

# A Spatial Analysis of Loop Closing Among Recycling, Remanufacturing, and Waste Treatment Firms in Texas

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## Keywords

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## Summary

Industrial ecology has emerged as a key strategy for improving environmental conditions. A central element of industrial ecology is the concept of closing the loop in material use (cycling) by directing used material and products (wastes) back to production processes. This article examines the issue of geographic scale and loop closing for heterogeneous wastes through an analysis of the location and materials flows of a set of recycling, remanufacturing, recycling manufacturing, and waste treatment (RRWT) firms in Texas. The results suggest that there is no preferable scale at which loop closing should be organized. RRWT firms are ubiquitous and operate successfully throughout the settlement hierarchy. The cycling boundaries of RRWT firms are dependent primarily upon how and where their products are redirected to production processes rather than the firm's location in the settlement hierarchy. In other words, loop closing is dominated by the spatial economic logic of the transactions of the firm involved. These results suggest that we cannot assign loop closing to any particular spatial scale a priori nor can we conceive of closing the loop via RRWT firms in terms of monolithic networks bounded in space or place with internal material flows.

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## Introduction

Industrial ecology has emerged as a key strategy in moving society toward a more environmentally sustainable future (Allenby 1994; Hawkins et al. 1999; Ehrenfeld 2000; Cohen-Rosenthal 2004). The element of industrial ecology of interest here is the concept of closing the loop in material use or cycling. Cycling refers to the substitution of used materials and products (i.e., wastes) for virgin materials during production processes. The resulting interactions are generally more environmentally benign because material use is optimized, waste is minimized, and the overall environmental impact of production and consumption is significantly reduced (Frosch and Gallopoulos 1992; Chertow 2000; Cohen-Rosenthal 2000; Korhonen 2002; Boons and Berends 2001).

Implicit in the concept of cycling is the need to close the loop on recovered products and materials to ensure their conversion from initial use to another use, either as a functional whole, as components, as material, or as fuel (Lifset 2002; Cohen-Rosenthal 2004). Flows (physical movement of items over space) of recovered products and materials are characterized by a high degree of heterogeneity in terms of their geographic and economic origin, physical characteristics, and ultimate destination. Spatially diffuse and materially heterogeneous flows raise the question of what geographic scale (individual plant, industrial park, corporation, town, metropolitan area) is the most useful to efficiently and profitably close these loops (Frosch 1995). Recycling, recycling manufacturing (making products from recycled material), remanufacturing (refurbishment and/or reconditioning of products or components), and waste treatment (RRWT) firms are experts at profitably coordinating diffuse and heterogeneous flows within the market place (see also Desrochers [2002, 2004]) and may offer some insights on how closing the loop actually operates in reality. The central goal of this article is to examine the issue of geographic scale and loop closing for heterogeneous wastes through the results of a questionnaire survey on the material flows of a set of RRWT firms in Texas in south central USA.

RRWT firms are not a panacea for all loop closing and the firms face technological, environmental, and economic limitations. Nevertheless, the advantages of recycling, remanufacturing, recycling manufacturing, and waste treatment are numerous. They can substantially reduce the ultimate volume of waste, the demand for virgin raw materials, and the pollution arising from production and the cost of waste disposal (Andrews and Maurer, 2001). RRWT firms have a clear profit motive for improving the efficiency of loop-closing networks which leads to environmental improvements without the firms having to be influenced by environmental concerns either collectively or individually (Lyons 2005).

## Literature Review

### *Cycling, Scale, and Settlement Hierarchy*

The question of what spatial scale is most suitable for cycling is still under investigation (Lambert and Boons 2002; Sterr and Ott 2004; Yang and Lay 2004; Lyons 2005). At the one end of the spatial spectrum, research has demonstrated the success of co-located or closely located firms operating pipe-to-pipe transfers of waste materials among primary processing industries that generate large continuous-process waste streams via the process of industrial symbiosis (Chertow 2000; Deschenes and Chertow 2004). The co-location model, in the form of manufacturing firms exchanging components within eco-industrial parks, has been less successful at by-product exchanges, although practices such as shared gray water recycling and other utility sharing have been implemented (Cohen-Rosenthal 1996; Côté and Cohen-Rosenthal 1998; Deutz and Gibbs 2004).

Pipe-to-pipe transfers or eco-industrial parks are unlikely to become the dominant models (even with the establishment of by-product exchanges) because very few firms will relocate solely to be part of a by-product exchange project (Chertow 2000). But among firms that are already located in close proximity to one another, the potential for developing new industrial symbiosis linkages that generate environmental improvements and profitable outcomes certainly exists (Chertow 2004; Yang and Lay 2004).

Furthermore, in cases where firms already gain substantial economic advantage from co-location, as is the case for some dedicated input supplier parks such as that constructed by Daimler Chrysler AG at Rastatt, Germany (Fichtner et al. 2004), the eco-industrial park model can provide a useful vehicle for industrial symbiosis.

