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Integrating Waste, Manufacturing and Industrial Symbiosis: an Analysis of Recycling, Remanufacturing and Waste Treatment Firms in Texas

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ABSTRACT The continually increasing volume of the waste stream has led to numerous calls for strategies to close the loop on material use through industrial symbiosis strategies which direct used material and products (wastes) back to production processes. By use of a survey of recycling, remanufacturing and waste treatment firms in Texas, this paper asks if these firms can operate as a bridge between production and consumption/waste to efficiently increase the flow of used materials and products back to production processes at the local level. The results suggest that while most materials and used products are collected locally, only some can be re(consumed) locally. Moreover, the firms face negative perceptions about their activities from industry and the public at large that likely slow both the rate of entry of new firms into these markets and the expansion possibilities of existing firms. In addition, the types of conventions that characterize the interactions of more successful firms are not well developed in this sector(s). It is unlikely that recycling, remanufacturing and waste treatment firms can become central players in the production, consumption and waste cycle loop until society develops production design, marketing and consumption philosophies that include recycling and remanufacturing at a fundamental level.

Introduction

Traditionally waste is defined as something that is perceived to have either no inherent value to its owner, or the amount of effort required to access that value is greater than the expected return. Hence, waste is a residual that is

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discarded. American society generates close to eight billion tons of non-hazardous waste per year from a variety of industrial and municipal sources (US Environmental Protection Agency, 2002). The continually increasing volume of the waste stream has led to numerous calls for practicable ways to restructure the waste dimension of the economy as part of a larger effort to move society toward a more environmentally sustainable future. One approach argues that society should strive toward reducing the generation of wastes by creating more efficient networks between firms such that used goods and materials (i.e., waste) are redirected back into production processes, thus more closely mimicking the material efficiency of natural ecosystems (Allenby, 1994; Chertow, 2000; Ehrenfeld, 2000). The central question of this paper is to examine if recycling, remanufacturing and waste treatment (RRWT) firms can be promoted as a bridge to close the loop and thereby increase flows of used materials and products (wastes) back to production processes at the local level.

While there are many limits to recycling and remanufacturing (technological, environmental and economic), the advantages are manifold. They can substantially reduce the ultimate volume of waste, the demand for virgin raw materials and the cost of waste disposal. Moreover, RRWT firms have a direct and immediate interest in improving the efficiency of recycling, remanufacturing and waste treatment networks for purely profit motives the outcome of which leads to environmental improvements without the firms having to be inculcated by environmental concerns either collectively or individually.

Literature Review

Industrial Symbiosis and the Role of RRWT Firms

Recognition of the negative environmental impacts of resource exploitation have led to the emergence of new approaches to the relationship between production and the environment (Brundtland, 1987; Hawkins *et al.*, 1999; Rifkin, 2000). The most extensive body of theoretical work that focuses on the connections between production, consumption and waste is 'industrial ecology' (Frosch and Gallopoulos, 1992; Ehrenfeld, 2000). The key element of industrial ecology that is of interest here is the concept of closing the loop on material use: diverting products and materials destined for disposal to productive uses through the process of industrial symbiosis (Chertow, 2000). Industrial symbiosis (IS) refers to the physical exchange of material, energy and water flows (especially unused byproducts) among networks of businesses and industrial firms operating in relatively close proximity and the context within which these flows are constructed and maintained over time (Cohen-Rosenthal, 2000; Korhonen, 2002; Boons and Berends 2001).

Within the literature there is a tug of war between two basic polarities: engineered systems and self-organizing systems (Côté and Cohen-Rosenthal, 1998). Engineered systems focus upon innovatively engineered

'pipe-to-pipe' strategies among co-located firms as the basis for a more sustainable industrial system. The self-organizing approach focuses on the development of profitable and environmentally sound input-output linkages among local clusters of firms and the surrounding community to achieve economic gains and improvements in environmental quality.

Research has demonstrated the success of pipe-to-pipe IS among co-located firms, especially among primary processing industries that generate large continuous process waste streams (Lowe and Evans, 1995). There is some evidence of complex profitable inter-industry recycling networks among firms in Styria (Austria) and the Ruhr region in Germany (Schwarz and Steininger, 1997), but whether loop closing through IS can be extended to localities where production and consumption are more spatially diffuse and wastes more heterogeneous is unclear and poorly understood (Lambert and Boons, 2002).

