THE SEWER IS [A] MINE.

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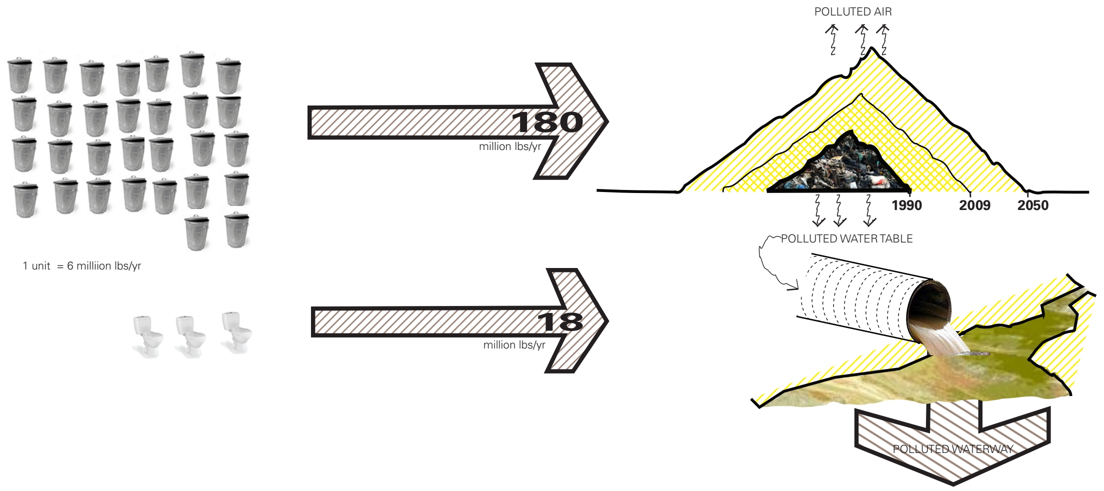
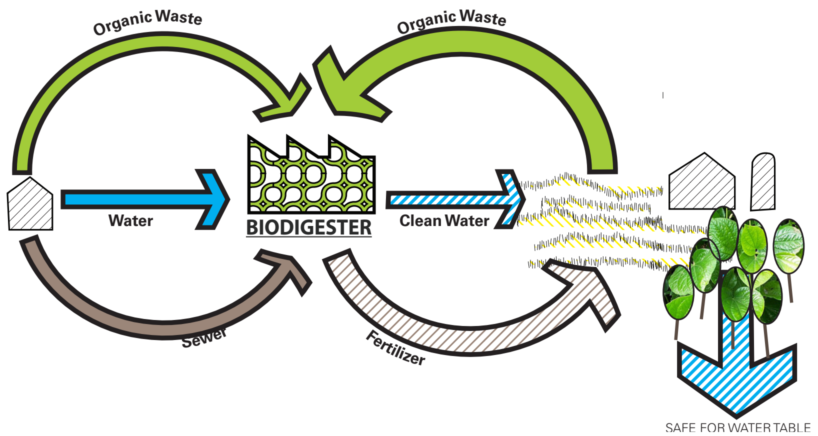
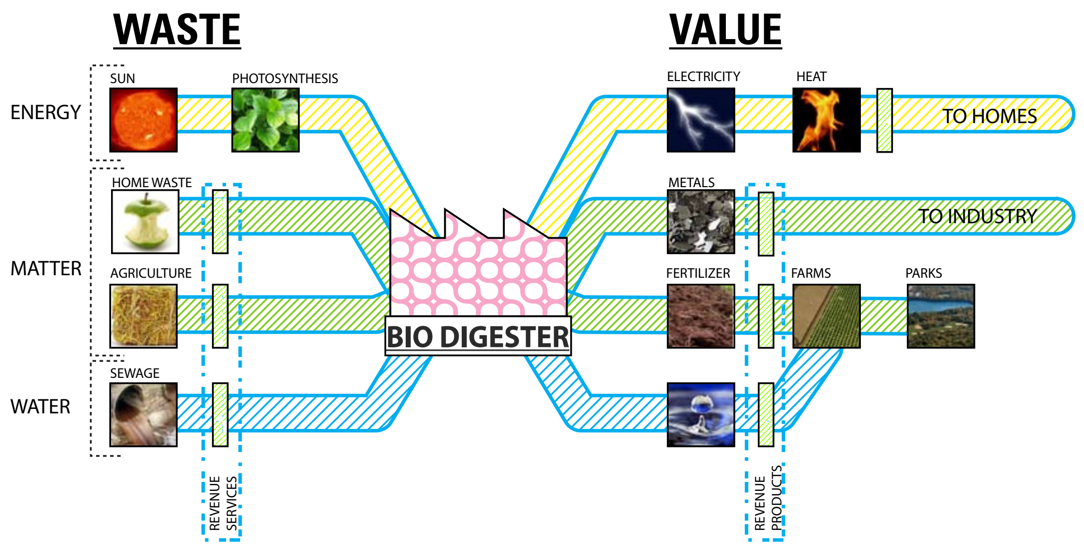
Americans generate 198 million tons of organic waste each year.[1]

This is a vast resource waiting to be tapped.





Communities can mine their sewers & waste streams, using the alchemy of biodigesters to create value ...

