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News & Highlights

Increasing Threat of Scarcity Prompts Rise in Water Recycling

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In January 2018, construction wrapped on Salesforce Tower (Fig. 1), a 61-story office building that now dominates the skyline of San Francisco, CA, USA. In addition to being the tallest building in the city, Salesforce Tower is the largest structure in the world with an onsite water recycling system. Built by the Australian company Aquacell (Milton, NSW, Australia), the system cleans 113 m^3 of sewage, sink, shower, and other wastewater each day for use in irrigation and flushing toilets, saving an estimated 35 000 m^3 of water annually [1]. The building is just one of dozens in San Francisco outfitted with their own water recycling systems, thanks to a city mandate enacted in 2015 [1].

While the city of San Francisco is on the vanguard of onsite water recycling, record-setting droughts and increasing demand for water are prompting communities across the globe to embrace water recycling at a variety of scales. Centralized, regional systems such as those in Singapore and Orange County (CA, USA), are recycling water at the rate of hundreds of thousands of cubic meters per day, while smaller systems are enabling individual buildings—including homes—to engage in onsite recycling, greatly reducing the use of city water supplies and sewers, in a way analogous to how solar panels and batteries allow some structures to draw less power from the electrical grid.

"Everyone is having to get creative about how to be more efficient with their use of water," said Katherine Jashinski, supervising engineer for the onsite water reuse program in Austin, TX, USA. "Reuse is just inevitable."

A recent study found that more than half the world's lakes have lost significant water volume over the last 30 years [2]. By 2050, the United Nations estimates that five billion people could experience water shortages [3]. "Increasingly, two forces are driving water scarcity in cities: population growth and climate change," said David Sedlak, professor of civil and environmental engineering at the University of California, Berkeley, and author of the book *Water for All, Global Solutions for a Changing Climate* (Yale University Press, 2023). "When local water resources become inadequate for growing cities, they will have to start importing water. And as certain regions become more arid and have longer periods of drought, those imported water sources will be under increasing strain, forcing us to find ways to make existing water resources go further."

Water recycling typically entails disinfecting and filtering wastewater to remove waterborne pathogens, then filtering it again to remove solids and trace contaminants. Wastewater comes in two forms: blackwater, from toilets, dishwashers, and kitchen sinks; and greywater, from washing machines, showers, and bathtubs. Recycling greywater alone can save substantial amounts of water. Using it to flush toilets and wash clothes reduces demand for new water by about 40% [1]. Using recycled water for showers would eliminate another 20% of demand for new water [1].

Orange County, CA, USA, runs one of the world's largest water recycling facilities. The operation cleans 100% of the county's water—500 000 m^3 of blackwater a day—in a process called indirect

Fig. 1. With a height of 326 m, Salesforce Tower is the tallest building in San Francisco, CA, USA. It also features the world's largest onsite water recycling system in a commercial high-rise building. The system collects water from rooftop rainwater, cooling towers, showers, sinks, and toilets, and treats it for reuse, including in toilets and drip irrigation systems. Overall, the system reduces the building's new water consumption by 76%. Credit: Dead.rabbit (CC BY-SA 4.0).

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potable reuse [4]. Highly treated wastewater, normally discharged into the ocean, is put through an advanced three-step purification process that includes micro-filtration, reverse osmosis, and disinfection with ultraviolet light and hydrogen peroxide. The output is injected into nearby groundwater, and later treated to drinking-water standards by local utilities [1].

Though only about two dozen communities in the United States use some form of recycled water for drinking, that number is projected to more than double in the next 15 years. Supporting this transition is an infrastructure bill passed by the US Congress in 2021 that includes 1 billion USD for water reuse projects in the western United States [5].

Among the largest water recycling endeavors under development in the United States is in southern California. The project, costing an estimated 3.4 billion USD, could produce enough recycled water to supply 500 000 homes, according to the Metropolitan Water District of Southern California, which serves 19 million people in Los Angeles, CA, USA, and surrounding counties [6]. Another city in a precarious water-supply situation, Phoenix, AZ, USA, plans to open a multibillion-dollar purification facility to recycle 227 000 m^3 of wastewater per day into drinking water—enough for 200 000 households—by the end of the decade [7]. The move will diversify its water sources and lessen the city's dependence on the shrinking Colorado River.

On the island nation of Singapore, which has few natural water sources and wants greater control over its water supply, the massive Changi Water Reclamation Plant cleans and purifies 1×10^6 m^3 of wastewater a day to potable standards [8]. However, most of the water, branded "NEWater," is used in the country's heavily water-dependent microchip manufacturing sector.

While water recycling, as occurs in Orange County and Singapore, has been centralized for decades, onsite or "premise" recycling is now emerging as an important strategy to make water use more sustainable. Premise recycling not only saves water, but it can also save the cost of pumping water over long distances and the costs associated with digging up streets to install and replace pipelines. Eventually, it is hoped that buildings outfitted with premise recycling systems, along with rainwater and air conditioning catchment, may no longer need to hook up to central water infrastructure such as sewer lines and water supplies, simply by reusing the same water over and over in a closed loop. However, some municipalities require backup connections to central water infrastructure for instances when onsite systems need maintenance or repair.

