doi: 10.2166/9781780409566

Outlook for the carbon-negative circular water economy

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My first public statement concerning the recovery of resources from the used (waste) water stream was an editorial I published in *Water Environment Research* in 1998 [1]. My first set of formal presentations was in 2001 when I was the American Academy of Environmental Engineers (now American Academy of Environmental Engineers and Scientists, AAEES) Kappe Lecturer. I visited about a dozen universities during the year of service to this lectureship, and one of the lectures I offered was titled 'The Future of Wastewater Treatment'. In it I presented a vision of wastewater treatment plants as 'factories' harvesting water, energy, nutrients, and other material from the used water stream. Examples of treatment systems where this was already happening were also offered. I relate this, not to suggest that I am prescient, but to simply indicate that I have been thinking this way for a long time. I was at least partially helped along by the fact that I grew up on a farm. On a farm the total focus is on creating useful products out of nature. By the way, it was a pig farm, so I had quite an early introduction to the business end of waste management!

So, let me suggest that, rather than asking 'why should we extract resources from the used water stream?', the truly relevant question is 'since we can extract useful products out of the used water stream, why wouldn't we?'. Assuming we can extract them practically, and at a cost that is at least partially compensated by the value of the product, why not produce the inherent value created by their production? I have never seen a reason why we would not create as much value for society as we reasonably can. We have actually been doing this as a profession for decades. Water reuse is a long-standing practice, with a history that goes back into at least the 1950s and much earlier if one considers historic practices in some cultures. Anaerobic digestion and biogas utilization to produce heat and electricity is also quite a long-standing practice. In fact, through the 1960s there were quite a number of plants that were energy self-sufficient based on this practice. This was possible because effluent discharge standards were not as strict as they are today. Consequently, liquid stream treatment often progressed to the point that electricity produced from biogas could sustain it. Recycling of nutrients and organic matter through biosolids reuse is also quite a long-standing practice. When I was new to the profession I heard plenty of stories about how people lined up to take digested and dried biosolids from sand drying beds because it was such an excellent fertilizer.

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So, what is different today? For one thing, effluent discharge standards have become much stricter, and compliance is more strictly enforced. Financial support for treatment used to be much more problematic than today, so the priority was to keep operating costs low (e.g. by producing all the energy needed for treatment), and plants did the best they could in terms of effluent quality given these financial constraints. The establishment of specific discharge standards and their strict enforcement (resulting from passage and enforcement of the Clean Water Act in the U.S. and similar legislation elsewhere) reversed this. The first priority today is compliance with effluent discharge standards, mandating the provision of sufficient resources to do the job. A combination of factors in the 1970s and 1980s also led to a decline in the practice of anaerobic digestion (which was quite popular before that), including enthusiasm for new technologies, the procedures established for economic analysis to receive Clean Water Act funding, and poor industrial waste control practices at the time. Sometimes the old practices return, and this has happened in the U.S. where anaerobic digestion has returned as a preferred biosolids stabilization technology.

Another difference between the time prior to the 1970s and today is that, at least in the developed countries, we are financially much wealthier than we were in the 1960s and earlier. It may not ‘feel’ this way to many, but by every objective measure we are wealthier. While we have greater financial wealth, and corresponding freedom in terms of the actions we can take, we are increasingly resource constrained. Our use of renewable resources (including water) exceeds the rate at which these resources can be renewed naturally, and we are consuming non-renewable resources at alarming rates. There is also the issue of climate change. While the population of the developed countries has roughly stabilized, population growth is continuing in the developing countries and living standards are increasing in many of these countries. Thus, demand continues to grow while supplies shrink, as long as we continue to live the way we do. This shortfall between resource availability and our current rate of consumption means that we have no choice but to change. We have to use our available resources much more efficiently (become much more resource-efficient), and it will be better if we do so by choice rather than be forced to do so by scarcity. I am convinced that we have sufficient resources to allow all humans on earth to lead enriching and productive lives. To do so we will have to use our available resources (including water) much more efficiently, including a dramatically increased rate of recycling and reuse. The good news is that, since our current and growing resource constraints are human-made, we have the means to correct the situation.

This brings us back to the water cycle. The planet’s renewable fresh water supply is already fully allocated (and in some instances over-allocated), while water demands continue to increase. The only available means to meet the growing demand are conservation and reuse. The most valuable resource in used water is the water itself. The practice of water reuse is already well established, and it is increasing rapidly in water-short locations around the planet. There are few constraints on dramatic acceleration of this practice, except for the limiting quantity of used water in some locations. Water reuse is already the norm (as compared to treatment and discharge) in many water-short locations, and this will become quite common as more than half the human population faces water scarcity in the not too distant future.