At the opposite end of the spatial spectrum, Sterr and Ott (2004) suggest that larger regional areas may be more suitable for closing material loops and creating sustainable industrial ecosystems. Heterogeneous wastes from consumption are generally dispersed widely across space and are of relatively low economic value. Larger areas may provide the necessary volumes to achieve the economies of scale required to ensure profitability. Heterogeneous wastes often need to be reconstituted before they can be returned to the marketplace, and new uses may be different from initial uses or may be sold to different market segments. Larger areas provide a greater variety of potential customers to consume the newly reconstituted items and solve problems of redundancy by providing alternative customers if or when a particular cycling transaction fails (Posch 2004; Sterr and Ott 2004).

As with all businesses, certain minimum thresholds (the minimum volume of business necessary for an establishment to be economically viable) are necessary for RRWT firms to achieve successful loop closing. Heterogeneous wastes are spatially diffuse, of relatively low value, and bulky and expensive to transport, and need to be aggregated locally<sup>1</sup> before they can be profitably shipped. The threshold for a business is the minimum volume of waste generated by a place at which a firm is able to profitably aggregate and ship that recovered waste to a customer. This threshold will vary according to the characteristics of the waste (i.e., inherent value, volume and transport costs, processing costs), but above a certain minimum, RRWT firms are likely to be located throughout the settlement hierarchy. A settlement hierarchy refers to the classification and ranking of settlements (places) within an area according to population size. As you move up the hierarchy the population size increases, whereas the number of settlements decreases. Conversely, as you move down the hierarchy settlement size decreases whereas the frequency of settlements

increases. In other words, *ceteris paribus*, as long as a place can generate the required minimum volume of particular consumed products and materials, a RRWT firm redirecting (diverting from disposal) that waste should be able to operate successfully.

In this study, the settlement hierarchy was defined as major metropolitan areas (population in excess of 1 million residents), small metropolitan areas (between 100,000 and 1 million), and nonmetropolitan areas (villages, towns less than 100,000 and rural locations). The logic behind this classification revolves around differences in infrastructure capacity and the ability to generate urbanization and localization economies, including economies of scale and scope. Larger metropolitan areas should be able to support both a wider variety of types of RRWT firms and greater absolute numbers of RRWT firms. Smaller metropolitan areas are likely to have fewer types of RRWT firms. Firms in nonmetropolitan areas face additional costs (particularly aggregation and transport costs) because their inputs are likely to be more widely dispersed and the number of firms and variety of inputs are likely to be even more limited.

### **Territorial Boundaries and Cycling**

Heterogeneous wastes present a set of coordination and knowledge problems for both generators and consumers of waste. Small and medium-sized (SME) firms or commercial businesses are unlikely to have the personnel to keep track of changing disposal opportunities, prices, supplies, and/or quality. Larger firms may have the available personnel to monitor the uncertainties of waste markets, but such monitoring is unlikely to be within the core competence or interest of these firms (Gibbs and Deutz 2005). SMEs and larger firms are more likely to outsource (via either open market transactions or subcontracting arrangements) to specialist RRWT firms that can guarantee the proper handling of the output waste flows<sup>2</sup> and/or the quality and volume of recycled or remanufactured input flows. As is the case in natural ecosystems, where scavengers metabolize waste before it becomes useful to other members of the ecosystem, RRWT firms provide the metabolizing function between recovered

products and materials and their reuse as materials or functional wholes.

RRWT firms purchase or charge for raw inputs (unprocessed material or used goods) from suppliers, process them (via sorting, aggregating, separation, compaction, and/or refurbishment), and search for customers to sell their outputs. The spatial extent of this interaction represents the firm's cycling boundary. Collectively, the input-output boundaries of a set of firms located in a given place constitute the cycling boundaries of that place. In some cases RRWT firms will source a large share of their inputs from within the region and/or find the outlet for their goods within the same territory. In other cases they may source their inputs or outputs beyond the region, with the majority of suppliers and customers being located in other places.

Much of the internal activity of RRWT firms is gathering, sorting, aggregating, and reprocessing relatively low-value and often bulky materials, with high transport costs and tight profit margins. RRWT firms (like other primary commodity industries) are likely to source high levels of input locally, thus limiting the cycling boundary of RRWT firm input flows to the local region. RRWT outputs, however, may not find the best markets within their local region. For example, outputs redirected to specific primary processing firms (e.g., mills) will stay in the region only if an economically viable mill is present. Scarcity in other regions may drive prices high enough to cover the additional costs of shipping output to a more distant region (e.g., waste paper from Texas to Mexico). Differences in labor and technology costs may influence flows also. For example, cheap labor rates in Singapore allow Citiraya Industries Ltd. to recapture 90% of the electronic waste it receives as opposed to the 65% recapture rate in Europe using automated systems. Such differentials in labor and technology costs are shifting greater volumes of U.S. electronic waste flows to Southeast Asia (Prystay, 2004).

