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ABSTRACT

The global nexus between energy and water introduces cross-sectoral vulnerabilities whereby water problems can become energy problems and vice versa. This creates cross-cutting opportunities where solutions for one sector might also be good for the other. However, the tradeoffs between prospective technical and policy solutions are not obvious. To address that challenge, this article presents a novel framework for analyzing coherence in technologies and policies at the energy-water nexus. Challenges are laid out, examples of mixes of technology and policies that can meet political objectives relevant to the energy-water nexus are given, gaps that inhibit future policy development are identified, and key findings are discussed. The analysis is presented through data specific to the United States along with a few case studies from other countries for illustration, but the framework is relevant to policymakers and decision makers globally. The article covers technical and environmental issues linking water and energy in electricity generation, liquid fuels production, and freshwater and wastewater treatment. It also explores the tradeoffs between specific technologies and policies relevant to the energy-water nexus. Some policies and technologies present solutions that achieve water and energy security, while others do not. Institutional reforms that could help water and energy policy to be more coherent, robust, and sustainable in the future are identified, and case studies from different countries are included to broaden the discussion. Finally, the article concludes by discussing emerging issues and information gaps in the energy-water nexus.

I. INTRODUCTION

The nexus between water and energy is important and pervasive. At the same time, constraints on energy and water resources are forcing difficult policy choices. Humans are depleting fossil energy resources

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while consuming or degrading water supplies faster than alternatives are being developed. Some renewable energy and water resources do not deplete over time, but have limited flow rates that either temporally or geographically restrict their use. As countries confront water resource constraints, their arsenal of policy options has typically included energy-intensive solutions such as long-haul transfer and desalination. The corollary is also true: historically countries address energy constraints with water-intensive options such as steam-cycle power plants or biofuels. When water planners assume they have all the energy they need and energy planners assume they have all the water they need, unsustainable resource management is possible. In order to optimize the consumption, conversion, transfer, and use of precious water and energy resources, governments would benefit from implementing policies that enable coherent management between these two commodities. By contrast, countries that deploy incoherent policies might find themselves with severe scarcity of one resource, or both. While significant challenges remain, recent attention to the problem is an optimistic sign that progress will be made towards integrated energy and water policymaking.

Water is a critical aspect of meeting future energy demands. Estimates of global peak production of conventional oil vary from as recently as sometime in the last decade to a few decades in the future, and almost every liquid fuel alternative to crude oil withdraws and consumes more water while often exacerbating challenges to water quality. For example, biofuel production converts native and existing pasture and agricultural lands for feedstock agriculture. This change in land use creates political and social pressures to avoid impacting wildlife and food for fuel. In a conceptual sense, most agricultural land in pre-industrial agriculture was to provide energy resources—the food and fodder that fed the people and animals performing physical work on the farm. Modern liquid biofuels production is thus reversing the 200-year trend of fossil fuels liberating us from using land as the main investment for capturing and storing energy. Countries that promote biofuel production are caught between displacing food crops on productive lands that require little to no irrigation and irrigating less-productive lands. Even biofuel feedstocks watered by natural precipitation impact local environments and climate via water runoff and evapotranspiration (ET) changes that affect local and regional hydrology. A carbon-constrained world also encourages capturing the carbon dioxide from coal and natural gas power plants for underground sequestration. The leading candidate carbon dioxide capturing processes (e.g. using amines) require a heating and cooling cycle that consumes more gross energy from within the power plant, which lowers its net electricity production, thus raising water consumption per net electricity output and overall water consumption per quantity per fuel (e.g. coal) input. Efforts to reduce water consumption at power plants are accompanied by the tradeoff between increased costs and lower power efficiency. New shale gas resources are produced by injecting tens of millions of liters (L) per well of high pressure water underground to fracture low-permeability formations, releasing otherwise inaccessible natural gas. While the volume of water needed at the start of production is significant, the amount of energy extracted from the shale over the lifetime of the well is usually high. Relatively little water is required per cubic meter (m^3) of gas that is ultimately produced; thus, the water quantity issues for shale gas production change with time depending on the productivity and lifespan of the well. Water quality threats from shale gas production are also a risk requiring careful management, so it is essential to properly handle the water during the entire shale gas production cycle to garner acceptability of the process. The different regional geologies of shale resources pose challenges that can be unique to certain basins. Similarly, conventional fossil fuels and biofuels pose risks to water quality. Other fossil fuel alternatives include unconventional petroleum sources such as those from oil shale, tar sands, and heavy oils—all of which have greater impacts on water than conventional petroleum.

In addition to new sources of energy that require more water than today's conventional supplies, new sources of freshwater require more primary energy than today's conventional supplies. Deep well water production, desalination, and long-haul transfer schemes all require energy for treating and conveying potable water. These include steps such as heating the water, removing dangerous microbes, forcing the untreated water through membranes and filters, and then moving water to the point of end use. Growing populations and depleting water supplies are pushing many countries to the boundaries of technologies in order to provide new freshwater supplies, only to find that their constrained water situation exacerbates their energy constraints.

This article lays out some of the challenges, gives examples of mixes of technologies and policies that can meet political objectives relevant to the energy-water nexus, identifies gaps that inhibit future policy development, and discusses key findings. While this article is intended to serve the global community, much of the quantified information and illustrative examples are based on data and policy actions from within the United States, but additional short case studies of other countries exemplify the scope of challenges and solutions to the energy-water nexus. The United States serves as context for a longer case study because 1) its continental breadth includes a range of energy and water issues that suitably capture most of the challenges witnessed worldwide (for example, water abundance varies dramatically from the desert Southwest to the wet Northeast, and energy resources have significant geographic variability); and 2) the energy and water data for the United States are in greater abundance and more accessible than for most other regions and countries in the world. This article is not exhaustive for any country that is discussed; rather each case study is included to illustrate a different aspect of the global energy-water nexus.

Section II discusses the technical and environmental issues linking water and energy in electricity generation, liquid fuels production, freshwater treatment, and wastewater treatment. Section III discusses technologies in the context of their energy-water tradeoffs and introduces policies that impact the energy-water nexus. Some policies and technologies present solutions that achieve policy objectives such as water and energy security, while some do not. Due to technical constraints, it is not possible for all policy actions to fall into a "win-win" category where all policy objectives advance by incorporating a technology or policy. These tradeoffs are noted and discussed. Section III continues with a discussion of some institutional reforms that could help water and energy policy to be more coherent, robust, and sustainable in the future. Section IV presents case studies that discuss existing situations and strategies employed by selected countries that reveal recent significant progress; yet challenges remain. Section V concludes the article by discussing emerging issues and information gaps in the energy-water nexus.

II. LINKS BETWEEN ENERGY, WATER, AND THE ENVIRONMENT

A. Timeline of Energy Water-Nexus Attention Worldwide

Despite the close interaction of energy and water since the dawn of the Industrial Revolution (for example: steam-driven engines, large-scale waterworks and mills, and so forth) and an abundance of literature and scientific research about energy and water separately, until recently there had been relatively little attention about the intersection of these two commodities. Unfortunately, this lack of attention can be problematic because a constraint on one can constrain the other. Thus, there are cross-sectoral vulnerabilities—challenges and risks that overlap both the energy and water sectors—that have not been adequately addressed by most policy institutions.

One of the first systematic and rigorous examinations of the relationship between water and energy came in 1978.[1] That article was followed by some thought-leading work on the topic by Dr. Peter Gleick in

1. John Harte & Mohamed El-Gasseir, *Energy and Water*, SCIENCE, Feb. 10, 1978, at 623.

the early 1990s.[2] Starting with the publication of "*Energy Down the Drain*" in 2004, the pace and intensity of scientific analysis and policy attention quickened dramatically.[3] This joint publication by the National Resources Defense Council and the Pacific Institute examined the energy costs embedded in California's water system. Given the strained water resources in the American West, it is not surprising that groundbreaking work originated from that region of the United States.

The energy-water nexus continued to grow as a topic of central concern. In 2005, the California Energy Commission (CEC) issued a series of studies on the topic of integrated energy and water policy.[4] The U.S. Department of Energy (DOE) wrote a widely-cited energy-water nexus report to Congress and created a website as a centralized location for information.[5]

Since that time, the topic has become popular worldwide. More scientific, scholarly and popular articles have been published, popularizing the topic all over the world. Outlets included traditional scientific journals, popular outlets such as *Scientific American* and *Earth Magazine*, and leading newspapers such as *New York Times* and *Daily Telegraph*. Books with dramatic titles like *Peak Water*, *Unquenchable*, and *When the Rivers Run Dry* brought attention to the topic and conveyed a tone of seriousness and crisis. Conferences, symposia, and workshops dedicated to this topic have also been organized by international scientific organizations such as the American Association for the Advancement of Science, American Society of Mechanical Engineers, Groundwater Protection Council, and European Cooperation in Science and Technology (COST).

The U.S. Government Accountability Office (GAO), DOE, and National Academies have produced reports for legislative and executive audiences outlining the major issues of the water-energy nexus.[6] The fo-

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2. Peter H. Gleick, *Water and Energy*, ANN. REV. OF ENERGY & THE ENV'T, Nov. 1984, at 267.

3. RONNIE COHEN ET. AL., ENERGY DOWN THE DRAIN: THE HIDDEN COSTS OF CALIFORNIA'S WATER SUPPLY (Emily Cousins, ed., Natural Resources Defense Council 2004), *available at* http://www.nrdc.org/water/conservation/edrain/edrain.pdf.

4. *See, e.g.*, GARY KLEIN ET AL., CALIFORNIA ENERGY COMMISSION, REPORT CEC-700-2005-011-SF, CALIFORNIA'S WATER-ENERGY RELATIONSHIP (2005).

5. U.S. DEP'T OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES: REPORT TO CONGRESS ON THE INTERDEPENDENCY OF ENERGY AND WATER (2006), *available at* http://www.sandia.gov/energy-water/congress_report.htm.

6. *See, e.g.*, *id.*; U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-10-116, ENERGY-WATER NEXUS: MANY UNCERTAINTIES REMAIN ABOUT NATIONAL AND REGIONAL EFFECTS OF INCREASED BIOFUEL PRODUCTION ON WATER RESOURCES (2009), *available at* http://www.gao.gov/assets/300/299103.pdf [hereinafter U.S. GOV'T ACCOUNTABILITY OFFICE, MANY UNCERTAINTIES]; U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-09-862T, ENERGY AND WATER: PRELIMI-

cus on the energy-water nexus over the last several years has culminated with the inclusion of relevant language in energy and climate bills in the U.S. Congress and calls for further study of the energy-water nexus, including research into water use for energy and energy consumption for brackish groundwater desalination.[7] For example, the American Clean Energy Leadership Act of 2009 called for studies and assessments on integration within the energy-water nexus.[8] In addition, the American Clean Energy and Security Act of 2009 (ACES) called for changes to the energy mix with implications for water use.[9] More recent bills include the Energy and Water Research Integration Act of 2012 (HR5827), introduced to the House Committee on Science, Space and Technology by Representative Eddie Johnson from the Texas 30th District[10] and the Energy and Water Integration Act of 2011 (S. 1343) introduced to the Senate Committee on Energy and Natural Resources by Senator Jeff Bingaman, from New Mexico.[11] Consequently, despite a dearth of concrete action in terms of bills passed into law, the legislative attention to energy-water issues with an eye towards coherent integration is increasing in the United States.

COST, funded via the European Science Foundation through a European Commission contract, worked through the Australian National University (ANU) in 2009-2010 to provide a global context for policy decisions within the water-energy nexus. Case studies highlighting these issues from around the world have been put into policy context and organized for journal publication.[12]

Researchers within the U.S. National Laboratories, and the authors of this article, are investigating the planning of electrical transmis-

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NARY OBSERVATIONS ON THE LINKS BETWEEN WATER AND BIOFUELS AND ELECTRICITY PRODUCTION (2009), *available at* http://www.gao.gov/assets/130/122965.pdf [hereinafter U.S. GOV'T ACCOUNTABILITY OFFICE, PRELIMINARY OBSERVATIONS]; JERALD L. SCHNOOR, ET AL., NAT'L RESEARCH COUNCIL, WATER IMPLICATIONS OF BIOFUELS PRODUCTION IN THE UNITED STATES (NAT'L ACADEMIES PRESS 2008).

7. *See, e.g.*, Robert H. Abrams & Noah D. Hall, *Framing Water Policy in a Carbon Affected and Carbon Constrained Environment*, 50 NAT. RESOURCES J. 3 (2010); U.S. GOV'T ACCOUNTING OFFICE, ENERGY-WATER NEXUS: IMPROVEMENTS TO FEDERAL WATER USE DATA WOULD INCREASE UNDERSTANDING OF TRENDS IN POWER PLANT WATER USE (2009); U.S. GOV'T ACCOUNTABILITY OFFICE, MANY UNCERTAINTIES, *supra* note 6; U.S. GOV'T ACCOUNTABILITY OFFICE, PRELIMINARY OBSERVATIONS, *supra* note 6; I. El Saliby et al. *Desalination Plants in Australia, Review and Facts*, 247 DESALINATION 1 (2009).

8. American Clean Energy Leadership Act of 2009, S. 1462, 111th Cong. § 141 (2009).

9. American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (2009).

10. Energy and Water Research Integration Act of 2012, H.R. 5827, 112th Cong. (2012).

11. Energy and Water Integration Act of 2011, S. 1343, 112th Cong. (2011).

12. Karen Hussey & Jamie Pittock, *The Energy-Water Nexus: Managing the Links Between Energy and Water for a Sustainable Future*, 17 ECOLOGY & SOC'Y 31 (2012).

sion lines in the western United States that can connect renewable solar and wind resources. Brazil's Bioethanol Science and Technology Laboratory in Campinas, São Paulo is researching the balances between energy, greenhouse gas (GHG), water quantity, and water quality impacts of expanded sugar cane production. Along with these governmental actions, many non-governmental organizations—including foundations like the Energy Foundation, Cynthia and George Mitchell Foundation, Kresge Foundation, and Johnson Foundation; environmental groups such as the Environmental Defense Fund and Union of Concerned Scientists; and multi-national institutions such as the United Nations and the Organization for Economic Co-operation and Development (OECD)[13] —are paying attention to and contributing information to the topic.

B. The Impact on Water Resources from Electricity Production

Thermoelectric generation requires water to mine, process, and convert primary fuels into electricity. These operations impact and depend upon local water resources. Furthermore, for thermoelectric power plants to operate reliably, they usually require consistent and sufficient access to a significant amount of water for cooling. If access to water becomes severely constrained due to drought or allocations to other water users, then power generation can be curtailed. In addition, heat waves inhibit the ability for thermoelectric power plants to get the cooling they need. This high water temperature situation can force power plants to draw down on their power output. Thus, an environmental restriction on the water supply can directly restrict the electricity supply. Unfortunately, droughts and heat waves often occur at the hottest times of the year when electricity for air-conditioning is at the highest demand. Population growth and economic growth further exacerbate these tensions by increasing demand for consumption of water and energy resources.

The increasing demands and environmental protections upon finite flows of accessible freshwater have induced technological changes in power plant cooling. U.S. thermoelectric power plants constructed before 1960 almost exclusively used open-loop cooling designs that withdraw water at high flow rates and return the heated water back to the environment. When these power plants were built, water was perceived as abundant, and environmental regulations were practically nonexistent. During the 1960s and 1970s, environmental concerns about water in-

13. OECD is an organization of 34 member countries aimed at promoting policies that increase economic, social, and environmental well-being. *About the OCED*, ORG. ECON. CO-OPERATION & DEV., http://www.oecd.org/about/ (last visited Nov. 16, 2012).

creased. These concerns led to increased regulatory pressure on some water users' claims to large rivers and reservoirs. New power plants incorporated new designs to withdraw less water, leading to the widespread implementation of cooling towers. The closed-loop design of these cooling towers serves many environmental interests by reducing the entrainment[14] and impingement[15] of aquatic wildlife.[16] They also prevent the artificial heating of aquatic environments.[17] While cooling towers withdraw less water than open-loop cooling systems, they consume more water (up to twice as much consumption).[18] As human population and energy demands continue to grow, the power industry might implement even less water-intensive cooling designs, such as dry-cooled systems, that withdraw and consume less than 10 percent of the water of wet-cooled systems. However, dry cooling systems have higher capital costs, and reduce overall efficiency of the plant, which increases costs and flue gas emissions per unit of electricity generated.

1. Water Demand for Thermoelectric Power Plant Cooling

In the United States, the thermoelectric power sector accounts for 49 percent of all water withdrawal and 41 percent of freshwater withdrawals,[19] more than any other sector. However, this sector accounts only for 3 percent of freshwater consumption. Other industrialized countries have similar proportions of water withdrawal and consumption for thermoelectric power generation, and these proportions relate to the physical process of the steam cycle.[20] Typically, thermoelectric power plants generate electricity by burning or reacting fuel to provide heat to a

14. When fish and aquatic organisms are withdrawn from the environment into the power plant facility.

15. When fish and aquatic organisms are pinned against water intake screens.

16. *Clean Water Act Section 316(b) Existing Facilities Proposed Rule Qs and As*, U.S. ENVIRONMENTAL PROTECTION AGENCY (Mar. 28, 2011), http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/upload/qa_proposed.pdf.

17. *See infra* section II.B.1 for more details about power plant cooling.

18. This article uses the terms water *withdrawal* and water *consumption* to describe water use. However, this terminology is not consistently used across countries. Here, water withdrawal refers to the volume of water removed from a water source; this water is not lost, but it cannot be allocated to other users before discharge. Consumption, on the other hand, refers to the volume of water lost via evaporation, transportation, or any other means by which water is not returned to its native source in liquid form. Since consumption is a subset of withdrawal, it is less than or equal to withdrawal, by definition.

19. JOAN F. KENNY ET AL., U.S. GEOLOGICAL SURVEY, CIRCULAR 1344, ESTIMATED USE OF WATER IN THE UNITED STATES IN 2005 (2009); WAYNE B. SOLLEY ET AL., U.S. GEOLOGICAL SURVEY, CIRCULAR 1200, ESTIMATED USE OF WATER IN THE UNITED STATES IN 1995 (1998).

20. *See* MICHAEL A. MORAN & HOWARD N. SHAPIRO, FUNDAMENTALS OF ENGINEERING THERMODYNAMICS (John Wiley & Sons, 6th ed. 2008).

high-pressure boiler that generates steam from treated freshwater. The superheated steam turns a turbine connected to an electric generator. Water then cools the steam, condensing it into "boiler feed" water so the steam cycle can begin again.

Two broad categories of wet cooling technologies are typical at thermoelectric plants (with important site-specific qualities and impacts): open-loop cooling or closed-loop cooling. Open-loop or "once-through" cooling withdraws large volumes of water from a source like a lake, river, or ocean. The water passes through the tubes of a condenser to cool steam discharged from the turbine. The water, warmed from heat transferred from the steam, is discharged back into the original source. Closed-loop or "wet-recirculating" cooling systems reuse 80 percent or more of the water withdrawn, but evaporate more water than open-loop systems.[21] Closed-loop cooling often involves a cooling tower in which water flows over pipes that contain the process steam, thereby removing the heat and condensing the steam. Much of the cooling water evaporates, but the non-evaporated water is collected for use again (i.e. in a closed loop). A man-made cooling reservoir often substitutes for a cooling tower in wet-recirculating systems. In these systems, the power plant waste heat is dissipated by discharging the recirculating cooling water into the cooling reservoir. Here, the heat transfers to the environment via conduction, convection, radiation and latent heat from evaporation.

Forty-three percent of U.S. thermoelectric power plants are large power facilities with generation capacity of over 100 MW. Of these large power plants, 42 percent use wet-recirculating cooling towers (i.e. closed loop) and 15 percent use cooling reservoirs.[22] The remaining 43 percent of these large power plants use once-through cooling. Only 0.9 percent use dry-cooling.[23] Once-through designs are very unlikely for new plant sites in the United States due to ecosystem impacts, regulations, and water availability limitations.[24] In response to potential environmental

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21. U.S. DEP'T OF ENERGY, *supra* note 5. For example, most cooling water that is consumed from recirculating cooling systems is due to evaporation.

22. ERIK SHUSTER, NATIONAL ENERGY TECHNOLOGY LABORATORY, U.S. DEP'T OF ENERGY, DOE/NETL-400/2008/1339, ESTIMATING FRESHWATER NEEDS TO MEET FUTURE THERMOELECTRIC GENERATION REQUIREMENTS 13 (updated 2008).

23. Percentages add to greater than 100 percent due to rounding.

24. *See, e.g.*, Cal. State Lands Comm'n, Proposed Resolution by the California State Lands Commission Regarding Once-Through Cooling in California Power Plants, (proposed Apr. 16, 2006), *available at* http://www.energy.ca.gov/siting/documents/2006-04-13_SLC_PROPOSED_COOLING.PDF; Cassandra Sweet, *California Rules Restrict Power Plants' Marine Water Use*, WALL ST. J., May 5, 2010, http://online.wsj.com/article/SB10001424052748703961104575226041502104432.html; National Pollutant Discharge Elimination System: Amendment of Final Regulations Addressing Cooling Water Intake Structures for New Facilities, 68 Fed. Reg. 36749 (June 19, 2003) (codified at 40 C.F.R. § 125).

impacts upon marine life when using open-loop cooling systems, the California State Lands Commission proposed a moratorium on construction of new power plants with open-loop cooling systems.[25] California is often at the forefront of environmental regulation, but it is unclear if this moratorium will be replicated nationally or globally. This moratorium clashes with an alternative strategy to push power plants to coastal regions where open-loop cooling can use seawater, avoiding the use of continental freshwater sources. Thus, environmental concerns about oceanic wildlife are in direct conflict with environmental concerns about inland freshwater supply.

More water-efficient cooling technologies exist; however, these systems have drawbacks. Power plants with dry-cooling towers consume and withdraw less than 10 percent of the water needs of wet-cooling towers, but have higher associated energy and cost penalties. The increased physical infrastructure necessary to create the larger cooling surfaces in dry-cooling systems increases capital costs. Furthermore, a power plant with dry-cooling can experience a 1 percent loss in efficiency for each 5–10°F increase of the condenser, or reduce power generation by up to 1–3 percent, for every 1°F increase in ambient air temperatures over 100°F.[26] Because they include both closed-loop wet and dry-cooling, hybrid wet-dry cooling systems provide a compromise between wet- and dry-cooling systems. Thus, hybrid wet-dry cooling systems can have low water consumption for much of the year by operating primarily in dry mode, but have the flexibility to operate more efficiently in wet mode during the hottest times of the year. Unfortunately, water resources are typically less available during these peak demand times. Although dry and hybrid cooling systems are proven technologies, low water prices and senior water rights for power generators usually prevent them from being economically-competitive designs. However, in water-constrained regions where water is not available for cooling, dry-cooling is often the only alternative. In such cases, the upfront capital costs and parasitic efficiency loads are more readily justifiable, and newer and more efficient power plant designs using dry cooling can often achieve better than historical energy efficiency.

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25. Cal. State Lands Comm'n, Proposed Resolution by the California State Lands Commission Regarding Once-Through Cooling in California Power Plants, (proposed Apr. 16, 2006), *available at* http://www.energy.ca.gov/siting/documents/2006-04-13_SLC_PROPOSED_COOLING.PDF.

26. U.S. DEP'T OF ENERGY, CONCENTRATING SOLAR POWER COMMERCIAL APPLICATION STUDY: REDUCING WATER CONSUMPTION OF CONCENTRATING SOLAR POWER ELECTRICITY GENERATION, REPORT TO CONGRESS 5 (2010), *available at* http://www.nrel.gov/csp/pdfs/csp_water_study.pdf.

Table 1 provides a range of water requirements for each type of thermoelectric cooling system. Many fuels and resources can supply heat for steam generation including coal, fuel oil, natural gas, fissile material, solar radiation, biomass, combustible waste, and geothermal energy. Thus, there are wide differences in water use due to power plant design, fuel, efficiency, and operating conditions even within specific cooling technologies.[27] Table 2 provides a summary of water consumption by electricity generation technology for wet and dry cooling technologies. The water withdrawal of power plants can vary considerably from below 300 L per megawatt hour (MWh) to over 3,000 L per MWh.

TABLE 1. Water withdrawals and consumption across thermoelectric cooling technologies.[28]

	Withdrawal (L/MWh)		**Consumption (L/MWh)**	
Cooling Technology	Low	High	Low	High
Open-loop cooling	28,000	230,000	380	1,100
Closed-loop cooling tower[29]	870	4,200	680	3,500
Hybrid wet-dry cooling[30]	<380	4,200	190	3,500
Dry cooling	0	0	0	0

TABLE 2. Water consumption for electricity generation by fuel source and generation technology.[31]

Electricity Generation Technology	**Water for Fuel Production** (L/MWh)	**Wet Cooling**[32] (L/MWh)	Dry Cooling[33] (L/MWh)	Water for Non-Cooling Aspects of Power Generation (L/MWh)
Geothermal	0	5,300	0	Not available

27. KELLY TWOMEY & ASHLYNN STILLWELL, ELECTRICITY GENERATION CHALLENGES AND OPPORTUNITIES (2009).
28. *Id.*
29. Range includes NGCC cycle at low end and nuclear at high end.
30. Range includes near full dry operation at low end and near full wet operation at high-end.
31. Range includes near full dry operation at low end and near full wet operation at high-end.
32. Using wet cooling as closed-loop cooling tower or cooling reservoir.
33. Using dry cooling as air-cooled condenser.

Enhanced Geothermal	Not available, potentially significant[34]	5,300	0	Not available
CSP – Solar Trough	0	2,900–3,500	0	300[35]
CSP – Solar Tower	0	2,800	0	340[36]
Nuclear	170–570	1,500–2,700	Unlikely technology choice[37]	110[38]
Coal	19–280	1,100–1,800	0	110[39]
Biomass – Irrigated	Highly variable, depending on geography[40]	1,100–1,800	0	110[41]
Biomass – Non-Irrigated	0[42]	1,100–1,800	0	110[43]
Natural Gas Combined-Cycle	42	760	0	26–38[44]
Coal IGCC[45]	170–570	760	0	530[46]

34. Limited data are available since technology is not available at commercial scale.

35. U.S. Dep't of Energy, *Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation, Report to Congress* 5 (2010), *available at* http://www.nrel.gov/csp/pdfs/csp_water_study.pdf.

36. *Id.*

37. Safety concerns and cost make dry cooling for nuclear power plants an unlikely choice.

38. Source references did not specify whether values are for withdrawal or consumption.

39. Source references did not specify whether values are for withdrawal or consumption.

40. Water consumption for irrigated biomass fuel production was not reported. Reported withdrawal for dedicated energy crops is greater than 130,000 gallons (gal)/MWh, but is highly variable. Dana Larson, ET AL., *California's Energy-Water Nexus: Water Use in Electricity Generation* SOUTHWEST HYDROLOGY , Sept./Oct. 2007.

41. Source references did not specify whether values are for withdrawal or consumption.

42. Non-irrigated biomass is rain-fed; Congressional Research Service did not estimate the water consumed through plant ET.

43. Source references did not specify whether values are for withdrawal or consumption.

44. Source references did not specify whether values are for withdrawal or consumption.

45. Integrated Gasification Combined-Cycle.

46. Source references did not specify whether values are for withdrawal or consumption.

Hydroelectric	0	—	—	0 for no allocation of evaporation; up to 17,000 for full allocation of evaporation[47]
PV	0	—	—	19[48]
Wind	0	—	—	3.8[49]

2. *Water Demand for Hydropower*

Hydropower is a power generation technology that provides important sources of electricity without the use of steam boilers.[50] Hydroelectricity provides the largest share of non-thermoelectric generation worldwide, accounting for over 16 percent of generation.[51] The water use implications of hydroelectric power differ significantly from thermoelectric generation because it does not withdraw or consume water for cooling. Instead, hydroelectric facilities use the force of gravity to pass water through turbines to generate electricity. Although hydropower does not require water for cooling like thermal generation, it is often considered a highly water consumptive technology due to the large volumes of water evaporated from the surface of reservoirs behind dams that house turbines. Because natural river flows lose water to evaporation, only the additional water evaporated from a reservoir due to the increased surface area produced by the existence of the dam in comparison to the free-flowing river is considered in consumption statistics.[52] Increased evaporation from the additional surface area of the reservoirs varies significantly globally based on climatic conditions, but in some cases it is several times larger than the evaporation associated with thermal power plant cooling. However, because reservoirs often have multiple purposes (e.g. recreation, navigation, flood control, water supply) in

47. *See infra* Section II.B.2 a fuller discussion of hydroelectric power.

48. Arnold Leitner *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*. NREL, (2002), http://www.nrel.gov/csp/pdfs/32160.pdf.

49. American Wind Energy Association (AWEA) estimate, based on data obtained by AWEA, available at http://www.awea.org/faq/water.html.

