ECO-INDUSTRIAL DEVELOPMENTS IN THE U.S.

SPATIAL FORMS, CONTEXTUAL FACTORS, AND INSTITUTIONAL FABRICS

OF GREENER PLANTS AND OFFICES

by

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ABSTRACT OF THE DISSERTATION

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The main goal of this dissertation is to examine the current practices and strategies of eco-industrial development in the U.S. Traditional studies of eco-industrial development focus on successful case studies and their internal systems, but overlook external systems enabling those cases. By reconsidering eco-industrial development from the viewpoint of agglomeration economies, this dissertation investigates the spatial forms and contextual factors of greener plants and offices as key actors in potential eco-industrial developments, and the institutional fabrics of on-going eco-industrial developments to identify potentially favorable locations for eco-industrial developments.

Spatial forms of eco-industrial developments tend to follow given geographical distributions of plants in the industrial context and of offices in the post-industrial context. The exploratory spatial data analyses and regression analyses illustrate that larger and greener plants in selected pollution-intensive industries tend to cluster in and

around a group of major U.S. cities. Greener offices are also likely to be located in and near the similar group of cities, as revealed from the descriptive analyses.

Selected contextual factors appear to influence the environmental performance and locational behavior of greener plants and offices significantly. Through a series of regression analyses, it is revealed that the economic performance of larger and greener plants is largely conditioned by the internal economies of scale, and the environmental performance is by factors of localization economies. The event-history analyses and panel data analyses of greener offices show that demographic, economic, governmental, and geographic factors have considerable impacts on the adoption speed and size of green building projects at the county level. Factors associated with urbanization economies seems to work significantly in the diffusion of green buildings in the U.S.

Institutional fabrics of on-going eco-industrial developments are probed by a series of case studies on the Rutgers EcoComplex, the regional By-Product Synergy projects, and green towers at Battery Park City in Manhattan. Findings from case studies support the importance of balanced institutional building processes between local communities and non-local networks. The pre-existence of enlightened local anchor is instrumental, while the role of non-local anchor as enabler or facilitator in local eco-industrial development deserves more attention.

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Chapter 1. Eco-Industrial Development in Question

1.1 Introduction

This dissertation examines the relevance of the practices and strategies of eco-industrial development in sustainable development in the recent industrial settings in the U.S. In the era of climate change, environmental concerns on current industrial systems have grown significantly, and brought noteworthy national and international policy reactions in the name of sustainable development in all developed and developing countries (Dryzek, 2003; Mol, 2001; Vig & Kraft, 2006). Urban planning has embraced the importance of sustainable development, and has extended the field with new greener theories and practices (Evans, 2002; Moavenzadeh, Hanaki, & Baccini, 2002; Satterthwaite, 1999; Wheeler & Beatley, 2004). While the intersection between economic development and environmental planning has been probed extensively as a key problematic and conflicting area in urban planning (Agyeman, Bullard, & Evans, 2003; Lake, 1987), the literature of sustainable cities and communities tends to neglect the role of industries and local industrial systems as engines for sustainable economic development (Robins, 1999). Since sustainable cities and communities cannot remain sustainable if their local industrial systems are not sustainable both economically and environmentally, this negligence is unsatisfactory and undesirable.

In that sense, sustainable development in urban planning should rethink how to make the current local industrial systems greener in pursuing sustainable cities and communities, which is the main topic in eco-industrial development (Cohen-Rosenthal &

Musnikow, 2003; David Gibbs, Deutz, & Proctor, 2005; Lifset & Graedel, 2002). Eco-industrial development is an under-represented part of sustainable development, which focuses on greener practices of firms, institutions, and organizations in business networks and local communities to promote higher economic vitality, better environmental quality, and wider equal participation altogether (Cohen-Rosenthal & Musnikow, 2003). Since eco-industrial development is still an elusive concept, practitioners, as well as academics, tend to frame the boundaries of eco-industrial development heuristically by categorizing old and new types of projects that share common features valued in past and present eco-industrial developments (Cohen-Rosenthal & Musnikow, 2003; Côté, Dale, & Tansey, 2006). Energy-efficient and resource-saving infrastructure, eco-industrial and resource recovery parks, industrial clusters of green products and environmental technologies, and green buildings and associated sustainable land use planning are typical examples of eco-industrial developments in action.

Most of all, eco-industrial developments share an inclination toward synergetic interactions among economic units to achieve better environmental performance collectively and tend to favor market-oriented, voluntary strategies and policies on environmental concerns of the industrial practices, processes, and programs through collective actions among local and non-local stakeholders. Current research in industrial ecology and industrial symbiosis tends to define eco-industrial development with its focus on material and energy exchanges among local actors (Chertow, 2000; Desrochers, 2004). By defining eco-industrial development by its goals, not by its conditions and processes, however, this focus tends to overlook wider locational factors and institutional processes enabling local eco-industrial practices. The recent bridge between industrial symbiosis and agglomeration economies sheds a light on this issue (Desrochers, 2002a). Marshall's (1890) three sources of agglomeration economies, including local labor pool, non-traded inputs, and information spillovers, can be valuable ones not only for economic vitality, but also environmental excellence. In that sense, eco-industrial development can be considered a unique product of agglomeration economies. Agglomeration economies may not be sufficient conditions for eco-industrial developments, but can be necessary ones. Eco-industrial developments are more likely to appear if there are special sources of agglomeration economies, such as common talent pool of eco-industrial experts and practitioners, greener local infrastructure and utilities, and easier environmental technology transfer practices. By focusing on those potential sources of eco-industrial development in terms of agglomeration economies, this dissertation not only pursues better understanding of existing eco-industrial development cases mainly in the extraction and manufacturing sectors, but also investigates a burgeoning area of green buildings as eco-industrial development in the service sector.

Although on-going cases of eco-industrial development are limited in number, insights from eco-industrial developments set a new viewpoint to look through a relatively neglected intersection of sustainable development between ecology and economy in urban planning; eco-industrial development offers a way in which existing local industrial systems transform into cleaner ones through joint coordination among economic units and related institutions and organizations, without the compulsory replacement with new greener industries (Mirata & Emtairah, 2005; Sterr & Ott, 2004).

By economic units, I mean plants and industrial buildings in use in the manufacturing sector, and occupied offices and commercial buildings in the service sector. Economic units are functional places of economic activities and key actors in eco-industrial development. Occupied buildings as economic units are valid to urban planning and real estate development (DiPasquale & Wheaton, 1996; Feagin & Parker, 1990; E. H. Green, 1981; Kirkwood, 2001; Ratcliffe & Stubbs, 1996), as well as to architecture and construction (Kibert, 1999; Kibert, Sendzimir, & Guy, 2002) and to industrial ecology (Graedel & Howard-Grenville, 2005). Firms and enterprises are bundles of various economic activities, within which they take advantage of scale and scope economies generated by business organizations and networks between economic units of different shapes and locations (Schoenberger, 1999). Similarly, regions can embrace bundles of a variety of economic units that use materials and energy and take advantage of agglomeration economies. Eco-industrial development typically concentrates more on intra-regional and inter-firm solutions than on intra-firm and inter-regional ones. In such a region, not firms themselves, but economic units of firms try to establish eco-industrial developments, sharing material and energy flows among them and with related institutions and organizations locally, and achieving better economic and environmental performance collectively (Cohen-Rosenthal & Musnikow, 2003).

Eco-industrial development has its own discontents, which need to be complemented by the viewpoints of urban planning and geography. It is crucial to recognize that eco-industrial development has never been an autonomous process, a natural goal of industrial modernization (Mol, 2001; Spaargaren, Mol, & Buttel, 2000; Weinberg, Pellow, & Schnaiberg, 2000). Nevertheless, current studies of eco-industrial development focus on how to make eco-industrial development, but not necessarily on how to make eco-industrial development work. The constant focus on limited eco-industrial cases and their industrial systems in the literature of eco-industrial development tends to hide the role of social, cultural, and institutional environments enabling or hindering the initiation and operation of eco-industrial developments (Andrews, 2001b, 2002). Historical records of market relationships encouraging resource recovery and reuse of materials and energy, mainly in cities, suggest that there have been and are favorable environments for eco-industrial development (Desrochers, 2002a, 2002b). However, potential locations and factors of the favorable environments are largely uncharted in the literature of eco-industrial development. This dissertation will present that it is possible to identify geographical patterns of existing greener economic units and their contextual factors of influence with a series of analyses in spatial social sciences. On-going cases of eco-industrial development can also reveal different local institutional capacities and structures built for sustaining eco-industrial development.

Extension of the current focus on the industrial context into one on the post-industrial context will be another contribution of this dissertation. While there is a significant line of research on the manufacturing sector as a main polluter in the developed and developing economies, specially in environmental economics (Fredriksson, List, & Millimet, 2004; Kahn, 2000; Millimet & Slottje, 2002), the changing role of the manufacturing sector as a contributor to sustainable development has been a ‘missing link’ in the literature of sustainable cities, and of economic development in the industrial context (Robins, 1999). In the case of the service sector, this state of ignorance is even deeper. There is hardly any discussion on the role of the service sector in sustainable development, except a handful of environment-related service industries, such as eco-tourism, logistics, and environmental professional and technical services

(Hayter & Le Heron, 2002; Honey, 2008; Matthews & Hendrickson, 2002; Zimmerer & Bassett, 2003). That is based on the perception that the service sector is generally a cleaner part of an economy which does less harm to the environment, but direct impacts of the service sector on the environment are greater than generally perceived, and indirect impacts caused by a group of service industries in the sector significantly overpower those by the most pollution-intensive manufacturing industries (Suh, 2006). Furthermore, the economic structure of developed countries has been significantly changed from the industrial to the post-industrial one which is dominated by the service sector (Bell, 1973; Inozemëtìsev, 1998). To take the possibility of sustainable industrial development in a developed economy seriously, it is necessary to complement the focus on the industrial context with one on the post-industrial context.

This dissertation aims to address those relatively overlooked, but recently emerging issues in urban planning, especially in the field of sustainable development and of economic development. Focused on the U.S., this dissertation will identify current geographical patterns of greener economic units, test influential conditions facilitating or deterring their presence, and probe enabling institutional configurations for eco-industrial developments in the industrial context and in the post-industrial context, to explore the potential of eco-industrial developments in the current U.S. industrial system. In the next section, three research questions and possible directions to track them will be suggested.

1.2 Research Questions and Directions

Despite the current attention to green businesses and environmental strategies of firms (Esty & Winston, 2006; Friedman, 2008; Makower, 2008), more gaps than understanding of their potential roles and functions in eco-industrial development are found in the literature of economic development, let alone of sustainable development. This dissertation addresses three interconnected research questions on the forms, factors, and fabrics of eco-industrial development, to fill some gaps in the existing theoretical and empirical works on this topic.

First, have greener economic units formed and continued to form spatial clusters, particularly in and around central cities? Although there is no direct former research on spatial patterns of environmentally friendly plants and offices, it is possible to regard central cities and existing industrial clusters as potential clusters of greener economic units, on the analogy of them as environmental innovations or as early adopters of those innovations (Breschi & Malerba, 2005; Hayter & Le Heron, 2002; Jaffe, Newell, & Stavins, 2003). Innovation studies keep rediscovering the role of cities and clusters where innovations grow out (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007), while recent discussion of decentralization trends of economic units in the manufacturing and the service sectors makes it difficult to predict the direction of clustering of greener economic units (Hayter, 1997; Lang, 2003; M. K. Nelson, 2003). Further empirical research is required to determine whether the spatial patterns of greener economic units follow the given clustering patterns or generate their own geographic patterns.

Second, are there measurable contextual factors of economic units and of their locations that enhance or worsen the performance of those units? Understanding the key factors driving eco-industrial development is critical in transforming current regional economic development into a more sustainable one, not only in its economic aspects, but also in its environmental aspects. Among those factors, it is particularly appropriate for policy makers to identify a set of driving factors over which they have some control. Although this dissertation does not cover and assess all of the industries in the U.S. economy in the industrial and the post-industrial contexts, findings from the dissertation will be instrumental in formulating and performing eco-industrial strategies for greener regional economic development, aimed at ordinary economic units – plants and offices – in industries of 'related variety' (Frenken, Van Oort, & Vervurg, 2007) that have potentials to enhance their economic and environmental performance collectively.

Third, how can institutional fabrics of locational and organizational characteristics in different contexts make a difference in starting and operating eco-industrial development projects? Studies of eco-industrial parks in the literature of industrial symbiosis tend to consider them 'islands of sustainability' (Côté & Wallner, 2006; Wallner, 1999), and overly focus on locational actors and features in those parks, just like in the earlier cluster research in economic geography. Recent studies in the cluster research have started to balance its focus on local uniqueness by introducing perspectives on the importance of organizational outreach to other locations in local institutional building process (Braunerhjelm & Feldman, 2006; Breschi & Malerba, 2005; Gertler, 2003, 2008). Those new studies suggest that the right combination of external stimuli flowed through institutional and organizational networks and the internal competences built by locally connected communities makes clusters sustainable. Case studies of eco-industrial developments in action will examine the effectiveness of this new argument by dissecting those projects with internal and external networks and related local and non-local actors identifiable, and comparing their similarities and dissimilarities.

The first and second questions are about the spatial forms and contextual factors of eco-industrial development in the industrial and the post-industrial contexts, which can be probed by identifying and testing the hypothesized relationships between locational factors and eco-industrial developments. There are two quantitative approaches in which the environmental influence of locational characteristics on economic units can be investigated. In principle, the selection between the two is coerced by the limitations of available data. If a sample of environmental and locational data of individual economic units from a population of an industry, a sector, and an economy is available, the sample data allows us to build models to examine the link between various features of existing agglomerations and environmental performance of those economic units. More often than not, however, those data are very limitedly available, or even do not exist. Locational data for environmentally friendly economic units are more likely to be publicly accessible. Although it is improbable that those data have detailed environmental data for individual economic units, those data provide locational information on those greener units designated by certain criteria. By testing spatial patterns of greener units with those data, it becomes feasible to construct models to study the relationship between different characteristics of given locations and the locational behaviors of environmentally friendly economic units.

Environmental and locational data of plants in the manufacturing sector in the U.S. are limitedly available in the U.S. from the Environmental Protection Agency (EPA) and the Census Bureau, while the equivalent data of offices in the service sector do not exist. On the other hand, locational data of energy-efficient, low-impact commercial buildings and offices are accessible from at least two institutions – the Department of

Energy (DOE), and the U.S. Green Building Council (USGBC) – in public, but the locational data for greener plants are not publicly available. Therefore, it would be logical to analyze plants in the manufacturing sector with the former approach of environmental performance, and offices in the service sector with the latter approach of locational behavior.

The final research question is about the institutional fabrics of eco-industrial development projects in action. Existing data on eco-industrial development in the U.S. lack reliable sources and necessary details to investigate this question effectively with any quantitative research. A qualitative approach of case studies on selected eco-industrial developments is a reasonable alternative. Eco-industrial development can vary in its scale and scope, in its developmental stage, and in its internal and external contexts, but the limited numbers of on-going cases of eco-industrial development in the U.S. make it improbable to observe a significant range of different eco-industrial developments in practice. Hence, instead of trying to catalog various cases, it is logical to develop a framework from theoretical research and quantitative studies and focus on a few representative cases fit to the framework. My dissertation will be organized along with these research questions and directions. A detailed outline of my dissertation follows.

1.3 Dissertation Outline

In addition to this introduction, the dissertation consists of 6 chapters. Chapter 2 reviews the theoretical and empirical literature relevant to this dissertation. Since there is no comprehensive literature of eco-industrial development in a single discipline, it is inevitable to construct a review by filling the gaps with theoretical and empirical studies in multiple disciplines. This chapter begins with a discussion of industrial symbiosis as a key research field of industrial ecology, which focuses on the improvement of collective economic and environmental performances of economic units by recycling materials and energy among them. Industrial symbiosis offers an approach of combining environmental concerns with economic development, relatively lacked in the discipline of economics, geography, and urban planning, while it has its own discontents, including its focus on limited case studies of success, its relative ignorance of the locational mechanisms behind the genesis and evolution of eco-industrial development in different contexts, and the missing role of the service sector where eco-industrial development in the post-industrial era occurs. To resolve those issues, I rethink the industrial symbiosis with discussions of classic locational theories, agglomeration economies, and industrial cluster development, as well as with new understandings and metaphors of symbiosis and of niche in biology and their relevance to the eco-industrial development research. In other words, I attempt to position and understand the concept of eco-industrial development within the framework of economic development and economic geography. The review concludes that quantitative analyses of the environmental performance of economic units in the industrial context, and of the locational behavior of greener economic units in the post-industrial context, and qualitative analysis focused on the relationships between eco-industrial developments and their different institutional structures are required to investigate redefined issues of the industrial symbiosis in urban planning. Hypotheses will be refined through the review, and presented at the end of the chapter.

Chapter 3 performs quantitative analyses of the economic and environmental behavior of plants as economic units in the industrial context. Instead of dealing with all industries in manufacturing, the five most pollution-intensive industries are identified and analyzed. I create two plant-level datasets that contain employment, sales, and pollution emission data of individual plants by joining the Toxics Release Inventory (TRI) with the Dun and Bradstreet (D&B) Directories in 1990 and in 2000. County-level datasets in both years are created from various sources to provide necessary contextual data for plants. Then, impacts of plant-level, local, and regional factors on the economic and environmental performances of larger and greener plants as ‘anchor tenants’ (Chertow, 2000; Korhonen & Snäkin, 2001) are evaluated by a series of regression analyses in each year and in each pollution-intensive industry with a specific focus on the importance of agglomeration economies in different types.

Chapter 4 offers quantitative analyses of diffusion patterns of green buildings in the post-industrial context. Since no office-level economic and environmental data exist, methods and techniques used in Chapter 3 cannot be used for the service sector. However, the recent emergence of the Leadership in Energy and Environmental Design (LEED) green buildings in the U.S. since 2000 opens another way to probe locational behaviors of green offices in the service sector by analyzing the distributions of green buildings as environmentally friendly economic units. County-level panel datasets of the LEED green building projects between 2000 and 2005 are created. Descriptive analyses are performed to discern the locational and clustering patterns of green building projects. With demographic, economic, governmental, and geographic sets of factors from diverse sources, I model two closely interrelated topics in the diffusion of green building projects in the U.S.; The relationship between the speed of green building adoption and those factors will be probed with the event-history analysis models, and the relationship between the size of green building growth and those factors with the panel data analysis models at the county level.

Chapter 5 contains my case studies. The analyses in Chapters 3 and 4 provide the foundation for in-depth assessments of emerging eco-industrial developments in the U.S. Although it is not possible to pinpoint potential locations for successful eco-industrial developments, those analyses in Chapters 3 and 4 offer some insightful trends about the relationship between eco-industrial development and its context. On-going cases of eco-industrial development have been selected and classified with reference to a typology of eco-industrial development, developed in Appendix, and to the distinction between local and non-local anchor tenants. The Rutgers Eco-Complex, which is a mixture of research facilities, offices, and a business incubator in Southern New Jersey, is a typical example of the first 'catalyst' pathway that attempts to boost regional sustainable industrial development by locating eco-industrial developments in under-developed areas. Two cases of the second 'symbiote' pathway that locates eco-industrial developments as new materials and energy loops in developed areas are studied in the industrial context and in the post-industrial context respectively. Regional By-Product Synergy (BPS), which started as an intra-firm project, but evolved into urban and regional eco-industrial networks in multiple locations in the U.S. over time, is my case of eco-industrial development in the industrial context. In reality, BPS is a series of industrial symbiotic networks, loosely coupled by a consulting entity, the U.S. Business Council for Sustainable Development (USBCSD). Among regional BPS networks, I focus on two earlier regional networks in Kansas City and in Chicago. Finally, as a case of eco-industrial development in the post-industrial context, the LEED green building practices in Manhattan, especially at the Battery Park City, are studied in detail, with their relationships to the USGBC, hosting the LEED green building rating systems. Findings from cases will be compared and summarized at the end of the chapter.

Chapter 6 contains my overall conclusions. Reflections for policy implications and the directions of future research on the issue of eco-industrial development in the industrial and the post-industrial contexts are presented.

In Appendix, a typology of potential interactions between eco-industrial developments and its local industrial systems is presented with two feasible strategic pathways of using an eco-industrial development as a catalyst to boost regional economic development in a nascent industrial ecosystem and of putting an eco-industrial development as a symbiote in a mature industrial ecosystem to become a successful loop in the ecosystem ultimately. The typology offers an operational framework to classify and compare on-going cases of eco-industrial development in the U.S. in Chapter 5.

Chapter 2. Eco-Industrial Development and Its Discontents

2.1 Introduction

This chapter reviews the theoretical and empirical research relevant to the research questions of this dissertation. The review starts from a brief overview of eco-industrial development through a lens of industrial ecology and industrial symbiosis, in which eco-industrial development is framed originally. Then, discontents with the current studies on eco-industrial development are enlisted and explained in two areas of interests. Three topics from research questions on eco-industrial development – spatial forms, contextual factors, and institutional fabrics – are identified and assessed by concepts and ideas in different disciplines of urban economics, economic geography, regional sciences, as well as of biology and ecology. My three research hypotheses are introduced at the end of the chapter.