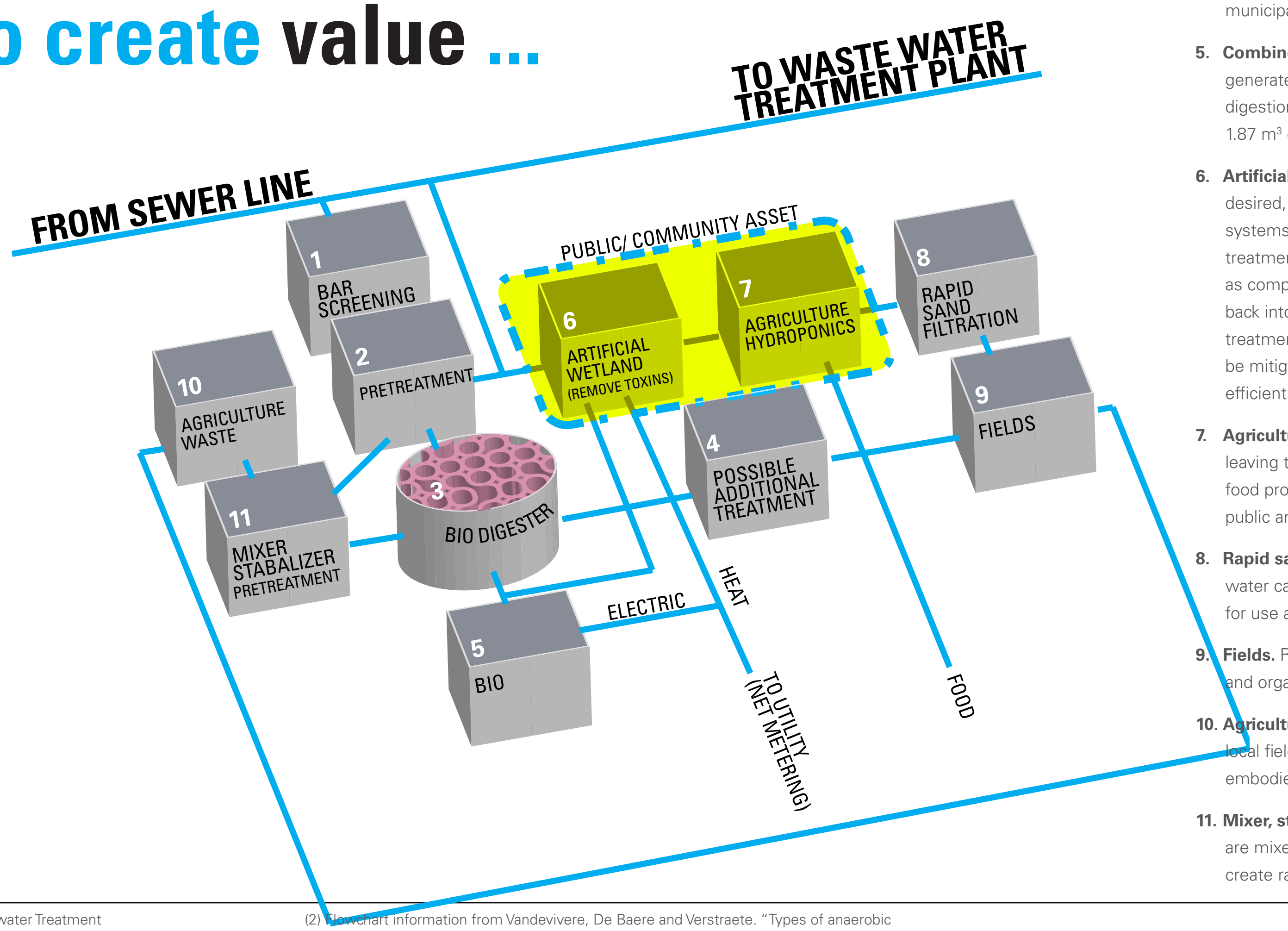


Biodigesters convert liability to profit, providing multiple benefits to cities and communities: they generate revenue on the front end by providing waste treatment services, and on the back end by creating valuable end products (fertilizer, natural gas, energy, clean water, and recovered metals).

The capital cost of the system is quickly offset by the value it creates, making it a lucrative proposition for communities or private interests.

Additionally, sustainable policies on the horizon have the potential to increase profitability, by valuing the ecological services the biodigester provides.

Correctly pricing greenhouse gasses would make biogas and cogeneration more profitable, and would favor the low embodied energy of the biodigester's local products and services. Correctly pricing potable water would create a market for the biodigestor's sewage treatment services and water recycling.



1. **Bar screening.** Removal of bulk waste.
2. **Pretreatment.** All wastes are pulped and density separation occurs. Other pretreatment, such as pasteurization and hydrolysis, may also occur here.
3. **Biodigester.** Anaerobic digestion takes place here. Inputs are monitored to maintain desired Carbon-to-Nitrogen ratios and pH levels.
4. **Possible additional treatment.** As required for hazardous materials which may be present in municipal wastes.
5. **Combined heat & power.** Biogas is used to generate heat and electricity. Product of anaerobic digestions approx. 50-75% CH_4, 25-50% CO_2. 1.33 – 1.87 m^3 of biogas is equal to 1 liter of gasoline.
6. **Artificial wetland.** If 100% water treatment is desired, large wetlands are required. Biodigestion systems can be designed either as complete treatment systems, including water treatment, or as complementary systems that feed excess water back into the sewers to be treated by a central treatment plant. The amount of water in sewers can be mitigated by other strategies, such as water-efficient fixtures and low impact development.
7. **Agricultural hydroponics.** Nutrient-rich liquids leaving the system can be utilized hydroponics for food production. These "living machines" can be a public amenity and teaching tool.
8. **Rapid sand filtration.** Removes particulates. Filtered water can be used to irrigate fields, or purified further for use as potable water.
9. **Fields.** Receive water and fertilizer, producing food and organic waste that is fed back into the system.
10. **Agricultural wastes.** Carbon-rich wastes from local fields. Proximity reduces transportation and embodied energy.
11. **Mixer, stabilizer, pretreatment.** Agricultural wastes are mixed with pulped sewage from settling tanks to create raw material for anaerobic digestion.[2]

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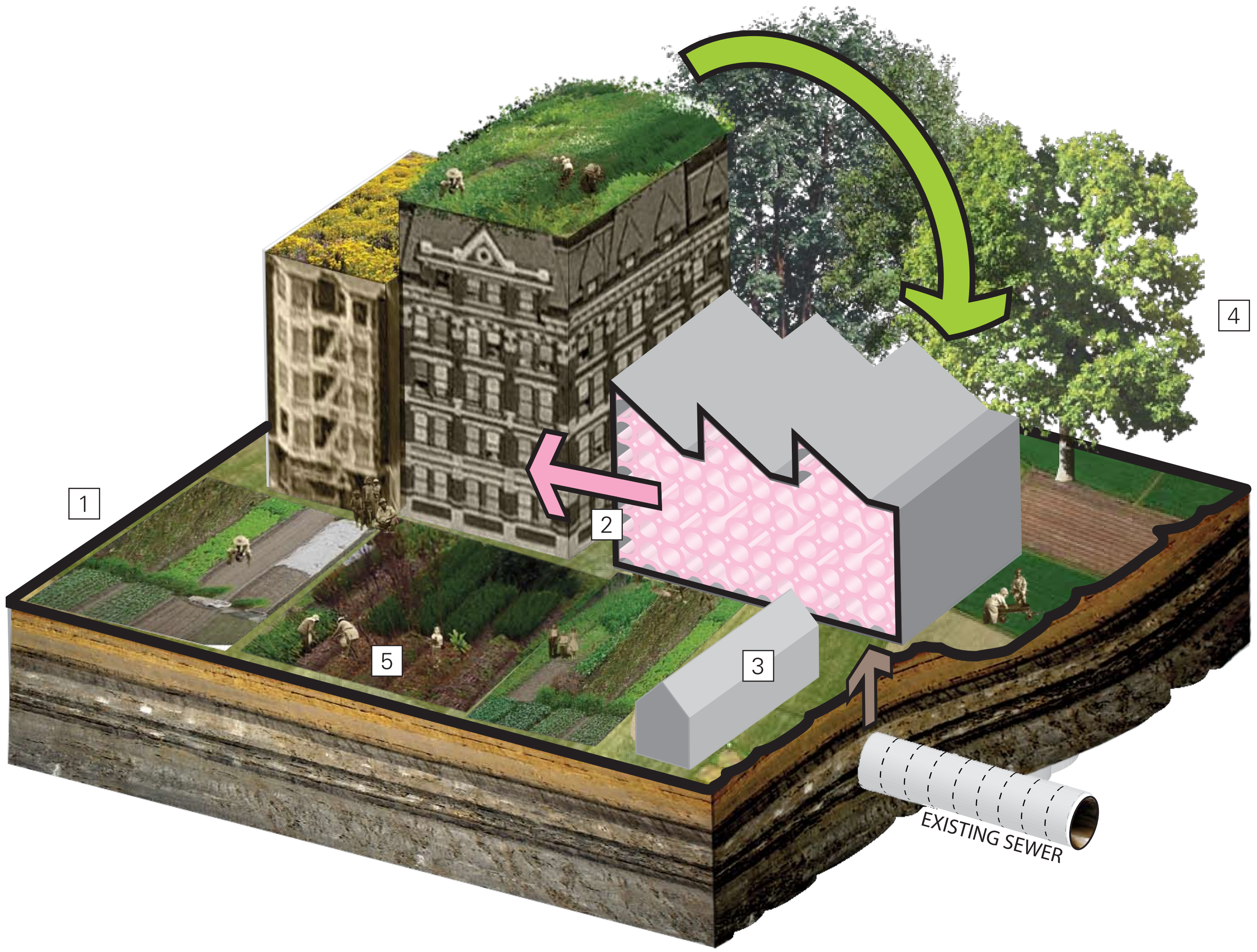
(1) United States Environmental Protection Agency, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007. Available at: http://www.epa.gov/osw/nonhaz/municipal/msw99.htm#links

