the original source of the waste. However, these new technologies will take time to develop.

Agriculture already consumes more than 80% of U.S. fresh water. Increased demand for agricultural crops to produce energy invariably leads to a series of unresolved discussions regarding food security and the relationship with increased demand for energy crops, and to what extent this drives conversion of forests into agricultural land.

Box 2. Unresolved Issues Regarding the Relationship between Energy, Agriculture, and Deforestation



Source: World Policy Institue-EBG Capital Analysis

FINDINGS II: ELECTRICITY GENERATION

Holding aside hydroelectric generation, natural gas-fired power plants are the most water-efficient conventional electricity generators. Coal and nuclear consume two and three times, respectively, more water per unit of electricity.

Emerging alternatives pose no clear-cut answers. In fact, they vary significantly in terms of water intensity. Wind and the photovoltaic method of solar electricity generation consume little water. Another solar variant, called solar thermal, consumes more than four times as much water as natural-gas derived electricity. Geothermal consumes more than seven times. Although IGCC is an example of a carbon reduction technology that could reduce emissions from coal-fired power plants, other types of carbon reduction technologies increase water consumption.

Although emerging small-scale "run of the river" hydroelectric generation is thought to consume minimal amounts of water, different arms of the US government have vastly different estimates of the water consumed by large-scale hydroelectric generation. This is a particularly clear example of how different underlying assumptions and poor quality data can lead to divergent policy conclusions, and how important the need is for accurate data.

Coal, gas, and nuclear power plants

Power generation consumes enormous amounts of water. Gas, coal, and nuclear power plants together consume more than 20% of non-agricultural water. This is the reason most power plants are located close to large bodies of water. When water levels are low, as during droughts and/or very hot summers, electricity production may need to be reduced – exactly when it is needed most.

Cooling constitutes the vast majority of the water consumed by power plants. Energy cooling jargon is particularly difficult to penetrate, largely because it often focuses on engineering minutiae of power plant cooling techniques. We've simplified the data in Box 3, which illustrates the average amount of water needed to cool an 18,000 BTU air conditioner 12 hours/day for one week.

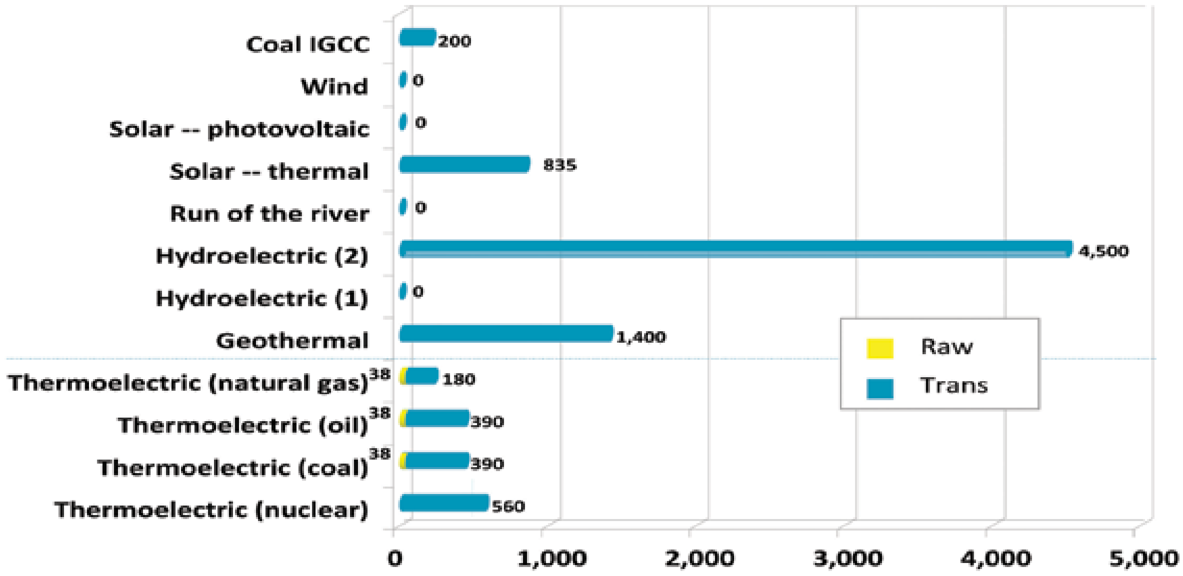
In sum, there are a range of cooling systems. However, two types of systems account for the vast majority of power plant cooling. The first system (open-loop wet cooling) withdraws a lot of water but consumes relatively little of what it withdraws; the second system (closed-loop wet cooling) withdraws less water but consumes a larger proportion of what it withdraws. Unfortunately there is a tradeoff between water withdrawal and water consumption. Either withdrawal is relatively high but consumption is relatively low or withdrawal is relatively low and consumption high.