2.2 Overview of Eco-Industrial Development

2.2.1 Definition of Eco-Industrial Development

Eco-industrial development is a member of sustainable development family, respecting three aspects of the sustainable development – economy, environment and equity, but it has been exploring new frontiers, walking different paths, and building its uniqueness in sustainable development since its introduction. Nevertheless, eco-industrial development is still a changing, elusive concept that has rarely been formally defined (Cohen-Rosenthal & Musnikow, 2003; Côté, et al., 2006). It is mainly because it has been used to illustrate a loosely-coupled and wide variety of applications, still growing in types and numbers in practice.

Eco-industrial development covers wider range of cases and fields than its next of kin, industrial symbiosis which will be also introduced in the next section. Eco-industrial development ranges from manufacturing to services, from plants and offices to eco-industrial parks and networks, while industrial symbiosis tends to focus on eco-industrial development in the extraction and manufacturing sectors (Chertow, 2000, 2004). Examples of eco-industrial development encompass, but are not limited to, energy-efficient infrastructure (Guy, Marvin, & Moss, 2001), eco-industrial centers, parks and networks (David. Gibbs & Deutz, 2005; Heeres, Vermeulen, & de Walle, 2004; Krause & Brinkema, 2003), clean and green industry clusters (Pernick & Wilder, 2007), environmentally conscious industrial facilities (Graedel & Howard-Grenville, 2005), and green buildings and communities (Guy & Moore, 2005; Kibert, 1999). While there are certain similarities among those examples, distilling an overarching definition from them is quite a challenge.

First and foremost distinction of eco-industrial development from other practices in sustainable development is its focus on business and industry and its relationships to the surrounding regions and communities. Côté and Cohen-Rosenthal (1998, p. 182) underlined this point and said that “since industry is a human creation and humans are social animals, we need an approach with brings industry and environment together with a social or community perspective.” Therefore, eco-industrial development results from attempts to apply ecological principles to work and workplace design, to local communities, and to business network (Schlarb & Cohen-Rosenthal, 2000). For those attempts, eco-industrial development has to deal with the twin concerns of economic accomplishment and environmental excellence. In that sense, Cohen-Rosenthal (2003, p. 22) defined eco-industrial development in its alias of eco-industrialism:

> Eco-industrialism is a voluntary, market-driven approach that uses the discipline of internal and external markets to assure price, performance and quality. Eco-industrialism supports the end results of profit enhancement and frugal use of resources, but it asks us to rethink our relationships, the effect of our products on ecosystems and the impact of the process of production on employees and affected communities. The elegant solution, the one we may need to dig deeper to fine, is one that accomplishes both business and environmental improvement.

Although Cohen-Rosenthal (2003) described eco-industrial development as a 'framework', perspectives regarding eco-industrial development as 'practice' or 'project' is more relevant and operational in this dissertation (Deutz & Gibbs, 2004; David Gibbs, et al., 2005; Sterr & Ott, 2004), since this dissertation uses a hybrid of theoretical and empirical works in interrelated disciplines to research different types and aspects of eco-industrial development. Without explicit reference, the term 'eco-industrial development' in the dissertation means 'case' of eco-industrial development, and is defined as such. In this dissertation, eco-industrial development is defined as greener practices and projects of firms, institutions, and organizations in business networks and local communities to promote higher economic vitality, better environmental quality, and wider equal participation together. Therefore, eco-industrial developments favor market-oriented, voluntary strategies and policies on environmental concerns of the current industrial practices, processes, and programs through collective actions among local and non-local stakeholders.

Eco-industrial development is intellectually indebted to the more established discipline of industrial ecology and its subdivision of industrial symbiosis. To identify research questions and testable hypotheses with the working definition of eco-industrial development, it is inevitable to go through theoretical and empirical works in the industrial symbiosis literature. In the next section, a brief introduction of industrial ecology and industrial symbiosis will be offered.

2.2.2 Industrial Ecology and Industrial Symbiosis

Industrial ecology is an emerging field popularized by Frosch and Gallopoulos (1989) in *Scientific American*. They suggested that if industrial systems were modeled after ecological systems, they could be more environmentally friendly, as well as more efficient.[1] While the idea of industrial ecology has been popularized since the late 1980s, cases and practices of industrial ecology have existed at least since the industrial revolution, especially in the form of resource reuse and recovery (Desrochers, 2002b, 2002c). In their first textbook on industrial ecology, Graedel and Allenby (1995, p. 9) stated the essence of industrial ecology, as follows:

> Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.

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1 'The analogy of industrial systems to natural systems' (Richards, Allenby, & Frosch, 1994) has been repeatedly developed in a series of books from the National Academy of Engineering (Allenby & Richards, 1994; Richards, 1997; Richards & Pearson, 1998). Recently, McManus and Gibbs (2008) re-evaluated and criticized the validity of the analogy. However, they tended to ignore a similar history of constructive evaluation of analogies and metaphors in industrial ecology (Ehrenfeld, 2003). For example, Richards and Frosch (1998) summarized the limits of the analogy and the differences between ecological and industrial systems.

With its initial interests in analogies to natural ecosystems, industrial ecology has focused on systems analysis, management of material and energy flows, and development of closed loops of those flows in an interdisciplinary framework (Graedel, 1996; Graedel & Allenby, 1995; Lifset & Graedel, 2002).[2]

Practices of industrial ecology can occur at three different levels – facility or firm level, inter-firm level and regional / global level (Lifset & Graedel, 2002). Industrial symbiosis is a key subdivision of industrial ecology, which is mainly working at the inter-firm level of industrial ecology, like eco-industrial parks and regional eco-industrial networks. Chertow (2000) provided a widely-accepted, working definition of industrial symbiosis, as follows.

> The part of industrial ecology known as industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity. Eco-industrial parks are examined as concrete realizations of the industrial symbiosis concept.

As she said, if industrial symbiosis is a series of ideas, concepts, and principles, eco-industrial park is a representative manifestation of industrial symbiosis in reality. President's Council on Sustainable Development (1996) defined eco-industrial park as:

> A community of businesses that co-operate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure and natural habitat), leading to economic gains, gains in environmental quality and equitable enhancement of human resources for the business and local community.

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2 The boundaries of industrial ecology have been defined and redefined by various authors (Andrews, 2001a; Cohen-Rosenthal, 2000, 2004; Ehrenfeld, 2000; Korhonen, 2002, 2004, 2005; Seager & Theis, 2002). Bey (2001), Cohen and Howard (2006) and O'Rourke, Connelly and Koshland (1996) provided more critical visions for and against the field of industrial ecology.

Lowe (2001) provided a more practical way to differentiate a 'real' eco-industrial park from practices of eco-industrial development within the park. According to him, eco-industrial park should be more than the following practices:

- A single by-product exchange pattern or network of exchanges;
- A recycling business cluster;
- A collection of environmental technology companies;
- A collection of companies making 'green' products
- An industrial park designed around a single environmental theme (i.e. a solar energy driven park)
- A park with environmentally friendly infrastructure or construction
- A mixed-use development (industrial, commercial and residential)

His fully-developed or 'real' eco-industrial park is an ideal type, a vision. Most of the existing eco-industrial parks started from one of the enlisted relationships that Lowe presented, and many of them still do. In practice, industrial parks embedding those industrial relationships are defined as eco-industrial parks in a loose fashion.

Industrial symbiosis, like other disciplines, is built on successful historical examples. That is why industrial symbiosis keeps finding lessons from self-organizing cases of industrial ecology, as well as engineered cases of eco-industrial parks (Chertow, 2004; Desrochers, 2004). The Danish case of Kalundborg town is the most prominent example of self-organizing industrial symbiosis (Côté & Cohen-Rosenthal, 1998; Ehrenfeld & Chertow, 2002; Ehrenfeld & Gertler, 1997; Hardy & Graedel, 2002; Jacobsen, 2006), but there are other examples of industrial symbiosis, including cases in Massachusetts and Texas, USA (Forward & Mangan, 1999; Frosch & Gallopoulos, 1989), in Styria, Austria, and in Ruhr region, Germany (Schwarz & Stininger, 1997), in Jyväskylä city, Finland (Korhonen, 2001a, 2001b, 2002), in Kwinana, Australia (van Beers, Bossilkov, & van Berkel, 2005), and in Dartmouth, Canada (Côté & Hall, 1995;

Côté & Smolenars, 1997). In addition, there are various cases and initiatives of engineered eco-industrial parks – industrial parks with artificially designed industrial symbiotic structures (Chertow, 2002; Lowe , 2001), such as eco-industrial park programs in the U.S. and in Netherland (Chertow, 2007; Côté & Cohen-Rosenthal, 1998; Heeres, et al., 2004), the National Industrial Symbiosis Program (NISP) in the U.K. (Mirata, 2004; Scott Wilson Business Consultancy, 2007), and the case of the Guitang Group in China (Zhu & Côté, 2004; Zhu, Lowe, Wei, & Barnes, 2007).

2.2.3 Selective Typologies of Eco-Industrial Development

As cases of eco-industrial development have been filed up, several typologies to classify those cases have been developed. Chewtow (2000, p. 321) drew a typology containing five different types of exchange, and argued that type 3-5 can be identified as industrial symbiosis.

Type 1: through waste exchanges
Type 2: within a facility, firm, or organization
Type 3: among firms co-located in a defined eco-industrial park
Type 4: among local firms that are not co-located
Type 5: among firms organized "virtually" across a broader region.

Her typology is insightful in classifying eco-industrial projects by material and energy exchanges, while that hindered defining geographical scale of each type clearly.

There are other typologies of eco-industrial development regarding different geographic scales. Nemerow (1995) classified three strategies of resource recovery: recovery and reuse within the same plant, recovery and sale of wastes to other manufacturers, and bringing the waste producer and user together in one industrial complex. Similarly, Lowe (2001) identified eco-industrial park or estate, by-product exchange, and eco-industrial network. A spatially framed typology of Cohen-Rosenthal (2003) summarized cases of eco-industrial development in three different scales, ranging from factory through eco-industrial park to regional eco-industrial network. Those typologies are valuable because they identify different geographical scales of eco-industrial development, but they are descriptive and static and do not capture connections and movements between different scales. To follow the evolution of eco-industrial development, development paths in and between different scales of eco-industrial development are needed to be identified.

In that sense, Chertow (2000) argued that evolutionary approaches to eco-industrial development are desirable to understand the emergence of industrial symbiosis. Côté and Wallner (2006) suggested a typology of industrial symbiosis concerning its evolutionary path. Five stages of evolution are implied in their order: single material exchanges, single-material cycles, multi-material symbiosis, eco-industrial parks, and regional network. Their typology suggests an evolutionary path from simple exchanges to complex systems and from inter-firm transactions to regional networks. On the other hand, Baas and Boons' (2004) three-stage development model of eco-industrial parks from regional efficiency through regional learning to sustainable industrial district emphasizes learning networks and capacity building processes that enable eco-industrial developments to be further developed and matured after their initiation.

The surrounding locational characteristics of eco-industrial development are generally ignored in typologies of eco-industrial development, as if eco-industrial developments are independent to their environments. The only valuable exception is

Lambert and Boon’s (2002) distinction between greenfield and brownfield projects. Lambert and Boon (2002) separated greenfield projects which refer to the establishment of new eco-industrial parks, from brownfield projects which refer to the revitalization of old industrial parks, with their classification of industrial complexes, mixed industrial parks, and eco-industrial regions.[3] The prospect of new eco-industrial development in nascent or ‘greenfield’ sites is generally questioned, because of their lack of physical infrastructure and social, human, and business networks, while eco-industrial development in mature or ‘brownfield’ sites is considered being benefited by those infrastructure and networks. This approach is different from former typologies, since the typology conceptualizes the interactions between eco-industrial development and its local industrial systems explicitly. Similarly, Jensen (2001) develops a typology of green building development by the interactions between green buildings and their local infrastructure networks.

Overall, earlier typologies of industrial symbiosis have been mainly developed along with eco-industrial developments in the industrial context, focusing on types of internal flows of material and energy. More recent typologies start to classify eco-industrial developments by their geographic scales, institutional maturity, and interactions between eco-industrial developments and their local environments. Since this dissertation covers eco-industrial developments in the post-industrial context, as well as in the industrial context, and recognizes considerable influence of local industrial systems on eco-industrial developments, it is necessary to analyze and refine former typologies

3 Mixed industrial park, which consists of various small- and medium-sized firms, sometimes complemented by larger firms, is a newly identified type by them. However, as they said, this type of eco-industrial development is very limited. Burnside Industrial Park in Canada (Côté & Cohen-Rosenthal, 1998; Côté & Hall, 1995) is a rare exception.

and develop a new typology to frame eco-industrial developments in a more flexible way. From the viewpoint of spatial social sciences, two neglected areas in industrial ecology and industrial symbiosis are identified and discussed in the next section, which are required to elicit research questions and to fabricate an eco-industrial development typology in the Appendix accordingly.

2.3 Discontents with Current Research on Eco-Industrial Development

2.3.1 Systems within Systems within Systems

Industrial symbiosis tends to focus on internal dynamics of eco-industrial developments and their sub-systems, and to ignore external systems in which eco-industrial development are positioned.[4] As Wallner (1999) precisely mentioned, the focus of industrial symbiosis is on 'ancillary flows of the industrial metabolism', while "the major raw material and product flows are more or less completely excluded from observations" (Wallner, 1999, p. 55). Desrochers (2001) pointed out that even Kalundborg, the most-quoted example of industrial symbiosis, is not an isolated system. Kalundborg is rather "a typical industrial city in that it is a nexus of trade whose firms import and export numerous components and products on a much larger geographical scale" (Desrochers, 2001, p. 348).

This ignorance of external systems of eco-industrial development is somewhat ironic, since industrial ecology has a scholarly connection to general systems theory,

4 It does not mean that that approach has not existed in industrial symbiosis. Comparative approach to eco-industrial park initiatives implies that different national 'systems' can influence performances of eco-industrial parks (Côté & Cohen-Rosenthal, 1998; David Gibbs, et al., 2005; Hardy & Graedel, 2002; Heeres, et al., 2004). However, national system is just one of many systems that have impacts on industrial ecosystems. For example, eco-industrial parks are certainly a subset of industrial parks, and "industrial symbiosis is one type of industrial network" (Jacobsen & Anderberg, 2004, p. 313).

which emphasizes the interactions among different but related systems (Gunderson & Holling, 2002). Hierarchy theory, a cousin of general systems theory, has suggested that sustainability cannot be achieved in isolation (T. F. H. Allen & Hoekstra, 1992; T. F. H. Allen & Starr, 1982). The hierarchy theory's central view is that "sustainability issues can only be understood in terms of systems embedded in systems which are also embedded in systems" (Kay, 2002, p. 79). The hierarchical nature of complex systems implies that there is no one right solution, rather diversity of perspectives at different levels are required to fix effective solutions (Kay, 2002). Same types of problems can be identified in many different systems, but that does not necessarily mean that same solution can be applied to those problems (Jacobs, 1961). At least, if we want to understand a system broadly, we should have some knowledge of the system in its key meta-systems, as well as of key sub-systems of the system. That means that industrial symbiosis and eco-industrial development are also needed to be analyzed in different scales and contexts. Beyond reading successful cases of 'islands of sustainability' (Wallner, Narodoslawsky, & Moser, 1996), approaches to put those islands in different contexts, and to identify various dynamics enabling them are required.

At the meta-system level, we need to position eco-industrial developments in the existing geographical patterns of firms and industries, and to identify various factors causing and enabling eco-industrial developments. In the existing case studies of industrial symbiosis, logics behind the locational choice of economic units in eco-industrial development tend to be black-boxed. However, it is clear that internal dynamics of eco-industrial development alone are not enough to attract and sustain an eco-industrial development of firms and organizations, since "firms' locational choices will include evaluation of many factors besides the proximate reuse of by-products" (Desrochers, 2002a, p. 39). If self-organizing eco-industrial developments are results of various market-driven, but locally nuanced processes of economic units (Desrochers, 2004), it is probable that successful eco-industrial developments will take place in the existing agglomerations – cities and industrial clusters, where economic activities are attracted by various locational advantages, and open opportunities for economic units of environmental quality, pursuing both economic and environmental efficiency.

In that sense, locational pattern-matching of greener economic units – plants and offices – over the existing industrial patterns of an economy might reveal potential sites of eco-industrial development. That means that two new fields of research are required for the literature of eco-industrial development in positioning specific eco-industrial developments in a general framework of locational behaviors of economic units, especially greener ones.

First, potentially favorable locations of eco-industrial development can be probed by tracking locational behaviors and spatial patterns of greener economic units. Limited numbers of on-going eco-industrial developments in the U.S. make it improbable to identify their original patterns statistically with cases, but it is possible to compare spatial trends of greener economic units as potential eco-industrial developments with existing spatial patterns, such as cities and clusters. Since existing cases of industrial symbiosis have been developed around a group of extraction and manufacturing industries of large flows of wasted materials and energy (Chertow, 2000), it is logical to focus on spatial clusters of those pollution-intensive industries, and of greener economic units in them to investigate potentially favorable locations of eco-industrial development in the industrial context. On the other hand, spatial patterns of green buildings as greener economic units in the post-industrial context can be probed by overlaying spatial clusters of greener economic units on the existing urban centers of service industries (Taylor, 2004). Second, location-specific factors, as well as project-specific characteristics, that may promote or hinder clustering of greener economic units can be identified and tested in different contexts. Cities and mature industrial areas have been identified as complimentary locations of eco-industrial development (Desrochers, 2002a; Sterr & Ott, 2004).

At the sub-system level, researches of eco-industrial development need to embrace much diverse social, economic, and geographic sub-systems and their behaviors embedding meta-system principles in their analysis. Most of studies in industrial symbiosis are dominated by 'descriptive and design studies of physical processes and technical solutions' (van den Bergh & Janssen, 2004, p. 3). However, influential authors in the discipline have recognized that the question of 'how' – rather than 'what' – is needed in industrial ecology to probe the human dimensions of industrial ecology (Andrews, 2001a), and have made few attempts to probe relevant social, economic, and geographic conditions and mechanisms of eco-industrial development (Ehrenfeld, 2000; O'Rourke, et al., 1996; Socolow, 1994). Nevertheless, industrial symbiosis, which mostly focus on geographic clusters of eco-industrial activities, have made almost no bridge to spatial social sciences, including urban planning, geography, and regional science until recently. Jacobsen and Anderberg (2004) highlighted the importance of understanding spatial context of firms and industries in improving the analysis of eco-industrial development, and asked the long-due participation of spatial social sciences.

Current findings of industrial symbiosis strongly support the role of the market, not necessarily that of the state (Chertow, 2007; Desrochers, 2004). However, this view of market-based, self-organizing symbiosis model is implicitly based on the accidental initiation of clusters, in which market forces, geographical variations, and historical chances bring an industrial cluster come to life by coincidence. The genesis of eco-industrial development is often conveniently closed in brackets. As a result, eco-industrial development has built significant knowledge on how to design and manage eco-industrial projects, but not on how to start and build them. Self-organizing power of the market enables eco-industrial development, but the organization and survival of eco-industrial developments at different sites need more than the ample presence of market mechanism; they need to build their capacities and competences from existing physical, human, historical, and geographical resources available (Porter, 1990, 1998b).

To follow up these capacity-building processes, the current emphasis on closed-loop systems of materials and energy should be complemented by 'open systems' of knowledge and information (Best, 2001). Recent studies in industrial clusters in economic geography emphasize the generation of local knowledge through 'local buzz' and 'global pipelines' (Bathelt, Malmberg, & Maskell, 2004). Eco-industrial development is diffused across the space as an idea or a strategy at first, but institutional building processes between local communities of practice and non-local networks of knowledge enables the idea to be initiated and realized in cities and clusters (Bathelt, 2003, 2005; Bathelt, et al., 2004; Gertler, 2008). In practice, these institutional building processes often take a form of project to establish more long-lasting institutions and organizations (Grabher, 2002a, 2004a). Different institutional fabrics emerging from those institutional building processes are needed to be investigated more to understand the genesis and operation of eco-industrial development.

In that sense, instead of 'islands of sustainability' (Wallner, et al., 1996), eco-industrial development as 'nodes of sustainability in a world system'[5] would make a better metaphor, for its heuristic position in developing a model regarding systems in which eco-industrial development is embedded.[6] The interactions between eco-industrial developments and their local industrial systems and between local and non-local actors are needed to be systematically probed for better understandings and applications of eco-industrial development in practice.

2.3.3 Lost in Sectors, Destination Services

Eco-industrial development has a strong focus on the extraction and manufacturing sectors, but relatively ignores the service sector. Industrial ecology and industrial symbiosis have recognized the role of different service industries, but their focus has been on a limited view of service industries' useful relationships to manufacturing industries, not necessarily on the service sector as a whole (Graedel & Allenby, 2003; Tukker & Tischner, 2006). For instance, Socolow (1994) emphasized the emergence of professional service companies that mediate the relationship between goods and service providers and consumers and offer energy- and cost-savings in resource management.

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5 I construct this metaphor by borrowing from Amin and Thrift (1992) and Knox and Taylor (1995).

6 As Ehrenfeld (2003) said there is no good or bad metaphor. Metaphor only can be useful and not useful. I follow the position of Krugman (1995), who pointed out every metaphor is at last a heuristic modeling tool, and argued that the heuristic position behind a metaphor is an important criteria in determining its usefulness.