United States Environmental Protection Agency. Primer for Municipal Wastewater Treatment Systems. Available at: http://www.epa.gov/npdes/pubs/primer.pdf

(2) Flowchart information from Vandevivere, De Baere and Verstraete. "Types of anaerobic digesters for solid wastes". Available online at: http://www.adelaide.edu.au/biogas/anaerobic_digestion/pvdv.pdf

... and empower communities.

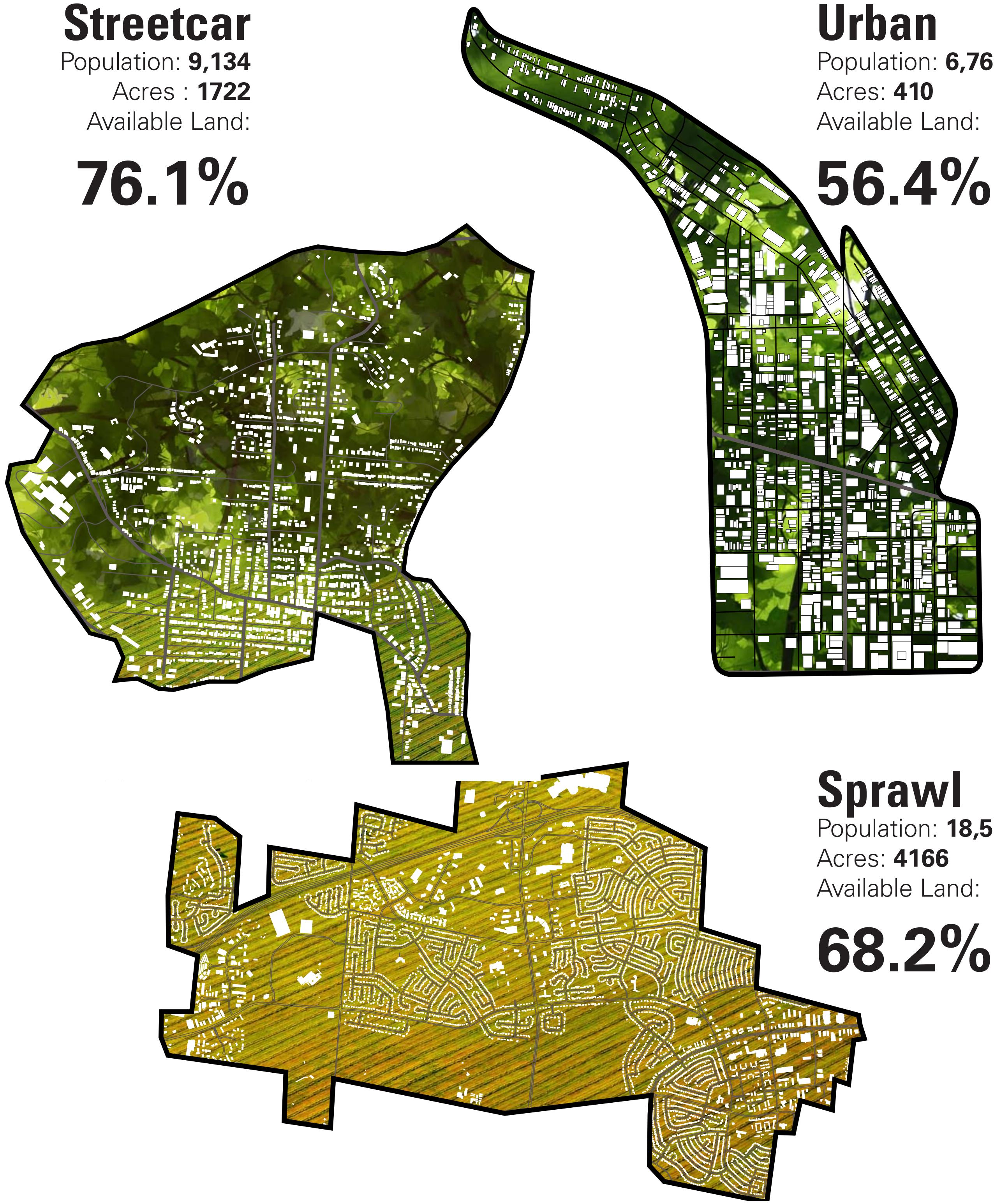


The biodigesters become the new urban center, the "living core." They are co-located with public space and civic buildings. They directly provide numerous community benefits, and stimulate the growth of many more.

1. **Local agriculture.** Biodigesters provide high-quality fertilizer and a market for agricultural wastes, encouraging the greening of the city and the blossoming of urban agriculture.
2. **Free energy.** The heat and electricity generated by the biogas powers local civic buildings, such as schools and libraries.
3. **Amenity & education.** The biological treatment (living machines and artificial wetlands) become a public amenity, the new botanical garden.
4. **Parks, street trees, and habitat.** Biodigestors create a demand for carbon sources, and for trees in particular. Thus they create financial incentive for public parks, street trees, and riparian corridors.
5. **Green jobs.** Biodigesters and their accompanying green infrastructure require less capital investment but more maintenance than conventional (gray) infrastructure. This creates a wealth of green-collar jobs.
6. **Local self-determination.** Biodigestors are managed by local communities, allowing them greater autonomy and solidarity.

Eventually communities rise up and cap their sewers to protect this most valuable source of wealth.