Plants built before the 1970s tended to withdraw large amounts of water via open-loop wet cooling systems. In response to concerns about their impact on marine life, most plants built since the 1970s use closed-loop wet cooling systems that withdraw relatively less water, but consume large quantities of water.

Broadly, existing closed-loop wet cooling in gas-fired power plants consumes approximately 180 gallons to produce one MWh of electricity. To provide some context ,1 MWh is roughly the electricity required by an average plasma screen TV per year (Graph 3).

All thermoelectric power plants including natural gas, coal, oil, nuclear and solar thermal also have options for alternative cooling systems (dry or hybrid). However these options generally reduce plan efficiency and are more expensive. Data on emerging technologies, including modular nuclear, also need evaluation.

Graph 3. Average Number of Gallons of Water Consumed to Produce 1 MWh



Electricity generation data caveat: Solar Thermal refers to installed base only

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy, 2006, and World Economic Forum and Cambridge Energy Research Associates, 2009. See Appendix V, Table 2 for additional

Box 3. The WPI-EBG Capital Air Conditioner Chart – Making Sense of Energy Jargon

An 18,000 BTU air conditioner 12 hours/day for one week consumes:

Hydroelectric	Minimal- 2,000 gallons
Geothermal	700 gallons
Solar Thermal	400 gallons
Nuclear	300 gallons
Thermoelectric, coal	200 gallons
Thermoelectric, oil	200 gallons
Thermoelectric, natural gas	100 gallons
Coal IGCC	100 gallons
Wind	Minimal
Solar PV	Minimal

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy, 2006; World Economic Forum and Cambridge Energy Research Associates, 2009; and http://www.consumerenergycenter.org/home/heating_cooling/window_ac.html accessed on August 15, 2010. See Appendix V, Table 2 for additional information.

On average, coal- and oil-fired power plants consume roughly double the water required by gas-fired plants to produce for the same amount of electricity. Nuclear consumes roughly three times more water than gas-fired plants and 1½ times more than coal- or oil-fired plants.

As the discussion below indicates, water intensity of other electricity generation technologies ranges. Some consume more and others consume less than traditional electricity generation technologies.

Integrated gasification combined cycle (IGCC)

Integrated gasification combined cycle is a process that reduces carbon emissions in coal-fired power plants. It does so at the beginning of the power production process rather than after the carbon reaches the smokestack. It consumes about the same amount of water as a gas-fired plant but only half as much water as a conventional coal-fired plant. IGCC, however, is expensive and has limited availability.

Carbon capture

Although the world hopes to capture massive amounts of carbon dioxide from coal-fired power plants, current carbon capture technologies can consume 30% to 100% more water. This primarily is because contemplated carbon capture technologies reduce plant efficiency. In other words, larger plants (which require larger cooling systems) are required to produce the same amount of energy as a traditional coal-fired plant.

Hydroelectric

Data on hydroelectric consumption are particularly inconsistent, even from different parts of the U.S. government. The National Laboratories estimate that hydroelectric plants consume more than 20 times as much water as gas-fired power plants, more than ten times more than coal- and oil-fired plants, and more than eight times as much as nuclear plants. On the other hand, the U.S. Geological Survey estimates that hydroelectric consumes almost no water. The difference stems from assumptions about water diversion and evaporation rates of human-made reservoirs behind dams, although most data users would not be in a position to dive into the assumptions to determine which are most appropriate.

Large-scale hydroelectric plants around the world have come under fire for a number of reasons, including damage to the environment and marine life, loss of cultural/historical sites, and social disruption. By contrast, there is a growing consensus that "run-of-the-river" hydroelectric plants consume minimal water. They return temporarily diverted water back into the running water source, and do not require reservoirs. At the moment, however, they are too small in scale to supply large amounts of energy.

"Renewable" electricity (wind, solar)

Wind and solar photovoltaic power do not require cooling systems. However, renewable energy is not created equal in terms of water use.