50. Energy Info. Admin., U.S. Dep't of Energy, An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook (2008), *available at* http://www.eia.gov/oiaf/servicerpt/stimulus/index.html.

51. Int'l Energy Agency, Renewable Energy Essentials: Hydropower 1 (2010), *available at* http://www.iea.org/publications/freepublications/publication/name,3930,en.html.

52. P. Torcellini et al., Nat'l Renewable Energy Lab., Consumptive Water Use for U.S. Power Production 3 (2003).

addition to hydropower, attributing all reservoir evaporation to power production is often dubious.

Just as with thermoelectric power plants, hydropower facilities are not immune from inducing temperature impacts on the environment. The dam causes temperature changes above and below the dam. Aside from a long length of the river that is subsumed, the species that live in the free-flowing river must migrate away from or adapt to the now-stagnant lake that varies in temperature from warm to cold from the top to the bottom of the water column. Because the water flowing through the turbines comes from the bottom part of the reservoir, it exits at a lower temperature than the temperatures to which the native river species are adapted. Native river species must often migrate upstream of the dam to reach normal conditions or move downstream until temperatures stabilize. In addition, hydropower facilities alter natural stream flows in ways that can also affect the riverine ecosystems.

Although hydropower facilities produce electricity with almost no GHG emissions at the point of generation, reservoirs release notable amounts of methane, and their environmental and water quality impacts can be significant.[53] In particular, GHG emissions are associated with the anaerobic decomposition of organic matter that is submerged during the creation of reservoirs and from the embedded energy in the construction of the dam. Additionally, methane emissions continue to occur from the decaying organic matter deposited in sediments from rivers that feed the reservoirs. Warmer temperatures induce more methane formation. Although dams do not generate GHG emissions from the process of power generation, the construction of the dams and the reservoirs do cause GHG emissions. Because conventional hydropower development through dam building often significantly alters river ecosystems, the new construction of large dams is contentious in most OECD countries. Therefore, efforts to identify opportunities for increasing hydropower generation have focused on smaller-scale opportunities ("small hydro") or improved efficiency and expansion of hydropower at existing facilities through uprating processes.[54] However, hydroelectricity development is expanding in many areas of the world; 157 GW of additional hydroelec-

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53. RENEWABLE ENERGY SOURCES AND CLIMATE CHANGE MITIGATION: SPECIAL REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 437–96 (Ottmar Edenhofer et al. eds. 2011).

54. Installing additional generators at a hydroelectric facility, allowing for increased peak capacity, is known as uprating. The U.S. Bureau of Reclamation states that "uprating hydroelectric generator and turbine units at existing power plants is one of the most immediate, cost effective, and environmentally acceptable means for developing additional electrical power." U.S. Bureau of Reclamation, *Generator Power Uprate Program Report*, http://www.usbr.gov/power/data/uprate/uprate.html#bor_program (revised Oct. 5, 2004).

tric capacity was planned in 2008 worldwide, over 80 percent of which was planned in Asia.[55] Three Gorges Dam in China, with the largest hydroelectric capacity in the world, was completed in 2012 and has a generating capacity of 22.5 GW.[56] Large-scale hydropower capacity additions are also underway in India, Iran, Turkey, and Brazil.[57]

Pumped storage hydroelectricity provides energy storage by pumping water to elevated levels during hours when there is excess power generation. During periods of peak demand, electricity can be produced by releasing the stored water through turbines back into the lower reservoir. This technology can also coupled with intermittent energy sources such as wind turbines to provide additional reliability when resources are low. These projects typically have high capital costs, however, and are limited by geographical characteristics. Nonetheless, pumped storage projects are growing in popularity as a means of load-leveling. They can also reduce the need to build peaking power plants, facilities used to meet peak power demand.[58]

3. Water Demand for Renewable Electricity

The water use implications of non-hydropower renewable electricity generation vary tremendously across technologies. Renewable electricity technologies such as wind turbines and solar photovoltaic (PV) panels do not use thermoelectric processes and have minimal water requirements for electricity generation. Water is used in manufacturing equipment for these systems and they require small volumes of water for cleaning, but they otherwise use no water directly for electricity generation. Other types of renewable technologies such as concentrating solar power (CSP) designs, enhanced geothermal, and biomass powered-plants use conventional thermoelectric processes to convert heat into electricity raising the same water use concerns as thermoelectric power plants using traditional fuels.

Many large-scale solar developers historically favored CSP over PV because CSP systems readily achieve utility scale and easily couple to thermal storage technologies—such as heat exchangers with molten salts

55. R. Sternberg, *Hydropower's Future, the Environment, and Global Electricity Systems*, 14 RENEWABLE & SUSTAINABLE ENERGY REVIEWS 713, 722 (2010).

56. David Stanway, *China Declares Three Gorges Hydro Project Complete*, REUTERS, July 4, 2012, http://www.reuters.com/article/2012/07/04/china-threegorges-idUSL3E8I42ZW20120704.

57. R. Sternberg, *Hydropower's Future, the Environment, and Global Electricity Systems*, 14 RENEWABLE & SUSTAINABLE ENERGY REVS. 713, 721 (2010).

58. Ioannis Hadjipaschalis et al., *Overview of Current and Future Energy Storage Technologies for Electric Power Applications*, 13 RENEWABLE & SUSTAINABLE ENERGY REVIEWS 1513, 1521 (2009).

that can save daytime heat for nighttime power generation—and natural gas turbines that allow CSP facilities to more consistently produce electricity during the day and into the night hours. This coupling characteristic has facilitated the entrance of commercial-scale CSP facilities onto the electricity grid. The first large-scale CSP plant with thermal storage, Andasol I, began operations in Granada, Spain, in November 2008: a 50 MW plant with seven hours of thermal storage.[59] The Andasol 2 and 3 expansions have each added 50 MW more of capacity.[60] Another large CSP installment (250 MW) with energy storage is being developed in the Southwestern United States by Arizona Public Service.[61] CSP plants operate at lower temperatures than fossil and nuclear powered plants. As a consequence, their steam cycles are less efficient, which requires more cooling water per unit of electricity generated. Furthermore, areas that provide the best solar insolation for CSP are typically dry and hot, which limits large-scale use of wet-cooling technologies because of water resource scarcity. Although dry-cooling technology can be coupled to CSP, doing so introduces parasitic efficiency losses, particularly on hot days. Nonetheless, some CSP companies have committed to dry cooling to avoid the political, availability, and environmental barriers because of concerns over water issues. These new systems demonstrate the feasibility of dry-cooling technology for large-scale systems and might be indicators of a new trend in electricity.

Geothermal power plants utilize naturally occurring convective hydrothermal sources inside sub-surface hot rock to create steam and generate electricity. However, the majority of the global geothermal resource is deep dry hot rock that does not contain adequate water to recover the embedded thermal energy necessary to run steam-powered turbines. Enhanced geothermal systems exploit the dry hot rock by injecting large volumes of water into fractured rock. Thus, an external water supply is necessary to use this worldwide geothermal resource. The injected water absorbs the geothermal heat and is pumped to the surface to power the steam cycle. The same water volume is then injected back into the rock to form a closed loop system.

Electricity generation from combustion of renewable biomass requires the use of similar amounts of cooling water as coal and nuclear-fueled thermoelectric facilities.[62] Volumes of water allocated for non-

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59. *Andasol 1 Goes Into Operation,* http://www.renewableenergyworld.com/rea/news/article/2008/11/andasol-1-goes-into-operation-54019 (last visited Dec. 27, 2012).

60. AKO, *Electrical Tracing System for the Andasol III Thermo-solar Power Project*, http://www.ako.com/w4pu/page/caso_exito_andasol3/en (last visited Dec. 27, 2012).

61. Arizona Public Service, *About Solana Generating Station*, http://www.aps.com/main/green/Solana/About.html?source=101 (last visited Nov. 17, 2012).

62. TWOMEY & STILLWELL, *supra* note 27.

combustion purposes vary widely depending on what type of feedstock is used, where it is harvested, and whether or not it requires irrigation. Some biomass sources, such as forest trimmings and pulp and paper industry waste, use only natural precipitation for biomass growth. In contrast, dedicated energy crops and crop residues often come from irrigated lands with large volumes of human-applied water in addition to natural precipitation. However, these dedicated energy crops and residues are also targeted for liquid transportation fuel production, so it is not obvious how or if one should apportion the water requirements.[63] It is always important to consider technology or fuel-specific metrics of water use within the larger context of the watershed in which the water uses are taking place.

C. The Impact on Electricity Production from Water Resource Scarcity

1. Heat Waves and Drought

Water shortages and heat waves have detrimental impacts on electricity reliability, especially in drought-prone and water-scarce regions of the world. Periods of drought increase the risk of electricity supply interruptions from generators that require water for operations. Unfortunately, water supplies are often most constrained during the summer months when ambient temperatures are highest, which is also when electricity demand is greatest in many regions. Drought severe enough to limit water use by electricity generators can force facilities to reduce electricity generation or shut down completely. Heat waves can also affect power plants because higher temperatures limit the cooling effectiveness of the water source and can push power plants up against environmental limits; specifically, thermal pollution regulations limit the water temperature that is discharged from the power plant. On August 16, 2007, a nuclear reactor at the Browns Ferry Nuclear Power Plant in Alabama shut down for one day because cooling water discharge exceeded temperature regulations that protect the surrounding environment and wildlife. That plant again operated at reduced output in 2010 due to temperature discharge limits.[64] For the same reason, other plants sited near Raleigh, NC, and Charlotte, NC, have come close to

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63. *See infra* Section III.B.2.s for additional discussion of the water requirements for biomass below

64. *Hot River Forces Costly Cutback for TVA*, CHATTANOOGA TIMES FREE PRESS, Aug. 23, 2010, http://www.timesfreepress.com/news/2010/aug/23/hot-river-forces-costly-cutback-tva/.

mandatory shut downs. In total, twenty-four of the United States' 104 nuclear reactors are sited in drought-prone regions.[65]

Similar episodes have happened with nuclear reactors in other countries. Nuclear energy supplies nearly 80 percent of France's electricity demand.[66] The 2003 heat wave that hit Europe caused many of France's nuclear reactors to run at reduced capacity. This severe reduction in electricity generating capacity occurred at a time when electricity demand was at its highest due to increased demands for air-conditioning and refrigeration in response to the higher temperatures.

Hydropower has also been compromised due to water shortages associated with dry climate and drought in many regions of the world. Flow reductions limit the amount of hydropower that can be produced and can potentially cause a loss of generation altogether if reservoir levels fall below the turbine intake structures. Lower stream flows in the Southwestern United States mean lower reservoir levels at Lake Mead's hydropower facilities at the Hoover Dam, consequently reducing the dam's electricity generation capacity. In the Colorado River Basin, every 1 percent decrease in stream flow reduces hydropower generation by 3 percent.[67] Even in regions that are not characteristically dry, changes in stream flow have reduced water storage in reservoirs and water availability for hydroelectric facilities throughout the year. For example, in the Northwestern region of the United States, climate change and its effect on variability in the region's hydrology have raised concerns about the future hydropower generation from existing facilities.[68]

2. Climate Change

Climate change models suggest that the Southwestern United States will get warmer and drier, placing increasing strain on water supplies.[69] Seasonal runoff from mountains in the Southwestern United States is also likely to become less dependable as increasing tempera-

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65. Associated Press, *Drought Could Shut Down Nuclear Power Plants*, MSNBC, http://www.msnbc.msn.com/id/22804065 (last updated Jan. 23, 2008, 2:54:19 PM); *see also* Mike Hightower & Suzanne A. Pierce, *The Energy Challenge: Global Energy Consumption is Expected to Grow by 50% by 2030, Squeezing Already Scarce Water Resources*, 452 NATURE 285, 285 (2008).

66. Ministere de L'Écologie Du Développement Durable et de L'Énergie, *La Production D'électricité*, *available at* http://www.developpement-durable.gouv.fr/La-production-d-electricite.html (last updated Mar. 10, 2011).

67. NAT'L OCEANIC AND ATMOSPHERIC ADMIN., GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 59 (Thomas R. Karl et al. eds, 2009).

68. T. P. Barnett et. al. *Potential Impacts of a Warming Climate on Water Availability in Snow-Dominated Regions*, 438 NATURE 303, 305 (2005).

69. NAT'L OCEANIC AND ATMOSPHERIC ADMIN., GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 83 (Thomas R. Karl et al. eds, 2009).

tures continue to shift the quantity, timing, and duration of snowpack melt.[70] Projections of earlier snow melt, less snowpack, and more frequent and severe drought conditions indicate that water supply issues will likely be exacerbated in the future, increasing competition between municipal, environmental, agricultural, and electricity sector demands. Storing early season water is often difficult for multi-purpose reservoirs in some regions because the strategy conflicts with the need for storage space to be available in case of flooding later in the season. This pattern is likely to be repeated in many locations globally.

While water supply constraints have already affected electricity generation at existing power facilities, they have also limited the development of new water-intensive generation in very dry regions.[71] Water scarcity can reduce the expansion of new thermoelectric capacity in the Southwestern and Western United States. With the exception of the Pacific coast states, this region currently generates the largest portion of its electricity from water-cooled coal, natural gas, and nuclear power plants.[72] Three proposals for wet-cooled thermoelectric plants in Arizona have been denied state water permits to build due to water availability constraints.[73] Sempra Energy of Nevada has halted the development of new coal power plants because of concerns over local water resources, and some CSP developers in the region have committed to dry cooling technology to avoid water resource conflicts.[74] Water scarcity has also raised concerns in siting new power plants in relatively-dry inland watersheds of the western and southeastern United States that are susceptible to extended droughts.[75] From 2006 to 2008, Idaho instituted a moratorium prohibiting the construction of new coal-fired power plants because of water supply and environmental concerns.[76] Despite their economic and efficiency drawbacks, dry cooling systems are becoming increasingly utilized at Southwestern power plants as an alternative to abandoning facility proposals because of water constraints.[77] More than

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70. *Id*. at 133.

71. Thomas J. Feeley III et al., *Water: A Critical Resource in the Thermoelectric Power Industry*, 33 ENERGY 1, 1 (2008).

72. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, FORM EIA-923 (2011), *available at* http://www.eia.gov/electricity/data/eia923/ (last visited Jan. 4, 2013).

73. THE ENERGY FOUND. & THE HEWLETT FOUND., THE LAST STRAW: WATER USE BY POWER PLANTS IN THE ARID WEST (2003), *available at* http://www.catf.us/resources/publications/files/The_Last_Straw.pdf.

74. Feeley III et al., *supra* note 71; KRISTEN AVERYT ET AL., FRESHWATER USE BY U.S. POWER PLANTS: ELECTRICITY'S THIRST FOR A RPECIOUS RESOURCE (2011).

75. NAT'L OCEANIC & ATMOSPHERIC ADMIN., GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 56 (2009); KRISTEN AVERYT ET AL., *supra* note 74.

76. Feeley III et al., *supra* note 71, at 1.

77. THE ENERGY FOUND. & THE HEWLETT FOUND., *supra* note 73.

50 dry-cooled power plants in states such as Nevada, New Mexico, California, and Texas are now in operation.[78] These challenges (i.e. water scarcity inhibiting the construction of new power plants) and solutions (i.e. dry cooling or different generation technologies) are also common and applicable in many other parts of the world.

D. Liquid Fuel Production's Impact on Water Resources

1. Water Demand for Liquid Fuels

Refining crude oil from both conventional and unconventional petroleum, like oil sands, tends to require water consumption in the range of 1–3 L water per L fuel.[79] Water consumption for extracting unconventional oil shale and oil sands can be another 1–4 L per L of crude[80], and much of the water is now increasingly recycled or from saline sources.[81] For corn-starch based ethanol, the biorefinery water consumption is 3–10 L water per L,[82] and for Brazilian sugar cane ethanol the water consumption is 12–24 L water per L ethanol.[83] While the water used per L of fuel might not seem high, the size of biorefineries necessitates the consumption of hundreds of millions of liters per year for a single point source location, creating potentially significant local impacts.[84]

Furthermore, freshwater consumption for biofuels during the agricultural phase of the life cycle is important to consider, and has been

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78. *Id.*

79. Gleick, *supra* note , at 288.

80. Carey W. King & Michael E. Webber, *Water Intensity of Transportation*, 42 ENVTL. SCI. & TECH. 7866, 7869 (2008).

81. CANADIAN ASS'N OF PETROLEUM PRODUCERS, RESPONSIBLE WATER MANAGEMENT IN CANADA'S OIL AND GAS INDUSTRY, REPORT 2010-0018 (2010).

82. Dennis Keeny & Mark Muller, *Water Use by Ethanol Plants: Potential Challenges*, INSTUTITE FOR AGRICULTURE AND TRADE POLICY (Oct. 24, 2006), http://www.iatp.org/documents/water-use-by-ethanol-plants-potential-challenges; King & Webber, *supra* note ; May Wu et al., *Water Consumption in the Production of Ethanol and Petroleum Gasoline*, 44 ENVTL. MGMT. 981, 987–88 (2009).

83. Based upon biorefinery consumption of 1,000–2,000 L water per tonne of sugar cane and 85 L of sugar cane per tonne. JOSE ROBERTO MOREIRA, WATER USE AND IMPACTS DUE ETHANOL PRODUCTION IN BRAZIL (2007) (presented at the International Water Management Institute and Food and Agriculture Organization of the United Nations conference: Linkages between Energy and Water Management for Agriculture in Developing Countries), *available at* http://www.iwmi.cgiar.org/EWMA/files/papers/Jose_Moreira.pdf; Isaias C. Macedo et al., *Green House Gases Emissions in the Production and Use of Ethanol from Sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020*, 32 BIOMASS & BIOENERGY 582, 589–90 (2008).

84. Keeny & Muller, *supra* note .

raised as a major concern.[85] Although the oil and gas industry often injects large quantities of water into hydrocarbon reservoirs to stimulate production during secondary recovery, this water is often saline and not drawn from fresh water sources. Thus, water demands for upstream oil and gas production often do not raise the same concerns as biofuels related to water quantity, but they can have similar or worse water quality concerns[86]. For example, U.S. shale gas production via hydraulic fracturing is occurring in some urban areas and relatively close to freshwater aquifers. Concerns have arisen regarding competition for water quantity during production and concern for water quality from production activities as well as during disposal of fracturing fluid water.[87]

The water demand for irrigated biofuels is very high compared to conventional transportation fuel sources. For irrigated U.S. corn in 2003, the average irrigation withdrawal equated to 780 L water per L ethanol translating to an average of 82 L water per kilometer (km) traveled (from 15–260 L water per km depending upon which state the corn is grown) when weighted as E85 (a fuel blend of 85 percent ethanol and 15 percent gasoline or other hydrocarbon, by volume) and a vehicle operating at 6–7 km per L of fuel.[88] Water consumption for 2003 U.S. irrigated corn grain was 3–146 L water per km (average 66 L water per km).[89] On a per-km-driven basis, water consumption for irrigated corn-based ethanol in the United States is up to 100 times greater than water consumption from non-irrigated corn-based ethanol. For irrigated U.S. soybeans, the average irrigation withdrawal was 510 L water/L biodiesel translating to an average of 35 L water/km.[90] Average water consumption for irrigated soybeans in the United States translates to 28 L water/km. Thus, the water intensity of biofuels is highly dependent on regional differences. For example, a 2009 study estimated that the U.S. state-wide differences

85. *See* Gören Berndes, *Future Biomass Energy Supply: The Consumptive Water Use Perspective*, 24 INT'L J. WATER RES. DEV. 235 (2008); U.S. GOV'T ACCOUNTABILITY OFFICE, PRELIMINARY OBSERVATIONS, *supra* note 6; Winnie Gerbens-Leenes et al., *The Water Footprint of Bioenergy*, 106 PROC. OF THE NAT'L ACAD. OF SCI. 10219; SCHNOOR, *supra* note 6 at 19.

86. *See infra* Section IV.B for the Canada case study.

87. DANIEL J. SOEDER & WILLIAM M. KAPPEL, U.S. GEOLOGICAL SURVEY, WATER RESOURCES AND NATURAL GAS PRODUCTION FROM THE MARCELLUS SHALE (2009); Nathaniel R. Warner, *Geochemical Evidence for Possible Natural Migration of Marcellus Formation Brine to Shallow Aquifers in Pennsylvania*, 109 PROC. OF THE NAT'L ACAD. OF SCI. 11961, 11961–11966 (2012).

88. King & Webber, *supra* note 80; U.S. DEPARTMENT OF AGRICULTURE, AC97-SP-1, 1997 CENSUS OF AGRICULTURE: FARM AND RANCH IRRIGATION SURVEY (1998) [hereinafter USDA 1998]; U.S. DEPARTMENT OF AGRICULTURE, AC-02-SS-1, 2002 CENSUS OF AGRICULTURE: FARM AND RANCH IRRIGATION SURVEY (2003) [hereinafter USDA 2003].

89. King & Webber, *supra* note 80.

90. *See id.*; USDA 1998, *supra* note 88; USDA 2002, *supra* note 88.

in irrigation water embodied in bioethanol from corn in the United States ranged from 5 to 2,138 L water/L ethanol.[91]

Both irrigated and non-irrigated biofuel feedstocks[92] need significant amounts of water for ET[93] during photosynthesis. This ET from natural water is sometimes included in analyses of water consumption and often termed the "green water footprint."[94] Because there are still water concerns for non-irrigated biofuels, water resources managers must consider ET changes when converting land usage to biofuel feedstock production.

Producing biofuels in water rich regions is more sustainable from a water consumption standpoint than in those areas that require irrigation to grow biofuel feedstocks. For example, the vast majority of biofuels produced in Brazil are rain-fed, decreasing the irrigation water requirements for ethanol production.[95] Thus, the natural environment can provide an important ecosystem service by distributing water. However, this distribution can also have detrimental impacts on water quality due to excess nutrients from agricultural runoff. Second and third generation biofuels, like lignocellulosic crops[96] and harvest and forest residues, present opportunities to decouple irrigation from biofuels and significantly reduce water demand for feedstocks. However, the feedstocks still consume water via ET of precipitation.[97] Thus, bioenergy and food agriculture and biofuel production need to be well-integrated into a broader water resource management perspective.

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91. Yi-Wen Chiu, et al., *Water Embodied in Bioethanol in the United States*, 43 ENVTL. SCI. & TECH. 2688, 2689 (2009).

92. Feedstocks for biofuels include traditional energy crops such as corn, soybeans, and sugarcane, and non-traditional energy crops such as switchgrass. OXFORD ENGLISH DICTIONARY (2nd ed. 1989), available at http://www.oed.com/.

93. Evapotranspiration (ET) accounts for water vapor flux via both evaporation and transpiration (water vapor is released when plants open stomata to take in carbon dioxide). *Id.*

94. Gerbens-Leenes et al., *supra* note 85, at 10220.

95. David M. Lapola, et al., *Modeling the Land Requirements and Potential Productivity of Sugarcane and Jatropha in Brazil and India Using the LPJmL Dynamic Global Vegetation Model,* 33 BIOMASS AND BIOENERGY 1087, 1090 (2009); *see* Joao Martines-Filho et al., *Bioenergy and the Rise of Sugarcane-Based Ethanol in Brazil*, 21 CHOICES 91, 93 (2006).

96. Lignocellulosic crops contain both cellulose and lignin. The carbohydrates necessary for producing biofuels are bound to the lignin. An example is *Miscanthus*.

97. Gerbens-Leenes et al., *supra* note 85; King & Webber, *supra* note 80; Lapola, *supra* note 95; ORG. ECON. CO-OPERATION & DEV., SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN AGRICULTURE (2010) [hereinafter OECD SUSTAINABLE].

2. Water Pollution from Liquid Fuel Production

During the life cycle of liquid fuel production from fossil fuels or biomass, the environment can be harmed through spills and other chemical pollution. The 1989 *Exxon Valdez* oil spill is one memorable instance of oil negatively affecting aquatic environments. Forty-two million L (11 million gal) of oil were spilled in Prince William Sound, Alaska.[98] Another was when the *Amoco Cadiz* broke in two off the coast of Brittany, France in 1978, spilling 255 million L (67 million gal) of oil. The explosion and subsequent oil spill by BP-operated Deepwater Horizon drilling rig on April 20, 2010, in the Gulf of Mexico is a recent reminder of low-probability, high impact risks of petroleum exploration in aquatic environments.[99]

Unconventional fossil fuel development raises water quality concerns that in some cases are not yet fully understood. For instance, shale gas and oil recovery from using hydraulic fracturing produce brines during the hydraulic fracturing process that require treatment and disposal. Water delivery, disposal, and treatment needs for the hydraulic fracturing life cycle often require new infrastructure. In the Marcellus Shale region of the Northeastern United States, the majority of injected water used to extract shale gas must be recovered and treated in wastewater treatment plants, which can be very expensive and possibly require new technology to filter new contaminants. The wastewater could also be shipped to more distant disposal sites. In the Barnett Shale in Texas, contaminated produced water is often re-injected into the ground as a means of disposal. However, the deep geologic features are amenable to waste injection in the Barnett region. Such injections raise concerns regarding drinking water contamination in regions with poor geology not suited for hazardous fluid disposal. Thus, the reinjection of produced water has not been widely adopted in other regions such as the Marcellus Shale.[100] New research also shows that production of Canadian oil sands has contributed to increased concentrations of polycyclic aromatic compounds (PACs) through airborne deposition onto the snowpack and dissolution in the Athabasca River in Canada.[101]

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98. Sarah Graham, *Environmental Effects of Spill Still Being Felt*, SCIENTIFIC AMERICAN (Dec. 19, 2003), http://www.scientificamerican.com/article.cfm?id=environmental-effects-of.

99. *See* RESTORE THE GULF, http://www.restorethegulf.gov/task-force/joint-info-center/about (last visited Nov. 20, 2012); *Deepwater Horizon Response & Restoration*, U.S. DEP'T OF INTERIOR http://www.doi.gov/deepwaterhorizon/ (last visited Nov. 20, 2012).

100. SOEDER & KAPPEL, supra note 87.

101. Erin N. Kelly et al., *Oil Sands Development Contributes Polycyclic Aromatic Compounds to the Athabasca River and its Tributaries*, 106 PROC. OF THE NAT'L ACAD. OF SCI. 22346, 22349 (2009); *see infra* Section IV.B for more discussion.

While the water quality regulations regarding the oil, natural gas, coal, and uranium industries are relatively strict in developed countries, those associated with non-traditional forms of transportation fuel are not as well controlled. Fossil fuel mines are point source polluters because contamination can be traced to a single outfall, whereas agricultural operations are classified as nonpoint source water polluters. In the United States, point source discharges are regulated under the Clean Water Act (CWA). Under the CWA, any entity other than an individual home that discharges pollutants into surface water must obtain a permit to pollute—effectively placing a limit on discharge to a water body.[102] Because coal and uranium mining and oil and natural gas operations fall within the CWA's definition of "point sources," the water quality impacts associated with traditional fossil fuel sources are relatively straightforward to regulate.

Quantifying the water quality impacts of the agricultural portion of the biofuel life cycle presents new challenges since most agricultural producers fall under the classification of "nonpoint source" polluters.[103] Unlike point source pollution, which enters surface water sources by direct conveyance or manmade ditches, nonpoint source pollutants are transferred into water by means of rainfall or snowmelt that flow over and through the ground as runoff, collecting manmade pollutants as it moves. Since pollutants transferred to water bodies via contaminated runoff or percolation through the ground cannot be attributed to discrete sources, this type of water pollution is much more difficult to regulate. Consequently, even though the relationship between nutrient loading to surface and groundwater and upstream agricultural activity in the United States is widely accepted, pollution from agricultural sources is largely unregulated.

Increased production of biofuels in the United States has increased water pollution through increases in nitrogen and phosphorus agricultural chemical concentrations and hypoxia[104] in surface waters draining from farmland in the Mississippi River basin, and groundwater near farmland, into the Gulf of Mexico.[105] This increase in nutrient loading from crop production has contributed to the growth of a large hyp-

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102. The Clean Water Act, 33 U.S.C. § 1342 (2008).

103. The Clean Water Act, 33 U.S.C. § 1362(14) (2008).

104. Hypoxia is a condition in which the dissolved oxygen in a body of water has been depleted, resulting in "dead zones" where aquatic life cannot survive. OXFORD ENGLISH DICTIONARY, *supra* note 92.

