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Water Cultivation: The Path to Profit in Meeting Water Needs

Water is the single vital resource for which there is literally no substitute, but as world water needs increase 40% by 2030, today's stressed water sources and systems can't be sustained. A new approach that we call "water cultivation" – typified by efficiency, reuse, and source diversification – will meet water requirements as GDP, irrigation, and population continue to rise. Disruptive technologies and business models will yield profits as revenues in the "hydrocosm" – the universe of water-related businesses – grow from $522 billion in 2007 to nearly $1 trillion in 2020.

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Executive Summary

Water is the single vital resource for which no substitute exists: Without water, industry halts, crops fail, and life ceases. But stress on this precious resource is having severe repercussions for vast swathes of the global population. Society presently "hunts" its water, resulting in profligate waste and overuse that is threatening extinction of traditional supplies. The future will require a drastic break in how we obtain and use our finite supplies: New technologies and business models will enable a shift to a new paradigm of "water cultivation," defined by efficiency, source diversification, and reuse.

Because the need for water is both non-negotiable and rapidly rising, it has attracted intense interest from investors and executives looking to harness it for financial gain. But turning the obvious – "the world will need more water" – into revenue and profit has consistently flummoxed business and investment strategists. The constellation of water related services, technologies, and infrastructure – collectively referred to as the "hydrocosm" – is a complicated morass that is fragmented, highly local, and has a history of long adoption cycles. This report aims to unravel the story of growth and innovation opportunities in water, starting with a broad landscape of water-related businesses and ending with focus areas for investment, alliances, and business development.

Landscape: Confusion Clouds Water's Commercial Potential

To cut through the confusion surrounding water, we developed a comprehensive map of water-related businesses and the resources they rely on – which we refer to as the "hydrocosm" – sizing 2007 revenue in each segment of water-related business and tallying up the volume of water that flowed through it. We developed our map through exhaustive secondary research; primary interviews with water executives, investors, academics, public servants, and other thought leaders; and bottom-up revenue accounting and estimation for more than 300 water-related companies. At the highest level, we found that the hydrocosm generated $522 billion in revenue in 2007 while conveying 4,166 km^3 of water spread across four top-level categories (see Figure 1):

- **Services**. Services represent 74% of hydrocosm revenue, totaling $386 billion in 2007. Of this, businesses in the treatment segment – specifically, water and wastewater utilities – claim 56% of category dollars. All other segments, like engineering and infrastructure services, support treatment, and all are much smaller, with no individual one exceeding $55 billion.

- **Equipment**. The equipment category – durable equipment that is purchased through capital expenditure amortized over a lifetime – took 12% of hydrocosm revenue in 2007 at $64 billion. Segments that reduce the energy or physical space required for treatment have seen high growth, while other segments have crept along with incremental improvements.

- **Chemicals**. Widely considered a necessary evil of the treatment process, chemicals are consumables that must be used – and purchased – continuously. They accounted for 2% of hydrocosm dollars in 2007, generating $8.8 billion in revenue. Biocides, coagulants, polymers,

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Fig. 1: The Hydrocosm Is Immensely Complex and Interconnected

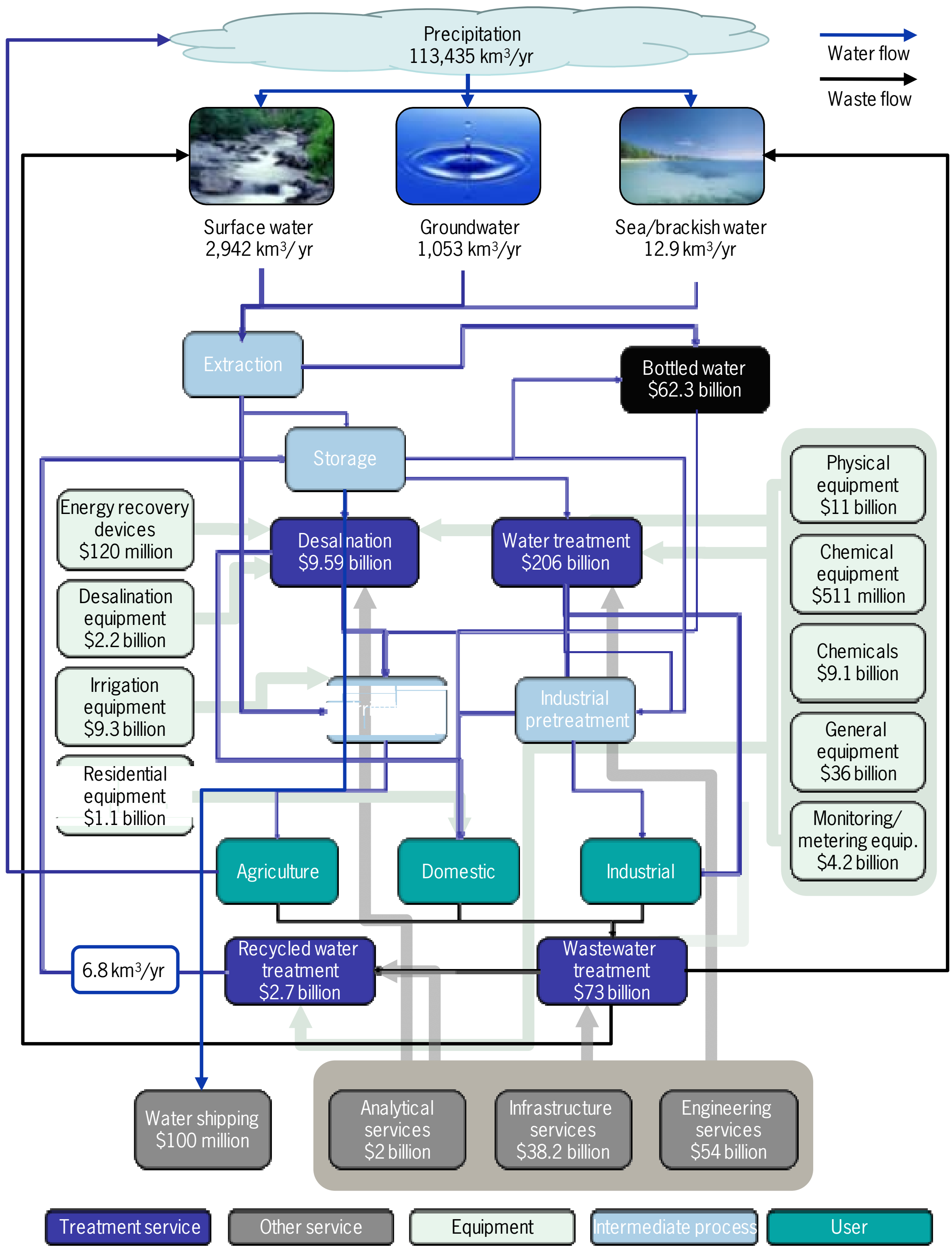

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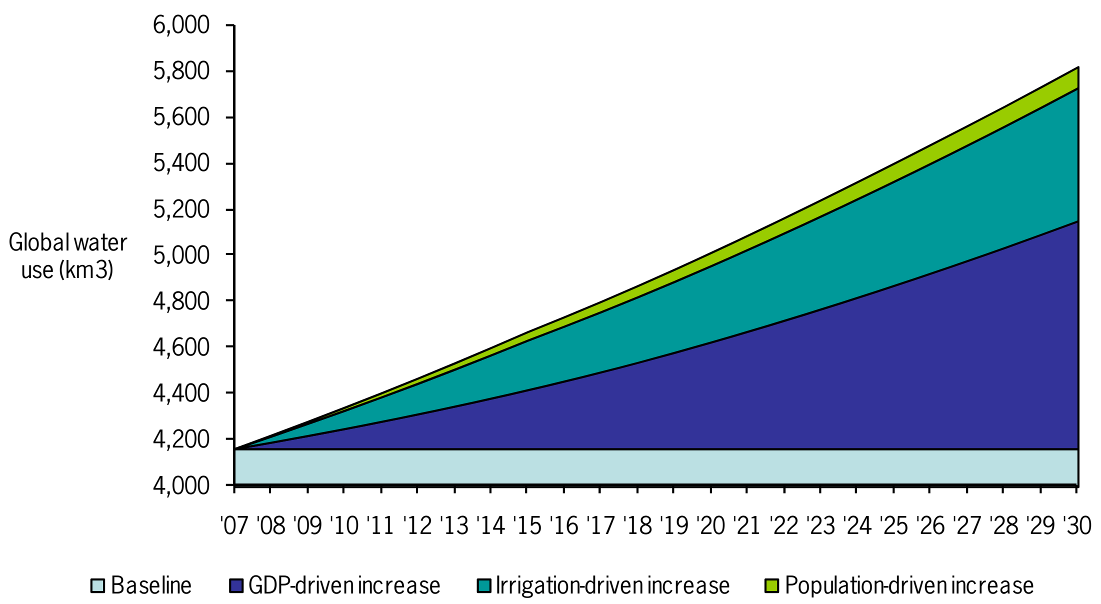
Fig. 2: Global Incremental Water Usage by Driver, 2007 to 2030



anticscalants, and caustic soda dominate the 10 sub-segments we identify in this category, claiming 94% of revenue within it.

- **Bottled water**. Global bottled water sales – including still and sparkling waters – claimed 12% of hydrocosm revenue in 2007 at $62 billion. While revenues were up more than 7% last year, the rate of growth is slowing down as established markets approach saturation.

Water Needs: Signs of Water Crisis Make Headlines

In 1900, the world used 770 km^3 of water. By 1950, that amount had risen to 1,480 km^3, reflecting a compound annual growth rate (CAGR) of 1.3%. From 1950 through 2000, the growth rate accelerated to 1.9% per year – and the world consumed 3,840 km^3 at the end of century, nearly five times the value 100 years earlier. During this same period global population grew by a factor of 3.7, from 1.7 billion to 6.1 billion. As the growth in water usage outpaced growth in people, water usage per capita rose from 467 m^3 per person per year in 1900 to 634 m^3 in 2000. We built a stepwise, multivariate regression model at the country level to determine how water use will change in the future and found that (see Figure 2):

- **GDP, irrigation, and population drive water needs.** Every incremental million dollars of GDP means about 22,000 m3 of water per year, every new hectare of land irrigated means about 10,000 m3 of water each year, and every additional person uses about 60 m3 of water annually.

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- **World water resources will stretch thin as requirements grow 40% by 2030**. When we fed our regression model with growth forecasts of GDP, irrigated land, and population, we determined that world water requirements will increase from 4,166 km3 last year to 5,817 km3 in 2030 – 40% growth representing a 1.5% CAGR. Water requirements will rise as GDP nearly doubles in real terms – from $32 trillion to $63 trillion; as irrigated land rises 20% – from 293 million hectares to 351 million hectares; and as population rises 23% – from 6.7 billion to 8.2 billion.

- **Pollution and climate change could drive water needs still higher**. GDP, irrigation, and population accurately predict water requirements today, accounting for more than 98% of the variance in water needs between countries at present. However, in the next two decades other factors could become significant as well, potentially driving water needs even higher than our incremental 5,817 km3 projection for 2030. The potential combined impact of – climate change and pollution could increase water requirements another 10% by 2030, leading to a worldwide water need in 2030 of 6,233 km3 – 50% greater than today.

Financing: Capital Flocks to Water

When financiers see the sheer size of the $522 billion hydrocosm set against rapidly rising water needs, dollar signs form in their eyes. Merger and acquisition (M&A) deals have dominated water finance transactions for the last 10 years, with the number of M&A events rising steadily from nine in 1998 to an all-time high of 106 in 2007; initial public offerings (IPOs) of stock, usually from long-established firms, eked along throughout at a pace of four or so per year. What's new in the last two years is the influx of venture capital (VC) in the hydrocosm, as top-tier investors put cash into hot start-up companies.

To date, no complete inventory of water finance transactions has been available. We filled this gap by building a comprehensive database containing every round of institutional VC funding in water-focused firms worldwide, every relevant IPO on a major exchange, and every relevant M&A event in which a majority share of a firm has been acquired. Spanning a period from January 1998 through October 2008, our database includes 695 transactions involving 654 companies in 32 countries. We found that:

- **Water is becoming the hot venture category as VC firms realize its potential.** Since 1998, 109 individual water companies have received VC funding totaling $1.12 billion – but the field has only come into its own recently, as 59% of this value has been invested since 2007. Indeed, 2007 formed water's breakout year as a venture investment category, the first year that the number of deals exceeded 20 (see Figure 3).

- **Water IPO activity remains muted.** Since 1998, 39 water-focused companies have gone public on major exchanges and in aggregate have raised a total of $4.8 billion, with combined valuations of $18.9 billion. IPO numbers have remained consistent since 1998, but valuations have fluctuated wildly.

- **M&A dominates water transactions, worth a combined $176 billion since 1998.** Since 1998, water M&A deals have grown rapidly, with 506 transactions for a total value of $176 billion. Nine out of 10 water M&A deals fall into one of two categories: 1) 209 of the 508 deals to date

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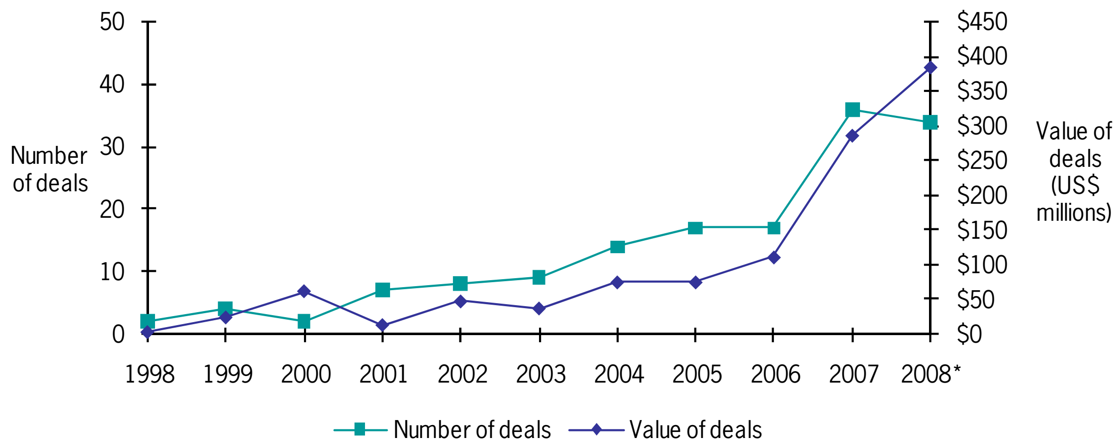
Fig. 3: Water VC Deals and Value, 1998 to 2008



* 2008 data through October

involve a national or international water utility purchasing another smaller utility accounting for 65% of the $114 billion cumulative deal value. 2) 244 deals have involved large manufacturers building or augmenting existing water business units.