The focus on the extraction and manufacturing sectors of industrial ecology and industrial symbiosis is understandable, since the service sector is considered more dematerialized and less pollution-intensive than those sectors (Angel, 2000). However, this focus is unsatisfactory at least in two intertwined aspects of current economic development. First, many developed, industrialized economies transformed their economic structures into more service-oriented, post-industrial ones a few decades ago (Bell, 1973). Although still majority of pollution is generated from the manufacturing sector, the sector has been declining in its share in the industrialized economies. On the other hand, the share of service sector has grown, and is still growing. Second, dematerialization of the service sector is largely exaggerated. Even the most dematerialized service firm has to have its location, and to consume significant amount of materials and energy (Sassen, 1997). Recent analysis on the service sector revealed the direct impacts of the service sector on the environment are more than we perceive, and the indirect impacts induced by the sector are even larger and sometimes as pollution-intensive as the dirtiest industries in the manufacturing sector (Rosenblum, Horvath, & Hendrickson, 2000; Suh, 2006). As the service sector grows, its direct and indirect impacts on the environment grow as well. In sum, lack of perspectives of eco-industrial development in the service sector is untimely in a post-industrial economy like the U.S.

As eco-industrial development in the manufacturing sector is based on plants and industrial buildings, so eco-industrial development in the service sector is based on offices and commercial buildings. Then, eco-industrial developments in the industrial context of the manufacturing sector and in the post-industrial context of the service sector can be examined through a common framework of their physical materialized economic units of occupied industrial and commercial buildings, or of plants and offices. As far as we focus on the relationship between economic units – plants in the manufacturing sector and offices in the service sector – and their surrounding environments, issues identified in the last section can be investigated in a common way of research. In the next section, those issues are refined in three research questions on eco-industrial development in the industrial and the post-industrial contexts.

2.3.4 Forms, Factors, and Fabrics

From discontents against the current research of eco-industrial development, three interconnected research questions of forms, factors, and fabrics of eco-industrial development are developed. In the following literature review, each research question will be refined with theories in urban economics, economic geography, and regional science, as well as in biology and ecology, in close connections to discussions in industrial ecology and industrial symbiosis. First, where do eco-industrial developments take place? Do greener economic units follow the existing spatial forms of ordinary units, or create new patterns of their own? Do eco-industrial developments tend to be clustered or to be decentralized? Industrial symbiosis offers some insights on spatial forms of eco-industrial developments from historical and case studies (Desrochers, 2002a, 2002b, 2002c). To turn those insights into operational hypotheses, it is necessary to make connections of them to classical locational theories and agglomeration economies and to formulate theoretical foundations for spatial forms of eco-industrial developments.

Second, what make eco-industrial developments feasible? Can contextual factors of a location enhance environmental performance of economic units at the location or attract greener economic units to the location? Are there locational conditions favorable or hostile to eco-industrial developments at a specific location? If any, are they quantifiable or measurable? One of the key debates in industrial symbiosis addresses a distinction between self-organizing and engineered eco-industrial systems and between the market and the government (Desrochers, 2004; Ehrenfeld & Chertow, 2002). While industrial ecologists tend to prefer market coordination over strategic intervention of governments and institutions, on-going eco-industrial developments aren't the results of neither the market nor the government alone. They are more likely to result from balanced impacts of them. Furthermore, self-organization does not necessarily mean that successful eco-industrial development has been organized by solely market forces. Nearly untradeable local factors in a short period of time, such as industrial mixture of economic units, social, institutional, and cultural environments, and geographical and physical location, can also be contextual factors to influence the success of eco-industrial developments (Braunerhjelm & Feldman, 2006; Breschi & Malerba, 2005; Storper, 1997). Niche and niche construction models between features of an organism and factors of its environment in biology and ecology supply an analogous and practical framework to model the relationships between features of eco-industrial developments and factors of their local industrial systems (Boogert, Paterson, & Laland, 2006; Odling-Smee, Laland, & Feldman, 2003; Popielarz & Neal, 2007).

Third, how can eco-industrial developments be organized? Do different institutional fabrics generate different results of eco-industrial development? Are the interactions between different institutional anchors within and beyond local and regional boundaries are necessary to create operational institutional fabrics that lead to eco-industrial developments? Can successful institutional fabrics in a location be replicated in other locations? Industrial symbiosis literature does recognize the important role of institutional anchor tenants that control flows of information and knowledge essential in seeking eco-industrial developments (Burström & Korhonen, 2001). However, the interactions among different institutional anchors are not generally detailed, in contrast with the fact that networks of materials and energy among physical anchor tenants and their related actors are closely analyzed in the industrial symbiosis literature. In addition, institutional anchors do not have to be local like physical anchors. Recent industrial cluster studies have analyzed local capacity building processes with non-local networks, as well as with local communities of practice (Braunerhjelm & Feldman, 2006; Breschi & Malerba, 2005; Gertler, 2003, 2008). Those studies support a hypothesis that institutional fabrics consisting of external collaboration through non-local business and institutional networks and internal cooperation within local communities of businesses and institutions is essential to build lucrative clusters. Since eco-industrial developments are often local manifestations of non-local ideas and concepts, it is necessary to discern different types of institutional anchor tenants and their interactions in analyzing institutional fabrics organizing and replicating eco-industrial developments in practice.

In the next three sections of Chapter 2, those theoretical and empirical considerations to formulate hypotheses of spatial forms, contextual factors, and institutional fabrics for eco-industrial development will be reviewed.

2.4 Spatial Forms: Where Do Eco-Industrial Development Take Place?

2.4.1 Economies of Materials versus Economies of Locations

Chertow proposed three evolutionary approaches to make industrial symbiosis take off (Chertow, 1999, 2000). First, it is capable of exploiting simple material or energy exchange – so-called 'green-twining' – to 'springboard' to other exchanges. Second, 'pre-existing organizational relationships and networks' can be a fertile ground to which industrial symbiosis is rooted. Finally, 'the anchor tenant model' is suggested.[7]

> Just as shopping malls are built around several large department stores that anchor the commercial development within, one or two large industries can provide the same critical mass for an eco-industrial park. (Chertow, 2000, p. 333)

Among these three approaches, the anchor tenant model has proven its usefulness in driving and evaluating various eco-industrial development projects (Deschenes & Chertow, 2004; Korhonen, 2001a; Lowe, 1997; Spiegelman, 2006; Wallner, 1999). Although it is totally neglected in the industrial symbiosis literature, large anchor tenants providing significant portion of wasted flows of materials and energy as resources to other tenant firms in the same industrial cluster (Ayres, 1995) are usually those producing large amounts of pollutants in 'dirty industries' (Grether and de Melo, 2003) or pollution-intensive industries by definition.

This physical anchor tenant (Burström & Korhonen, 2001) has an interesting connection to locational theory. Industrial symbiosis tends to implicitly or explicitly

7 The concept of 'anchor tenant' came from real estate industry, specifically from the development of shopping malls (Brueckner, 1993). Originally, anchor tenant or anchor store means 'a store that increases, through its reputation, the traffic of shoppers at or near its location' (Konishi & Sandfort, 2003, p. 413). Having anchors at the mall, retailers are willing to move in to take advantage of the brand power of those anchors (Pashigian & Gould, 1998). Therefore, the recruitment of anchor tenants is crucial to attract other retailers, and to lead the shopping mall project to the success. The extended definition of anchor tenant in Chertow's suggestion probably result from the fact that eco-industrial park development in the U.S. is typically both a real estate development project in need of attracting other tenants and an industrial symbiosis practice looking for steady sources of sufficient material or energy flows.

presuppose that a certain group of industries are required for its take-off. They are 'large industries' that could generate bulky and steady waste streams to make industrial symbiosis feasible (Chertow, 2000; Ehrenfeld & Gertler, 1997). Ayres (2002, p. 45) exemplified some industries of this quality in his explanation of scale economies.

> The benefits of scale are most obvious (and easiest to analyze econometrically) in the case of homogeneous commodities such as steel, petrochemicals or electric power. Economies of scale tend to encourage industrial gigantism, and oligopolies, at the expense of competition.

This presupposition is supported by the fact that most applied cases of industrial symbiosis are bounded to existing large scale production units and realize additional economic and environmental gains by supplementing existing production systems with necessary technological and institutional changes to reuse and recycle streams of wastes and by-products (F. Boons & Baas, 1997; Côté & Cohen-Rosenthal, 1998; Mirata, 2004; Mirata & Ristola, 2005).

The favorable relationship between large scale production and practices of resource recovery has existed (Desrochers, 2002b, 2002c), and some locational theorists have offered their insights on this issue. Most of classical and neo-classical locational theories are basically about the location or production optimization of firms, which can be pursued by calculating the location of a firm of pre-defined production characteristics in relation to exogenously given spatial locations of input and output markets (McCann, 1995, 1999; McCann & Sheppard, 2003). To identify and organize components of eco-industrial development scattering out in several different locational theories, it is advantageous to bring the concept of joint production. Joint production means a case that for technical reasons a single production process intrinsically produces several outputs jointly (Baumgärtner, 2000).[8] The history of joint production in economics is arguably almost as long as that of economics itself and the reuse of by-products as raw material or intermediate products from a joint production often attracted interests of locational theorists, as well as economists.[9]

In the late 19th century, Alfred Marshall found the decreasing importance of 'economy of materials' from an observation that "no doubt many of the most important advances of recent years have been due to the utilizing of what had been a waste product" (A. Marshall, 1890, p. 340). His observation was based on a specific industrial organization of 'production on a large scale', which innately have 'the advantage of continuity of process' (A. Marshall, 1920, p. 239). In *Industry and Trade*, Marshall (1920, pp. 238-239) clarified the relationship between large-scale production, by-product utilization, and their dynamics through new technologies and demands.

> There is an intimate connection between the massive manufacture of homogeneous products and the utilization of by-products… By-product industries are however liable to great vicissitudes. Something which was apparently almost valueless is suddenly made the foundation of an important product, either through a new technical discovery or through the rise of a new demand.

Marshall's argument buttressed the preference to large industries in industrial symbiosis in practice. As mentioned, anchor tenants in Chertow (2000)'s definition are typically large production units in mature industries, insuring bulky and steady provision of by-products.

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8 There are other authors that regarded joint production as any form of multiple output production (Nadiri, 1987). However, Baumgärtner and his colleagues focused on joint production due to technical necessity, and developed an analysis of the industrial production process in terms of thermodynamics (Baumgärtner, 2000, 2002; Baumgärtner & de Swaan Arons, 2003; Baumgärtner, Dyckhoff, Faber, Proops, & Schiller, 2001). Their main conclusion is that due to first law (conservation of energy) and second law (entropy) of thermodynamics, all goods produced necessarily generate by-products that are often unwanted outputs of high specific entropy.

9 Kurz (1986) and Baumgärtner (2000) provided very helpful lists of economists and their viewpoints of joint production in the history of economics.

Marshall specified the advantages of production at large scale in by-product utilization, but did not identify locational relationships between large production units and industries using their by-products. It was Weber (1929) who offered insights on those location relationships. Among his various works, his explanation of the connection between industries through materials overlaps the basic insights from industrial symbiosis, especially when he brought in the concept of joint production in his framework by arguing that some productive processes are "*technically* connected if the material of one process is the by-product of the second main product of any one of the stages of another process" (Weber, 1929, pp. 201-202).[10] He proposed that the location of joint production is mostly oriented toward not the location of by-product, but that of main material.[11] Weber's observation suggests that the location of eco-industrial development is seriously conditioned by the location of potential anchor tenants.

Hoover (1937)'s evaluation of industries connected with a joint production is similar to that of Weber's. Like Weber, Hoover indicated that the concentration of one 'principal industry' in a city may lead the concurrent concentration of its 'dependent industries', and this auxiliary growth can be an important element in localization economies. Hoover also signified the peculiar advantage of co-location of them, and implied that nascent stage of material exchanges can be extended by finding new uses of by-products and recruiting new processes for treating them accordingly. The cumulative nature of Hoover's 'economy of integration' could back up the evolutionary approach in

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10 Weber identified economic connection through materials, too. Here, technical connection indicates inter-industrial joint production, while economic connection is a case of different production processes using the same material or half-finished product. (Weber, 1929, pp. 201-202)

11 By 'by-product', Weber meant a jointly produced material that very inferior in weight or in value to the main material. He also provided cases of the technical connection between the dye-stuff industry and other industries using coke through coal tar, and of the location of slaughter-house which did not be influenced by its insignificant by-product, bones (Weber, 1929, pp. 202-203).

industrial symbiosis, since it suggests a mechanism that sometimes even a parasitical link can extend and evolve into a symbiotic loop.

Isard (1990) observed and researched a vital case of resource recovery in motion: the emergence of scrap industry and its influence upon the location of steel industry. He paid attention to the substitutability of scrap for iron ore in the steel industry, and regarded it as ‘one other major change in the set of locational vectors’ (Isard, 1990, p. 69). Isard’s work about changing locational patterns of steel industry due to the establishment of feedback loops of scrap metals around big cities revealed a new aspect of eco-industrial development. Economic and technological changes may generate new locational patterns of old industries in mature environments, which eco-industrial development has to consider and use in its development path.

Jane Jacobs contributed to the final piece of eco-industrial development in locational theories. She observed that firms built local and regional offices in places where they used to just export products and services by their interests, and said “economies of location often override and outdo economies of scale” (Jacobs, 2000, p. 81). Focusing on scale economies of managing and treating materials among firms, most of the former theorists observed inter-firm food chain flowing from big plants to small plants. Jacobs (1969) was the only exception who imagined a potential agent collecting wasted materials from different plants to build economies of scale in handling those materials. Although large part of her imagination still reside in the conceptual ground, her description of the agent is very similar to that of specialized waste treatment firms, or ‘scavengers and decomposers’ (Geng & Côté, 2002) as dubbed in the industrial symbiosis literature.

In sum, classical locational theories support the anchor tenants approach. Marshall pointed out the benefits of production at large scale in by-product utilization, and Weber and Hoover identified co-location tendency of principal industries of large production and dependent industries with by-products from principal industries. On the other hand, more recent locational theorists find new possibilities in eco-industrial development. Isard observed how the establishment of material feedback loops by technical innovations can change spatial patterns of industrial location, and Jacobs imagined small waste recycling firms that may find their niches in large cities.

There are two issues to be addressed at this point. First, as mentioned, anchor tenants are usually large production units in pollution-intensive industries generating a large amount of wasted resources by definition. Brief review in this section support their leading role in locational choices of eco-industrial development. Hence, it is logical to focus on locational choices of those large units in 'dirty' industries and examine performance of them in relation to their local environments to find favorable environments for eco-industrial development. In Chapter 3, eco-industrial development in the industrial context will be investigated in this fashion.

Second, it is difficult to find insights for eco-industrial development in the post-industrial context in classic locational theories that are mostly theories of factories and plants (Hayter, 1997). Central place theory (B. J. L. Berry & Pred, 1965; Christaller & Baskin, 1966; Lösch, 1954) is a notable exception. While central place theory did not address environmental aspects of the service sector explicitly, it did emphasize the benefits of central places that make offices and buildings in service industries cluster in them. The relevant question here is whether those benefits of central places are also attractive to economic units of eco-industrial development – more precisely, whether agglomeration economies benefit eco-industrial developments in the industrial and the post-industrial contexts. To examine this question, discussion in agglomeration economies will be introduced in the next section.

2.4.2 Urbanization Economies versus Localization Economies

Agglomeration economies, location-specific economies of scale, have been a major research field in urban and regional economics, since Marshall's (1890) formulation of the sources of agglomeration economies, including local labor pool, non-traded inputs, and information spillovers. Hoover (1937, pp. 90-91) suggested a classification of three distinguished categories of agglomeration economies, which is still widely used in urban and regional economics[12]:

a) *Large-scale economies* within a firm, consequent upon the enlargement of the firm's scale of production at one point.
b) *Localization economies* for all the firms in a single industry at a single location, consequent upon the enlargement of the total output of that industry at that location.
c) *Urbanization economies* for all firms in all industries at a single location, consequent upon the enlargement of the total economic size (population, income, output, or wealth) of that location, for all industries taken together.

In urban economics, localization economies are equal to the Marshall-Arrow-Romer (MAR) externalities (Fujita & Thisse, 2002), and urbanization economies are equal to Jacobian externalities (Glaeser, Kallal, Scheinkman, & Shleifer, 1992). Theoretically, localization economies support intra-industry specialization, while urbanization economies support inter-industry diversity as a source of economic growth.

12 Ohlin (1933, p. 203) presented the original typology in international economics.

The distinction between localization economies and urbanization economies was first made for the extraction and manufacturing sectors, but has been applied to the service sector as well. Glaeser *et al.* (1992) tested impacts of those types of agglomeration economies on the growth in the service sector, as well as in the manufacturing sector in the U.S. Recent studies on industrial clusters also identified the important role of clusters in the service sector (F. McDonald, Huang, Tsagdis, & Tüselmann, 2007; Porter, 2003). Different from the manufacturing industries, however, service industries are less oriented to locations of resources; service industries are mostly demand-oriented (Illeris, 1996). Therefore, service industries are supposed to be concentrated in existing centers of population and employment – where demands for service industries are. That is also the central insight from the literature of central place theory (B. J. L. Berry & Pred, 1965; Christaller & Baskin, 1966; Lösch, 1954).

Recent studies in the industrial symbiosis found the advantages of urbanization economies in cities and in mature industrial areas to eco-industrial developments (Desrochers, 2002a, 2002b, 2002c; Sterr & Ott, 2004). In contrast, anchor tenant approach of large production units in pollution-intensive industries has elements that support positive impacts of localization economies on eco-industrial developments, based on a single industry or a small group of related industries (Chertow, 2000, 2007). It should be noticed that localization economies do not limit their presence in local areas, and urbanization economies in urban areas.[13] For example, an eco-industrial development can be located in an urban area with a name of eco-industrial district, like financial or garment district in New York. Since "to a great degree, cities form around and depend on

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13 Classical example of localization economies in the urban setting is the heavy industrial district in Harris and Ullman's multiple nuclei model of internal structure of cities (Harris & Ullman, 1945).

clusters of industry" (Arthur, 1988, p. 85), major cities tend to be both places of diversity and of specialization in reality.

Overall, the perspectives from agglomeration economies suggest that eco-industrial developments in nascent local industrial systems have more limitations than in-situ restructuring among existing actors in mature local industrial systems. It is hard to expect that eco-industrial developments in nascent local industrial systems have enough size or diversity to take advantages of urbanization economies from the start. Therefore, it is reasonable for them to lean on anchor tenants or 'large industries' of localization economies in initiating and sustaining eco-industrial developments, as illustrated in the last section of classic locational theories. On the contrary, eco-industrial developments in mature local industrial systems can take advantages of urbanization economies of size and diversity and increase the possibility of genesis and survival of eco-industrial developments. However, the initiation of eco-industrial development in mature local industrial systems is still likely to rely on localization economies of a small group of related industries, since the growth of eco-industrial development generally comes from simple loops and extends to complex networks. The strengths of mature local industrial systems are not only from their urbanization economies, but also from their localization economies. Hence, it is reasonable to expect that generally eco-industrial developments tend to be located in major cities and clusters of industries, and to follow existing spatial forms and distributions of economic units in the industrial and the post-industrial contexts.

Current spatial forms of eco-industrial development can be analyzed in more details with proper models of contextual factors controlling those forms. Key theoretical and empirical considerations in identifying contextual factors and designing a relevant modeling framework are examined in the next section.

2.5 Contextual Factors: What Make Eco-Industrial Developments Feasible?

2.5.1 Self-Organization versus Strategic Intervention

Studies of eco-industrial development have not paid proper attentions to contextual factors of eco-industrial development much, but they do have a key debate of policy interventions, relevant to the research question of contextual factors. Cohen-Rosenthal (2000) made a distinction between self-organizing and engineered systems. Certainly, industrial ecology is an applied field to utilize principles from ecological systems to build better industrial systems. Engineered industrial system working along principles form natural, self-organizing systems, therefore, is one of the main goals of industrial ecology. In the industrial ecosystem at Kalundborg, Denmark, key partners including oil refinery, power station, gypsum board facility, pharmaceutical plant, and the City of Kalundborg, share water, steam, and electricity and exchange wastes as resources for other processes (Ehrenfeld & Gertler, 1997; Jacobsen, 2006).[14] Kalundborg is not a result of presupposed plan or design, so it is typically referred as a self-organizing industrial ecosystem (Chertow, 2000; Ehrenfeld & Gertler, 1997). The very existence of the Kalundborg case stimulated scholars to find other self-organized industrial symbioses, and identify similar industrial structures in mature industrial complexes, as enlisted in 2.2.2.

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14 The very term 'industrial symbiosis' was coined by the power station manager in Kalundborg (Chertow, 2000).

