Supporting Information for:

A New Planning and Design Paradigm to Achieve Sustainable Resource Recovery from Wastewater

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Tables

Table S1. Proposed *Guiding Principles* for the design of sustainable resource recovery systems (RRS) applied to water. Inspired by (*1*).

Category	Characteristics of a Sustainable RRS	Related Discussions from the Water, Wastewater, and Sustainability Literature
environmental	will not generate waste	(*2*, *3*)
	will be net energy positive or neutral	(*4-8*)
	will not deplete water resources nor alter natural hydrological processes	(*9-12*)
	will achieve responsible nutrient management and contribute to soil fertility	(*2*, *10*, *13-16*)
	will not consume non-renewable or non-recoverable resources	(*3*)
	will not contribute to global warming	(*8*, *17-19*)
ecological	will not diminish ecosystem health	(*9-12*)
	will not reduce biodiversity nor threaten individual species	(*10*, *11*, *20*, *21*)
economic	will have lifecycle costs that are affordable to all stakeholders	(*22-26*)
	will contribute to the economic development of the municipality and beyond	(*24*, *25*)
social	will provide access to safe drinking water and appropriate sanitation for all	(*27*, *28*)
	will protect public health	(*24*, *27*)
	will be understood and accepted by all stakeholders	(*22*, *29-31*)
	will not disproportionately impact a segment of the population	(*1*, *32*)
	will apportion costs equitably and in proportion to benefits received	(*1*, *26*, *33*)
functional	will be flexible and adaptable	(*24*, *34*, *35*)
	will be reliable and resilient	(*9*, *34*, *36*)
	will be manageable and safe for operational staff	(*25*)

Note: A discussion of competing factors at various spatial scales (e.g., household objectives and external influences versus city objectives and external influences) can be found elsewhere (*24*, *37*). It is important to note that the Guiding Principles identified in Table S1 are an idealized set of goals for resource recovery systems, and will not all be achieved simultaneously by a given project. Instead, they are meant to do exactly what their name indicates – *guide* stakeholders as they undergo the process of elucidating their own locality- and project-specific definition of sustainability and identification of specific sustainability targets (see (*38*) for a discussion of sustainability *goals* and *targets*)**.**

Table S2: Challenges for and future technologies in resource recovery systems (RRS).

Challenge	Current Technology	Technology of the Future
energy and climate	• In 2000 the energy required to treat and convey drinking water in the U.S. had a typical range of 0.37 kWh/m^3 and 0.48 kWh/m^3 for surface and groundwater freshwater sources, respectively (*39*). In Southern California, these values are up to 10× higher because of energy requirements for source water conveyance (*40*). • Typical range for wastewater treatment energy requirements is 30-105 kWh per person-equivalent per year (*6, 19, 41, 42*). Aeration accounts for roughly half of on-site electricity consumption (*41, 43, 44*). • Of the total U.S. greenhouse gas emissions in 2007 (7,150 Tg CO_2 equivalents), 15.8 Tg CO_2 equivalents (eq.) were associated with CH_4 production and 4.9* Tg CO_2 eq. were associated with NO_2 production from domestic wastewater treatment (data from (*45*)).	• Water reuse and urban green design will minimize the conveyance of water by matching the geographic location of supply with the location of demand. Indirect potable reuse will be utilized to minimize the transportation of water between watersheds. • Wastewater treatment will be achieved using energy recovery technologies (e.g., methane- and biofuel-generating treatments, microbial fuel cells) with reduced reliance on energy-intensive aeration. Decentralized wastewater management will facilitate heat energy recovery. • The water industry will not be a major contributor of greenhouse gas emissions globally as systems approach energy neutrality and minimize fugitive emissions (e.g., CH_4 and N_2O) during both conveyance and treatment.
water	• Water is treated to potable quality (regardless of end-use) and distributed from central locations to support one-time use. • Recent estimates suggest roughly 0.6% of non-agricultural water consumption is reused in Europe (*46*) and 7.4% of wastewater is reused in the U.S. (*47*). • Pathogen removal is primarily based on indicator organisms specific to the end-use (e.g., for drinking water – total coliform; for wastewater effluent – total coliform, fecal coliform, and MS2 coliphage) (*43*).	• Direct non-potable reuse will be achieved in water stressed regions using decentralized infrastructure. Water and wastewater infrastructure will be adaptable to achieve indirect or direct water reuse as climate change increases the prevalence of drought-prone regions. • The level of water treatment will match end-use requirements. • Culture-independent detection methods will allow for rapid and comprehensive monitoring of indicator organisms and emerging pathogens. • Address emerging chemicals of concern (e.g., pharmaceuticals) through technology implementation and upstream management (reduced use, source control).
nutrients and materials	• Nutrient management strategies in the wastewater industry are based primarily on removal to minimize impacts on receiving bodies of water. • Nitrogen in wastewater is oxidized aerobically and, where required, removed as dinitrogen gas (often with the addition of an exogenous electron donor). Phosphorus is chemically precipitated and land-filled or captured biologically and land-filled or land-applied. Land-application of enhanced biological phosphorus removal biosolids reduces allowable application rates and economic viability of the practice (*6*).	• Nutrient management strategies will focus on opportunities for recovery and reuse. • Integrated water management systems will decouple the water and nutrient metabolisms of cities to enhance the aquatic environment and assist food production (*11*). • Source-separation of waste streams (including urine) will allow for efficient recovery of nutrients (*48*) and will reduce the need for nitrification and denitrification at the wastewater treatment plant (*49*). • Bioelectrochemical systems (BES) may be utilized for the production of high-value products during wastewater treatment (*50*).

*****EPA estimates for N_2O production during domestic wastewater treatment are based on data from a wastewater treatment plant that did not perform nitrification or denitrification (*51*). N_2O production would likely be significantly higher for biological nutrient removal processes.

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