Outlook: The World Will Shift from Water Hunting to Water Cultivation

Just as early people hunted food, today humanity hunts water. Society exploits easily available fresh surface and ground water resources as quickly as possible – usually in a wasteful manner – and disposes of the polluted wastewater "carcass." People today believe that water will never run out and as such, we treat water as if it were free. However, water stress from east Africa to the western U.S., however, demonstrates that accessible freshwater is sharply bounded. "Ownership by no one in particular" coupled with "availability to everyone"' creates an economic disincentive for stewardship. As a result, three key principles mark water use worldwide: Inefficiency, disposability, and homogeneous supply. Change is in the works, however:

- **Water hunting can't continue.** A water system marked by inefficiency, disposability, and homogenous supply can't sustain itself. Current events indicate that the system is reaching its breaking point, as evidenced by threatened food supplies, hiccups in industrial expansion, and political instability – a system that can't continue as usage keeps on rising, resources keep on depleting, and costs keep on rising.
- **Water cultivation will enable society to adapt to water scarcity.** These driving forces will lead governments, companies, and individuals to permanently change the way they use water – cultivating water as a renewable resource rather than hunting it to extinction (see Figure 4). The new approach will be embodied in three principles that oppose today's norms: 1) efficiency – maximizing economic output per unit of water; 2) reuse – turning water from a throwaway

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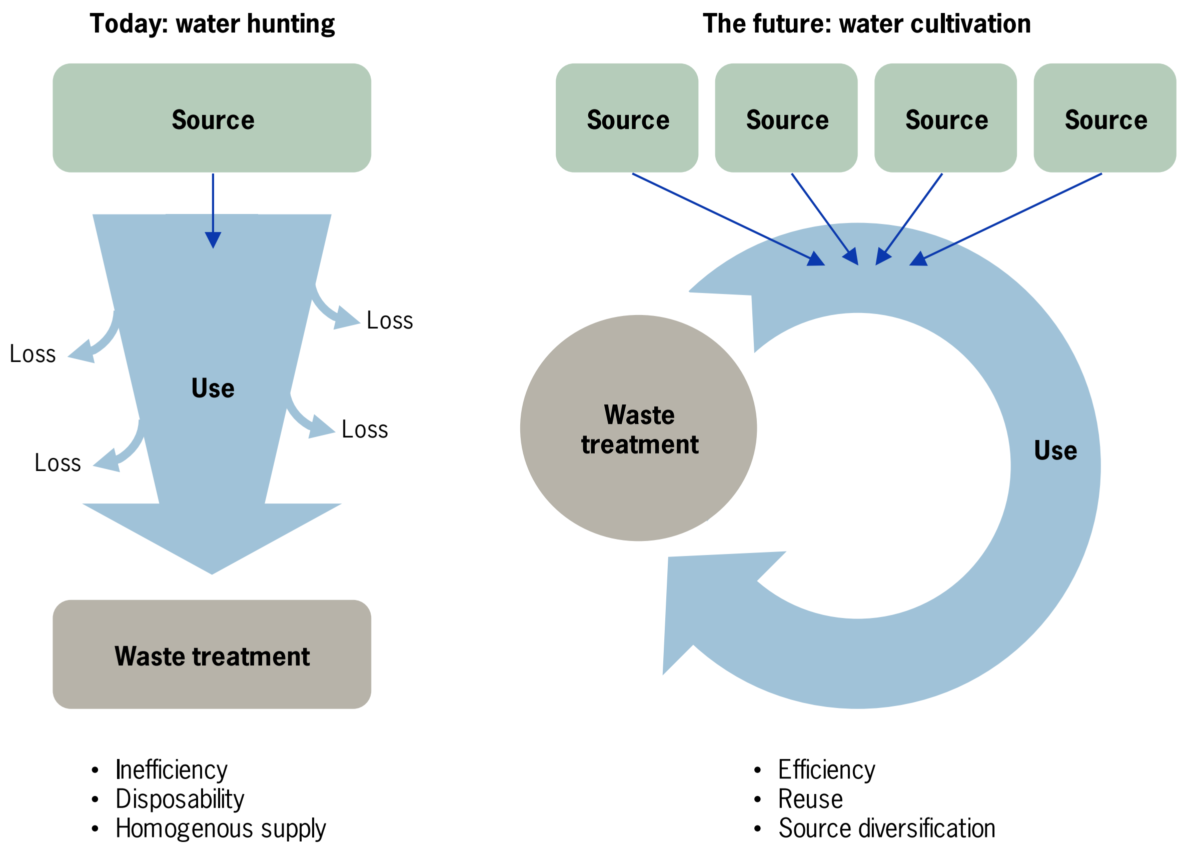
Fig. 4: Water Hunting Will Give Way to Water Cultivation



consumable into a durable asset; and 3) source diversification – drawing water from a variety of sources according to lowest lifecycle cost.

- **The shift to water cultivation will proceed through three phases.** Developed countries will move from water hunting to water cultivation over a long time span – measured in decades, not years – enabled by changes in public awareness, water pricing, ownership of water assets, density of water infrastructure, technology, and regulations. While this shift will occur at different times and speed in different geographies, current evidence indicates that a three-phase transition will hold. In Phase One abundance makes water hunting easy – public awareness is low, ownership is strictly public, infrastructure is centralized and uses basic technology. In Phase Two, economic development and industrialization accelerate water demand, which butts up against the natural limits of water availability within the geographic region. Phase Three is defined by chronic water stress that forces water cultivation including widespread water reuse and recycling, widespread adoption of efficient agriculture methods, creating pricing and business models.

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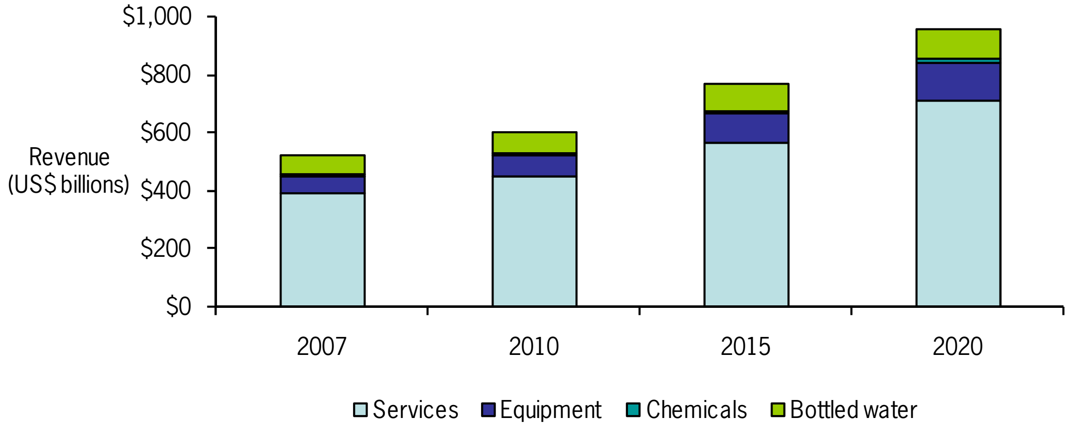
Fig. 5: Hydrocosm Revenue Forecast, 2007 to 2020



Forecast: Growth to $961 Billion in 2020 Heralds Diverse Growth Opportunities

The shift to water cultivation will yield growth opportunities for new technologies and business models. At the highest level, we project that hydrocosm revenue of $522 billion in 2007 will grow to $961 billion in 2020. Of the $439 billion in added revenue in 2020, we found that $377 billion, or 86%, will derive from *mature* segments; these are good areas for incumbents to seek acquisitions or market share gains, but poor targets for disruptive innovation. Instead, it's the $87 billion, or 14%, of 2020 revenue growth from *developing* segments that will attract attention from growth executives and investors. Breaking the forecast down by category, we found that (see Figure 5):

- **Services will grow 83%, but with only 6.9% of the growth from developing segments.** We project that services revenue will rise from $386.1 billion in 2007 to $706.2 billion in 2020, reflecting a 4.75% CAGR, driven by the 40% increase in world water requirements during this period. However, the vast majority of the services category comprises mature lines of businesses like water and wastewater treatment, engineering and construction, pipe laying, and well drilling, where innovation opportunities are few and far between. Key areas for focus include water exploration, long-distance transport, and pipe rehabilitation.

- **Equipment will rise 120%, with the highest share – 55% – of growth in developing niches.** Equipment revenue will rise at a 6.24% CAGR from $61 billion in 2007 to $133.4 billion in 2020, driven by a number of factors including cost, water stress (and the resultant needs for new water sources), reuse and recycling, and greater efficiency. The need to replace or renovate crumbling infrastructure will also power growth in the category. Unlike services, a higher proportion of revenue growth in equipment will derive from developing segments; key opportunities include waste management and recovery, UV disinfection, drip/microdrip irrigation, energy mitigation, advanced oxidation approaches, metering and monitoring, residential point-of-use/point-of-entry equipment, desalination and reuse equipment, and low-water crops.

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- **Chemicals will rise 18% in a uniformly mature field.** The chemicals category presently stands at $7.8 billion and will rise to $9.2 billion by 2020, reflecting a 1.25% CAGR. Chemicals are a necessary ingredient in modern water treatment systems and, as such, tend to grow at a rate reflecting overall water use. However, chemicals by their very nature are commodities with little to no differentiation: As such, margins are slim and customers quick to jump to lower-cost solutions – which increasingly involve replacing chemicals with physical processes or on-site generation. As a result, we rate the chemical category as uniformly mature.
- **Bottled water will rise 71%, with technology innovation playing no major role.** We peg the bottled water market to grow from $62.3 billion in 2007 to $106.3 billion in 2020, reflecting a 4.2% CAGR, with growth flagging from 2011 on as a bottled water backlash takes root in established markets. However, we treat the category as a mature monolith driven by marketing, not technology or business model innovation.

Targeting Focus Areas for Innovation

Clearly, opportunities for new technologies abound – they're just challenging to separate from the hydrocosm's overwhelming mass. To inform business and investment decisions in these segments, the final section of our report profiles six such focus areas in detail:

- **Next-generation desalination.** Desalination of seawater is far more energy-intensive than conventional treatment of freshwater sources. New desalination technologies that use low-grade or waste heat instead of electricity have the potential to substantially reduce energy inputs, yielding a more environmentally benign process and lower operation costs. Other opportunities exist for advanced membranes that require lower pressure for effective operation and therefore use less energy.
- **Waste management.** Desalination waste streams contain concentrated salt and other contaminants removed during treatment, as well as up to 50% of the feed water that enters the facility. Industrial waste streams contain high concentrations of valuable metals that are typically discharged to the environment. Many companies are developing innovative technologies to solve pollution problems, investigating how to convert the waste into an asset by extracting valuable resources from waste effluent, and seeking to minimize waste volume.
- **Energy mitigation.** An intimate link exists between water and energy that, for the most part, goes unrealized. Conventional energy generation requires enormous amounts of water. Conversely, tremendous amounts of energy are required for the treatment and distribution of water. New approaches to reduce the energy footprint of water treatment systems involve capturing waste energy throughout the treatment process. Innovative technologies include energy recovery devices in desalination plants, microbial fuel cells that feed off wastewater, and cogeneration plants co-located with wastewater treatment facilities.
- **Infrastructure maturity.** Complex and aging water treatment, distribution, and wastewater treatment systems are quickly reaching the end of their useful lives. In the U.S. 18% of total water treated is lost during distribution by leaking pipes while in some low-income countries leakage exceeds 50%. In response, companies are developing new rehabilitation and monitoring

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technologies and services to meet growing infrastructure needs that will ultimately improve efficiency, reduce maintenance costs, and decrease frustration to citizens in the areas they serve.

- **Advanced oxidation processes.** Antibiotics, mood stabilizers, and sex hormones are finding their way into drinking water supplies. These compounds are present in treated wastewater effluent that is often discharged back into freshwater sources, which are subsequently used as to supply drinking water. Because conventional treatments are unable to remove these contaminants from water, new approaches using advanced oxidation processes are required. Four such processes could eliminate the need for chemical addition: 1) ozone/UV/hydrogen peroxide, 2) high-energy electron beam (e-beam), 3) cavitation, and 4) TiO_2-catalyzed UV oxidation
- **Water sourcing and transport.** Although the total renewable freshwater supply greatly exceeds human demand, uneven results in severe water stress over vast swathes of the globe. By employing new methods of sourcing, transportation, and management, governments can increase available freshwater resources and reduce waste. Several new business models aim to meet the sourcing and transportation needs of water-stressed regions including exploration, transportation, and private water districts.

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1: Landscape

A confusing mishmash of businesses, the water universe comprises services, equipment, chemicals, and bottled water – accounting for $522 billion in 2007 revenue.

Confusion Clouds Water's Commercial Potential

Water is the single vital resource for which no substitute exists: Without water, industry halts, crops fail, and life ceases. Because the need for water is both non-negotiable and rapidly rising, it's attracted intense interest from investors and executives looking to harness it for financial gain – as witnessed by 506 water-related merger and acquisition (M&A) deals, 39 initial public offerings (IPOs) of stock, and 109 venture-backed start-up companies funded over the last 10 years for a total of $196 billion in transaction value. But turning the obvious – "the world will need more water" – into revenue and profit has consistently flummoxed business and investment strategists because:

- **The universe of water-related businesses – the "hydrocosm" – is fragmented.** Water-related businesses vary dramatically – from sleepy, government-owned water utilities that deliver a consumable to end users and operate at subsidized losses, to high-tech equipment manufacturers that ship durable products and earn double-digit operating margins (see Figure 1.1). The water universe fragments not only *between* these categories, but also *within* them: Thousands of firms may operate in one segment – such as pipes, which has a few big players but is mostly served by tiny companies spread all over the globe. This patchy landscape means that executives and investors struggle to separate attractive growth opportunities from background noise.

  The field is so diverse that we feel terms like "water industry" or "water sector" are misleading: They imply that water-related businesses with radically different models, customers, and margins are somehow homogenous. Further, different water participants use these terms to mean very different things: When an engineer from Black & Veatch says "the water industry," she means municipal utilities, but when a line-of-business manager from Siemens says the same thing, he's referring to water equipment and chemical manufacturers. To avoid this confusion, we refer to the universe of water-related businesses as "the hydrocosm."

- **Water is hyper-local.** Every municipality faces a different combination of factors, including water availability, quality, and demand – and every new water facility constructed has a treatment process custom-designed to address these factors at the lowest cost. For example, one community facing increasing water demands may turn to desalination to treat water from a brackish source, while another community that has detected arsenic in groundwater supply adds a new treatment process, like ion exchange, to address the problem. As a result, executives at water-related companies find it maddeningly difficult to project potential adoption of any new technology or business model, and shy away from making generalizations about demand.

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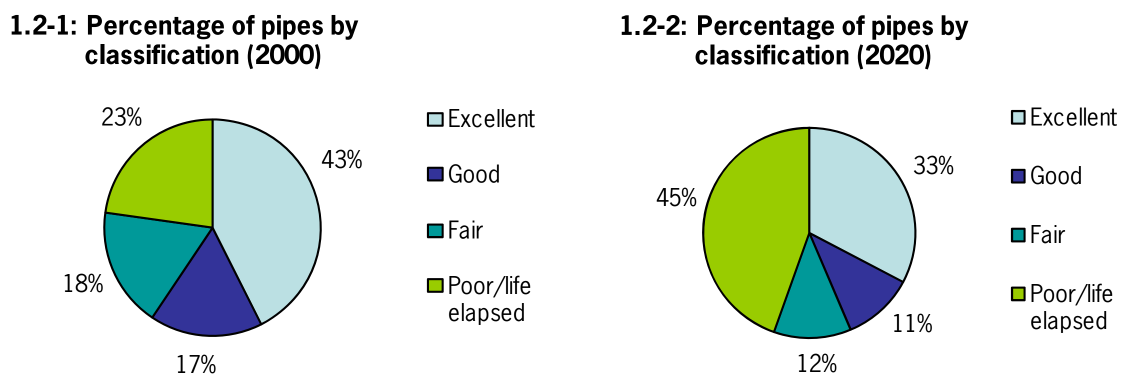
Fig. 1.1: Water-Related Businesses Vary Dramatically from One Another

Business	Type	Status	Capital intensity	Operating margins	Technology intensity
Pipes	Product	Very mature	High	Low single digits	Low
Water treatment	Service	Very mature	High	Low single digits	Medium
UV disinfection	Product	Mid-stage	Medium	Teens	High
Engineering services	Service	Very mature	Low	High single digits	Low
Hydroxides	Product	Very mature	High	High single digits	Low
Microbial fuel cells	Product	Emerging	Medium	N/A	Very high

Fig. 1.2: Water Conservatism Is Evident in Aging North American Infrastructure



Source: U.S. Environmental Protection Agency.

- **Water is undervalued.** Generally, the more valuable a product, the higher its price – and when demand eclipses supply, prices go up. Not so for water, where the public perceives that water should be free because it literally falls from the sky. As a result, water prices in the Organization for Economic Co-operation and Development (OECD) have risen at only 2.6% annually during the last 15 years – a rate lower than inflation, meaning that the price has fallen in real terms. Even severe water needs fail to increase prices: Australia is experiencing some of the world's greatest water stress, yet 3,000 liters of tap water costs the same amount as a 1 liter unit of bottled water. With these dynamics, water executives and investors can't be certain that they'll be able to exert pricing power for any particular product or service.

- **Water's key players are exceptionally conservative.** In most cases, products that the world needs to keep turning receive continuous and accelerating innovation – think of semiconductors, for example. But users of water technologies are generally loath to pay more to switch to something new, so old solutions to problems persist for decades (see Figure 1.2). For example, municipal water utilities have hung on to pipe infrastructure far beyond its useful life – Thames Water reports that many pipes in London are more than 150 years old. Industrial water

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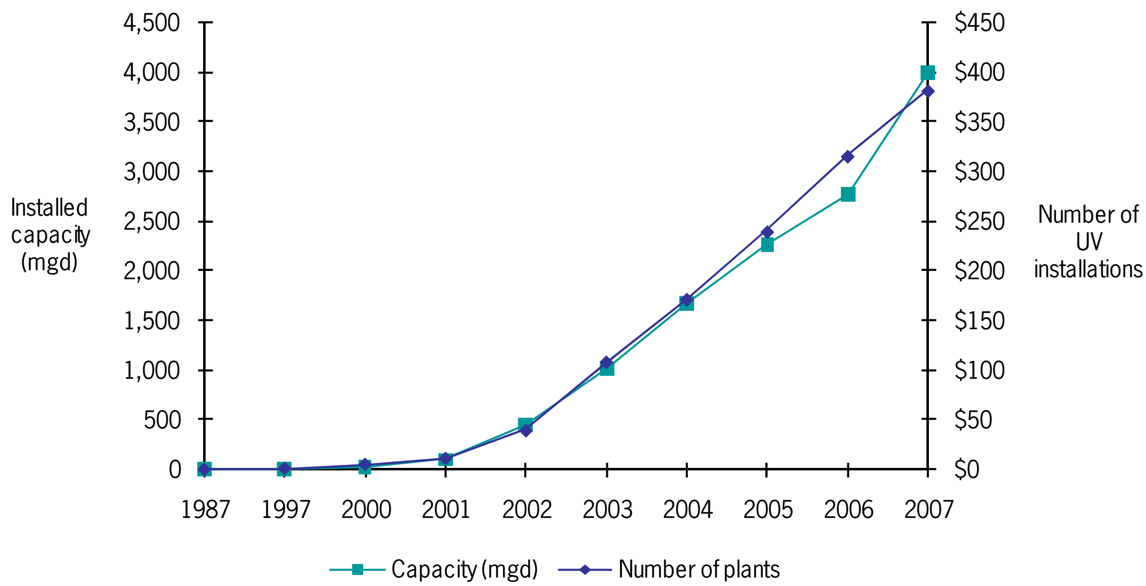
Fig. 1.3: North American UV Disinfection Installations, 1987 to 2007



users are less conservative, but not by much: Because water isn't their core business, they generally aim to spend as little money as possible on it – sometimes going so far as to willingly incur fines for untreated wastewater discharge because the price of correcting it is too high.