This system is flexible enough to work in multiple contexts:



Streetcar
Population: **9,134**
Acres : **1722**
Available Land:

76.1%

Urban
Population: **6,768**
Acres: **410**
Available Land:

56.4%

Sprawl
Population: **18,514**
Acres: **4166**
Available Land:

68.2%

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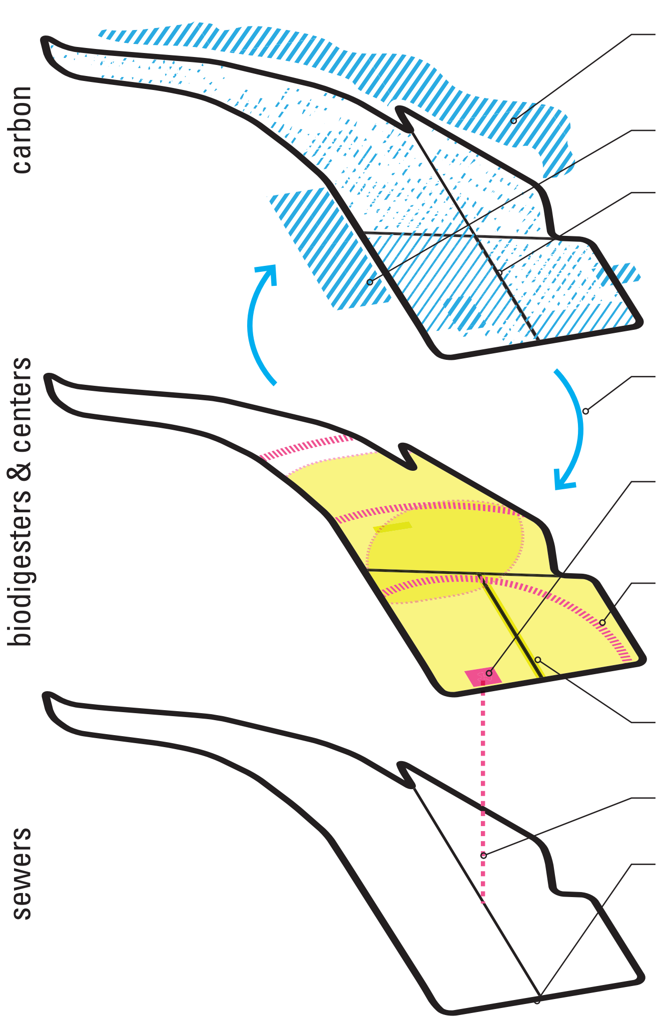
(3) Population figures from the United States Census 2000. Available online at: http://www.census.gov

urban core [forest]



public parks on treed hillsides

urban agriculture in former industrial areas

street trees, green roofs, and pocket parks allow the tree canopy to approach the pre-development baseline

carbons feeds the biodigester; fertilizer returns to parks, farms, and gardens

modular biodigesters, designed to expand as carbon sources grow, power public buildings

biodigester catchment basin (population served) expands over time

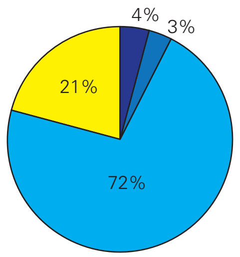
biodigesters located in or near walkable neighborhood centers

biodigesters draw from main sewer lines

as demand grows, sewers are capped

Green the city to create local carbon. Locate **small, modular biodigestors** near neighborhood centers.

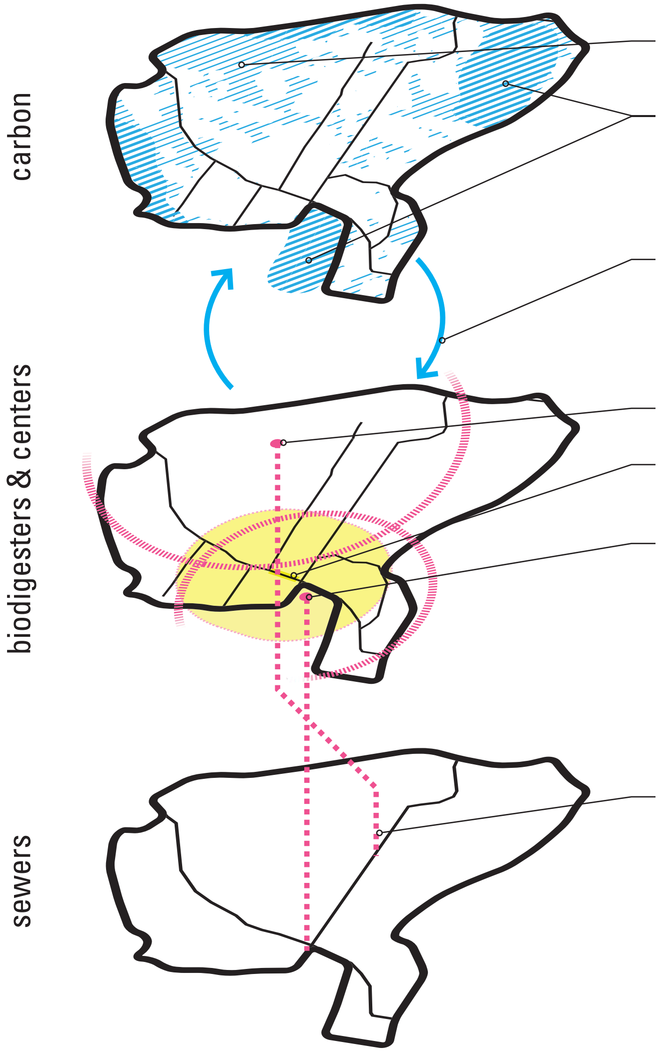
Small, modular biodigesters reduce upfront capital cost and capital investment over time, as well as allowing for flexibility and growth. This makes them ideal for dense, impoverished urban areas. A single pretreatment system can serve multiple biodigesters, which can be added incrementally as carbon sources (in the form of urban greenery) become more available. The system can be stacked vertically to reduce footprint, allowing seamless integration into the urban fabric.



Carbon & nitrogen sources
Total influent: 8,078 tons

🟨 human wastes (N)
🟦 ag wastes (C)
🟦 leaf litter (C)
🟦 municipal green waste (C)

streetcar suburbs [filter]



urban agriculture utilizes graywater for irrigation

large parks provide carbon sources and large permeable areas for water infiltration

carbon feeds the biodigesters; fertilizer and graywater return to farms and parks

large-scale agricultural biodigester near farm

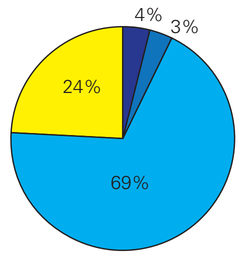
increased density in neighborhood centers allows greater greenery elsewhere

biodigester with living machine and artificial wetlands treats both waste and stormwater from combined sewers, creating graywater for irrigation and potable drinking water

biodigesters draw sewage and stormwater from main sewer lines

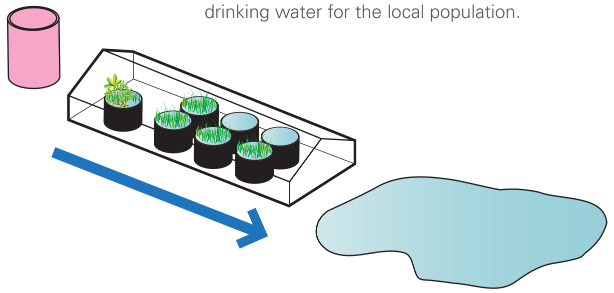
Utilize large available land area to **recycle 100% of wastewater**. Use this water for irrigation and drinking water.

Many North American cities have combined sewer and stormwater systems. Adding biological treatment systems such as living machines and artificial wetlands allows the system to treat both sewage and stormwater. Streetcar suburbs are ideal for this type of system because they have both the land area required for the treatment systems, and multiple ways to utilize the clean water: irrigation of parks and farms, and as drinking water for the local population.