105. Richard Alexander et al., *Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin*, 42 ENVTL. SCI. & TECH. 822, 826 (2008); Simon D. Donner & Christopher J. Kucharik, *Corn Based Ethanol Production Compromises Goal of Reducing Nitrogen Export by the Mississippi River*, 105 PROC. OF THE NAT'L ACAD. OF SCI., 4513

oxic area referred to as a "dead zone" in the Gulf of Mexico, which is currently the second largest hypoxic zone in the world after the Baltic Sea.[106]

Although all fertilized crop production can cause nutrient leaching, corn is particularly inefficient. It uses only 40–60 percent of the nutrients delivered to its roots.[107] Cellulosic feedstocks from perennials such as switchgrass and woody materials can be used to produce ethanol with less water quality impacts than row crops due to reduced soil erosion and the reduced need for agricultural chemical inputs.[108] In addition to their anticipated high net energy, high geographic distribution, resistance to drought, and high carbon sequestration, perennials provide important services in terms of soil management, flood management, and nutrient uptake. These services in turn positively contribute to overall water quality. For these ecological reasons and because of social and political pressures to disassociate water and food from energy production, many companies and research institutions focus upon non-irrigated biofuel feedstocks and life cycles that can contribute to better soil and water quality. However, in spite of the U.S. Renewable Fuels Standard mandate to produce cellulosic advanced biofuels, today's technological and economic limitations make it uneconomical to produce fuels from cellulosic feedstock on any significant scale.[109]

As countries shift from conventional fossil fuel production towards unconventional fossil fuels and biofuels, the nature, extent, and location of water use and water pollution will be different. Consequently, the existing regulatory frameworks for protecting water quality might need to be updated and revised.

(2008); Charlotte de Fraiture et al., *Biofuels and Implications for Agricultural Water Use: Blue Impacts of Green Energy*, 1 WATER POL'Y SUPPLEMENT 67 (2008).

106. Alexander et al., *supra* note 105; James Owen, *World's Largest Dead Zone Suffocating Sea*, NAT'L GEOGRAPHIC NEWS (Mar. 25, 2010), http://news.nationalgeographic.com/news/2010/02/100305-baltic-sea-algae-dead-zones-water/.

107. Thomas W. Simpson et al., *The New Gold Rush: Fueling Ethanol Production while Protecting Water Quality*, 37 J. ENVTL. QUALITY 318, 320 (2008).

108. ANSELM EISENTRAUT, INT'L ENERGY AGENCY, SUSTAINABLE PRODUCTION OF SUSTAINABLE-GENERATION BIOFUELS (2010); S.B. McLaughlin & M.E. Walsh, *Evaluating Environmental Consequences of Producing Herbaceous Crops for Bioenergy*, 14 BIOMASS & BIOENERGY 317 (1998); David Pimental & Tad W. Patzek, *Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower*, 14 NATURAL RES. RESEARCH 65, 69 (2005); Simpson et al., *supra* note 107, at 321; D. Tilman et al., *Carbon-Negative Biofuels From Low-Input High-Diversity Grassland Biomass*, 314 SCIENCE 1598, 1598–1600 (2006).

109. EISENTRAUT, *supra* note 108, at 43; Simpson et al., *supra* note 107 at 321; U.S. ENVT'L PROT. AGENCY OFFICE OF TRANSP. & AIR QUALITY, EPA-420-F-10-007, REGULATORY ANNOUNCEMENT: EPA FINALIZES REGULATIONS FOR THE NATIONAL RENEWABLE FUEL STANDARD PROGRAM FOR 2010 AND BEYOND (2010).

E. Energy Demand for Water Treatment, Distribution, and Use

1. Energy Requirements for Fresh Water Treatment

Collection, conveyance, treatment, distribution, and heating of water for the public consume large quantities of energy—usually in the forms of electricity and natural gas. This energy consumption varies with distance to the water source, existing water quality, water treatment standards, distribution system terrain, and the end-use of water.

Except in locations where geographic terrain allows for gravity-fed systems, moving water requires energy. Pumping water uphill over long distances or from deep aquifers usually requires more energy to collect the water than from local surface water sources. Pumping groundwater for drinking water requires energy, which increases with depth to the water table. For example, pumping from a depth of 37 m requires 140 kWh per million L while pumping from 61 m requires 240 kWh per million L.[110]

After source water is collected, industrialized countries typically treat the water to achieve minimum health standards. Though only a small portion of the water leaving a water treatment plant typically ends up being used for drinking, all water produced by drinking water treatment plants is generally required to meet pertinent government drinking water standards. Thus, much embedded energy is wasted by irrigating lawns and operating toilets using high quality drinking water. Standard water treatment employs physical and chemical treatment processes to remove contaminants. Depending on the water source, groundwater treatment can require little more than chemical disinfection due to the natural filtration characteristics of soil. In general, energy consumption for water treatment increases as the source water quality degrades, as shown in Table 3.

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110. RONNIE COHEN & BARRY NELSON, NATURAL RESOURCES DEFENSE COUNCIL, ENERGY DOWN THE DRAIN: THE HIDDEN COSTS OF CALIFORNIA'S WATER SUPPLY (2004).

TABLE 3. Energy requirements for water treatment (u.s. national average values).[111]

Water Source	Energy for Water Treatment[112] (kWh/million L)
Groundwater	58
Surface Water	160
Brackish Groundwater	1,000–2,600
Seawater	2,600–4,400

Using alternative water sources can dramatically increase energy consumption for drinking water treatment. As shown in Table 3, pumping and desalination of brackish groundwater or seawater can increase energy for water treatment by a factor of 6–27 over use of local surface water supplies.[113] While different processes exist to separate dissolved solids (salts) from seawater and brackish water, most commercial-scale desalination facilities treat water with reverse osmosis membranes or thermal separation technologies.[114] Desalination requires large amounts of energy to overcome osmotic pressure during reverse osmosis and to alter water temperature and pressure during thermal desalination. Despite these large energy consumption consequences, various municipalities worldwide turn to desalination after drought or other circumstances have strained existing water supplies.[115]

In areas of the Middle East, waste heat from thermoelectric power plants, including CSP plants, is used for thermal desalination of seawater to produce a reliable drinking water supply.[116] In such co-located desalination facilities and power plants, steam leaving the power plant's

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111. R. GOLDSTEIN & W. SMITH, ELECTRIC POWER RESEARCH INSTITUTE, NO. 1006787, 4 WATER & SUSTAINABILITY: U.S. ELECTRICITY CONSUMPTION FOR WATER SUPPLY & TREATMENT—THE NEXT HALF CENTURY (2000); KLEIN ET AL., *supra* note 4.

112. This does not include raw water collection and conveyance or treated water distribution and heating.

113. GOLDSTEIN & SMITH, *supra* note 111; Carey W. King, et al., *Thirst for Energy*, 1 NATURE GEOSCIENCE 283 (2008); KLEIN ET AL., *supra* note 4; ASHLYNN S. STILLWELL ET AL., UNIV. OF TEXAS AT AUSTIN, ENVIRONMENTAL DEFENSE FUND, ENERGY-WATER NEXUS IN TEXAS (2009).

114. Bart Van der Bruggen & Carlo Vandecasteele, *Distillation vs. Membrane Filtration: Overview of Process Evolutions in Seawater*, 143 DESALINATION 207, 208 (2002).

115. *See infra* Section II.C. and G for further discussion relating to the Australia and Israel case studies.

116. E. Cardona, et al., *Performance Evaluation of CHP Hybrid Seawater Desalination Plants*, 205 DISALINATION 1, 2 (2007); Franz Trieb & Hans Müller-Steinhagen, *Concentrating Solar Power for Seawater Desalination in the Middle East and North Africa*, 220 DESALINATION 165 (2008).

steam generator preheats seawater in a heat exchanger upstream of the thermal desalination process. The net result is coupled benefits: the fuel consumed in the thermoelectric power plant produces electricity and contributes to desalinating the seawater, making a more efficient use of energy.

After source water has been treated to acceptable health standards, the treated water is then distributed to residential, commercial, and industrial users. In the United States, pumping treated water in distribution systems is an energy-intensive step that typically represents 80 percent—approximately 28 billion kWh[117]—of the total energy consumed during the water process that includes collection, conveyance, treatment, and distribution.[118] Additionally, aging water distribution infrastructure increases the energy required to deliver drinking water because of losses that arise from leaks and friction on the distribution pipe walls.

Recent estimates show the use of hot water in the U.S. residential and commercial sectors consumes an estimated 4 exajoules (EJ)—4 percent of total primary energy consumption in the United States.[119] In the United States, an average of 35 percent of the volume of water delivered to residential customers is used indoors; outdoor uses constitute 58 percent, with leaks at 6 percent and unknown losses at 1 percent.[120] Over half of the water used indoors in the United States is heated water.[121] This allocation is not unusual for OECD countries. Due to the large energy requirements for water heating and expensive energy resources, Israeli and Hawaiian laws now require builders to install solar hot water heaters on newly constructed homes. As a result, by 2009, 85 percent of Israeli households used solar hot water heaters.[122] The increase in using solar water heating reduces the consumption of grid electricity or natural gas, thus reducing the impact of water heating on primary energy demand and power plant cooling water.

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117. GOLDSTEIN & SMITH, *supra* note 111.

118. *Id.*

119. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, DOE/EIA-0383, ANNUAL ENERGY OUTLOOK 2010 (2010); Kelly T. Sanders & Michael E. Webber, *Evaluating the Energy Consumed for Water Use in the United States*, 7 ENVTL. RESEARCH LETTERS 1, 7 (2012).

120. AM. WATER WORKS ASS'N RESEARCH FUND, RESIDENTIAL WATER USE SUMMARY (1999), *available at* http://www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf.

121. *Id.*

122. David Sterman, *Israel's Solar Industry: Reclaiming a Legacy of Success*, CLIMATE INSTITUTE, (July 2009), http://www.climate.org/topics/international-action/israel-solar.html; Gershon Grossman, *Renewable Energy Policies in Israel, in* HANDBOOK OF ENERGY EFFICIENCY AND RENEWABLE ENERGY 26 (Frank Kreith & D. Yogi Goswami eds., 2007).

2. Energy Requirements for Wastewater Treatment

Following water use by residential, commercial, and industrial customers, adequate wastewater sanitation is required to protect human health and the surrounding environment. Wastewater treatment requires more energy than conventional surface water or groundwater treatment because wastewater facilities employ physical, biological, and chemical treatment operations that process both solid and liquid waste (see Table 4). As more sophisticated wastewater treatment technologies are developed, the quality of the treated wastewater effluent increases. While wastewater operations such as aeration and solids-handling consume a large portion of the total process energy,[123] large wastewater treatment plants in the United States could greatly reduce primary energy consumption by recovering energy from processes like anaerobic digestion and biosolids incineration.[124]

TABLE 4. U.S. national average values by technology of energy for wastewater treatment.[125]

Wastewater Technology	Energy for Wastewater Treatment (kWh/million L)
Trickling Filter	250
Activated Sludge	340
Advanced Treatment without Nitrification	400
Advanced Treatment with Nitrification	500

Another alternative freshwater source that has been discussed in a policy context is water reuse. After wastewater has been sufficiently treated, the effluent water can be further treated for direct or indirect reuse of water. For water reuse as a drinking water supply, energy-intensive membrane treatment is usually required after advanced wastewater treatment operations to ensure removal of disease-causing agents and other contaminants. In countries like the United States, non-potable reuse is preferred over direct or indirect potable reuse due to adverse public perception. On the other hand, Singapore uses direct potable reuse

123. FRANKLIN L. BURTON, ELECTRIC POWER RESEARCH INSTITUTE, CR-106941, WATER AND WASTEWATER INDUSTRIES: CHARACTERISTICS AND ENERGY MANAGEMENT OPPORTUNITIES (1996)

124. Ashlynn S. Stillwell et al., *Energy Recovery from Wastewater Treatment Plants in the United States: A Case Study of the Energy-Water Nexus*, 2 SUSTAINABILITY 945, 945–46 (2010).

125. GOLDSTEIN & SMITH, *supra* note 111.

with advanced membrane treatment to produce NEWater that exceeds existing health standards.[126]

Wastewater management itself affects aquatic ecosystems and the surrounding environment. Reducing these impacts requires more energy for distribution, dispersal, and removal of contaminants. Depending on the level of treatment, wastewater effluent disposal can increase nutrient loading in receiving streams, which contributes to unwanted algae blooms. Large-scale seawater desalination plants produce concentrated salt waste streams that are usually disposed via return to the ocean or gulf water source. Disposing the concentrate stream from inland brackish groundwater facilities requires evaporation ponds, deep well injection, or drying to form solid waste. Studies of seawater desalination waste show that disposal of concentrated salts can negatively affect aquatic life through localized increases in salinity.[127] Removing particulates and contaminants from water supplies necessitates the disposal of those materials, which increases energy demands even further.

Understanding the interconnections between energy and water is important for evaluating the possible positive and negative impacts of implementing various policies and technologies. Overlap between the two sectors reveals areas where energy policies can have negative water impacts, and vice versa. Policies and technologies exist to address the gaps and disconnect between traditional planning and management in the energy and water sectors.

III. INSTITUTIONAL REFORMS THAT ENHANCE COHERENCE BETWEEN WATER AND ENERGY POLICIES

A. Common Institutional Gaps that Hinder Coordination Between Energy and Water Policies

The following is a discussion of institutional gaps, some identified by the OECD, that commonly compromise coordination efforts within governments.[128]

Policy frameworks and agendas can hinder coordination. Differing political agendas, visibility concerns, and power rivalries across ministries and agencies at the federal level can focus too much effort on

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126. *NEWater: The 3rd National Tap*, PUB (last updated July 9, 2012), http://www.pub.gov.sg/WATER/NEWATER/Pages/default.aspx ; *see infra* Section IV.H for the Singapore case study.

127. Sabine Lattemann & Thomas Höpner, *Environmental Impact and Impact Assessment of Seawater Desalination*, 220 DESALINATION 1, 3 (2008).

128. Organisation for Economic Co-operation and Development [OECD], *Mind the Gaps: Managing Mutual Dependence in Relations Among Levels of Government*, OECD Working Papers on Public Governance, No. 14 (2009).

unproductive tasks not tuned to solving resource problems. Additionally, national ministries often dictate top-down vertical approaches to cross-sectoral policies that would benefit from co-design at the local level where more of the necessary knowledge is located.

Unclear and overlapping administrative roles and responsibilities among government ministries often do not correspond well with the economic, social, and physical boundaries of water and energy flows. Water issues are localized, while water basins cross political and administrative boundaries. There is an ongoing challenge in creating effective and accountable water-governing institutions across political lines, but some countries use these water boundaries to create agreements where few others exist.

A lack of and/or asymmetry in capacity resources (knowledge, enforcement, and infrastructure) within all levels of government can potentially leave no one in charge. Asymmetry of revenues and distribution of resources across ministries and levels of government can lead to certain ministries dominating the counter-balancing ministry or being in charge of its own regulation. An example exists when the ministry in charge of producing tax revenues from land leases is in charge of environmental regulation of those leases.

Data gaps and inconsistencies create informational challenges between and within the levels and ministries of government. Different schedules and deadlines between ministries and within election cycles create difficulty for engaging in strategic planning over appropriate time frames. Without evaluation, governance practices cannot be assessed, and very often feasibility is limited.

Institutional gaps between energy and water policies mean water supply decisions such as use of seawater desalination or long-haul water transfer are often made without regard for energy consumption.[129] However, both Australia and Israel have integrated energy consumption and GHG emission impacts into desalination planning. Furthermore, energy decisions, like the use of biofuels, and climate mitigation strategies are often made without regard to water impacts.[130] Moving forward, climate change projections show strained water resources, and long-term decisions might need to be made as additional GHG emissions exacerbate climate change. However, these problems hobble the policy formulation process.

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129. *See* Abrams & Hall, *supra* note 7, at 3, 10 n.9.

130. Jamie Pittock, *National Climate Change Policies and Sustainable Water Management: Conflicts and Synergies*, 16 ECOLOGY & SOC'Y, art. 25, 2011, *available at* http://www.ecologyandsociety.org/vol16/iss2/art25/.

An almost inherent assumption in most of the discussion in this paper is that energy and water policies have not generally been made in coordination and that future coordination involves some new technology, best practice, or regulation. However, a prominent example of energy-water policy coordination in the United States was actually the removal of regulation. In section 322 of the Energy Policy Act of 2005, due to the chemical composition of hydraulic fracturing fluids, these fluids were exempted from the Safe Drinking Water Act because it would have otherwise been illegal to inject the fluids for natural gas, oil, and or geothermal energy production. State laws are still applicable for protecting underground sources of drinking water, but this exemption was clearly coordinated energy policy that understood that existing water law was a hindrance to accessing new energy resources.

The problem of simultaneously considering multiple constraints on energy and water can be stifling. Of the institutional gaps mentioned previously, governments can start addressing energy-water policy by addressing the informational challenge. Gathering information is possible through the creation of well-structured and maintained databases and reporting functions for energy and water data. Many energy databases were created after the 1970s oil embargo, and those data-gathering efforts serve as a model. Governments have a solid foundation for integrated policymaking by designing policies based on these data and the latest scientific and engineering understanding.

B. Existing Coordination Mechanisms Aimed at Bridging Institutional Gaps

Within the context and constraints of each region of the world, the best technologies and policies are likely to be different. Just as energy and water are intimately coupled, so too are policies and technologies that affect the energy-water nexus. Thus, while some technologies leverage policy changes, some policies encourage or need technology to be effective.

The impact of these policies and technologies on water or energy prices and demand are not represented in the following descriptions. For example, desalination is a technology that, if pursued as a part of policy for providing potable water supply, is intended to *increase* the secure supply of freshwater for higher consumption. However, with this technology comes a higher price to pay for necessary infrastructure and energy consumption. Because the energy and monetary costs of desalinated water are higher than conventional surface and groundwater supplies, higher prices for desalinated water might deter increased consumption per capita while aggregate consumption may vary. Thus, the discussion in this section does not consider indirect economic effects involving supply and demand feedbacks from pursuing the listed policies and technologies.

Table 5 illustrates a sample list of technologies that are relevant to the energy-water nexus. These various technologies impact water and energy policy objectives in different ways. Nations have different policy objectives related to energy, water and carbon. Some of the most relevant and universal objectives for the energy-water nexus are listed here and used as an organizing framework for this discussion. For each listed technology (left column), a relationship to policy objectives is given as follows: an up arrow (↑) indicates that the technology helps to achieve the policy objective, a down arrow (↓) indicates that the technology hinders achievement of the policy objective, a level arrow (↔) indicates that the technology has choices and tradeoffs that make its effect upon the policy objective site-specific or unclear, and dashes (—) indicate that the technology has no appreciable impact on the policy objective. In situations where a technology can be used for widely varying purposes (e.g. hydraulic fracturing, which can be used for accessing natural gas and geothermal resources), multiple arrows indicate the outcome can be different depending upon the application. The ? symbol indicates policy choices that can be effective in affecting increased or decreased use of a technology, and the ? symbol indicates policy choices that are only moderately effective. The effectiveness of a particular policy in promoting a technological solution is independent of whether that solution produces good or bad outcomes for the policy objectives. In other words, it is possible to craft a policy that is effective at creating a negative outcome for any one policy objective.

The technologies in Table 5 are listed in an approximate order of increasing scale (top to bottom) of the decision-making body. For example, the installation of low-flow fixtures in a home is a decision that a personal consumer can make, but approving and allocating funds for a desalination plant or transfer of water across water basins typically requires governmental coordination and investment. Similarly, the policy options are ordered according to an approximate scale of capital investment required. Again, installing low-flow fixtures is a very small investment that directly reaches only the person using the fixture while desalination facilities serve many people and require large capital and energy investments.

Several technologies from Table 5 show a "win-win" scenario in terms of reaching both energy and water security: low-flow fixtures, energy-efficient appliances, rainwater collection for non-potable uses, solar hot water heating, geothermal heat pumps, electricity peak shaving as a demand response method, solar PV power, wind power, combined heat and power (CHP), hydropower, and converting municipal waste to energy. Other technologies have various tradeoffs: biofuels development, groundwater pumping, electricity peak shifting for demand management, carbon capture and storage (CCS), greywater reuse for potable purposes, and inter-basin water transfer. The rest of the listed technologies have mixed benefits for energy and water security. We list the impacts on the additional policy objectives of carbon management, renewable energy, and water quality as those that have more indirect relationships with obtaining water and energy security from a quantitative standpoint. The technologic impacts on these other three objectives are quite varied.

Notably, two policies—namely right-pricing and mandates—are deemed "effective" or "moderately-effective" for a wide range of technologies. These two policy approaches represent different forms of policy intervention: 1) mandates tend to be more direct and command-and-control oriented—e.g. requiring homebuilders to install solar hot water heaters—whereas 2) right-pricing approaches are indirect and market-oriented—e.g. allowing prices for energy to increase with the intent that they would cause homebuilders to install solar hot water heaters. That these policy categories can both be widely-effective despite their very different approaches is important to keep in mind for policymakers. Furthermore, both approaches can be used simultaneously.

Table 5 also shows that the technologies that require large-scale capital investment and affect many people tend to fall in the jurisdiction of governments. Conversely, lower capital cost items are controlled by individual consumers and the companies selling the products. The government can generally use efficiency mandates and product labeling standards to facilitate the adoption of lower-cost consumer goods and appliances.

TABLE 5. Various technologies impact water and energy policy objectives in different ways.[131]

→ Increasing scale of capital investment and citizen reach →

Consumer/Residential → Business/Commercial → Government

Technologies	Policy Objectives					Policy Choices that can influence use of Technologies							
	Water Security	Energy Security	Water Quality	Carbon Mgmt.	Renewable Energy	Product Labeling	PR Campaign	Data Gathering	Mandate/ Regulation	Right Pricing	Subsidy	Financing	Public Works
Low-flow fixtures	↑	↑	--	↑	--	○	○		●	○	●		
Energy-efficient appliances	↑	↑	--	↑	--	○	○		●	○	●		
Distributed rainwater collection (non-potable uses)	↑	↑	↑	↑	--		○		●	○	●		
Distributed rainwater collection (potable uses)	↑	↓	↑	↓	--				●	●	●	○	
Solar hot water heating	↑	↑	↑	↑	↑	○	○		●	●	●	○	
Geothermal heat pumps	↑	↑	↔ to ↑	↑	↑	○	○		●	●	●	○	
Electricity peak shifting	↔	↔	↔	↔	↔		○	●		●	○		
Electricity peak shaving	↑	↑	↑	↑	--		○	●		●	○		
Groundwater pumping	↔	↓	--	↓	--		○	●	●	●	●	○	
Solar photovoltaic	↑	↑	--	↑	↑				●	●	●	●	○*
Wind power	↑	↑	--	↑	↑				●	●	●	●	○*
Combined Heat and Power	↑	↑	↑	↑	↔				●	○	●	○	○*
Wet-cooled power plants	↓	↑	↔	--	--				○				○*
Dry-cooled power plants	↑	↔	--	↔	--				○	●		●	○*
Concentrating Solar power (steam cycle)	↓	↑	--	↑	↑				●	●	●	●	○*
Hydraulic fracturing (for natural gas from shale or enhanced geothermal)	↓	↑	↔	↔	↑ and ↓				●	○			
Hydropower	↑	↑	↓	↑	↑				●	○		●	●
Desalination	↑	↓	↓	↓	↔				●	●		●	●
Carbon Capture and Storage	↓	↔	↔	↑	↓			●	●	●	●	●	○
US Corn Ethanol (Midwest)	↔	↔	↓	↔	↑			●	●	●	●		
Brazilian (State of Sao Paulo) sugar cane ethanol	↔	↑	↔	↑	↑			●	●	●	●		
Municipal waste to energy	↑	↑	--	↑	↑				●	●			●
Greywater and reclaimed water use	↑	↔	--	--	--				●	●	○^	○^	●
Inter-basin water transfer	↔	↓	--	↓	--			●		●			●

○* Because many cities and regions have electric grids operated by government-owned utilities, electric generation infrastructure projects are public works projects.

○^ Greywater use applicable for residential and commercial buildings is most applicable for help from subsidies and financing.

(blank)	not likely effective
○	somewhat effective
●	effective

1. Policies Relevant to the Energy-Water Nexus

A variety of policy options are available for countries to pursue their policy objectives. While the discussion in this section and the information organized in Table 5 focus on different technological solutions

131. *Water security* relates to consistent and reliable availability of freshwater or the services it provides. *Energy security* relates to consistent and reliable availability of energy resources or the services they provide. "Security" here refers to increased supply, increased efficiency, or increased conservation. Increased *water quality* relates to efforts to mitigate impacts from human activity that alter the ambient natural aquatic environment due to, but not limited to release of total dissolved solids, unnaturally warm or cold water, dissolved gases, and dissolved nutrients. *Carbon management* relates to efforts that reduce or avoid anthropogenic GHG emissions in aggregate or sequester carbon from the atmosphere. To assess impacts of carbon management from increased energy consumption, the descriptions of technologies assume energy comes from a typical worldwide fossil energy mix of 85%. Thus, the default assumption is that higher energy consumption equates to higher GHG emissions. *Renewable energy* relates to efforts that generate more energy from solar (sunlight, wind, waves, biomass), gravitational (tides and falling water), and geothermal resources.

and the policies that enable their widespread adoption, it is important to note that behavioral changes are also an important piece of the policy discussion. In particular, even technologies that are cost-effective to implement—e.g. they pay for themselves within a reasonable timeframe—and for which there is policy support often do not get implemented because of behavioral, cultural, or financial hurdles.[132] According to a recent study by the U.S. National Academy of Sciences (NAS), some of the barriers that remain—even for technological solutions that are cost-effective—include the following:[133]

- Potentially high up-front costs
- Alternative uses for investment capital that appear more attractive
- Volatility in energy prices (which creates uncertainty in payback times)
- Lack of information to consumers about relative performance and costs of alternatives
- Marginal energy costs are often a small part of an individual's or family's budget (especially true for the United States)
- Substantial investments in time and effort might be necessary to find/study relevant information
- Purchasers focus on up-front costs, NOT lifecycle costs
- Risk aversion(new products are unfamiliar)

In addition, there are important structural gaps, whereby the people or institutions that make the investment decisions for energy or water-efficient technologies are different than the people or institutions that benefit. Two classic examples of this conundrum are: 1) landlords pay for the capital for buildings (including appliances, windows, insulation, heating/cooling systems, etc.), while tenants pay the energy and water bills, and 2) homebuilders specify home designs and building materials, but homeowners pay the energy and water bills.

According to the same NAS study noted above, there are examples of successful policies and programs, including:[134]

- Efficiency standards for vehicles and appliances
- Regulatory reforms for the adoption of large-scale systems like combined heat and power (CHP)
- Product labeling and promotion
- Building energy codes

132. *See* COMM. AM. ENERGY FUTURE ET AL., AMERICA'S ENERGY FUTURE: TECHNOLOGY AND TRANSFORMATION 77–79 (2009).

133. NAT'L ACAD. SCIS., ET AL., AM. ENERGY FUTURE PANEL ON ENERGY EFFICIENCY TECHS., REAL PROSPECTS FOR ENERGY EFFICIENCY IN THE UNITED STATES 208, 245–50 (2010).

134. NAT'L ACAD. SCIS., *supra* note 133, at 265–66, 269, 274–75.

It is important to note that there are also cultural pressures that impact decision-making. These cultural attitudes manifest themselves in individual decisions to conserve energy and water, even when policies or economic arguments do not require or justify those actions. Despite the importance of cultural forces, the discussion in this section focuses on policies that can overcome these barriers to help bring forth new technologies, as opposed to bringing forth new behaviors or attitudes. Some typical policy choices for the energy-water nexus are considered here based on traditional policies that are available and including the effective policies listed above.

Product labeling includes the dissemination of water and energy consumption information on consumer products. Labels on products inform consumers how the product compares to those of competitors and alternative technologies.

Public relations (PR) campaigns encompass targeted educational and outreach activities like public service announcements that inform those who can take direct action upon learning about a topic of interest. PR campaigns include informing the public about the science, economics, and government involvement regarding water and energy issues.

Data gathering involves data collected from a wide demographic. It can be used to create statistics for policy decisions and track whether policy decisions produce intended outcomes.

Mandates and regulations encompass government laws and rules that consumers and businesses must follow to avoid civil and/or criminal penalties. Water or energy quotas and allocations are included in this category, as are building codes and efficiency standards.

Right-pricing and full-cost recovery describe policies that ensure energy and water tariffs are sufficient to cover the supply costs, scarcity value, environmental costs of energy and water; and economic costs of energy and water.[135] Included in this definition are concepts such as ecological zoning and carbon pricing as means to incorporate externalities.

Government subsidies encompass targeted monetary incentives given by the government to specific projects, categories of projects, or industrial sectors.

Financing as a policy includes options that enable private businesses and consumers to spread the capital costs of technology over time rather than paying 100 percent up-front. Examples include traditional loans and Property-Assessed Clean Energy (PACE) financing where cap-

135. ORG. ECON.CO-OPERATION & DEV., SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN AGRICULTURE 18 (2010).

ital costs of renewable energy and energy efficiency projects are blended into the property owner's annual taxes.[136]

Public works projects encompass public capital projects funded entirely by the government via bonds or other public financing instruments.