- **Adoption cycles last decades, not years.** In other domains receiving similar levels of investment attention as water, new technologies can go from development to market in very short amounts of time – years in solar, months in software. But adoption of new technologies and business models in water has historically taken far longer, and factors that spark intense uptake (like fickle regulations) have been unpredictable. For example, German physicist Johann Wilmhem Ritter discovered the principle of ultraviolet (UV) water disinfection in 1801, and the first UV-equipped plants appeared in the U.S. in the early 1900s. But UV didn't take off until it emerged as a viable treatment option for the chlorine-resistant protozoan *Cryptosporidium* in 1999 – and even then, it took until 2006 for the U.S. Environmental Protection Agency (EPA) to promote it as a viable component of the treatment toolbox. The number of U.S. installations did not exceed 100 until 2003 (see Figure 1.3).[1]

Confusion about the Hydrocosm Has Consequences

These factors make it extremely difficult for executives and investors to pinpoint valuable opportunities in the hydrocosm – causing them to:

- **Make bad bets.** Opportunities that look like low-hanging fruit in the hydrocosm may in fact take decades to mature, leading investors and management to cut their losses when they miss targets. Consider Sensicore, a water sensor network start-up founded in 2000 that received a

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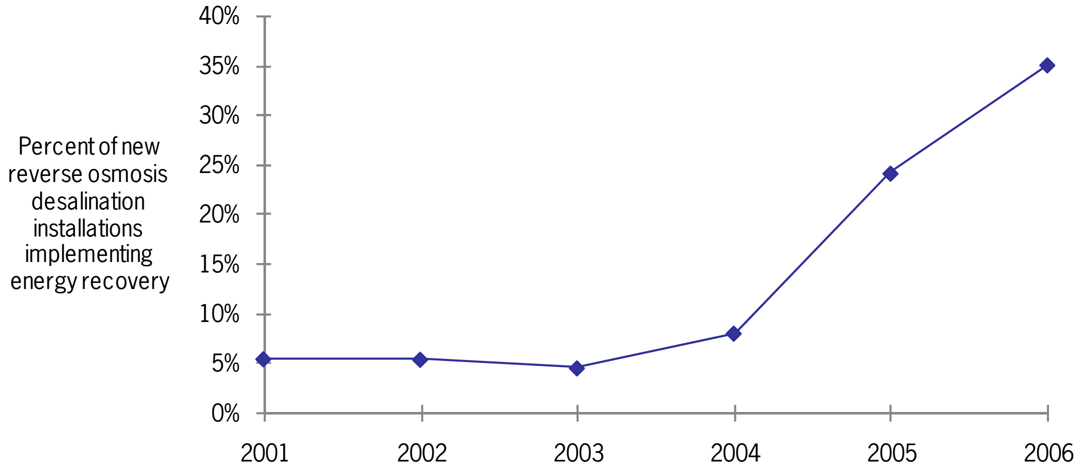
Fig. 1.4: Growth of Energy Recovery in New Reverse Osmosis Desalination Plants, 2001 to 2006



Source: International Desalination Association and Lux Research analysis.

cumulative $27.5 million in venture capital; water utilities took much longer than expected to even evaluate its technology, leading the company to sell to General Electric (GE) in 2008 for a sum rumored to be in the single-digit millions – washing its investors out.

- **Miss good opportunities.** More rarely, technologies that have received little attention can see their fortunes shift dramatically when an external factor – regulatory or otherwise – changes the business case, sparking faster-than-usual adoption. Consider energy recovery devices for desalination plants: As water shortages sparked increased adoption of desalination outside of energy-rich locales like the Middle East in the middle of this decade, deployment of energy recovery systems in reverse osmosis plants shot up from 8% of newly installed capacity in 2004 to more than 40% in 2007 – a factor that helped drive market leader Energy Recovery Inc. to a successful IPO in June 2008 (see Figure 1.4).

Capitalizing on Water Starts with Answering Fundamental Questions

To make wise decisions, those seeking to harness water needs for financial gain must know:

- How big is the hydrocosm?
- How is it organized?
- How do its segments compare with one another?

The Hydrocosm in 2007: $522 Billion in Revenue, 4,166 km^3 in Water Flow

To cut through the confusion, we developed a comprehensive map of the hydrocosm, sizing 2007 revenue in each segment of water-related business and tallying up the volume of water that flowed

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through it (see Figure 1.5). We developed our map through exhaustive secondary research; primary interviews with 66 water executives, investors, academics, public servants, and other thought leaders; and bottom-up revenue accounting and estimation for more than 300 water-related companies. We arrived at conclusions by making multiple estimates of revenue and water volume in each segment through different methodologies, and then arriving at consensus via team debate and peer review from other hydrocosm experts. At the highest level, we found that the hydrocosm generated $522 billion in revenue in 2007 while conveying 4,166 km^3 of water.

Our map has six high-level categories. The first two focus on where water is drawn from and why:

- **Sources.** Water sources, ranging from lakes to oceans, are the origin of water flows in the hydrocosm.
- **End users.** Agricultural, industrial, and residential end users are the hydrocosm's reason for being.

In between lies the hydrocosm's $522 billion in revenue, spread across four top-level categories (see Figure 1.6):

- **Services.** Services represent 74% of hydrocosm revenue, totaling $386 billion in 2007. Of this, businesses in the treatment segment – specifically, water and wastewater utilities – claim 56% of category dollars. All other segments, like engineering and infrastructure services, support treatment, and all are much smaller, with no individual one exceeding $55 billion.
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- **Bottled water.** Global bottled water sales – including still and sparkling waters – claimed 12% of hydrocosm revenue in 2007 at $62 billion. While revenues were up more than 7% last year, the *rate* of growth is slowing down as established markets approach saturation.

We will address each of these six categories in turn.

Sources: Only 3% of the World's Water Is Freshwater

At a high level, it would seem that the earth faces no water crisis: The planet holds 1.3 billion km^3 of water, of which people used only 4,166 km^3 in 2007 – a scant 0.0003%. But 97% of the planet's water is saline and can't be consumed in its natural state, and another 1.7% of water is locked up in glaciers and polar ice caps – so while it's fresh and drinkable, it can't be easily accessed. That leaves

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Fig. 1.5: The Hydrocosm Is Immensely Complex and Interconnected

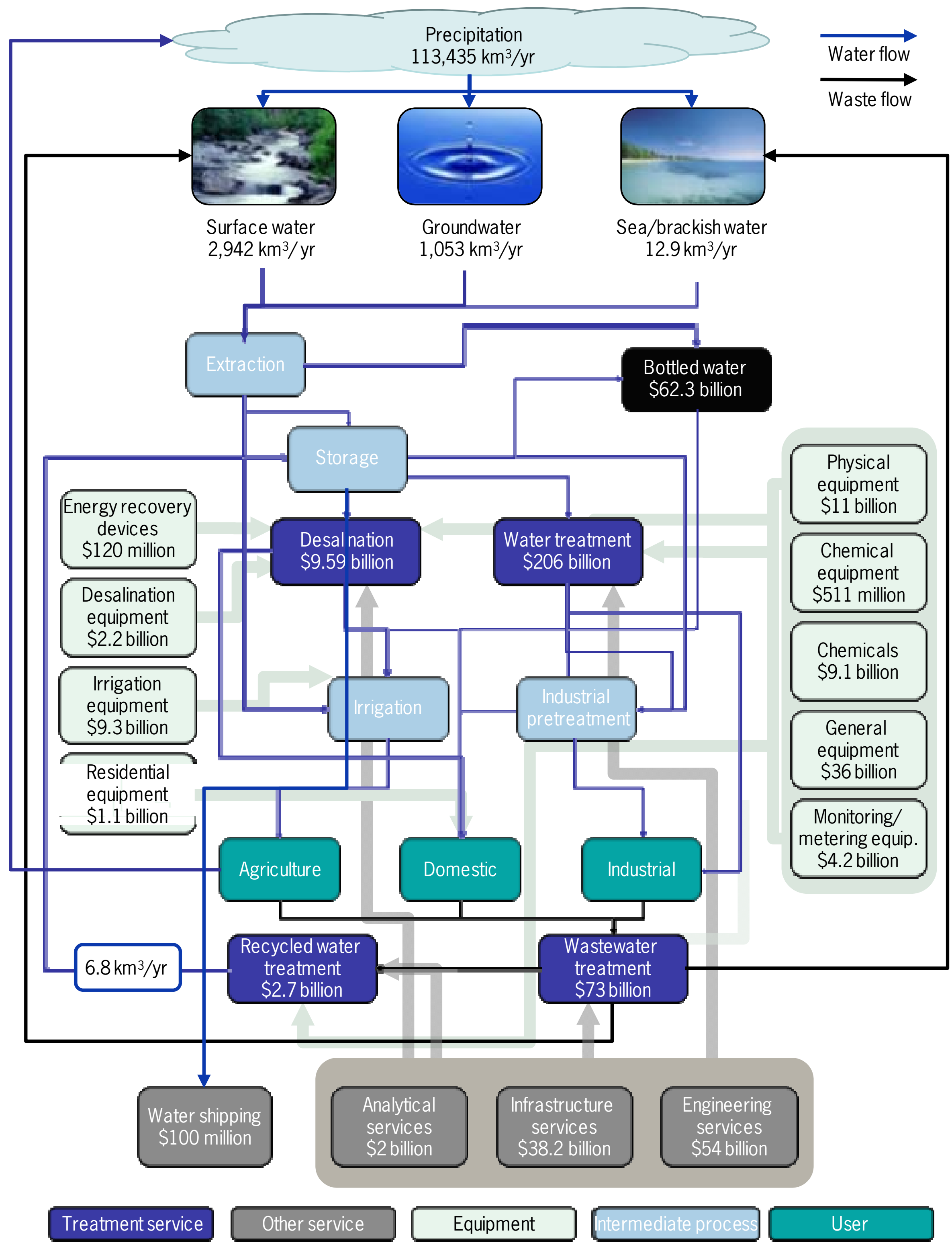

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Fig. 1.6: Hydrocosm Revenue Breakdown, 2007 (US$ Billions)

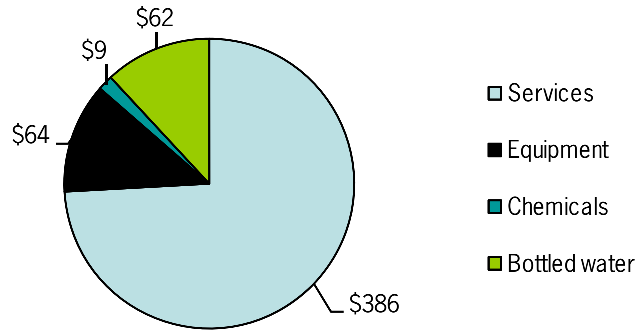
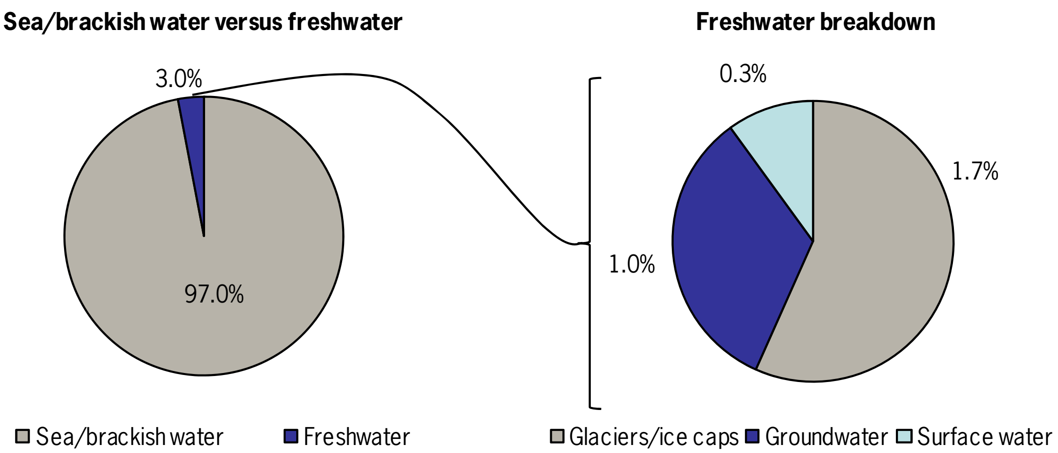


Fig. 1.7: The World's Water Sources



Segment	Volume available(km³)	Volume consumed in 2007 (km³)
Groundwater	10.5 million	1,053
Surface water	93,123	2,942
Seawater and brackish water	1.3 billion	12.9
Recycled water	4,166 (in 2007 – equal to water used)	6.8

Sources: U.S. Geological Survey, U.N. Food and Agriculture Organization, Lux Research analysis.

only 1.3% of volume in fresh groundwater and surface water that humans can immediately consume.[2] In descending order of current use, the world's water sources consist of (see Figure 1.7):

- **Groundwater – 29% of 2007's volume; 10.5 million km³ available.** Groundwater is located beneath the earth's surface in aquifers, which are underground formations of permeable rock that water can easily move through. Accessed by tapping wells, these aquifers provided 1,202

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km^3 of water used in 2007.[3] Groundwater represents the largest volume of freshwater supply at 10.5 million km^3, but its current use is not sustainable: The global "recharge rate," or the percent of groundwater resources replenished each year, is only about 0.1% per year by volume and currently groundwater abstraction is at a rate of 0.01% per year by volume.

- **Surface water – 70.6% of 2007's volume; 93,120 km^3 available.** Lakes, rivers, and streams compose the world's surface water resources, and provided 2,942 km^3 of water used in 2007. In total, only 93,120 km^3 of surface water is available – equivalent to 0.9% of groundwater resources. In many areas, the nearest surface water source is either fully utilized or located far from population centers, forcing communities to build reservoirs as intermediate surface water buffers: Spain, for example, has more than 1,200 such reservoirs.
- **Seawater and brackish water – 0.4% of 2007's volume; 1.3 billion km^3 available.** As freshwater sources dwindle, communities must look to unconventional sources to meet rising demands. Seawater and brackish water (water found in aquifers, rivers, and lakes, with a much lower salt concentration than seawater) are increasingly being tapped, accounting for a scant 15.7 km^3 of 2007 water use. These resources represent the largest potential source of water at a whopping 1.3 billion km^3 – 97% of total world water resources – but high costs of desalination have historically limited their use. Today, 7,500 desalination plants operate worldwide, with volume growing at about 32% annually over the last two years.[4] Further, desalination plants are extending far beyond their early locations in the Middle East: In California alone, municipalities are considering 18 proposals for desalination plants as of this writing.
- **Recycled water – 0.1% of 2007's volume; 4,166 km^3 available.**[5] Why treat sea or brackish water when water that's already been treated once may cost less to return to a pristine state? Industrial and municipal water planners are asking this question, and increasingly turning to recycled water as a way to meet targeted water needs. Recycled water forms the newest source out of our four, accounting for only 6.2 km^3 of water used in 2007 – overwhelmingly for targeted industrial applications, since consumers struggle to overcome the psychological barrier to drinking treated sewage. But in water-stressed regions like Singapore, Namibia, and California, recycled water is emerging as a viable option for targeted uses: In Singapore, four plants produce recycled "NEWater" that provides 15% of the island nation's needs, primarily for semiconductor manufacturing facilities that require large volumes of ultrapure water to operate.[6]

Uses: Agriculture Dominates, Followed by Industrial and Domestic Use

Water usage falls into three primary categories (see Figure 1.8):

- **Agricultural.** Worldwide, 70% of water drawn goes to irrigate crops through flooding or via spray, sprinkler, and drip irrigation systems. The share of water used for agriculture correlates negatively with GDP per capita: For example, in first-world Germany, only 20% of water used goes to agriculture, whereas the fraction reaches 97% in third-world Guyana.[7] Agricultural water is generally not treated, but instead drawn directly from its source and conveyed to fields – so it's untouched by treatment equipment or chemicals.