Wind turbines consume minimal amounts of water, primarily when they are cleaned.

Broadly, there are two primary categories of solar technologies. The first is "photovoltaic" – commonly known as solar panels. PV converts solar energy directly into electricity. Like wind, solar PV consumes minimal water during the cleaning process.

The other major solar technology is called concentrating solar, commonly known as solar thermal. Though there are variants, basically the technology concentrates solar rays similar to the way a concave mirror focuses rays that can burn a hole in a sheet of paper. Today's generation of technology and cleaning frequency assumptions result in approximately five times more water consumption than a gas-fired power plant, twice as much water as coal-fired power, and 1½ times as much as a nuclear plant. There are efforts in many parts of the solar thermal system, ranging from mirrors to fluids to thermal storage, to reduce this need for water. In addition, dry cooling is a near-term option that will require further evaluation.

CONCLUSION AND RECOMMENDATIONS

Nations are beginning to evaluate their energy options and to develop policies that apply appropriate financial carrots and sticks to various technologies to encourage responsible, sustainable energy production. Water is an increasingly scarce resource. As our energy demands grow, conflict over water will increase. Competition for water among municipalities, farmers, industrial and power suppliers is already evident in a range of locations, notably in the West and Southwest United States. In some cases around the globe, outright conflict—protests, riots, and other violence– has erupted over water: in China, Yemen, Pakistan, Somalia, and Ethiopia, to name just a few.[7]

Energy technologies, no matter whether they are conventional or alternative, must be sited in light of local water availability and mindful of the consequences of declining water tables. On-shore natural gas production may be less of an issue in rural areas but extremely challenging in New York City's watershed. Water-hungry technologies might make sense where water is abundant, but concerns about building solar thermal plants in arid American Southwestern deserts deserve further probing. First-generation irrigated biofuels pose difficult questions. Newer technologies are being developed to reduce water consumption; however, they are expensive, can reduce efficiency, and will need time before they can be commercially available at scale.

There are no easy answers to any of these challenges. There is, however, an increasing consensus that nations will have to develop a diverse portfolio of traditional and alternative energy technologies.

WPI and EBG suggest a broad analytic framework to evaluate the water energy relationship and policies to balance competing needs and identify policy options that address various trade-offs:

1. Update and improve the quality of the data underlying analysis of water consumption in energy production. The most recent US Geological Survey on water consumption, for example, was published in 1998. Some examples of improvements to the data include adding the full range of emerging technologies to the analysis of existing technologies; updating and filling in holes in data on hydraulic fracturing and Canadian oil sands; and incorporating data about aggregate water consumption according to type of energy technology and industry sector.

2. Carry out complementary analyses of water withdrawal and quality by energy type, including breakdowns by technology including aggregate data and details by industry sector.

3. Identify possible portfolios of traditional and alternative energy sources designed to meet projected future water needs for an array of water scarcity hot spots.

4. Create a cost analysis of water efficient technologies. Attempt to quantify or monetize their impact on water, business, and elsewhere. Recognize and identify the impediments these can pose.

5. Identify technologies that both maximize water efficiency and minimize carbon dioxide emissions.

6. Assess the impact of energy choices on water availability for agriculture and forests.

7. Analyze how the state of the existing power grid in a given area affects cost implications of water-efficient energy choices—i.e., the capacity to get clean, water-efficient energy to users.

8. Analyze how well existing governance mechanisms support the process needed to develop water-efficient, cost-effective, and carbon minimizing policies, and how to harmonize regulatory bodies at the local, national, regional, and global levels (for example, the UN General Assembly Law of Transboundary Aquifers, the Water Cooperation Committee of the Gulf Cooperation Council, and so on).

9. Focus these analyses on water-scarce border regions where water and energy decisions affect stakeholders of different nationalities or jurisdictions.

Now—as new energy policies are emerging– is the time to consider water. Energy decisions are a series of complex tradeoff decisions between water, national security, cost, and carbon. Another concern is development and functional operation of the electric grid. Furthermore, energy is inextricably linked with agriculture (biofuels consume more than one third of the US corn crop) and forests (increased demand for energy crops may drive conversion of forests into agricultural land). When forests are removed, many important functions are lost. For example, at the level of the local ecosystem, forests mitigate floods and droughts, while acting as natural water filters. As a result, policy makers and leaders across all sectors of society also must consider national security, cost, and carbon consequences of energy's impact on agriculture and forests.