2. Technologies Relevant to the Energy-Water Nexus

a. Low-flow Fixtures

Toilets that require less water per flush subsequently reduce water consumption, wastewater, and the embodied energy consumed in treating water and wastewater distribution especially when potable water is used. Low-flow showerheads promote water conservation for similar length showers. They also reduce the need for primary and secondary energy resources required to heat the water used in showers. Both pre-treatment of clean water and post-treatment of the wastewater after showering subsequently require less energy. The lower energy consumption down the supply chain reduces the quantity of GHG emissions emitted and water used to produce and convert the energy resources.

Because low-flow fixtures are low-cost consumer items, effective policies can be used to induce change by giving away the items or informing consumers of the items' low cost and environmental benefits. It is also effective to label products based on water efficiency as a method of educating the consumer to distinguish between products. Governments may also mandate use of low-flow fixtures in new construction. Full-cost recovery pricing of water, wastewater, and energy provides proper feedback to the consumer regarding use of fresh and hot water for non-potable home needs.

b. Energy-Efficient Appliances

Appliances, such as clothes washers and dryers, dishwashers, and televisions that require less energy also require less embodied water from energy. The lower energy consumption down the supply chain reduces the quantity of GHG emissions emitted and water used to produce and convert the energy resources.

Product labeling and PR campaigns can provide information about purchasing energy-efficient appliances. Additionally, governments often set standards for energy efficiency of appliances such that manufacturers have clear targets. For products that go beyond efficiency stan-

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136. BETHANY SPEER & RON KOEING, NAT'L RENEWABLE ENERGY LAB., PROPERTY-ASSESSED CLEAN ENERGY (PACE) FINANCING OF RENEWABLES AND EFFICIENCY (2010), *available at* http://www.nrel.gov/docs/fy10osti/47097.pdf.

dards, the government can provide rebates to consumers to adopt newer and more efficient technologies. The correct pricing of energy is critical in allowing the consumer to make the proper choice in purchasing appliances that consume considerable energy over their lifetime.

c. Distributed Rainwater Collection

By collecting rainwater runoff from roofs of residential and commercial buildings, water is captured in a relatively pure form. Water treatment is required to make it potable. For non-potable uses such as irrigation, rainwater collection bolsters energy security by avoiding the energy consumption from distributing water through a centralized system.

In treating distributed water to potable standards, smaller treatment systems, such as ultraviolet technologies that kill pathogens, require more energy per L than municipal-scale water treatment. Additionally, the energy consumption per L for running individual water pumps at each building is more than that from a centralized municipal system, thus decreasing energy security.[137] Using decentralized systems might also decrease water consumption indirectly because users tend to conserve when they have more information about the resources they consume, including its source.[138] A rainwater collection tank makes this source readily apparent. The carbon emissions associated with the extra energy consumed to treat distributed rainwater can hinder carbon management if total water consumption does not decrease. In some regions of the world, particularly dense cities with a high percentage of impervious ground cover, storm water runoff can overwhelm wastewater treatment facilities and cause overflows of sewage into local waterways that hinders water quality. Collecting and absorbing rainwater (e.g. on green roofs) on many buildings and homes mitigates and delays the storm water surge. Thus, rainwater collection can help keep existing wastewater treatment facilities with combined sewers below maximum capacity.

Rainwater collection can be relatively cheap when not using the water for potable uses, and the extra capital investment to treat the water to drinking quality can be helped by subsidies and financing mechanisms (e.g. those that include the costs into mortgage payments). In some cases water rights laws and regulations can heavily influence the integration of rainwater collection. For example, Colorado zoning policies and

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137. Cara Beal et al., Energy and water metabolism of a sustainable subdivision in southeast QLD: the little toe of the urban ecological footprint? (2008) (unpublished) (on file with author) (presented in Melbourne, Australia at Enviro 2008).

138. NAT'L ACAD. SCIS., *supra* note 133, at 291–92.

water rights laws actually prevented home and building owners from legally collecting water that fell on their property until 2009.[139] Similarly, rainwater collection in Utah was illegal until Senate Bill 32 was passed in 2010; however, there are still restrictions on storage volumes.[140] PR campaigns can inform home and building owners of the benefits of and subsidies available (i.e. free rain barrels from the government) for using collected rainwater for irrigation and storm water runoff prevention.

d. Solar Water Heating

Using renewable solar energy to directly heat water enhances energy security by minimizing the need for primary and secondary energy sources (e.g. fossil fuels, biomass, electricity) while also enhancing water security and quality by reducing the water requirements for mining fuels and cooling thermoelectric power plants. Eliminating the need for grid-based electricity eliminates GHG emissions associated with fossil-fueled power plants.

Governments can mandate the use of solar hot water systems for residential (e.g. Israel, Hawaii) or commercial construction. Subsidies also help promote retrofitting solar hot water systems onto existing buildings and homes to offset the up-front capital cost. A PR campaign can inform citizens that this is often the most cost-effective technology for incorporating renewable energy into their home that saves money over time by eliminating the need for heating fuels. Proper labeling of all hot water heaters enables consumers to effectively compare solar hot water systems to those powered by electricity, natural gas, or other fuels. Because solar hot water systems are applicable for retrofitting existing homes and businesses, some financing assistance can help overcome the up-front capital expense of integrating the system into the existing home plumbing.

e. Geothermal Heat Pumping

Geothermal heat pumps use the relatively constant temperature of the shallow earth to regulate room temperature in both cold and hot climates. This technology enhances energy security by reducing the need for primary energy (e.g. natural gas, heating oil, biomass, and fuels burned for thermoelectric power) for heating and cooling. Using this carbon-free energy from the earth helps carbon management, and geother-

139. Kirk Johnson, *It's Now Legal to Catch a Raindrop in Colorado*, N.Y. TIMES, June 28, 2009, http://www.nytimes.com/2009/06/29/us/29rain.html.

140. S.B. 32, 2010 Leg., Gen. Sess. (Utah 2010), *available at* http://le.utah.gov/~2010/bills/sbillenr/sb0032.pdf (limiting storage to one 2,500 gallon underground tank or two 100 gallon above-ground tanks).

mal heat is normally considered a renewable energy resource. Water security also increases because of reduced water requirements for mining fuels, cooling thermoelectric power plants, and hydropower operation. The working heat transfer fluid of closed-loop designs stays within the system. For properly functioning systems, water quality is not affected because no external water is required. However, open-loop systems exchange water with underground aquifers and present opportunities for thermal water degradation if not designed properly. Thus, proper design and use of geothermal heat pumps can prevent harm to water quality.

Geothermal heat pump systems are applicable for residential and commercial heating and cooling. Subsidies and financing can give incentive to those contemplating investment in new construction. Furthermore, other subsidies and financing mechanisms can help deter the cost of retrofitting existing buildings. Public Relation campaigns and product labeling help educate and inform consumers and businesses of the costs and benefits of installing geothermal heat pump systems. Right pricing of both water and energy helps provide the proper market signals for this effective but capital-intensive technology.

f. Electricity Peak Shifting

Electricity peak shifting describes the coordinated and scheduled operation of electric devices and processes at times of low demand when their operation at peak demand is not crucial. Example processes that need not operate at peak hours of the day are refrigeration, pool pumping, and water treatment. Energy storage systems also fall under the category of peak shifting. For example, air-conditioning systems can use nighttime electricity to create ice that can be used later for cooling buildings during hot days. This shift in electricity demand prevents the need to run high-powered air conditioning systems during peak times of the day. By relieving stress on the electric grid, this helps energy security. However, the trade off for energy security is that more energy is consumed in the aggregate in the storage-based peak shifting cycle. The full water and energy benefits from shifting electricity demand may not be generalized across regions because they depend heavily on the characteristics of local electricity grids. Electric generating plants that operate in the day versus night can have various characteristics regarding water consumption and quality, renewability, and GHG emissions. For example, wind turbines in many regions produce more electricity at night than during the day. Shifting the load to night hours can help integrate that low-carbon and low-water consuming renewable technology. Additionally, the least energy efficient power plants are usually the last to serve demand, and peak shifting reduces the need to use the least efficient plants.

Time-of-use pricing—where consumers are exposed to low prices during low demand and high prices during high demand—is an effective policy for managing electricity demand to shift consumption from times of high demand to those of lower demand. Public Relation campaigns help inform consumers and businesses of the economic benefits of peak shifting. In order to determine the effectiveness of peak shifting, it is crucial to gather sufficient data to describe the relationships and correlations among policies, time-of-use pricing, and the actual timing of electricity consumption. Subsidies can help consumers integrate infrastructure such as smart grid devices and electronics that facilitate automated shifting of electricity demand.

g. Electricity Peak Shaving

Electricity peak shaving differs from peak shifting; it describes absolute reductions in electricity demand at peak electric load, without shifting that demand to other times of the day. An example of a peak shaving technology is the cycling of air conditioners during summer afternoons to prevent them from operating simultaneously while allowing them to run a sufficient duration to cool effectively. Reducing demand for electricity at peak consumption, when cooling loads are the highest, such as during summer afternoons and evenings, can reduce the water and fuel requirements at power plants. Summer afternoons and evenings are when cooling systems, both wet and dry, are the least energy efficient and water evaporation from cooling is the highest. When power plants need less cooling water, they discharge less warm cooling water into the environment. Peak shaving enhances energy security by consuming less fuel while keeping system load below the electricity grid's capacity.

The same policies that promote electricity peak shifting generally help promote peak shaving behavior. Some inexpensive subsidies can be effective. Such subsidies include utility companies providing households with thermostats that control the cycling of air conditioners.

h. Groundwater Pumping

Crop irrigation using water pumped from aquifers has enabled tremendous gains in agricultural production by providing a secure medium-term supply of water. However, pumping groundwater faster than it is recharged turns the aquifer into a quasi-fossil resource[141] that is not renewable and decreases long-term water security. Thus, groundwater pumping can increase or decrease water security depending upon the rate of pumping relative to recharge. Because overdrawing an aquifer lowers the water table, pumping that groundwater to the surface requires more energy. This overdraft of an aquifer causes a reduction in energy security and more GHG emissions from fossil power plants. A recent study notes the increasing amount of groundwater pumping and GHG emissions required to irrigate Chinese agriculture and feed an increasingly affluent citizenry.[142] China is not unique to this situation as significant aquifer drawdown occurs in Northwest India and the Ogallala aquifer of the Central United States, among other regions.[143]

In some parts of the world, the Rule of Capture governs groundwater ownership and use. This rule based in English Common Law, states that a landowner has the right to pump water beneath his or her property without regard for effects on neighboring wells.[144] Consequently, groundwater can potentially be used with less cost and fewer legal steps than surface water. Scholars question whether the Rule of Capture, originally used to determine the ownership of game animals, is appropriate for groundwater, especially in context of the hydrological linkage between groundwater and surface water.[145]

When irrigators use groundwater for agricultural purposes, the introduction of subsidies leads to increases in groundwater extraction.[146] For example, irrigated agriculture in France and Spain has increased in response to subsidies for installing irrigation equipment and guarantees

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141. Fossil aquifers are those that are geologically sealed such that they do not accumulate water recharged from precipitation. Here we use 'quasi' to mean that the aquifer is recharged over thousands of years as opposed to withdrawing the water over decades.

142. Jinxia Wang et al. *China's Water-Energy Nexus: Greenhouse-Gas Emissions from Groundwater Use for Agriculture*, ENVTL. RES. LETTERS, (IOPScience, Phila.), Mar. 14, 2012, at 1, 2.

143. Yoshihide Wada et al., *Global depletion of groundwater resources*, GEOPHYSICAL RES. LETTERS, Oct. 26, 2010, at L20402, 3.

144. *Texas Water Law*, TEX. WATER, http://texaswater.tamu.edu/water-law (last visited Nov. 16, 2012).

145. *See generally*, Response to Petition for Review, *Edwards Aquifer Authority v. Day*, 369 S.W.3d 814 (Tex. 2012) (No. 08-0964).

146. ORG. ECON. CO-OPERATION & DEV., AGRICULTURAL AND FISHERIES POLICIES IN MEXICO: RECENT ACHIEVEMENTS, CONTINUING THE REFORM AGENDA 167–68 (2006) [hereinafter OECD REFORM]; Leena Srivastava & I.H. Rehman, *Energy for sustainable development in India: Linkages and strategic direction*, 34 ENERGY POL'Y. 643, 649 (2006); OECD SUSTAINABLE, *supra* note 97, at 84; *see* Tushaar Shah et al., *Water Sector Reforms in Mexico: Lessons for India's New Water Policy*, 39 ECON. & POL. WKLY. 361, 365 (2004).

of low water prices.[147] Research models show that, contrary to popular belief, subsidies for water-efficient irrigation equipment such as drip irrigation are unlikely to reduce water use in a river basin. Optimal agricultural water application leads to higher crop yield and higher water consumption via ET. Higher ET coupled with zero return flows and decreased aquifer recharge lead to less water available for an entire basin.[148] Approaches to mitigating groundwater depletion include rules that prohibit expansion of groundwater pumping. Such laws are currently in place in most provinces in The Netherlands.[149] Proper scientific data collection and dissemination on groundwater levels are crucial for groundwater resource management, and some studies have shown that informing citizens about their water supply can influence their behavior.

i. Wind Power, Solar PV Panels, and Non Steam Cycle CSP

Behind hydropower, wind power is often the most cost-effective renewable energy technology within good resource areas characterized by wind speeds greater than 7.5 m per second at 50 m height. By providing locally-derived energy while only consuming the water necessary to wash windmill blades, wind power enhances water and energy security without directly emitting GHGs. Solar PV and CSP systems that avoid using steam cycles (e.g. Stirling engines) have the same GHG, water, and renewable energy benefits as wind power.

Globally, wind and solar power have benefitted from subsidies such as feed-in tariffs and the production/investment tax credit (PTC/ITC) in the United States. A feed-in tariff guarantees a (usually) high price to the renewable asset owner for selling excess electricity into the grid, thus providing a revenue stream in addition to offsetting some need to purchase electricity from the grid. The PTC is a subsidy much like the feed-in tariff except it is usually beneficial to commercial-scale renewable systems. The PTC provides a direct tax offset for every kilowatt-hour (kWh) of electricity produced from a renewable installation (e.g. 2.2 cents for every kWh from a wind farm). The ITC is based upon a percentage—30 percent—of capital costs of renewable installations. However, because the PTC and ITC are "tax credits," the renewable energy plant owner must have profits, and thus a federal tax liability, in order to take advantage of the PTC or ITC. If the renewable energy plant

147. *See* DAVID BALDOCK ET AL., ENVT. DIRECTORATE OF THE EUROPEAN COMM'N, THE ENVIRONMENTAL IMPACTS OF IRRIGATION IN THE EUROPEAN UNION ii (Mar. 2000).

148. Frank A Ward. & Manuel Pulido-Velazquez, *Water Conservation in Irrigation Can Increase Water Use*, 105 PROC. NAT'L ACAD. SCI. 18215, 18218 (2008).

149. BALDOCK ET AL., *supra* note 147, at 25.

owner does not have a tax liability, it can sell the tax credits to another business, such as a bank, that does have taxes.

Renewable Portfolio Standards mandate a target installed capacity or percentage of total generation that must come from renewable energy technologies. They also provide medium to long-term certainty for investments in these capital-intensive systems whose benefits include the low operating costs. Because of the high costs, mechanisms such as Property Assessed Clean Energy financing[150] help reach residential consumers by spreading the costs of solar PV installation over time via property tax assessments. Wind and solar PV also stand to benefit by incorporating externalities such as water consumption and GHG emissions into markets and prices. "Time-of-use" pricing policies that expose consumers to higher costs during peak demand times (e.g. midday in summer) help provide more value to solar technologies because their generation profile is better matched with summer demand. Data gathered in renewable energy resource assessments help facilitate government and business planning to effectively develop projects in the most effective locations.

j. Combined Heat and Power (CHP)

Using "waste heat" from thermal power plants and distributed energy generation systems for heating and cooling makes better use of the fuel source to enhance energy security. Because services like electricity, heating, and cooling require less fuel, less water is used for mining those fuels, and GHG emissions from fossil fuels are minimized per unit of energy delivered. CHP systems can use biomass or fossil fuels. The impacts of needing less water for cooling should also lead to benefits for water quality in addition to water security.

While CHP technologies are readily available, policies are often necessary to incentivize the whole systems thinking[151] required to minimize energy consumption for the infrastructure projects large enough to take advantage of CHP. CHP systems can include district heating and cooling such that public works projects can enable distribution of energy in the form of hot or cool water. Subsidies can induce commercial and

150. Bethany Speer & Ron Koeing, Nat'l Renewable Energy Lab., Property-Assessed Clean Energy (PACE) Financing of Renewables and Efficiency (2010), *available at* http://www.nrel.gov/docs/fy10osti/47097.pdf.

151. In the context of energy, "whole systems thinking" relates to the beneficial integration of individual energy production technologies and demands such that overall energy use and costs can be reduced rather than focusing on only one aspect at a time. Example concepts are when architects and heating ventilation and cooling engineers design a building together to minimize energy needs by proper building orientation, minimizing plumbing pipe bends to reduce pumping needs, and other concepts.

industrial facilities to invest in CHP when the opportunity costs seem too high compared to investing to produce more products like consumer electronics and petrochemicals. Relative to a corporation, governments might have more incentive to pursue strategies that lower importation of fuels. Mandates might also be a policy for forcing industrial facilities to incorporate CHP.

k. Wet-cooled Power Plants

Wet-cooled power plants depend upon access to a reliable supply of water and thus reduce water security, but wet-cooled power plants are also more power efficient than dry-cooled facilities and thus enhance energy security. Water quality can be affected by the discharge of hot water into aquatic environments (e.g. using once-through or open-loop designs) such that wildlife is detrimentally impacted, but wet cooling towers prevent most appreciable thermal issues.[152]

Wet-cooling systems are common practice for the electric generation industry. Thus, there is little policy incentive needed to affect their usage. However, some governments may wish to mandate or incentivize that a certain type of wet-cooled design be used over another (e.g. cooling towers versus once-through).[153]

l. Dry-cooled Power Plants

Using dry-cooled systems on steam-driven thermoelectric power plants (e.g. coal, natural gas, nuclear, steam-based CSP) reduces water consumption by up to 90 percent, enhancing water security.[154] However, dry cooling requires additional fuel for the same net electrical generation because it reduces the efficiency of converting fuel into electricity. Depending upon its application, dry cooling can both help and deter the objectives of carbon management and reduction. For applications such as CSP in desert environments where water may be unavailable, dry cool-

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152. For example, as part of section 316(a) of the Clean Water Act and the National Pollutant Discharge Elimination System permitting process, the United States Environmental Protection Agency establishes thermal discharge limits for some power plants to prevent water effluent from potentially killing wildlife due to raised water temperatures. 33 U.S.C. §1326(a) (2012).

153. *See e.g.*, *Clean Water Act Section 316(b) Regulations on Intake Structures for Industrial and Cooling Facilities*, U.S. ENVTL. PROT. AGENCY (Mar. 28, 2011), http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/index.cfm (accessed Nov. 21, 2012); 33 U.S.C. §1326(b) (2006).

154. Ashlynn S. Stillwell et al., *The Energy-Water Nexus in Texas*, 16 ECOLOGY & SOC'Y 2 (2011); JORDAN MACKNICK ET AL., NAT'L RENEWABLE ENERGY LAB., A REVIEW OF OPERATIONAL WATER CONSUMPTION AND WITHDRAWAL FACTORS FOR ELECTRICITY GENERATING TECHNOLOGIES 25 (2011), *available at* http://www.nrel.gov/docs/fy11osti/50900.pdf.

ing towers can enable the use of zero GHG-emitting CSP. Thermoelectric renewable and fossil power plants that use dry cooling are less efficient, increasing both GHG emissions and price per output.[155] However, we assumed dry-cooling can be viewed as either helping or hindering energy security depending upon the situation. For using dry-cooling for a power plant where water is available, less net electricity is delivered to the grid at higher cost —decrease in energy security—but in cases where water is not available, such as very arid and desert environments, dry-cooling can be viewed as a technology that enables thermoelectric power production that would otherwise not be possible—thus increasing energy security.

Mandates can dictate dry cooling as the best available technology. Incorporating externalities by zoning or pricing based upon water availability can influence the use of dry-cooling as full-cost accounting, or right-pricing of water in water-scarce regions can incentivize its use on power plants. Market signals show when water is too expensive to be used for power plant cooling. Because dry cooling towers are large capital expenditures, financing mechanisms can better enable their use.

m. Steam-Cycle CSP

Steam-cycle CSP systems such as parabolic mirror troughs and power tower designs[156] have the same GHG, energy, and renewable energy benefits as wind and solar PV, but the steam-cycle requires cooling historically provided by water.[157] Thus, steam-based CSP compromises water security even though dry cooling systems can enable functionality with very low water consumption. Because steam-based CSP systems are based upon thermal energy, they have the advantage of relatively easy integration with thermal storage technologies and traditional fossil fuel (e.g. natural gas combustion turbines) systems.

155. U.S. DEP'T OF ENERGY, CONCENTRATING SOLAR POWER COMMERCIAL APPLICATION STUDY: REDUCING WATER CONSUMPTION OF CONCENTRATING SOLAR POWER ELECTRICITY GENERATION, REPORT TO CONGRESS 5 (2010), *available at* http://www.nrel.gov/csp/pdfs/csp_water_study.pdf.

156. A "trough" design involves several rows of parabolic-shaped mirrors that concentrate sunlight on a tube that lies at the mirror focal point and runs along the length of the mirror trough. This tube is filled with a heat transfer fluid, and that fluid flows into a heat exchanger that heats the steam for running through a conventional steam cycle for electricity generation. A "power tower" design uses hundreds to thousands of mirrors that track the sun moving across the sky to reflect the sunlight to a single point located at the top of a tower. This focal point is a location for transferring heat to steam that runs in a conventional steam cycle for electricity generation. *See* ENERGY AND POWER GENERATION HANDBOOK: ESTABLISHED AND EMERGING TECHNOLOGIES ch. 1–5 (K.R. Rao ed. 2011).

157. MACKNICK ET AL., *supra* note 154, at 5.

Steam-based CSP systems benefit from the same policy choices mentioned previously for wind, solar PV, and other CSP designs. Steam-based CSP is influenced by the same efficiency and cost trends for wet and dry cooling technologies as for fossil fuel power plants. Because CSP systems are most effective in desert regions with ample direct sunlight but low water availability, it is important that policies coordinate CSP development with cooling strategies and technologies.

n. Hydraulic Fracturing

Hydraulic fracturing is the process of pressurizing water in either vertical or horizontal wells for the purpose of breaking apart rock in the subsurface while keeping the fissures propped open by additives such as sand. This fracturing technique is commonly used for accessing low-permeability shale layers to extract natural gas and petroleum liquids. In the future, the technique might be used to create flow paths for water to absorb heat from hot dry rocks in enhanced geothermal energy systems. Thus, hydraulic fracturing can be used for fossil and renewable energy production, and the type of energy produced affects carbon management. The fracturing process requires water, and it puts pressure on water security, especially in areas of existing water scarcity, although the quantity of hydrocarbon energy production per unit of water is still relatively large.

The beneficial tradeoff is enhanced energy production. Fracturing techniques and drilling are common practices. Water quality risks primarily stem from surface spills in handling saline water produced in the fracturing process rising to the surface in the well bore from the targeted geologic formations. The use of best management practices like using cement and steel casing to secure bore holes from contaminating shallow groundwater can minimize impacts to water quality. Additionally, treating produced water is necessary where there is a lack of proper geology to safely inject the produced water into hazardous disposal wells.

Because hydraulic fracturing is a well-established technological process that is integral to some energy production techniques, the technique itself does not require subsidies and incentives for use. However, there are still outstanding questions regarding short and long-term impacts to drinking water, particularly in regions where there are known natural pathways for water migration from near the targeted geologic shale formations.[158] Every geologic reservoir is unique, and adequate human resources for proper regulation will help enable the expansion of

158. Warner, *supra* note 87.

fracturing into new regions (e.g. those not accustomed to drilling activities) without harming local water resources and environments.

o. Hydropower

Hydropower presents one of the most direct connections between water and energy. Flowing water directly spins turbines connected to electric generators that produce renewable electricity. This enhances energy security and, oftentimes, water security as well by providing stored water for recreation, drinking, flood control, and irrigation behind the hydropower dam. However, they significantly alter the natural flow of the river and significantly change its temperature, which degrades both upstream and downstream water quality. Because the dam stores a large volume of water, more water evaporates than from the normal river, reducing fresh water inflows into bays and estuaries.[159] Although hydropower reservoirs emit methane, hydropower is considered a low GHG-emitting energy system that helps carbon management more than fossil fuel combustion. However, hydropower reservoirs that are shallow with large surface areas can have GHG emissions similar to natural gas combined cycle plants.[160]

Proper regulations and licensing procedures for hydropower dams enable due consideration of the environmental impacts of hydropower development. Proper ecological zoning and prices for GHG emissions help promote hydropower development. Financing and government funding are often involved because hydropower projects are capital intensive and the associated dams often serve many public needs.

p. Desalination

Desalination systems enhance water security by providing potable and irrigation water from sources of high salinity. This process incurs large energy costs,[161] and it can detrimentally affect environmental water quality because of the need to dispose of the highly-concentrated distillate byproduct. Instead of displacing fossil-fueled power generation, desalination adds pressure on carbon management due to associated GHG emissions from power plants and additional use of energy for

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159. Dams can also be "re-operated" with an environmental focus to support freshwater inflow into bays and estuaries. Brian D. Richter & Gregory A. Thomas, *Restoring Environmental Flows by Modifying Dam Operations*, 12 ECOLOGY & SOC'Y 2 (2007).

160. *See* TERRY BARKER ET AL., INTERGOV'T PANEL ON CLIMATE CONTROL, CLIMATE CHANGE 2007: MITIGATION, CONTRIBUTION OF WORKING GROUP III TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 273–74 (B. Metz et al., eds., 2007).

161. Menachem Elimelech & William A. Phillip, *The Future of Seawater Desalination: Energy, Technology, and the Environment*, 333 SCIENCE 712, 712–13 (2011).

water. Some project developers and governments have chosen to match renewable or low-carbon energy systems with desalination to avoid these GHG emissions, but there is no requirement for this association.[162] Using waste heat for thermal desalination can be a cooperative way to make use of energy resources to enhance water security.

A reliable water supply is fundamental for a good economy and healthy lifestyle. Governments can engage in public works projects for desalination to provide this water supply. Instead of directly owning desalination systems, some governments dictate that installation and operation of the systems by private companies is part of an overarching government strategy by mandating a certain number of systems to be installed over time, as in Israel. Properly priced water supplies gives the correct signal for whether investment in desalination is warranted versus conservation and development of cheaper supplies. For regions where desalination is deemed a priority to mitigate fluctuations in water supply, various financing mechanisms can help spread the costs over long time frames.

q. Wet-Cooled Carbon Capture and Storage (CCS)

CCS technologies reduce GHG emissions in fossil fuel power plants, increasing energy security by continuing coal and natural gas use. However, installing a carbon dioxide (CO_2) capture system on a fossil fuel power plant increases its fuel consumption for the same net power output as a plant without CO_2 capture, decreasing energy efficiency and depleting fuel supplies faster (assuming increased prices don't suppress coal or natural gas demand). The additional power requirements for operating the CO_2 capture and compression[163] systems use power otherwise available to the grid. Correspondingly, if the power plant uses wet cooling systems, the water consumption per net electricity (e.g. L/kWh) will also increase because the power plant sends less electricity to the grid for the same fuel input.

While there is some possibility for the CO_2 injected into deep saline aquifers to affect shallower fresh groundwater supplies, these adverse impacts have not yet been documented. Proper location and design of sequestration operations should avoid detrimental impacts.[164] Large-

162. Patrick Barta, *Amid Water Shortage, Australia Looks to the Sea*, WALL ST. J., Mar. 11, 2008, http://online.wsj.com/article/SB120518234721525073.html.

163. In order to economically transport via pipeline and subsequently inject CO_2 into the subsurface, the CO_2 must first be compressed to a liquid (or liquid-like supercritical) thermodynamic condition to minimize the handling volume. These compressors require electricity or natural gas to operate.

164. Katherine Romanak, Res. Assoc., Bureau of Econ. Geology, Presentation for the UNFCCC Subsidiary Body for Scientific and Technological Advice: Groundwater Protec-

scale implementation of CCS is necessary to significantly reduce GHG emissions, but because there are significant costs for implementation,[165] significant policy signals are required for CCS rollout. Policies that will most likely induce CCS use are those that include the external GHG emissions costs into markets or tax codes. Direct subsidies can help first-movers[166] for CCS and begin the learning process to bring CCS from pilot and prototype-scale projects to those of full-sized power plants. Data on the locations of high quality geologic storage locations helps both public and private entities target investments. As with any power plant scale infrastructure project, financing plays a large role in the large capital costs involved in CCS. Public works projects could be influential in starting and continuing CCS development because some pipeline infrastructure and geologic reservoirs might be under the domain of governments or regulated private entities.

r. Biofuels

The biofuel lifecycle generally requires more water withdrawal and consumption than for conventional fuels. Irrigated biofuel feedstocks require 2–3 orders of magnitude more water per service than non-irrigated feedstocks (10–300 L/km versus 0.2–0.5 L/km).[167] When the water consumed during crop ET is taken into account, that quantity dominates the point source consumption compared to water consumed at biorefineries that convert feedstocks to fuels.[168] Thus, the agricultural aspect of biofuel production dominates the water-related impacts for both quantity and quality. Accordingly, land management and agricultural practices impact the water footprint of crops whether they are grown for food or fuels.