What about other resources in the used water stream? Practices for recycling some resources are already well-established, and new technologies are developing. We can expect resource recovery to increase, not only in quantity but also in the specific resources recovered as scarcity created by resource constraints drives increased prices and opens up opportunities for alternate sources of certain materials. Resource recovery is also a strategic issue for utilities as, unless the residual resources in the used water stream are recovered as valuable products, they remain as wastes that must be disposed of. Utilities are better positioned to continue operation if they are producing products that have a market, rather than wastes that many will oppose. Thus, the strategic advantage of resource recovery is that it can garner public support for the utility to continue necessary operations. This offers intrinsic value to the utility, even if revenue from reuse of the resources does not fully cover the cost of production.

Returning to my farming days, the old saying about a slaughter-house was that 'all parts of the pig are used, except the squeal!'. Why would we not do the same for used water?

Resource recovery is achieved by implementing a combination of separations and conversions. In this regard, one wonders why we begin by combining all of the sources of used water into a single stream. The historic answer, of course, is to minimize the piping network given that we were transporting all of the used water from the metropolitan area to a single or a small number of quite large processing facilities (which we historically called treatment plants). So, we save on infrastructure in a centralized configuration, but at the cost of making separation and recovery more difficult. What if we distribute processing more throughout the service area and, thereby, make the piping infrastructure needed to keep individual streams separate less burdensome? At the household and commercial building scale, we can easily think about keeping blackwater, yellow water, and greywater separate. Blackwater (containing feces and kitchen waste) accounts for much of the carbon in used water, yellow water (urine) contains much of the nutrients, and greywater (water used for washing clothes, ourselves, and other things) represents the stream from which much of the actual water content of used water originates. This approach is typically referred to as source separation, which is a misnomer in that the sources originate separately. We could, more accurately, refer to this as 'maintaining separation'.

Resource recovery is inherently enabled with an approach like this, as we avoid difficult separations required when we mix these sources. This approach also allows us to optimize the scale where we apply various separations and conversions, minimizing the transport of the heavier components of used water and optimizing the size of individual treatment facilities relative to their economies of scale. Water represents the largest mass in the used water stream. By separating greywater this less contaminated water can be aggregated from a small subset of the urban population and treated economically using less chemical- and energy-intensive approaches to produce fit-for-purpose product water closer to locations of demand. Water reuse is thereby enabled by a distributed system of greywater treatment and fit-for-purpose water production facilities. Because of their much lower mass, blackwater and yellowwater can be conveyed to more centralized facilities for processing. Greywater treatment technologies are well established and their economies of scale are well known. For example, the attractive size from an economy of scale perspective for greywater treatment may be around 20 000–50 000 PE, while effective sizes are likely different for for blackwater and yellow water processing. Hybrid combined distributed and centralized systems of this type represents one of my visions of the future.

Current practice is to extract nutrients, energy, and water (NEW) from the used water stream. Water is, and will likely continue to be, the most valuable resource in the used water stream and will continue to be recovered. The recovery of nutrients (nitrogen, phosphorus, and also ideally potassium) is also likely to continue. The changing energy picture may refocus us from converting carbon into energy and, instead, recover it as feedstock into the production of carbon-based materials. Declining costs for renewables (solar, wind) are making policy discussions about continued use of fossil fuels for energy production moot. We currently need carbon-based energy production as a component of the energy system because of its ability to turn on and turn off in response to demand (meet peak demands). How long will this persist, and will this function be replaced by dramatically improved battery technology? We shall see. Even if carbon-based energy production remains as part of the energy mix, the market may yet intercede as the higher value of some carbon-based products may make conversion of carbon collected from used water into such products economically more attractive than conversion to energy. Again, we shall see. The key point is that we must be more flexible in the products we produce to adjust to varying market conditions, not only in the future but even today.