## Research Methodology

The central question posited here is at what geographic scale loop closing for heterogeneous and spatially diffuse wastes is best achieved. In other words, at what spatial scale can used mate-

rials and products be cycled back to production processes? The answer to this question is structured in two ways using data generated from a questionnaire survey<sup>3</sup> sample of recycling, remanufacturing, recycling manufacturing, and waste treatment firms in Texas. First, the location patterns of the firms are analyzed to query if RRWT firms are concentrated at any single level of the settlement hierarchy. Second, the cycling (territorial) boundaries of RRWT input-output linkages are examined to assess the extent to which they are constructed locally.

The names, addresses, employment sizes, and materials handled by RRWT firms operating in Texas were identified from the State of Texas's Commission on Environmental Quality's Material Exchange Web site during the spring of 2002 (Texas Commission on Environmental Quality 2002). The total population of firms was 367. The survey employed a modified total design method (TDM), which is a four-stage mailing sequence technique designed to generate high response rates (Dillman 2000). Of the 367 questionnaires sent out during the spring of 2002, the U.S. Postal Service returned 80 as undeliverable and 103 were completed, generating a response rate of 38 percent. The questionnaire was directed to the contact person listed on the material exchange Web site. T-tests comparing mean employment levels among the sample firms and employment levels of the total population of firms listed on the Material Exchange Web site revealed no statistical differences.

## Results of the Survey

### General Characteristics of the Sample Firms

The firms in the sample are classified in the first instance as follows: recycling (60%), remanufacturing and recycling manufacturing (33%), and waste treatment firms (7%) (table 1). Recyclers are subdivided into scrap metal recyclers, municipal recyclers (principally aluminum cans, paper,<sup>4</sup> PET and HDPE bottles, and soda-lime-silica glass), paper recyclers, and niche recyclers (e.g., precious metals, oil, food, grease, construction fill). Remanufacturers are subdivided into niche components (e.g., wood pallets, industrial

**Table 1** Basic characteristics of Texas RRWT sample firms in 2002 ( $N = 103$ )

Type of Firm	% of total	% <50 employees	% HQ <sup>a</sup> in Texas	% founded pre-1970
<b>Recycling</b>	<b>60</b>	<b>89(53<sup>b</sup>)</b>	<b>88</b>	<b>66</b>
Scrap metals	28	92(25 <sup>b</sup> )	89	57
Municipal	18	94(16 <sup>b</sup> )	71	24
Paper	5	100(3 <sup>b</sup> )	60	40
Niche	10	67(9 <sup>b</sup> )	67	22
<b>Remanufacturers and recycling manufacturers</b>	<b>33</b>	<b>77(26<sup>b</sup>)</b>	<b>89</b>	<b>47</b>
Compost manufacturers	12	72(7 <sup>b</sup> )	100	8
Niche components	7	100(5 <sup>b</sup> )	100	14
Electronic components	6	83(6 <sup>b</sup> )	100	0
Plastic recycling manufacturers	5	50(4 <sup>b</sup> )	60	0
Paper recycling manufacturers	4	75(4 <sup>b</sup> )	50	75
<b>Waste treatment</b>	<b>7</b>	<b>82(6<sup>b</sup>)</b>	<b>43</b>	<b>29</b>
<b>Total</b>	<b>100</b>	<b>82(85<sup>b</sup>)</b>	<b>79</b>	<b>31</b>

Source: Author questionnaire, 2002.

<sup>a</sup>Percentage of firms with company headquarters located in Texas.

<sup>b</sup>Raw number of firms responding to this question.

reels, textiles, furniture) and electronic components (e.g., toner cartridges) firms, whereas recycling manufacturers include compost manufacturers, plastic recycling manufacturing (e.g., garden decks, primary compounds), and paper recycling manufacturing (e.g., industrial packaging, paperboard, boxes). Waste treatment firms include those treating and/or disposing of hazardous and nonhazardous industrial and municipal waste.

Most of the recycling firms are small, although the niche recyclers include a few large firms that recycle precious metals and petroleum products. Scrap recyclers are generally small, older, Texas-based firms, in contrast to municipal, paper, and niche recyclers, which are younger and somewhat more likely to be branches of companies headquartered outside the state. Compost manufacturers and niche and electronic recycling and remanufacturers are dominated by small, young, Texas-based firms, with about one-third of the composters directly owned wholly or in part by local governments. Waste treatment firms and paper and plastic recycling manufacturers are somewhat larger in size, are more likely to be headquartered outside the state, and are relatively older.

Approximately one-fifth of the firms listed future expansion plans, ranging from increasing the size and scope (more materials/component types)

of operations to new capital inputs. Another one-fifth said they had expansion plans but did not specify their nature. Expansion plan rates were highest among paper and niche recyclers, electronic recyclers and component remanufacturers, paper recycling manufacturers, and waste treatment firms. Electronic recyclers and component remanufacturers, along with compost manufacturers, were also the most optimistic about the future<sup>5</sup> of their business.