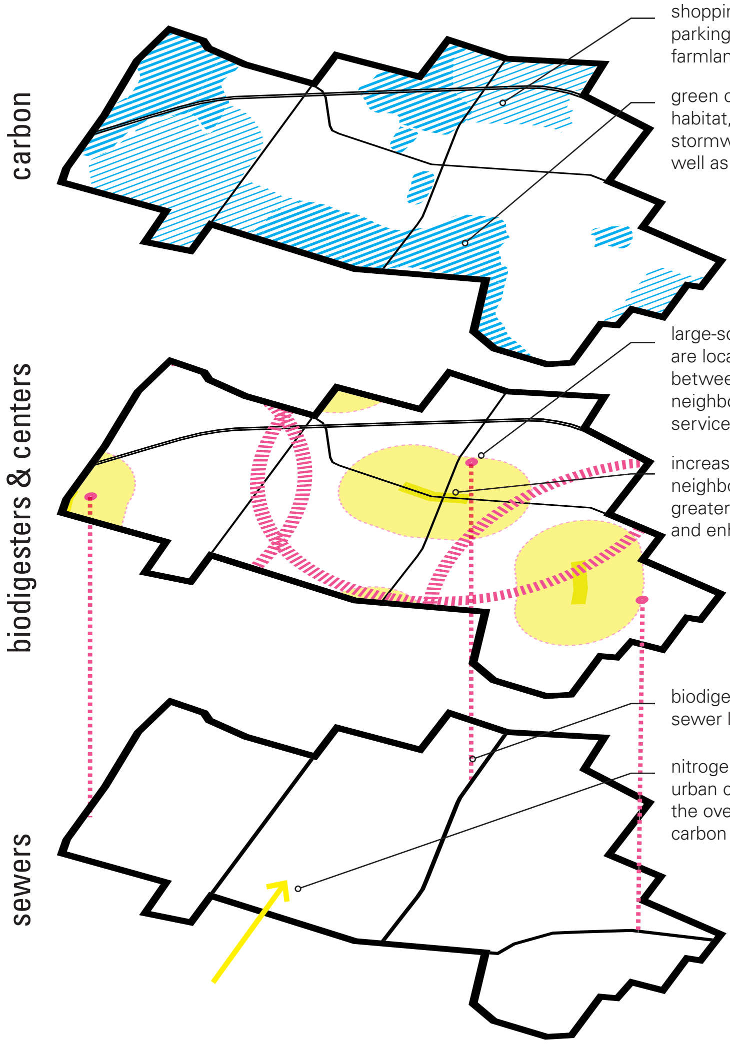


Carbon & nitrogen sources
Total influent: 35,424 tons

🟨 human wastes (N)
🟦 ag wastes (C)
🟦 leaf litter (C)
🟦 municipal green waste (C)



suburban sprawl [farm]



shopping malls and big box parking lots are converted to farmland

green corridors provide habitat, recreation, and stormwater management, as well as additional carbon

large-scale biodigesters are located on the edges between farmland and neighborhood centers, and service both

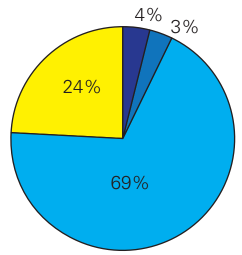
increased density in walkable neighborhood centers allows greater greenery elsewhere, and enhance access to transit

biodigesters draw from main sewer lines

nitrogen is imported from the urban core to complement the overabundance of local carbon

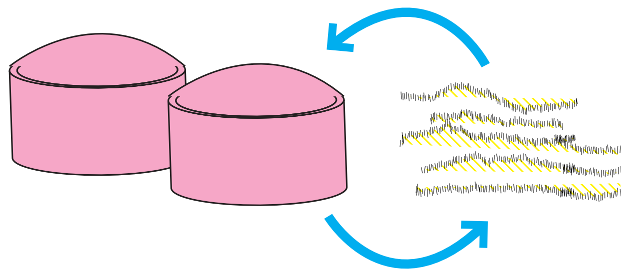
Make farming profitable by creating demand for ag waste. Convert malls to urban farms with **large commercial biodigestors** nearby.

Suburban sprawl has a great deal of underutilized land area that can be converted to farmalnd. This large, accessible source of carbon and demand for fertilizer makes large-scale biodigesters profitable for private interests. It also benefits farms, creating a positive feedback loop. Over time, populations migrate to denser centers, freeing more land are for symbiotic farming / biodigestion operations.



Carbon & nitrogen sources
Total influent: 35,424 tons

🟨 human wastes (N)
🟦 ag wastes (C)
🟦 leaf litter (C)
🟦 municipal green waste (C)



Carbon-to-nitrogen ratios will begin to impact urban design ...

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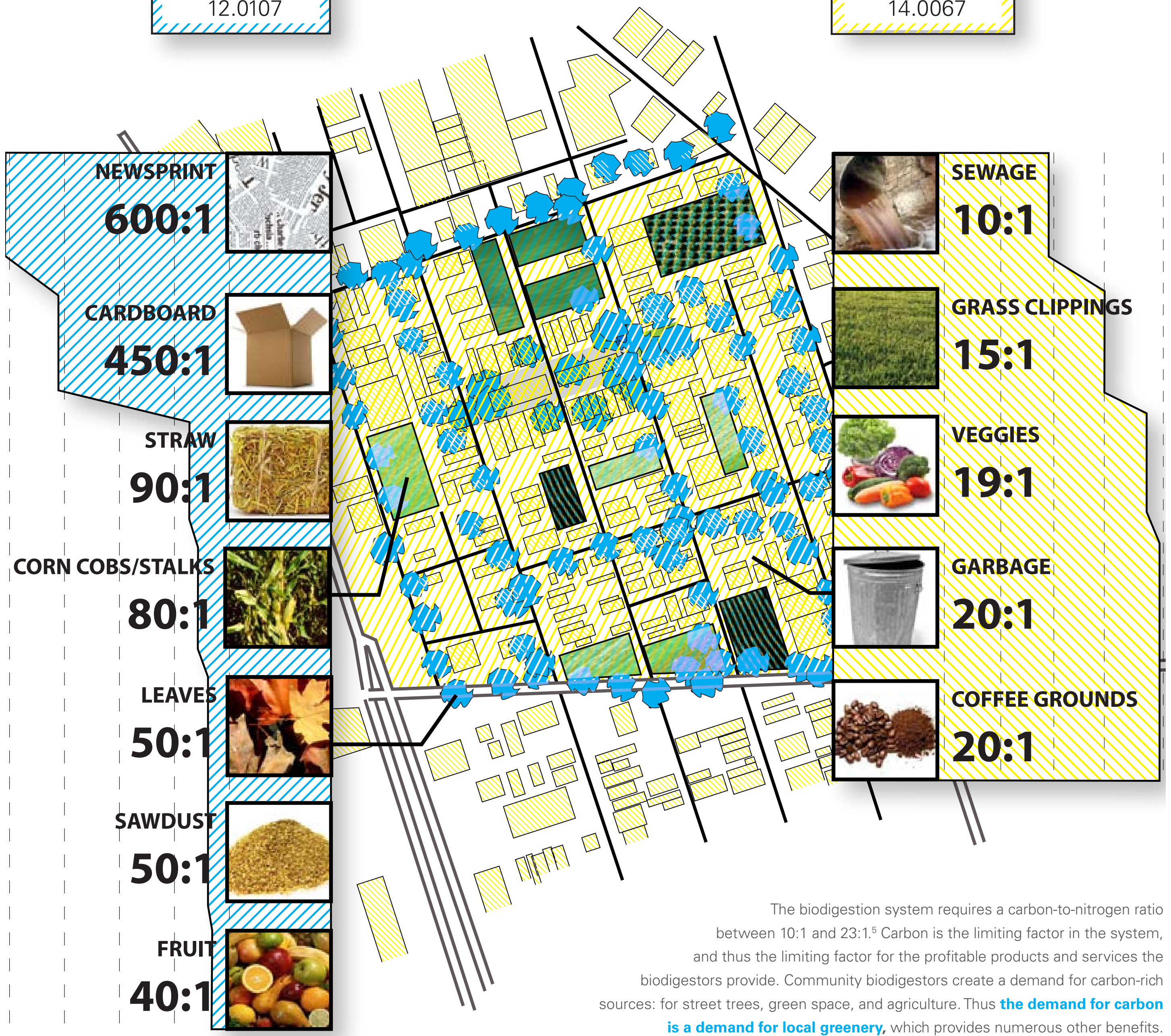
23 : 1