Producing commercially viable products requires meeting product specifications, in sufficient quantities, according to the scheduled needs of the consumer, and with necessary marketing and distribution channels. The water profession knows how to do this for water (our core business), but we are not particularly good at this for other products. The products that can be produced from used water also depend on the quantity of raw materials (what we have traditionally called COD, BOD_5, TN, TP, etc.). Thus, while product quality is under our control, quantity and timing is not. While individual utilities can produce product, there may be the need for commercial entities (public or private, for-profit or non-profit) that aggregate products from several utilities and provide logistics, marketing, and distribution to the customer. There are actually many examples in the commercial world. My brother is a family farmer running a dairy farm and is in business because entities like this make the milk that he produces commercially viable.

When might all this come to pass? The answer is that it is already happening. Thus, it is a matter of scaling up and continuing to evolve. I have always been impatient when I see solutions, especially those needed as badly as these. This will all certainly be 'old hat' by the end of the 21st century, but I am hopeful that the transition will be well underway by the middle of the century. This represents the first major re-invention of our profession in the past hundred years or so, and I am hopeful that it will occur in my lifetime. I am also envious of those coming into the profession at this time. I know that they will find inventing this new future to be an exciting and enriching endeavor. I do hope, however, that they will come to know the past as I have so that we can build on what we have learned and avoid the mistakes of the past. But, what a glorious future we have in front of us!

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doi: 10.2166/9781780409566

Hastening the arrival of the resource recovering water future

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Over the past decade, water technologists have put forward the idea that wastewater is an outmoded concept [1–6]. Following up on the observation that sewage contains valuable resources that are not being recovered, these pioneers have been building bench-top and pilot-scale prototypes of treatment plants capable of obtaining energy, clean water, nutrients and minerals from municipal and industrial wastewater. In several cases, resource recovery has been realized in full-scale resource recovery plants that produce recycled water, fertilizer and electricity from wastewater [7]. Despite these achievements and the strong advocacy of leading members of the water research community, design engineers and decision-makers in most parts of the world have been slow to embrace resource recovery by investing in this new concept [4, 8].

The apparent disconnect between the advocates of resource recovery and those responsible for designing, building and operating urban water infrastructure raises questions about whether or not the resource recovery future will ever arrive. By considering the forces that shape current investments in urban water infrastructure and the ways in which water institutions have changed in the past in response to various challenges and opportunities, we can gain insight into the best ways to assure that the resource recovering future will arrive.

When attempting to predict future changes in any type of infrastructure, it is important to recognize that the adoption of new technologies usually depends upon forces unrelated to engineering design and process performance. Factors such as the rate at which equipment is normally replaced, the size and competitiveness of the market for the new technology and the nature of the institutions responsible for managing and regulating the infrastructure are critical to change in every technological endeavor [9]. One of the most important factors influencing technology adoption is the nature of the industrial sector.

At one extreme, the telecommunications sector undergoes rapid change. In this sector, innovative technologies are rapidly adopted because most of the necessary equipment has a lifespan of less than a decade and equipment manufacturers and service providers gain advantages that translate into large profits from modest advances. Change comes more slowly to the infrastructure involved in electricity production because existing infrastructure (e.g. oil refineries, pipelines, power plants) has lifetimes of several decades and the market is subject to considerable government regulation. Wastewater

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Table 17.1 Representative technologies in telecommunications, energy and wastewater treatment from 1990 to 2050.

Sector	Sectorial Nature	1990s	2020	2050
Telecommunications	Rapid replacement; competition	Landlines, modem	Wireless, fiber optic	Internet-of-things
Electricity production	Longer lifetimes; private and public	Coal, oil, nuclear	Distributed solar, windfarms	Decarbonization, battery storage
Wastewater treatment (nutrients)	Slow renewal; public ownership	Biological nutrient removal, biosolids	Annamox, struvite recovery	Anaerobic N&P recovery
Wastewater treatment (water reuse)	Slow renewal; public ownership	Non-potable reuse; agric., industry	Centralized potable reuse	Building-scale potable reuse

infrastructure is even slower when it comes to embracing new technologies because the useful lifetime for this infrastructure is often half a century or more [10]. Furthermore, the potential risks to public health and the environment from mismanagement of water systems have led to public ownership and extensive government regulation.