The main policy objective of biofuels is energy security via a domestically produced renewable alternative to petroleum. However, the true energy security benefits of existing biofuel life cycles are unclear.

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tion (Sept. 7–8, 2011), *available at* http://unfccc.int/files/methods_and_science/other_methodological_issues/application/pdf/groundwater_protectiion.pdf (Powerpoint slide show that accompanied presentation).

165. Edward S. Rubin et al., *Cost and Performance of Fossil Fuel Power Plants with CO2 Capture and Storage*, 35 ENERGY POL'Y 4444, 4452 (2007).

166. The term "first-movers" generically refers to companies that install or construct technologies that are not yet fully commercially proven or economically viable, but for which the company can still find some benefit. An example is a company that captures CO_2 to sell for use in enhanced oil recovery operations in mature oil fields.

167. King & Webber, supra note 80, at 7866.

168. Göran Berndes, *Future Biomass Energy Supply: The Consumptive Water Use Perspective*, 24 INT'L J. WATER RES. DEV. 235, 238–40 (2008); Gerbens-Leenes et al., *supra* note 85, at 10220.

Brazilian sugar cane ethanol is produced with an appreciably higher net energy (ratio of energy output: energy input of 8:1 to 10:1) than U.S. corn-based ethanol (ratio of energy output:energy input of 0.8:1 to 1.5:1), making it more energetically and economically viable.[169] Compared to most biofuel life cycles, Brazilian sugar cane ethanol has less water consumption and irrigation per energy output because of the sufficient rainfall in the south-central region of Brazil where the vast majority of sugar cane agriculture occurs.[170] The United States and Brazil both have irrigated and non-irrigated biofuel feedstocks, and future expansion of biofuel production in both countries can increase irrigation needs and water consumption via additional biorefineries depending upon technology and policy developments.

The two biofuel countries that represent the vast majority of worldwide biofuel production have unequal energy and water security effects. Brazilian sugar cane ethanol likely improves energy security in Brazil without creating significant water scarcity problems. There are few data or studies on water quality impacts from the Brazilian biofuels life cycle, but some show less biodiversity and higher nitrogen content in streams containing runoff from sugar cane agriculture.[171] Because of its high nutrient content, the proper redistribution onto soils of the byproduct vinasse from the ethanol fermentation process is critical for maintaining long term soil and water quality. U.S. corn grain ethanol hinders water quality while not significantly enhancing energy or water security. Direct emissions from both Brazilian sugar cane ethanol and Midwestern U.S. corn grain ethanol reduce carbon emissions versus the petroleum life cycle.[172] However, indirect emissions from land use changes cloud the issue of GHG emissions from biofuel development because agriculture for biofuel feedstocks and food are fully intertwined. For example, farming more corn and less soy in the United States presents an opportunity for more soy agriculture in Brazil. This triggers deforestation from pasturing new areas, which releases stored carbon.[173]

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169. Alexander E. Farrell et al., *Ethanol can contribute to energy and environmental goals*, 311 SCIENCE 506, 507 (2006); Macedo et al., *supra* note 83; David Pimentel et al., *Ethanol Production: Energy, Economic, and Environmental Losses*, 189 REVS. ENVT'L CONTAMINATION & TOXICOLOGY 25, 31 (2007).

170. Gerbens-Leenes et al., *supra* note 85, at 10221.

171. Juliano José Corbi & Susana Trivinho-Strixino, *Relationship Between Sugar Cane Cultivation and Stream Macroinvertebrate Communities*, 51 BRAZ. ARCHIVES BIOLOGY & TECH. 769, 773 (2008).

172. U.S. ENVTL. PROT. AGENCY, OFF. OF TRANSP. & AIR QUALITY, EPA LIFECYCLE ANALYSIS OF GREENHOUSE GAS EMISSIONS FROM RENEWABLE FUELS 3–4 (2010); Macedo et al., *supra* note 83, at 590–91.

173. Joseph Fargione et al., *Land Clearing and the Biofuel Carbon Debt*, 319 SCIENCE 1235, 1237 (2008); Timothy D. Searchinger, et al., *Fixing a Critical Climate Accounting Error*, 326

The full implications of GHG emissions related to biofuels are complex and beyond the scope of this article. For example, land use models that calculate the GHG emissions of ethanol production in Brazil due to U.S. ethanol demand show its life cycle GHG emissions to be less than 50 percent of gasoline GHG emissions.[174]

Renewable liquid fuels such as ethanol and biodiesel have traditionally required subsidies and targeted government mandates to ensure that the private sector commits the large investment to enable alternatives to petroleum. Additionally, governments have provided energy subsidies to the agricultural sector directly through support for biodiesel and electricity use and indirectly for feedstocks to produce biofuels and bioenergy.[175] These subsidies can increase pressure on water resources if more total irrigated land is brought into agricultural production or additional land is cultivated in areas where evapotranspiration rates are higher. Thus, subsidies for bioenergy could increase water withdrawal and/or consumption just as subsidized electricity costs for groundwater pumping in some countries leads to excessive extraction of groundwater.[176] Policies that remove energy subsidies for providing water needed for biofuels, such as full-cost recovery, may contribute to more sustainable water use. However, full-cost accounting of water may directly hinder the subsidies meant to promote increased production of biofuels, making the need for coordinated policy of paramount importance. To assist in carbon management objectives, the inclusion of costs from all water use and carbon emissions from the biofuel lifecycle (e.g. energy inputs, soil emissions, and carbon debt) along with structured, scientific, and repeatable accounting procedures will clarify the true costs and benefits of biofuels. Resource data gathered in renewable energy resource assessments help governments and businesses effectively plan and develop projects in the most effective locations.

s. Municipal Waste to Energy

Collecting methane gases from landfills and wastewater treatment plants (e.g. using anaerobic digestion) reduces GHG emissions while cre-

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SCIENCE 527, 528 (2009); Timothy D. Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*, 319 SCIENCE 1238, 1240 (2009).

174. ANDRÉ M. NASSAR ET AL., INST. INT'L TRADE NEGOTIATIONS, REPORT TO THE U.S. EPA REGARDING THE PROPOSED CHANGES TO THE RENEWABLE FUEL STANDARD PROGRAM: IMPACTS ON LAND USE AND GHG EMISSIONS FROM A SHOCK ON BRAZILIAN SUGARCANE ETHANOL EXPORTS TO THE UNITED STATES USING THE BRAZILIAN LAND USE MODEL (BLUM) 23–24 (2009).

175. OECD REFORM, *supra* note 146, at 77; OECD SUSTAINABLE, *supra* note 97, at 74; Shah, *supra* note 97, at 363–65; Srivastava & Rehman, *supra* note 146, at 646–47.

176. OECD SUSTAINABLE, *supra* note 97, at 85.

ating a renewable combustible resource.[177] Solid biomass waste can also be burned for heat and electricity. Additionally, the produced energy can power the wastewater treatment facilities. This on-site energy generation makes the facilities more self-sufficient, enhances energy security, and cleans water for discharge into the environment.

Municipal governments typically own landfills and wastewater treatment facilities. Thus, new public works projects can incorporate the additional infrastructure required to capture energy, and it is possible to retrofit wastewater treatment plants. These public works projects can often be funded by municipal bonds and by incorporating the initial costs into regulated rate structures that should actually decrease over time. Additionally, waste to energy projects become more cost feasible with a mandated emissions standard or a price on the externality of GHG emissions.

t. Greywater and Reclaimed Water

Greywater is the product of applications that do not involve human or animal excrement— water from sinks, showers, dish washers, and clothes washers; water from kitchen sinks is not consistently included due to high organic content.[178] After minimal treatment and filtering, greywater can be used in residential and commercial applications such as irrigation and sewage systems. While greywater treatment does not consume as much energy as treating water back to potable condition, decentralized treatment systems[179] are typically less energy-efficient than large centralized systems that can benefit from larger, more-efficient pumps. Decentralized greywater treatment uses approximately twice the energy per unit of water as pumping and treating sewage in a centralized system.[180] Thus, treating, distributing, and using greywater enhances water security by recycling water but could decrease energy security.

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177. When organisms undergo respiration in an aerobic environment (oxygen is present), the end products are carbon dioxide and water. In an anaerobic environment (no oxygen present), methane (CH_4) is one of the end products. *See* ENERGY AND POWER GENERATION HANDBOOK: ESTABLISHED AND EMERGING TECHNOLOGIES, *supra* note 156.

178. B. Jefferson et al., *Technologies for domestic wastewater recycling*, 1 URBAN WATER 285, 285–92 (1999); Fangyue Li et al., *Review of the technological approaches for grey water treatment and reuses*, 407 SCI. TOTAL ENVT. 3439, 3439–49 (2009); Jakob Ottoson & Thor Axel Stenstrom, *Faecal contamination of greywater and associated microbiological risks*, 37 Water Res. 645, 645–655 (2003); Ralf Otterpohl et al., *Source Control in Urban Sanitation and Waste Management: Ten Systems with Reuse of Resources*, 39 WATER SCI. & TECH. 153, 153–60 (1999).

179. Decentralized water treatment systems are those operating on the scale of small neighborhoods, buildings, or even single homes. Beal et al., *supra* note 137.

180. Beal et al., *supra* note 137.

Distinct from greywater, treated effluent from centralized wastewater treatment plants, is reclaimed water. While reclaimed water does not generally meet potable standards,[181] it has undergone more treatment than greywater prior to being distribution in a piped network ("purple pipe"). With high existing levels of wastewater treatment and minimal distribution, reclaimed water use can reduce energy consumption while reducing freshwater demand for applications such as cooling systems for power plants, irrigation, and city wastewater plumbing. However, compared to conventional potable surface water treatment, reclaimed water use can require more energy than it saves because of less efficient wastewater treatment and significant distribution requirements.[182]

Because it is important for health reasons to keep potable and greywater flows separate, greywater systems are usually confined to small-scale residential or commercial use. Financing and subsidies can help overcome the up-front capital expense of installing these systems or integrating them into existing plumbing of homes and businesses. To produce reclaimed water, large-scale municipal systems require additional wastewater treatment before distribution in plumbing and sewer networks. Thus large-scale reclaimed water systems usually require publicly-funded projects and financing to lay piping infrastructure that connects to buildings and homes. Additionally, clear regulations and plumbing practices help enable building contractors to properly design and install water reuse systems that safely connect to any available municipal reclaimed water systems.[183] Right pricing of water based on quality can help provide feedback to consumers and governments for making decisions about investments in greywater and reclaimed water infrastructure.

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181. In Texas, for example, reclaimed water intended for use without human contact can have 800 colony-forming units (CFU) of *E. coli* per milliliter in a single grab sample. 30 TEX. AMIN. CODE §210.33 (2009). Drinking water must test negative for *E. coli*. *Drinking Water Contaminants*, U.S. ENVTL. PROT. AGENCY, (May 2009), http://water.epa.gov/drink/contaminants/index.cfm.

182. Ashlynn S. Stillwell & Michael E. Webber, *Water Conservation and Reuse: A Case Study of the Energy-Water Nexus in Texas*, *in* WORLD ENVIRONMENTAL AND WATER RESOURCES CONGRESS 2010: CHALLENGES OF CHANGE 4102–04 (Richard N. Palmer ed., 2010).

183. For example, Texas Administrative Code outlines required spacing between drinking water, reclaimed water, and wastewater pipes underground to prevent cross-contamination from leaking. Additionally, reclaimed water infrastructure is painted purple to minimize confusion and prevent mistaking reclaimed water pipes for drinking water pipes. 30 TEX. AMIN. CODE §210.21–210.25 (2009).

u. Inter-basin Water Transfer

Inter-basin water transfer involves conveying water from one water basin to another with an engineered structure such as a pipeline and pump system. Even though water security is only enhanced for the basin targeted for delivery, total water consumption for both basins could increase, decrease, or remain constant depending upon any contractual agreements and the water availability in the outflowing basin. Furthermore, inter-basin transfer works against energy security due to both the required energy embodied in the infrastructure and the energy used for operating pumps that move the water over elevation changes. With increased fossil-fuel energy consumption comes more carbon emissions that hinder the carbon management objective. However, it is possible to pair inter-basin transfers with conservation measures to meet energy and carbon policy objectives.

Inter-basin water transfer projects primarily fall within the public interest domain of municipal, regional, and state governments. Thus, governments often directly fund such public works projects via bonds, tax increases, or increasing regulated rates for water. However, private businesses may contract with government authorities to own and/or operate water transfer projects. Incorporating externalities into the planning process can help mitigate environmental and legal issues associated with transferring water from one basin to another. Examples include designing appropriate rights-of-way and downgrading senior water rights for water taken from its natural basin.[184]

3. Energy and Water Coordination Among Agencies

As noted in Table 5, enhanced data collection is a valuable policy approach to solve the informational challenges that exist for many of the technologies that involve large-scale impacts. Some policy mechanisms can be enacted to effectively coordinate data collection both between and among all levels of government. It is effective to require water consumption and withdrawal data to be included in federal and state forms filled out by energy production facilities. Having senior facility personnel record and be accountable for these water data can ensure data consistency from local to federal levels. Additionally, collecting energy consumption data from major water users and producers such as desalination plants, wastewater and water treatment facilities, and irrigation pumps is valuable. The data can be reported on environmental and/or energy reporting forms. The collected data would preferably state the water body and basin from which the water is withdrawn, the quantity of water in units of

184. *See* S.B. 1, 1997 Leg., 75th Sess. (Tex. 1997).

volume per time, and the associated energy production (e.g. megawatt-hours, volume of liquid fuel, etc.). All levels of government must coordinate data to avoid reporting conflicting data. This coordination requires clarification of the words used to describe water usage and their definitions, the physical location within a water system at which the data are taken, and clear designation of the party responsible for collecting and verifying data.

Regional and federal data collected for the same purpose sometimes use different units or are completed by different persons. In such cases, data can conflict. For example, in the United States, some environmental managers or engineers who complete state-level water consumption and withdrawal forms at power plants do not fill out corresponding federal forms. These federal and state forms aim to collect the same information, but some collect water withdrawal information while some collect consumption information. The U.S. Energy Information Administration has made recent changes to its reporting forms (e.g. forms 860 and 923). These changes include providing useful diagrams to obtain more meaningful and accurate water use information about power plants. Furthermore, the water flow location in the power plant system often is not the same or is ambiguous. Data collection mechanisms could better inform policy for water and energy by using engineering-like diagrams to indicate where water is being consumed and withdrawn in the energy system and where energy is being generated or consumed in the water system.[185] If there is a reported flow of 1 gigaliter per year (GL/yr) in a power plant, a diagram could indicate if this flow refers to a one-time diversion of water from a river into a cooling reservoir or whether it represents a continuous water withdrawal—and return—from the cooling reservoir into the plant cooling infrastructure. Without a meaningful diagram and/or explicit definitions, these important distinctions are difficult to know.

Integrated water resource management is often seen as a way to consider multiple interests for allocating water use. In many cases, an integrated, scientific approach is officially-sanctioned by federal and regional governments, yet there is still controversy. The case of Canadian oil sands along the Athabasca River in Alberta presents an example where laws and policy are in place to maintain the wildlife and water quality, with scientific assessments used to objectively analyze the solution. Agreements are in placed to limit water extraction for oil sands pro-

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185. EIA form 923 now displays a diagram to distinguish among different flows of water. *See* U.S. Energy Info. Admin., U.S. Dep't of Energy, Form EIA-923 : Annual Electric Generator Report (2013), *available at* http:// http://www.eia.gov/survey/form/eia_923/instructions.pdf (last visited Dec. 17, 2012).

duction during times and seasons of low river flows to maintain environmental flows. This is one example of policy strategies to avoid conflict when multiple values of water use can easily be in conflict. However, in this case, considerable debate still exists as to the full water quality impacts from oil sands operations, and better monitoring methods have been suggested.[186]

For proper integrated planning, a robust, accepted, and open set of scientifically-measured and collected data is an important input. It would be useful for these data to show the fresh and saline water requirements for energy resource mining and refining and the energy requirements for water collection, treatment, and distribution. If the data are not transparent in both access and reporting, then it is difficult for stakeholders to engage in the resource management process. Jointly creating a common set of data and facts amongst stakeholders enables the beginning of conversations regarding resource usage and reconciliation from water-energy impacts. Stakeholders and governments should use existing coordination mechanisms to integrate energy and water concerns. These coordination mechanisms include Environmental Impact Assessments and the Regulatory Impact Analysis Statements in Canada that require departments and agencies to identify cost and benefits of proposed regulations, and enables the government to consider multi-dimensional impacts for horizontal and vertical policy coherence.

4. Scientific Coordination

In addition to integrating policies, it is also important to coordinate among scientists and scientific institutions. While this type of cross-fertilization of ideas is relatively new, we have listed three examples that are underway. COST, funded via the European Science Foundation through a European Commission contract, worked through the ANU in 2009 to provide a global context based on scientific input for policy decisions within the water-energy nexus. Scientists from around the world came together to examine case studies that highlight the energy-water

186. *See e.g.*, PETER DILLON ET AL., EVALUATION OF FOUR REPORTS ON CONTAMINATION OF THE ATHABASCA RIVER SYSTEM BY OIL SANDS OPERATIONS (2011), *available at* http://environment.alberta.ca/documents/WMDRC_-_Final_Report_March_7_2011.pdf (prepared for the government of Alberta, Canada); Sarah M. Jordaan, *Land and Water Impacts of Oil Sands Production in Alberta*, 46 ENVTL. SCI. & TECH., no. 7, Apr. 3, 2007, at 3611; Erin N. Kelly et al., *Oil Sands Development Contributes Polycyclic Aromatic Compounds to the Athabasca River and its Tributaries*, 106 PROCS. NAT'L ACAD. SCIS., no. 52, Dec. 29, 2009, at 22346; PIERRE GOSSELIN ET AL., THE ROYAL SOCIETY OF CANADA EXPERT PANEL: ENVIRONMENTAL AND HEALTH IMPACTS OF CANADA'S OIL SANDS INDUSTRY (2010), *available at* http://rsc-src.ca/sites/default/files/pdf/RSCreportcompletesecured9Mb_Mar28_11.pdf.

nexus.[187] In addition, the water-energy nexus is also being investigated by the U.S. national labs. The labs provide a central information website and reports for Congress[188], and new research findings such as integrating water resources into the planning of electrical transmission lines in the western United States that will connect renewable energy solar and wind resources. Brazil's newly-formed Bioethanol Science and Technology Laboratory in Campinas, São Paulo, aims to focus initial research on energy and GHG balances as well as the water quantity and quality impacts of expanded sugar cane agriculture in Brazil.[189] While scientific coordination is not enough to ensure robust policy formulation, it can be a positive step towards that goal by creating valid data-reporting and environmental monitoring methods.

C. Extent that Mechanisms are Able to Bridge Institutional Gaps

1. Successes for Bridging Institutional Gaps

It is difficult for any specific policy or set of policies to solve all energy-water conflicts, but openness and a focus on mutually beneficial solutions (e.g. solar hot water heating in Table 5) present a starting point. Often, the combined scarcity and/or economic costs of both freshwater and energy must reach critical levels to enable certain policies and technologies to become successfully and widely used. Solar hot water heating systems integrated into planning and building codes in Israel, China, and Hawaii show that areas with resource constraints have market incentives to use this technology. As shown by this solar hot water heating example, government policy can follow or lead the effort. Thus, when social and economic drivers already present solutions to the energy-water nexus that save expenses while conserving energy and water resources, policy can reinforce this behavior.

Data collection has proven successful in bridging institutional gaps, but questions remain as to whether more accurate data and a more integrated regulatory framework can effectively translate to better policy. Good resource governance often begins with good measurement and open data records. The physical flows of water and energy need to be measured and recorded to produce consistent and reliable time series. A

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187. *See* Karen Hussey & Jamie Pittock, *The Energy-Water Nexus: Managing the Links Between Energy and Water for a Sustainable Future*, 17 ECOLOGY & SOC'Y 31 (2012).

188. U.S. DEP'T OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES: REPORT TO CONGRESS ON THE INTERDEPENDENCY OF ENERGY AND WATER (2006), *available at* http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf.

189. Brazilian Bioethanol Science and Technology Laboratory, *Impact of New Technolgies on Sustainability*, http://www.bioetanol.org.br/english/interna/index.php?chave=sustainability (last visited Dec. 27, 2012).

pure free market advocate might suggest that proper pricing can reflect the scarcity and allocation of freshwater and therefore cause corrective consumption decisions, but there are no obvious patterns in the water use data that suggest water prices follow classic supply and demand principles.

2. Water and Energy: Availability, Trade, and Pricing

The Earth is awash in free energy. Earth's surface absorbs over 7,500 times as much solar energy—3,850,000 EJ per year—as humans consume as primary energy in one year (~ 510 EJ in 2009).[190] The Earth is also awash in water: the oceans hold 1,338,000 cubic kilometers (km^3),[191] over 175 times that of the total worldwide human water withdrawal footprint of 7,700 km^3 per year.[192] However, those energy and water resources are diffuse, low-quality, and difficult for humans to reap compared to energy-dense fossil fuels.[193] These resources combine to drive the global hydrological cycle by using 1,000,000 EJ to evaporate, or "desalinate", 440,000 km^3 of seawater each year.[194] Humans have proliferated in the last 200 years because of the use of high-purity freshwater and concentrated high-density fossil energy resources.[195]

Energy commodities such as oil, coal, and natural gas are traded internationally. However, very little water is traded internationally except for very small quantities of relatively expensive drinking water (for example, 200 billion L of bottled water were sold in 2007[196] amounting to < 0.01% of basic global water access requirements assuming 1 million L/person/yr). In contrast, 4,900 billion L of petroleum were consumed in 2007—twenty-five times as much volume as bottled water and constituting 35 percent of world primary energy.[197] While petroleum makes

190. *See e.g.*, VACLAV SMIL, ENERGY IN NATURE AND SOCIETY: GENERAL ENERGETICS OF COMPLEX SYSTEMS (2008) for total solar energy; EJ = 1×10^{18} joules; *International Energy Statistics*, U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=5&aid=2&cid=regions&syid=2007&eyid=2011&unit=QBTU (last visited July 2012).

191. Taikan Oki & Shinjiro Kanae, *Global Hydrological Cycles and World Water Resources*, 313 SCI. MAG., no. 5790, Aug. 25, 2006, at 1068, 1069.

192. Water withdrawal as green and blue water. *See* Arjen Y. Hoekstra & Mesfin M. Mekonnen, *The water footprint of humanity*, 109 PROC. NAT'L ACAD. SCI. 3232, 3232–37 (2012).

193. SMIL, *supra* note 190.

194. *See* Oki, *supra* note 191.

195. *See* SMIL, *supra* note 190, at 243–72.

196. P. H. Gleick & H. S. Cooley, *Energy Implications of Bottled Water*, 4 ENVTL. RES. LETTER 1, 1 (2009).

197. *International Energy Statistics*, U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=5&aid=2&cid=regions&syid=2007&eyid=2011&unit=QBTU (last visited July 2012).

globalized trade possible, the possibility of shipping all human water needs across the globe is slim. This resource quality and distribution discontinuity inherently makes water impacts and concerns more local than energy impacts. Thus, global pressures can decrease local water security to provide enhanced energy security elsewhere.

"Right-pricing" of water and energy resources is an important approach for advancing technological solutions to achieve policy objectives.[198] However, while market pricing is typical for producing, upgrading, and distributing energy resources, using markets for collecting water in raw form and distributing it in treated form is not as common. In both cases, prices are often centrally regulated, and many countries have subsidies or fixed prices that distort their markets. The typical consequence of subsidized pricing is falsely-low prices that affect both supply and demand. For example, water policies that set a price of water below its proper level—the price that takes into account all the costs of producing water as well as relevant externalities—can lead to overproduction and overconsumption of both water and energy, thus reducing water and energy security and sustainability. Pricing schemes such as inverted block pricing —for which there is a low price for the first few thousand L of water consumed per household each month, after which prices per additional unit increase steeply—have been implemented to reduce water consumption while maintaining an economically viable quantity for basic needs.[199]

In industrialized countries, right-pricing also includes efforts to implement "smart" meters to give customers more information about their consumption and to enable pricing that varies with time-of-use and other factors. It is necessary to couple data collection and effectively label utility bills through the use of smart meters to create a coherent policy around time-of-use pricing. Unfortunately, there is little research about the behavioral economics of water prices.

Despite the importance of accurate pricing in energy and water markets, many disagree about the effectiveness of price as the key indicator for the security or availability of these resources, because some important parameters (e.g. ecosystem health and aquatic habitats) are not commoditized or incorporated into the price. Thus, price signals might not perfectly align with societal or environmental aims. The price consumers pay for energy commodities such as gasoline and electricity also

198. *See* ORG. ECON. CO-OPERATION & DEV., PRICING WATER RESOURCES AND WATER AND SANITATION SERVICES (2010).

199. Peter Rogers et al., *Water is an Economic Good: How to Use Prices to Promote Equity, Efficiency, and Sustainability*, 4 WATER POL'Y 1, 7 (2002).

does not match with all societal aims, such as protection of ecosystems and climate change mitigation, that are difficult to price.[200]

In contrast to energy, the relative price consumers pay for water varies much more widely worldwide. Desalinated water in Australia has a much higher price than free irrigation water in India. Even within an OECD country, price variances can be unrelated to consumption patterns and resource availability. In the United States many municipalities with a water utility are authorized to charge water customers a price that recoups capital and operating costs for treatment plants and distribution systems (e.g. full-cost recovery), but not for the water itself. As a result, water customers pay a fee reflecting the cost of service instead of the total cost of treated drinking water. However, recovering these capital costs are an important part of creating a sustainable energy policy.[201] On the other hand, municipal utility districts in rural regions of the United States that purchase water from a wholesaler can pass on the cost of water to the customer in addition to the cost of service. Also, when performing cost-benefit analyses for water provision options, industrial and municipal users might be able to afford higher prices than individuals, and thus might be favored over agricultural and environmental uses.[202] Table 6 below indicates sample capital costs for different water treatment equipment based on U.S. cost data. These representative values show that more advanced, energy-intensive treatment technologies require more capital investment. Generally, these capital cost increases translate to consumer water price increases, but this trend is not always the case. "Right-pricing" of water should include infrastructure costs.

200. *See* Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital*, 387 NATURE 253 (1997); Johan Rockstrom et al., *Planetary Boundaries: Exploring the Safe Operating Space for Humanity*, 14 ECOLOGY & SOC'Y, art. 32, 2009.

201. ORG. ECON. CO-OPERATION & DEV., *supra* note 198, at 22.

202. *See* Rogers et al., 199 at 7–10.

TABLE 6. Sample costs data for water treatment equipment show increases in cost for more sophisticated treatment technologies.

Type of Treatment Facility	Sample Capital Cost (USD)
Surface Water Treatment Plant	$290,000/million L/d treatment capacity[203]
Groundwater Well Drilling	$200–$1,000/m depth[204] (plus $8,700–$142,000 fixed cost based on production rate)
Reverse Osmosis Desalination Membranes	$500,000–$1,000,000/million L/d treatment capacity[205]

The price consumers pay for water can reflect the level of treatment required to deliver treated water or the amount of water available for use before pursuing alternative supplies. However, some water-stressed areas charge lower prices than water-rich areas. For example, a recent survey of U.S. cities shows that some areas with low water availability have some of the lowest water prices and highest water use rates.[206] A U.S. family of four living in water-stressed Phoenix, Arizona, and using 380 L/person/day (100 gal/person/day) would have an average monthly water bill of $34 USD. The same family would have an average monthly water bill of $73 in water-rich Seattle, Washington. Of the thirty United States cities surveyed, the average monthly water bill ranges from $20 in San Antonio, Texas, to $121 in Santa Fe, New Mexico.[207] As a result of contextual variability, water price is an important policy tool. However, used in isolation it can be a misleading metric of water policy coherence because prices do not always properly reflect scarcity or necessarily ensure universal access to basic needs.

203. City of Austin, *Austin's Water Treatment Plant 4: History, Finances and Next Steps* (July 17, 2009), http://www.ci.austin.tx.us/edims/document.cfm?id=129448.