7 2 5
N
NITROGEN
14.0067



Carbon source	Ratio
NEWSPRINT	600:1
CARDBOARD	450:1
STRAW	90:1
CORN COBS/STALKS	80:1
LEAVES	50:1
SAWDUST	50:1
FRUIT	40:1

Nitrogen source	Ratio
SEWAGE	10:1
GRASS CLIPPINGS	15:1
VEGGIES	19:1
GARBAGE	20:1
COFFEE GROUNDS	20:1

The biodigestion system requires a carbon-to-nitrogen ratio between 10:1 and 23:1.[5] Carbon is the limiting factor in the system, and thus the limiting factor for the profitable products and services the biodigestors provide. Community biodigestors create a demand for carbon-rich sources: for street trees, green space, and agriculture. Thus **the demand for carbon is a demand for local greenery,** which provides numerous other benefits.

... creating demand for green cities, policy & planning.

green cities

(1) Demand for local carbon in urban areas can be met by street trees, green roofs, and green streets.

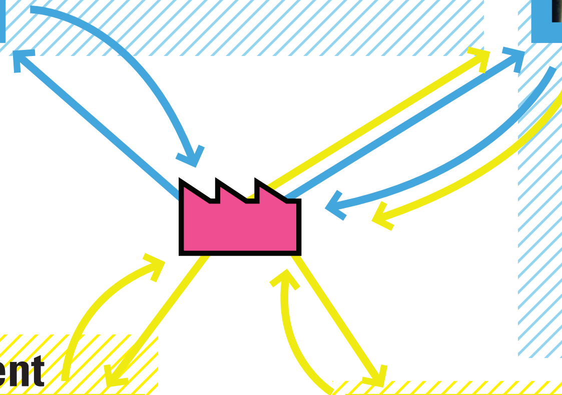
(2) Greenery supports low-impact development (LID), which reduces stormwater runoff, making the sewers purer sources of nitrogen.

(3) Greenery reduces urban heat island effect and sequesters carbon.

urban agriculture

Agricultural wastes are an excellent source of carbon.

Agriculture also benefits from the abundance of high-quality fertilizer the digester produces.



mixed-use development

Mixed-use development creates a more even flow of sewage throughout the day, allowing the biodigester to operate more efficiently.

transit-oriented development

TOD favors centralized development around transit hubs. This density (1) creates more room for green space elsewhere, and (2) allows larger populations and increased nitrogen.

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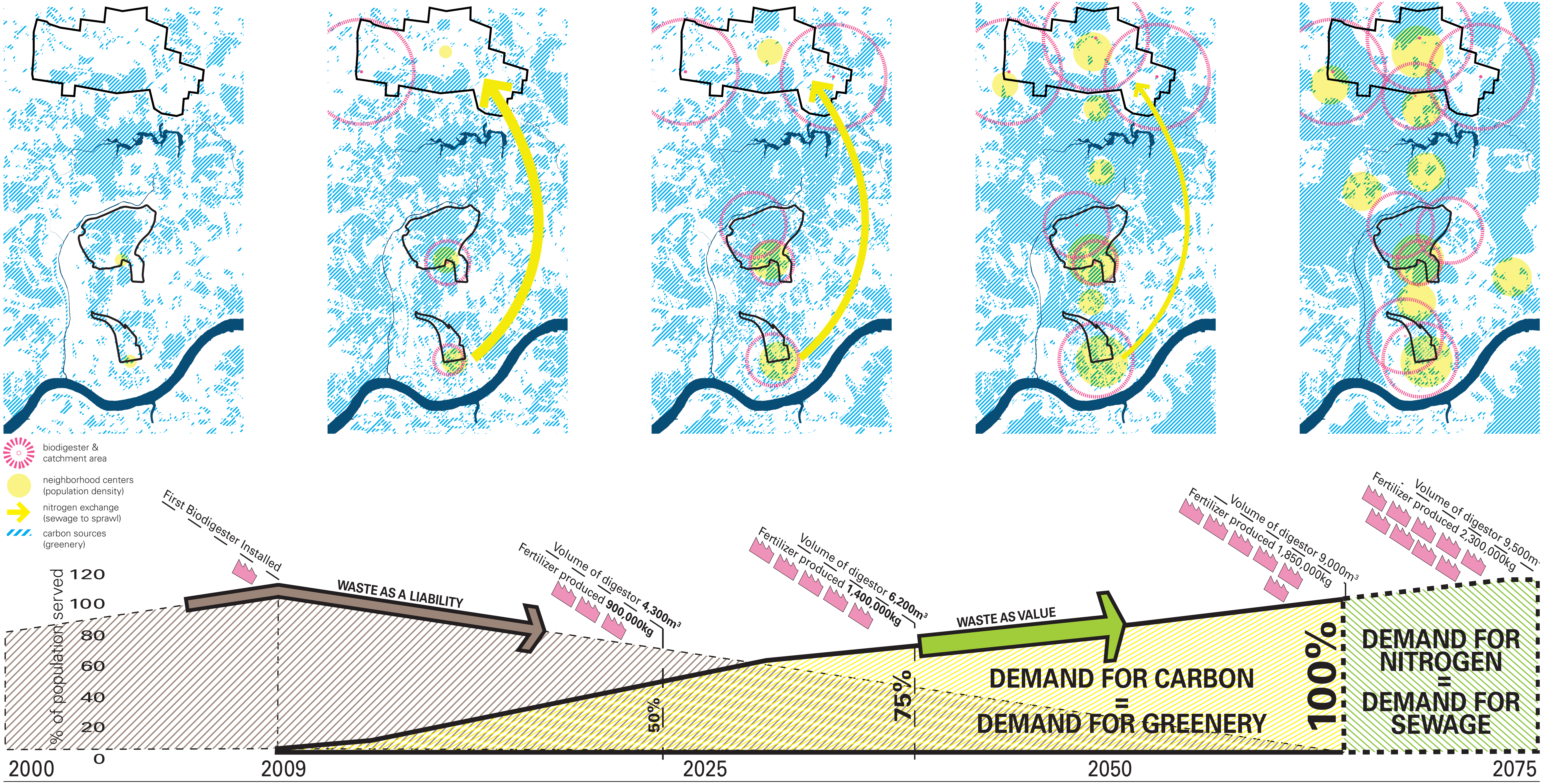
(4) Carbon / Nitrogen data sources: Gotaas, Harold B. 1956. Composting - Sanitary Disposal and Reclamation of Organic Wastes. World Health Organization, Monograph Series No. 31. Geneva and Rynk, Robert, ed. 1992. On-Farm Composting Handbook. Northeast Regional Agricultural Engineering Service. p. 106-113. Some data from Biocycle, Journal of Composting and Recycling, July 1998, p.18, 61, 62; and January 1998, p.20.