To illustrate the importance of the industry sector to the rate of adoption of new technologies, consider the period from 1990 to 2050 (Table 17.1). Since 1990, the telecommunications industry evolved from wired to wireless communication. On the basis of current investments, it seems likely that the wireless revolution will soon see more innovation and investment as it transitions to the internet-of-things [11]. Since 1990, electricity generation infrastructure also has undergone substantial change in response to efforts related to public policies to curb the release of greenhouse gases. As a result, we can expect continued expansion of wind and solar power generation along with greater availability of energy storage systems (e.g. batteries) over the next three decades. In contrast, progress towards recovery of resources from wastewater since 1990 has been modest, with advances largely confined to a small number of locations populated by early adopters of new technologies. Using current trajectories, we can expect that a handful of new resource recovery technologies will progress to the full scale over the next three decades and that more efficient processes will be invented, but few wastewater facilities will look substantially different from the systems that existed in 1990. Thus, without more effective coordination and collaboration, the resource recovering water future may not arrive in many places prior to 2050.

Environmental engineers interested in seeing the widespread adoption of resource recovery from wastewater during their professional careers need to understand the ways in which infrastructure investments are made, the attributes that appeal to decision-makers use this knowledge to develop their technologies and introduce them into practice.

Under most conditions, change comes to urban water systems because design engineers and their clients choose technologies that offer perceived social, environmental or financial benefits. But these advantages alone may not be enough. The people responsible for making decisions about the use of public funds are hesitant to take risks on unproven technologies. To overcome this barrier and achieve acceptance by the practitioner community, research and development needs to demonstrate reliable performance under realistic operating conditions (e.g. at full scale). Such success is even more potent if the technology can be adopted into design manuals [12].

Technologists often struggle to make the transition from the bench-top to the demonstration scale without help from the community of practicing engineers and equipment manufacturers. Resource recovery technologies are more likely to be accepted if they are supported by a healthy innovation ecosystem (i.e. professionals who work for equipment manufacturers, water service providers and regulators who interact with each other and develop mutual trust) and a critical mass of potential users of the technology. For example, over the past 30 years, on-site wastewater treatment has made considerably more progress in Beijing than in other Chinese cities because the city had a vigorous innovation ecosystem that lobbied for government mandates to install treatment systems [13]. The innovation ecosystem that built up around an initial program designed to serve international hotels grew over time and adapted to changing needs of the city for wastewater treatment in low density developments on the perimeter of the city. A similar process is likely to apply to the diffusion of nutrient recovery technologies: as more wastewater treatment plants build facilities to recover nutrients from wastewater, opportunities for vendors who market fertilizers produced from the recovered materials will increase, which will, in turn, create more incentives for designers to include nutrient recovery in new projects.

In addition to the incremental pathway described above, change also comes to urban water infrastructure as a response to a real or perceived crisis. In situations in which existing practices are unable to solve a problem that is a high priority for members of the public or government officials, the traditional reluctance of environmental engineers and their clients to take risks diminishes. This mode of change has been crucial to the two periods of the 20th century when many of the largest investments were made to urban water systems: the construction of drinking water treatment plants in the early part of the 20th century and the upgrading of municipal wastewater treatment plants that occurred between 1970 and 1990 [14]. In both cases, the change only occurred after the public's attention was focused on the problem and the engineers tasked with coming up with solutions recognized the inadequacy of their existing technology toolbox.

The common threads unifying the incremental and the rapid modes of change that will determine the timing of the resource recovery future are the development of new technologies that offer substantial benefits relative to existing practices and the existence of external forces (i.e. crises) that create opportunities for the new technologies to gain a foothold in the market although it is difficult to accurately predict the specific technologies that will dominate the resource recovery future, it is possible to anticipate where and when the greatest opportunities for resource recovery are most likely to occur. With this knowledge, environmental engineers should have a better idea about how to speed the transition to a resource recovery future throughout the water sector. Some of the most prominent opportunities for hastening the arrival of the resource recovering future are briefly described below.

The Fourth Industrial Revolution: Many industries are currently undergoing rapid change driven by advances in robotics, additive manufacturing, electronics and materials science [11, 15]. As these changes start to affect the water industry, modular wastewater treatment equipment will become less expensive to build, easier to control and more reliable. These modules will affect the ways in which centralized (i.e. large) wastewater treatment plants are designed and operated, favoring standardized treatment trains instead of the current approach to design in which each element of the treatment train is based upon a customized design. Early development of modules that enable resource recovery may create opportunities for the technologies to be adopted. Modularization and autonomous control may also create opportunities for distributed treatment and/or resource recovery at the household or building scale [16, 17].