All of these decisions must be evaluated as well for their implications on business (opportunities, supply chain costs/inefficiencies, and risks), security (food, military, and energy), and the environment (agriculture, forest, climate). These are made more complicated by issues of justice (ownership, pricing, and equity) and sustainable development (poverty, sanitation, health, and gender).

Societies must find an appropriate balance among trade-offs, on both the national and local levels, taking into consideration both water availability and energy needs. The additional research we propose will help to provide the objective, high quality information necessary to these decisions. ●

APPENDIX I — METHODOLOGY

This report was compiled based on the conviction that information can lead to changes in opinion and to the creation of new alliances that can break the gridlock over energy policy. WPI and EBG seek to encourage improvements in data collection methodologies that can elevate the level of awareness and discussion regarding water and energy – and its broad implications, which cut across business, security, and environment.

This analysis is intended to provide a baseline of the most credible currently available data and to encourage additional work and collaboration to improve overall data quality regarding energy and water. Based on existing research on current energy technologies, it depicts this information using a framework that normalizes different energy technologies around a common unit to help identify data holes and questions that deserve further evaluation. Numerous technology developments that are underway or contemplated may result in different data on water consumption which can be compared to the baseline established here.

We have assembled and simplified extremely technical, fragmented, stove-piped and frequently politically biased information. Omissions such as water quality, early stage technologies, the state of the grid, or land use, are made for the sake of clarity. We do not, however, wish to suggest they are unimportant.

Our data sources are available in Appendix VI below. Our primary data source is a report jointly produced by 12 US National Laboratories based on 2006 data and and presented to Congress in 2008. It is widely cited, relatively comprehensive, and appears to be impartial. Weaknesses include omissions of several important emerging energy technologies that postdate its creation, and the general need for some updating.

Process:

1. WPI and EBG assembled existing research from wide range of sources. The data are frequently incomplete, fragmented, inconsistent and/or dated. Some data are biased by political persuasion.

2. WPI and EBG attempted to determine the most credible source(s) available. We identified a report prepared by 12 of the National Labs and submitted to Congress, "Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water," ("Congressional Report") as relatively independent, and credible. Subsequent research, including a 2010 Harvard Belfer Center paper published as this paper was in editing stages, cites the report. However, the Congressional Report is unclear about and/or omits some

energy technologies such as oil sands extracted via the SAGD method, enhanced oil recovery and in particular the carbon dioxide method of enhanced oil recovery, carbon sequestration, and various carbon capture technologies**.** Additionally, some of the underlying data needs updating. For example, the Congressional Report was created just as hydraulic fracturing began its explosive growth trajectory. Hydraulic fracturing data quality in general needs improvement. The Belfer Center paper is based on similar underlying data and complements the analysis carried out in this paper, but targets an audience more familiar with both the findings of the Congressional Report and comfortable with energy jargon. We are pleased to see their interest in this subject and we hope to encourage collaboration and further research.

10. WPI and EBG used other sources to fill in as many as possible of the data holes in the Congressional Report. Those sources are identified in our bibliography and in chart and graph source legends.

11. WPI and EBG have attempted to identify data weaknesses and holes to provide guidance to efforts to enhance data robustness and increase awareness of the water-energy relationship.

12. Our approach is intended to help to identify key further questions. It does not attempt to answer those questions, but rather seeks to encourage collaborative efforts to address them.

Key assumptions:

1. WPI and EBG focused on water consumption per unit of energy. Water withdrawal and water quality/pollution are extremely important, but outside the scope of this paper.

2. For the purposes of analytical clarity, WPI and EBG separated transportation fuels from electric power production technologies.

3. WPI and EBG identified common metrics to compare a range of technologies: gallons of water consumed per million BTUs in the case of transportation fuels, and gallons of water consumed per MWh in the case of electricity generation technologies.

4. As possible, WPI and EBG identified water consumed in the production of energy in its raw state, and the water consumed by transforming it into a useful product.

5. All data are straight averages of ranges that can sometimes be wide. This analytic tradeoff was made in the interest of clarity. Data to determine weighted averages were not available to WPI and EBG.