(5) Marchaim, Uri. Biogas Principles for Sustainable Development. Available online at: http://www.fao.org/docrep/T0541E/T0541E00.htm#Contents

Over time, a new urban morphology begins to emerge.



(6) Population projections assume a growth rate of 0.54%, based on data from the United States Census Bureau. Available online at: http://www.census.gov/population/www/pop-profile/natproj.html

sewers & scientific thought

by Carl S. Sterner

Nineteenth Century: Miasmic Theory

In the 1850s sewers were state-of-the-art. At this time the predominant understanding of illness was miasmic theory—the idea that disease was caused by foul or corrupt air—a legacy of Greek and Medieval medical thought, passed down from Hippocrates and Galen to Renaissance and Enlightenment thinkers [1]. The solution to the sanitary problems of burgeoning cities, according to miasmic theory, was to prevent bad air by evacuating waste from the city and diluting it in running water [2]. The sewers of Paris and London, marvels of nineteenth-century engineering, promised to clean the city by dumping raw sewage into their waterways.

Germ theory, developed by Louis Pasteur in the 1860s and Robert Koch int he 1870s, cast doubt on this strategy. Outbreaks of cholera in London were linked, controversially, to waterborne illness by Dr. John Snow in the 1849. But by the time germ theory gained wide acceptance, sewer systems has already been constructed in most European and American cities.

Twentieth Century: Germ Theory

The sewers, rooted in miasmic theory, made no distinction between wastewater and stormwater (based upon the mistaken belief that once waste was diluted it was effectively treated); thus retrofitting the sewers proved difficult. The germ-theory-inspired waste treatment facilities, affixed like filters to the end of the pipe, assuaged the worst of the human health concerns, but were not sized for major rain events. Today, major North American cities from Vancouver to Cincinnati regularly discharge sewage into local waterways [3]—a legacy we owe, ultimately, to miasmic theory.

Twenty-first Century: Biology & Ecology

Since the installation of sewage treatment facilities, biological and ecological sciences have continued to illuminate the myriad effects of sewage—even treated sewage—on human and ecological health. PCBs, endocrine disruptors, heavy metals, and phosphates are routinely discharged into waterways, with mounting negative consequences [4]. Treatment facilities—rooted in the science of germ theory—were not designed to remove these contaminants.

What is the waste system that will be inspired by the new science of ecology? Can it be applied as a band-aid fix to existing infrastructure—that lingering built expression of Medieval science? Or does it require something else entirely?

Architect William McDonough and chemist Michael Braungart propose a cradle-to-cradle paradigm in which "waste equals food," flows are cyclical, and toxins are designed out of the system from the outset [5]. This paradigm recognizes both the human health impacts illuminated by germ theory and ecological understanding of the twenty-first century. What will a no-waste, 100% good, cradle-to-cradle waste system look like? This is our challenge.

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[1] John M. Last, "Miasma Theory," Encyclopedia of Public Health, ed. Lester Breslow (New York: Macmillan Reference, 2001), 765. For a discussion of the intellectual lineage of 19th-century sewers, see Rebecca Williamson, The Breath of Cities, in Aeolian Winds and the Spirit in Renaissance Architecture, ed. Barbara Kenda (London: Routledge, 2006).

[2] Carlo M. Cipolla, Fighting the Plague in Seventeenth-Century Italy (Madison: University of Wisconsin Press, 1981). See also Leon Battista Alberti's *On the Art of Building in Ten Books* (1450), which was oft cited by Enlightenment thinkers.

[3] Elaine MacDonald, The Great Lakes Sewage Report Card (Canada: Sierra Legal, 2006). www.sierralegal.org/reports/great.lakes.sewage.report.nov.2006b.pdf.

[4] Graeme Wynn, Graeme. Risk and Responsibility in a Waste-Full World, forward to The Culture of Flushing, by Jamie Benidickson (Vancouver: UBC Press, 2007).

[5} William McDonough and Michael Braungart, Cradle to Cradle: Remaking the Way we Make Things (New York: North Point Press, 2002).

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biodigestor primer

by Daniel Divelbiss

What is a biodigester?

It is a vessel or container which is utilized to facilitate an environment conducive for anaerobic digestion of organic wastes into biogas and a nutrient rich, pathogen-free digestate which can be used as fertilizer. Biodigestion has been used all over the world in a variety of contexts ranging from household sized systems [1] to large commercial and municipal scale treatment [2, 3]. The versatility, scalability, productivity and new European government policies have caused an increase in the adoption of this technology [4].

What is biogas?

Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of biofuel.

One type of biogas is produced by anaerobic digestion of biodegradable materials such as biomass, manure or sewage, municipal waste and energy crops. This type of biogas comprises primarily methane and carbon dioxide

The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. Air contains 21% oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. It can also be used in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power. Biogas can be compressed, much like natural gas, and used to power motor vehicles and in the UK for example is estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel, so it qualifies for renewable energy subsidies in some parts of the world [5].

Typical composition of biogas [6]

Compound	Chem	%
Methane	CH4	50-75
Carbon dioxide	CO2	25-50
Nitrogen	N2	0-10
Hydrogen	H2	0-1
Hydrogen sulfide	H2S2	0-1
Oxygen	02	0-2

The composition of biogas varies depending on the organic material being digested and varies other factors including temperature, pH and pressure. Pure methane has a calorific value of 9,100 kcal/m3 at 15.5°C and 1 atmosphere; the calorific value of biogas varies from 4,800 - 6,900 kcal/m3 . In terms of energy equivalents, 1.33 - 1.87, and 1.5 - 2.1 m3 of biogas are equivalent to one litre of gasoline and diesel fuel, respectively [7].

What is digestate?

The digestate produced by anaerobic digestion is nutrient-rich and pathogen-free slurry which can be used as a soil conditioner for crops or, in some cases, animal feed. Acidogenesis and methanogenesis occurring during anaerobic digestion create the digestate and give it its fibrous and high quantities of nitrogen and phosphorous, respectively.

In addition to being nutrient-rich, digestate from operating anaerobic digestion plants have passed the standard for "Exceptional Quality" as defined by US Environmental Protection Agency when being tested for elements of concern, suggesting it is a high-quality and safe fertilizer [8].