Creation and replication of eco-industrial parks as engineered systems has been turned out to be a difficult task.[15] Failures of many engineered, planned eco-industrial park projects brought a typical response among eco-industrialists that successful eco-industrial parks are not likely to occur as an outcome of engineering or planning, so the market process should be involved in as a main self-organizing, coordinating force (Chertow, 2000; Desrochers, 2004; Desrochers & Ikeda, 2003; Ehrenfeld & Chertow, 2002). However, this argument does not necessarily ban the possibility of strategic interventions in eco-industrial development. The lack of comprehensive design and plan for the Kalundborg does not mean that there has not been any plan at all. In fact, physical links among key partners in Kalundborg have been established and evolved by their careful and considerate plans and contracts (Ehrenfeld & Chertow, 2002; Ehrenfeld & Gertler, 1997; Jacobsen, 2003; Jacobsen & Anderberg, 2004). Many new linkages has been successfully incorporated in agreement with Danish authorities, thanks to the more flexible regulatory system of Denmark (Desrochers, 2000, 2002a).[16] Although there is no guarantee to generate required self-organization process intentionally at the right time and place, some policies, incentives, and strategies to trigger self-organization process are available to assist eco-industrial developments (Mirata & Ristola, 2005).

It is desirable to borrow some insights from empirical researches on industrial clusters to bring a new perspective to studies of eco-industrial development. Current findings in industrial symbiosis are somewhat limited to successful self-organizing cases

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15 A report of the Center for Sustainable Resource Processing identified more than 60 eco-industrial park projects around the world from documents, reports, and published articles, but due to lack of relevant information, it found difficult to discern successful and successive projects from other ones (Bossilkov, van Berkel, & Corder, 2005).

16 While it is certainly valuable to know about Kalundborg's contribution to Danish economy or historical construction of Danish environmental and industrial policy in transplanting the Kalundborg experience in different soil, further research about Denmark and its economic and regulatory systems is hard to find in industrial ecology. Remmen (2001) summarized the process of 'greening of industry' in Denmark.

– just like the earlier research in industrial clusters (Amin & Graham, 1997), but if we consider on-going cases of industrial clusters, it is not difficult to find thriving planned clusters all over the world (Bresnahan & Gambardella, 2004b; Castells & Hall, 1994). Certainly, decades-long trials and errors of benchmarking high-tech clusters – especially Silicon Valley – have confirmed that there is no easy way to copy or transplant a successful case to different locations (Bresnahan & Gambardella, 2004b). However, that does not mean that the self-organization of industrial clusters is wholly up to serendipity and accidents. The success of self-organizing eco-industrial developments depends not only on their unique economic, social, cultural and technical contexts, but also – at least partly – on the result of human will and endeavor (Braunerhjelm & Feldman, 2006; Bresnahan & Gambardella, 2004b; Castells & Hall, 1994; Cooke & Schwartz, 2007; Saxenian, 1994). Bresnahn and Gambardella (2004a, p. 338) summarized their experiences of industrial clusters as follows:

> Many attempts to creating new clusters and successful new firms in certain industrial or technological trajectories will fail, and they will fail in spite of the fact that the key actors have done all the right things that are to be done in these contexts. In this area it appears that luck and skill are complements; those initiatives which embody a superior business model or technology are more likely to find the "luck" they need.

Scott (1988b) presented a similar argument that to be successful, firms and clusters need to pass brief economic 'windows of opportunity' before they are closed. In addition, Boschma and Lambooy (1999) argued that urbanization economies may offer variety for local actors and open up the windows of locational opportunity, as well as of economic opportunity, for local actors in terms of chance and human agency. Then, local actors can be benefited from specific assets cumulated from localization economies as a result of industrial growth out of spatial and temporal chances. Chance events and path dependency are unpredictable and uncertain phenomena on which policy makers and entrepreneurs have little controls, so it is reasonable for them to focus on the identification and generation of variety of practical responses to changing selection pressures of the market (Lambooy & Boschma, 2001). In that sense, policy makers should not be optimizers but adapters that continuously interact with selection environments and human agents in mutually adaptive processes and create locally embedded policies. Therefore, it is valuable for policy makers to identify and understand economic and locational factors in different local contexts that may create favorable environments for economic develop in general and for eco-industrial developments in particular (Boschma, 2004; Boschma & Lambooy, 1999; Lambooy & Boschma, 2001).

Self-organization and strategic intervention in industrial symbiosis do not need to be two different modes of eco-industrial development. As reviewed in this section, on-going eco-industrial developments result from contextual factors of strategic intervention, as well as of self-organization (Andrews, 2002; F. Boons & Janssen, 2004; Chertow, 2007; Ehrenfeld & Chertow, 2002). That implies if proper contextual factors can be identified, it becomes possible to build models to frame favorable or hostile environments for potential eco-industrial developments. The next section will introduce a useful framework from current studies in ecology and in biology to address this topic.

2.5.2 Features of Organisms versus Factors of Environments

To better understandings of complex relationships between self-organization and strategic intervention, and between eco-industrial developments and their environments, the concepts of the niche and the niche construction in ecology and in biology can be helpful (Boogert, et al., 2006; Crain & Bertness, 2006; Odling-Smee, et al., 2003; Wright & Jones, 2006). Niche concepts were originated from biology and ecology, but have been applied and redefined in a group of social science fields, such as business management, economics, and sociology (Popielarz & Neal, 2007; Schot & Geels, 2007; Tisdell & Seidl, 2004). Instead of enlisting various concepts of the niche in those different fields, this review focuses on a specific concept of niche, developed by Hutchinson (1978). His definition of the niche revolutionized qualitative and functional studies of the niche in biology, dominant at his times. He defined a niche as a set of physical factors enabling an organism's survival and reproduction through its interactions with its environments. Geometrically, he imagined a niche as a field constructed by vectors of environments' factors in a multidimensional space. If environmental factors of a species and the species' features can be observed and acquired quantitatively, the current and future states of a given niche of the species can be studied by analyzing matching interactions between those factors and features.

Following Hutchinson's (1978) definition of the niche as 'the set of environmental states in which [a species] thrives' (Popielarz & Neal, 2007, p. 68), Odling-Smee et al. (2003) formulated the niche with the subsequent equation.

$$N(t) = h(O,E)$$

Here, *N(t)* represents the niche of the population of organisms *O* at time *t*, and *E* represents its environments. Mathematically, *O* is a vector of organism's features and *E* is a vector of environment's factors. Changes over time in *O*'s features and in *E*'s factors can transform matching relationships between *O*' features and *E*'s factors. Then, the dynamics of *N(t)* over time can be regarded as 'niche evolution' (Odling-Smee, et al., 2003, p. 42).

This formulation can be easily applicable to quantitative analyses in this dissertation. Although no reference on niche or niche construction was provided, Lewis (2003) used a similar function of both incubator quality and regional capacity vectors to condition the success of an incubator program, in relation to Nelson and Winter's (1982) models in evolutionary economics. My second research question of contextual factors is a well fit to this formulation. By collecting publicly available features of eco-industrial development and factors of their environments over time, I will build diffusion and growth models of eco-industrial developments in the industrial context in Chapter 3, and in the post-industrial context in Chapter 4. Since lack of data on quantifiable features of eco-industrial developments, my models are mainly constructed with environmental factors, focusing on the identification of effective contextual factors attracting or defying eco-industrial developments, closer to the original definition of Hutchinson's (1978).

In biology and ecology, Hutchinson's formulation changed the discipline, but did not eliminate qualitative researches of niches, since the semantic information framing niche construction is largely not quantifiable (Stuart, 1985). Just like that, the interactions between features of eco-industrial developments and factors of their environments can be probed qualitatively with the general framework of the formulation, when it is not feasible to perform quantitative analyses of the interactions (Aldrich, 2008). Inspired by the organism-environment dichotomy, a typology of eco-industrial developments in different environments is developed in the Appendix. By crossing a vertical axis of the strength of eco-industrial developments with a horizontal axis of the maturity of their local industrial systems, four types of interactions between eco-industrial developments and their local industrial systems are identified. Those interactions can be changed from one type to another. Among possible pathways among four types, two strategic pathways for sustainable industrial and economic development are discerned, focusing on the ways in which initiate eco-industrial developments in nascent or in mature local industrial systems; strong eco-industrial development can be a catalyst for an nascent local industrial system, or a symbiote for a mature system. This typology and strategic pathways, presented in the Appendix, will frame my case studies of eco-industrial development in Chapter 5.

Traditionally, niche concept assumes a biased relationship between organisms and their environments: organisms adapt to their environments by changing their features fit to varying factors of their environments. However, relatively recent conceptualization of niche construction (Odling-Smee, et al., 2003) or ecological engineering (Hastings, et al., 2007) in biology and ecology emphasizes a group of organisms that actively change their environments. Ecosystem engineers are those organisms that “directly and indirectly control the availability of resources to other organisms by causing physical state changes in biotic or abiotic materials” (C. G. Jones, Lawton, & Shachak, 1997, p. 1947), and niche construction or ecological engineering happens when an organism modifies the relationship between itself and its environments by changing factors in its environments. Although those concepts were developed for better understandings of the interactions between organisms and their environments, we can analogically use them in the interactions between eco-industrial developments and their local industrial systems.

Odling-Smee et al. (2003, p. 297) effectively illustrated the role of niche construction in an evolutionary perspectives as follows:

> While natural selection typically takes many generations to work, niche construction is individual based, and can therefore immediately be put to work by individual organisms. As a consequence niche construction is likely to permit much more rapid responses to changing natural selection pressures than conventional traits… Niche construction is likely to be a more rapid route to complementarity between an organism's features and the factors in its local environment than natural selection.

Their argument is well resonant with suggestions for eco-industrial developments in the last section. Analogically, natural selection is to market pressure what niche construction is to eco-industrial development. May market pressures alone create accidental eco-industrial developments in the long run, but eco-industrial developments can intentionally generate a swift variety of eco-industrial niches responsive to changing market pressures. From an evolutionary perspective in economic geography (Boschma & Frenken, 2006; Boschma & Martin, 2007), intentional eco-industrial developments can have their edge over accidental ones in terms of these rapid and diverse reactions to the market.

Like niche construction is driven by ecosystem engineers, eco-industrial development is driven by key actors. While physical anchor tenants are major players of eco-industrial development (Chertow, 2000), as introduced in 2.4.1, there is another type of anchor tenant managing information and knowledge flows of eco-industrial development, distinctive from ecosystem engineers in niche construction. In the next section, I will introduce conventional definitions of this new type of anchor tenant, institutional anchor tenant, in industrial symbiosis and itemize some variations of new institutional anchors by introducing a distinction between local and non-local transactions of information and knowledge, which is essential to investigate institutional fabrics in different contexts in Chapter 5.

2.6 Institutional Fabrics: How Can Eco-Industrial Developments Be Organized?

2.6.1 Physical Anchor Tenant versus Institutional Anchor Tenant

After reviewing equivalent units of anchor tenant in industrial symbiosis literature, Kohornen and Sänkin (2001, p. 448) suggested an alternative definition of anchor tenant approach, which was first articulated by Chertow (2000) and introduced in 2.4.1 of this dissertation. By anchor tenant, they mean:

> an influential organisation in the region, which drives the main material and energy flows and is already engaged in some environmental management efforts. The argument is that this company or organisation can serve as the key actor in the environmental management of the network, or the network of collaborative actors can gradually emerge around such a support system, which has existing potential for environmental management, and in particular, for inter-organisational environmental management.

Basically, they argued that anchor tenant is not only a source, but also a manager of material and energy flows.

Based on both traditional and alternative definitions, Burström and Korhonen (2001) identified two types of anchor tenant. One is a physical anchor tenant, and the other is an institutional anchor tenant. Physical anchor tenant can be defined as ‘an influential driver of the main physical material and energy flows of the region’ (Burström & Korhonen, 2001, p. 40), while institutional anchor tenant takes a role ‘to provide the system with education, information, social and economic infrastructure, a decision-making forum, institutional and political support etc.' (Burström & Korhonen, 2001, p. 41). In other words, physical anchor tenant is supposed to dominate flows of material and energy, while institutional anchor tenant is to lead flows of information and knowledge in pursuing eco-industrial development.

Various actors can make institutional anchor tenants in both self-organizing and engineered eco-industrial developments. Like the Symbiosis Institute created by six partners at the Kalundborg industrial symbiosis, an institutional anchor tenant can be organized from capacity building processes of industrial ecosystems to alleviate coordinative problems and disseminate new information and knowledge (Ehrenfeld & Chertow, 2002; Jacobsen & Anderberg, 2004). As can be seen in many cases of eco-industrial parks, governmental agencies are natural candidates for institutional anchor tenants. Burström and Korhonen (2001) probed the role of municipalities as institutional anchor tenants to enter into and support industrial symbiosis projects. It is also viable to start an eco-industrial development project from existing institutions, such as industry association, as in case of a by-product synergy project in Tampico, Mexico (Chertow, 2000; Ehrenfeld & Chertow, 2002). More recent examples of by-product synergy show that local coalition of governmental agencies, industry representatives, and non-government organizations can be a potential option to build a powerful institutional anchor tenant in promoting eco-industrial development as an important part of sustainable development (Mangan, et al., 2003).

The introduction of institutional aspects and the further elaboration of established focus on physical flows are current trends in industrial symbiosis. Recent studies in industrial symbiosis attempt not only to identify and establish social, political and institutional relationships among firms and organizations that condition the paths of eco-industrial parks (Desrochers, 2004; Fichtner, Tietze-Stöckinger, & Rentz, 2004; Mirata & Emtairah, 2005), but also to elaborate and quantify its resource recovery practices out of material and energy flows (Chertow & Lombardi, 2005; Jacobsen, 2006).

The recent institutional focus in industrial symbiosis, represented by the concept of institutional anchor tenant, is valuable, but it has its own limitations. First, Burström and Korhonen's (2001) distinction between physical and institutional anchor tenants is based on an assumption that those anchor tenants are local. This assumption may be well fit to physical anchor tenants dominating flows of materials and energy, while institutional anchor tenants dominating flows of knowledge and information do not have to be local. For example, consultant firms usually offer information and knowledge for different localities in distance, or conduct local projects for pre-determined time periods (Perron, Cote, & Duffy, 2006; Wood, 2002). Second, non-local relationships of local institutional anchor tenants, which are sources of learning and innovation, also tend to be overlooked, just like in traditional analyses in industrial symbiosis, ignoring non-local material and energy flows (Wallner, et al., 1996). The distinction between local and non-local relationships, and the different ways in which non-local connections manifest locally raise important research questions in the eco-industrial development literature.

In the next section, I will develop a typology of possible new institutional anchor tenants as replication strategies of eco-industrial development, based on local and non-local transactions and movements of local actors and given institutional anchor tenants.

2.6.2 Local Communities versus Non-local Networks

Recent studies in economic geography share similar issues of local and non-local relationships driving local economic development (Bathelt, et al., 2004). Earlier studies of institutional fabrics in industrial clusters in economic geography have been developed around the notion of 'territorial innovation models' (Moulaert & Sekia, 2003), focusing on territorial systems of learning and innovation, functioned by local communities of institutions and organizations. However, more recent studies of industrial clusters found similar communities of practice in firms and organizations, as well as in regions (Amin & Cohendet, 2004; Amin & Roberts, 2008; Wenger & Snyder, 2000) and emphasized a more balanced approach on institutional fabrics between local communities of businesses and institutions and non-local networks of experts and business organizations in analyzing internal mechanisms of industrial clusters (Bathelt, 2003, 2005; Gertler, 2003, 2008). It is a common practice in those studies to identify key local and non-local actors and illustrate various connections among them to articulate unique institutional fabrics of different industrial clusters (Benner, 2003; Grabher, 2002b, 2004b). This practice can be applied to probe different institutional fabrics of on-going eco-industrial development, if a proper typology of institutional fabrics is pre-defined by different relationships between local and non-local institutional anchor tenants.

Marshall and Wood (1995) embraced Sapir (1993)'s typology of international service exchange by different modes of contact between service provider and user to illustrate various roles of service industries enabling local economic development in the globalization era. Services can be delivered not only by direct trades between co-located provider and user, but also by movements of the provider to the user or of the user to the provider in different locations. Service provider may move to service user temporarily or permanently, while the user only moves to the provider temporarily to deliver necessary services. As a result, they identified four dominant forms of international service exchange. Since institutional anchor tenants are service providers of information and knowledge on eco-industrial development by definition and local actors are users of their information and knowledge, Sapir (1993)'s typology of international service exchange can be adopted to classify different modes of creating new institutional anchor tenants internationally or inter-regionally.

		MOVEMENT OF ANCHOR		
		LOW	HIGH	
			Temporary	Permanent
MOVEMENT OF ACTOR	LOW	**Type 1** No movement of anchor or actor Modular Anchor	**Type 3** The anchor moves temporarily to the actor Temporary Anchor	**Type 4** The anchor moves permanently to the actor Subsidiary Anchor
	HIGH	**Type 2** The actor moves temporarily to the anchor Non-Local Anchor		

Figure 2.1 A Typology of Information and Knowledge Exchange between Local Actors and Existing Institutional Anchor Tenants

In Figure 2.1, four types of information and knowledge exchange between local actors and existing institutional anchors are briefly illustrated. Each type is matched to a new institutional anchor tenant strategically designed to facilitate and intensify information and knowledge flows at that specific type of exchange and to ultimately transfer and replicate experiences of an eco-industrial development to other locations.

Type 1 represents a mode of exchange in which local actors are co-located with institutional anchor tenants. It is a traditional viewpoint of institutional anchor in industrial symbiosis (Korhonen & Snäkin, 2001). 'Pre-existing organizational relationships and networks' (Chertow, 2000) can be transformed into local institutional anchor tenants to begin local eco-industrial developments, while dedicated local anchor of eco-industrial development can be launched as eco-industrial development evolves (Ehrenfeld & Chertow, 2002; Ehrenfeld & Gertler, 1997; Jacobsen, 2006). Similarly, academic institutions and R&D-intensive firms have been considered local anchors in the economic development literature (Adams, 2005; Agrawal & Cockburn, 2003; Braczyk, Cooke, Heidenreich, & Krauss, 1998; Cooke & Schwartz, 2007).

Establishment of new local anchor of eco-industrial development has been attempted to drive local eco-industrial development more efficiently and effectively. Since the creation and operation of new anchor requires a significant amount of human and financial resources, there have been tryouts to develop and use a small standardized framework or unit of eco-industrial development as a starter for local eco-industrial development (Cohen-Rosenthal & Musnikow, 2003). Business incubators and growth centers are economic development tools that have similar goals and objectives (Hansen, 1972; Lewis, 2003). I would name this standardized framework or unit of eco-industrial development that is designed to facilitate the reproduction and mass-production of eco-industrial development as modular institutional anchor tenants or modular anchors. Modular anchor can be primarily applicable to rather nascent local industrial systems that lack existing local actor and anchors, while it is feasible to locate it in mature systems to stimulate given networks of local actors and anchors.

Type 2 illustrates a case that local actors temporarily move to institutional anchor tenants in other locations. Even highly motivated local actors and institutional anchor tenants cannot initiate local eco-industrial development by themselves and they certainly don't have to do. Local actors and anchors visit and contact the leaders and members of former eco-industrial developments and consult researchers and consultants in various institutions related to eco-industrial development. The growth and expansion of eco-industrial development practices may generate a new institutional anchor tenant that offers general services of eco-industrial development for multiple locations. Non-local institutional anchor tenants or non-local anchors are those anchors that are not located in local areas but can offer crucial information and knowledge matching local needs and demands of eco-industrial developments.

Type 3 demonstrates a case that non-local institutional anchor tenants temporarily move to local actors. Local actors and anchors can invite external experts and consultants for business meetings and workshops to introduce new ideas and concepts of eco-industrial development and acquire necessary information and knowledge for local eco-industrial development for a few days. On the other hand, most of eco-industrial developments nowadays start as projects, which are 'temporary systems' with 'institutionalized termination' often evolving into long-term relationships (Grabher, 2002a; Lundin & Söderholm, 1995). During the running periods of projects, non-local actors, including consultant firms, academic institutions, and non-profit organizations, can be involved in temporarily to guide eco-industrial projects and boost eco-industrial developments. They can be dubbed as temporary institutional anchor tenants or temporary anchors.

Finally, Type 4 indicates a case that non-local anchor tenants permanently move to local actors. Although it might be possible to actually move a successful local existing institutional anchor tenant to another location, it is not feasible to find such a case, since relocation of a local institutional anchor tenant to other locations is likely to break its close links to local actors and seriously weakens its performance as an institutional anchor. Therefore, this permanent movement is usually achieved to establish local branches and chapters of the original institutional anchor, as in retail banking and insurance (N. Marshall & Wood, 1995). Subsidiary institutional anchor tenants or subsidiary anchors seem to be a right title for those local chapters and branches that retain their organizational links to original non-local institutional anchors.

New institutional anchor tenants, emerged from each type of institutional fabrics, can be regarded as replication mechanisms that are instrumental in the initiation and reproduction of new eco-industrial developments in different locations. Since analysis of institutional fabrics regarding replication mechanisms of eco-industrial development has been rare, it will be valuable to use this framework to case studies. Institutional fabrics of on-going eco-industrial developments will be analyzed further with this scheme of interactions between local and non-local actors and anchors in Chapter 5, with strategic pathways from the typology of eco-industrial development illustrated in Appendix.

2.7 Statement of Hypotheses

Based on the above review of the theoretical and empirical literature, three hypotheses in spatial forms, contextual factors, and institutional fabrics of eco-industrial development are proposed.