One possibility to close the loop more effectively is to promote recycling, remanufacturing and waste treatment (RRWT) firms as a way of achieving a greater degree of industrial symbiosis among industrial firms and consumers at the local level. A viable scrap industry has existed in the US since the middle of the nineteenth century (Zimring, 2002) and 'loop closing' through industrial symbiosis was part of the everyday culture of industrial firms in nineteenth century Victorian England (Desrochers, 2000). Beck (2001, p. ES.2) estimate that the US hosts 56,061 recycling, remanufacturing and reuse establishments, employing approximately 1.1 million people, while Andrews and Maurer (2001, p. 152) estimate that US reuse, repair, remanufacturing and recycling industries together employ over 2 million people—numbers that are considerably larger than the entire waste disposal industry.

At the same time, many potentially valuable materials end up as waste, overall recycling rates for many materials and goods are still relatively low[1], and the total volume of waste continues to increase each year (Goldstein and Madtes, 2001). Can RRWT firms be used to increase the amount of materials and goods being redirected to production processes at the local scale, and, if so, what obstacles do they face? To begin to answer this question we must examine both RRWT firm input-output linkages and the inter-firm and local cultural context within which these linkages are constructed.

Territorial Economy and Industrial Symbiosis

RRWT firms purchase or charge for raw inputs (unprocessed recyclables) from suppliers, process them (via sorting, aggregating, and/or refurbishment)

[1]Approximately 30% of all US municipal waste was recycled in 2001 (Goldstein and Madtes, 2001); aluminum recovery from scrap recycling accounts for 35–40% of the available supply of aluminum (US Geological Survey, 2001); iron, including steel, rates were at 64%—rising to 95% for automobiles and construction structural beams and plates, 84% for appliances, 58% for steel cans and 40% for rebar and other materials (Steel Recycling Institute, 2002); soda-lime-silica glass bottles are recycled at about 37%, PET and HDPE plastic bottles a little less than 25% with remaining types less than 5%; 4% for rubber and 35% for paper (Institute of Scrap Recycling Industries, 2002a, b).

and search for customers to sell their outputs. The spatial extent of this interaction constitutes their territorial economy, i.e., the economic boundaries of a set of firms within a given segment of space (See Dicken and Malmberg, 2001) and is analogous to the spatial manifestation of their industrial symbiosis potential. Given that much of the internal activity of RRWT firms is sorting, aggregating and reprocessing relatively low value and often bulky materials, with high transport costs and tight profit margins, it is likely that RRWT firms (like other primary commodity industries) would source high levels of input locally thus limiting the territorial economy of RRWT firm input flows. However, to the extent that outputs are redirected to primary sector point sources (e.g., mills) outputs are very likely to move beyond the local territory. On the other hand, outputs redirected to the secondary sector may find both local and non-local markets.

Firm Conventions and Industrial Symbiosis

Like all markets, the input-output transactions of RRWT firms (i.e., their industrial symbiosis potential) involve a variety of uncertainties and fluctuations (e.g., supply, quality, demand and price) which are resolved through the evolution of 'conventions', or 'taken for granted' rules and routines that allow firms to communicate, interpret and coordinate their actions (Storper, 1999). The specific nature of these conventions varies widely across different networks of firms in territories with some being more successful than others. The conventions that emerge among firms and territories characterized by high rates of innovation and economic growth include certain untraded interdependencies such as, flows of knowledge, customs or understandings, and trust (Granovetter, 1985; Grabher, 1997). These allow for the smooth development and exchange of tacit information leading to the possibility of new firm learning, rapid innovation and growth. Where such conventions and linkages are lacking competitiveness is reduced (Scott, 1996) thus limiting the volume of industrial symbiosis.

Since current production design strategies are geared toward processing virgin raw materials rather than recycled or remanufactured goods it may be more difficult for RRWT firms to respond with innovative production solutions to design problems that emerge in mainstream manufacturing thus reducing the need for interdependencies to emerge to disseminate new knowledge, opportunities or innovations (O'Brien, 1999).