### RRWT Firm Location and Settlement Hierarchy

RRWT firms are found throughout the Texas settlement hierarchy (table 2). Approximately half (56%) of all RRWT firms are located in major metropolitan areas (Dallas-Fort Worth, Houston-Galveston, San Antonio, and Austin-San Marcos). This is a somewhat lower proportion than the settlements' share of total state population and manufacturing employment (61 and 68%, respectively). Minor metropolitan<sup>6</sup> areas account for an additional 23% of Texas RRWT firms—a share equivalent to their share of state population but somewhat larger than their share of manufacturing employment. Non-metropolitan areas account for 20% of RRWT firms compared to 15% of the population and 13% of manufacturing employment. Location in

**Table 2** Texas settlement hierarchy and RRWT firm location in 2002

Type of firm	Percentage of firms located in		
	Major metropolitan areas <sup>a</sup>	Minor metropolitan areas <sup>b</sup>	Nonmetropolitan areas <sup>c</sup>
<b>Recycling*</b>	<b>54.8</b>	<b>30.6</b>	<b>14.5</b>
Scrap metals	51.7	37.9	10.3
Municipal	38.9	44.4	16.7
Paper	100	0	0
Niche	70.0	0	30
<b>Remanufacturers and recycling manufacturers*</b>	<b>52.9</b>	<b>11.8</b>	<b>35.3</b>
Compost manufacturers	41.7	8.3	50.0
Niche components	57.1	28.6	14.3
Electronic recyclers and component manufacturers	66.7	16.7	16.7
Plastic recycling manufacturers	40.0	0.0	60.0
Paper recycling manufacturers	75.0	0	25.0
<b>Waste treatment*</b>	<b>85.7</b>	<b>14.3</b>	<b>0</b>
<b>Total</b>	<b>56.3</b>	<b>23.3</b>	<b>20.4</b>
State comparisons			
Population	61.0	23.8	15.2
Manufacturing employment	67.6	19.2	13.2

Source: Author questionnaire, 2002.

<sup>a</sup>Major metropolitan is defined as population size in excess of 1 million.

<sup>b</sup>Minor metropolitan is defined as population size between 100,000 and 1,000,000.

<sup>c</sup>Nonmetropolitan is defined as places that do not meet the U.S. Census Bureau's definition of a metropolitan area (e.g., Alpine, Crockett, Texas) or rural locations.

\* $\chi^2 = 11.00$ ,  $p = 0.027$  for a  $3 \times 3$  cross-tabulation between recycling, remanufacturing/cycling manufacturing, waste treatment and position within the settlement hierarchy.

the settlement hierarchy was statistically independent of firm size ( $\chi^2 = 3.85$ ,  $p = 0.697$ ), age ( $\chi^2 = 4.72$ ,  $p = 0.317$ ), and corporate organization ( $\chi^2 = 4.99$ ,  $p = 0.288$ ).

These results suggest that RRWT firms can operate successfully at many levels of the settlement hierarchy. In part, the reason is transport costs. Most of the firms strongly agree<sup>7</sup> that transportation costs limit their market areas. The unique pricing structure of many RRWT firm inputs is important also. Half of the ten types of firms listed in table 2 receive the largest portion of their inputs free. Scrap metals and plastic and paper recycling manufacturing firms buy (77, 60, and 67% respectively) the majority of their product, and compost manufacturers and waste treatment firms charge for their inputs (68 and 99%, respectively). Free inputs reduce the overall processing costs of the firms, allowing them to operate at lower minimum thresholds and consequently, at

lower levels of the settlement hierarchy. Charging for inputs shifts any additional transport or other costs away from the RRWT firm, allowing a greater range of locational possibilities. These results imply that no single level is the most suitable for RRWT firm loop closing.

### The Spatial Structure of Cycling

The sample firms were asked what proportions (in mass) of their current (2002) inputs and outputs were derived from, and sold to, local, regional (state of Texas), and national (U.S.) sources. Three types of closed-loop territorial structure are evident from an analysis of the origin of input flows and the destination of output flows, with all three having very high levels of local inputs (within the county or metropolitan area in which the firm is located) (table 3). A first group includes compost manufacturers and niche