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[1] http://www.arti-india.org/

[2] http://www.organics-recycling.org.uk/index.php?option=com_content&view=article&id=447:qlargestq-ad-facility-gets-planning-permission&catid=1:latest-news&Itemid=18

[3] http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=4112&pa2=4091&pg=4077#water

[4] http://www.anaerobic-digestion.com/html/brief_history_of_anaerobic_dig.html

[5] http://en.wikipedia.org/wiki/Biogas#cite_note-6

[6] http://www.kolumbus.fi/suomen.biokaasukeskus/en/enperus.html

[7] Marchaim, Uri. Biogas Principles for Sustainable Development. ISBN 92-5-103126-6. available online at: http://www.fao.org/docrep/T0541E/T0541E00.htm#Contents

[8]http://www.alexmarshall.me.uk/index_files/documents/ResponsetoConsultationonthesourcesegregationrequirementinParagraph7AofSchedule3totheWaste-Man.pdf

policy considerations for biodigester development

by Lyle Solla-Yates

A number of policies will improve the effectiveness of this biodigestor program and/or leverage its effects in a positive way. To optimize the biodigestors, the goals must be to: (1) Increase the availability of carbon for proper biodigestion; (2) Manage stormwater to prevent disruptive overflows in combined sewers; (3) Mine the sewer to encourage water re-use; and (4) Spread the wealth to ensure maximum impact and job creation.

Goal 1: Increase the local availability of carbon for proper biodigestion

1. Increase funding for street tree planting and maintenance.
2. Divert existing yard waste collection to the biodigestors, and provide on-site collection of yard waste, with compensation dependent on need.
3. Divert clippings from nearby parks to the biodigestors
4. Divert some cardboard and newspaper collection to the biodigestors, dependent on need.

Goal 2: Manage stormwater to prevent disruptive overflows

1. Institute stormwater utility fees based on the costs of maintaining the stormwater infrastructure
2. Strategically invest some of the revenue in Low Impact Development projects including street trees, bio-swales, permeable paving, rain gardens, and cisterns.
3. Retire or repurpose hard stormwater infrastructure as it becomes feasible.

Goal 3: Mine the sewer

Sewer mining is the capture of sewage before or after treatment for re-use by a third party. Typical applications are for irrigation, though commercial and industrial uses have been found, even including potable drinking water. Australia, California, and Israel have been leaders in the legal and technological advances in this area.

A legal agreement is established between the sewer miner and the utility guaranteeing that a minimum flow will be maintained in the sewer line. Some arrangements allow free access and some require payment based on the cost of providing the waste water or on the replacement cost of getting comparable water elsewhere.

Goal 4: Spread the wealth

The following policies deal with extending the positive impact of the biodigestor program throughout the community.

A biodigestor program creates new opportunities for the community:

1. Quality, inexpensive compost will be available at biodigestor locations.
2. Inexpensive irrigation-quality water will be available for multiple uses.
3. Costly sewer upgrades and compliance costs will be diminished.
4. Stream quality will be improved, providing superior aesthetic, recreational, commercial, and environmental resources.
5. Public spending will shift from costly infrastructure to green collar jobs.
6. New business opportunities will be created around biodigesters and their outputs.

These opportunities can be matched with policies to extend and improve their effects:

1. Urban farming, gardening, and tree planting programs to make good use of the compost.
2. Economic development programs to promote use of the cleaned water and pricing to discourage waste of drinking water.
3. Provisions to reinvest infrastructure and regulatory savings resulting from this program back into the program.
4. Targeted investments in stream restoration, parks, and economic development along stream corridors.
5. Green collar job training to ensure a local supply of experts to tend this new green infrastructure.
6. Incubator space and seed capital for businesses related to, supporting, or supplied by the new infrastructure.

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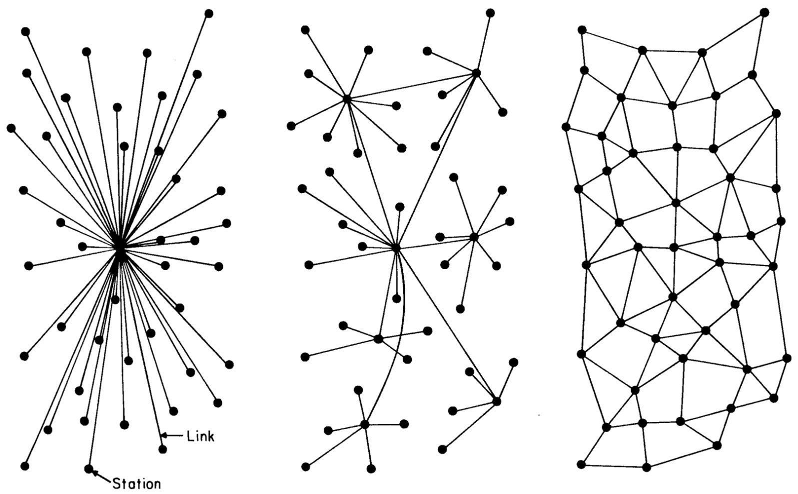
resilience & decentralization

by Carl S. Sterner

Sustainability is not only about efficiency and wise use of resources—that is, throughput through a given system—; it is also about the structure of that system. In his seminal book *Soft Energy Paths*, physicist Amory Lovins argues that systems are most efficient when matched in scale and distribution to end-use needs. Lovins was primarily concerned with the energy system, but the principles he outlines are universal. But perhaps more intriguing than the technical argument that Lovins advances is the socio-political argument: that matching scale and distribution to end uses—which, in our present-day hyper-centralized society, tends to mean some degree of decentralization—is also more equitable, egalitarian, and resilient.

The latter point is of particular importance. Whereas centralized systems are more vulnerable to fluctuations, less able to adapt to changing conditions, and often imply large capital investment in both the system itself and its supporting infrastructure, decentralized or distributed systems tend to be more flexible, able to adapt to local conditions, and can take advantage of mass production and modularity to be cheap and accessible. Because of these attributes, they often not only operate more efficiently, but also reduce embodied energy. Indeed, resilience is emerging as an importance theme in the sustainability debate.



Paul Baran made a similar link between resilience and decentralization in the 1960s. Baran, working for the Rand Corp. and the U.S. Air Force, researched communication networks that could withstand a catastrophic "enemy attack." He created a taxonomy to describe different types of systems—distributed, decentralized, and centralized—and advocated for distributed systems because of their resilience.

The social aspects of decentralization are also worth noting. Lovins argues that large, centralized systems are, by necessity, controlled by expert specialists and organizations that can leverage the requisite capital; as such, they are divorced from democratic decision-making processes. Centralized system also tend to centralize costs and benefits, which often accrue to different parties at opposite ends of the system: costs accure "downstream;" benefits go to those who control the systems that are "too big to fail." Thus these systems become engines of inequality.

These observations are consistent with those made by anthropologist Vernon Scarborough, who theorizes about two types of social trajectories: one characterized by increasing hierarchy, large-scale capital investments, environmental change, and ultimately collapse; the other characterized by local decision-making, incremental change, and long-term sustainability.

When speaking in generalities, it is best to be wary. Decentralization is not a panacea and should not be approach ideologically. As Lovins notes, the principle task is to correctly match solutions with end use needs. But we must look carefully at the structure of the systems we are designing if we hope to create a sustainable society.