Local Culture Context of Firm Activity and Industrial Symbiosis

A local culture within a territory that is supportive of the firms' activities is crucial for success also (Camagni, 1991). More specifically, to the extent that attitudes of the public, local financial institutions, governmental agencies, other firm sectors and business associations provide both material support (e.g., access to capital, applied scientific knowledge), and a sense of belonging and appreciation for the firms, an enabling environment is constructed within which firm and territorial success is more likely to

occur (Malmberg *et al.*, 1996). Myer and Kent (2001) have argued that federal government tax breaks and other subsidies for virgin material extraction and the waste disposal industry, estimated to be $2.6 billion per year by the Grassroots Recycling Network (1999), may make it harder for RRWT firms to compete, contributing negatively to the industry's sense of self worth. However, Koplow and Dietly (1994) and Ackerman (1997) contend that existing virgin material subsidies are not important barriers to recycling because virgin producers generally do not compete directly with recycling firms, and in the few cases where they do compete, the subsidies are too small to make a difference.

Demand for recycled goods may present another difficulty in the cultural fabric within which RRWT firms operate. Recycled or remanufactured goods are often seen as inferior and cannot command prices similar to those charged by virgin producers (Ackerman, 1997). Andrews and Maurer's (2001) highlight a similar problem concluding that outreach and marketing to both donors/suppliers and users/customers presents the greatest challenge for operators of Material Exchanges. To move industry in the direction of more sustainable practices, including the ready acceptance of remanufactured and recycled products and materials will require fundamental changes in the culture of industrial societies, the technologies and systems used in the design, and the manufacture of products (Hawkins *et al.*, 1999).

Research Methodology

The central research question posited here asks if it is possible to promote RRWT firms as a way of increasing the amount of industrial symbiosis at the local level by examining a set of RRWT firms in Texas. The answer to this question is framed in three ways though the use of a questionnaire survey of a sample of recycling, remanufacturing and waste treatment firms in Texas. First, I analyze the territorial economy of RRWT input–output linkages to assess the extent to which they are constructed locally. Second, I examine elements of the local cultural environment within which the firms operate to see if it is conducive to success. Third, I identify the nature of knowledge related conventions among the firms, their customers and suppliers and analyze if they are favorable toward innovation and economic growth.

The names, addresses, employment size and materials handled by RRWT firms operating in Texas were identified from the State of Texas' Commission on Environmental Quality's Material Exchange website 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), 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, 80 were returned as undeliverable by the US Postal Service and 103 were completed, generating a response rate of 38%. The questionnaire was directed to the contact person listed on the material exchange website. T-tests comparing mean employment levels

Table 1. Basic characteristics of the sample firms

Type of Firm	% of total	% lt 50 employees	% HQs in Texas	% founded pre-1970
Recycling	*60*	*89*	*88*	*66*
Scrap metals	28	92	89	57
Diversionary	18	94	71	24
Paper	5	100	60	40
Niche	10	67	67	22
Remanufacturers	*33*	*77*	*89*	*47*
Compost	12	72	100	8
Niche core	7	100	100	14
Electronic core	6	83	100	0
Plastic	5	50	60	0
Paper	4	75	50	75
Waste treatment	*7*	*82*	*43*	*29*
Total	100	82	79	31

N = 103
Source: Author questionnaire, 2002.

among the sample firms and employment levels of the total population of firms listed on the Material Exchange website revealed no statistical differences.

Results of the Survey

General Characteristics of the Sample Firms

The 103 firms in the sample recycle, remanufacture or treat a broad array of materials and cores (items that still retain functional value). They are classified in the first instance as recycling (60%), remanufacturing (33%) and waste treatment firms (7%) (Table 1). Recyclers are further classified as scrap metal recyclers, diversionary recyclers (principally aluminum cans, paper,[2] PET and HDPE bottles, and soda-lime-silica glass), paper recyclers, and niche recyclers (precious metals, oil, food, grease, construction fill, etc). Remanufacturers are subdivided into compost remanufacturers, niche core (remanufacturing wood pallets, industrial reels, textiles, furniture, etc), electronic cores (e.g., toner cartridges), plastic remanufacturers (garden decks, primary compounds, etc) and paper remanufacturers (such as industrial packaging, paperboard, boxes). Waste treatment firms included those treating hazardous and non-hazardous industrial and municipal waste.