**Table 3** The spatial structure of cycling among Texas RRWT firms in 2002, by mass

Type of firm	Local area		State of Texas		U.S./global	
	Inputs %	Outputs %	Inputs %	Outputs %	Inputs %	Outputs %
<b>Local cycling</b>	<b>83.5</b>	<b>56.5</b>	<b>9.1</b>	<b>25.8</b>	<b>7.4</b>	<b>17.7</b>
Compost manufacture	84.7	54.2	7.3	33.5	8.1	12.4
Niche components remanufacture	85.0	57.9	13.4	15.0	1.6	27.1
Electronic recycling and components remanufacture	78.6	59.6	7.4	24.2	14.0	16.2
<b>Export cycling</b>	<b>80.9</b>	<b>23.5</b>	<b>12.1</b>	<b>39.7</b>	<b>7.0</b>	<b>36.8</b>
Scrap metals recycling	81.0	27.4	11.5	37.6	7.5	35.0
Municipal recycling	84.2	31.7	12.8	47.5	3.1	20.9
Paper recycling	97.0	3.4	3.0	8.2	0.0	88.4
Paper recycling manufacture	48.8	3.8	22.5	70.0	28.8	26.3
<b>Multiscale cycling</b>	<b>36.5</b>	<b>39.7</b>	<b>34.8</b>	<b>30.6</b>	<b>28.8</b>	<b>29.7</b>
Waste treatment	34.0	43.5	19.3	10.3	46.7	46.2
Niche recycling	38.0	36.4	44.0	48.0	18.0	15.6
<b>Other</b>	<b>9.2</b>	<b>0.3</b>	<b>16.0</b>	<b>50.0</b>	<b>74.8</b>	<b>50.0</b>
Plastic recycling manufacture	9.2	0.3	16.0	50.0	74.8	50.0
<b>TOTAL</b>	<b>70.7</b>	<b>34.5</b>	<b>15.2</b>	<b>34.8</b>	<b>14.1</b>	<b>30.8</b>
One-way ANOVA, <i>P</i> -value	0.001	0.118	0.018	0.065	0.002	0.010

Source: Author questionnaire, 2002.

and electronic recyclers and component remanufacturers and can be described as local cycling. Here input and output flows are organized primarily at the local level: local inputs exceed 75% and more than half of outputs are redirected locally.

A second group consists of scrap, municipal, paper recycling, and paper recycling manufacturing firms and can be termed export cycling. Local inputs exceed 75%, but outputs (more than 75%) are primarily regional (throughout the state) and/or national/global. Paper recycling is a particularly good example of this tendency, with 97% collected locally and 44% of output flowing abroad (much of it to Mexico).

A third group is clustered also but was identified at different scales and consists of niche recyclers and waste treatment firms. Firms in this group that have high levels of local inputs tend to have higher levels of local outputs, firms with primarily regional inputs have regional outputs, and so on.<sup>8</sup> We can refer to this group as multiscale cycling. The remaining category, plastic recycling manufacturing, reflects a more distinctive case because of Texas' industrial concentrations in petrochemicals.<sup>9</sup>

Overall, the firms draw approximately equal portions (in mass) of their current inputs from commercial, industrial, and municipal sources and sell approximately equal portions of their outputs to the primary (e.g., pulp or steel mills) and secondary (e.g., finished products) sectors of the economy (table 4). The local cycling group (composters, niche, and electronic components) get the majority of their inputs from local commercial sectors, although municipal sources are also important, and redirect much of their outputs to secondary sector markets.

Input and output sources for the export cycling group are more diverse. Scrap and municipal recyclers obtain approximately half their inputs from local municipal sources, with a substantial majority of their outputs flowing to the primary sector. Paper recycling manufacturers acquire most of their inputs from municipal sources, and paper recyclers focus upon commercial sources; both direct their output to the secondary sector. Inputs to the multiscale cycling group (waste treatment and niche recycling firms) come from both commercial and industrial sources and outputs flow to secondary market sources.

**Table 4** The economic structure of cycling among Texas RRWT firms in 2002, by mass

Type of firm	Inputs (%)			Outputs (%)		
	Commercial	Industrial	Municipal <sup>a</sup>	Primary <sup>b</sup>	Secondary <sup>c</sup>	Other <sup>d</sup>
<b>Local cycling</b>	<b>53.8</b>	<b>15.4</b>	<b>30.8</b>	<b>14.6</b>	<b>71.3</b>	<b>14.2</b>
Compost manufacture	50.9	11.4	37.7	1.0	80.0	19.1
Niche components remanufacture	48.9	26.4	24.7	23.6	62.0	14.3
Electronic recycling and components remanufacture	65.0	10.0	25.0	29.2	65.8	5.0
<b>Export cycling</b>	<b>26.1</b>	<b>28.5</b>	<b>45.4</b>	<b>63.0</b>	<b>36.3</b>	<b>0.7</b>
Scrap metals recycling	20.3	34.9	44.8	71.6	28.4	0
Municipal recycling	32.5	18.6	48.8	68.3	28.4	3.3
Paper recycling	52.4	33.6	14.0	30.0	70.0	0
Paper recycling manufacture	5.5	21.3	73.3	10.0	90.0	0
<b>Multiscale cycling</b>	<b>40.1</b>	<b>48.0</b>	<b>11.9</b>	<b>18.2</b>	<b>67.8</b>	<b>14.1</b>
Waste treatment	48.9	41.4	9.8	5.0	95.0	0
Niche recycling	32.5	53.8	13.8	21.1	61.7	17.2
<b>Other</b>	<b>38.0</b>	<b>47.0</b>	<b>15.0</b>	<b>53.3</b>	<b>46.7</b>	<b>0</b>
Plastic recycling manufacture	38.0	47.0	15.0	53.3	46.7	0
<b>TOTAL</b>	<b>35.6</b>	<b>29.2</b>	<b>35.2</b>	<b>42.0</b>	<b>51.5</b>	<b>6.6</b>
One-way ANOVA, P-value	0.005	0.035	0.005	0.000	0.004	0.214

Source: Author questionnaire, 2002.