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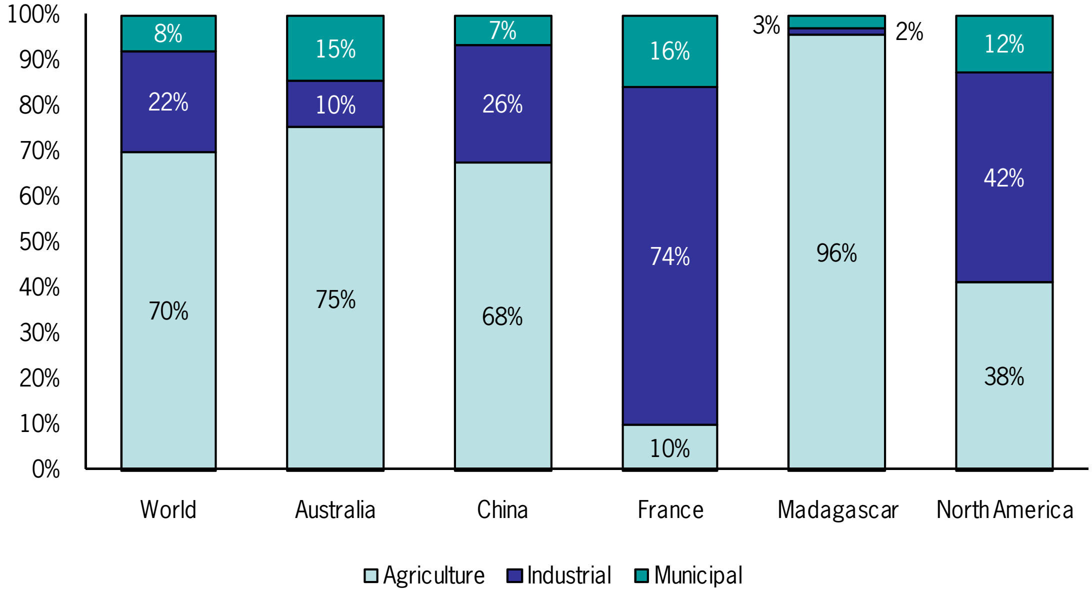
Fig 1.8: Water Use by Category, 2000



Source: U.N. Food and Agriculture Organization.

- **Industrial.** The industrial segment, broadly defined, accounts for 22% of water used. Electric power facilities such as nuclear and coal-fired plants consume half of this share; other heavy users include the metals, forest products, chemicals, and oil and gas industries. We define use as water drawn by industrial customers themselves, which is not obtained from municipal distribution networks. Depending on their needs, industrial users may or may treatment this water: For example, power plants generally pull water directly from their source without treatment and return it to that source in a closed-loop fashion.
- **Municipal.** Municipal water comprises water flows through public distribution networks, regardless of whether they're publicly or privately owned. Its users include residences, businesses, fire protection bodies, as well as industrial users drawing from the pipe network. Overall, 8% of water withdrawn worldwide goes to municipal use, and it is this water that the overwhelming majority of equipment and chemicals goes to treat.

Services: $386 Billion – 74% of Hydrocosm Revenue

The largest share of the hydrocosm's $522 billion in revenue lies in the services category, accounting for $386 billion in 2007. We divide services into six segments: 1) treatment, 2) engineering, 3) infrastructure, 4) analytical services, 5) water transportation/shipping, and 6) water rights (see Figure 1.9):

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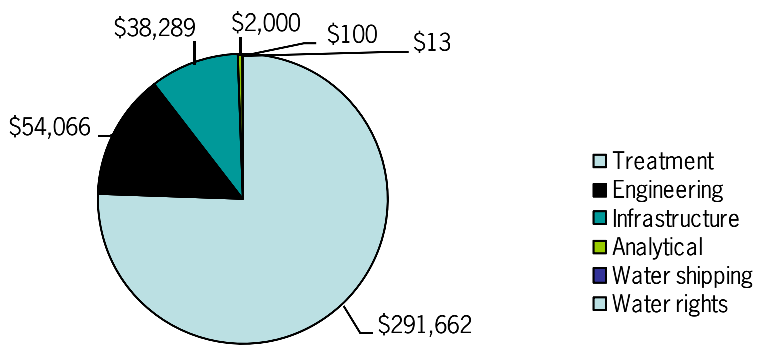
Fig. 1.9: Water Services Revenue, 2007 (US$ Millions)



Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Treatment services	Treats water for delivery to end customers	$292 billion	Municipalities (Thames Water, San Francisco Public Utilities); private companies (United Water, Suez, Vivendi)	*Mature* – generally conservative about adopting innovations from other hydrocosm segments	Low single digits
Engineering services	Design, construction, and operation of water and wastewater treatment facilities as well as distribution systems	$54 billion	CH2M Hill; Skanska, Furgo, Arcadis, URS, Vinci	*Mature* – engineering services must constantly grapple with utilities looking for the lowest price for services	Mid-single digits
Infrastructure services	Includes pipe rehabilitation, drilling, and well production	$38 billion	Insituform Technologies, Miller Pipeline, TT Technologies	*Mature* – opportunities for innovation as improvements are made in drilling and pipe repair	Mid-single digits
Analytical services	Water quality analysis by a certified laboratory	$2 billion	Underwriters Laboratories, Gap EnviroMicrobial Services	*Mid-stage* – Improved instrumentation allows detection of pharmaceuticals and endocrine disrupting contaminants in water	Mid-single digits
Water shipping	Transports water via tanker or pipeline	$100 million	Local shipping companies; Solar Sailor	*Introduction* – modifications to tankers for water shipments	Double to triple digits
Water rights	Manages and enables trading of rights to water	$13 million	Mesa Water; Vidler Water	*Introduction* – relatively new concept	Double digits

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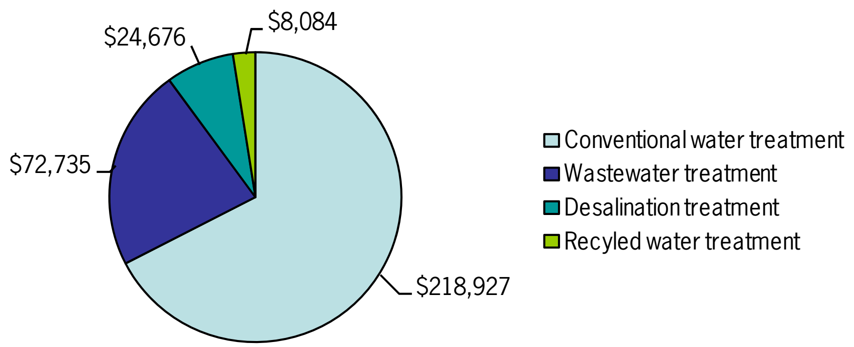
Fig. 1.10: Water Treatment Services Revenue by Sub-segment, 2007 (US$ Millions)



Sub-segment	Amount of global volume addressed (km^3/yr)	Percent of global volume addressed	Aggregate 2007 revenue	Example organizations
Conventional water treatment	311	7.5%	$207 billion	Municipalities (Thames Water, San Francisco Public Utilities); private companies (United Water, Suez, Vivendi)
Wastewater treatment	167	4.0%	$73 billion	Municipalities (D.C. Water & Sewer Authority, Nordkanal); private companies (IntegraWater, Vivendi)
Desalination	16	0.4%	$9.6 billion	Municipalities (Tampa Bay Water, Abu Dhabi Municipalities); private companies (Suez, Veolia, Poseidon)
Recycled water treatment	6.2	0.1%	$2.7 billion	Municipalities (Water Factory 21, Singapore Water); private companies (Willunga Basin Water Company, Jeddah Advanced Water Treatment Company)

Treatment Dominates Water Services, with $292 Billion in 2007 Revenue

Water treatment accounted for 76% of services revenue in 2007, spread across three sub-segments (see Figure 1.10):

- **Water and wastewater treatment: $279 billion.** Water treatment – publicly or privately owned utilities treating water and delivering it through pipes to end users in exchange for fees – generated $207 billion in 2007. We estimate that approximately 8% of all water used worldwide was treated last year; key privately-held companies include water treatment giants like Thames Water and Veolia. In contrast, wastewater treatment formed a much smaller market totaling $73 billion in revenue in 2007, because only half of the water treated on the front end undergoes wastewater treatment on the back end. For example, in China more than half of the country's 1.3 billion people, including residents in 278 cities, have no form of wastewater treatment. Eight

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of the cities concerned have populations of over 500,000, while an estimated 5,000 "administrative towns" and 20,000 small villages also have no facilities.[8]

- **Desalination: $9.6 billion.** Growing water demand has increased the use of alternative sources like seawater and brackish water, which require extensive treatment and employ advanced equipment that's typically not used in conventional water treatment plants. Water from desalination plants is billed to end users just like water from conventional treatment plants, and the substantial difference in cost per cubic meter – $0.64/m^3$ for typical desalinated water versus $0.45/m^3$ for conventional water treatment – is not generally reflected in prices.[9] We estimate that water supplied from desalination facilities represented only 3% of the treatment market, with revenues of $9.6 billion in 2007.

- **Recycled water treatment: $2.7 billion.** Recycled water plants are only beginning to be constructed even in areas that face severe water stress, and represent 1% of the treatment market, with revenues of $2.7 billion in 2007. Consider one plant brought online in 2007 in Brisbane, Australia, which was experiencing one of the worst droughts on record and could not meet existing water demands: To offset the consumer and industrial demand for water, the municipality built a treatment facility that processes 200,000 cubic meters of wastewater effluent per day, which is then sent to the region's power plants to be used as cooling water. Whatever water that is not used by the power plants is then dispatched to the existing reservoir that supplies the community with drinking water.

Other, Smaller Services Segments Support Treatment, with $94.8 Billion in 2007 Revenue

The remaining five water service segments represent 24% of services category revenue, supporting treatment either through designing new treatment facilities, rehabilitating old treatment infrastructure, monitoring treatment facilities and their output, or shipping water from one region to another.

- **Engineering services: $54 billion.** Engineering services includes design, construction, and operation of water and wastewater facilities. We value the market at $54 billion, with a little more than half of the revenue in construction of treatment facilities and distribution networks. Big players include firms like CH2M Hill, Bechtel, and Veolia. Engineering services are being fueled in part by new infrastructure being deployed in newly industrialized countries – like China, which has a water treatment market growing at 15% per year. For example, Veolia is currently working on 25 projects for municipal and industrial partners in 19 Chinese cities covering drinking water production and distribution as well as municipal and industrial wastewater treatment.

- **Infrastructure services: $38 billion.** The infrastructure services market includes well production, drilling/tunneling, and pipe rehabilitation. While well production and drilling/tunneling are relatively slow-growing categories with growth gated by water needs alone, pipe rehabilitation – the replacement of existing pipes by either conventional or trenchless methods – is growing rapidly as municipalities seek to upgrade existing infrastructure with minimal interruption to service and traffic, instead of ripping up streets and laying down whole new pipes. The pipe rehabilitation segment boasts one large, publicly traded firm – Insituform Technologies, with

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$495 million in 2007 revenue – as well as many smaller, mostly regional players such as Nu Flow and Link-Pipe.

- **Analytical services: $2 billion.** Analytical services include lab analysis for water quality parameters (such as total organic carbon) and measurement of contaminants (such as pesticides). Many utilities can provide basic water quality measurements in-house, but require the services of an accredited laboratory to detect minute concentrations of contaminants in the drinking water – creating demand for services from key players like Underwriters Laboratories. Stringent water quality regulations in the United States and Europe increase the need for analytical services, as utilities must document their finished water quality to ensure that the water being sent to consumers meets mandated standards.
- **Water shipping: $100 million.** Water shipping is the transportation of water by means ranging from tankers to polyurethane bags. A single tanker can ship about 250,000 m^3 of water, as was done this year with shipments to Spain and Cyprus; local shipping companies like Ocean Tankers (Cyprus' source) have dominated in the past, but dedicated players focused on water like Solar Sailor with its purpose-built "aquatanker" are now cropping up. However, this market has sputtered in recent years: Aquarius Water Trading transported water in large polyurethane bags that could hold 2,000 cubic meters of water, but is now defunct.
- **Water rights: $13 million.** As freshwater becomes more scarce, people, cities and towns are looking for additional sources and are enlisting the services of businesses who can execute and coordinate water rights transfers, like Vidler Water.; however, today, this is a tiny segment.

Equipment: $64 Billion – 12% of Hydrocosm Revenue

Water equipment accounted for $64 billion in revenue in 2007 (see Figure 1.11). We divide the equipment category into seven segments: 1) general equipment, 2) physical equipment, 3) chemical equipment, 4) mechanical equipment, 5) metering/monitoring equipment, 6) energy recovery, and 7) residential equipment. Investors and executives have focused on the equipment segment looking for the next breakthrough technologies that will drive growth and profitability – as reverse osmosis equipment, membrane bioreactors, and UV disinfection gear have in the past. These opportunities exist, but spotting them is like looking for needles in a big, messy haystack: Most equipment used to treat water and wastewater is based on technologies that have been around for 50 years or more.

General Equipment: $36 Billion and Stagnant

General equipment includes well-understood and slow-growing equipment that's required for any type of water treatment installation, such as pipes, pumps, valves, and storage tanks (see Figure 1.12). Opportunities for innovation are limited in this segment, where cost reigns supreme, annual revenue growth languishes in the low single digits, and regional and local suppliers proliferate to serve local needs. All told, the segment totaled $36 billion in 2007 revenue, 55% of equipment overall. Pipes dominate general equipment with $23 billion in 2004 revenue, led by companies such as Hanson Pipe and Precast and Saint-Gobain Pipelines; pumps and valves follow with roughly equal revenues an order of magnitude smaller, with storage tanks bringing up the rear.

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Fig. 1.11: Water Equipment Revenue, 2007 (US$ Billions)

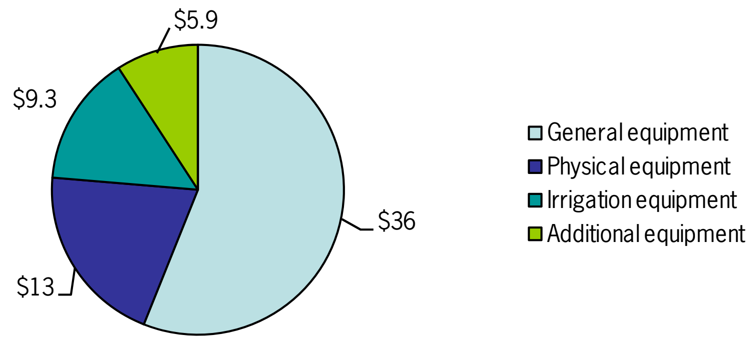

Fig 1.12: General Equipment by Sub-segment

Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Pipes	Moves water throughout treatment facilities and distribution networks	$23 billion	Hanson Pipe and Precast, Saint-Gobain Pipelines, Uponor,	*Very mature* – little opportunity for innovation	Mid-single digits
Pumps	Forces water against gravity from source through treatment and distribution	$7.0 billion	ITT, Grundfos Flowserve, Ebara	*Very mature* – little opportunity for innovation	Mid-single to mid-double digits (varies by subsegment)
Valves	Isolates and regulates flow throughout treatment process and distribution networks	$5.0 billion	Crane Valves, IT, Mueller Water Products, Tyco Flow Control	*Very mature* – little opportunity for innovation	Mid-single digits
Storage tanks	Provides storage of water as well as disinfection contact time	$182 million	Preload, Natgun	*Very mature* – little opportunity for innovation	Low single digits

Physical Equipment: $13 Billion and Growing

Physical equipment removes particles from water or disinfects biological contaminants through physical means – like mechanical removal or denaturing from ultraviolet light – rather than through chemical reactions (see Figure 1.13). While physical equipment is much smaller than general equipment – $13 billion in 2007 revenue for 21% of equipment overall – it's growing much faster, with several sub-segments seeing recent annual revenue increases of 10% per year or more. Key areas for innovation in physical equipment are energy-efficient variants that either consume less energy per unit of water treated or use otherwise-wasted sources of energy, like waste heat:

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Fig 1.13: Physical Equipment by Sub-segment

Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Solids treatment	Processes waste removed during water treatment	$3.9 billion	Suez, Kurita Water Industries, Andritz	*Mature* – focus will shift to treatment options as disposal limits are restricted	Low single digits
Membrane filtration cartridges	Disposable component of membrane filtration systems	$3.5 billion	GE, Pentair, ITT	*Mature* – growing as a pre-filter for reverse osmosis	Mid-single digits
Thermal distillation equipment	Removes inorganic salts through thermal processes; multistage flash evaporation and multi-effect distillation are key variations	$2.2 billion	Aquatech, Doosan (multistage flash); VWS Envig, IDE Technologies, GE (multi-effect distillation)	*Very mature* – little opportunity for innovation	Low single digits
Reverse osmosis equipment	Removes 90% to 95% of inorganic salts and 95% to 99% of organic matter	$944 million	GE, Kurita Water Industries, Metito	*Mature* – incremental innovation in membrane selectivity	9.6%
Microfiltration	Removes suspended particles, algae, protozoa, bacteria	$450 million	Suez, Kurita Water Industries, GE	*Very mature* – little opportunity for innovation	9.4%
Ultrafiltration	Removes molecular-size compounds, particulates, and microbes	$450 million	Kurita Water Industries, ITT, Dow	*Very mature* – little opportunity for innovation	9.4%
Membrane bioreactor (MBR)	Combines membrane filtration with the activated sludge process to enhance organic and solids removal	$358 million	Kubota, GE	*Mature* – key innovation period was in 1990s	Low double digits
Ion exchange	Removes contaminants by binding them to a resin via exchange of ions	$350 million	Lanxess, Siemens, Rohm & Haas	*Mature* – improvements in resin selectivity still possible	High single digits
UV disinfection	Inactivates bacteria, viruses and protozoa using ultraviolet light	$350 million	BWT, ITT, Trojan Technologies	*Mature* – recent advances focus on lighting sources	25%
Clarification	Removes suspended solids by either gravity settling or flotation	$100 million	GL&V, Siemens, Walker Process Equipment	*Mature* – incremental innovations possible	Mid-single digits
Zero liquid discharge	Concentrates waste streams to remove liquid so product can be disposed of or sold	$90 million	GE, Aquatech, HPD	*Early-stage* – opportunities to lower equipment cost and energy requirement	Mid-double digits

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Fig 1.13: Physical Equipment by Sub-segment (continued)

Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Nanofiltration	Removes natural organic matter, viruses, calcium, and magnesium	$73 million	ITT, Siemens, GE	*Mature* – incremental innovation possible in membrane selectivity	Low single digits
Electrodialysis	Removes ionized salts using an electric current	$62 million	GE, Normura Micro Science, Veolia	*Very mature* – little opportunity for innovation	Low single digits
Electrode ionization	Used as a polishing step for reverse osmosis, combining a membrane element with ion exchange resins	$7.8 million	GE, Kurita Water Industries, Nomura Micro Science	*Mature* – some opportunity for innovation	Low single digits

- **Solids treatment: $3.9 billion.** Solids refer to the constituents removed from water during the treatment process, either through settling, filtration, or chemical precipitation. Treated solids are typically disposed of at landfills or applied to agricultural land. Therefore, proper treatment of solids requires extensive equipment, including equipment to thicken the solids (like centrifuges, gravity belt, rotary drum, and flotation equipment), equipment to dewater the sludge (like filter presses, centrifuges, and belt filter press), and pumps to convey solids from one treatment step to the next (see Figure 1.14).

  However, disposal of solids is becoming increasingly difficult because of stringent legislation. Innovation in solids disposal is on the rise, including thermal utilization, which transfers solids into a product that can be used as a secondary source of fuel, like at a coal-fired power plant. Andritz has developed drying technology that can process solids for thermal utilization; the company is a key supplier of solids treatment gear, as are Kurita Water Industries and Suez.

- **Membrane filtration cartridges: $3.5 billion.** Membrane filtration cartridges are the only disposable item we have listed in the equipment category, with market revenue of $3.5 billion in 2007. The filtration cartridge market is growing because of its use as a pre-filter before membrane treatment for water and wastewater applications, or on its own for ultrapure water in pharmaceutical and semiconductor plants. Key filtration cartridge manufacturers include GE, Pentair, and ITT.

- **Thermal desalination equipment: $2.1 billion.** Thermal desalination technologies, like multi-stage flash (MSF) and multiple effect distillation (MED), account for 43% of installed, online desalination capacity worldwide. However, their share of new capacity deployed each year has been shrinking compared to RO for the past 20 years, falling from a high of 97% in 1980 to 7% in 2003, because these technologies have up to two times the capital costs of RO along with high energy requirements – driving the average cost of MSF to $1.10/m^3 and MED to $0.89/m^3, compared with $0.61/m^3 for RO (see Figure 1.9).[10] Key suppliers include IDE Technologies and

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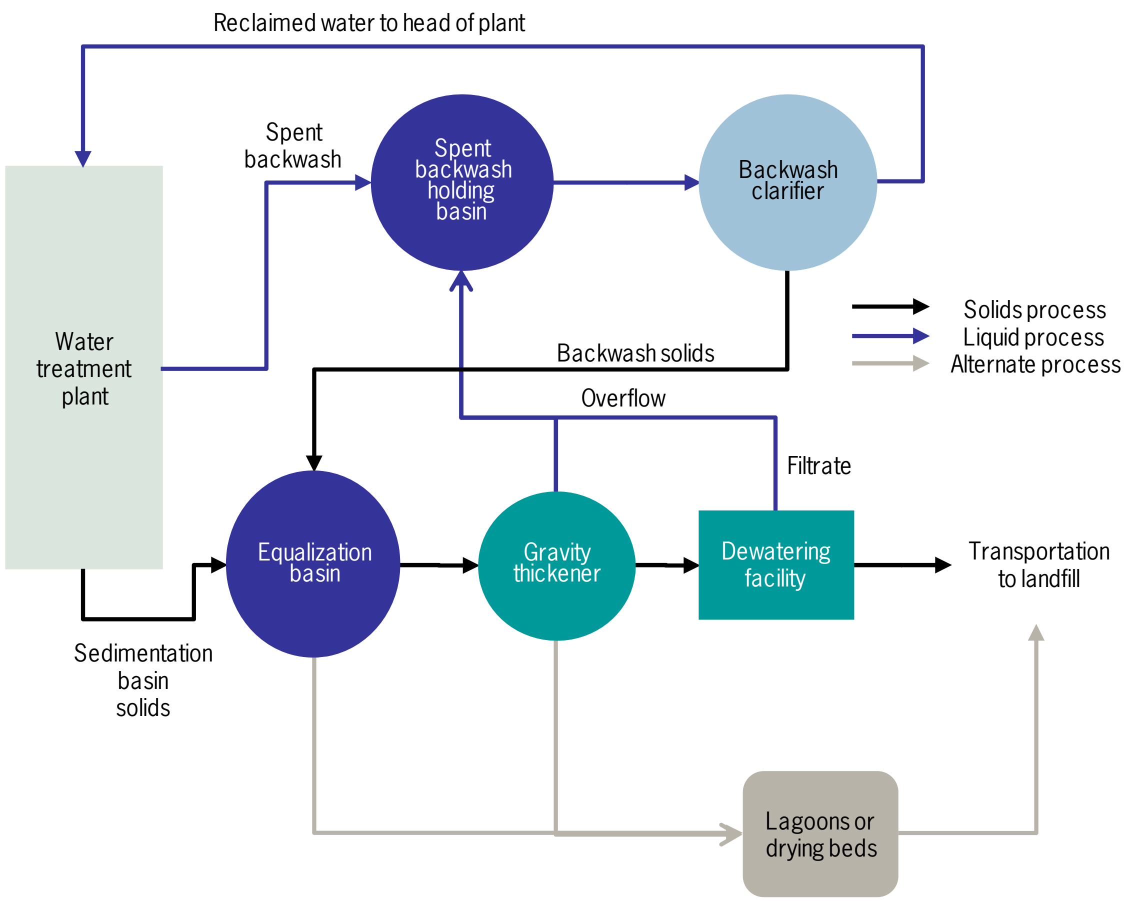
Fig. 1.14: Example of Solids Treatment Process



VWS Envig. Thermal desalination dominates in the Middle East because of the region's low energy costs and the ability to integrate thermal desalination with available power plant steam.

- **Reverse osmosis (RO) equipment: $1 billion.** In recent years, RO has become the market-leading technology for seawater and brackish water desalination, and an increasingly-used tool in the kit for removing tough particles such as radionuclides and inorganic compounds. Leaders include GE, Metito, and Kurita Water Industries seeing annual revenue growth of 8% to 19% from 2000 to 2005.[11]

- **UV disinfection: $350 million.** At first glance, UV disinfection might not seem to fall in the "physical equipment" category because it doesn't work through mechanical means. We place the segment here because UV equipment is a durable good purchased through capital expenditure, as opposed to consumable chemicals which can provide similar disinfection results but have to be continuously repurchased or regenerated. Growth of UV disinfection equipment increased by 25% in 2007 because of the regulations enacted in the United States that required

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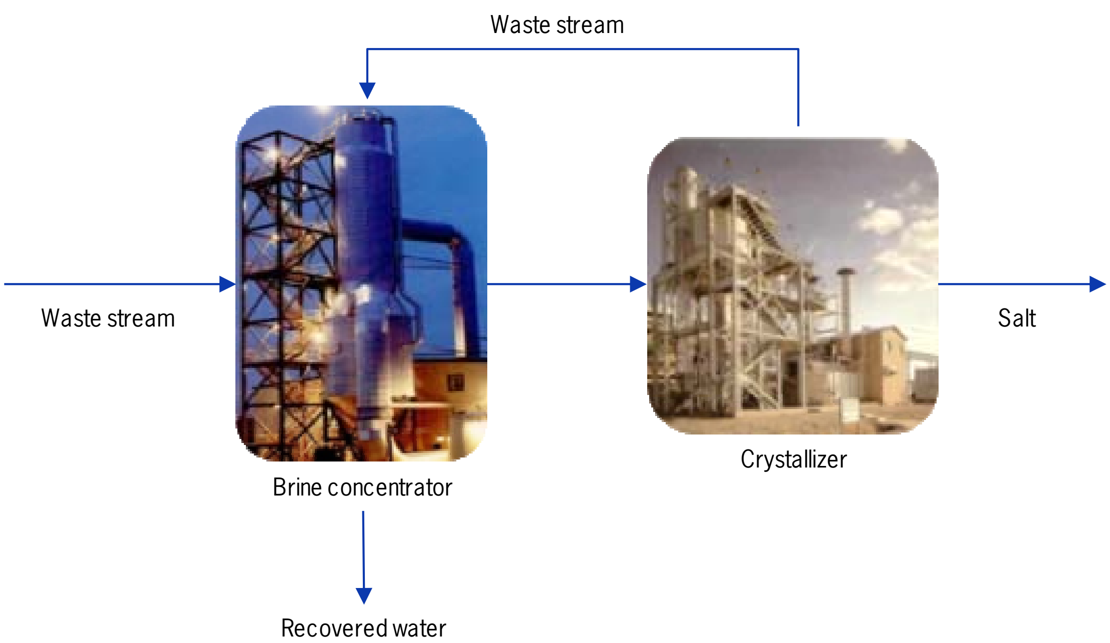
Fig. 1.15: Example of Zero Liquid Discharge Process



Cryptosporidium inactivation and listed UV disinfection as a best-available technology.[12] Global growth in recycled water, which typically uses UV in combination with hydrogen peroxide to oxidize organic contaminants in the water, also played a role. Beneficiaries of this growth have been leading suppliers like Trojan Technologies and Halma.

- **Zero liquid discharge: $90 million.** Zero liquid discharge (ZLD) is a process that uses a series of equipment to minimize the liquid waste from a water or wastewater treatment plant or an industrial process. The equipment used in the ZLD process includes brine concentrators that distill water from waste streams and crystallizers to remove/recover salts (see Figure 1.15). ZLD is gaining attention in the hydrocosm because of disposal issues with brine concentrate, a byproduct of the RO process. Desalination plants located on the coast can discharge the brine concentrate back to ocean – provided they have proper permits – but inland plants can't. Currently, ZLD is a very expensive process, around $3.30/m^3, because of the costly equipment required and the energy it consumes, and therefore is not a viable option for many sites considering desalination.[13] However, ZLD is at the early stage of development and technological improvements could dramatically drive down its costs.

- **Other physical equipment: $2.3 billion.** Our remaining 10 physical equipment sub-segments constitute a grab bag of membrane filtration equipment, clarification equipment (which is used to enhance solids settling during the treatment process), and ion exchange (which selectively removes organic compounds from water). Of particular note are membrane bioreactors (MBR), which combine clarification and filtration into one treatment step by using an activated sludge

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Fig. 1.16: Irrigation Equipment by Sub-segment

Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Spray/sprinkler irrigation	Distributes water to a field using a spray or sprinkler	$7.8 billion	Jain Irrigation Systems, Deere	*Very mature* – little opportunity for innovation	6.5%
Drip irrigation	Delivers water to the root of plants	$1.5 billion	Rain Bird, Netafim, Deere	*Mid-stage* – variety of mechanical changes possible	15%

bioreactor to break down organics and microfiltration to remove them from water. This combination gives MBR a smaller footprint than conventional clarification followed by filtration. MBRs are now becoming an established treatment process for wastewater and recycled water applications, with an installed capacity of 1.5 million m^3/d in 2004 compared to only a 0.25 million m^3/d in 2000.[14] Key MBR vendors include Kubota and GE (via its acquisition of major MBR supplier Zenon Environmental).

Irrigation Equipment: $9.3 Billion and Steady

Irrigation is the artificial application of water to the soil for growing crops or decorative plants. In 2007, 445 million hectares of land were irrigated. Forty percent received flood irrigation, where water is either pumped or brought to the fields and is allowed to flow along the ground among the crops, and therefore requires no equipment beyond pipes and pumps. The relevant land for the irrigation equipment segment, then, was the 8% that was irrigated through spray, sprinkler, or drip irrigation. We peg sales of irrigation equipment at $9.3 billion last year (see Figure 1.16).[15]

- **Spray/sprinkler irrigation: $7.8 billion.** Sprinkler irrigation systems pipe water to one or more central locations within a field and distribute it by overhead high-pressure sprinklers or guns. Spray/sprinkler irrigation systems served 7.5% of irrigated land in 2007, with sprinkler-irrigated land growing at roughly 6.5% per year in recent years. While spray/sprinkler irrigation systems are low-tech and haven't changed a great deal in recent decades, the steady increase of irrigated land worldwide – particularly in developing countries – have sparked the growth of suppliers like India's Jain Irrigation Systems and led to acquisitions like Deere's 2008 roll-up of Israel's Plastro Irrigation Systems and U.S.-based T-Systems International.

- **Drip irrigation: $1.5 billion.** Drip irrigation systems deliver water near the roots of plants; while more water-efficient than sprinkler irrigation (by 15% on average), drip irrigation systems are more costly (ranging from $800 to $1,600 per acre versus $600 to $1,000 per acre for spray/sprinkler), have shorter lifetimes (typically 10 years versus 20), and require more maintenance to prevent clogging.[16] By our estimates, only 0.5% of irrigated agriculture used drip irrigation in 2007 – but this sub-segment has grown at a faster rate in recent years of 15%. Opportunities for innovation focus on reducing equipment cost, improving lifetime, and reducing maintenance requirements, driving R&D at suppliers like Rain Bird and Netafim.

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Fig. 1.17: Metering/Monitoring Equipment by Sub-segment

Sub-segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Water meters	Meters water entering houses and commercial buildings	$2.9 billion	Sensus Metering Systems, Elster Metering, Badger Meter	*Mid-stage* – improvements in automatic meters will continue	5% for standard meters; 15% for automatic meters
Flow meters	Measures the rate of flow through pipes	$581 million	Krohne, Fluid Components International	*Very mature* – little opportunity for innovation	Mid-single digits
Infrastructure monitoring products	Equipment that can monitor infrastructure integrity using radar, sonar, distributed sensors, robotic inspection, etc.	$500 million	Redzone Robotics, Primayer, Echologics Engineering, Sensicore	*Mid-stage* – continued development to improve technology and lower cost	Mid-single digits

Additional Equipment Categories: A Motley Crew Worth $5.9 Billion

General equipment, physical equipment, and irrigation equipment account for 91% of equipment revenue altogether. The remaining four equipment segments – metering/monitoring equipment, residential equipment, chemical equipment, and energy recovery – make up the rest, all differing greatly from one another.

- **Metering/monitoring equipment: $4.2 billion.** Utilities and industrial users deploy metering and monitoring equipment in treatment facilities and distribution networks to meter water entering houses and commercial buildings, to measure flow through pipes, and to monitor water quality parameters either at the treatment plant or in the distribution systems. Key sub-segments for innovation include water meters – measuring water usage through meters like the one at your house or apartment – where the growth of automatically-read water meters utilizing radio signals jumped 15 % in 2007 as utilities moved to automated systems, creating opportunity for vendors like Sensus Metering Systems and Elster Metering (see Figure 1.17).
- **Residential equipment: $1.1 billion.** Residential equipment includes products that can treat water just prior to use (point-of-use [POU] devices) or as it enters the entire home (point-of-entry [POE] devices). POU devices range from pitchers with carbon filters that remove impurities from water, to filters attached directly to faucets, to specialized portable units for campers located far from clean water. Key suppliers range from Brita (of the eponymous pitchers) to GE (which offers an under-the-sink reverse osmosis system). POE devices are smaller versions of large-scale equipment discussed previously, like UV disinfection and reverse osmosis systems; as a result, innovations in POE equipment generally trickle down from larger-scale versions. One key supplier is Trojan Technologies, which offers a whole-house UV disinfection system. Drivers of growth in this segment are the public's growing awareness of water quality issues as well as concerns about the water quality in the distribution system (see Figure 1.18).