[2]Paper is classified under three different categories, depending upon specificity and function. Firms collecting paper along with other diversionary materials are classified under diversionary recycling, firms specializing in paper are classified under paper recycling, while firms using pre or post consumer paper to make new products (e.g., boxes) are classified under paper remanufacturing.

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 diversionary, paper and niche recyclers that are younger, and somewhat more likely to be branches of companies headquartered outside the state. Compost, niche and electronic remanufacturers are dominated by small, young, Texas based firms, with about one-third of the composters directly affiliated with local governments. Waste treatment firms, paper and plastic remanufacturers are somewhat larger in size, more likely to be headquartered outside the state and are relatively older.

The firms demonstrate relatively moderate rates of success: 19% of the firms listed future expansion plans ranging from increasing the size and scope (more materials/core types) of the operation to new capital inputs; an additional 22% said they had expansion plans but did not specify their nature. Expansion rates were highest among paper and niche recyclers, electronic core and paper remanufacturers and waste treatment firms. Electronic core remanufacturers, along with compost remanufacturers, were also the most optimistic about the future.[3]

The Territorial Economy of the Firms

An analysis of the territorial economy of the firms allows us to answer the question of whether RRWT firms can help close the loop at the local level. The firms exhibit three general types of territorial economy, with almost all firm categories having very high levels of local inputs (Table 2). A first group includes compost, niche and electronic core remanufacturers. Here input and output flows are generated primarily at the local level: inputs from local sources exceed 75%, while over half of outputs are redirected locally. This pattern is independent of firm size or corporate type. We can describe this pattern as locally clustered. A second tendency is reflected by scrap, diversionary and paper recycling and paper remanufacturing firms. Here, inputs are also primarily local (greater than 75%), but outputs are primarily regional and/or national (greater than 75%). Thus it is defined as export-oriented. Paper recycling is a particularly good example of this tendency with 97% collected locally and 44% of outputs flowing overseas (much of it to Mexico). This pattern is influenced by firm size and corporate type, with larger more corporate firms having lower levels of local input. A third tendency is also clustered but was identified at different scales and is reflected by niche recyclers and waste treatment firms. Here firms with high levels of local inputs tend to have higher levels of local outputs, firms with primarily regional inputs have regional outputs and so on.[4] The remaining

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[3]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'.

[4]These tendencies are statistically significant. Firms with primarily: local inputs/outputs, Rs = .587, p = .045, regional inputs/outputs, Rs = .857, p = .000, and national inputs/outputs, Rs.737, p = .006. They are also independent of firm size and corporate type.

Table 2. Geography of material inputs and outputs

	Local Area		State of Texas		US/Global	
Type of firm	Inputs	Outputs	Inputs	Outputs	Inputs	Outputs
Locally clustered	*83.5*	*56.5*	*9.1*	*25.8*	*7.4*	*17.7*
Compost remanufacture	84.7	54.2	7.3	33.5	8.1	12.4
Niche core remanufacture	85.0	57.9	13.4	15.0	1.6	27.1
Electronic core remanufacture	78.6	59.6	7.4	24.2	14.0	16.2
Export oriented	*80.9*	*23.5*	*12.1*	*39.7*	*7.0*	*36.8*
Scrap metals recycling	81.0	27.4	11.5	37.6	7.5	35.0
Diversionary 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 remanufacture	48.8	3.8	22.5	70.0	28.8	26.3
Multi-scale clustered	*36.5*	*39.7*	*34.8*	*30.6*	*28.8*	*29.7*
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
Other	*9.2*	*0.3*	*16.0*	*50.0*	*74.8*	*50.0*
Plastic remanufacture	9.2	0.3	16.0	50.0	74.8	50.0
Total	70.7	34.5	15.2	34.8	14.1	30.8

Source: Author questionnaire, 2002.

category, plastic remanufacturing reflects a more unique case given Texas' industrial concentrations in petrochemicals.

Overall, the firms draw approximately equal portions of their inputs from commercial, industrial and municipal[5] sources and redirect approximately equal portions of their outputs to either the primary (e.g., pulp or steel mills) or secondary (finished products) sector of the economy (Table 3). The locally clustered group (composters, niche and electronic cores) source primarily from local commercial sectors, although municipal sources are also important, and redirect much of their outputs to secondary markets, primarily for direct use. Input and output sources for the export-oriented group are more varied. Scrap and diversionary recyclers source close to half their inputs from local municipal sources, with a substantial majority of their outputs flowing to the primary sector. Paper remanufacturers also draw heavily from municipal sources, while paper recyclers focus upon commercial sources with both directing their output to the secondary sector. The third group, (waste treatment and niche recycling firms) are among the least likely to use municipal sources, and redirect to secondary sources.