<sup>a</sup>Municipal includes local government contracts, brokers, drive-ups, and smaller firms.

<sup>b</sup>Primary includes larger firms in the same sector and/or firms that transform RRWT outputs to meet standard mill specifications.

<sup>c</sup>Secondary includes firms that use RRWT outputs directly in their business or that manufacture finished products.

<sup>d</sup>Other includes firms that use RRWT outputs for energy recovery and for other nonspecified purposes.

The local cycling group seems to represent the ideal type of closed loop conceptualized originally by IE, with the remanufacturing and recycling manufacturing firms closing the loop between used and new goods emanating from and being (re)consumed by the local commercial sector. Without primary industries to absorb the recovered wastes, it is unlikely, however, that the export-oriented group could be structured similarly. Even with primary industries, however, areas below a certain volume threshold would not be able to sustain a primary sector firm, so it is likely that closing the loop for scrap, municipal, and paper recycling and recycling manufacturing will be characterized by flows beyond the local level.

The multiple scale group seems to fit the conceptual framework of IE also, but with the potential to operate at (or across) a variety of scales. In part, however, this may reflect the variety of firm types within this group. For example, the waste treatment group includes both hazardous

and nonhazardous waste handlers. Whereas nonhazardous waste cannot absorb substantial transport costs and is likely to be organized locally, the hazardous waste sector is driven by technology and differences in state environmental regulation. As one hazardous waste CEO stated, it is cheaper to ship hazardous wastes from California to Texas for processing than to establish or expand a hazardous waste facility in California. A larger sample of waste treatment and niche recycling firms in a future study might clarify this pattern.

The cycling boundaries identified above are statistically independent of firm location within the settlement hierarchy (table 5). Although there is some tendency for firms located in major metropolitan areas to have higher levels of local input and outputs (e.g., large metropolitan areas source 72% of inputs locally compared to 61% percent for nonmetropolitan areas) and firms in nonmetropolitan areas to draw greater shares of inputs and sell outputs beyond the local area,

**Table 5** Texas settlement hierarchy and the spatial structure of cycling flows in 2002, by mass

Position in settlement hierarchy	Local area		State of Texas		U.S./global	
	Inputs %	Outputs %	Inputs %	Outputs %	Inputs %	Outputs %
Large metropolitan area	72.0	37.5	14.2	30.1	14.1	32.4
Small metropolitan area	76.3	35.7	12.7	35.9	11.0	28.4
Nonmetropolitan area	61.4	30.7	20.9	44.2	17.7	25.1
One-way ANOVA, <i>P</i> -value	0.403	0.861	0.472	0.418	0.711	0.790

Source: Author questionnaire, 2002.

these differences do not reach the level of statistical significance. These results suggest that the cycling boundaries of RRWT firms are not dependent upon a firm's location in the settlement hierarchy. In addition, they suggest that we cannot assign loop closing to any particular spatial scale a priori, nor can we conceive of closing the loop via RRWT firms in terms of monolithic networks bounded in space or place with internal material flows.

## Discussion and Conclusions

The central question of this article is what is the best geographic scale for loop closing to take place for consumed materials and goods. The results suggest that there is no preferable scale at which loop closing should be organized. RRWT firms operate successfully throughout the settlement hierarchy—echoing Andrews and Maurer's (2001) comment that such firms are ubiquitous in the industrial ecosystem. The high proportions of free inputs suggest that many of these activities remain economically marginal to the larger economy, but in a capitalist system, firms will always emerge if profits can be realized (Desrochers 2002). This is encouraging because it demonstrates that loop closing can take place throughout the settlement hierarchy.

The local cycling group (compost, niche, and electronic recycling and component remanufacturers) may represent the ideal type of industrial cycling, but it is unlikely that loop closing can occur at the local level for the export cycling group, for two reasons. First, the dominant economic logic of the transactions of the export group is driven by their inputs rather than by their outputs. Just as paper mills locate near forests, and petrochemical plants near refineries, the export

cycling group locates at the sources of their inputs (i.e., wastes). In each case, the reason is that bulky, relatively low-value inputs are expensive to ship. This limits the territory from which a firm can gather inputs.<sup>10</sup> By sorting and aggregating the inputs locally, the firms increase their economic value and decrease their overall volume, both of which reduce the significance of transportation costs. Higher value outputs can incur greater transportation costs, allowing the firms to search for markets over a wider area than for inputs.