Decarbonization of Electricity Production: In response to concerns about climate change, the rate of transformation of electricity generating systems is likely to accelerate over the next two decades. One possible outcome of these investments is significant reductions in the cost of electricity (e.g. a wind farm was recently contracted with a promise to deliver electricity at $0.02 per kWh [18], which is considerably lower than the present cost of generating electricity from coal, oil or natural gas). Although the potential for replicating this type of low-cost renewable energy project in densely populated areas around the world is unclear, current trends in development of renewable energy and natural gas extraction suggest that renewable electricity will be less expensive than fossil fuels in the near future [19]. If such changes materialize, resource recovery technologies that are energy intensive (e.g. reverse osmosis) may become more attractive. Alternatively, government policies (e.g. taxes on fossil fuels) could make energy recovery from wastewater more attractive relative to energy sourced from traditional, non-renewable sources. Either way, the rate of adoption of resource recovery systems at wastewater treatment plants will be affected by changes in the ways in which electricity is produced.

Increasing Water Scarcity: Changes in precipitation patterns, higher temperatures and increased competition for water resources are likely to result in more water scarcity in the future, especially in large cities in arid regions [20]. In locations where water scarcity is already being experienced, such as Southern California, Western Australia and Israel, large investments have already been made in infrastructure for water reuse (i.e. the recovery of drinking water or water suitable for irrigation, cooling or industrial uses from municipal wastewater). Such projects have created opportunities for new technologies to be developed and implemented at scale, despite their relatively high costs and the risks associated with their adoption [7, 21]. The construction of water recycling facilities may also provide opportunities to integrate resource recovery into the overall treatment train (e.g. reuse of wastewater for agriculture or landscaping is a form of nutrient recovery whereas nutrients are sometimes a problem when water is reused for cooling or toilet flushing).

Urbanization of the Global South: Population projections for Africa, South America and Southeast Asia indicate rapid increases in urban populations over the next 50 years. In many cases, this urbanization will not be accompanied by industrialization. For example, Lagos, Nigeria is expected to grow from a population of around 15 million today to approximately 90 million people by 2100 [22] without the kind of industrialization and increase in wealth that accompanied the rapid growth of cities in China, Korea and Singapore. Irrespective of the per capita income in these emerging megacities, large investments in wastewater infrastructure are going to be needed for protection of public health and water security in the coming decades. As illustrated by many of the proposed designs of distributed sanitation systems [6], resource recovery may prove beneficial to the overall business model for these systems.

The difference between a waste disposal problem and a resource recovery opportunity is the value that society places on the social, environmental and financial costs and benefits associated with resource recovery. Advances in technologies for resource recovery will eventually reach a point at which some form of resource recovery will be implemented whenever wastewater is treated. However, a variety of factors related to the ways in which wastewater treatment plants are designed and operated is currently slowing or preventing the adoption of resource recovery technologies. Environmental engineers interested in accelerating the rate of technology adoption need to expand their perspective beyond the technological framework described in engineering textbooks. By designing technologies that are compatible with the opportunities and challenges facing the water sector by understanding the needs of decision-makers, regulators and investors, a resource recovering future may arrive in time to make a difference.

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doi: 10.2166/9781780409566

One water/one health: Used water management in 2050 and beyond

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I appreciate the authors asking me to share my thoughts on the challenges and opportunities related to the future of used water management. I want to commend them for this publication, because although there are plenty of textbooks and reference materials on this topic that review today's needs and state of the practice, very few address the importance of changing our future approach.

Certainly, our industry's recent emphasis on adopting a Circular Economy paradigm is a welcome departure from the traditional approach to used water management over the past century. However, the concept of recovering resources from our environmental health protection efforts is not a new one. Buckminster 'Bucky' Fuller (1895–1983, American philosopher, technology icon, and visionary), known for inventing the geodesic dome and coining the term Spaceship Earth, could not have anticipated this better with his 1971 quote 'Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we've been ignorant of their value.'

My perspective on used water management is empirically derived, the result of more than 30 years' experience as a practitioner in the consulting engineering sector, mostly as a technologist involved in process design of treatment facilities, and more recently, in long range planning efforts for several large cities worldwide. In sharing my vision of how we must confront the future in our industry, let us begin by looking at what got us here.