That future is already here, in San Francisco at least. The city's 2015 mandate required that all new buildings larger than 18 580 m^2 have onsite recycling systems. In 2022, the requirement expanded to all new buildings larger than 9290 m^2 [9]. The program is purposefully designed to promote a gradual change to water recycling, avoiding expensive retrofits of existing buildings that would involve opening walls and redoing the piping. The San Francisco Public Utilities Commission estimates that there are 48 reuse systems in operation and 29 more projects being planned in the city. By 2040, the agency says, its Onsite Water Reuse program will save 5000 m^3 of potable water daily [1].

"I live in San Francisco, and I think this policy ordinance has worked very well," said Newsha Ajami, chief development officer for research at the earth and environmental sciences area at Lawrence Berkeley National Laboratory and a water expert. "A lot of the high-density buildup in San Francisco happens in the downtown area, where land is scarce and not cheap. Economically, it is better to let people do onsite reuse rather than trying to build a centralized water recycling system offsite. Ultimately, the only way we can push this forward is through policy change."

Ajami also pointed out a commonly cited economic advantage of premise recycling. "Sending water from your home to the wastewater treatment plants and back has a huge energy footprint," she said. "When you do it onsite, you use far less energy."

Leading by example, the headquarters of the San Francisco Public Utilities Commission has a blackwater system called the Living Machine that treats its 20 m^3 of wastewater per day in engineered wetlands built into the sidewalks around the building. The reclaimed water is also used to flush low-flow toilets and urinals. The process reduces the building's imported potable supply by 65% [10].

Among the industry's largest providers of premise recycling systems is San Francisco-based Epic Cleantec. The company has designed a system called OneWater that it claims can treat up to 95% of a building's wastewater. Named one of the Best Inventions of 2022 by *Time* magazine [11], OneWater will treat 113 m^3 of blackwater per day for the Park Habitat office building under construction in San Jose, CA, USA [3], some of which will irrigate a living green wall on the tower's 20-story exterior. The system collects water from rain, cooling towers, showers, toilets, and sinks, then circulates it through a multistep treatment process in the basement. The solids are separated, sterilized, and turned into a soil amendment.

In Austin, TX, USA, where the number of water customers is projected to quadruple in the next 100 years, the city has been offering up to 500 000 USD incentives for developers to install reuse systems [12]. As of April 2024, the city will require new commercial and multi-family developments of 23 225 m^2 or more to have onsite water reuse systems [13]. Similar requirements have recently been mandated in Sacramento, CA, USA [14].

New York City, NY, USA, has also implemented an incentive program that provides commercial, industrial, and multi-family residential property owners a 25% discount on water bills for installing fixture retrofits and other water efficiency technologies, such as onsite water reuse systems [12]. The city's Domino Sugar Refinery redevelopment project, currently under construction on the Brooklyn waterfront, will recycle 1500 m^3 of blackwater a day, enough to take all five buildings in the development off the city's sewer system and reroute any excess clean water into a nearby river [12].

On a smaller scale, home-based water recycling technology has begun to hit the market. The Hydraloop (Fig. 2), created by Hydraloop Systems (Leeuwarden, the Netherlands), received a Consumer Electronics Show Innovation Award in 2020 [15]. The device recycles up to 95% of a household's water, disinfecting water from showers and washing machines to irrigate lawns, flush toilets, and fill swimming pools. And RainStick, a company in Vancouver, Canada, makes a system, named one of *Time* magazine's Best Inventions of 2023 [16], that recycles shower water over and over while you shower.

"Water reuse can and should happen at every scale: home, building, or neighborhood," Ajami said. "Currently, return on investment for individual homes is low because water is still inexpensive, but for public utilities, the return on investment is not about saving money but rather achieving reliability across the system. It is an extra cost, but it is a way of diversifying your water supply."

Ajami said that effective water-recycling technologies already exist, but there are plenty of opportunities to build tools and technologies that can help utilities operate satellite systems and connect them to centralized systems. Sedlak added that there is also a need to develop sensors and actuators to ensure the systems operate safely.

Challenges preventing wider adoption of water reuse center around regulation and infrastructure. "The regulatory system is just not set up for this, and the public health officers who write permits are unfamiliar with the technology," Sedlak said. The lessons offered by the high-tech buildings rising in San Francisco should drive down costs, increase reliability, and make permit writers more comfortable, he added. "What is being learned in San Francisco has the potential not only for wealthy water-stressed

Fig. 2. Packed behind the Hydraloop's concealing faceplate (left) is a system (right) capable of recycling 0.2 m^3 of water per day. The system, which costs 1995 USD, removes dirt, soap, and other pollution from greywater without the use of filters, membranes, or chemicals. Flushed water is piped up to the top of the treatment tank on the right, then travels down to be treated with six different technologies: sedimentation, floatation, dissolved air floatation, foam fractionation, an aerobic bioreactor, and disinfection of the cleaned water with powerful ultraviolet light. Waste is piped into the sewer. A pump under the tank redistributes the treated water for reuse, including in toilets and washing machines. Credit: Hydraloop Systems (public domain).

cities but could also help us imagine a different future for rapidly growing cities in Africa and Asia with buildings designed to include onsite water recycling from day one."

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