APPENDIX II

The WPI-EBG Capital Transportation Chart: Making Sense of Energy Jargon

Gallons of water consumed to produce the energy required to drive from New York City to Washington, D.C.
(1 million BTUs = approximately 8 gallons at 25 mpg)

Transportation Fuel	Gallons consumed/round trip drive NYC to DC (2 million BTUs)
Oil (traditional)	28
Natural gas (as onland)	5
Unconventional natural gas (shale)	30
Oil sand	546
Oil (enhanced oil recovery)	2,858
Biofuel (irrigated corn)	31,518
Biofuel (irrigated soy)	89,015

* Transportation fuel data caveats:

* Biofuels exclude NON-irrigated first generation (i.e., the majority of soy and corn) and second and third generation including cellulosic, agricultural waste, camelina, jatropha, algae, etc.

* SAGD constitutes a large part of future oil sands growth

* Unconventional natural gas data were captured largely before the boom in hydraulic fracturing

* Conventional oil data exclude water flooding and EOR techniques such as C02 injection, etc.

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009. See Table 1 for additional information.

APPENDIX III

The World Policy Institute-EBG Air Conditioner Chart: Making Sense of Energy Jargon

Gallons of water consumed by 18,000 BTU air conditioner operating 12 hours/day for one week.

Electricity	Gallons consumed/air conditioner
Natural gas (thermoelectric)	96
Oil (thermoelectric)	189
Coal (thermoelectric)	189
Nuclear (pond and tower)	248
Wind	minimal
Solar -- photovoltaic	minimal
Solar -- thermal	370
Geothermal	620
Hydroelectric	Minimal to 1,994
with IGCC w/CC:	222

Electricity generation data caveat: Solar Thermal refers to installed base only

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009. Appendix V, See Table 2 for additional information.

APPENDIX IV

The Water-Energy Nexus: Key Glossary Terms

Barrel (see Box 1)

A barrel of oil contains 42 gallons of petroleum, or approximately 159 liters. During the refining process, the 42 gallons of oil are separated into approximately 18.5 gallons of gasoline, 10 gallons of diesel, 4 gallons of jet fuel, and 9.5 gallons of other products.

The average automotive gas tank holds on average approximately 16 gallons, or just less than the gasoline produced by a barrel of petroleum. Assuming 25 miles/gallon, a car can travel approximately 450 miles on a full tank, which is just under the rough distance from NYC to Washington, D.C., roundtrip. In other words, one barrel of oil gets an average car back and forth from NYC to DC.

Graphs 1 and 2 depict water consumed by different transportation fuels to produce 1 million BTUs, which is roughly the amount of energy in half a tank of gas, or the energy required to travel roughly 200 miles, or roughly the distance between New York City and Washington, D.C., or Sao Paulo to Rio de Janeiro, or Rome to Bologna.
(see "British thermal unit")

Biofuels (see Boxes 1 and 2)

Broadly, "biofuel" refers to any fuel derived from organic matter that can replace transportation fuels such as gasoline, diesel or jet fuel. A range of oils (e.g., soy, palm oil, canola/rapeseed, camelina, jatropha, etc.) and sugars/starches (e.g., corn, cane sugar, etc.) can be transformed into biofuels.

Municipal solid waste consists of a range of inputs, and alternative fuels derived from it are often also referred to as biofuels.

In general, the biofuel discussion primarily involves irrigated "first-generation" soy-, corn-, rapeseed (canola), and palm oil-based biofuels, which are available today in large quantities.

Intensive effort is underway to develop "second" and "third" generation" algae- and cellulosic-based biofuels that do not compete with food, and reduce land-use impact. Alternative biofuels sources are also in development and address water, such as residues, perennial grasses, no/low irrigation crops, etc. In addition, overall sustainability criteria for biofuels are under development.

British Thermal Unit or BTU (see Box 1)

A unit of heat equal to the amount of heat required to raise one pound of water one degree Fahrenheit at sea level (one atmosphere pressure), used widely in the power, steam generation, heating, and air conditioning industries. One BTU is equivalent to the amount of energy released by a blue tipped match stick. An air conditioner consumes 6,000 BTU/hour to cool a 200 square foot bedroom.

An average automotive gas tank, which holds approximate 16 gallons of gasoline, contains roughly 2 million BTUs. Graphs 1 and 2 depict the water consumed to produce 1 million BTUs, or the amount of energy in half a tank, or the energy required to travel 200 miles, or approximately the distance between New York City to Washington, D.C.; Sao Paulo to Rio de Janeiro; or Rome to Bologna.
(see "barrel")

Carbon capture

A series of technologies designed to "capture" some of the carbon emissions from coal-fired power plants. These technologies are generally not available at widespread commercial scale.