204. TEXAS WATER DEVELOPMENT BOARD, BRACKISH GROUNDWATER MANUAL FOR TEXAS REGIONAL WATER PLANNING GROUPS (2003).

205. UNITED NATIONS ENVIRONMENT PROGRAMME, SOURCE BOOK OF ALTERNATIVE TECHNOLOGIES FOR FRESHWATER AUGMENTATION IN LATIN AMERICA AND THE CARIBBEAN." UNITED NATIONS ENVIRONMENTAL PROGRAMME INTERNATIONAL ENVIRONMENTAL TECHNOLOGY CENTRE (1997); Allen W. Sturdivant et al., *Economic Costs of Desalination in South Texas: A Case Study*, 137 J. CONTEMP. WATER RES. & EDUC. 21, 21–39 (2007).

206. Brett Walton, *The Price of Water: A Comparison of Water Rates, Usage in 30 U.S. Cities*, CIRCLE OF BLUE (Apr. 26, 2010, 7:22 PM), http://www.circleofblue.org/waternews/2010/world/the-price-of-water-a-comparison-of-water-rates-usage-in-30-u-s-cities/.

207. *Id.*

3. *Policy Mechanisms to Manage the Agriculture-Energy-Water Nexus*

Agriculture accounts for approximately 70 percent of global water use, so policy choices regarding the agriculture-energy-water nexus are especially critical in crafting sustainable resource policy.[208] Policies designed to increase agricultural production have historically increased the use of energy and water resources because high market prices and governmental support for agricultural inputs tend to give farmers incentive to maximize yield and excessively use water and energy.[209]

Reducing or eliminating support for farm inputs such as water, diesel fuel, fertilizers, electricity, and irrigation systems give farmers incentives to increase resource efficiency, rather than to withdraw fossil resources to maximize crop yields. Although the cost of rain-fed agriculture rises with energy prices because it requires a lot of energy to transport agricultural products and inputs, the cost of irrigated agricultural production incurs additional cost spikes to pump water and run irrigation systems when energy prices rise.[210] Thus, higher water and/or energy prices tend to lead farmers to use more efficient farming practices to reduce costs.[211] Consequently, decoupling financial support for agriculture from commodity production to reduce energy and water inputs for agricultural production has become a popular policy tool in many OECD countries[212] for the past 20 years.[213] This approach has proven to be an effective policy mechanism to reduce the energy and water allocated to agricultural practices in many countries, including many European Union member states.[214]

However, several factors increase fossil energy prices: fossil fuel depletion, extraction of more marginal resources, and environmental constraints. These factors also encourage alternative fuel use at the higher marginal prices.[215] This assessment includes biofuels even though,

208. FOOD & AGRIC. ORG. OF THE UNITED NATIONS, http://www.fao.org/nr/water/aquastat/water_use/index.stm (last visited Dec. 27, 2012).

209. KEVIN PARRIS, IMPLICATION OF HIGHER ENERGY PRICE FOR WATER USE IN AGRICULTURAL (2008); OECD SUSTAINABLE, *supra* note 97, at 85.

210. Id.; OECD SUSTAINABLE, *supra* note 97, at 58.

211. PARRIS, *supra* note 209.

212. EU member states, the United States, Mexico, and Turkey are among countries that have implemented decoupled support programs. John Baffes & Harry De Gorter, *Disciplining Agricultural Support through Decoupling 20-28* (World Bank Policy Research, Working Paper No. 3533, Mar. 2005).

213. OECD SUSTAINABLE, *supra* note 97, at 74; OECD REFORM, *supra* note 146, at 110.

214. OECD SUSTAINABLE, *supra* note 97, at 74; OECD REFORM, *supra* note 146, at 110.

215. Carey W. King et al., *Relating Financial and Energy Return on Investment*, 3 SUSTAINABILITY 1810 (2011); Carey W. King, *Energy Intensity Ratios as Net Energy Measures of United States Energy Production and Expenditures*, 5 ENVIRON. RES. LETT., Nov. 10, 2010, at 9.

with respect to conventional petroleum fuels, they currently produce less energy output relative to how much energy input is required during their life cycle. All biofuels are not equal, as sugar cane-based ethanol in Brazil has much more favorable net energy than corn-based ethanol. A 1:1 substitution of biofuels for petroleum requires a higher share of energetic input from the rest of the economy. Thus, a subsequent increase in biofuels production might actually increase overall agricultural and industrial activity in the energy sector, and possibly economy-wide energy and water use. Second and third generation biofuels, if grown without irrigation on marginal lands, provide the opportunity to attenuate water use for feedstock production in comparison to first generation biofuels.[216] However, their impacts cannot yet be realized because they are not yet produced at a commercial scale. Many OECD and non-OECD countries have supported next generation biofuel research with governmental funding.[217] Most developing countries have not had the funding necessary for such efforts. Consequently, although they have incorporated biofuels blending quotas into their energy policies, countries such as Brazil, China, India, South Africa, and Thailand have not typically included second-generation biofuels in their policy discussions.[218] However, in 2010 Brazil christened a national laboratory that is focused upon both first generation and lignocellulosic biofuel development from sugar cane.

The energy-water nexus in the context of food is not only limited to agriculture, but also extends to aquaculture. As demand for seafood has risen over the past several decades, aquaculture has provided more seafood than wild-caught. Less than 1 million tons of seafood came from aquaculture in the 1950s compared to almost 52 million tons in 2006.[219] When comparing aquaculture to open water fishing where no freshwater is directly consumed during fishing, the general trend is for aquaculture to consume more of both energy and water. The energy consumption of aquaculture systems goes up as the total water taken or withdrawn from the natural environment goes down. Little primary energy consumption is associated with wild caught seafood (e.g. marine fuel) and the ecosystem service of growing the seafood is 100 percent provided by the environment. By contrast, a closed-loop recirculating aquaculture pond must

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216. *See* King & Webber, *supra* note 80, at 7870; Gerbens-Leenes, et al., *supra* note 85, at 10220; Rosa Dominguez-Faus et al., *The Water Footprint of Biofuels: A Drink or Drive Issue?*, 43 Envtl. Sci. & Tech. 3005, 3006 (2009).

217. Example: The United States issues research grants and performs research at national energy laboratories and the United States Department of Agriculture.

218. Anselm Eisentraut, Int'l Energy Agency, Sustainable Production of Second-Generation Biofuels 2 (2010).

219. Food & Agric. Org. of the United Nations Food, *supra* note 208, at 6.

input food and treat its water effluent before recycling, and this water treatment necessitates high energy consumption to prevent hindering water quality.[220] Thus, the water-energy impacts of aquaculture cannot be neglected and should be considered alongside agricultural policies.

Many technologies and policies can interact to increase efficient and resilient use of energy and water resources. Organizations, both public and private, must remember that sustainable water use is a local issue that can be influenced by global energy drivers (e.g. global oil trade pushing exploration and production into new areas) or regional needs (e.g. electricity from hydropower). While the listed policy choices describe governmental policy options, larger stakeholder engagements involving private energy and water companies, governments, non-governmental energy and environmental organizations, landowners, and others are effective means to discuss which options of Table 5 make sense for a given region. We see stakeholder use of the technologies and policies discussion of this section as a valuable contribution aside from the need to catalog energy and water interactions.

IV. CASE STUDIES OF WATER AND ENERGY POLICY COHERENCE/INCOHERENCE

This section includes brief case studies of water and energy policies for a few countries facing slightly different challenges or using different policy options to mitigate their challenges. These case studies are intended only to illustrate some of the range of water-energy policy coherence and incoherence; they are not intended to be an exhaustive discussion of all the different issues, nor are they meant to be the definitive analysis for each country. The United States case study is examined in greater detail because 1) its continental breadth includes a range of energy and water issues that suitably capture most of the challenges witnessed worldwide (for example, water abundance varies dramatically from the desert Southwest to the wet Northeast, and energy resources have significant geographic variability), and 2) the energy and water data for the United States are in greater abundance and more accessible than for most other regions and countries in the world. The countries discussed include: the United States, Canada, Australia, France, Brazil, India, Israel, and Singapore.

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220. Nathan W. Ayer & Peter H. Tyedmers, *Assessing Alternative Aquaculture Technologies: Life Cycle Assessment of Salmonid Culture Systems in Canada*, J. CLEANER PROD., Feb. 2008, at 4.

A. United States: Scarce Water Resources in the West and Policy Mismatches

The United States has extensive variability in water resources, and its energy consumption is similar to global energy consumption in terms of fuel distribution: 37 percent petroleum, 23 percent natural gas, 23 percent coal, 9 percent nuclear, and 8 percent renewables.[221] In addition, the United States has extensive data on its water and energy use, much of which is applicable to other regions of the world.

1. Policy Framework

Policymaking in the United States for resource, energy and environmental issues is complicated because the resources, economic benefits, and environmental impacts have significant geographic variability. Furthermore, few policies require collaboration between energy and water supply entities. Consequently, many policy decisions that affect the energy-water nexus are made to safeguard one resource while inadvertently compromising the other.[222]

Because of the regional variability in water resources and energy use and environmental impacts of both, it is difficult to generalize about the United States as a nation. However, several regions of the United States have recently performed assessments of the energy requirements and impacts on water resources and/or the water requirements for energy production. For instance, California discovered that approximately 19 percent of its electricity and 32 percent of natural gas is used for water usage[223] in the state.[224] In addition, an extensive study of the energy-water nexus was recently performed for Texas, and the Great Lakes Commission is conducting an ongoing study of the topic for states that border the great lakes.[225]

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221. U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, 2009 ANNUAL ENERGY REVIEW 8–9 (2010).

222. *See* Abrams & Hall, *supra* note 7, at 38–64; Adell L. Amos, *Freshwater Conservation in the Context of Energy and Climate Policy: Assessing Progress and Identifying Challenges in Oregon and the Western United States*, 12 U. DENV. WATER L. REV. 1 (2008); Petra Hellegers et al., *Interactions Between Water, Energy, Food and Environment: Evolving Perspectives and Policy Issues*, 10 WATER POL'Y S1 (2008); P.G. McCornick et al., *Water–Food–Energy–Environment Synergies and Tradeoffs: Major Issues and Case Studies*, 10 WATER POL'Y 23 (2008); I. El Saliby et al., *Desalination Plants in Australia, Review and Facts*, DESALINATION, Oct. 2009.

223. Including treatment, conveyance, water heating, oil and gas extraction, etc.

224. Ralf Otterpohl, et al., *Source Control in Urban Sanitation and Waste Management: Ten Systems with Reuse of Resources*, 39 WATER SCI. & TECH. 153 (1999).

225. Ashlynn S. Stillwell, et al., *The Energy-Water Nexus in Texas*, 16 ECOLOGY AND SOC'Y, art. 2, 2011.

Energy-water issues in the United States manifest in several different ways. With hydropower, capacity factors[226] have declined over the last fifty years even though more capacity has been installed.[227] In the Southwest, strained water supplies on the Colorado River continually threaten hydropower output because policies that allocated water almost a century ago did so based upon average stream flows that are now known to be much higher than normal.[228] In the Southeast, droughts brought nuclear power plants within days of turning off.[229] In the Midwest, increased irrigation has ramped-up biofuels production from corn. In the Northeast, the Yankee nuclear power plant has been cited with numerous complaints of radioactive water leaks.[230] In some areas of the United States, the gasoline additive MTBE leaked into groundwater supplies and degraded water quality, leading to its ban and the use of ethanol as a substitute.[231] Many more examples that are useful proxies for similar experiences in other countries can be found in the United States.

Adopting renewable electricity and fuel standards intended to reduce GHG emissions might also impact water resources in the future. However, the extent of these impacts is unclear because some renewable technologies[232] are more water-efficient than conventional energy sources while others are less water efficient.[233] In addition, other carbon reduction initiatives that encourage carbon sequestration technologies increase strain on water resources.[234]

Despite the large amounts of energy required for pumping and/or advanced contaminant removal, declining water supplies, increased droughts, and population growth have also promoted the growth of

226. Capacity factor refers to the ratio of the actual output of a power plant over a period of time to its output if it had been operating at its full nameplate capacity over the specified time period.

227. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, 2007 ANNUAL ENERGY REVIEW 140–41 (2008).

228. U.S. GLOBAL CLIMATE CHANGE RES. PROGRAM, GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 51 (2009); McCornick et al., *supra* note 222; Sally Adee & S.K. Moore, *The Power of Water in the American Southwest, the Energy Problem is Water*, 47 IEEE SPECTRUM 30 (2010).

229. John Manuel, *Drought in the Southeast: Lessons for Water Management*, 116 ENVIRON. HEALTH PERSP. A168, A168 (2008); Associated Press, *Drought Could Shut Down Nuclear Power Plants*, MSNBC (Jan. 23 2008), http://www.msnbc.msn.com/id/22804065.

230. Matthew Wald, *Vermont Senate Votes to Close Nuclear Plant*, N.Y. TIMES, Feb. 25 2010, at A14.

231. Thomas O. McGarity, *MTBE: A Precautionary Tale*, 28 HARV. ENVTL. L. REV. 281, 281–82, 288 (2004).

232. Such as wind and solar PV electricity; biofuels derived from non-irrigated feedstocks.

233. King & Webber, *supra* note 80, at 7866.

234. Abrams & Hall, *supra* note 7, at 61.

desalination and long-haul water transfer for recovering potable water in water-stressed areas. For example, the CEC found that approximately 6 percent of all California electricity consumption is needed just for domestic and irrigation water pumping.[235] Much of this electricity is to pump water nearly 1,000 m over the Tehachapi Mountains from the San Joaquin Valley to Southern California. The pumps that move this water are the single largest power load in the state.[236] The embedded energy in some of the pumped water is as high as 2,600 kWh per ML—within the lower ranges of energy requirements for desalination.[237] Policies that promote the use of this energy-intensive water supply over water conservation, local water reuse, and aquifer recharge adversely impact one sector to serve another.

2. Allocation of Roles and Decisions

One key challenge in increasing the cohesion between energy and water policy decisions is that there are many federal agencies and committees that regulate or impact one or both of these resources, but none of which has clear over-arching authority. Furthermore, federal energy and water policymakers are only a small piece of the puzzle. Municipal governments, state governments, tribal governments, and private entities also share a large role in managing energy and water resources. Consequently, energy and water decisions have historically been made independently of each other. Energy planners typically assume they have the water they need, and water planners assume they have the energy they need

In the United States, there are more than twenty federal agencies and bureaus in charge of water resources; many of their responsibilities for water quantity and quality overlap.[238] Federal agencies with major water management interests include the Environmental Protection Agency (EPA), Army Corps of Engineers, U.S. Department of Agriculture (USDA), Department of Interior (DOI) (which includes the Bureau of Land Management; U.S. Geological Survey (USGS); Bureau of Reclamation; Bureau of Ocean Energy Management, Regulation, and Enforcement), and others. There is no "Department of Water." Various responsibilities vary with agency: the EPA focuses on water quality, the

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235. Gary Klein et al., Cal. Energy Comm'n, California's Water-Energy Relationship 10 (2005), *available at* http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF.

236. *Id.*

237. *Id.* at 25.

238. Erik K. Webb & Joshua Johnson, *Federal Engagement in Water Resource Technology Development: Current Programs and the Future*, 143, J. Contemporary: Water Res. & Ed. 3, 4–6 (2009).

Bureau of Reclamation focuses on irrigation, the Army Corps of Engineers focuses on flood control and inland water navigation, the USDA focuses on water for farming, and the USGS is responsible with quantifying water resources and uses.[239] While the EPA clearly has a mandate to address water quality issues, there is no clear mandate for any one agency to be in charge of water quantity issues.

Likewise, there are at least eighteen different Federal agencies under the authority of dozens of Congressional committees and subcommittees that control over 150 energy-related programs and eleven income tax preferences. This makes it difficult to maintain cohesion between federal energy policymakers.[240] The Executive Branch of the federal government has two primary agencies with significant influence in energy production—DOE and DOI—though other agencies such as the USDA and Department of Defense (DOD) also play important roles in energy policy. As the United States researches alternative fuels to replace petroleum, the USDA and DOD are playing larger roles in energy research funding.[241]

In addition, the vertical hierarchies of policymaking regarding energy and water management are dissimilar. Energy policy in the United States is usually structured in a top-down fashion with powerful federal agencies such as the DOE and EPA setting rigid standards. However, some roles such as siting electricity plants are allocated to the states, municipalities, and market participants.[242] By contrast, water policy in the United States is usually structured in a bottom-up fashion with decisions driven by local water agencies and authorities because water supply management is generally the responsibility of the states.[243] Thus, local governments are forced to meet federal standards, often without sufficient input.[244]

Despite the mismatch in energy and water policymaking structures, attempts are being made to integrate the management of energy and water policy in the United States. Recent legislation proposed in the

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239. *Id.* at 5.

240. U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-05-379, NATIONAL ENERGY POLICY: INVENTORY OF MAJOR FEDERAL ENERGY PROGRAMS AND STATUS OF POLICY RECOMMENDATIONS (2005), *available at* http://www.gao.gov/new.items/d05379.pdf.

241. The DOD is the largest fuel consumer of the United States. Cheryl Pellerin, *DOD Gives High Priority to Saving Energy* (Sept. 29, 2011), http://www.defense.gov/news/newsarticle.aspx?id=65480.

242. Michael E. Webber, *Energy versus Water: Solving Both Crises Together*, Oct. 2008, SCI. AM., 1, 4 (2008).

243. William Goldfarb, *Watershed Management: Slogan or Solution?* 21 B.C. ENVTL. AFF. L. REV. 483, 494 (1994).

244. *Id.* at 495.

U.S. Congress calls for further study of the energy-water nexus, including water use for energy and energy consumption for brackish groundwater desalination.[245] For example, Subtitle D of the American Clean Energy Leadership Act of 2009[246] called for studies and assessments on integration within the energy-water nexus.[247] In addition, this bill called for changes to the energy mix[248] with implications for water use. At the state level, the 2009 Texas Legislature developed a bill that considered water a part of the permitting process for power plants.[249] Consequently, legislative attention to energy-water issues with an eye towards coherent integration is increasing in the United States despite a dearth of concrete action. Many of the proposed legislative studies focus upon horizontal coordination rather than vertical coordination.

3. Capacity and Funding Resources

Because energy and water resource management is spread across many agencies and governmental levels in the United States, the funding, oversight, and regulatory mechanisms for energy and water are disaggregated. Little collaboration exists between energy and water stakeholders; roles and responsibilities regarding resource management are often unclear and redundant amongst entities, making it difficult to identify knowledge gaps and assimilate cohesive and holistic energy-water policy.[250] Consequently, appropriating money across agencies for energy and water investments is contentious and unclear,[251] and there is controversy over where major investment should be directed even within the agencies themselves.

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245. U.S. GOV'T ACCOUNTABILITY OFFICE, MANY UNCERTAINTIES, *supra* note 6; U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-10-23, ENERGY-WATER NEXUS: IMPROVEMENTS TO FEDERAL WATER USE DATA WOULD INCREASE UNDERSTANDING OF TRENDS IN POWER PLANT WATER USE (2009), *available at* http://www.gao.gov/new.items/d1023.pdf; U.S. GOV'T ACCOUNTABILITY OFFICE, PRELIMINARY OBSERVATIONS, *supra* note 6; Abrams & Hall, *supra* note 7; E. Salibya et al., Desalination plants in Australia, review and facts, 247 Desalination 1, 1–14 (2009).

246. The purpose of S. 1462 (111th): American Clean Energy Act of 2009 was "to promote clean energy technology development, enhanced energy efficiency, improved energy security, and energy innovation and workforce development, and for other purposes." S. 1462, 111th Cong. (2009) (enacted).

247. *Id.*

248. "Fuel mix" refers to the amount of each primary energy source used in the United States.

249. H.B. No. 4206, Leg. 81st Sess. (Tex. 2009) (In effect as of September 1, 2009.).

250. Claire Charbit & Maria Varinia Michalun, *Mind the gaps: Managing Mutual Dependence in Relations among Levels of Government*, 14 OECD WORKING PAPERS ON PUB. GOVERNANCE 1, 13 (2009).

251. Webb & Johnson, *supra* note 238, at 6.

For example, in the water sector, there is general agreement among most stakeholders that the United States needs direct investment in: 1) repairing and building new infrastructure; 2) collecting more data regarding water quality, quantity, use, and changes in availability; 3) integrating water planners; and 4) investing in research and design (R&D) to increase the available water supply through gains in efficiency or better treatment options.[252] The water infrastructure gap alone will require at least $400 billion by 2019, and the operations and maintenance gap[253] will be at least another $150 billion over the same time period.[254] Estimates for necessary energy infrastructure investments[255] in the United States over the next decade exceed $1 trillion.[256] However, in the face of limited funds, it is not clear whether investment should focus primarily on repairing and renovating current infrastructure or on developing cheaper technological solutions to recover adequate water to meet growing population demand.[257] Because there is no overarching strategy to set priorities for all agencies, each agency pursues its independent goals based on a series of short-term priorities.

Although there is investment in each of the targeted areas, efforts are largely uncoordinated and underfunded; there is no consensus regarding which government agencies should be responsible for completing tasks.[258] The Federal government of the United States has made substantial investments in drinking water and wastewater systems in the past, but some believe that local, state, and private agencies should share more responsibility in managing the nation's water infrastructure.[259] Others believe that the Federal government should carry more fiscal responsibility in repairing current water infrastructure.[260] Funding has stayed relatively constant or has declined since the 1970s despite a nearly twofold increase in overall federally funded R&D efforts.[261] In addition to aging infrastructure, population increased by more than a quarter and

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252. Webb & Johnson, *supra* note 238, at 5.

253. To meet increasingly stringent treatment standards, for example.

254. U. S. ENVT'L PROT. AGENCY, THE CLEAN WATER AND DRINKING WATER INFRASTRUCTURE GAP ANALYSIS (2002).

255. Including electric transmission, fuel pipelines, smart grid equipment, and biorefineries.

256. Am. Soc'y of Civil Eng'rs, *Report Card for America's Infrastructure: Energy* (2009), http://www.infrastructurereportcard.org/fact-sheet/energy.

257. Webb & Johnson, *supra* note 238, at 4.

258. *Id.* at 5.

259. Goldfarb, *supra* note 243, at 495.

260. Webb & Johnson, *supra* note 238, at 4.

261. *Id.* at 5.

gross domestic product doubled during the same period, which increased the stress on the U.S. water system.[262]

Despite this stagnation in federal investment, private investment has grown at an average rate of about 10 percent per year. The expansion of desalination accounts for much of this increase in private spending. As desalination projects become increasingly common, some analysts predict that the privatized water market could grow to exceed $300 billion USD.[263] Others contend that the profit margin in the privatized water industry is low, limiting its growth. Federal investment is also critical for developing high-risk technologies that are unlikely to be pursued in privatized markets.

Unlike water, federal funding across energy agencies has substantially increased in the past few decades, with large increases focused on increasing the energy supply.[264] Unlike water investments, energy-related activities recover large returns to the federal and state governments by means of oil and gas profits, royalties, excise taxes, and property taxes. Thus, as water regulation has been pushed on municipal and state water governments, the majority of energy regulations and investments remain within the power of federal agencies.[265]

4. Information Challenges

In addition to the policy and funding hurdles, there are also substantial data problems that inhibit development of coherent, integrated policies. One problem is a lack of consistency in water terms. For example, the terms "diversion," "demand," "use," "withdrawal," and "consumption," all have a variety of overlapping meanings in the United States. If the United States cannot achieve consistent use of language and terminology within its own boundaries, then trans-boundary issues in areas of the world with multiple languages are likely to be even more challenging.

Furthermore, there is a lack of consistency in the scientific units that are used to describe water. For example, in the western United States, "acre-feet" are used to describe a volume of water, but in the eastern United States, "gallons" are used. Because 1 acre-foot has 325,851 gal, mistaking the units can lead to significant errors. Additionally, flow rates

262. *Id.* at 6.
263. *Id.* at 5.
264. U.S. GOV'T ACCOUNTABILITY OFFICE, *supra* note 240.
265. Other factors such as the location of the resource extraction also contribute to this trend.

are described on different time scales—from seconds[266] to days and years[267]—all describing the same water withdrawal for power plant cooling. These different data units send confusing signals as to what time frames are important for water and energy planning and regulation.

There are also significant data differences between the state and federal water agency, partly because of the mix of units and the mix of terminology. Many states produce databases with water information, and the U.S. Department of Energy's Energy Information Administration (EIA) provides data on water use for the electricity sector. However, these two sets of data do not uniformly agree which can cause errors during analysis and policy formulation.[268] Furthermore, state and federal agencies do not always collect the same types of data[269] at the same flow point in the system.[270] Water managers at power plants that fill out forms for state data collection requirements sometimes do not know that similar federal forms exist and/or become confused over reporting the same information in different units for water volumes and flow rates, making it difficult to create consistent data sets. The combination of collecting and reporting of water data for energy systems using different units, locations of interest, and agencies makes even simple concepts unintelligible. Both federal and state agencies can continue improvements to data collection, and the EIA regularly collects feedback and updates its data forms and collection procedures.

While the data that exist are often error-prone and contain inconsistent use of terminology and units, they are also sparse. Many data sets regarding water use for energy and energy use for water are not directly measured (e.g. forced evaporation related to once-through power plant cooling designs) or reported to a central agency. In many cases they are unreliable, which hinders decision-making.[271] One ongoing challenge for data is that the funding resources for data collection (especially for water) have decreased in the United States.[272] As a result, critical infor-

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266. E.g. "average cubic feet per second" as collected by the Department of Energy. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, FORM 860, ANNUAL ELECTRIC GENERATOR REPORT, PART F: COOLING SYSTEM INFORMATION – DESIGN PARAMETERS (2009).

267. "Million gal per day" and "acre-feet per year," as reported by the USGS. WAYNE B. SOLLEY ET AL., U.S. GEOLOGICAL SURV., ESTIMATED USE OF WATER IN THE UNITED STATES IN 2005, at 6 (1998).

268. CAREY W. KING, IAN DUNCAN & MICHAEL WEBBER, WATER DEMAND PROJECTIONS FOR POWER GENERATION IN TEXAS, TEXAS WATER DEVELOPMENT BOARD (2008).

269. e.g. withdrawal versus consumption

270. e.g. at the power plant intake versus the point of withdrawal from a river.

271. NAT'L ENERGY TECH. LAB., IMPACT OF DROUGHT ON U.S. STEAM ELECTRIC POWER PLANT COOLING WATER INTAKES AND RELATED WATER RESOURCE MANAGEMENT ISSUES 21 (2009).

272. Webb & Johnson, *supra* note 238, at 5.

mation is not available to policy makers. For example, in 1995, the USGS stopped estimating water consumption by use, state, and sector, but will continue this practice in estimating 2010 consumption.[273] One important type of energy data not collected for water distribution is energy consumed for agricultural irrigation. The USDA reports irrigation costs in dollars, but not in units of electricity consumed.[274] Because electricity costs vary widely within and across countries, and many countries subsidize both water and electricity prices for agriculture, it is not possible to reverse calculate the full energy consumed to grow crops.[275]

5. Timeframe and Strategic Planning

Another hurdle to formulating coherent policy is a mismatch in planning timeframes. Forward-looking water plans often look 50–60 years ahead,[276] whereas energy plans may look 20–30 years ahead.[277] These differences are the consequence primarily in the different amounts of time it takes to build water infrastructure,[278] and how long that water infrastructure lasts.[279] Private companies acting under market forces often dictate the location of energy infrastructure whereas water infrastructures are often located using more public interest criteria. Thus, water planners trying to plan fifty years ahead for new power plant cooling water cannot possibly know where that demand will manifest itself. This mismatch in planning objectives by different actors can prevent the beneficial siting and combining of technologies.[280]

6. Moving Forward

In the United States, integration of water and energy policy is in its infancy, but there has been increasing discussion of the water-energy nexus issues over the last five years. The DOE coordinated an effort among the various national energy labs that culminated in a widely-cited energy-water nexus report to Congress[281] and a website[282] to act as a centralized location for information. Furthermore, the environmental im-

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273. Feeley III et al., *supra* note 71.

274. TORCELLINI ET AL., *supra* note 52.

275. *See* India case study *infra* Part III.F.

276. Webb & Johnson, *supra* note 238, at 5.

277. Timothy E. Wirth, C. Boyden Gray & John D. Podesta, *The Future of Energy Policy*, 82 FOREIGN AFFAIRS 132, 154 (2003).

278. For example, it takes decades to build large-scale waterworks, whereas only years to build power plants.

279. Canals, dams, etc., can last hundreds of years, whereas most power plants or transmission lines last decades.

280. For example, thermal power plant waste heat for water treatment.

281. *See* U.S. DEP'T OF ENERGY, *supra* note 5.

pacts of expanded biofuels production as mandated by the Renewable Fuel Standard (RFS) have pushed the associated water usage and pollution into the spotlight of both the government and the public.[283] Even though many of the water impacts from U.S. biofuels production relate to the cultivation of corn and not the act of turning corn starch into ethanol, the RFS has caused increased concern. The GAO, DOE, and National Academies have produced water-energy nexus reports for legislative and executive audiences outlining the major issues.[284] The focus on the energy-water nexus over the last several years has culminated in language included in the pending Energy and Water Integration Act of 2011 in the U.S. Congress.[285] At the federal level, other examples include information-based labeling that could be used by consumers to select water- or energy-efficient goods. The EnergyStar label is used to identify energy-efficient appliances, while the WaterSense label is used for water-efficient bathroom fixtures. Hawaiian law now even requires energy-efficient hot water systems.[286] Many interpret this as a mandate for solar water heating systems on single-family homes.