Second, the outputs of the export group are redirected to large integrated primary processing firms such as paper or steel mills, whose locations are determined by distance from both virgin and recycled inputs and final markets. Only the largest recycled material flows are likely to influence the location decisions of these firms. Technology has made it possible to operate some types of mills on a smaller scale (e.g., steel minimills consume smaller volumes of steel scrap as their primary material input and consequently have a much wider range of suitable geographic locations than integrated mills), but even small mills are constrained by minimum volume and quality input thresholds and proximity to markets for their outputs.

These results have implications for how we understand the scale at which cycling can take place. Closing the loop locally may be possible for some items, but it is probably the exception rather than the rule for heterogeneous wastes. This result should not be surprising. Firms sometimes source large shares of their inputs locally and/or find markets for their outputs within the local region, but more often firms are linked to the outside world, with the majority of their suppliers and customers located in other places. Even

in the celebrated industrial districts of Silicon Valley, Cambridge, U.K., Baden-Württemberg, Germany, or the Po Basin in Italy, the majority of linkages are to firms well beyond the local area (Lyons 2000). Closing the loop is ultimately about linkages between firms operating within free markets, so we should expect that cycling would operate in a manner similar to other firm linkages, that is, combinations of local, regional, national, and global relationships.

These results offer insights on the question of co-location to designers of eco-industrial systems. It should be pointed out, however, that the results are limited by the scale and scope of the study. Because there are just over 100 observations in the sample, caution is urged in interpreting the findings regarding the smaller subgroups, because chance variation could sway the results. In addition, Texas has spatial and economic characteristics that may not be representative of other parts of the world. For example, very large distances separate the four major metropolitan areas, and even the smaller metropolitan areas are relatively widely dispersed. The relative lack of manufacturing activity (compared to the concentrations in the states of the traditional manufacturing belt of the United States) and the highly concentrated petrochemical industry along the Texas Gulf Coast may influence the geography of some cycling flows also.

Nevertheless, the study presents an empirical snapshot and interpretation of the spatial structure of RRWT firms in Texas and presents three questions that can be explored more deeply in future research. First, much more work needs to be done on the issue of transportation costs, economies of scale, and location. For example, are more capital-intensive RRWT firms able to overcome the issue of transport costs, and to what extent are consumers of RRWT outputs influenced by flows of recycled inputs? Second, the physical characteristics of input-output flows are only the beginning of our understanding of interfirm connections. Profitable input-output relationships (and subsequently successful firms and territories) occur within the context of information flows between the firms and their suppliers and customers that include elements of the local business environment and the sociocultural nature of the transaction(s) between the firms

(Lyons 2005). An understanding of how RRWT firms communicate with each other is of central importance. Finally, further studies need to examine individual RRWT sectors using either national or international frameworks. This would allow researchers to design measurement tools (e.g., questionnaire surveys) specifically oriented to particular sectors and to examine whether those dynamics vary across different places.

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## Notes

1. *Local* or *locally* generally refers to the immediate place (e.g., town, city, county, metropolitan area) within which the firm is situated. In the questionnaire, local was defined as the county or metropolitan area within which the firm or establishment resides.
2. This is becoming increasingly important in the disposal of electronic waste (e.g., CRTs). Electronic manufacturers are worried that improper disposal of used electronic goods may result in costly litigation in the future.
3. A copy of the questionnaire and related data from the survey are available as an e-supplement to this article on the journal Web site.
4. Paper is classified under three different categories, depending upon specificity and function. Firms collecting paper along with other municipal materials are classified under municipal recycling, firms specializing in paper are classified under paper recycling, whereas firms using pre- or postconsumer paper to make new products (e.g., boxes) are classified under paper recycling manufacturing.
5. Scoring 4.5, on a 5-point scale, with 5 being most important, in response to the statement, "The potential for growth in this sector is high."
6. An additional 21 metropolitan regions (e.g., Lubbock, Waco).
7. Scoring 4 on a 5 point scale, with 5 being very important, in response to the statement, "Transport

costs limit the size of the market area in which I can operate.”

8. These tendencies are statistically significant. Firms with primarily: local inputs/outputs,  $R_i = 0.587$ ,  $p = 0.045$ ; regional inputs/outputs,  $R_i = 0.857$ ,  $p = 0.000$ ; and national inputs/outputs,  $R_i = 0.737$ ,  $p = 0.006$ . They are also independent of firm size and corporate type.
9. The Texas Gulf Coast contains the single largest concentration of petrochemical industries in the country (Lyons and Luker, 1998).
10. In certain situations differential labor, regulatory, and disposal costs may outweigh the impact of transportation costs.