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Fig. 1.18: Residential Equipment by Sub-segment

Segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
POU devices	Treats water at the tap or in a portable device	$447 million	Brita, Pur, GE	*Mid-stage* – opportunities to improve portability and lower cost	Low double digits
POE devices	Treats water entering a house using activated charcoal filters, membrane filters, and/or UV disinfection	$691 million	Culligan, R-Can Environmental, Pentair	*Mid-stage* – opportunities for third world treatment applications	Mid-single digits

Fig. 1.19: Chemical Equipment by Sub-segment

Segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Ozone	Provides disinfection and organic oxidation; generated on-site	$275 million	Degremont, ITT, GE	*Mature* – incremental improvements to reduce equipment footprint and energy consumption	Mid-single digits
Chemical feed equipment	Doses and conveys chemicals to application point within the treatment process	$150 million	GE, Wallace & Tiernan	*Very mature* – little opportunity for innovation	Low single digits
Chlorine dioxide	Chlorine dioxide is generated on-site providing disinfection and organic oxidation	$56 million	Altivia, Wallace & Tiernan	*Mature* – chlorite legislation limits applicability	Low single digits
On-site generation	Generate chlorine gas, sodium hypochlorite, or mixed oxidants on demand	$30 million	Miox, Severn Trent Services	*Early-stage* – at beginning of adoption cycle	Mid-single digits

- **Chemical equipment: $511 million.** Chemical treatment, discussed below, involves loading consumable chemicals into water and wastewater to provide disinfection and/or oxidation of substances like iron and manganese. Chemical equipment creates and feeds these chemicals used in treatment processes. One key area of innovation is generators that produce chemicals onsite. Onsite generation of ozone and chlorine dioxide is required because these chemicals are unstable and cannot be shipped. However, generators are available that produce chlorine gas, sodium hypochlorite, or a combination of mixed oxidants onsite instead of transporting them from suppliers. Key developers include Miox and Severn Trent Services (see Figure 1.19).

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Fig. 1.20: Energy Recovery Equipment by Sub-segment

Segment	What it does	2007 market size	Key companies	Key innovations	Recent annual growth
Pressure recovery	Transfers concentrate pressure to reverse osmosis feed stream or into mechanical power	$112 million	Energy Recovery Inc., Calder, Fluid Equipment Development, Pump Engineering	*Mid-stage* – becoming an established product category	25%
Microbial fuel cells	Bacteria oxidize sugars to create electrical power	$0	Hy-SyEnce, InTact Labs, Lebônê	*Development stage*	N/A

- **Energy recovery: $120 million and skyrocketing.** As discussed, the downside to the RO process that dominates new desalination plants today is the high energy requirements of RO equipment. Pressure recovery devices – which account for nearly the entire energy recovery segment today – recover the pressures used to push water through reverse osmosis membranes and convert it into a useful form that can mitigate some of the process's energy needs. These devices can either transfer the concentrated pressure directly to the RO feed stream or concentrate the pressure into mechanical power, which is then converted back to feed pressure. Rising energy costs have focused intense interest on energy recovery for RO, driving double-digit annual growth rates and creating rich pickings for leading suppliers like Energy Recovery Inc. and Calder. Opportunities for innovation include improving the efficiency of pressure recovery devices as well as launching completely different systems that are not coupled specifically to RO, like microbial fuel cells – in which bacteria create electrical power by oxidizing sugars present in wastewater. Microbial fuel cells are pre-revenue today, but being pursued by multiple start-up companies for wastewater treatment applications, including Hy-SyEnce and InTact Labs (see Figure 1.20).
- **Emerging equipment:** $12 million. The emerging equipment segment amounts to $12 million today, and includes devices that convert water from air, as well as technologies to mitigate evaporation from open storage tanks and agricultural fields.

Chemicals: $8.9 Billion – 2% of Hydrocosm Revenue

Chemical treatment is the addition of chemicals to improve the quality of the water by aiding particle settling, inactivating microorganisms in the water, optimizing filtration processes, or adjusting water pH. The number of chemicals used to treat water in any given facility varies widely, depending on initial water quality and the facility's treatment goals. For example, a drinking water facility treating water to a high quality standard (e.g., low concentration of suspended solids and bacteria) may use only one chemical for treatment, namely chlorine for disinfection. However, another facility treating water of a degraded quality (e.g., high concentration of suspended solids and bacteria) may employ a complex mix of several chemicals to optimize solids removal, reduce bacteria concentration, and optimize the pH. Chemical treatment is not limited to water and wastewater applications; chemicals are also applied to industrial waters, like the addition of

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Fig. 1.21: Chemicals by Sub-segment

Segment	What it does	2007 market size	Key companies	Recent annual growth
Antiscalants	Prevents scaling and inorganic fouling on surfaces	$2.5 billion	Nalco, Dow, Rohm & Haas	Mid-single digits
Biocides	Kills living organisms found in water; chlorine is most familiar biocide	$2.0 billion	Rohm & Haas, Arch Chemicals	Mid-single digits
Coagulants	Bind with suspended solids to aid in removal process	$1.3 billion	Kemira, Nalco	Mid-single digits
Hydroxides	Provides softening, pH control, neutralizing agent activity, precipitation of heavy metals	$1.3 billion	Dow, Carmeuse	Mid-single digits
Other chemicals	Various chemicals provide odor reduction, fluoride addition, iron and manganese oxidation, etc.	$522 million	Calgon Carbon, Carus	Mid-single digits

antiscalants to cooling water to prevent the buildup of salt crystals on equipment and extend equipment life. Chemical segments include the following (see Figure 1.21):

- **Antiscalants: $2.5 billion.** Antiscalants (also known as scale inhibitors) are chemicals that are used to prevent scaling and inorganic fouling of membranes, cooling towers, and other surfaces that water comes into contact with. In membrane treatment, the addition of antiscalants is critical to extend membrane life and to maintain the optimum membrane flux rate (transfer of water volume across the membrane surface). Therefore, as membrane installations continue to increase, so will the use of antiscalants, which are typically supplied in proprietary formulas from companies like Dow and Rohm & Haas.

- **Biocides: $2.2 billion.** Biocides – chemicals capable of killing living organisms – include disinfectants, antiseptics, pesticides, and preservatives. Chlorine (sodium hypochlorite and chlorine gas) is the best-known biocide; others include proprietary biocides, used to control microorganism growth on membranes, which must be custom-designed to be compatible with membrane materials, as well as biocides that control algae and fungi growth in cooling towers.

- **Coagulants: $1.3 billion.** Coagulants help remove solids from water by causing suspended solids to clump together and settle to the bottom of a basin, where they can be removed. Coagulation is a necessary pretreatment step before any type of filtration, including membrane filtration, to ensure that the solids do not clog the filter. As a result, nearly all treatment processes employ coagulation at some step, creating steady – if not rapidly-growing – demand for key suppliers such as Kemira and Nalco.

- **Hydroxides: $1.3 billion.** Hydroxides, like calcium hydroxide and sodium hydroxide, are used for pH control, softening, and impurity removal in potable water systems as well as a

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neutralizing agent and precipitant of heavy metals in many industrial and wastewater applications. Hydroxides' versatility creates a steady demand for key suppliers like Carmeuse and Dow.

- **Other chemicals: $522 million.** The remaining five chemical segments – fluoride, powdered activated carbon, hydrogen peroxide, ammonia, and potassium permanganate – are uniformly small, with individual segment revenue for each in the $20 million to $250 million range.

Bottled Water: $62 Billion – 11% of Hydrocosm Revenue

Bottled water is the curiosity of the hydrocosm, representing an odd business model in which a commodity product sold nearly for free is repackaged in branded form and sold at a price premium averaging $1 per liter. Sales of bottled water in 2007 totaled $62 billion. Bottled water sources range from glaciers, springs, and wells to purified municipal water, and thrive on (real) convenience advantages as well as (largely perceived) safety advantages. While bottled water is still growing strongly worldwide – by our estimates, revenues were up 7.2% last year – the *rate* of growth is slowing down as established geographic markets approach saturation. Major bottled water brand owners, like Coca-Cola with Dasani, are discounting by 6% to 10% to spark demand in light of these slackening growth rates.

Conclusions

From our comprehensive map of the hydrocosm, we conclude that:

- The hydrocosm – the collection of water-related businesses – is fragmented and complex, frustrating executive and investors looking for profitable innovation opportunities.
- Total revenue in the hydrocosm reached $522 billion last year on 4,166 km^3 of water used worldwide.
- Slow-moving services, primarily water and wastewater treatment, accounted for 76% of hydrocosm revenue in 2007; equipment, historically the best prospect for innovation and growth, grabbed 12%, while chemicals took 2% and bottled water took 11%.

Endnotes

1 We developed these figures based on installation data collected from UV manufacturers for drinking water installations in North America.

2 Source: U.S. Geological Survey.

3 Estimated from U.N. Food and Agriculture Organization Aquastat data and data from the World Resources Institute.

4 Estimated from International Desalination Association data.

5 We make a distinction between reused water and recycled water. We define reused water as water that is put to beneficial use after being discharged from a wastewater treatment plant into natural surface waters. Reused water is outside the scope of our analysis because the reuse water does not go directly to a user.

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6 NEWater currently supplies only 1% of Singapore's water consumption. Three million gallons per day of NEWater is blended with raw water in the reservoir before conventional treatment. Source: Ministry of the Environment and Water Resources, Singapore.

7 Source: U.N. Food and Agriculture Organization.

8 Source: Chinese Ministry of Construction.

9 Both costs for desalination and conventional water treatment will be impacted by water quality and treatment capacity. Also, costs for conventional treatment vary widely from one country to the next. For example, the cost of conventional water treatment in Canada is $0.40/m^3 compared to Germany at $1.80/m^3.

10 Averages calculated from values presented in "Review of Water Resources and Desalination Technologies," James Miller, Sandia National Laboratories, 2003. Costs for desalination are impacted by water quality and treatment capacity.

11 Estimated from International Desalination Association data.

12 Lux Research estimate based on the number of UV facilities operating and under construction in North America.

13 Source: Zero Liquid Discharge for Inland Desalination (Project 3010), Awwa Research Foundation, 2007.

14 Source: "Survey of European MBR Market, Trends and Perspectives," B. Lesjean and E.H. Huisjes, IWA 4th International Membrane Technologies Conference, 15 to 17 May 2007, Harrogate, U.K.

15 Source: U.N. Food and Agriculture Organization.

16 Spray and sprinkler and drip irrigation cost estimates based on information from Washington State University and Idaho Department of Natural Resources.

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2: Water Needs

The world will consume 40% more water in 2030 as GDP, irrigated land, and population grow. Climate change and pollution could drive this requirement higher.

Signs of Water Crisis Make Headlines

In 1900, the world used 770 km^3 of water. By 1950, that amount had risen to 1,480 km^3, reflecting a compound annual growth rate (CAGR) of 1.3%. From 1950 through 2000, the growth rate accelerated to 1.9% per year – and the world consumed 3,840 km^3 at the end of century, nearly five times the value 100 years earlier.[1] During this same period global population grew by a factor of 3.7, from 1.7 billion to 6.1 billion.[2] As the growth in water usage outpaced growth in people, water usage per capita rose from 467 m^3 per person per year in 1900 to 634 m^3 in 2000 (see Figure 2.1). Yet throughout, the amount of accessible water worldwide remained fixed.

The pressure of increased water utilization coupled with fixed supply has consequences that you'd have to be living under a rock not to hear about. The OECD projects that the number of people living in areas of severe water stress will rise by 1 billion through 2030 to reach 3.9 billion, and academic researchers claim that the number facing "water poverty" – i.e., those who may be located near water, but can't access it due to political turmoil or lack of infrastructure – is far higher.[3] Executives find that water scarcity goes from theoretical to eminently real when they consider:

- **Multiplying zones of water scarcity.** When someone says "water scarcity," most people think about places like Saudi Arabia (the world capital of desalination) or Singapore (at the vanguard of water reuse). But today, headlines complain of water stress from Australia (where farmers choose whether to tend their sheep, or to sell the water that would nourish them on exchanges like Waterfind), to the U.S. state of Georgia (where the Governor began convening the faithful regularly to pray for rain last November), to China (where imminent depletion of North China Plain aquifers has sparked a $62 billion water transfer project to shuttle 45 km^3 of water from the south to the north annually).
- **Water availability out of sync with population.** At first glance, water scarcity seems nonsensical. Total water use worldwide in 2007 was 4,166 km^3, but the world's total annual renewable water resources total 46,629 km^3 – so the world uses only about 9% of what literally falls from the sky.[4] Water scarcity exists because the water isn't located where people live: China and India together account for 38% of the world's population but only 10% of its fresh water (see Figure 2.2). The problem persists within countries: How can 23% of Russia's population, mostly in the developed western part of the country, be facing severe water stress if the country has 10% of the world's accessible fresh water and only 2% of its population? Because much of this water is in Lake Baikal, a massive resource located in sparsely populated Southern Siberia.

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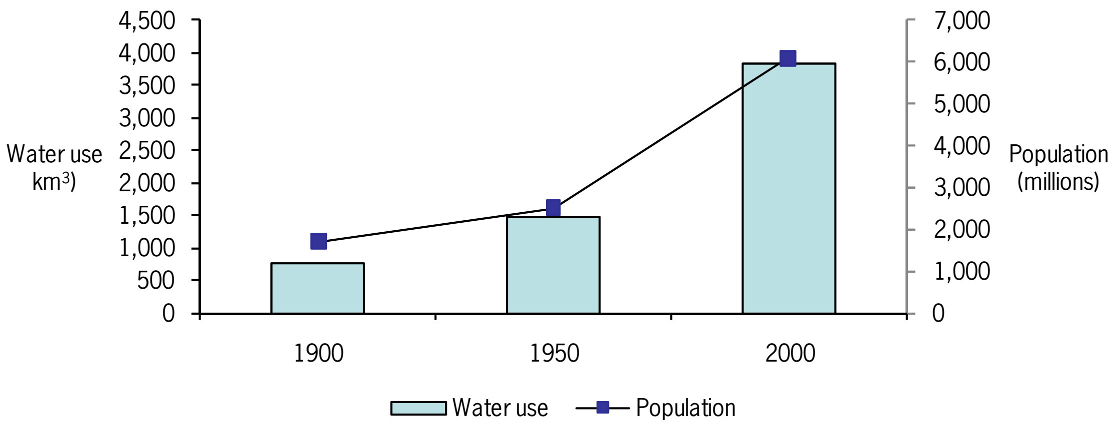
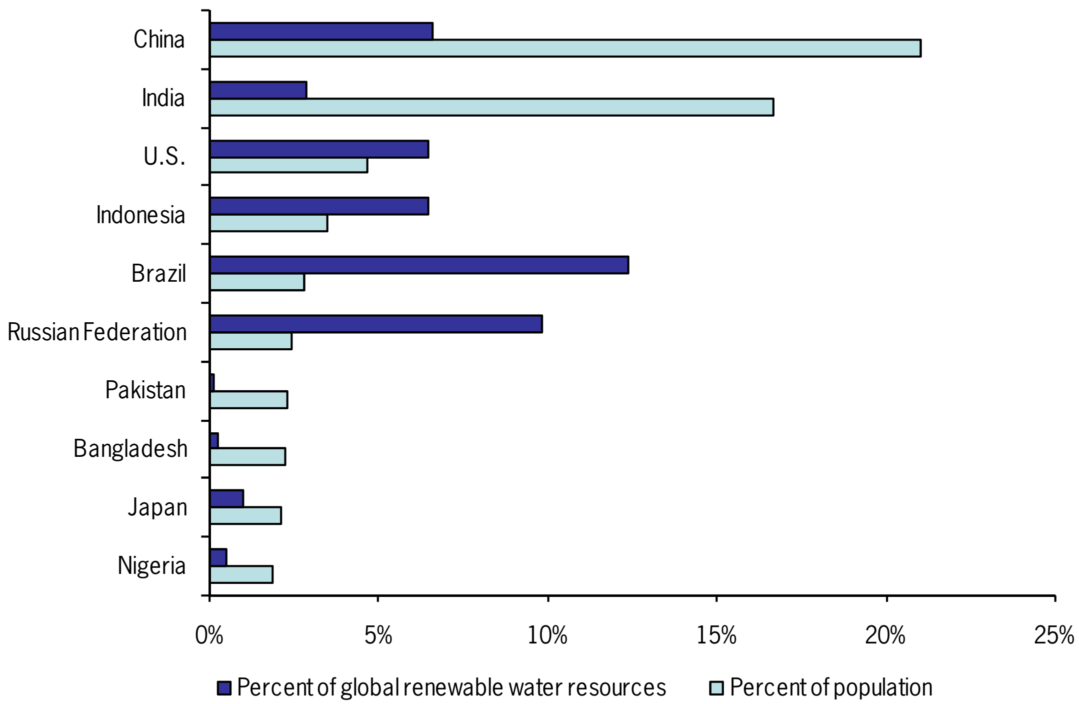
Fig. 2.1: Historical Growth in Water Use Has Exceeded Population Growth