These results suggest that the territorial economies of materials and cores are dependent primarily upon how and where they are redirected to production processes. As such, we cannot assign loop closing to any particular spatial scale *apriori* nor can we conceive of closing the loop via RRWT firms in terms of monolithic networks bounded in space or place with internal

[5]Includes local government contracts, brokers, drive-ups and smaller firms.

Table 3. Economic source and destination of material flows

Type of firm	Inputs			Outputs		
	Commercial (%)	Industrial (%)	Municipal (%)	Primary (%)	Secondary (%)	Other (%)
Locally custered	*53.8*	*15.4*	*30.8*	*14.6*	*71.3*	*14.2*
Compost remanufacture	50.9	11.4	37.7	1.0	80.0	19.1
Niche core remanufacture	48.9	26.4	24.7	23.6	62.0	14.3
Electronic core remanufacture	65.0	10.0	25.0	29.2	65.8	5.0
Export oriented	*26.1*	*28.5*	*45.4*	*63.0*	*36.3*	*0.7*
Scrap metals recycling	20.3	34.9	44.8	71.6	28.4	0
Diversionary 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 remanufacture	5.5	21.3	73.3	10.0	90.0	0
Multi-scale clustered	*40.1*	*48.0*	*11.9*	*18.2*	*67.8*	*14.1*
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
Other	*38.0*	*47.0*	*15.0*	*53.3*	*46.7*	*0*
Plastic remanufacture	38.0	47.0	15.0	53.3	46.7	0
Total	35.6	29.2	35.2	42.0	51.5	6.6

Source: Author questionnaire, 2002.

material flows. The locally clustered group seems to represent the 'ideal type' of closed loop conceptualized by IS, with the remanufacturing firms bridging the gap between used and new goods emanating from and being (re)consumed by the local commercial sector.

It is unlikely that the export-oriented group could be structured spatially in a similar manner in the absence of local primary industries to absorb locally generated waste. Even with the presence of primary industries, however, places 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, diversionary and paper recycling and remanufacturing will always require some flows beyond the local level. Finally, 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 non-hazardous wastes. While non-hazardous waste cannot absorb substantial transport costs and is likely to be structured 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

rather than attempting 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 provide a clearer answer.

General Business Environment in which RRWT Firms Operate

The general business and public climate within which firms operate is an important element of firm success. To evaluate RRWT firm perceptions of the general business environment within which they operate, the firms were asked to rate, on a scale of one to five, the importance of a series of statements (Table 4). The most important issues to emerge were local negative perception to establishing or expanding a RRWT firm and convincing the local economic development community of their significance. On the other hand, only waste treatment firms reported they had a difficult time gaining access to expansion capital and only plastic and electronic core remanufacturers and diversionary recyclers faced resistance from the public and businesses to using their products. Similarly, unfair competition due to tax subsidies to virgin suppliers was not considered important for most firms, and few firms (plastics, diversionary recyclers) felt that competition from lower priced virgin material suppliers was a problem.

For the most part, these results are independent of firm size, corporate structure, expansion plans, future growth prospects, or the spatial structure of the material loops described above. Only in responses to convincing the economic development community of their significance do we find

Table 4. General milieu of the firms

On a scale of 1 to 5, indicate the importance of the following statements to the recycling, remanufacturing and waste treatment business	Mean	Range by firm type
Local public perception is a major problem when attempting to establish a recycling/reuse/waste management business	3.6	2.6 to 4.4
Convincing the economic development community would help with expansion	3.5	2.4 to 4.0
Lack of access to expansion capital makes it difficult to grow my business	3.0	1.9 to 3.7
Resistance among manufacturers/public to using recycled products reduces competitiveness and profitability	2.7	1.9 to 3.9
Tax subsidies to virgin material suppliers makes it harder to compete	3.0	2.0 to 3.4
Differences in the price of virgin versus recycled raw materials make it hard to secure a steady market for my outputs	3.0	1.6 to 4.0

Source: Author questionnaire, 2002.

differences. Single location firms and/or firms that were more optimistic about their future were statistically more likely ($p = .025$ and $.000$ respectively) to think that convincing the economic development community of their significance would help them expand more quickly.