Carbon sequestration

Carbon sequestration refers to a series of technologies designed to "sequester" (store or consume) captured carbon. Some technologies involve pumping the carbon into depleted oil and gas wells or unused coal fields, reacting the carbon with other substances to make the carbon inert, putting it into saline aquifers, consuming the carbon as part of the oil recovery process, etc.
(See "enhanced oil recovery")

Coal liquefaction

The process of converting coal into liquid transportation fuels that can power cars and airplanes. In coal liquefaction, synthetic (as opposed to petroleum-based) transportation fuels are produced from coal.

Cooling

The process of cooling steam produced by thermoelectric power plants consumes enormous amounts of water. This is why low water levels, for example during hot summers or periods of drought, may require reduction in electricity production when it tends to be most needed. It can also lead to competition for limited water resources, e.g., from municipalities, farmers, fishermen, miners, industrial users, etc.

Cooling in energy plants is a science unto itself with complex terminologies, including open loop, closed loop, wet cooling, dry cooling, pond, tower, etc. The following bird's eye view is for the layperson.

There are different types of cooling. The first distinction is between wet versus dry cooling systems. Wet cooling involves pumping hot water through cold water, which causes water loss through evaporation. Dry cooling involves heat transfer to an intermediate surface rather than evaporation.

Wet (as opposed to dry) systems comprise the vast majority of cooling systems. Relatively few dry cooling systems have been built, and they are small in scale. This is because dry cooling is both more expensive and reduces a power plant's efficiency.

The remainder of this discussion focuses on wet cooling because dry cooling comprises only a minimal amount of cooling systems -- less than 1% of US cooling. Within wet cooling systems, the primary distinction is between open and closed loop systems.

According to the Congressional Report, open loop wet cooling systems withdraw large amounts of water to cool the warm water and then return the heated water to its source, such as a river. Relatively small amounts of water are consumed. However the process of withdrawing massive amounts of water kills marine life. Increased temperature of returned water and potential pollutants can also have negative impacts.

Since the 1970's, closed loop wet cooling processes have been implemented that pump water through a closed loop to a tower or pond from which the water evaporates. Although closed loop wet cooling systems can withdraw 5% of the water withdrawn by open loop cooling systems, most of it is lost to evaporation.

Enhanced oil recovery (EOR, tertiary recovery) and carbon storage

An umbrella term to describe attempts to remove additional oil from a partially depleted reservoir. In general, the first time that oil is extracted about 60-80% remains behind in the reservoir. Enhanced oil recovery techniques can remove some of what is left behind.

EOR has been utilized by the oil and gas sector for decades. In general, oil and gas companies (e.g., Exxon, BP, Shell, Chevron, etc.) subcontract drilling, extraction, and EOR to oil services companies (e.g., Schlumberger, Halliburton, Baker Hughes, etc.)

EOR methods can involve injecting carbon dioxide and/or other gasses, chemicals or microbes into the reservoir and/or heating the reservoir. These methods help the oil flow more easily within the reservoir. As a result, greater amounts of oil can be recovered, in particular from depleted reservoirs.

EOR injection techniques are similar to those needed to "store" carbon dioxide in depleted oil and gas reservoirs. Although these could potentially address a significant amount of captured carbon dioxide, they have not yet been demonstrated at a scale required to sequester massive amounts of carbon dioxide.

Geothermal

Geothermal electricity production generally involves drilling a well into heat source within the earth, and then using water to generate stream that can power turbines.

Hydraulic fracturing (fracking, fracing)

Hydraulic fracturing is a technique that pumps liquids under high pressure to fracture rocks that could not previously release their natural gas; and, increasingly, rock formations that contain petroleum; at an acceptable economic cost. North America is richly endowed with shale and other rock formations that could potentially release their natural gas via hydraulic fracturing. The press and public have become familiar with the Barnett Shale underneath Dallas/Ft. Worth and the Marcellus Shale underneath western Pennsylvania and New York. There are enormous shale formations around the world, including in Europe, China, Australia, and Latin America. Formations outside North America are currently at the earliest stages of commercial development but will undoubtedly stimulate water discussions over time.