Hypothesis One: economic units of better environmental performance are spatially concentrated in clusters and cities

Hypothesis Two: contextual characteristics of locations, as well as of economic units, have measurable impacts on the environmental performance of economic units and on the locational behavior of greener economic units

Hypothesis Three: collective institutional building process among key local and non-local actors enables economic units to initiate and maintain their joint pathways to eco-industrial development in different contexts

The first two hypotheses are tested for the plants in the industrial context in Chapter 3, and for the offices in the post-industrial context in Chapter 4 respectively. The third hypothesis is examined with cases studies of on-going eco-industrial development projects in the U.S. in Chapter 5.

Chapter 3. Eco-Industrial Development in the Industrial Context

3.1 Introduction

This chapter tries to identify favorable locational conditions for potential eco-industrial development in the manufacturing sector. Indebted to anchor tenants approach (Chertow, 2000; Korhonen, 2001a) in the industrial symbiosis literature, this chapter test the first two hypotheses of spatial forms and of contextual factors in the industrial context, refined in Chapter 2. The literature review shows that physical anchor tenants are likely to be large production units in pollution-intensive industries. Existing greener plants in those industries and their surrounding locations provide lessons for potential eco-industrial developments in the U.S.

In the next section, the five most pollution-intensive industries in the U.S. will be identified, and the role of greener plants as potential anchor tenants is discussed in relation to agglomeration economies. Then, existing counties of industrial specialization and industrial clusters of counties in 1990 and in 2000 will be identified by spatial statistics and compared to track changing patterns of those pollution-intensive industries. In each industry, maps of locational quotients and of local Moran statistics in 1990 and in 2000 are created. With calculated spatial statics, a series of regression analyses of the economic and environment performance of large manufacturing plants on features of those plants and on factors of local and regional industrial systems are developed. Results for each industry are reviewed correspondingly. At the end of the chapter, the summary of findings is presented.

3.2 Finding Greener Plants in Pollution-Intensive Industries

3.2.1 Pollution-Intensive Industries in the U.S.

As mentioned in Chapter 2, the very idea of physical anchor tenant industries in the literature of industrial symbiosis is theoretically in common with the definition of 'dirty' industries: both of those definitions assume a large amount of material and energy flows from those industries to identify them as anchor tenants or pollution-intensive industries. In environmental economics, those flows are considered wastes, but in industrial symbiosis, they can be resources for other industries (Ayres, 2002; Chertow, 2000; Jänicke, Binder, & Monch, 1997; Kahn, 2000). To extend the insights from the anchor tenants approach into a series of industry-wide analyses, the first step should be to define and identify pollution-intensive industries in the U.S.

There is no official definition of pollution-intensive or 'dirty' industries (Jänicke, et al., 1997). However, environmental economists have been applied the ratio of the pollution abatement operating costs (PAOC) of industries to their value added as a yardstick to separate pollution-intensive industries from relatively clean ones (Cole & Elliott, 2005; Cole, Elliott, & Shimamoto, 2005; Kahn, 2000). Five industries are typically classified as pollution-intensive industries in this framework: paper, chemical, petroleum, nonmetallic mineral (i.e. stone, clay and concrete), and primary metal industries. Cole and Elliott (2005) ranked industries in terms of an average of the PAOC as a percentage of industry value added for the period 1989-1994, and find those industries are on the top of their dirty industry list.

The descriptive analysis of the renewed 1999 Pollution Abatement Costs and Expenditures (PACE) survey in Table 3.1 shows that those industries are still the most pollution-intensive ones (U.S. Census Bureau, 2002).[17] Except the integrated food / beverage / tobacco industry, those industries are top five ones in the list: petroleum (1), primary metal (2), chemical (3), paper (4), and nonmetallic mineral product (6).

Table 3.1 U.S. Industries Ranked by Pollution Abatement Operating Costs in 1999

NAICS	Sector*	PAOC (Mil. $)	VA** (Bil. $)	PAOC/VA (%)	Rank
311-312	Food mfg / Beverage & tobacco product mfg	990.4	153.6	0.6	5
313-314	Textile mills / Textile product mills	109.9	26.4	0.4	8
315-316	Apparel mfg / Leather & allied product mfg	21.4	24.7	0.1	17
321	Wood product mfg	134.9	31.9	0.4	7
322	Paper mfg	945.6	54.2	1.7	4
323	Printing & related support	80.3	48.2	0.2	14
324	Petroleum & coal products mfg	1697.9	22.4	7.6	1
325	Chemical mfg	2808.0	157.1	1.8	3
326	Plastics & rubber products mfg	164.7	66.1	0.2	11
327	Nonmetallic mineral product mfg	281.5	45.1	0.6	6
331	Primary metal mfg	1543.9	47.3	3.3	2
332	Fabricated metal product mfg	405.3	116.4	0.3	9
333	Machinery mfg	97.7	105.6	0.1	16
334	Computer & electronic product mfg	325.4	162.8	0.2	13
335	Electrical equipment, appliance, & component mfg	97.0	48.2	0.2	12
336	Transportation equipment mfg	454.4	179.7	0.3	10
337	Furniture & related product mfg	39.1	31.0	0.1	15
339	Miscellaneous mfg	42.8	52.5	0.1	18

* Some sectors have been integrated, due to the limitation of available data
** Data of value added by industry in 1999 are retrieved at the Bureau of Economic Analysis (BEA)

Although the food / beverage / tobacco industry is ranked in the fifth place, they are small in the number of establishments, or release less or negligible amount of toxic chemicals. For example, there are only 11 establishments in tobacco industry in the 1990 Toxics Release Inventory (TRI) data, and 6 in the 2000 data (Environmental Protection Agency, 2005). Toxic releases of the food industry, measured in the original 1988 core chemicals,

17 The PACE survey was performed annually from 1973 to 1994, except 1987, and was revived in 1999 as a pilot for future surveys (Shadbegian & Becker, 2004). After 1999, the PACE survey was conducted in 2005, and the 2005 PACE survey report was released in April, 2008 (U.S. Census Bureau, 2008).

are filled with zeros both in 1990 and in 2000. In either case, these industries are hardly pollution-intensive in the above criteria, and not suitable for the statistical analysis considered in this dissertation. Hence, throughout the analysis of economic and environmental performance of manufacturing plants, I will focus on those five most pollution-intensive industries.

3.2.2 Greener and Larger Plants as Potential Anchor Tenants

Anchor tenants are also considered large economic units, emitting massive and continuous flows of wasted materials and energy (Chertow, 2000; Ehrenfeld & Gertler, 1997). However, the large size of plant is only a necessary condition for anchor tenants. Kohornen and Sänkin (2001) argued that anchor tenants should be also conducting some kinds of environmental management. In that sense, anchor tenants are not only larger, but also greener plants in the industrial context. In the perspective of sustainable industrial development, initiating eco-industrial developments around given greener and larger plants seems to be a feasible strategy along with anchor tenants approach.

The effectiveness of this strategy, however, heavily depends on different types and scales of environmental management in which anchor tenants are involved. Three types of agglomeration economies, introduced by Hoover (1937), are useful in framing this issue. First, larger plants may have large-scale economies or internal economies of scales enough to perform their own environmental management projects and initiatives. In the context of pollution prevention, manufacturing plants and facilities have developed a variety of managerial and engineering solutions for green manufacturing (Graedel & Howard-Grenville, 2005). Although it is certainly a form of eco-industrial development, it might not be its most desirable form, since the vision of industrial symbiosis in the market economy implies the improvement of performance of economic units by organizing, constructing, and participating in regional systems or networks of material and energy flows (Chertow, 2000, 2004; Graedel, 1996).

Second, larger plants may achieve better environmental performance through local inter-firm relationships in the same industry. This localization economies argument has two potential interpretations. First, environmental excellence may be self-organizing practices among economic units within an industry, since sometimes economic efficiency and environmental efficiency can be achieved at the same time. In this case, those plants do not perform environmental management per se, but conduct general management practices in an environmentally effective and responsive way through inter-firm relationships. Second, environmental management of larger plants may be extended through their former industrial links. Each industry has its sub-industries sharing similar industrial structures and characteristics, which assist both economic and environmental inter-firm relationships among those sub-industries. In either accidental or intentional case, existing industrial clusters of an industry are promising places to find these relationships.

Third, larger plants may use their resources to make connections to various actors in the market to achieve better environmental performance. Distinction between accidental and intentional environmental managements still holds in this urbanization economies argument. If the activities of material exchange and resource recovery have been common in the market – and in cities – throughout different histories and geographies, as argued in the industrial symbiosis literature (Desrochers, 2002a, 2002c, 2004), some existing trends of better economic and environmental performance of plants in different industries may be found in urban areas. On the other hands, emerging clean technology and green consulting firms enable larger plants to their environmental management practices in closer relationships to them (Pernick & Wilder, 2007). Here, cities of diverse industries are promising places in which inter-firm relationships among different industries can be found.

Finding conditions of greener and larger plants in the existing spatial patterns, in terms of agglomeration economies, is definitely helpful to initiate new eco-industrial development in the future, since that can show which conditions support accidental and intentional environmental performances in practice, and where the future eco-industrial developments take advantages of given conditions best. Depending on whether current performances of greener and larger plants tend to rely on internal economies of scale, localization economies, or urbanization economies, effective strategies for future eco-industrial developments can be differentiated accordingly. In the next three sections, a series of regression models on economic and environmental performances of greener and larger plants will be developed, which are solidly grounded on discussions on different types of agglomeration economies in this section.

3.3 Modeling the Performance of Plants in Pollution-Intensive Industries

3.3.1 Data to Model the Performance of Plants in Pollution-Intensive Industries

Regression analysis of this chapter relies heavily on the information of the environmental and economic performances of plants. The main data source for the environmental performance of plants is the TRI from the U.S. Environmental Protection

Agency (EPA), and for the economic performance, Dun and Bradstreet (D&B) directories. Under the Emergency Right-to-Know Provision, an industrial facility with 10 or more full-time employees that manufactures, imports, processes, or otherwise uses listed toxic chemicals in excess of specified thresholds must file a separate form for each released chemical (EPA, 1989; 1992). TRI includes plants' emission data, and the D&B Million Dollar databases and directories provide employment and sales data on plants in the U.S.[18] Since TRI denotes each plant a nine-digit identifier assigned by the D&B, it becomes possible to join two datasets into a joint dataset.[19] The final data tend to contain biased data on large plants. Usually, that is recognized as a key limitation in this kind of research, but that is rather fit to the intent of testing the anchor tenants approach, which are usually larger production units.

Although both datasets are available annually, it is improbable to build longitudinal or panel dataset from the TRI data, since each year different plants are asked to report their chemical releases based on their employment and the amount of chemicals they consumed in that year. As an alternative way of research, a comparative framework between years – 1990 and 2000 – is selected to probe changes in impacts of factors on spatial forms over time with the joint data. For the continuity of data between 1990 and 2000, chemical releases of the 1988 core chemicals, which have been reported in all years since 1988, are included in the joint datasets. The 1990 and 2000 datasets are created in the five most pollution-intensive industries, including Paper and Allied Products (SIC 26), Chemicals and Allied Products (SIC 28), Petroleum and Allied Products (SIC 29), Stone,

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18 The D&B database is a reliable source in identifying U.S. plants in many federal agencies, including EPA (McConnell and Schwab, 1990). The 1990 and 2000 D&B Million Dollar Directories are used for the research, which are available from the Rutgers library.

19 Grant and Jones (2003) and King and Lenox (2001) used similar methods to create joint datasets of both TRI and D&B data.

Clay, Glass and Concrete Products (SIC 32), and Primary Metal Industries (SIC 33). Due to unique industrial structures of different industries and limitations of available data, each dataset has limited number of records of individual plants. In some cases, especially datasets in 1990, results from regression analysis should be interpreted with apprehensions on small-sized samples.

This analysis includes other datasets and calculates relevant measures from them. County Business Patterns (CBP) is a key source of the industrial data of establishment and employment. Since the TRI and D&B datasets and the 1990 CBP data are coded in the SIC, the 2000 CBP data coded in the NAICS have to be recoded in the SIC for comparison with the concordance from the Census Bureau. CBP is also notorious for its censored data. Consulting Lahr and de Mesnard (2004) and Isserman and Westervelt (2006), gaps in the CBP data are estimated and filled with biproportional techniques. Metropolitan Statistical Areas (MSA) data in 1990 and in 1999 from the Census Bureau, the PACE survey data in 1989 and in 1999, and data of Gross Domestic Products (GDP) by State from the BEA in 1990 and in 2000 are also used to construct relevant independent variables for regression models.

3.3.2 Analyses to Model the Performance of Plants in Pollution-Intensive Industries

Two sequential analyses will be conducted. First, exploratory spatial data analysis (ESDA) of the five pollution-intensive industries will be performed to detect existing spatial clusters of those industries in the U.S. Since the idea of industrial symbiosis is all about links among economic units, clusters will be detected with locational data of plants, not with employment data in the joint datasets at the county level. For each industry, the location quotient as a measure of county-level industrial specialization and the local Moran's *I* as a measure of multi-county-level industrial specialization are calculated and mapped at the county level in 1990 and in 2000. Since there has been an overall decline in the manufacturing sector in the U.S., it is unlikely that the massive introduction of new clusters or the instant evaporation of old clusters is found in those industries between 1990 and 2000 (Dumais, Ellison, & Glaeser, 2002; Ellison & Glaeser, 1997), but still changes in overall clustering patterns may be present and observable. Although grouped in the name of pollution-intensive industries, those five industries are different in their industrial structures and locational behaviors. Similarities in their spatial patterns are found, but differences are also recognized. This section also reveals the current distributions of selected industries, enabling richer interpretation in the next section.

Second, factors conditioning the economic and environmental performances of larger plants will be examined. Greener plants in the current economic systems may be influenced by different types of agglomeration economies, including internal economies of scale, localization economies, and urbanization economies (Hoover, 1937), and each type of agglomeration economies reflects different factors of favorable local industrial system for existing greener plants. With calculated measures of industrial specialization, a series of regression analyses of the economic and environment performance of larger plants on features of those plants and on factors of agglomeration economies of local industrial systems are developed in the selected pollution-intensive industries. The rest of this chapter will be sequenced in that order.

3.4 Clusters of Pollution-Intensive Industries

3.4.1 Exploratory Spatial Data Analysis (ESDA) to Identify Clusters of the Pollution-Intensive Industries

Spatial clusters of pollution-intensive industries can be identified with a set of relevant techniques in the ESDA. The ESDA consists of techniques for exploring spatial data, such as techniques "summarizing spatial properties of the data, detecting spatial patterns in data, formulating sets of cases that are unusual given their location on the map" (Robert P. Haining, 2003, p. 182). Spatial cluster or hot spot identification is one of the most common ESDA techniques to detect spatial patterns. Since the main dataset for the analysis are organized and aggregated at the county level, spatial statistics for cluster detection in area data are required to identify spatial clusters of selected pollution-intensive industries. All spatial data analysis techniques in this section are applied to plant data to detect industrial clusters of plants, possibly promoting inter-firm relationships which are the main supposition of the industrial symbiosis (Chertow, 2000).

Specialization, supported by the Marshall-Arrow-Romer (MAR) externalities (Fujita & Thisse, 2002) or localization economies (Hoover, 1937), is identified by the ratio of the share of sector *s* in the county *i* divided by the share at the national level. This specialization index is equivalent to the location quotient (LQ), popular in urban and regional analysis.

$$LQ_i = \frac{L_{is} / L_i}{L_s / L}$$

where L_{is} is the number of plants of sector s in the county i; L_i is total number of plants in the county i; L_s is the number of plants of sector s in the U.S.; and L is total U.S. number of plants. Theory on the MAR externalities supports the key role of industrial specialization in regional growth (Fujita & Thisse, 2002; A. Marshall, 1890; McCann, 1995). Although the LQ is not strictly a part of ESDA, dealing with spatial data, it offers location-specific – county-specific – measures that can be compared to the next spatial statistic.

Spatial clusters are identified by a local measure of spatial autocorrelation, local Moran's *I*, which is the most old and common measure of spatial autocorrelation in spatial statistics (Cliff & Ord, 1981). Moran's *I* can be defined as

$$I = \frac{\mathbf{z}'\mathbf{W}\mathbf{z}}{\mathbf{z}'\mathbf{z}}$$

where $\mathbf{z}$ is the vector of the n locational observations; and $\mathbf{W}$ is the row-standardized spatial weight matrix. While diverse specifications of spatial weight matrix can be considered, a binary contiguity matrix, where 1 if two locations are close to each other, 0 otherwise, is used as a basic specification for the analysis. Then, if the Moran statistic is higher than the expected value, spatial autocorrelation is positive, and vice versa.

Moran's *I* is a global statistic, which means that it measures the general tendency of spatial autocorrelation in a given area, but cannot identify local 'pockets of nonstationarity' (Anselin, 1995). Simply put, global statistics of spatial autocorrelation measure overall tendency of clustering in a given area, while local statistics identify existing local hot spots, or clusters in the area (Fotheringham, Brunsdon, & Charlton, 2000, 2002). To evaluate local variation of spatial autocorrelation, local statistics should be used to detect local hot spots.

Anselin (1995) defined a Local Indicator of Spatial Association (LISA) with two criteria. First, the LISA at a location should spot whether a significant spatial clustering of similar values around the observation is present. Second, the sum of the all LISA for each observation is proportional to the global version of the same indicator of spatial association. Based on those criteria, he suggested local version of Moran's *I*. Local Moran's *I* is

$$I_i = \frac{(x_i - \bar{x}) \sum_j w_{ij} (x_i - \bar{x})}{\sum_i (x_i - \bar{x})^2 / n}$$

where x_i is the value of *x* at location *i*; $\bar{x}$ is the mean of *x*; *n* is the number of values; and w_{ij} is spatial proximity between *i* and *j*. Positive local Moran's *I* indicates spatial clusters of similar values, and vice versa. Since this statistic does not particularly identify spatial clusters of high values, Anselin suggested four types of local spatial association between a location and its neighboring locations. An observed value of a location may be higher or lower than the total mean of observations, while weighted average of observations in neighboring locations may also be higher or lower. Hot spots in this context indicate a location of higher value which is also surrounded by neighboring locations of higher values in average.[20]

20 Local G statistic can be an alternative measure to identify local clusters at the multi-county level (Getis & Ord, 1992; Ord & Getis, 1995). However, this local statistic can be problematic in the presence of global spatial autocorrelation and of common neighbors between any two locations (Anselin, 1995; Ord & Getis, 1995). Local Moran's I is preferred here in that context for multiple comparisons between different sectors and counties.

Local Moran statistic represents a type of spatial measure to identify local concentration (Arbia, 2001). Different from the LQ, different arrangements of location change local Moran statistic, since the built-in spatial weight matrix reflects the neighboring values of different locations. In comparison, the LQ identifies locations of higher shares solely based on observations of individual location, while local Moran's *I* points out locations of higher values based on observations of individual location and its surrounding locations. Namely, the LQ scans industrial clusters at the county level, and local Moran's *I* at the multi-county level in this research.

In the next section, using the LQ and local Moran's *I* with cleaned CBP data, spatial cluster maps in 1990 and in 2000 are generated for each of five pollution-intensive industries, including Paper and Allied Products (SIC 26), Chemicals and Allied Products (SIC 28), Petroleum and Allied Products (SIC 29), Stone, Clay, Glass and Concrete Products (SIC 32), and Primary Metal Industries (SIC 33).

3.4.2 Changing Patterns in the Locations of Clusters of the Pollution-Intensive Industries

Although both the LQ and local Moran's *I* are measures of industrial specialization, what they measure are different aspects of specialization. The LQ identifies counties of the higher local share of plants in an industry, while the cluster detection technique with the local Moran's *I* identifies a spatial group of counties of higher number of plants in the industry at the multi-county level. Generally, in each industry, only a handful of spatial clusters of counties are recognized, while individual counties of industrial specialization measured by the LQ show overall geographical tendencies across the U.S. General trends of selected pollution-intensive industries, unraveled by the LQ and the global Moran's *I*, are presented first. Then, similar patterns of five pollution-intensive industries are posited and noticeable pattern for each industry is described respectively in the order of Paper and Allied Products (SIC 26), Chemicals and Allied Products (SIC 28), Petroleum and Allied Products (SIC 29), Stone, Clay, Glass and Concrete Products (SIC 32), and Primary Metal Industries (SIC 33).

Table 3.2 Number of Counties with Location Quotient over 1 by Industry

Year	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33
1990	772 (24.8%)*	942 (30.3%)	663 (21.3%)	1790 (57.5%)	900 (28.9%)
2000	835 (26.8%)	1032 (33.2%)	734 (23.6%)	1852 (59.5%)	985 (31.7%)

* ( ) percent out of 3,111 counties and county equivalent areas

Table 3.2 shows the number of counties with the LQ of plants over 1 by industry. The percent of those counties in each industry is presented within parenthesis. All five pollution-intensive industries had more counties of industrial specialization in 2000. However, that does not mean those five industries growing between 1990 and 2000. In that decade, the share of the manufacturing sector in the U.S. decreased significantly. The number of manufacturing plants was declined by more than 13,000 from 1990 to 2000. In contrast, the number of total establishments in the U.S. increased by about 900,000 during the same time. Namely, increase in the number of counties with LQ over 1 was mainly induced by the shrinking national share of each industry. However, the increase also means that in spite of the general decline trend, manufacturing bases persisted in the significant amount of counties in the U.S. between 1990 and 2000.