These results suggest that the environment in which these firms operate has some substantial difficulties with the perception of the firms but not at the level of day-to-day operations. RRWT firms face a unique dilemma. Not only do people not want RRWT firms to locate in their community (a locational problem that has been studied widely (Lake, 1986) and is not unique to RRWT firms), but the broader economic development community fails to recognize their significance also. At the very least, such general negative attitudes are likely to slow both the rate of entry of new firms into these markets and the expansion possibilities for existing firms. On the other hand, they have access to expansion capital, can find markets for their products and feel they can compete fairly against firms using virgin inputs.

RRWT Firm Conventions

The extent to which the conventions which evolve among networks of firms, their customers and suppliers are conducive to the smooth flow of knowledge within the network thus speeding the rate and consistency of innovation and continued economic success are also central. RRWT firm conventions were evaluated by asking the firms to rate the importance of a series of statements (Table 5). With the exception of the niche and electronic core

Table 5. Elements of the nature of firm interaction

On a scale of 1 to 5, indicate the importance of each of the following statements to the recycling, remanufacturing and waste treatment business	Mean	Range by firm type
A major difficulty in this business is ensuring the purity of inputs	3.8	2.2 to 4.5
A major difficulty in this business is ensuring a steady supply of inputs	3.7	3.1 to 4.3
New techniques for difficult to recycle materials would significantly increase the size and scope of this business	3.5	2.0 to 4.2
My primary source for new information/opportunities or innovations comes from businesses that buy my products or services	3.7	2.7 to 4.8
My primary source for new information/opportunities or innovations comes from interaction with other firms in this sector	3.4	2.4 to 4.0
My primary source for new information/opportunities or innovations comes from firms I get my inputs from	3.2	2.5 to 4.2
My primary source for new information/opportunities or innovations comes from trade magazines	3.2	2.0 to 4.3

Source: Author questionnaire, 2002.

remanufacturers, ensuring the purity of inputs was the most important issue facing the firms and almost all firms had difficulties maintaining a steady supply of inputs. Most firms felt that the development of new techniques for difficult to recycle materials was only moderately important for future firm growth. The most important knowledge flows regarding new innovations and opportunities flow backward from interaction with customers and to a lesser extent from other RRWT firms. Information on new innovations and opportunities from suppliers and trade magazines was not considered important.

Problems with input purity may reduce the amount of trust between firms and their suppliers and, along with difficulties ensuring steady supplies, may make it more difficult for the firms to develop the type of conventions with suppliers that characterize successful firms and territories. This is also suggested by the limited flows of information up the value chain between suppliers and the firms. Given the large volume of wastes that are not captured by the existing RRWT infrastructure, and the existing problems with purity of inputs, it is somewhat surprising that most firm categories felt that new techniques would not help very much. Part of the reason is that the dominant types of material processing (sorting and aggregating) conducted by many of the firms, while requiring large capital inputs, does not necessarily require intensive technological inputs.

Knowledge flows between the firms and their customers were somewhat more important but even here they were not rated very highly. RRWT firm customers' generally operate with design infrastructures developed for either virgin materials or new components so there may not be sufficient opportunities for the firms to respond innovatively to the problem solving needs of their customers thus contributing to the relatively modest importance of knowledge flows from customers back to RRWT firms and the perceived limited importance of new technological inputs also. Overall, the results suggest that in both cases (suppliers and customers) the types of conventions that characterize the interactions in more successful networks of firms and territories are not well developed in this sector(s).

Discussion and Conclusion

The central question of this paper asked if recycling, remanufacturing and waste treatment firms could be promoted as a way to close the loop at the local level. With regard to the physical flow of materials the answer is yes for some items and partially for others. Almost all the firms had high levels of local inputs and some (the locally clustered group, including compost, niche and electronic core remanufacturers) had high levels of local outputs also. It is probably unrealistic to think of local output destinations for some types of RRWT firm simply because of how they re-enter the production chain. For example, although steel mini-mills consume steel scrap as their primary material input and have a much wider range of suitable geographic locations than integrated mills, they are still constrained by certain minimum scrap volume thresholds and produce different outputs from integrated mills.