Today's typical developed-world used water management urban solutions can be traced back to early 20th century planning efforts. They are usually comprised of a highly-articulated collection system connected to treatment facilities near a receiving water body. Our current infrastructure has evolved from these early planning concepts into implementation (and subsequent expansions) almost unchanged. Initially driven by the goal of protecting public health, then evolving to embrace environmental health goals to mitigate impacts on nature from discharges, the solutions we currently depend on were developed within the context of a very different world. That 'world' had a highly predictable climate, resources to spare, and only a few billion people, mostly in rural areas. Utilities provided wastewater management services by developing long-term master plans focused on the needs of what they thought (or wanted to believe) was a discernable future. Treatment options were based on technologies that arguably had evolved little in almost a century. The adopted solutions were based strictly on a consumer perspective, one that determined the best option to be the one requiring the least financial, energy, chemical, and manpower resources to meet demands defined by a certain vision of the future.

However, all recent predictions of what the world will look in the year 2050 and beyond paint a drastically different picture to that under which we currently operate – altered climate, constrained resources, and populations in excess of 10 billion living mostly in mega-urban centers, which makes us even more susceptible to the ravages of a pandemic as demonstrated recently by COVID-19. Therefore, it is highly unlikely that our current used water management approaches – and corresponding enabling technologies – will adequately meet tomorrow's radically different environmental, social, and financial requirements. So, in simple language, counting on current approaches for future needs seems downright stupid! Here are three general concepts I suggest should be part of a better approach to develop used water solutions aligned with the circular economy precept of this book, and still be relevant in 2050…and hopefully a bit beyond.

17.1 ONE WATER, ONE HEALTH

Like the now widely-accepted concept of *One Water* (one that recognizes the integrity of the water cycle and water as a single resource), we must adopt a *One Health* triple-component goal with social (public), environmental, and economic (financial) components, in the same way we have embraced the triple bottom line concept to properly evaluate sustainability in infrastructure decisions. Adding the financial health component incorporates the basic tenets of the Circular Economy concept, involving the necessary shift of the water industry's role from one of being a consumer of resources to a producer of them.

However, successfully engaging the economy's value chain must be based on offering products that the market needs (what the market 'pulls') and not by 'pushing' recovered products with no demand or with a substantial competitive disadvantage. This approach will require our industry to learn how to assess (and effectively compete) in markets using recoverable resources, but not at the expense of non-transferable public and environmental health protection responsibilities. Of equal importance, of course, will be the task of educating the public that we serve about the urgency of adopting this more holistic perspective.

17.2 GIVE UP THE CRYSTAL BALL

We must acknowledge that we cannot futureproof today's decisions by hoping to predict the future with certainty. To position for the future, utilities must abandon their traditional long-term master planning exercises, replacing them with more dynamic adaptive and strategic positioning approaches based on shorter planning horizons and multiple likely future end-point scenarios. This approach allows for short-term decision-making (by discarding least-adaptable alternatives) while still offering other plausible, longer-term opportunities. For the practitioner, process flow sheets and corresponding facility recommendations will need to be highly flexible to enable course corrections if assumptions regarding externalities should change. External factors may include climate, regulations, service area needs, technology advances, financial conditions, and (in the Circular Economy) viable markets for recoverable resources. The challenge is that flexible alternatives are inherently more expensive (at least in the short term) than highly-optimized, rigid options, so it is important that we also develop new evaluation methodologies and gain acceptance and support for them from those in decision making circles.

17.3 DARE TO DISRUPT

Expanding or upgrading existing facilities or developing greenfield solutions under the Circular Economy concept will require changing how we configure unit processes. In addition to the traditional 'how much I must remove' point of view (satisfying the traditional public and environmental goals we have relied upon) we must now also think about 'how much can we recover' (the proposed new financial aspect of *One Health*). So, it is not just about considering facility configurations on their 'percent removal' merits any more, but also on their 'percent recovery' potential. Apart from reclaimed water, energy generation (from recovered biogas), and agricultural and landscape use of biosolids, there are few examples in our industry of successfully applying this way of thinking. Most of our 'proven' unit processes (and their arrangement) are still based on removing pollution, not recovering a resource. Adopting 'disruptive' technologies, rather than continued tweaking of existing solutions, is probably the answer to our industry's current needs, because it provides necessary flexibility and adaptability to plan for an uncertain future in this new Circular Economy paradigm.

Developing these new (and somewhat unproven) technologies may be time and resource consuming for a utility. Therefore, it is essential to adopt collaborative applied research and product development strategies, including participating in subscriber-based research and marketing programs, so that we can share knowledge and resources across the industry.

So, I fare you well, users of this book, as you embark on one of mankind's most importance quests – the proper management of the limited resources we depend on for our survival, now adding to your toolbox the sound principles brought forward by this book. Saludos!