Distributions of counties of higher LQ in the selected pollution-intensive industries share a loose pattern of relative absence of the Mountain States, which are representative rural areas in the U.S., and show the presence of the Rust Belt, which covers areas roughly from Chicago in Illinois to New York in New York. Although sometimes there were noticeable changes between 1990 and 2000 in the distribution of each industry, overall geographical patterns remained alike.

Table 3.3 Global Moran's *I* by Industry

Year	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33
1990	0.2516	0.2631	0.2554	0.3480	0.2488
2000	0.2880	0.2988	0.2953	0.3529	0.2948

Results from the global Moran's *I* analysis of plants are summarized in Table 3.3. Overall, clustering trends in selected five pollution-intensive industries became stronger from 1990 and 2000. Moran's *I* statistics as a measure of spatial autocorrelation increased in all industries during the decade in the U.S. Ellison and his colleagues presented that industrial clustering tends to be higher in the initial and the mature stages of an industry with their own global measure of industrial concentration, since an industry generally initiate in a small set of industrial clusters, and only the strongest clusters survive after its peak (Dumais, et al., 2002; Ellison & Glaeser, 1997). In that sense, the overall increase in Moran's *I* during the decade reflects the fact that those pollution-intensive industries had been in their mature stage between 1990 and 2000. That implies that a little change can be observed in the spatial clusters of counties in the selected pollution-intensive industries, but the growth of given spatial clusters may be an option.

Spatial cluster maps show more focused patterns than LQ maps. A same group of major cities appear intermittently in maps of the spatial clusters of counties identified with local Moran's *I*, as centers of clusters in the selected pollution-intensive industries.

In the West region of the U.S. Census, Seattle in Washington, Portland in Oregon, and San Francisco, Los Angeles, San Diego in California are located in spatial clusters of the five pollution-intensive industries.[21] Las Vegas in California, and Phoenix, Yuma, and Tucson in Arizona are occasional centers. Dallas, Ft. Worth, and Houston in Texas, Atlanta in Georgia, and Ft. Lauderdale in Florida are common cluster centers in the South region. A few spatial clusters are also around Birmingham in Alabama, Raleigh and Charlotte in North Carolina, and Orlando, Tampa, and Miami in Florida. Traditional manufacturing cities in the Rust Belt are frequent centers, too. In the Midwest region, St. Paul in Minnesota, St. Louis in Missouri, Milwaukee in Wisconsin, Chicago in Illinois, Grand Rapids and Detroit in Michigan, and Cleveland and Cincinnati in Ohio are recurrent centers in spatial clusters of pollution-intensive industries. Pittsburgh and Philadelphia in Pennsylvania are also occasional centers in the Northeast region. A group of cities in BosWash, from Washington, D.C. to Boston in Massachusetts, appear repeatedly as centers of spatial clusters in the selected pollution-intensive industries.

21 The Census Bureau classifies the U.S. states into four regions. The Northeast region contains Connecticut, Marine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. The Midwest region consists of Indiana, Illinois, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, and Wisconsin. The West region includes Alaska, Arizona, California, Colorado, Hawaii, Idaho, Nevada, New Mexico, Montana, Oregon, Utah, Washington, and Wyoming. Other states are classified as the South region.

3.4.2.1 SIC 26: Paper and Allied Products

The LQ maps in 1990 and in 2000 shows similar trends, although more counties have LQ over 1 in 2000. While it is difficult to discern, the distribution of counties of higher location quotient loosely overlap that of major cities in the U.S. This trend is clearer in the LISA maps. Identified spatial clusters of counties embrace the group of major cities enlisted above. The majority of spatial clusters stayed still, and had grown bigger from 1990 to 2000.

3.4.2.2 SIC 28: Chemicals and Allied Products

Overall patterns in the LQ maps are alike. It is worth mentioning, though, that Nevada and Utah appear to gain counties of higher LQ from 1990 to 2000. The LISA maps show the growth of given spatial clusters from 1990 to 2000. Expansion of a spatial cluster around Los Angeles and San Diego in California to Las Vegas in Nevada was notable. In addition, a few new spatial clusters of counties were identified in 2000, near Denver in Colorado and Grand Rapids in Michigan. In the LISA maps, a spatial cluster near Kansas City in Missouri was lost between 1990 and 2000.

3.4.2.3 SIC 29: Petroleum and Coal Products

The ascendancy of the Rust Belt in the Northeast region in this industry is clear in the LQ maps. It appears that concentration of counties of higher LQ in the Northeast region was reinforced between 1990 and 2000. In the LISA maps, it is observable that spatial clusters had grown from 1990 to 2000. New spatial clusters in 2000 were found near Portland in Oregon, Austin in Texas, Baton Rouge in Louisiana, Kansas City in

Missouri, and Birmingham in Alabama. A spatial cluster around Oklahoma City in Oklahoma was gone in 2000.

3.4.2.4 SIC 32: Stone, Clay, Glass, and Concrete Products

Due to its pervasiveness of this industry, it is difficult to discern specific changing patterns between 1990 and 2000 in the LQ maps. Overall, spatial clusters identified in the LISA maps remained still from 1990 to 2000. The 2000 LISA map reveals new spatial clusters around Portland in Oregon, Denver in Colorado, Austin in Texas, St. Paul in Minnesota, and Charlotte in North Carolina.

3.4.2.5 SIC 33: Primary Metal Industries

This industry also reveals its superiority in the Rust Belt in the Northeast region, while new counties of higher location quotient were added in 2000, for example in Wyoming. In the LISA maps, the growth of given spatial clusters is discernible. No significant new spatial cluster of counties emerged, while the extension of a spatial cluster around Los Angeles and San Diego in California to Las Vegas in Nevada appeared distinct.

In sum, the LQ maps of selected pollution-intensive industries generally reveals their preference to the both coasts of the U.S., and to the Rust Belt, while their presence in the Mountain States was relatively low between 1990 and 2000. A group of cities are repeatedly present in the LISA maps as centers of identified spatial clusters of counties in those industries.

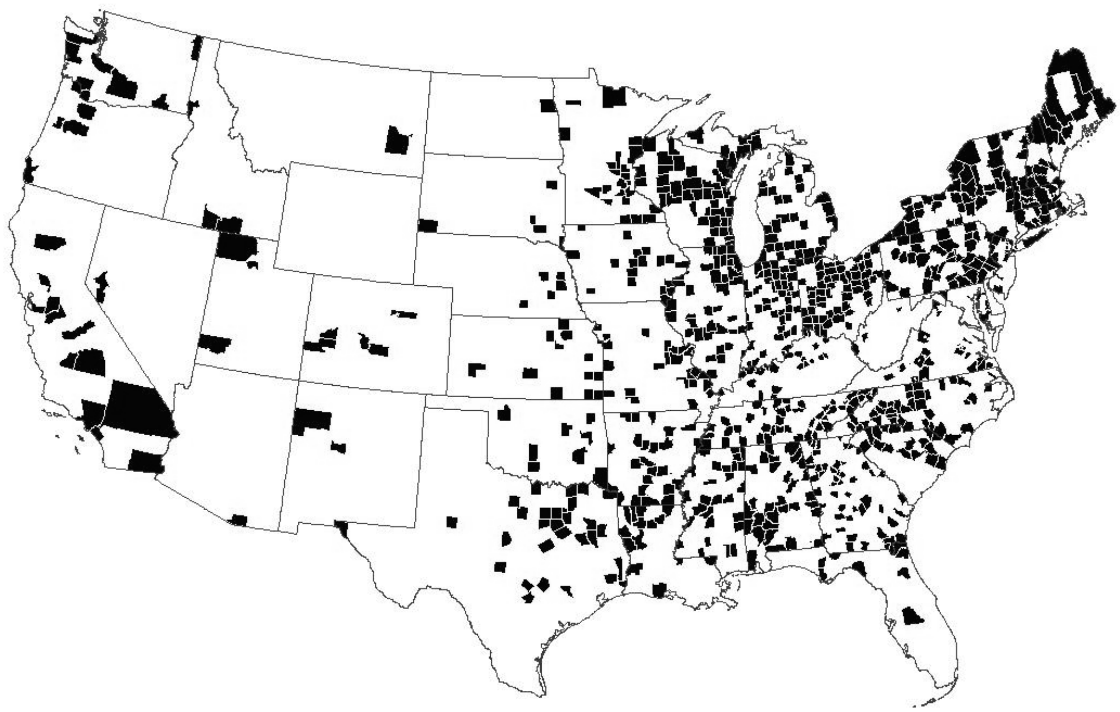

Figure 3.1 Counties with Location Quotient over 1 in 2000
(SIC 26: Paper and Allied Products)

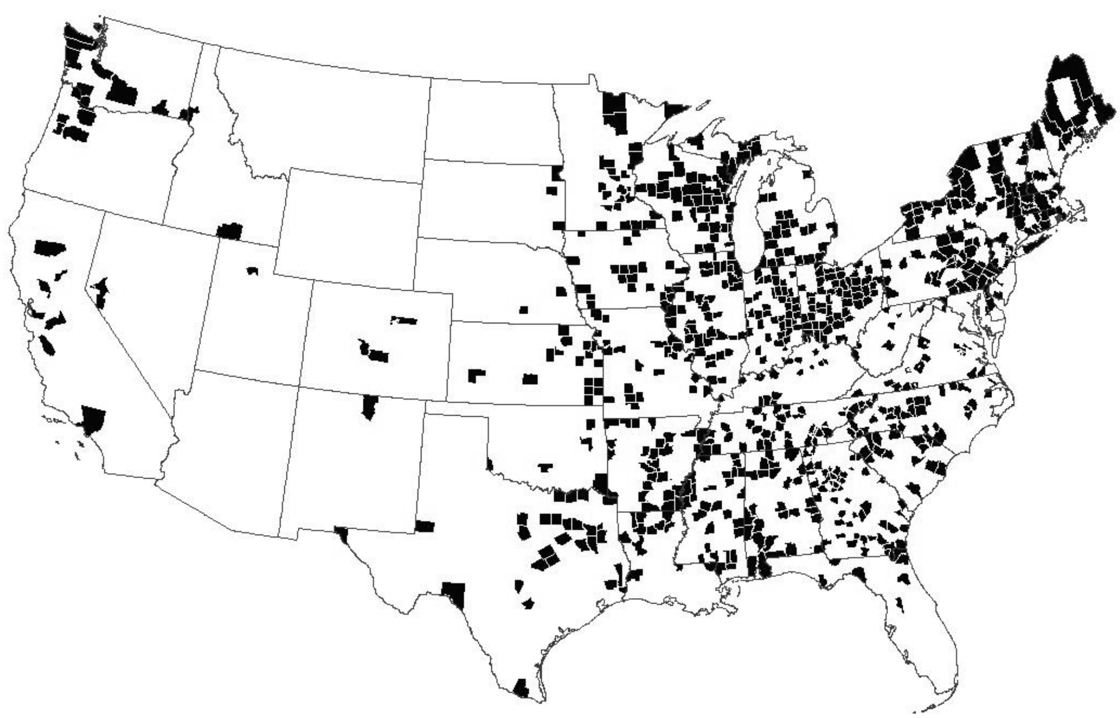

Figure 3.2 Counties with Location Quotient over 1 in 1990
(SIC 26: Paper and Allied Products)

Figure 3.3 Spatial Clusters of Counties in 2000 (LISA High-High Spatial Clusters)
(SIC 26: Paper and Allied Products)

Figure 3.4 Spatial Clusters of Counties in 1990 (LISA High-High Spatial Clusters)
(SIC 26: Paper and Allied Products)

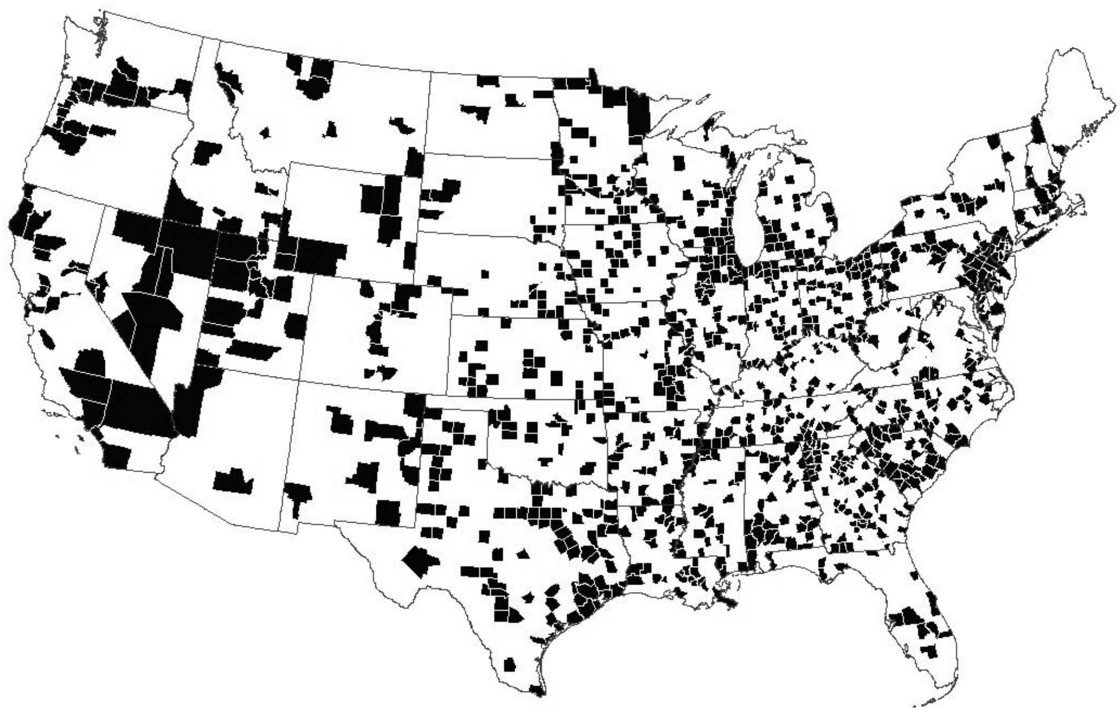

Figure 3.5 Counties with Location Quotient over 1 in 2000
(SIC 28: Chemicals and Allied Products)

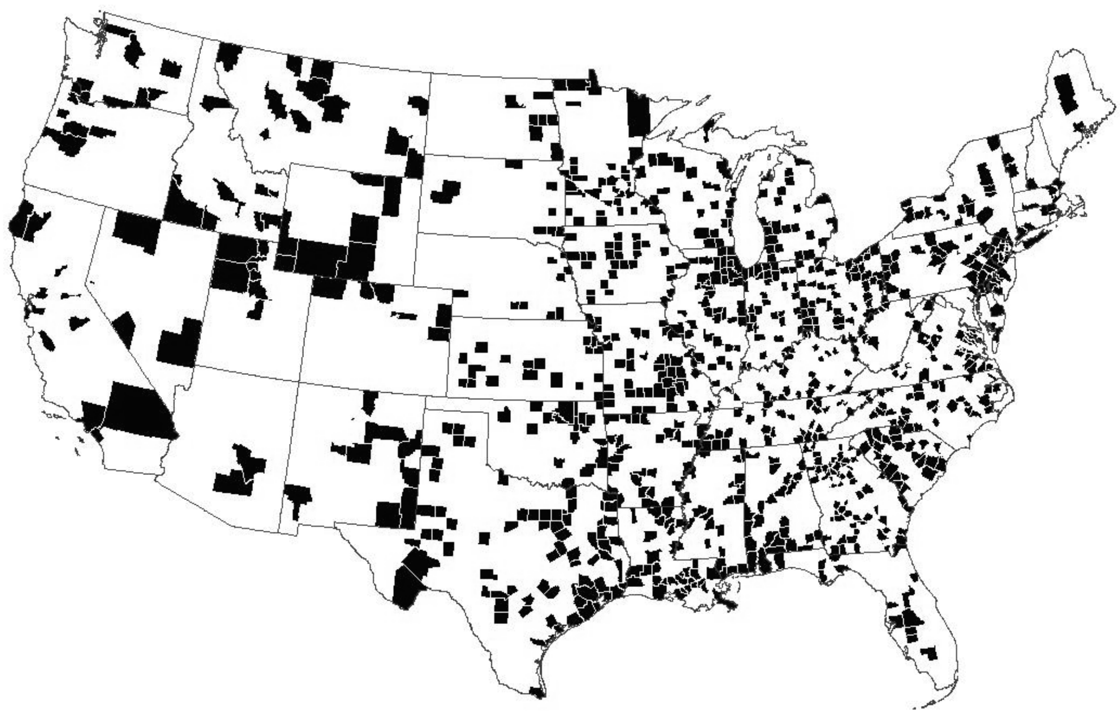

Figure 3.6 Counties with Location Quotient over 1 in 1990
(SIC 28: Chemicals and Allied Products)

Figure 3.7 Spatial Clusters of Counties in 2000 (LISA High-High Spatial Clusters)
(SIC 28: Chemicals and Allied Products)

Figure 3.8 Spatial Clusters of Counties in 1990 (LISA High-High Spatial Clusters)
(SIC 28: Chemicals and Allied Products)

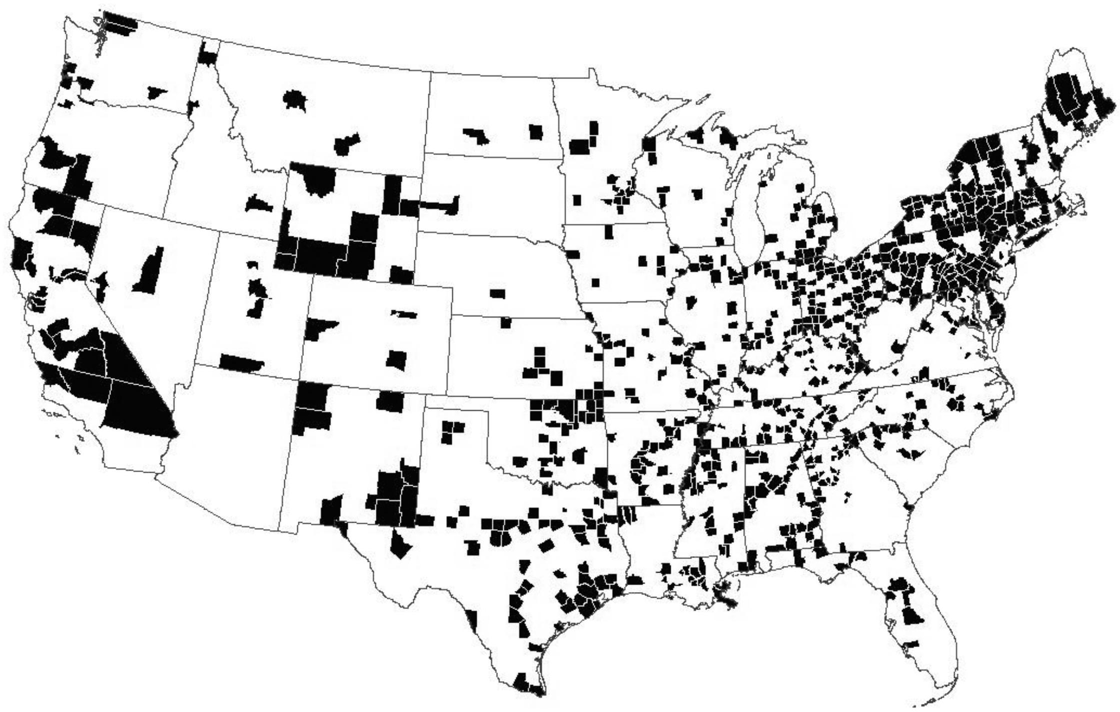

Figure 3.9 Counties with Location Quotient over 1 in 2000
(SIC 29: Petroleum and Coal Products)

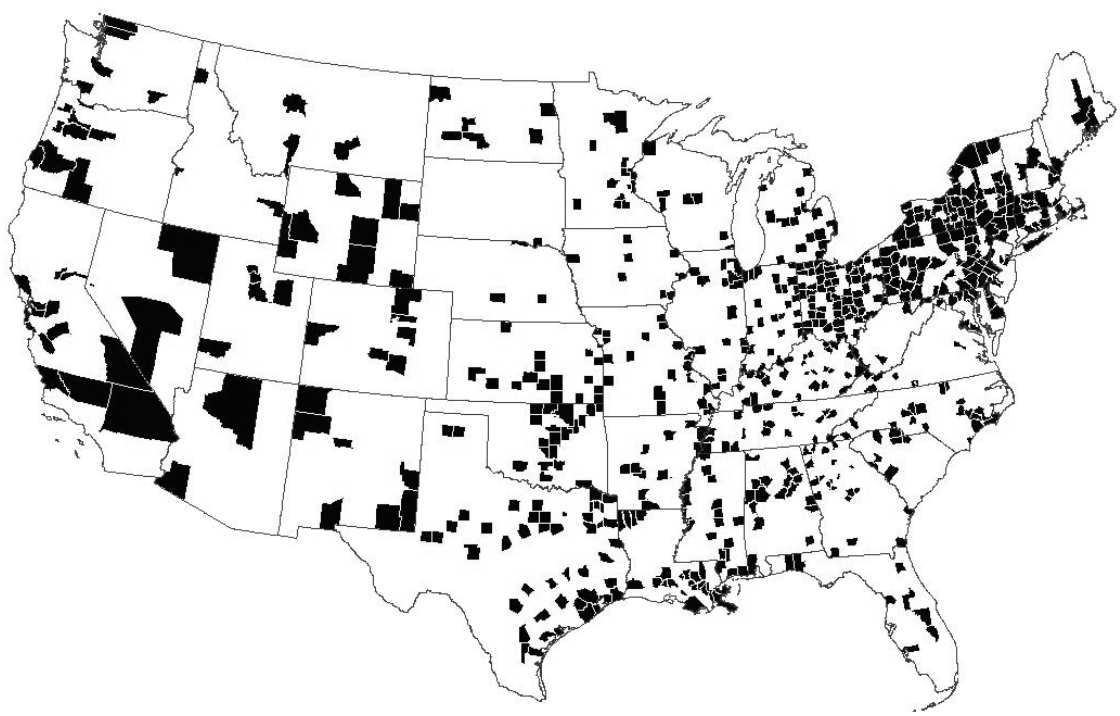

Figure 3.10 Counties with Location Quotient over 1 in 1990
(SIC 29: Petroleum and Coal Products)