We should be wary, however, of assigning too much similarly to the different types of RRWT firm within the three categories of territorial economy identified earlier since even though their territorial economy's are similar, the logic by which those boundaries are constructed is likely to vary widely. For example, both compost production and toner cartridge remanufacturing are organized at the local level but for very different reasons (transport costs and service provision, respectively).

Industrial symbiosis proceeds from the assumption that change within existing institutions will generate significant improvement in the environmental performance of economic activity worldwide. Can the efficiency of RRWT firms be increased to more effectively close material loops? Among the most consistent findings of the research presented here was the firms' perception of negative attitudes toward their activities from the public at large, potential customers and the economic development community. At the very least, such perceptions slow the entry of new firms to the sector. Modifying these perceptions will require fundamental changes in the culture of consumption while allowing for the reality of capitalist growth to continue. Greater emphasis on 'function purchasing' as opposed to 'product purchasing' may prove useful here. Consumers generally expect all the components in the goods they purchase to be new, thus limiting demand for RRWT products. If products were competitively positioned in the market place via leasing arrangements with service agreements (e.g., many office photocopy machines) rather than sold, and provided they look new and perform properly, consumers may be less sensitive to the fact that products may contain older recycled/remanufactured components.

On the other hand, fewer difficulties were identified in the day-to-day operation of RRWT firms. That the firm's did not believe there was unfair subsidies to virgin material suppliers was somewhat surprising given how strongly these arguments are presented in the recycling advocacy literature cited earlier. It may be, however, that the firms are unaware of the exact nature of subsidies to virgin suppliers. Nevertheless, it is the firm's perception of their competition with virgin suppliers that is the important dimension of their cultural environment.

Problems with purity of supplier inputs and consistency of supply were identified as significant problems also. Third party quality standards, such as the recently developed SPEQ^{TM} (Specified Pallets, Engineered Quality) standards for pallets might increase levels of trust between suppliers and the RRWT firms and reassure potential customers of the quality of the input. Such standards could be developed as part of a supply chain management strategy or as part of a cooperative marketing strategy. And while the development of industry standards is not easy since it requires considerable cooperation between large numbers of firms with their own agendas, such cooperation might also translate into more cross communication and the slow development of the necessary conventions for knowledge flows, problem solving, innovation and growth.

The perceived limited importance of the ability of new techniques to increase the size and scope of the sector(s) and the limited flows of

information about new innovations and knowledge between suppliers, customers and other firms, coupled with modest rates of innovation and optimism also suggests that the basic ingredients necessary for high rates of innovation and growth (i.e., the need to solve complex but potentially highly profitable problems) are not very extensive within the networks of RRWT firms in Texas.

The problem lies with the technologies and systems used in the design, manufacture and use of products. Product design and manufacturing processes have been developed using virgin materials and new components, and although a certain amount of recycling and recovery have always existed within capitalism (Zimring, 2002), and RRWT firms can, and do, compete with virgin OEM and other second market, off-the-shelf component suppliers they do so in production systems not designed to process their outputs. The opportunity for RRWT firms to solve more complex problems on a level playing field and thus develop the capacity for sustained innovation and economic growth can only occur in response to questions that emerge as industry and consumers adopt the philosophy of loop closing and begin to develop more sophisticated disassembly technologies and design strategies where recycling and remanufacturing are integral and fundamental requirements of the process and final product. It is not just in terms of innovative problem solving for loop closing strategies that RRWT firms can grasp new opportunities for economic growth. The gathering of materials or used products is often beyond the core competencies and/or interest of most companies. New market niches for RRWT firms may emerge if companies begin to incorporate recycling and remanufacturing in their production designs but are not interested in actually managing the process of collection.

To some extent this has always occurred. While a few RRWT firms are primarily driven by environmental concerns, the majority (and, ultimately all those that survive) do so by identifying and profitably exploiting new market opportunities that have emerge(d) from stricter government regulation, consumer demand, pressure from environmental groups, or technological changes that render unprofitable wastes profitable. However, while there are large numbers of RRWT firms operating today it is unlikely that they can become central players in the production, consumption and waste cycle loop until fundamental changes in the way we produce and consume products comes about.

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