Sources: U.N. Food and Agriculture Organization (water use), U.N. Population Division (population)

Fig. 2.2: People Don't Live Where the Water Is



Sources: U.N. Food and Agriculture Organization (water use), U.N. Population Division (population)

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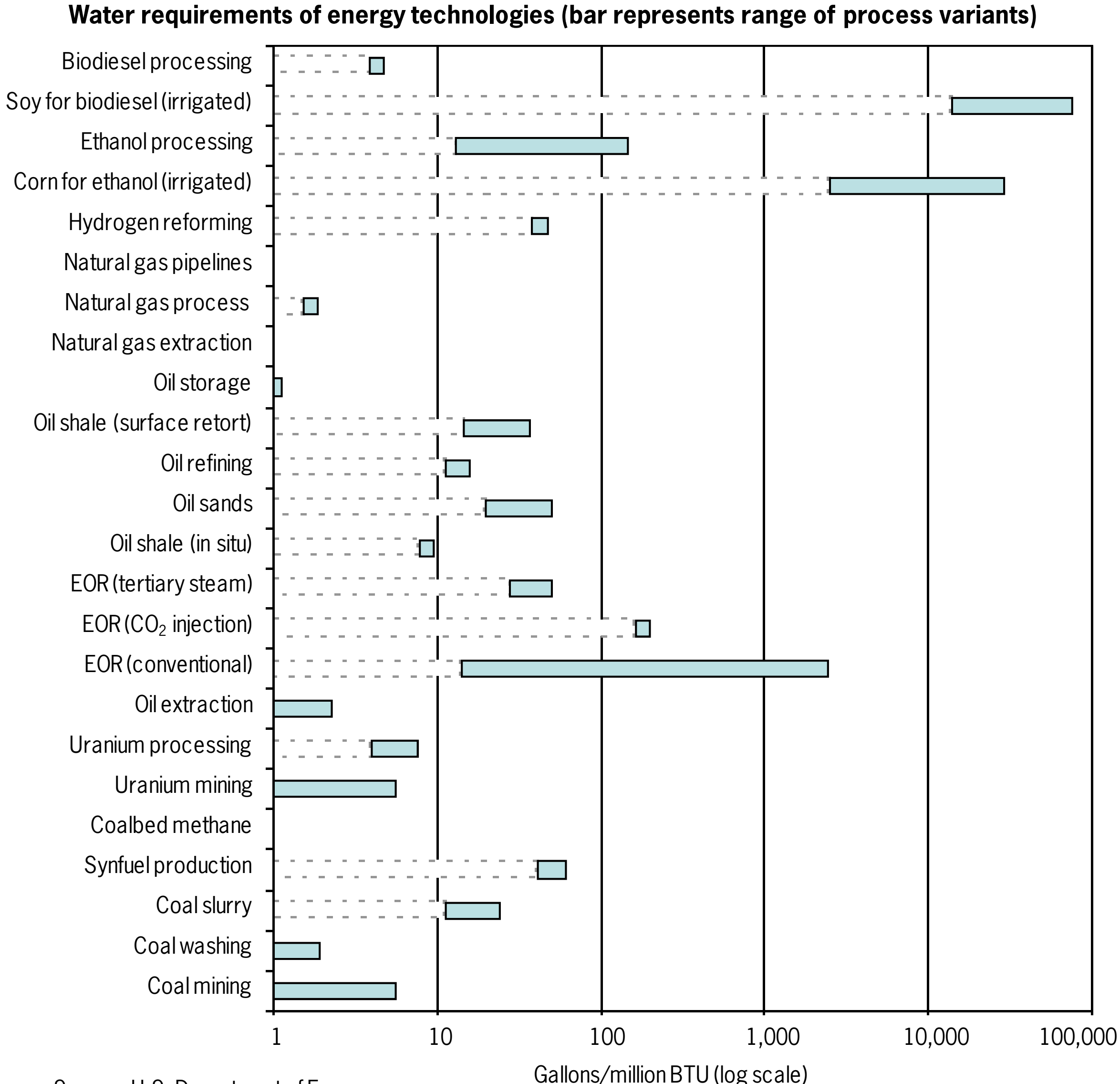
Fig. 2.3: Clean Energy Technologies Have a Dirty Secret: Water Requirements



Source: U.S. Department of Energy

- **Energy needs driving water needs.** Conventional energy technologies have always required a great deal of water – the practice of pumping water underneath depleting oil wells to maintain reservoir pressure is widespread, such that the "water cut" (water extracted as a fraction of well output) in many overdriven oilfields exceeds 90%. But new energy technologies that promise to offset fossil oil and gas consumption have dirty secrets of their own in their water usage: A U.S. Department of Energy (DOE) study found that some of the most profligate energy technologies in terms of water usage are biodiesel, ethanol, and hydrogen reforming (see Figure 2.3).[5] These supposedly sustainable energy technologies will only accelerate water stress.

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GDP, Irrigation, and Population Drive Water Needs

Business cases throughout the hydrocosm ultimately trace back to water needs – whether they're for prosaic technologies like slow sand filtration or cutting-edge ones like reverse osmosis. Executives and investors must understand when, where, and how rapidly these needs will rise in order to minimize risk and maximize profits. However, data is thin on the ground: Individual municipalities collect scrupulous statistics and make occasional projections of future water requirements, but global bodies like the United Nations Food and Agriculture Organization (U.N. FAO) focus on tracking instead of forward-looking projections, and forecasts based on sophisticated hydrological models like Goethe University's WaterGAP can be inscrutable.

To project future water needs, we built a stepwise, multivariate regression model at the country level, drawing on water usage and irrigation data from the U.N. FAO along with economic data from a wide variety of sources, including the U.N. Population Division, the OECD, and the World Bank. Summing up the country-level data from our model yields global results. We tested a broad set of variables that might potentially predict water needs – from straightforward ones like the total area of land under cultivation to more obscure ones like semiconductor manufacturing output – and used our regression model to determine whether each one accounted for a significant proportion of the variance in water usage between countries. We found that three variables predict water usage:

- **GDP: Every million dollars of GDP means about 22,000 m^3 of water.** GDP measured at fixed exchange rates strongly correlates with water usage (see Figure 2.4-1). For example, Japan's GDP in 2000 was 13 times bigger than that of the Netherlands, and its water usage was 11 times greater. These correlations hold well for countries that share a similar economic composition but not for those that don't – for example, Argentina and Sweden both had economies around $250 billion in 2000, but Argentina uses eight times as much water, largely because agriculture accounts for 10% of its economy as opposed to 2% in Sweden.

- **Irrigation: Every hectare of land irrigated means about 10,000 m^3 of water.** The area of land subject to full- or partial-control irrigation within a country also relates closely to its water usage, with a correlation only slightly less strong than that for GDP (see Figure 2.4-2). For example, Thailand irrigates about 13% more hectares of land than Indonesia and uses about 5% more water in total. Our calculated figures align well with empirical norms: While irrigation requirements vary from 2,000 m^3 per hectare to 20,000 m^3 per hectare, depending on soil characteristics and the type of crop planted, 10,000 m^3 per hectare is a typical average value.

- **Population: Every person means about 60 m^3 of water.** Each incremental person consumes a global average of 60 m^3 of water for personal needs like drinking, bathing, and toilet flushing, after the water used to make the goods people consume and the crops they eat is factored out. This correlation is far less strong than those for GDP and irrigation because these personal needs vary so widely between countries (see Figure 2.4-2): Average yearly household consumption of water in France stands at about 120 m^3, but the corresponding figure in a sub-Saharan African country like Namibia would be two orders of magnitude less.[6]

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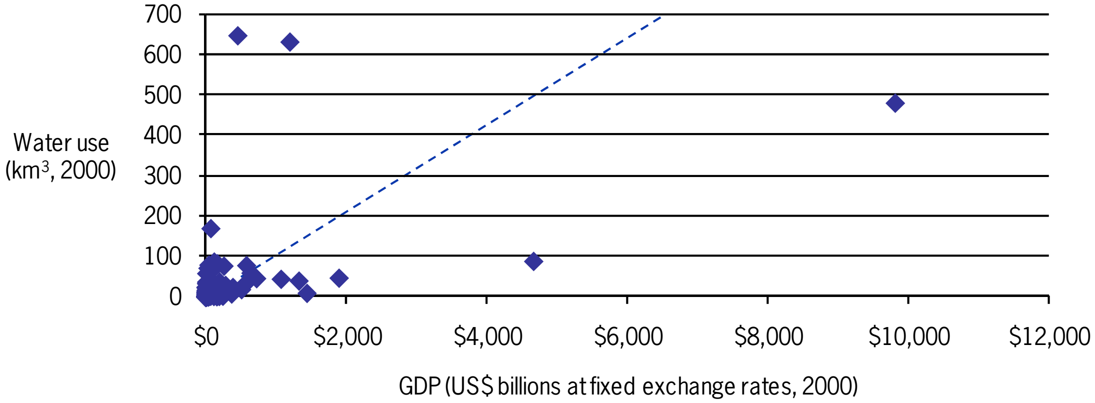
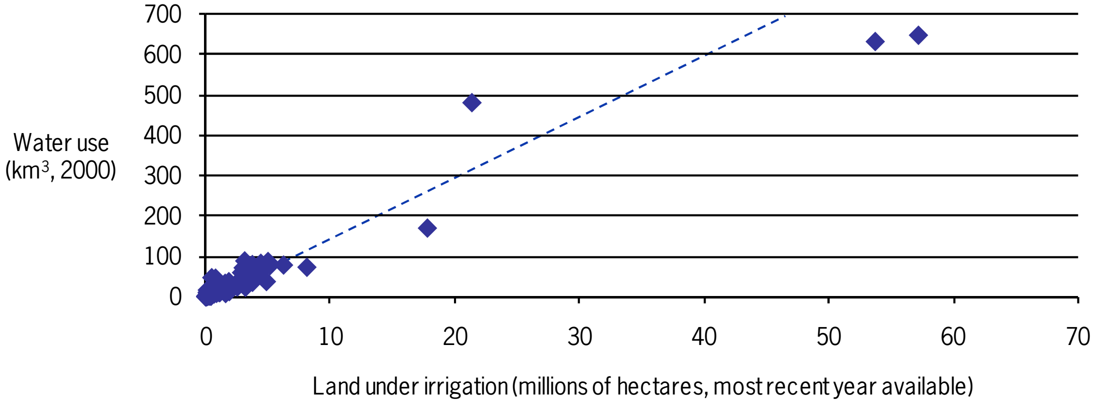
Fig. 2.4: Three Variables Predict Water Usage Across Countries

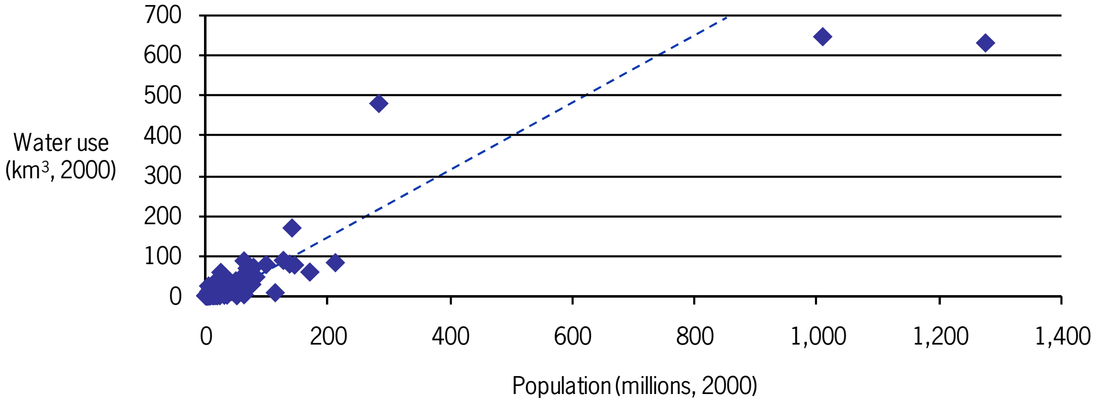
2.4-1: GDP correlates strongly with water use



2.4-2: Irrigated land correlates slightly less strongly than GDP



2.4-3: Population correlates more weakly with water use



Sources: International Monetary Fund (GDP), U.N. Food and Agriculture Organization (water use, land under irrigation), U.N. Population Division (population)

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Fig. 2.5: Water Use and Its Drivers, 1950, 2000, and 2030

Measure	1950	2000	2030
Global water use	1,480 km^3	3,840 km^3	5,817 km^3
CAGR from previous date	*N/A*	*1.9%*	*1.4%*
GDP (2000 US$, fixed exchange rates)	$13.3 billion	$26.7 billion	$63.0 billion
CAGR from previous date	*N/A*	*1.4%*	*2.9%*
Irrigated land (hectares)	110 million hectares	276 million hectares	351 million hectares
CAGR from previous date	*N/A*	*1.9%*	*0.8%*
Population	2.5 billion	6.1 billion	8.2 billion
CAGR from previous date	*N/A*	*1.8%*	*1.0%*

Sources: U.N. Food and Agriculture Organization (historical water use, irrigation), International Monetary Fund (GDP), U.N. Population Division (population)

These rules of thumb do a good job at predicting the water usage of large countries that have diversified economies and contain several different types of climates; generally, the smaller a country is, the more it deviates from these guidelines. It's important to note, however, that even countries with fairly similar climates and GDP per head can have significantly different levels of water usage because of extraneous factors, like the importance that public officials have placed on water conservation. For example, according to the factors above, Switzerland "should" use about 6.2 km^3 of water per year, or about 853 m^3 per capita – but in reality it uses less than half this amount, because it's been a pioneer in water efficiency measures like low-flow shower heads and toilets. In contrast, Canada's actual water usage of 46.0 km^3 is way above the 25.5 km^3 that it "should" use because water is plentiful in the country and Canada's resource-extractive industries use lots of it.

World Water Resources Will Stretch Thin as Requirements Grow 40% by 2030

When we fed our regression model with third-party growth forecasts of GDP, irrigated land, and population, we determined that world water requirements will increase from 4,166 km^3 last year to 5,817 km^3 in 2030 – 40% growth representing a 1.5% CAGR. This growth rate is lower than that seen in the last 50 years – which makes sense, because the annual growth expectations for irrigated land, and population that we relied on are lower for the next 30 years than the last 50, which contained the Green Revolution and the baby boom (see Figure 2.5). Water requirements will rise as (see Figure 2.6):

- **GDP nearly doubles in real terms, from $32 trillion to $63 trillion.** Consensus between International Monetary Fund and World Bank figures puts world GDP on track to grow 98% through 2030, reflecting a 3.0% CAGR (at fixed exchange rates in constant 2000 dollars). We project that increased water requirements arising from GDP will account for 60% of the total 1,651 km^3 increase in future water usage.

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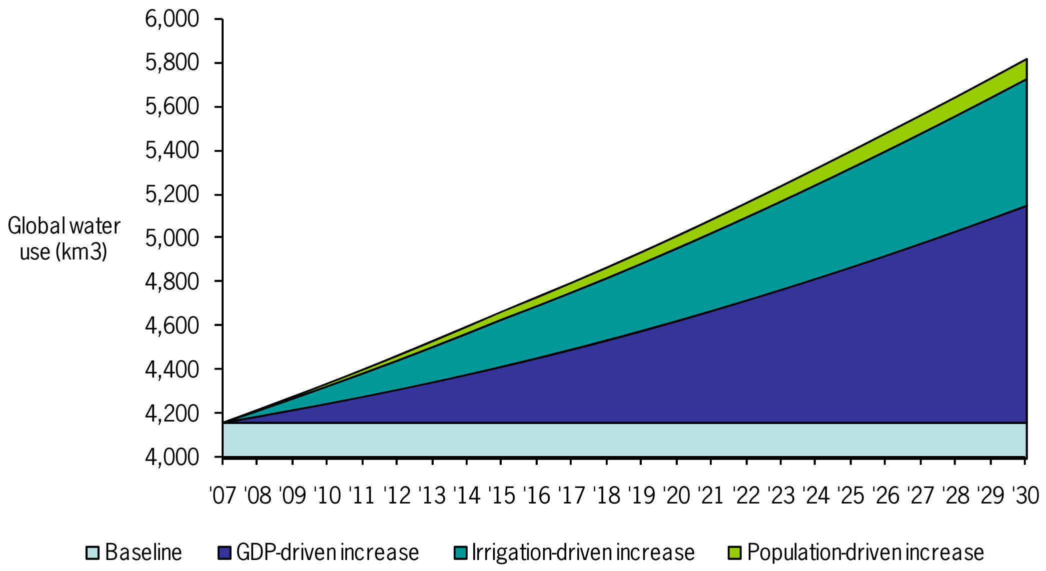
Fig. 2.6: Global Incremental Water Usage by Driver, 2007 to 2030



- **Irrigated land rises 20%, from 293 million hectares to 351 million hectares.** Figures from the U.N. FAO indicate that land under full- or partial-control irrigation will increase by 20% through 2030. Why so much slower growth than GDP? The answer lies with the observable fact that as people become wealthier, they spend a larger portion of their budgets on items other than food. Hence, irrigation generally grows only slowly – even in thirsty regions like sub-Saharan Africa. And since the most-irrigated regions like North America have slower irrigated land growth rates (around 0.5%), annual growth of irrigated land worldwide through 2030 will manage a CAGR of only 0.8%. Irrigation accounts for 35% of future incremental water usage in our projections.