Figure 3.11 Spatial Clusters of Counties in 2000 (LISA High-High Spatial Clusters)
(SIC 29: Petroleum and Coal Products)

Figure 3.12 Spatial Clusters of Counties in 1990 (LISA High-High Spatial Clusters)
(SIC 29: Petroleum and Coal Products)

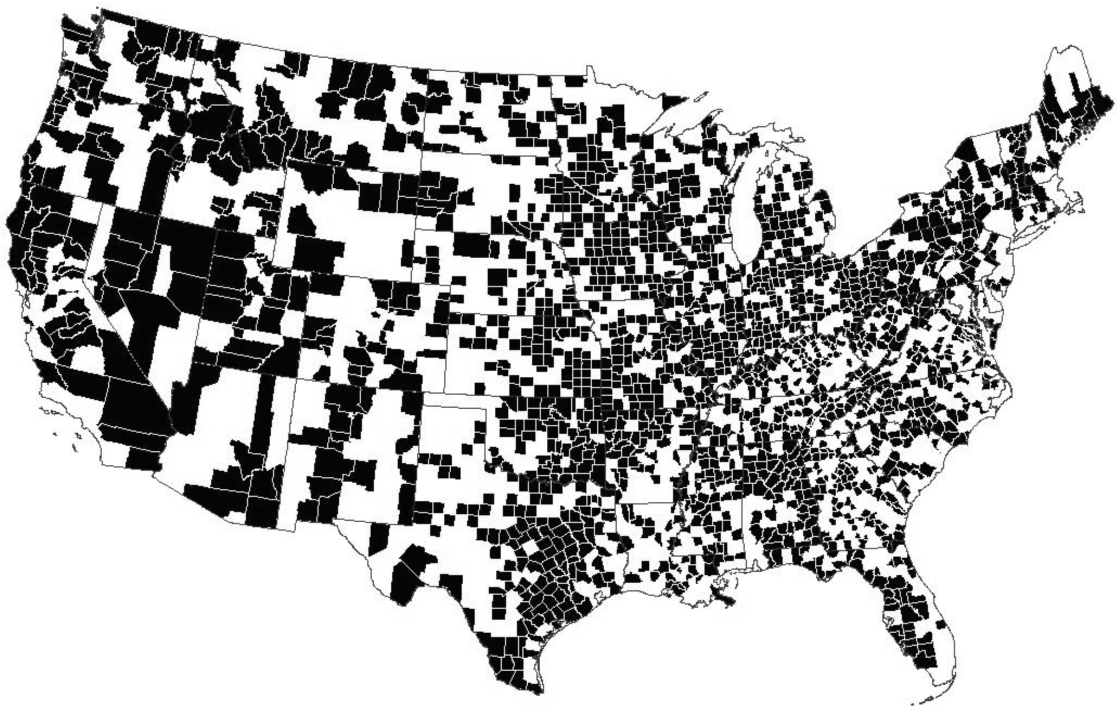

Figure 3.13 Counties of Location Quotient over 1 in 2000
(SIC 32: Stone, Clay, Glass, and Concrete Products)

Figure 3.14 Counties of Location Quotient over 1 in 1990
(SIC 32: Stone, Clay, Glass, and Concrete Products)

Figure 3.15 Spatial Clusters of Counties in 2000 (LISA High-High Spatial Clusters)
(SIC 32: Stone, Clay, Glass, and Concrete Products)

Figure 3.16 Spatial Clusters of Counties in 1990 (LISA High-High Spatial Clusters)
(SIC 32: Stone, Clay, Glass, and Concrete Products)

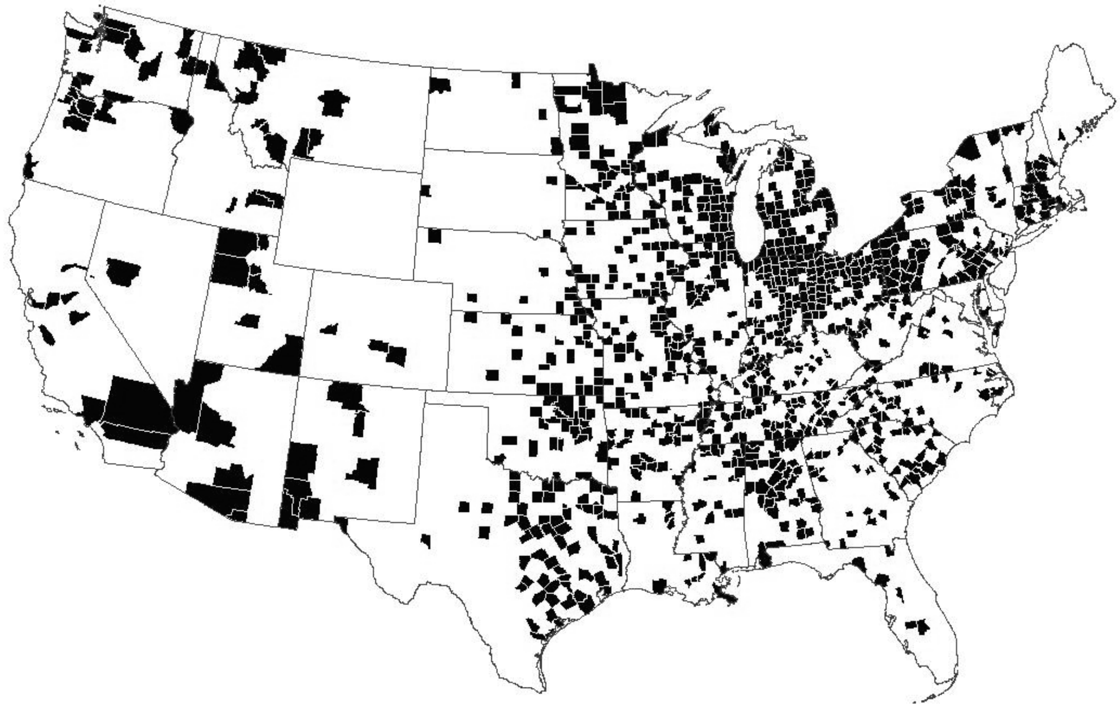

Figure 3.17 Counties of Location Quotient over 1 in 2000
(SIC 33: Primary Metal Industries)

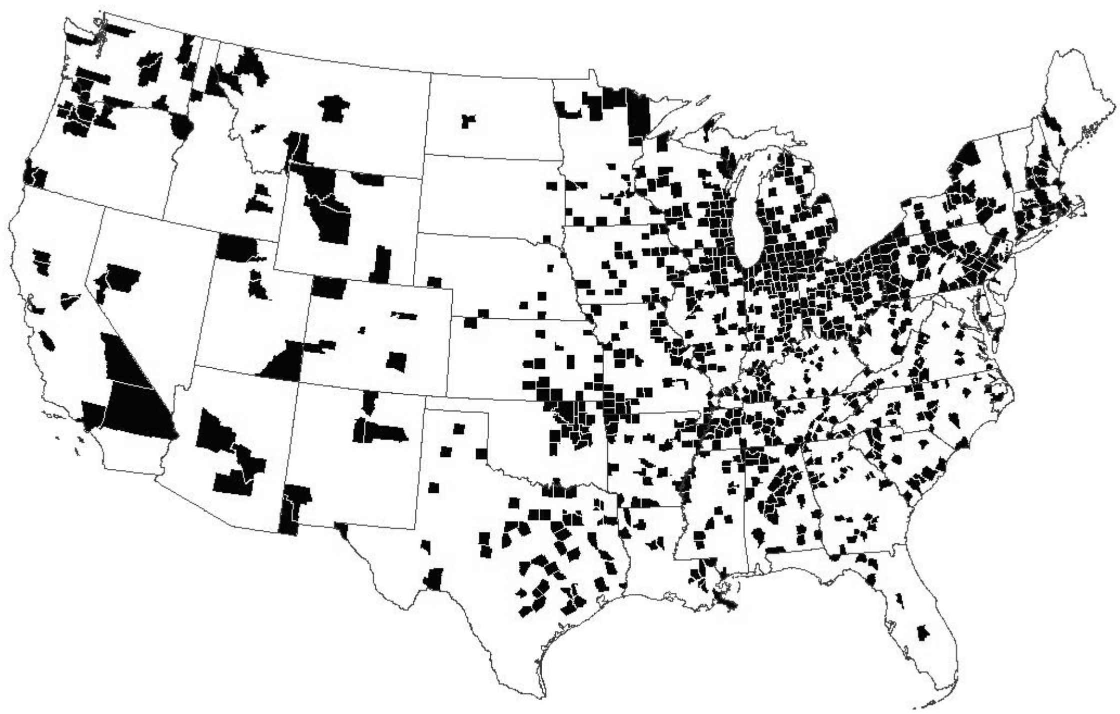

Figure 3.18 Counties of Location Quotient over 1 in 1990
(SIC 33: Primary Metal Industries)

Figure 3.19 Spatial Clusters of Counties in 2000 (LISA High-High Spatial Clusters)
(SIC 33: Primary Metal Industries)

Figure 3.20 Spatial Clusters of Counties in 1990 (LISA High-High Spatial Clusters)
(SIC 33: Primary Metal Industries)

3.5 Performance of Plants in Pollution-Intensive Industries

3.5.1 Regression Analysis to Model the Performance of Plants in Pollution-Intensive Industries

Glaeser *et al.* (1992) investigated the most prominent theories of agglomeration economies in their research on growth of cities in the U.S., by developing and including indices for each theory in their analysis. Their analysis was performed on all manufacturing industries, and on all service industries, so they were not particularly concerned about the use of normalized variables. Actually, they only normalized the specialization and competition variables. Later, Ó hUallacháin and Stterthwaite (1992) and Henderson *et al.* (1995) refined and expanded their research into each industrial sector respectively, and suggested the use of normalized diversity variables for the better comparison between sectors. The literature on this topic has grown considerably since those initial papers (Combes & Overman, 2004; Suedekum & Blien, 2005), and Combes (2000) integrateed previous works and developed a coherent cross-sectional framework to research impacts of agglomeration economies on regional growth.[22] I use their formulation of agglomeration economies to estimate impacts of agglomeration economies on labor productivity and pollution intensity. Labor productivity is a measure of economic productivity, and pollution intensity is a measure of environmental efficiency or eco-efficiency.

It is necessary to know about eco-efficiency in more details for the analysis. The concept of eco-efficiency was first introduced by Schaltegger and Strum (1989), but widely recognized in 1992 by the publication of *Changing Course* (Schmidheiny, 1992)

22 Temporal dynamics of externalities has been probed by Henderson (1997) and Combes et al. (2004) with panel data analysis. Since it was impossible to get proper panel datasets for my research, the cross-sectional framework is used in 1990 and in 2000.

from the World Business Council for Sustainable Development (WBCSD). Eco-efficiency generally means ‘getting more from less’ (Kuosmanen, 2005). The concept's explicit link between two pillars of sustainable development, economics and the environment, has made it widely accepted, while the lack of equity concerns remains its methodological weakness (Brattebø, 2005; Ehrenfeld, 2005).

Eco-efficiency is barely a well-defined measure (DeSimone & Popoff, 1997). It's more like a heuristic concept overarching and enabling various measures of the relationship between economic and environmental impacts of a given unit. Eco-efficiency measures can be created with various measures of economic and environmental impacts at different scales, from an individual firm to a region, or a nation (Dahlström & Ekins, 2005; Morioka, Tsunemi, Yamamoto, Yabar, & Yoshida, 2005; Suh, Lee, & Ha, 2005). From simple indicators to complex life cycle assessment, the pursuit for more relevant economic and environmental measures is still on-going issue, too (Figge & Hahn, 2005). In this chapter, I focus on eco-efficiency indicators that can be calculated from available datasets. Dependent and independent variables are described in more details in the next section.

3.5.2 Descriptions of the Variables for the Regression Analysis

Overall, the selection of eco-efficiency indicator in this chapter lies in the choice of a scale for the research, and the limitation of available data at the scale. Publicly available data on general firm performance at the U.S. scale are very limited, so it is reasonable to focus on basic eco-efficiency indicators to compare and analyze economic and environmental performances of plants in the U.S. Originally, eco-efficiency means the ratio of economic value to environmental impact (Schmidheiny, 1992). However, a diversity of indicators has been suggested and developed under the general concept of eco-efficiency ever since (Tyteca, 1996; WBCSD, 2000). Considering the limitations of the joint datasets, I choose and use pollution intensity, an indicator of eco-efficiency, throughout the analysis, which has been used in environmental economics as a normalized pollution measure (Blackman, 2006; Pagoulatos, Goetz, Debertin, & Johannson, 2004).

As mentioned in 3.3.1, by matching the TRI data with the D&B Million Dollar Directories, it is possible to obtain a dataset containing information of employment, sales, and amounts of emitted pollutants of plants. Then, labor productivity, an indicator of economic productivity, and pollution intensity, an indicator of eco-efficiency, can be measured as follows:

$$\text{Labor Productivity} = Y_o/L_i$$

$$\text{Pollution Intensity} = P_o/L_i$$

Here, Y_o = sales as economic output, P_o = pollutants as environmental output, and L_i = workers as resource input. Sales per worker as a labor productivity indicator, and the amount of pollutants per worker as a pollution intensity indicator are constructed as dependent variables.

Independent variables are organized in three different levels: plant-level, local-level, and regional-level. Plant-level variables are plants' features at the plant level.

Local-level variables are measured within a county, while regional-level variables are defined with data beyond the boundaries of a county.

Plant Level: Plant

Sales (*sales*) and employment (*emp*) of each identified plant are included to control the size of output and input of an individual plant on the labor productivity and on the pollution intensity. Because of internal economies of scale, larger plants are typically expected to be more efficient in terms of productivity and eco-efficiency (Ayres & Ayres, 1996; Côté, et al., 2006). The higher the sale of a plant is, the higher labor productivity and pollution intensity are. It is mainly because massive production usually produces massive wastes and by-products (Baumgärtner, 2002; Baumgärtner & de Swaan Arons, 2003). On the other hand, larger input of employment is expected to have some impacts to lower labor productivity and pollution intensity.

Local Level: County

Industrial specialization has been considered a major source of better economic performance of plants (A. Marshall, 1890). However, no clear connection has been made between industrial specification and environmental performance of specialized industries. Porter hypothesis may be the only exception on this topic. In their bold paper, Porter and van der Linde (1995) argued that "properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them" and opened a debate about positive relationship between economic and environmental benefits in economic entities, such as sectors, industries, and firms. If we link this theoretical position to Porter's designation of industrial clusters as innovative, productive, and competitive places of industrial specialization (Porter, 1990, 1998a), it is feasible to set a new hypothesis that industrial specialization may also improve environmental performance of industries and their plants.

LQ (*spec*) may be the oldest and the most popular index still being used and adjusted in measuring the degrees of spatial concentration of industries (O'Donoghue & Gleave, 2004). Since it was developed in the 1940s by Hildebrand and Mace (1950), it has been used extensively in regional economic analysis to measure the degree of industrial specialization of an area to other areas (Bendavid-Val, 1991; Klosterman, 1990). LQ provides a ground to compare different counties of industrial concentration by using the U.S. as reference, but it does not incorporate any measure of association among counties. In other words, it is an a-spatial measure, since its value are invariant to spatial order of other locations (Arbia, 2001). Therefore, it is desirable to complement this aspatial measure of industrial specialization with another spatial measure, local Moran's *I*, as shown in 3.4.

The inverse of the Herfindahl index of local concentration between sectors, except the one considered, is chosen as a proxy of local diversity (*div*).[23] The results of Glaeser *et al.* (1992) supported the positive relationship between local growth and diversity, and popularize the term Jacobian externalities, named after Jane Jacobs (Jacobs, 1969, 1984), which is equivalent to urbanization economies in urban economics (Hoover, 1937). As in Combes (2000), and Suedekum and Blien (2005), this variable is normalized by the same index at the U.S. level.

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23 A variety of diversity indices are available for regional economic analysis (Dissart, 2003; Stirling, 2007). This specific diversity index is selected because of its normalization form, which other indices are not particularly constructed for (V. Henderson, et al., 1995).

$$div_{is} = \frac{1 \Big/ \sum_{s'=1, s' \neq s}^{S} \left(L_{is'} / \left(L_i - L_{is} \right) \right)^2}{1 \Big/ \sum_{s'=1, s' \neq s}^{S} \left(L_{s'} / \left(L - L_s \right) \right)^2}$$

It is zero if plants in county *i* is concentrated into a single sector *s*, and reaches its highest if all other sectors have an identical share of employment. This index is constructed not to be necessarily negatively correlated with the specialization of sector *s* in county *i* by excluding the share of sector *s* in the diversity index. If local industrial diversity promotes better economic and environmental performance of plants, as argued in the Jacobian hypothesis (Jacobs, 1969, 1984) and in the literature of industrial symbiosis (Desrochers, 2002a, 2004), this variable will be positively correlated with labor productivity, and negatively correlated with pollution intensity.

Average size of neighboring plants (*asize*) is the next. Glaeser *et al.* (1992) originally considered the number of firms per worker a working proxy for competition, which is regarded as a key determinant of local growth by Porter (1990). However, as Ó hUallacháin and Stterthwaite (1992) argued, the inverse of this index, the average size of establishments located in county *i*, had better be interpreted as an index of internal economies of scale of neighboring firms in average. This index is also normalized by the same ratio in sector *s* in the U.S.

$$asize_{is} = \frac{L_{is} / N_{is}}{L_s / N_s}$$

Where N_{is} is the number of plants of sector *s* in county *i*; and N_s is the number of plants of the same sector in the U.S. This variable tests whether a specific county is an industrial concentration of relatively small or large plants. In that sense, this variable reflect different developmental stages in the life-cycle of an industry (Combes, 2000). New plants are generally of small size and of novel equipments, while larger plants may have reached their optimal size with established technologies. Industrial concentration of smaller plants in an industry implies that the concentration is rather younger, and vice versa. Plants in the concentration of older and larger plants may lag in productivity and in eco-efficiency, since local technologies are equipments that they can take advantages of may be out-of-date, and not as efficient as more recent ones.

Regional Level: Multiple Counties

Local Moran's *I* as a spatial measure of industrial specialization is included in the models (*cluster*). With the results from the industrial cluster identification in 3.3, a dummy variable is constructed from this statistic, where 1 if a county is identified as a hot spot, 0 otherwise. Similar to the LQ variable, I expect that plants in industrial clusters, hot spots identified with local Moran's *I* as a group of neighboring counties, are more environmentally friendly and economically productive.

Metropolitan designation of each county (*metro*) is identified by the definitions of the MSAs in 1990 and in 1999 by the U.S. Office of Management and Budget (OMB), applied to the Census Bureau data. This variable is coded 1, if a county was in defined MSAs in 1990 and in 1999 respectively, and 0 otherwise. Counties in metropolitan areas are likely to be more populated, and are expected to have stronger concerns on economic and environmental issues. Plants in metropolitan areas are expected to feel more environmental pressure from local communities. They are also likely to pay higher rents because of their metropolitan orientation, and to use new technologies and innovations to mitigate rent costs. Hence, it is possible that they are economically and environmentally more efficient.

Differences of environmental stringency among the U.S. States (*reg*) are measured by Levinson's industry-adjusted index of state environmental compliance costs (Levinson, 2001). The Census Bureau's PACE survey has been widely used among researchers as a source of capturing industrial pollution trends across the U.S. The PACE survey collected data of pollution abatement capital and operating costs from manufacturing plants. The survey was lasted from 1977 to 1994, with an exception of 1987. In 1999, the US EPA and the Census Bureau renewed and collected the PACE survey (Shadbegian & Becker, 2004). Levinson calculated his index for the all available PACE surveys, except for the renewed 1999 pilot survey. For the analysis, I choose Levinson's 1989 index and calculate Levinson's index for the U.S. states from the 1999 survey, using his method.

Levinson's index compares the actual pollution abatement costs, unadjusted for industrial composition of each state, to the predicted abatement costs (Levinson, 2001). Unadjusted measures of state environmental stringency, such as these costs over gross domestic products by state, tend to overestimate the environmental stringency of states with more pollution-intensive industries. Levinson proposed an adjustment procedure for them with national abatement costs decomposed by each state's industrial composition, which are publicly available, uncensored part of the PACE survey. The actual pollution abatement costs are denoted

$$S_i = \frac{P_i}{Y_i}$$

Where P_i is total pollution abatement costs in state i; and Y_i is the manufacturing sector's contribution to the gross domestic product by state of state i. This is the unadjusted measure of abatement costs.