Natural gas produced via hydraulic fracturing is called "unconventional" although it is the same as traditional natural gas. It can be processed into a transportation fuel or burned in gas-fired electric power plants. Due to improvements in hydraulic fracturing and other techniques such as "horizontal" drilling, the United States has reversed its longstanding trend of declining natural gas production. Massive domestic production of low-cost unconventional natural gas in the last five years is the most important North America energy development in decades. Enormous production increases have led to plentiful supplies of low-cost, domestically produced energy that enhances national security, creates jobs and reduces carbon emissions relative to oil. The same techniques are beginning to be applied to North American oil production.

However concerns about the impact of hydraulic fracturing on water could impact its future. There is vigorous debate between proponents and opponents of hydraulic fracturing for unconventional natural gas regarding its impact on water quality, including from chemicals used in the hydraulic fracturing process and "produced" water (the water that comes up from the reservoir along with the natural gas – produced water is oftentimes salty and can contain compounds not found in water found close to or at the surface of the earth; oil extraction also results in produced water). A prominent example of the debate surrounds drilling for unconventional natural gas in the Marcellus Shale, which provides New York City's drinking water. Water availability could potentially act as a constraint on hydraulic fracturing.

Integrated Gasification Combined Cycle (IGCC)

IGCC is a process that reduces carbon emissions in coal-fired power plants. It does so at the beginning of the power production process rather than after the carbon reaches the smokestack. The process converts coal into a gas, and removes impurities, before the gaseous coal is combusted. The gas or steam is then used to drive turbines. IGCC is thought to be an improvement upon conventional pulverized coal as it reduces sulfur-based and mercury emissions, as well as carbon emissions.

Oil Sands (Also known as tar sands, bituminous sands, heavy oil, and unconventional oil)

Oil sands are a mixture of clay, sand, water and bitumen. Bitumen is a black, thick, oily material that is composed of hydrogen and carbon chains. In Canada, petroleum is extracted from oil sands using two primary methods. In the first method, oil sands are mined at the surface, then subsequently separated and "upgraded" into a "synthetic" crude oil that can feed into refineries. For oil sands that are too deep to be mined, a technique called Steam Assisted Gravity Drainage (SAGD) is used. In this method, natural gas is burned to generate steam which is pumped into a well. The heat makes it easier for the oily matter surrounding the well to flow into a parallel well nearby. Once the bitumen reaches the surface, it too needs to be upgraded in the same way that mined sand is upgraded. Significant amounts of carbon dioxide are generated during the upgrading process. Additional carbon dioxide is released when natural gas is burned in the SAGD process.

Run of the River

Run of the river produces hydroelectricity. While following the natural downhill flow of the river, some of the water is diverted through a pipe (penstock) which directs the water, again downhill, into the power stations. In the power station, the water is fed through turbines. The water at the top of the hill has potential energy which is converted to kinetic energy when it passes through the pipe since flow through the pipe occurs at high velocity. The high velocity water is able to turn the turbines in the power plant which converts the kinetic energy into electrical energy. The diverted water, then, returns to the stream below the power station.

Solar Photovoltaic (PV)

A photovoltaic cell is a type of solar cell that receives sunlight and converts it directly into electricity.

Solar Thermal

Solar thermal can also be known as concentrated solar. It uses heat from the sun to heat up water (or other fluids) to vapor which then drives a turbine to generate electricity. Much of the water is lost as steam and large amounts of water are required for cooling.

Thermoelectric

Refers to heat converted to electricity, generally by using a heat source such as coal, oil or natural gas that is burned to produce steam. The steam then turns turbines which generate electricity.

Water consumption

The complete removal of water from some type of source, whether on the surface or below the ground. Examples include evaporation from irrigation or cooling systems, consumption in chemical reactions and/or industrial processes, incorporation into crops and animals, human drinking or bathing water, etc. "Consumed water" is water presumed to be lost. It could be transported elsewhere. If the source is replenished, it could potentially take many years – decades, centuries, or longer.

Water quality

An umbrella term that can refer to pollutants that enter the water; changes to oxygen content, salinity, and acidity; temperature changes; destruction of organisms that live in the water; etc.

Water withdrawal

Gross quantity of water extracted or removed, and after some time, returned to its original source. Returned water may not be in the same state or quality as when it was withdrawn, e.g., it may be warmer and/or have different saline and/or other chemical properties. Furthermore, withdrawals of large amounts of water may kill fish and other organisms.