## References

- Allenby, B. R. 1994. Integrating environment and technology: Design for environment. In *The greening of industrial systems*, edited by B. R. Allenby and D. J. Richards. Washington, DC: National Academy of Engineering.
- Andrews, C. J. and J. Maurer. 2001. Materials exchanges: An exploratory US survey. *Local Environment* 6(2): 149–2001.
- Boons, F. and M. Berends. 2001. Stretching the boundary: The possibilities of flexibility as an organizational capability in industrial ecology. *Business Strategy and the Environment* 10(2): 115–124.
- Chertow, M. R. 2000. Industrial symbiosis: Literature and taxonomy. *Annual Review of Energy and the Environment* 25(1): 313–337.
- Chertow, M. R. 2004. Differentiating industrial complexes and industrial symbiosis. Paper presented at the Annual Meeting of the Association of American Geographers, March, Philadelphia.
- Cohen-Rosenthal, E. 1996. Designing eco-industrial parks: The US experience. *UNEP Industry and Environment* October–December: 14–18.
- Cohen-Rosenthal, E. 2000. A walk on the human side of industrial ecology. *American Behavioral Scientist* 44(2): 245–264.
- Cohen-Rosenthal, E. 2004. Making sense out of industrial ecology: A framework for analysis and action. *Journal of Cleaner Production* 12(8–10): 1111–1123.
- Côté, R. and E. Cohen-Rosenthal. 1998. Designing eco-industrial parks: A synthesis of some experiences. *Journal of Cleaner Production* 6(3–4): 181–188.
- Deschenes, P. J. and M. Chertow. 2004. An island approach to industrial ecology: Towards sustainability in the island context. *Journal of Environmental Planning and Management* 47(2): 201–217.
- Desrochers, P. 2002. Cities and industrial symbiosis: Some historical perspectives and policy implications. *Journal of Industrial Ecology* 5(4): 29–44.
- Desrochers, P. 2004. Industrial symbiosis: The case for market coordination. *Journal of Cleaner Production* 12: 1099–1110.
- Deutz, P. and D. Gibbs. 2004. Eco-industrial development and economic development: Industrial ecology or place promotion. *Business Strategy and the Environment* 13(5): 347–362.
- Dillman, D. 2000. *Mail and Internet surveys: The tailored design method*. New York: Wiley.
- Ehrenfeld, J. R. 2000. Industry ecology: Paradigm shift or normal science? *American Behavioral Scientist* 44(2): 229–244.
- Fichtner, W., I. Tietze-Stöckinger, and O. Rentz. 2004. On industrial symbiosis networks and their classification. *Progress in Industrial Ecology* 1(1–3): 130–142.
- Frosch, R. A. 1995. Industrial ecology. *Environment* 37(10): 17–337.
- Frosch, R. A. and N. E. Gallopoulos. 1992. Towards an industrial ecology. In *The treatment and handling of wastes*, edited by A. D. Bradshaw et al. London: Chapman and Hall.
- Gibbs, D. and Deutz, P. 2005. Implementing industrial ecology? Planning for eco-industrial parks in the USA. *Geoforum* 36(4): 452–464.
- Hawkins, P., A. Lovins, and L. H. Lovins. 1999. *Natural capitalism*. Boston: Little, Brown and Company.
- Korhonen, J. 2002. Two paths to industrial ecology: Applying the product-based and geographical approaches. *Journal of Environmental Planning and Management* 45(1): 39–57.
- Lambert, A. J. D. and F. A. Boons. 2002. Eco-industrial parks: Stimulating sustainable development in mixed industrial parks. *Technovation* 22(8): 471–484.
- Lifset, R. 2002. Editorial: Closing the loop and honing our tools. *Journal of Industrial Ecology* 5(4): 1–2.
- Lyons, D. 2000. Agglomeration, milieu and innovation in high technology districts: A Richardson Texas case study. *Environment and Planning A* 32(5): 891–908.
- Lyons, D. 2005. Integrating waste, manufacturing and industrial symbiosis: An analysis of recycling, remanufacturing and waste treatment firms in Texas. *Local Environment* 10(1): 71–86.
- Lyons, D. and B. Luker. 1998. The contemporary spatial structure of high-technology employment in Texas and the production context from which it emerged. *Urban Geography* 19(5): 431–458.

- Posch, A. 2004. Industrial recycling networks: Results of rational decision making or “organized anarchies”? *Progress in Industrial Ecology* 1 (1–3): 112–129.
- Prystay, C. 2004. Recycling ‘E-waste’: Singapore company finds global edge in processing toxic computers, TVs safely. *Wall Street Journal*, 23 September, B.1.
- Sterr, T. and T. Ott. 2004. The industrial region as a promising unit for eco-industrial development—Reflections, practical experience and establishment of innovative instruments to support industrial ecology. *Journal of Cleaner Production* 12(8–10): 947–965.
- Texas Commission on Environmental Quality. 2002. Recycle Texas online. <[www.tnrcc.state.tx.us/exec/sbea/rtol/](http://www.tnrcc.state.tx.us/exec/sbea/rtol/)>. Accessed February 2002.
- Yang, P. P. and O. B. Lay. 2004. Applying ecosystem concepts to the planning of industrial areas: A case study of Singapore’s Jurong Island. *Journal of Cleaner Production* 12(8–10): 1011–1023.

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