- **Population rises 23%, from 6.7 billion to 8.2 billion.** U.N. Population Division statistics expect population growth to slow from about 1.4% per year today to 0.5% per year in two decades. Set apart from the goods that people use and the food they eat, water requirements driven by population alone amount to increases in personal use that sum up to 5% of our total projection.

China, the U.S., and India Pose the Greatest Incremental Need – and Potential Opportunity

Our top-level forecast is the sum of nearly 200 individual country-level projections. Looking at the data at the country level, we found that:

- **Asia will see the greatest increase in water need.** Of the incremental 1,651 km^3 of water required in 2030, east Asian countries will claim 27% – dominated by China, which will account for 20% of the entire world's additional requirement based on lower-than average population growth but continued rapid gains in irrigation and GDP. North America will claim 17% of incremental worldwide need, with 16% accounted for by the U.S., due almost entirely to economic expansion. South Asia will account for 16% of incremental demand, with 12% in

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Fig. 2.7: Incremental Water Use to 2030 by Region

Region	2007 water use (km^3)	2030 water use (km^3)	Increase (km^3)	Percent increase	Percent of world increase
East Asia	1,078	1,518	440	41%	26.6%
China only	*698*	*1,028*	*330*	*47%*	*20.0%*
North America	575	856	281	49%	17.0%
U.S. only	*526*	*788*	*263*	*50%*	*15.9%*
South Asia	992	1,263	271	27%	16.4%
India only	*700*	*903*	*203*	*29%*	*12.3%*
Near East and North Africa	355	499	144	40%	8.7%
Latin America and Caribbean	293	432	139	48%	8.4%
European Union	241	372	132	55%	8.0%
Sub-Saharan Africa	132	209	77	58%	4.7%
Commonwealth of Independent States	295	349	54	18%	3.3%
Eastern Europe and Former Yugoslavia	65	82	17	27%	1.1%
Oceania	30	47	17	58%	1.0%
Other Western Europe	6	12	5	83%	0.3%
Baltic states	1	2	1	110%	0.1%
Other	104	177	73	70%	4.4%
Total	**4,166**	**5,817**	**1,651**	**40%**	**100%**

India from rises in all three of our forecast variables. The remaining 40% of need will be widely distributed, with only the Middle East, Latin America, and Europe exceeding 5% share (see Figure 2.7). Multinationals with strong Asian footprints like Veolia are best positioned to benefit from this growth pattern, as are domestic suppliers of basic equipment such as India's Jain Irrigation Systems.

- **Newly industrialized countries lead other markets.** Hydrocosm participants will find 41% of incremental water required in 2030 in the nine "newly industrialized countries" of Brazil, China, India, Malaysia, Mexico, the Philippines, South Africa, Thailand, and Turkey, driven by a combination of economic expansion and increased irrigation. The world's 46 advanced economies like the U.S., Japan, and Western European nations will claim one-third of incremental need (based almost solely on GDP growth), with the remaining 26% in the world's more than 150 remaining emerging and developing countries due to increases in all three factors (see Figure 2.8). Investment funds aimed at transferring water technologies and business models from advanced economies to recently industrialized ones, such as London-based private equity fund Four Winds Capital Management, can exploit this growth pattern successfully.

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Fig. 2.8: Incremental Water Use to 2030 by Economy Type

Grouping of economies	2007 water use (km^3)	2030 water use (km^3)	Increase (km^3)	Percent increase	Percent of world increase
Advanced	1,005	1,550	545	54%	33%
Newly industrialized	1,744	2,423	679	39%	41%
Developing and emerging	1,417	1,844	427	30%	26%
Total	**4,166**	**5,817**	**1,651**	**40%**	**100%**

Pollution and Climate Change Could Drive Water Needs Still Higher

GDP, irrigation, and population accurately predict water requirements today – our regression analysis tells us that these three factors account for more than 98% of the variance in water needs between countries at present. However, in the next two decades other factors could become significant as well, potentially driving water needs even higher than our incremental 5,817 km^3 projection for 2030. While the list of potential factors is long, two – climate change and pollution – loom largest. Their potential combined impact could increase water requirements another 10% by 2030, leading to a worldwide water need in 2030 of 6,233 km^3 – 50% greater than today.

- **Climate change's chaotic effects could reduce current net available water by 5%.** Despite lots of academic study and much spilled ink by the Intergovernmental Panel on Climate Change, climate change's impact on water availability is poorly understood. What is known, however, is that the effect will be unpredictable from one region to the next. Some areas may have less water because of higher temperatures and lower rainfall (like in Northern Africa); others may see net available water decline for the opposite reasons, as increased storm activity and glacial runoff overwhelm placid water sources with turbid water flows (like in Scandinavia). Finally, many regions may see a net increase in available water due to a combination of minimal temperature change and sharply increased precipitation (like northern China). Overall, our ballpark estimate from current literature is that climate change could result in a net global decrease in water availability of up to 5%, by 2030, which would require a 208 km^3 "backfill" of supply.

- **Pollution could render another 5% of current water supply unusable.** U.N. figures put the total amount of waste dumped daily into rivers, lakes, and streams worldwide at more than two million tons.[7] This pollution, particularly from industrial activities like mining, can poison water resources indefinitely at a large scale: Witness Thailand's Nakhon Si Thammarat province, where years of mining led to groundwater arsenic levels 50 to 100 times higher than the World Health Organization's safe drinking values – and where authorities expect the contamination to last 30 to 50 years. The very industrial growth that drives water requirements in newly industrialized countries like China, India, and Thailand may itself make currently available water resources impractical to use, forcing unprecedented water transportation or reuse to meet needs instead. Based on current literature, we think the effect of pollution could match that of climate change,

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potentially rendering 5% of today's water supply unusable and yielding an additional 208 km^3 of incremental need to be met in 2030.

Endnotes

1 Source: U.N. Food and Agriculture Organization.

2 Source: U.N. Population Division.

3 Sources: OECD (water stress); Oxford Centre for Water Research (water poverty).

4 Source: U.N. Food and Agriculture Organization.

5 Source: U.S. Department of Energy.

6 Source: Agence de L'eau Artois-Picadie.

7 Source: U.N. World Water Development Report 2.

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6.3: Energy Mitigation

Both water and energy consumption are of global concern, driving development of innovative technologies capable of reducing energy lost during water treatment.

The Need

An intimate link exists between water and energy that, for the most part, goes unrealized. Conventional energy generation from nuclear, fossil fuel, and hydroelectric plants requires enormous amounts of water: The energy industry is second only to agriculture as the largest user of water in the world, accounting for 22% of freshwater withdrawals. Conversely, tremendous amounts of energy are required for the treatment and distribution of water. For example, the energy required for desalination of seawater using reverse osmosis (RO) can account for 40% of the operating costs. Hence, energy pressures negatively impact the price and availability of water, and vice versa.

New approaches to reduce the energy footprint of water treatment systems involve capturing waste energy throughout the treatment process and repurposing it to reduce net energy requirements. Innovative technologies include energy recovery devices in desalination plants, microbial fuel cells that feed off wastewater, and cogeneration plants co-located with wastewater treatment facilities. These technologies recapture or generate energy that can supplement the energy requirements of the water facilities or even help power the grid through net metering. While energy recovery technologies offer the opportunities to recapture significant a share of energy demanded by the RO process, microbial fuel cells have the ability to generate energy from what was once simply "flushed down the drain." As increasing energy prices drive up the operating costs for water treatment facilities, utilities will increasingly turn to these technologies to generate energy from what was once simply considered waste.

Opportunities

There are several methods that water facilities can harness to recover or even generate energy. Of the three key options that follow, two are experiencing widespread adoption today while the third is currently being developed by universities and start-ups (see Figure 6.3.1).

- **Energy recovery devices.** Reverse osmosis desalination plants require large amount of energy – between 1.6 kWh/ m^3 and 3.7 kWh/ m^3 – much of which is required to pressurize the brine solution to separate fresh water from salt ions. Energy recovery devices (ERDs) – such as Pelton turbines sold by Grundfos, hydraulic turbochargers sold by Pump Engineering, piston pressure exchangers developed by Calder, and rotary isobaric devices commercialized by Energy Recovery Inc. – extract the residual energy in the high-pressure RO effluent. Much as recuperators and turbochargers are used in heat engines, these recovery devices recycle much of the energy to pressurize the intake water. While energy performance is clearly a deciding factor in ERD

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Fig. 6.3.1: Three Opportunities in Energy Mitigation

1) Energy recovery devices

Proposition: Recover high pressures used to force water through reverse osmosis membranes to help operate the plant, reducing net operating cost

Key variations:
- Pelton turbines
- Hydraulic turbochargers
- Piston pressure exchanges
- Rotary isobaric devices

2) Microbial fuel cells

Proposition: Harness microorganisms that oxidize sugars in waste streams to generate electricity

Key components:
- Electrochemically active bacteria
- Fuel cell assembly
- Cation-specific membrane

3) Cogeneration systems

Proposition: Use anaerobic digestive bacteria to break down organic waste from wastewater effluent, producing a biogas suitable for energy generation

Key components:
- Anaerobic digestive bacteria

implementation, the choice of technology in a specific application depends on the cost and availability of electrical power at the desalination plant balanced with the capital cost of the system. While centrifugal ERDS (Pelton turbines and hydraulic turbochargers) are cheaper, more robust, and easier to maintain and operate, isobaric ERDs (piston pressure exchangers and rotary isobaric devices) deliver more constant performance and higher efficiencies.

Outlook: Well-positioned, with room to grow in large market. ERDs are quickly becoming essential to desalination operations concerned about increasing energy prices and interested in significantly reducing energy consumption and waste.

- **Microbial fuel cells.** Waste sludge represents a vast untapped source of potential energy. Microbial fuel cells (MFCs) offer a way to recover this energy from wastewater while limiting sludge production. MFCs function similar to conventional fuel cells, in that they generate an electrical current from a chemical fuel feedstock and consist of anode and cathode compartments separated by a cation-specific membrane. However, microbial fuel cells do not use hydrogen or methanol as a fuel; instead, they directly convert microbial metabolic or enzyme catalytic energy into electricity by using conventional electrochemical technology. MFCs utilize microorganismic biocatalysts (specifically, electrochemically active bacteria), which

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Energy Mitigation Opportunity Comparison					
Opportunity	**Description**	**Advantages**	**Disadvantages**	**Status**	**Momentum**
Energy recovery devices (ERDs)	Recover the pressures used to push water through RO membranes and convert it into a useful form that can mitigate some of the process's energy needs	Can recover energy with up to 98% efficiency; reduces costs associated with RO desalination process by up to 60%	Centrifugal ERDs are cheaper and easier to maintain but have less constant performance and lower efficiencies; isobaric ERDs represent the converse, and are susceptible to vibrations and pulsations	*Scale* – adoption rose from single digit percentage of new desalination plants in mid-1990s to more than 25% today	*Very high* – energy recovery is now a default element of the RO toolkit
Microbial fuel cells (MFCs)	MFCs utilize microorganismic biocatalysts, which metabolically break down molecules in the wastewater via an oxidation process, resulting in a release of chemical free energy which is converted into electrical energy	Biocatalysts are essentially free, robust, and can self repair making the setup of such facilities relatively inexpensive while at the same time offering tremendous potential in terms of energy production	Low current density and power outputs; costly membranes; sensitivity to breakdown and decay	*Lab* – most MFC acitivities currently lie in research universities	*Average* – Not currently used at any wastewater treatment facility; some small-scale industrial treatment pilots
Cogeneration systems	Cogeneration systems uses biogas produced by anaerobic digesters to run turbines and engines to produce energy while capturing and recycling heat produced	Can generate both electric and thermal energy on site, offsetting the costs of grid power and purchased fuel while reducing the emissions of greenhouse gases	CHP systems depend on anaerobic digesters which require significant technical expertise; high capital costs	*Scale* –for example, 10% of U.S. wastewater treatment plants use cogeneration systems	*High* – in line with increasing energy costs

metabolically break down molecules in the wastewater via an oxidation process, resulting in energetic electrons that are captured into useful electrical energy at the electrode.

Unlike conventional fuel cells, which rely on expensive catalysts, biocatalysts are essentially free, robust, and self-replicating, while at the same time offering tremendous potential in terms of energy recovery and production. However, since MFCs are still in the development stage, several hurdles must be overcome before commercialization, including low current density, costly membranes, and sensitivity to breakdown and decay. While several start-ups are currently commercializing MFCs – such as IntAct Labs, Hy-SyEnce., Lebônê, and Emefcy – they remain, for the most part, within the university domain with government and corporate grants providing the bulk of their backing.

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Energy Mitigation Key Companies				
Name	**Type**	**Holding status**	**Country**	**Comments**
Energy Recovery Inc.	Energy recovery	Public; small/mid-sized company	U.S.	The company's PX systems are installed in more than 300 desalination plants around the world, with revenues growing more than 700% from 2003 to 2007.
Calder	Energy recovery	Private; small/mid-sized company	Switzerland	Has produced both Pelton turbines and piston isobaric devices since 1980.
Emefcy	Microbial fuel cell	Private; start-up	Israel	Uses Shewanella oneidensis and Rhodoferax bacteria capable of producing 1 kWh of electricity per kg of organic waste.

Energy Mitigation Key Venture Capital Transactions					
Company	**Deal size (US$ millions)**	**Date**	**Country**	**Round**	**Total VC funding (1998-2008; US$ millions)**
Emefcy	$5	1/1/2007	Israel	Seed/Series A	$5

Energy Mitigation Key M&A/IPO Events					
Company	**Deal size (US$ millions)**	**Date**	**Country**	**Type**	**Acquiring company or ticker**
Energy Recovery Inc.	$63.86	7/2/2008	U.S.	IPO	NASDAQ:ERII

Outlook: Early stage with significant potential. As of today, MFCs remain somewhat of a scientific curiosity because of their limited efficiency and power output, requiring a great deal of research and development to scale up. Nevertheless, MFCs undoubtedly have the potential to transform waste into a valuable energy source and decrease the costs for additional wastewater treatment. Increased voltages, currents, and power outputs may enhance the potential of MFCs as a valuable energy recovery technology, allowing them to occupy a market niche in terms of a stand-alone power source and also in the direct treatment of wastewater. For the next decade, however, we see their adoption limited to industrial environments like breweries that have optimal conditions for MFC output.

- **Cogeneration systems.** Anaerobic digestion, a widely-used wastewater treatment process, employs microorganisms to break down organic waste in the absence of oxygen. In the process, it produces a methane- and carbon-dioxide-rich biogas suitable for energy production. The biogas can fuel turbines, microturbines, fuel cells, or reciprocating engines to generate electricity and power, while the waste heat can be recaptured to meet heating demands such as

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maintaining optimal digester temperatures. A cogeneration system enables a wastewater treatment facility to generate both electric and thermal energy on site, offsetting the costs of grid power and purchased fuel while reducing the emissions of greenhouse gases. However, while cogeneration systems are highly efficient, the technical expertise required to maintain anaerobic digesters, coupled with high capital costs and lower process efficiencies, have to date limited the level of its industrial application as a waste treatment technology.

Outlook: Obvious benefits; growth depends on increased adoption of anaerobic digesters. Currently in widespread use, cogeneration systems provide critical power and thermal reliability for wastewater treatment plants by producing power and heat while reducing operating and maintenance costs and improving environmental performance. While less than 10% of treatment plants currently employ cogeneration, as anaerobic digesters become more commonplace, more utilities will implement these systems.

Conclusions

The tremendous energy costs required at water and wastewater treatment facilities – 56 billion kWh costing $4 billion in the U.S. alone – comprise a significant share of operating cost, so utilities are always on the lookout for ways of increasing energy efficiency.[1] As a result, utilities are increasingly adopting the use of systems like energy recovery and cogeneration because they offer utilities the ability to drastically increase energy efficiency and potentially provide the ability to become energy independent. Expect demand and usage for these technologies to increase as utilities increasingly worry about energy costs and environmental impact.

Endnotes

1 Source: U.S. Environmental Protection Agency.

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