Watt-hour (Wh)

A Watt-hour (Wh) is a measure of power over time. Power is a measure of energy over a square meter surface. A Wh is a unit of energy equal to the power of one watt operating for one hour. A Watt is a standard unit of power that specifies the rate electrical energy is dispersed. A standard incandescent light bulb consumes 100 watts per hour. Electric utilities generally charge consumers in units of 1000 watts (ten 100 watt light bulbs) per hour, or kilowatt hours. Power plants generally express their production in terms of megawatts (one million watts). Future power consumption estimates are generally expressed in terms of gigawatts (one billion watts).

APPENDIX V

Framework for Evaluating Water Consumption of Transportation Fuels, Normalized to gallons/million BTU

Table 1. Average Water Consumption by Transportation Fuel

	Water Consumed (gal/Million BTUs)												
	Raw Materials				Transformation				Total				Data Source
	Min	Max	Avg	Diff	Min	Max	Avg	Diff	Min	Max	Avg	Diff	
Oi, (traditional)	0.8	2	1.4	0.6	7	18	12.5	5.5	7.8	20	13.9	6.1	CERA 18
Natural gas (as on land)	0	0	0	0	2	2	2	0	2	2	2	0	CERA 18
Unconventonal Natural Gas (Shale)	10	15	12.5	2.5	2	2	2	0	12	17	14.5	2.5	CERA 18
Oil sands	20	500	260	240	7	18	12.5	5.5	27	518			CERA 18
Oil sands, SAGD* (no data)													
Enhanced oil recovery	14	2500	1257	1243	172	172	172	0	186	2672		1243	Gleick 1994, as cited in Congress 2006:57
Biofuels (irrigated corn)	2500	29000	15750	13250	4	14	9	5					CERA 18
Biofuels (irrigated soy)	14000	75000	44500	30500	4	14	9	5					CERA 18

* Transportation fuel data caveats:

- * Biofuels exclude NON-irrigated first generation (i.e., the majority of soy and corn) and second and third generation including cellulosic, agricultural waste, camelina, jatropha, algae, etc.
- * SAGD constitutes a large part of future oil sands growth
- * Unconventional natural gas data were captured largely before the boom in hydraulic fracturing
- * Conventional oil data exclude water flooding and EOR techniques such as C02 injection, etc.

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009.

Table 2. Average Water Consumption by Electricity Generating Technology, Normalized to gallons/per MWh

	Water Consumed (gal/MWh)												
	Raw Materials				Transformation				Total				Source
	Min	Max	Avg	Diff	Min	Max	Avg	Diff	Min	Max	Avg	Diff	
Nuclear (pond & tower)*					400	720	560	160	400	720	560	160	US DOE 2006:65
Coal (thermoelectric)	5	70	37.5	33	300	480	390	90	305	550	427.5	123	US DOE 2006:65
Oil (thermoelectric)	5	70	37.5	33	300	480	390	90	305	550	427.5	123	US DOE 2006:65
Natural gas (thermoelectric)	5	70	37.5	33	180	180	180	0	185	250	217.5	33	US DOE 2006:65
Geothermal	0	0	0	0	1400	1400	1400	0	1400	1400	1400	0	US DOE 2006:65
Hydroelectric (1)	0	0	0	0	0	0	0	0	0	0	0	0	US DOE 2006:20
Hydroelectric (2)	0	0	0	0	4500	4500	4500	0	4500	4500	4500	0	US DOE 2006:38
Run of the river					0	0	0	0	0	0	0	0	US DOE 2006:41
Solar thermal	0	0	0	0	750	920	835	85	750	920	835	85	US DOE 2006:38
Photovoltaic solar	0	0	0	0	0	0	0	0	0	0	0	0	CERA 21
Wind	0	0	0	0	0	0	0	0	0	0	0	0	CERA 21
Coal IGCC**					200	200	200	0	200	200	200	0	US DOE 2006:38

(1), (2) The U.S. Geological Survey, based on how they define water withdrawn and consumed, suggests that hydroelectric is zero, whereas US Department of Energy 2006 which includes different assumptions, suggests it is much greater.

*Closed loop, wet, tower and pond cooling since most common
**IGCC: Integrated Gasification Combined Cycle

Electricity generation data caveat: Solar Thermal refers to installed base only

Source: World Policy Institute-EBG Capital analysis based on U.S. Department of Energy 2006, and World Economic Forum and Cambridge Energy Research Associates 2009.

APPENDIX VI

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