Some state and local governments in the United States are foregoing Federal action on the issue and attempting to integrate energy and water policymaking themselves. The CEC issued a series of reports over the last five years on this topic to inform policy development aimed to improve cohesion between the state's energy and water planners.[287] In September 2008, the California Public Utility Commission (CPUC) adopted the California Long-Term Energy Efficiency Strategic Plan, which noted that one limitation of planning was that it did not address the water-energy nexus.[288] In spring of 2010, the CPUC launched the nation's largest home energy-efficiency retrofit program with the goal to

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282. *The Energy-Water Nexus,* Sandia National Laboraties, http://www.sandia.gov/energy-water/ (last visited Nov. 21, 2012).

283. TWOMEY & STILLWELL, *supra* note, at 27.

284. *See* U.S. DEP'T OF ENERGY, *supra* note 5; U.S. GOV'T ACCOUNTABILITY OFFICE, PRELIMINARY OBSERVATIONS, *supra* note 6; COMM. ON WATER IMPLICATIONS OF BIOFUELS PRODS. IN THE U.S., NAT'L RESEARCH COUNCIL, WATER IMPLICATIONS OF BIOFUELS PRODUCTION IN THE UNITED STATES (2008), *available at* http://www.nap.edu/openbook.php?record_id=12039&page=R1; U.S. GOV'T ACCOUNTABILITY OFFICE, MANY UNCERTAINTIES, *supra* note 6.

285. *See* Energy and Water Integration Act of 2011, S. 1343, 112th Cong. (2011).

286. *See* HAW. REV. STAT. § 196-5.5 (2010).

287. *See* CAL. ENERGY COMM'N, CALIFORNIA'S WATER - ENERGY RELATIONSHIP (2005), *available at* http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF.

288. CAL. PUB. UTIL. COMM'N, CALIFORNIA LONG TERM ENERGY EFFICIENCY STRATEGIC PLAN 7 (2008), *available at* http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/.

save 20 percent in residential energy usage.[289] The program will include some water-efficiency measures such as low-flow shower heads, and there is increased use of innovative financing for these programs.[290] For example, the San Francisco program GreenInvestSF ties financing to property taxes and allows inclusion of water conservation measures beyond those currently in the energy utility program.[291]

B. Canada: Hydropower and Water for Oil Sands

With one of the world's largest unconventional petroleum reserves and production rates,[292] Canada's situation exemplifies the challenges of managing water resources that are required to exploit lesser quality fossil resources. Canada is often viewed as a water-rich country because its large size and high-precipitation climate enable it to produce and export products with large water footprints like energy and agricultural commodities. However, due to water resources distribution and water quality degradation within the country, the Canadian government does not consider Canada to be water-rich.[293] The government opposes large-scale water exports and inter-basin water transfers from the ecologically delicate northern regions of the country. Of Canada's 125 GW of electric generation capacity in 2007, seventy-three GW was hydropower operating with a collective capacity factor between 54 percent and 62 percent over the last three decades, but with a declining trend over time. Of Canada's total 614 terawatt hours (TWh) of electric generation in 2008, 369 TWh, or 60 percent, was from hydropower,[294] and hydropower consistently generates nearly 60 percent of Canada's total electricity.[295] Additionally, the interconnection of the electric grid between Canada and the United States enables power flow between the two countries. For

289. Press Release, Cal. Pub. Util. Comm'n, CPUC Makes Largest Commitment Ever Made by a State to Energy Efficiency (Sept. 24, 2009), *available at* http://docs.cpuc.ca.gov/PUBLISHED/NEWS_RELEASE/107424.htm; *see also* Southern California Edison Co., No. 08-07-021, 08-07-022, 08-07-023, 08-07-31 (Cal. P.U.C. Sept. 24, 2009) (application for approval of 2009-2011 Energy Efficiency Programs), *available at* http://docs.cpuc.ca.gov/PUBLISHED/AGENDA_DECISION/107378.htm.

290. *See generally* Southern California Edison Co., *supra* note 289.

291. Interview by Exloco a.k.a Carpe Diem Project with Dian Grueneich, Comm'r, Cal. Pub. Util. Comm'n (April 2010).

292. *See Energy*, NATURAL RES. CANADA, http://www.nrcan.gc.ca/statistics-facts/energy/895 (last modified Aug. 18, 2011).

293. Tom McMillan, *Introduction* to ENVIRONMENT CANADA, FEDERAL WATER POLICY (1987), *available at* http://www.ec.gc.ca/eau-water/D11549FA-9FA9-443D-80A8-5ADCE35A3EFF/e_fedpol.pdf.

294. *Canada - Electricity*, U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, http://www.eia.gov/countries/cab.cfm?fips=ca (last updated Sept. 17, 2012).

295. *Id.*

example, water flows in Canada enable hydropower electricity exports to the northeastern United States from the 3 GW Nalcor hydropower project on the Churchill River in Labrador.[296]

The oil sands of the McMurray formation in the Canadian province of Alberta have important water-energy implications. The oil sands are a mixture of bitumen, sand, and clay.[297] The bitumen is characterized as either a heavy or very heavy oil and has a viscosity such that it does not readily flow under either ambient or reservoir temperatures and pressures. The viscosity is decreased by adding heat in the form of steam to make the petroleum resource flow. Typically, the bitumen is accessed through one of two methods: surface mining for shallow and easily accessible deposits, or *in-situ* drilling processes for deeper resources where removing the overburden[298] is too costly. Both methods have potential impacts on water resource quantity and quality.

Processing and/or mining oil sands requires approximately 2–5 m^3 water in the form of steam per m^3 of bitumen that is produced.[299] For in-situ mining using the steam-assisted gravity drainage recovery process, best practices recycle up to 90 percent of the injected steam, and there is increasing use of saline groundwater.[300] However, because the saline water is turned to steam, the high total dissolved solids (TDS) content must be lowered before injection. Desalinating that resource raises the energy requirements for such a process. The combination of a zero-discharge water policy and projections of increased annual production[301] from oil sands is causing developers to employ more energy intensive water treatment measures than they would otherwise.[302]

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296. Julia Pyper, *New Canadian Hydro Project Could Bring Clean Energy Into U.S.*, N.Y. TIMES, Sept. 13, 2011, http://www.nytimes.com/cwire/2011/09/13/13climatewire-new-canadian-hydro-project-could-bring-clean-73350.html?pagewanted=all.

297. Jacob Masliyah et al., *Understanding Water-Based Bitumen Extraction from Athabasca Oil Sands*, 82 CAN. J. CHEM. ENG'G 628, 630 (2004).

298. Overburden is the layer of sand, gravel, and shale between the surface and the underlying oilsand that must be removed before oilsands can be mined. *Oilsands Glossary*, OILSANDS REV., http://www.oilsandsreview.com/page.asp?id=glossary#O (last visited Nov. 19, 2012).

299. JOHN LEGROW, SAGD WATER AND NATURAL GAS USE PER CONOCO PHILLIPS (C. King ed., 2010); BRUCE PEACHEY, STRATEGIC NEEDS FOR ENERGY RELATED WATER USE TECHNOLOGIES: WATER AND THE ENERGYINET 35 (2005), *available at* http://www.aeri.ab.ca/sec/new_res/docs/EnergyINet_and_Water_Feb2005.pdf; JOHN A. VEIL ET AL., WATER ISSUES RELATING TO HEAVY OIL PRODUCTION (2009).

300. LEGROW, *supra* note 299.

301. To possibly double the 2010 level by 2015.

302. *Water Use by the Natural Resources Sectors-Facts*, NATURAL RES. CANADA, http://www.nrcan-rncan.gc.ca/com/resoress/publications/wateau/energ-eng.php (last updated Oct. 14, 2010).

Water quality is also an important concern in oil sands operations. Both airborne pollution deposited on snow and water bodies and the tailings ponds that hold the wastewater containing salts, metals, and hydrocarbons from oil sands operations present opportunities to pollute surface water and groundwater. Surface mining of oil sands in Canada has thus far contributed to 130 square kilometers (km^2) of tailing pond surface, or approximately 22 percent of the estimated 600 km^2 of the total land area disturbed by March 2009.[303] Potentially, 1,400 km^2 of land could be disturbed by oil sands operations by 2023[304], and approximately 20 percent of Athabasca oil sands can be obtained via surface mining.[305] The major concern with the tailings ponds is that seepage might transport contaminants to groundwater or surface water because the ponds are often very near rivers or streams and the water table is relatively shallow in the Athabasca region. The fact that the Athabasca River itself cuts through the oil sands themselves complicates matters in attributing poor water quality impacts to anthropogenic land use and mining. While previous studies seem to show no appreciable surface water contamination,[306] recent studies indicate otherwise.[307] Specifically, mining operations deposit dust onto snow (and subsequently spring melt water) and local streams. This dust contains contaminants like PACs. Immediately downstream of mining operations, PACs on the Athabasca River are measured at almost twice the concentration of measurements upstream from oil sands mining areas.[308] Also, PAC concentrations above what are known to harm fish embryos have been measured in close proximity to surface mining activities.[309] These preliminary findings are being validated by Government of Canada monitoring and research. In 2010, Jim Prentice, the Environment Minister of Canada, appointed an independent scientific review panels to provide valuable input into the optimal design of water monitoring programs in the region.[310] Because the

303. Gov't of Alberta, *Facts and Statistics*, ALBERTA ENERGY, http://www.energy.alberta.ca/OilSands/791.asp#Geography (last visited Nov. 19, 2012).

304. PEACHEY, *supra* note 299, at 35.

305. VEIL ET AL., *supra* note 299.

306. *Environmental Minister denies oil sands development has contaminated water in Athabasca region*, THE MELIORIST (2009), Oct. 28, 2009, http://themeliorist.ca/2009/10/environment-minister-denies-oil-sands-development-has-contaminated-water-in-athabasca-region/.

307. Bob Weinhold, *Alberta's Oil Sands: Hard Evidence, Missing Data, New Promise,* 119 ENVTL. HEALTH PERSP. A126, A129–A130 (2011).

308. Kelly et al., *supra* note , at 22349.

309. *Id.* at 22350.

310. *News Release: Environment Minister Appoints Oilsands Advisory Panel*, ENV'T CANADA, http://www.ec.gc.ca/default.asp?lang=en&n=714D9AAE-1&news=981D86D0-D3DB-4D71-8957-8EF52F85A05E (last modified Oct. 6, 2010).

Athabasca River itself cuts through oil sands deposits, it is difficult to accurately assess anthropogenic versus natural factors that impact water quality.[311]

The Canadian oil sands problem stems from a set of policies that have been evolving over the last decade. At play are policy concepts such as minimizing regulatory overlap between federal and provincial governments, local participation in regional land-use management decision-making, accessibility of environmental information, and the "polluter pays" principle. Implementation of these policy approaches could have a positive effect on water quality in the oil sands region. Recent policy evolution includes development of multi-stakeholder groups with the goals of strengthening scientific and governance processes, opening up data availability, increasing attention to landscape-based management, and increasing sophistication of measuring, monitoring and modeling techniques to meet the challenge of environmental management in the area.[312] Finally, increased federal engagement is evolving through collaboration with Alberta government officials and scientists.

C. Australia: Water Scarcity Forces Leadership on Conservation

The mismatch between energy and water resources has challenged Australia to develop a unified energy-water policy. This mismatch stems from Australia's abundance of energy resources, but is considered the most water-scarce of any of the six inhabited continents.[313] Consequently, developing water policy that protects the nation's limited water resources has been a critical national initiative for decades, while the development of cogent energy policy has been of less concern since the country's vast energy resources have allowed the country cheap and abundant energy.[314]

In recent years, Australia has begun to incorporate energy policy aimed at reducing the country's carbon emissions. In 2007, the National Greenhouse and Energy Reporting Act (NGER) established a framework to account for corporate energy production, consumption, and GHG emissions.[315] Increased interest in reducing the country's carbon emis-

311. Roland I. Hall, et al., *Has Alberta Oil Sands Development Altered Delivery of Polycyclic Aromatic Compounds to the Peace-Athabasca Delta?*, 7 PLOS ONE 1, 2 (2012), *available at http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0046089*.

312. *See* Jordaan, *supra* note 186, at 3614–15.

313. M.D. Young & J.C. McColl, *Robust Reform: The Case for a New Water Entitlement System for Australia*, 36 AUSTL. ECON. REV. 225, 225 (2003).

314. *See 4610.0 - Water Account, Australia, 2004–05*, AUSTL. BUREAU OF STATISTICS (Nov. 8, 2006, 11:30 am), http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Main+Features12004-05.

315. *National Greenhouse and Energy Reporting Act 2007* (Cth) pt 1, div 1, s 3 (Austl.).

sions—among the highest in the world—led to the institution of a carbon tax in 2012.[316] Future GHG concerns will likely lead to a more coherent energy-water policy in the future, especially as the country employs energy-intensive technologies like desalination to produce clean drinking water. Given the historical practice and need for long-term water planning, Australia could become a model for integrated energy-water policy to indicate the extent of water conservation efforts before employing solutions such as desalination.

Australia, unlike many countries, promotes competitive markets in its water reform efforts. Australia's Water Act of 2007 established a water market system that supports water trade as a means of getting water to regions that need it.[317] It requires that water entitlements be reassessed each season. Water rights are not granted based on seniority as they are in the United States.[318] Additionally, each state's water diversions are capped at a specified quantity each year.[319] Although this system has had economic benefits, it has also created environmental problems due to the over-allocation of water permits.[320]

Australia's National Water Initiative (NWI), an intergovernmental agreement managed by the Australian Government's National Water Commission (NWC), was instituted in 2004.[321] This initiative was implemented ten years after the country first developed a plan for sustainable water resource development in 1994.[322] The NWC advises the Council of Australian Governments on environmentally-conscious water policy development, pricing mechanisms improvement, over-allocated water systems placation, water accounting improvement, water trade improvement, and water resources demand management improve-

316. *See* Australia introduces controversial carbon tax, BBC ASIA, July 1, 2012, http://www.bbc.co.uk/news/world-asia-18662560.

317. *See Water Act 2007* (Cth) s 10 (Austl.), *available at* http://www.comlaw.gov.au/Details/C2012C00229.

318. *See* H. Stuart Burness & James P. Quirk, *Appropriative Water Rights and the Efficient Allocation of Resources*, 69 AM. ECON. REV. 25, 25 (1979) (discussing the history and evolution of water rights in the United States).

319. *Water Act 2007* (Cth) sch E (Austl.), *available at* http://www.comlaw.gov.au/Details/C2012C00229

320. Michael D. Young, *Environmental Effectiveness and Economic Efficiency of Water Use in Agriculture: The Experience of and Lessons from the Australian Water Reform Programme*, *in* OECD, SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN AGRICULTURE (2010).

321. *National Water Initiative*, ENV'T, WATER, POPULATION & COMMUNITIES, AUSTL. GOV'T, http://www.environment.gov.au/water/australia/nwi/index.html (last updated Nov. 21, 2012).

322. *Id.*

ment.[323] Each state and territory is required by the NWI to submit an implementation plan that the NWC critiques to ensure coherence between each government's water policy and the initiatives of the NWI. Published by the NWC, the Australian Water Resources Report (AWR) provides data that are pertinent to evaluating the effectiveness of the NWI by assessing the country's water resources. It reports how much water is available in Australia, how much water is stored, and the year-to-year variability in water availability across the country.[324] Many agencies contributing to the development of the NWC's AWR report are classified within Water Resources Observation Network alliance. Despite numerous stakeholders, water is still largely controlled by the states.[325]

At 65 percent of total consumption, irrigation is the largest user of water in Australia. Much of Australia's water policy framework focuses on sustainable water use in the agriculture sector rather than in the energy sector. Electricity generation facilities account for only 1–2 percent of Australia's total water consumption.[326] However, drought conditions in 2007 forced thermoelectric power plants to scale back power production as low water availability hampered electricity production.[327] As one example of a water-energy response to drought, the Queensland Government approved a power station based on use of dry cooling technology to reduce water consumption by 90 percent compared to wet cooling systems, to around 1,500 million liters per year, or 250-300 L/MWh. The cooling system uses an air-cooled condenser, only the second power plant using the technology in Queensland.[328] Water can also be sprayed beneath the condenser surfaces for additional cooling so that the plant can operate at full capacity even at temperatures of over 40°C.[329] The plant is designed for an efficiency rating of 45 percent that is comparable

323. *NWI Objectives*. NAT'L WATER COMM'N, http://nwc.gov.au/nwi/objectives (last visited Nov. 20, 2012).

324. Australian Bureau of Meteorology, *Australian Water Resources Assessment 2010*, http://www.bom.gov.au/water/awra/2010/index.shtml (last visited Jan. 26, 2013).

325. Young, *supra* note 320, at 8.

326. *4610.0 - Water Account, Australia, 2004–05*, AUSTL. BUREAU OF STATISTICS (Nov. 8, 2006, 11:30 am), http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Main+Features12004-05.

327. Greg Roberts, *Blackouts on way as power plants dry up*, THE AUSTRALIAN, Mar. 9, 2007, http://www.theaustralian.com.au/news/blackouts-on-way-as-power-plants-dry-up/story-e6frg6oo-1111113123985)2007.

328. CS ENERGY, KOGAN CREEK ENVIRONMENT FACTSHEET CS08 (2008), *available at* http://www.csenergy.com.au/userfiles/KCPS%20Env%20fact%20sheet.pdf (last visited Jan. 25, 2012); J. Harten, *Dry-cooled Tower Technology*, 26 ENERGY NEWS 14 (2008).

329. Siemens, *Energy for everyone - water demand in coal fired power stations. Pictures of the future Spring 2008*, http://www.siemens.com/innovation/en/publikationen/publications_pof/pof_spring_2008/energy/ohne_wasserkuehlung.htm (last visited January 25, 2013).

to water-cooled facilities, and Siemens claims that efficiency is one of the highest in the world for a dry-cooled plant. Siemens describe Kogan Creek as the most efficient coal-fired power plant in Australia.[330]

Unlike its scarce water supplies, Australia enjoys abundant energy resources. It is the world's fourth largest exporter of coal, supplies 8 percent of the world's liquefied natural gas, and has 40 percent of the world's uranium reserves.[331] Australia's energy supply mix consists predominately of coal (39 percent), petroleum (34 percent), and natural gas (21) with renewables accounting for most of the remaining 5 percent of primary energy consumption.[332]

Because of Australia's vast fossil fuel resources, the country has historically enjoyed cheap energy prices. Additionally, Australia has the fourth and fifth lowest gasoline and diesel taxes among OECD countries, respectively.[333] For this reason, relatively little attention has been devoted to sustainable energy policy in the past. In fact, while the carbon intensity of most of the world's developed countries has fallen since 1990 due to the increasing role of natural gas in the electricity mix, the carbon intensity of Australia's electricity supply has risen during this period because of the increasing role of coal.[334] Consequently, Australia currently has one the highest per capita carbon dioxide emissions of any other country in the world.[335]

In response to water shortages, Australian cities have turned to seawater desalination as a water supply. Public concern over embedded energy and GHG emissions led desalination facilities in Perth and Sydney to construct policy and business agreements to conceptually couple grid-connected wind farms to offset the carbon emissions of the desalination plants.[336]

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330. *Id.*

331. AUSTL. GOV'T, SECURING AUSTRALIA'S ENERGY FUTURE 3 (Dep't of the Prime Minister & Cabinet eds., 2004).

332. AUSTRALIAN DEP'T OF RESOURCES, ENERGY, AND TOURISM, ENERGY IN AUSTRALIA 2011, *available at* http://www.ret.gov.au/energy/Documents/facts-stats-pubs/Energy-in-Australia-2011.pdf.

333. AUSTL. GOV'T, *supra* note 337, at 13.

334. FRIDTJOJ UNANDER, FROM OIL CRISIS TO CLIMATE CHALLENGE: UNDERSTANDING CO2 EMISSIONS TRENDS IN IEA COUNTRIES 5–9 (2003).

335. *A change in the climate: Make us greener, oh lord. But not yet*, THE ECONOMIST, April 29, 2010, *available at* http://www.economist.com/node/16009369?story_id=16009369&source=HPtextfeature.

336. *See Perth Seawater Desalination Plant, Australia*, WATER TECH., http://www.water-technology.net/projects/perth/ (last visited Nov. 14, 2012); *see also* Edmund Tadros & Brian Robins, *Wind Farm Vow to Power Desalination*, THE SYDNEY MORNING HERALD (Austl.), May 14, 2008, at 7, *available at* http://www.smh.com.au/news/environment/wind-farm-vow-to-power-desalination/2008/05/13/1210444436869.html.

Despite Australia's effort to coordinate sustainable water policy, it is difficult to develop coherent national water policy because Australian water resource data are currently collected by over 200 organizations, making accurate projections regarding future water availability and water use difficult.[337] In efforts to streamline the aggregation of water resource data, the Water Act of 2007 granted the Bureau of Meteorology the rights to collect, hold, manage, interpret, and disseminate Australian water resource information from all water collection agencies.[338] Additionally, it provides water resource projections and conducts analysis to improve the effectiveness of water policy.[339] Researchers at the ANU and the University of Sydney have formed the Australia-United States Climate, Energy and Water Nexus Project to build upon existing water resource planning by adding an energy dimension to Australia's policies.[340]

D. France: Nuclear Power to the Core, but High Temperatures Mean Low Output

France illustrates the interconnectedness of power generation and water supplies through its extensive use of nuclear power, which has significant water needs for cooling purposes. Additionally, various related institutions make France an interesting example of energy and water policy formulation. Electricity generation in France is dominated by nuclear power at 78 percent of total power generation, with hydroelectricity second at 11 percent.[341] Some French nuclear power plants utilize open-loop cooling which requires high water availability to support large withdrawals of cooling water, but only consumes small amounts of water.[342]

A majority of France's water consumption originates in the agriculture sector, consuming 68 percent of the nation's water use; the remaining water consumption is for drinking water, industry, and power

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337. BUREAU OF METEOROLOGY, AUSTL. GOV'T, ANNUAL REPORT 2009–10, WATER INFORMATION RESEARCH AND DEVELOPMENT ALLIANCE 1 (2010), *available at* http://www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-WIRADA-annual-report2009-10.pdf.

338. *Water Act 2007* (Cth) pt 2, div 2, s 120 (Austl.).

339. *Id.*

340. The project maintains a website at http://www.water.anu.edu.au/project/auscew/.

341. *La Production d' Électricité*, MINISTÈRE DE L' ÉCOLOGIE, DU DÉVELOPPMENT DURABLE ET DE L' ÉNERGIE (updated Mar. 12, 2011), http://www.developpement-durable.gouv.fr/La-production-d-electricite.html.

342. World Nuclear Ass'n, *Cooling power plants* (Nov. 2011), http://www.world-nuclear.org/info/cooling_power_plants_inf121.html.

generation.[343] Private sector participation constitutes approximately 80 percent of drinking water services in France, illustrating potential for successfully privatizing water in a developed country.[344]

Energy and water policies in France fall under the jurisdiction of many different government ministries. The main ministries executing energy and water policies include the Ministry of Ecology, Energy, Sustainable Development and Sea (Ministère de l'Ècologie, de Ènergie, du Dèveloppement durable et de la Mer), Ministry of Food, Agriculture and Fisheries (Ministère de l'Alimentation de l'Agriculture et de la Pêche), and the Ministry of Health (Ministère de la Santé et das Sports), among other ministries handling energy and water spending and management. While energy policies are generally handled on the national scale, water agencies (les Agences de l'Eau) that manage water on the basin level implement water policies determined by the National Water Committee.[345] While managing water policies based on water catchment areas might seem like an obvious approach, a fair number of countries worldwide use political boundaries rather than hydrologic boundaries when managing water resources. Thus, France's water policies are a welcome exception.

Rainfall is generally plentiful in France, yet location and seasonality of rainfall does not always coincide with agricultural water needs. Because of particularly dry summers in the southern half of France, much of the agricultural production in the Mediterranean area of the country is irrigated.[346] Irrigation supplements rainfall for agricultural production in areas of west and central France as well.[347] Policy measures support the use and expansion of irrigation in agriculture via subsidies for farmers who install irrigation equipment and guaranteed low prices for irrigation water.[348] This regional dependence on irrigation for agriculture shows that agriculture policies are highly influenced by water poli-

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343. Arnaud Makrani, *Water and agriculture* (Oct. 1, 2009), http://www.snv.jussieu.fr/vie/dossiers/eau/eaugestion/eauagriculture.html.

344. Arnaud Reynaud, Social Policies and Private Sector Participation in Water Supply—the Case of France 12 (April 2007), *available at* http://www.unrisd.org/unrisd/website/document.nsf/d2a23ad2d50cb2a280256eb300385855/30625d1a28e4eb5ac12572b30041c487/$FILE/France_web.pdf.

345. *The Six French Water Agencies are Public Institutions of the Ministry of Sustainable Development*, The Water Agencies, http://www.lesagencesdeleau.fr/les-agences-de-leau/les-six-agences-de-leau-francaises/?lang=en (last visited Nov. 14, 2012).

346. *Maitriser l'Eau Pour une Agriculture de Qualité*, Ministère de l'Agriculture de l'Agroalimentaire et de la Foret, http://agriculture.gouv.fr/sections/thematiques/environnement/maitrise-de-l-eau (last visited Nov. 14, 2012).

347. *Id.*

348. *See* Environment Directorate of the European Commission, *The Environmental Impacts of Irrigation in the European Union*, at 117 (Mar. 2000).

cies. Because irrigation also requires electricity for pumping, these agricultural policies add to electricity demands.

Biofuels production in France is confined mostly to non-irrigated feedstocks such as sugar beets and rapeseed.[349] Because these biofuels are rain-fed, there is little conflict between water, agricultural, and biofuel policies. That is, if sugar beets or rapeseed were irrigated, policies that promote additional biofuels production would undermine policies that aim to conserve water. Consciously or unconsciously, by respecting the ecological environment through sustainable water use, French energy policy for biofuels does not conflict with water policy.[350]

France's dependence on large water withdrawals for irrigation of agriculture and cooling of nuclear and other thermoelectric power plants leaves the nation vulnerable to drought conditions. Historical heat waves in 2003 left France's rivers too hot with water levels too low to assure adequate cooling of nuclear power plants; after requesting temporary exemptions, nuclear facilities were forced to operate at reduced capacity as a result of heat and drought.[351] A similar heat wave combined with prolonged drought could jeopardize both power generation and food production in France due to the country's agricultural dependence on irrigation. Thus, both energy and water resources are vulnerable to drought and heat waves.

In 2007, France merged various ministries and departments to form the Department of Ecology, Energy, Sustainable Development and the Sea. This merger was motivated by the interdependence of energy, natural ecosystems, and sustainable development, and the need for a completely open plan as part of a policy for sustainable planning. In addition, the Master Plans of Development and Water Management—which represent France in the management plans required by the Water Framework Directive (WFD)—are applying the WFD coordinating hydropower operations and conservation of aquatic environments as far as possible to remove or operate dams to achieve or maintain good ecological potential.[352]

France illustrates both coherent and incoherent aspects of energy and water policy. Positive aspects include using non-irrigated agriculture for biofuels production and water management on a river basin scale. However, heavy reliance on hydropower and nuclear power facili-

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349. *See* de Fraiture et al., *supra* note 105, at 72.

350. *Resources: Water Management in France*, THE WATER ECONOMY WEBSITE, http://www.waternunc.com/gb/ageau2gb.htm (last visited Nov. 14, 2012).

351. *See* Hannah Förster & Johan Lilliestam, *Modeling thermoelectric power generation in view of climate change*, 10 REG'L ENVTL. CHANGE 327, 328 (2010).

352. *See* ORG. ECON. CO-OPERATION & DEV., OECD STUDIES ON WATER, WATER GOVERNANCE IN OECD COUNTRIES: A MULTI-LEVEL APPROACH 87, Box 4.7 (2011).

ties with open-loop cooling on rivers leaves the nation highly vulnerable to drought and other water shortages. Implementing dry or hybrid wet-dry cooling technologies would help mitigate drought-induced problems at power plants, but would also reduce efficiency of nuclear power generation. Energy and water conservation could also lessen the effects of additional power generation that requires additional water consumption, requiring more energy for treatment.

E. Brazil: Water Resources Enable a Global Leader in Bioenergy, but New Challenges Await

Brazil has perhaps the most ambitious, long-term plan to pursue an alternative to petroleum. The success owes much to Brazil's climate and water availability. The energy and water resources in Brazil are intimately tied to the economic productivity of the country. In 2010, approximately 50 percent of Brazil's primary energy consumption was directly dependent upon water, including 29 percent from hydropower and nearly 21 percent from biomass.[353] Approximately 13.6 quads[354] of energy were consumed in Brazil in 2010.[355] Depending on the success of the crop, sugar cane can supply more of Brazil's annual primary energy than hydropower. However, hydropower is the dominant *electricity* generation type in Brazil.[356] Still, Brazil is not immune to the controversies surrounding the establishment of new hydropower facilities. The Belo Monte hydropower project on the Xingu River in the eastern Amazon basin will be the third largest hydropower project in the world.[357] As an environmental concession, the facility was redesigned as a run-of-river style instead of a traditional large reservoir, flooding only a third of the area from the original plan two decades earlier.[358] Brazil's challenge for balancing the water-energy nexus for hydropower will continue as the country's National Energy Plan 2030 stipulates the addition of 95,000 MW of new hydro capacity by 2030.[359] Additionally, the Energy Plan calls for producing 11.4 percent of electricity, or 136 TWh, by 2030 from

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353. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, BRAZIL ANALYSIS BRIEF (2012), *available at* http://www.eia.gov/countries/cab.cfm?fips=BR.

354. 1 quadrillion BTU = 1 quad

355. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, *supra* note 353.

356. *Id.*

357. Mike Major, *Super-size Hydro; Wind in Pipeline*, RENEWABLE ENERGY FOCUS, July-Aug. 2011, at 22, 23.

358. Kathryn Hochstetler, *The Politics of Environmental Licensing: Energy Projects of the Past and Future in Brazil*, STUD. COMP. INT'L DEV., Dec. 2011, at 349, 358.

359. INTERMINISTERIAL COMMITTEE ON CLIMATE CHANGE, EXECUTIVE SUMMARY NATIONAL PLAN ON CLIMATE CHANGE 10 (2008) (Braz.).

burning bagasse, the fibrous part of the sugar cane not currently used for ethanol production.[360]

In 1975, Brazil reacted to the global oil crises by beginning its National Alcohol Program to make ethanol a significant fuel for its domestic fleet of light duty vehicles.[361] Today, fuel comes in a minimum ethanol mix variety, at 20 percent ethanol, and higher mixes that can be 100 percent anhydrous ethanol.[362] Over 80 percent of the cars produced in Brazil are now flex-fuel vehicles that can take the range of fuel mixtures from 25%/75% ethanol/gasoline to 100 percent ethanol.[363] The transformation of the ethanol industry in Brazil is possible because of the conversion of sugar cane into ethanol primarily in the south central region[364] of Brazil where the climate and rainfall are suitable for growing sugar cane.[365] Although many farms in the more mature sugar cane production areas of northeast Brazil[366] require irrigation because of the more arid environment, a large part of the success of National Alcohol Program (PROALCOOL) is due to suitable rain-fed lands in the south.

Achieving Brazil's move away from 100 percent petroleum dependence for light duty vehicle travel required coordination among several ministries of the federal government: the Ministries of Industry and Commerce, Agriculture, Science and Technology, Mines and Energy, Finance and Planning, and Environment.[367] Furthermore industrial groups[368] and consumer groups participated in the plan as the Brazilian government promoted blending ethanol into the fuel distribution system by a coordinated plan of subsidies that facilitated the transition. This coordination facilitated incredible growth in Brazilian sugar cane and ethanol production, from 1.5 GL in 1979 to 11.5 GL in 2001 to over 27 GL in 2008.[369] The National Energy Plan 2030 calls for a large increase in domestic ethanol demand from 20.3 GL in 2008 to 52.2 GL in 2017.[370]

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360. *Id.* at 11.

361. *See* Frank Rosillo-Calle, & Luis A.B. Cortez, *Towards ProAlcool II—a Review of the Brazilian Bioethanol Programme*, 14 BIOMASS & BIOENERGY 115, 115 (1998).

362. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, *supra* note 353.

363. William Coyle, *The Future of Biofuels*, AMBER WAVES, Nov. 2007, at 24, 29.

364. *E.g.*, state of São Paulo.

365. David M.Lapolaa et al., *Modeling the Land Requirements and Potential Productivity of Sugarcane and Jatropha in Brazil and India Using the LPJmL Dynamic Global Vegetation Model*, 33 BIOMASS & BIOENERGY 1087, 1093 (2009).

366. E.g. Paraiba.

367. Frank Rosillo-Calle & Luis A.B. Cortez, *Towards ProAlcool II—a Review of the Brazilian Bioethanol Programme*, 14 BIOMASS & BIOENERGY 115 (1998).

368. For example, sugar cane industry, fuel distributors, automobile.

369. CONSTANZA VALDES, U.S. DEP'T OF AGRIC., BRAZIL'S ETHANOL INDUSTRY: LOOKING FORWARD (2011), *available at* http://www.ers.usda.gov/media/126865/bio02.pdf .

370. INTERMINISTERIAL COMMITTEE ON CLIMATE CHANGE, *supra* note 359.

The recent expansion in ethanol production over the last decade caused growing pains for assuring soil and water sustainability, and the state and federal governments have acted to preserve water resources. The recently enacted Agroecological Zoning[371] for sugar cane and ethanol production includes measures to assure that new biorefineries are limited to water withdrawal less than 1000 L per ton of cane[372] processed, versus 20,000 L per ton 20 years ago. This has now become easily achievable due to improvements in plant technology such as incorporating internal infrastructure to treat and recycle water that was historically discharged. Additional specifications for sugar cane in the Agroecological Zoning relate to harvesting by machine instead of manual labor and consideration of soil and water availability when choosing sites for farms to both maximize yields and minimize irrigation needs. The effluent from these biorefineries is high in nutrient content. In the past, this caused environmental degradation by impairing local waters and eliminating much of the aquatic life in local rivers.[373] However, today it is common practice to recycle this "vinasse" by reapplying those nutrients onto the fields as fertilizers in irrigation, also known as "fertigation" or "ferti-irrigation."[374] The full environmental impacts regarding the eventual flow of nutrients within the hydrological system of these fertigation practices are unknown.

To better plan for water resources, including the implications for energy, the newly formed AgroHidro and Water Resources Research Network are means by which Brazilians hope to gain a much more thorough view of the hydrological systems in Brazil to better guide future industrial and agricultural practices. The history of a coordinated and coherent plan across multiple ministries for ethanol production provides some level of confidence that the same coherence can translate to water resource management. Now that the scale of energy infrastructure in Brazil has grown beyond the highest quality land and water resources, a new challenge emerges for coherent policy. Only 5 percent—approxi-

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371. *See Sugarcane Agro-Ecological Zoning a Welcome Step to Promote Sustainability, but Amendments will be Needed According to Brazilian Sugarcane Industry*, UNICA – Brazilian Sugarcane Industry Ass'n (Sept. 18, 2009), http://english.unica.com.br/releases/show.asp?rlsCode={6FF09728-9C40-4291-B419-47050EA5545F}.

372. One ton of sugar cane translates to approximately 85 L of ethanol. *See* Brazilian Sugarcane Industry Ass'n & AppexBrasil, *Virtual Tour of a Sugarcane Mill*, http://sugarcane.org/about-sugarcane/virtual-mill-tour/virtual-tour-of-a-sugarcane-mill-transcript (last visited Jan 27, 2013).

373. *See* Günter Gunkel et al., *Sugar Cane Industry as a Source of Water Pollution–Case Study on the Situation in Ipojuca River, Pernambuco, Brazil*, Water Air & Soil Pollution, Mar. 2007, at 261, 262.

374. *Id.*

mately 9 million hectares—of Brazilian agriculture and pasture land was used for sugar cane in 2010, and Brazil has more available arable land for general agricultural expansion than any other country.[375] The designation of agroecological zones to protect water quality and quantity shows that Brazil is trying to stay ahead of the energy-water curve with regard to its biofuel policies.

F. India: Renewable Water for Hydropower Allows Depletion of Fossil Aquifer

As India's population has grown and further developed technology, some energy and water resources have been exploited beyond their renewable capacity, especially groundwater resources.[376] Substantial conflicts between energy and water management make India a descriptive example of energy and water policies that can inadvertently undermine one another.

India is a diverse nation with large land area and energy and water resource potential.[377] However, development of India's energy and water resources has led to conflicts between agricultural production, domestic water supply, power generation, and more recently, biofuel production. In order to ensure adequate food supply for India's growing population, about 66 percent of total grain production depends on irrigation,[378] usually in the form of pumped groundwater irrigation.[379] Because of agriculture's strong dependence on irrigation, current Indian groundwater management practices have not prevented resource depletion.[380] As a result, water tables are falling such that 114 million people might experience water shortages for irrigation and drinking water.[381]

India's National Water Policy of 2002 prioritized development and management of the nation's water resources, emphasizing integrated management, sustainable use, conservation, and the creation of

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375. UN FOOD AND AGRICULTURAL ORGANIZATION STATISTICS, http://faostat3.fao.org/home/index.html; COMPANHIA NACIONAL DE ABASTECIMENTO, http://www.conab.gov.br (maps and data).

376. *See* Rakesh Kumar et al., *Water Resources of India*, 89 CURRENT SCI. 794, 810–11 (2005).

377. *See id.* at 796–99.

378. Irrigation accounts for 83 percent of total water use. Mohua Guha & Kamla Gupta, *Water Resources in India: Critical Issues Related to Availability and Sustainable Use*, IASSI Q., Jan.–Mar. 2007, at 90.

379. McCornick et al., supra note 222, at 29.

380. *See* Matthew Rodell et al., *Satellite-based Estimates of Groundwater Depletion in India*, 460 NATURE 999, 999–02 (2009).

381. *Id.*

water information systems.[382] To date however, India's water supply has remained relatively constant, and a growing population puts strain on existing supply.[383] Despite this strain, official statistics claim 90 percent and 97 percent of the urban and rural population, respectively, has access to reliable drinking water, yet only 50 percent and 5 percent, respectively, have access to sanitation.[384] The large percentage of the population without access to sanitation leads to conflicts between the National Water Policy and other environmental and ecological policies. Reliance on large amounts of energy for pumping water in long-haul pipelines also leads to conflicts between drinking water supplies and energy.[385]

Introduction of irrigated sugar cane for biofuels production exacerbates Indian energy and water policies even further. While Indian sugarcane represents large biofuels potential, irrigation of the crop exacerbates conflicts between energy, water, and agricultural policies in India.[386] Consequently, energy, water, and agricultural policies in India are highly disjointed and incongruent. As India aims to increase energy production from additional sugarcane biofuels and both hydroelectric and thermoelectric power generation, the gap between energy, water, and agricultural policies widens.[387] Current conflicts between reservoir water use for irrigation or hydroelectric power generation might only get worse. Ironically, more than half of the hydropower generated in India is used for groundwater pumping for irrigation.[388] Because most farmers do not have access to surface water in the reservoirs behind hydroelectric dams, the surface water is used to generate electricity to pump groundwater for irrigation. This dissipative Indian water cycle of surface water being used to generate electricity to pump groundwater might run itself dry without coordinated action and planning. The current state of energy and water policies in India illustrates the importance of whole systems thinking to prevent water policy decisions from exacerbating energy and water resources.

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382. Guha & Gupta, *supra* note 378, at 85.
383. *Id.*; Rodell et al., *supra* note 380.
384. Guha & Gupta, *supra* note 378, at 85–97.
385. Trieb & Müller-Steinhagen, *supra* note 116; Cardona et al., *supra* note 116.
386. McCornick et al., *supra* note 222.
387. Guha & Gupta, *supra* note 378; de Fraiture et al., *supra* note 105; Rodell, *supra* note 380.
388. McCornick et al., *supra* note 222.

G. Israel: Location, Location, Location Needs Technology, Technology, Technology

A history of employing innovative technology in a water-constrained and sun-drenched country has forced Israel into both energy-conserving and energy-intensive water solutions. Israel's arid environment and lack of fossil energy resources drive Israeli investment at the energy-water nexus, including use of desalination and solar hot water heating. Looking to a future with reduced carbon emissions and less available petroleum, Israeli companies are also increasingly pursuing solar technology to use the country's abundant sunshine for growing algae to turn into biofuels.[389]

Practically since its inception, Israel has struggled with the provisioning of fresh water for municipal and agricultural purposes. By the 1990s, a combination of drought, groundwater mining, and continued population increase prompted centralized desalination planning. The Israeli Water Commission began planning what became the Desalination Master Plan in 1997. The Master Plan targets a total capacity of 775 billion L/year.[390] Israel now has the world's largest reverse osmosis desalination plant at Ashkelon[391] which produced 111 billion L in 2008, approximately 15 percent of total domestic demand.[392] The Ashkelon facility's energy consumption is approximately 3,900 kWh/million L. Major desalination plants also exist at Hadera, Eilat, and Palmachim, and others are in the planning or construction phases at Ashdod and Shafdon (wastewater).[393] They aim to serve approximately 50 percent of Israel's municipal freshwater demand, and as of 2010 an estimated 875 million cubic meters per year, equal to 56 percent of natural freshwater resources, comes from recycled effluents and desalination.[394] However, the solutions to handling the environmental and engineering challenges of discharging large quantities of concentrated effluents into the sea and using desalinated water for crop irrigation are not yet fully realized.[395]

Israel's use of solar hot water heating began even before its inception as a country, and the first Prime Minister, David Ben-Gurion, had a

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389. Jaswinder Singh & Sai Gu, *Commercialization Potential of Microalgae for Biofuels Production*, 14 RENEWABLE & SUSTAINABLE ENERGY REVS. 2596, 2596–2610 (2010).

390. WATER WISDOM: PREPARING THE GROUNDWORK FOR COOPERATIVE AND SUSTAINABLE WATER MANAGEMENT IN THE MIDDLE EAST (Alon Tal & Alfred Abed Rabbo eds., 2010).

391. Capacity of 348 million L/day.

392. *See* ORG. ECON. CO-OPERATION & DEV., *The Environmental Performance of Agriculture*, *in* OECD REVIEW of AGRICULTURAL POLICIES: ISRAEL 2010, at 147, 147–98 (2010).

393. WATER WISDOM: PREPARING THE GROUNDWORK FOR COOPERATIVE AND SUSTAINABLE WATER MANAGEMENT IN THE MIDDLE EAST, *supra* note 390.

394. ORG. ECON. CO-OPERATION & DEV., *supra* note 198.

395. *Id.*

solar water heater in his home.[396] Solar hot water use increased in usage nationally due to fuel shortages and high prices over the decades, and in 1980 the Israeli government passed a law amending Article 9 of the Law for Planning and Building (1970) requiring builders to install solar hot water systems on new residential buildings.[397] Today, over 90 percent of all Israeli homes have solar hot water systems that can provide hot water needs for 9–10 months out of the year, saving 21 percent of domestic sector electricity consumption, or 5 percent of national electricity consumption.[398] Solar hot water heating in Israel is clearly a win-win scenario for the energy-water nexus because it conserves both resources.

Because the country lacks oil resources and has abundant solar resources and experience in growing algae for high value nutritional supplements and cosmetic applications, Israeli companies could be poised to lead development of algal biofuel technology. Several companies in Israel are working with various international partners in pursuit of deriving alternative liquid fuels. For example, Israeli-based Seambiotic is one of the worldwide leaders in algae cultivation, producing it on a site of 1,000 square meters using the CO_2-containing coal plant flue gas[399] as an input.[400] Partnerships with United States and Chinese companies poise the company at the forefront of algae cultivation for both consumer products and biofuels.[401]

Israel reported in an OECD energy-water survey that the coordination between policies for water allocations and energy consumption is explicitly addressed in the Israeli Water Authority's 2010 Master Plan for national water and wastewater management.[402] Within the Master Plan are several measures for minimizing water-related demand on the national power supply.[403] Promoting electricity demand management, the

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396. JOHN BACHER, PETROTYRANNY 70 (Shirley Farlinger & Derek Paul eds., 2000).

397. Grossman, *supra* note 122.

398. *Id.*

399. Flue gas refers to the combustion product gases discharged to the atmosphere through a flue-gas stack.

400. *Transformative Technologies 2010 nominees: Microalgae, cyanobacteria, lemna, and plankton*, BIOFUELS DIG. (June 7, 2010), http://www.biofuelsdigest.com/bdigest/2010/06/07/transformative-technologies-2010-nominees-microalgae-cyanobacteria-lemna-and-plankton/ (last visited Nov. 27, 2012).

401. *Seambiotic Press Release*, SEAMBIOTIC (Dec. 1, 2009), http://www.seambiotic.com/News/news-updates/seambiotic-and-chinese-power-company-to-build-10-million-commercial-microalgae-farm-in-china/ (last visited Nov. 27, 2012).

402. WATER AUTHORITY, MINISTRY OF NATIONAL INFRASTRUCTURES, A LONG-TERM MASTER PLAN FOR THE NATIONAL WATER SECTOR (2010) (policy document of the State of Israel).

403. Water related power demand accounts for approximately 8 percent of the total national electrical demand. *Id.*

Israeli Electricity Authority[404] encourages customers to minimize their demand on electricity during peak[405] hours by selling electricity at much higher prices during the day.[406] The Israeli Water Authority permits water pumping and purification operators the freedom to minimize their energy demands during these peak daytime hours. To minimize costs and maximize profits, operators pump larger proportions of the daily water-quotas during the night hours and store the pumped water in numerous reservoirs throughout the country. They thereby reduce energy-costs, while homogenizing energy demands across the day-night cycle. The Israeli Water Authority thereby works with the Israeli Electricity Authority to limit daytime energy consumption rates.[407]

H. Singapore: Old Water to NEWater

Singapore is notable for its innovative approach to water management and security. Substantial water recycling and reuse has increased the country's water security while also increasing energy consumption for water treatment. Coupling these water security measures with water conservation and energy efficiency leads to cohesive policies to manage both resources. The Asian country has faced many water challenges due to a relatively large population of 4.4 million on small land area.[408] Consequently, a large proportion of Singapore's water needs are domestic, and the supply of drinking water depends on constructed reservoirs and catchments, imported Malaysian water, desalination, and recycled wastewater known as NEWater.[409] Policy decisions regarding water have also affected Singapore's approach to energy management, making the small nation a suitable example of conservation and water reuse.

Desalination and production of NEWater both represent substantial supplies of water in Singapore at 25 percent and 30 percent of total supply, respectively.[410] Both require advanced membrane treatment,

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404. A division of the Ministry of National Infrastructure. *See* ORG. ECON. CO-OPERATION & DEV., COORDINATION ENERGY AND WATER POLICIES SURVEY RESULTS (2010).

405. Daytime hours when power demand is highest.

406. ORG. ECON. CO-OPERATION & DEV., *supra* note 404.

407. *Id.*

408. *Eco-efficient water infrastructure practices in Singapore*, ECOWIN (April 29, 2010), http://www.ecowaterinfra.org/knowledgebox/documents/case%20study%20in%20Singapore.pdf

409. *Id.*

410. PUB, *NEWater: The 3rd National Tap* (April 20, 2010), http://www.pub.gov.sg/water/newater/Pages/default.aspx; Lee Poh Onn, Water Management Issues in Singapore (2005) (unpublished), *available at*: khmerstudies.org/download-files/events/Water/Lee%20Nov%202005.pdf.

which creates a reliable yet energy-intensive drinking water supply.[411] The creation of the Ministry of the Environment and Water Resources (MEWR) in July 2002 reduced administrative barriers to policy and infrastructure development that advance Singapore toward a sustainable and reliable drinking water supply.[412]

The MEWR introduced the "10-Litre Challenge" in 2006, challenging citizens—responsible for more than half of Singapore's total water consumption—to reduce their daily water consumption by 10 L through water conservation.[413] A challenge was also launched to decrease water consumption of non-domestic users by 10 percent or more.[414] By promoting and using water-efficient appliances such as dual-flush toilets, these proactive conservation policies have decreased in per capita water consumption from 172 L per person per day in 1995 to 157 L per person per day in 2007.[415] Energy efficiency policies have also improved overall energy efficiency by 15 percent from 1990 to 2005.[416] By implementing a dual approach of water conservation and energy efficiency, Singapore has realized the possible synergies between water and energy policies.

I. Additional Examples of Coordination of Energy-Water Policy Amongst Countries

In the United Kingdom (UK), The Department of Energy and Climate Change has worked alongside the Department for the Environment, Food, and Rural Affairs to identify that 89 percent of the energy embodied in household water is used for hot water.[417] The UK government is working with the Energy Saving Trust to develop a policy to target hot water use as a way of mitigating emissions from energy consumed to heat household water.[418]

In Spain, the National Water Council, regulated by Royal Decree 1383/2009, is represented by the energy sector, the head of the Directorate General for Energy Policy and Mines, the Ministry of Industry, Tourism and Commerce and a representative from the Spanish Association of

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411. Notably, NEWater is less energy-intensive than water from desalination.

412. Deh Chien Chen et al., *Institutional Capacity and Policy Options for Integrated Urban Water Management: a Singapore Case Study*, 13 WATER POL'Y. 53–68 (2010).

413. MINISTRY OF THE ENVT. & WATER RES. (May 05, 2011), http://app.mewr.gov.sg/web/contents/Contents.aspx?ContId=475&pf=y&pf=y (last visited Nov. 27, 2012).

414. *The Singapore Water Story*, PUB (Aug. 22, 2012), http://www.pub.gov.sg/water/Pages/singaporewaterstory.aspx (last visited Nov. 27, 2012).

415. Deh Chien Chen et al., *supra* note 412.

416. *E² Singapore*, MINISTRY OF THE ENVT. & WATER RES. http://www.nea.gov.sg/cms/ccird/E2%20Singapore%20(for%20upload).pdf (last visited Jan 27, 2013).

417. ORG. ECON. CO-OPERATION & DEV., *supra* note 404.

418. *Id.*

Electrical Industry.[419] There are also regular meetings between the Ministry of Environment and Rural and Marine Environment and the Ministry of Industry.[420]

In Mexico, water reuse is a priority. Water is seen as a vital, vulnerable, and finite federal public good. Maintaining the sustainability of water quantity and quality is a fundamental task of the State and an issue of national security. Administering, planning, and implementing water management is coordinated based upon water catchment areas. As an example of coordinating policy to meet federal water policy objectives, the Technical Committee on Operation of Hydraulic Works (CTOOH)[421] meets weekly to address all operational aspects of dams throughout Mexico to sufficiently addresses all water management concerns and to minimize floods and droughts.[422] CTOOH is composed of representatives from the National Water Commission, Federal Electricity Commission, the Mexican Institute of Water Technology, and the Engineering Institute of the National Autonomous University of Mexico.[423] In particular, Mexico is reviewing the possibility of using mini-hydro plants in existing water infrastructure. Initial estimates are that 112 small projects could feasibly be developed by the private sector for a total installed capacity of 6,600 MW and annual generation of 16,000 GWh.[424]

In Portugal, the long-term National Energy Strategy is jointly prepared by the Ministry of Economy and the Ministry of the Environment and Land Use Planning.[425]

In Tunisia, electricity consumed for pumping groundwater is used to corroborate estimates of total groundwater withdrawal.[426]

In Costa Rica, the National Plan of Integrated Water Resources includes hydropower development initiatives and other subsectors like drinking water and irrigation.[427]

In order to reduce conflicts among multiple water use stakeholders in Panama, both the Public Services Authority and National Environ-

419. *Id.*
420. *Id.*
421. Comité Técnico de Operación de Obras Hidráulicas in Spanish.
422. ORG. ECON. CO-OPERATION & DEV., *supra* note 404.
423. ORG. ECON. CO-OPERATION & DEV., OECD STUDIES ON WATER MEETING THE WATER REFORM CHALLENGE 147 (2012).
424. ORG. ECON. CO-OPERATION & DEV., *supra* note 404.
425. *Id.*
426. *Id.*
427. *Id.*

mental Authority (ANAM)[428] work to determine water balances and availability. Developers must have final approval from ANAM.[429]

V. MAIN MESSAGES AND EMERGING ISSUES

A. Summary of Key Findings

While the policy context for energy-water issues is constantly evolving, today's policymaking processes are typically highly disaggregated. There are some examples of integrated, coherent energy-water policies, but they are the exception, not the rule. In fact, many existing water policies and technologies impinge on the energy system, and vice versa. While many local, regional and national governments are beginning to mandate beneficial policies, the global process would benefit from significant improvement. Using improved, more consistent terminology, units, and data for energy and water flows would begin the beneficial process of integrating water and energy policies horizontally and vertically within governments.

To date, countries and regions facing scarcity appear to address the energy-water nexus by mandating solar hot water heaters; setting water reuse and desalination as national priorities; and making conservation a priority. Other policies, including recent support for biofuels, have site-specific and often negative effects on the water-energy relationship. The local water and energy resources of each country play a large part in determining how any one technology will impact water and energy security objectives. As countries shift from conventional fossil fuel production towards unconventional fossil fuels and biofuels, the nature, extent and location of water and its use will change. Consequently, the existing regulatory frameworks for protecting water quality must be updated and revised as policies change and scientific research reveals new findings.

The tie between energy-water nexus policies and technologies is strong. Thus, different policy options can have either negative or positive influence on energy and water security depending upon how they relate to particular technologies. Water and energy infrastructure lasts for decades, therefore coordination of planning and allocation of responsibilities is needed to prevent embedded problems that will last long after policy decisions are made.

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428. La Autoridad Nacional del Ambiente.

429. ORG. ECON. CO-OPERATION & DEV., *supra* note 404.

B. Information Gaps and Emerging Issues

Among the most serious and quickly-addressable gaps for policymakers is the lack of suitable data and information that can be used to inform the policy process. These data gaps exist within a country, but also across political boundaries. As resource issues gain a more prominent global role through treaties and climate change legislation, these problems might be exacerbated. In addition, emerging issues might complicate the data problems even further. For example, "water footprint" and "energy footprint" are terms used by product manufacturers to estimate the amount of embedded water or energy. However, whether or not that embedded water in the water footprint is of concern will depend on the abundance and availability of the resources at the site of origin. While energy commodities are regularly traded around the world, large volumes of water are not. From the standpoint of globalized trade, an energy footprint has less of a regional context than a water footprint because the world's energy resources are traded much more than water. It is generally easier to move energy resources or produce energy in locales where water is abundant rather than move water to where energy is abundant.

Among the most critical emerging issues is the trend towards more energy-intensive water and more water-intensive energy. These two trends generally result from population pressure and a desire to preserve wildlife biodiversity. Populations in arid regions have grown to such sizes over the last century that the renewable and fossil water[430] supplies are often extremely stressed, and water reuse and desalination alternatives are inhibitive because they use more energy to purify and transport. These same water stresses make dry cooling technologies more prevalent in thermoelectric power plants, especially CSP in the sun-rich desert environments.

Natural gas from shale formations is touted as an important bridge fuel supply to a low-carbon future. Energy production from natural gas shales produces a large amount of energy for the quantity of water injected for fracturing the rock,[431] but the volumes of water used

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430. Fossil water refers to aquifers that are geologically isolated and/or recharge at such slow rates that they are effectively non-renewable. An example is the portion of the Ogallala aquifer in the Southern High Plains of Texas. *See* Bridget R. Scanlon et al., *Groundwater Depletion and Sustainability of Irrigation in the U.S. High Plains and Central Valley*. 109 PROC. NAT'L ACAD. SCI. 9320, 9320–25 (2012).

431. JAMES E. BENÉ ET AL., NORTHERN TRINITY/WOODBINE GAM ASSESSMENT OF GROUNDWATER USE IN THE NORTHERN TRINITY AQUIFER DUE TO URBAN GROWTH AND BARNETT SHALE DEVELOPMENT (2007) (report prepared for the Texas Water Development Board).

per well can stress regional ability to transport and properly treat the water.

With coal as an abundant and relatively affordable fossil fuel, carbon capture technologies installed on fossil power plants are likely to be important for reducing carbon emissions. These capture systems need process heat and electricity for compressing the carbon dioxide to supercritical[432] conditions required for transport and storage underground. If the same net electricity from carbon capture power plants is desired, these plants require more fuel and hence more water for cooling. Because dry cooling systems can be used with fossil or renewable thermoelectric systems, they might be a crucial technology for future focus.

Despite the many challenges, there are some policy opportunities at the energy-water nexus. Policies that promote energy conservation achieve water conservation, and vice-versa. In addition, there are some clear opportunities for governments to invest in R&D.[433] The case studies herein present evidence that water and energy scarcity induces innovation in both technology and policy, and countries facing these scarcities can focus on engineered solutions for future export to the rest of the world.

There are reasons for optimism. A variety of governments and multi-national organizations are starting to take this issue seriously. With a new push to obtain firm data and the right multi-stakeholder engagements, policies and market innovations can be developed and then implemented to achieve the goals of increasing energy and water conservation, making both systems more resilient, and impacting the environment less.

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432. A supercritical fluid is a substance that exists at a temperature and pressure above its critical point.

433. E.g. to develop low-water biofuels, low-energy desalination, etc.