The predicted abatement costs are constructed to adjust the actual costs reflecting industrial composition of each state. The predicted abatement costs are

$$\hat{S} = \frac{1}{Y_i} \sum \frac{Y_{is} P_s}{Y_s}$$

where Y_{is} is sector s's contribution to the GDP by state of state i; P_s is the national pollution abatement operating costs of sector s; and Y_s is the national contribution of sector s to national GDP. Sectors are indexed along with the 2-digit manufacturing SIC in the 1989 index, or equivalent NAICS in case of the 1999 index. The predicted abatement costs measure is the average pollution abatement costs weighted by the relative shares of each sector in state i.

Then, the industry-adjusted index of state environmental stringency for state i is measured by the ratio of actual costs to the predicted costs.

$$S_i^* = \frac{S_i}{\hat{S}_i}$$

S_i^* greater than 1 means sectors in state *i* spend more on pollution abatement than those same sectors in other states, and that implies that that state have relatively more stringent in environmental polices than other states. Levinson's index has been adopted in a series of research on industrial pollution trends in the U.S. (Fredriksson, et al., 2004; Fredriksson & Millimet, 2002a, 2002b; Keller & Levinson, 2002). Higher environmental stringency in State's public policies may do harm economic productivity, but reduce the amount of emitted pollutants. In the next section, results from the regression models which are built with the above dependent and independent variables are presented.

3.5.3 Results from the Regression Analysis

The full model is an OLS regression of the form:

$$\begin{aligned}\log(y) = I + \alpha_1 \log(sale) + \alpha_2 \log(emp) + \alpha_3 \log(spec) + \alpha_4 \log(div) + \alpha_5 \log(asize) \\ + \alpha_6 (cluster) + \alpha_7 (metro) + \alpha_8 (reg)\end{aligned}$$

where y is the labor productivity or the pollution intensity of a plant in a county. *I* is an intercept, and sale, emp, spec, div, asize, metro, cluster, and reg are independent variables corresponding respectively sales, employment, specialization (LQ), diversity, average size of neighboring plants, metropolitan areas, cluster (local Moran's *I*), and Levinson's environmental stringency index of the U.S. States. Except two dummy variables and Levinson's index, all variables are log-transformed to redress heteroskedasticity

(Combes, 2000; Suedekum & Blien, 2005). Since there are two dependent variables for each year, four full models in each pollution-intensive industry are estimated.

Due to small sample size of available joint dataset of larger plants in pollution-intensive industries, especially in the 1990 data, sometimes it is not so reliable to conduct regression analysis with the full model. Hence, six part models are developed and estimated along with the full model in each analysis of selected pollution-intensive industries. First three part models are constructed with plant-level (PLT model), local-level (LOC model), and regional-level (REG model) independent variables respectively. The rest of the part models are constructed with combinations of independent variables in two related levels (PLT-LOC model, LOC-REG model, and PLT-REG model). Those part models are estimated for each industry in each year.

In consideration of the low quality of voluntarily reported TRI data, and the limited sample size in the joint datasets between the TRI and the D&B data, I use another significant level ($p<0.10$) to capture weaker impacts of independent variables. Results from the regression analysis are summarized from Table 3.3 to Table 3.21 in the order of Paper and Allied Products (SIC 26), Chemicals and Allied Products (SIC 28), Petroleum and Allied Products (SIC 29), Stone, Clay, Glass and Concrete Products (SIC 32), and Primary Metal Industries (SIC 33).

3.5.3.1 SIC 26: Paper and Allied Products

Labor productivity of larger plants in the Paper and Allied Products (SIC 26), presented in Table 3.4 and in Table 3.6, appears to be mainly controlled by plant-level features. Both in 1990 and in 2000, larger sales and smaller employment brought higher labor productivity, as expected. Sales and employment variables are statistically significant in all part models and full models in both years. Although the sample size in 1990 is small, results from part models show that the general results here are rather reliable, and comparison between the full models in 1990 and in 2000 shows that impacts of plant-level variables had not been changed much during the decade. In the full model and the PLT-LOC part model in 2000, average size of neighboring plants in this industry becomes statistically significant at the level of $p<0.10$. That means that there is a weak tendency that co-location with neighboring larger plants lowers the labor productivity in this industry in 2000, which is possibly because this industry passed its peak and has arrived in its mature state.

Pollution intensity models in the Paper and Allied Products (SIC 26) are summarized in Table 3.5 and in Table 3.7. No model in 2000 is statistically significant. In 1990, the PLT, PLT-LOC, and the full model are statistically significant. As hypothesized, employment is negative and statistically significant in three models, and sales variable is negative and statistically significant in the PLT model. Specialization, measured by the LQ at the county level, is negative and statistically significant in the PLT-LOC and the full model. That implies that a plant in a highly specialized county tends to have low pollution intensity. This result supports the favorable impacts of localization economies on environmental performance of plants.

Table 3.4 Labor Productivity Models in 2000 (SIC 26: Paper and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.744***			0.759***		0.725***	0.729***
	(0.089)			(0.091)		(0.091)	(0.093)
Emp	-0.753***			-0.748***		-0.720***	-0.706***
	(0.087)			(0.087)		(0.090)	(0.091)
Spec		0.089		-0.066	0.200		-0.007
		(0.148)		(0.103)	(0.155)		(0.111)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-0.380		-0.335+	-0.470		-0.374+
		(0.285)		(0.192)	(0.305)		(0.214)
Cluster			0.396+		0.264	0.186	0.110
			(0.209)		(0.218)	(0.145)	(0.151)
Metro			0.057		0.325	0.007	0.138
			(0.227)		(0.263)	(0.157)	(0.184)
Reg			0.007		0.008	-0.042	-0.033
			(0.094)		(0.093)	(0.065)	(0.064)
Constant	5.994***	4.639***	4.432***	5.945***	4.245***	5.863***	5.711***
	(0.273)	(0.100)	(0.228)	(0.271)	(0.247)	(0.333)	(0.347)
N	64	64	64	64	64	64	64
Prob>F	0.000***	0.334	0.118	0.000***	0.091+	0.000***	0.000***
R2	0.563	0.035	0.093	0.586	0.148	0.588	0.609

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.5 Pollution Intensity Models in 2000 (SIC 26: Paper and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	-0.016			-0.314		0.020	-0.190
	(0.491)			(0.512)		(0.495)	(0.525)
Emp	-0.358			-0.204		-0.516	-0.396
	(0.469)			(0.471)		(0.476)	(0.489)
Spec		0.611		1.030+	0.420		0.739
		(0.512)		(0.561)	(0.555)		(0.596)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-0.164		-0.220	-0.037		0.146
		(0.944)		(1.005)	(1.065)		(1.135)
Cluster			-0.314		-0.420	-0.296	-0.325
			(0.749)		(0.821)	(0.773)	(0.819)
Metro			-0.899		-0.646	-1.233	-0.963
			(0.830)		(0.992)	(0.845)	(0.996)
Reg			0.075		0.041	0.114	0.076
			(0.338)		(0.345)	(0.338)	(0.341)
Constant	5.724***	3.586***	4.455***	5.657***	4.239***	7.311***	7.058***
	(1.427)	(0.350)	(0.840)	(1.417)	(0.908)	(1.739)	(1.832)
N	62	63	63	62	63	62	62
Prob>F	0.343	0.466	0.407	0.233	0.633	0.243	0.315
R2	0.036	0.025	0.048	0.092	0.057	0.110	0.135

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.6 Labor Productivity Models in 1990 (SIC 26: Paper and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.717***			0.703***		0.705***	0.722***
	(0.133)			(0.142)		(0.141)	(0.154)
Emp	-0.641***			-0.642***		-0.641***	-0.665***
	(0.126)			(0.134)		(0.134)	(0.148)
Spec		-0.070		-0.027	-0.058		-0.047
		(0.161)		(0.123)	(0.186)		(0.143)
Div		-0.313		-0.210	-0.325		-0.271
		(0.353)		(0.268)	(0.661)		(0.503)
Asize		0.236		0.213	0.259		0.227
		(0.238)		(0.181)	(0.273)		(0.208)
Cluster			0.179		0.184	-0.071	-0.074
			(0.281)		(0.298)	(0.219)	(0.233)
Metro			-0.071		-0.044	-0.005	-0.074
			(0.284)		(0.311)	(0.225)	(0.250)
Reg			0.984		0.167	0.376	-0.272
			(0.663)		(1.264)	(0.518)	(0.966)
Constant	5.460***	4.372***	3.404***	5.474***	4.125**	5.173***	5.909***
	(0.322)	(0.124)	(0.774)	(0.338)	(1.290)	(0.734)	(1.078)
N	35	34	35	34	34	35	34
Prob>F	0.000***	0.437	0.509	0.001***	0.807	0.001***	0.009**
R2	0.477	0.085	0.071	0.515	0.099	0.502	0.521

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.7 Pollution Intensity Models in1990 (SIC 26: Paper and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	1.008+			0.697		0.998	0.862
	(0.573)			(0.560)		(0.607)	(0.594)
Emp	-1.344*			-1.013+		-1.410*	-1.192*
	(0.544)			(0.532)		(0.574)	(0.572)
Spec		-1.262*		-1.274*	-1.450*		-1.522*
		(0.527)		(0.486)	(0.611)		(0.549)
Div		-1.311		-1.248	-2.225		-2.448
		(1.170)		(1.059)	(2.166)		(1.936)
Asize		-0.315		-0.002	-0.222		0.206
		(0.756)		(0.717)	(0.865)		(0.801)
Cluster			-0.056		-0.444	-0.459	-0.752
			(0.939)		(0.928)	(0.941)	(0.897)
Metro			-0.205		-0.075	-0.421	-0.360
			(0.956)		(0.967)	(0.968)	(0.964)
Reg			1.607		-2.465	0.875	-3.775
			(2.271)		(4.015)	(2.226)	(3.720)
Constant	7.830***	4.043***	2.408	7.327***	6.731	7.952*	12.121**
	(1.389)	(0.383)	(2.544)	(1.339)	(4.030)	(3.154)	(4.155)
N	35	40	41	34	40	35	34
Prob>F	0.024*	0.129	0.817	0.023*	0.423	0.115	0.077+
R2	0.208	0.144	0.025	0.359	0.158	0.252	0.400

+ p<.10, * p<.05, ** p<.01, *** p<.001

3.5.3.2 SIC 28: Chemicals and Allied Products

Results from labor productivity models in Chemical and Allied Products (SIC 28) are presented in Table 3.8 and in Table 3.10. Plant-level features, sales and employment, still control plant's labor productivity, as in the last models in SIC 26. Local-level factors show no effects in all models. The only exception was the average size of neighboring plants in the 1990 full model, which is positive and statistically significant at $p<0.10$. Some of regional-level factors have occasional impacts in 2000. Cluster variable is negative and statistically significant at $p<0.10$ in the REG model and the full model. State's environmental stringency index is also negative and statistically significant at $p<0.05$ in the PLT-REG model and the full model. Stringent environmental policies show harmful impacts on labor productivity in the Chemical industry. While the relationship is rather weaker, plants in industrial clusters tend to have lower labor productivity.

Pollution intensity models suggest different trends in Table 3.9 and in Table 3.11. Employment variable is negative and statistically significant in all models at $p<0.01$ in 2000, and $p<0.10$ in 1990. That means that larger plants tend to have low pollution intensity. In 1990, specialization is positive and statistically significant in the full model. Both cluster and metropolitan variables are statistically significant in the PLT-REG model and in the full model. Cluster is negative, and metropolitan is positive. In 2000, cluster is positive, diversity is negative and both variables are statistically significant in all models. In both years, plants in spatial clusters are likely to have lower pollution intensity. Higher industrial specialization and metropolitan location in 1990, and more diverse industrial structure in 2000, tend to increase pollution intensity.

Table 3.8 Labor Productivity Models in 2000 (SIC 28: Chemicals and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.738***			0.723***		0.737***	0.724***
	(0.026)			(0.026)		(0.026)	(0.026)
Emp	-0.746***			-0.731***		-0.744***	-0.730***
	(0.023)			(0.024)		(0.023)	(0.024)
Spec		0.765		0.492	0.841		0.517
		(0.779)		(0.456)	(0.778)		(0.455)
Div		0.149		0.069	0.131		0.062
		(0.092)		(0.054)	(0.093)		(0.054)
Asize		0.021		0.039	0.007		0.028
		(0.097)		(0.057)	(0.097)		(0.057)
Cluster			-0.143+		-0.151*	-0.070	-0.075+
			(0.076)		(0.075)	(0.044)	(0.044)
Metro			-0.151		-0.065	-0.020	-0.007
			(0.120)		(0.125)	(0.070)	(0.073)
Reg			-0.031		-0.037	-0.065*	-0.068*
			(0.056)		(0.055)	(0.032)	(0.032)
Constant	6.067***	4.913***	5.172***	6.040***	5.089***	6.190***	6.157***
	(0.066)	(0.035)	(0.129)	(0.066)	(0.135)	(0.094)	(0.098)
N	519	512	519	512	512	519	512
Prob>F	0.000***	0.247	0.064+	0.000***	0.143	0.000***	0.000***
R2	0.669	0.008	0.014	0.662	0.019	0.672	0.666

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.9 Pollution Intensity Models in 2000 (SIC 28: Chemicals and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	-0.087			-0.081		-0.107	-0.103
	(0.144)			(0.146)		(0.143)	(0.145)
Emp	-0.452***			-0.447**		-0.430**	-0.423**
	(0.134)			(0.135)		(0.134)	(0.134)
Spec		1.905		2.348	2.311		2.742
		(2.427)		(2.298)	(2.406)		(2.279)
Div		0.897**		0.850**	0.881**		0.860**
		(0.326)		(0.309)	(0.325)		(0.308)
Asize		-0.462		-0.240	-0.512		-0.261
		(0.360)		(0.342)	(0.358)		(0.341)
Cluster			-0.734**		-0.789**	-0.714**	-0.768**
			(0.263)		(0.261)	(0.249)	(0.248)
Metro			0.048		0.090	0.280	0.371
			(0.411)		(0.429)	(0.393)	(0.412)
Reg			0.055		0.052	0.017	0.012
			(0.213)		(0.211)	(0.203)	(0.202)
Constant	5.255***	2.802***	3.097***	5.147***	3.029***	5.271***	5.112***
	(0.379)	(0.124)	(0.457)	(0.381)	(0.480)	(0.551)	(0.568)
N	411	406	412	405	406	411	405
Prob>F	0.000***	0.020*	0.020*	0.000***	0.002**	0.000***	0.000***
R2	0.103	0.024	0.024	0.124	0.051	0.124	0.147

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.10 Labor Productivity Models in 1990 (SIC 28: Chemicals and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.733***			0.730***		0.733***	0.728***
	(0.043)			(0.043)		(0.043)	(0.043)
Emp	-0.720***			-0.722***		-0.716***	-0.718***
	(0.042)			(0.043)		(0.043)	(0.043)
Spec		0.086		-0.006	0.109		-0.003
		(0.113)		(0.079)	(0.113)		(0.080)
Div		-0.366		-0.135	-0.295		-0.062
		(0.298)		(0.210)	(0.322)		(0.228)
Asize		0.102		0.126	0.134		0.136+
		(0.111)		(0.079)	(0.112)		(0.080)
Cluster			-0.096		-0.112	-0.021	-0.024
			(0.082)		(0.083)	(0.058)	(0.059)
Metro			-0.021		0.050	-0.081	-0.052
			(0.124)		(0.139)	(0.088)	(0.099)
Reg			0.250		0.285	0.041	0.088
			(0.223)		(0.230)	(0.158)	(0.162)
Constant	5.847***	4.583***	4.410***	5.868***	4.313***	5.875***	5.830***
	(0.095)	(0.040)	(0.246)	(0.099)	(0.253)	(0.202)	(0.207)
N	296	292	296	292	292	296	292
Prob>F	0.000***	0.324	0.290	0.000***	0.261	0.000***	0.000***
R2	0.508	0.012	0.013	0.517	0.026	0.511	0.519

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.11 Pollution Intensity Models in 1990 (SIC 28: Chemicals and Allied Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.112			0.114		0.085	0.075
	(0.227)			(0.227)		(0.228)	(0.227)
Emp	-0.443+			-0.456*		-0.422+	-0.418+
	(0.226)			(0.227)		(0.227)	(0.227)
Spec		0.803+		0.654	0.936*		0.789+
		(0.436)		(0.427)	(0.437)		(0.428)
Div		0.661		1.124	0.306		0.623
		(1.090)		(1.069)	(1.180)		(1.155)
Asize		-0.164		0.139	-0.154		0.134
		(0.414)		(0.411)	(0.418)		(0.414)
Cluster			-0.728*		-0.770*	-0.682*	-0.716*
			(0.315)		(0.315)	(0.307)	(0.307)
Metro			0.609		0.784	0.779+	0.883+
			(0.468)		(0.526)	(0.459)	(0.514)
Reg			-0.340		-0.467	-0.581	-0.566
			(0.853)		(0.870)	(0.837)	(0.851)
Constant	4.453***	2.779***	3.000**	4.447***	2.879**	4.628***	4.462***
	(0.508)	(0.151)	(0.933)	(0.524)	(0.946)	(1.066)	(1.080)
N	274	270	274	270	270	274	270
Prob>F	0.000***	0.315	0.132	0.002**	0.124	0.001***	0.001**
R2	0.056	0.013	0.021	0.070	0.037	0.076	0.092

+ p<.10, * p<.05, ** p<.01, *** p<.001

3.5.3.3 SIC 29: Petroleum and Coal Products

Results from labor productivity models in the Petroleum and Coal Products (SIC 29) are summarized in Table 3.12 and in Table 3.14. Again, plant-level variables of sales and employment are key controls in labor productivity of plants in 1990 and in 2000. In 2000, specialization is positive and statistically significant at $p<0.10$ in the LOC and the PLT-LOC models. At the same significant level, cluster in the PLT-REG model and metropolitan location in the REG model are negative and statistically significant. However, none of these variables is statistically significant in the full model.

Pollution intensity models in 1990 and in 2000 are presented in Table 3.13 and in Table 3.15. In plant-level features, sales valuable has some impacts on environmental performance of plants. In 2000, larger sales – larger outputs – raise pollution intensity in all models. Petroleum and Coal industry is one of the most facility-intensive industries, and that explains the lack of employment's influence here. Only in the PLT model in 1990, sales variable is statistically significant, but the sign is still positive. Specialization and the average size of neighboring plants are both negative and statistically significant in the 2000 models. Although the full model in 1990 is not statistically significant, specialization and cluster are both negative and statistically significant in the REG and the LOC-REG part models. Localization economies appear to help lower pollution intensity of plants. In 2000, location in the concentration of larger plants was also helpful.

Still, small samples of this industry keep interpreting the results without reservation. In consideration to small samples in this industry, it may be more reliable to focus on strong relationships.

Table 3.12 Labor Productivity Models in 2000 (SIC 29: Petroleum and Coal Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.794***			0.755***		0.788***	0.768***
	(0.075)			(0.080)		(0.084)	(0.086)
Emp	-0.699***			-0.719***		-0.714***	-0.744***
	(0.096)			(0.098)		(0.097)	(0.099)
Spec		0.399+		0.216+	0.290		0.159
		(0.200)		(0.127)	(0.217)		(0.132)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-0.150		0.052	-0.053		0.063
		(0.185)		(0.111)	(0.198)		(0.118)
Cluster			-0.331		-0.210	-0.296+	-0.311
			(0.292)		(0.325)	(0.172)	(0.191)
Metro			-0.612+		-0.414	0.141	0.168
			(0.338)		(0.368)	(0.220)	(0.231)
Reg			-0.099		-0.086	-0.025	-0.034
			(0.144)		(0.149)	(0.085)	(0.087)
Constant	5.878***	5.267***	6.272***	6.035***	5.907***	6.038***	6.206***
	(0.311)	(0.132)	(0.353)	(0.324)	(0.441)	(0.421)	(0.461)
N	50	49	50	49	49	50	49
Prob>F	0.000***	0.017*	0.045*	0.000***	0.062+	0.000***	0.000***
R2	0.703	0.163	0.159	0.725	0.210	0.724	0.743

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.13 Pollution Intensity Models in 2000 (SIC 29: Petroleum and Coal Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	1.156**			0.868*		0.976*	0.858*
	(0.348)			(0.344)		(0.399)	(0.379)
Emp	-0.022			0.425		0.124	0.427
	(0.473)			(0.439)		(0.491)	(0.470)
Spec		-0.270		-1.207*	-0.507		-1.234+
		(0.689)		(0.589)	(0.825)		(0.694)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-1.781**		-1.665**	-1.492+		-1.571*
		(0.608)		(0.513)	(0.790)		(0.658)
Cluster			0.719		-0.177	1.254	0.132
			(1.245)		(1.333)	(1.070)	(1.082)
Metro			-2.704*		-0.970	-1.637	-0.293
			(1.171)		(1.518)	(1.071)	(1.244)
Reg			0.497		0.022	0.499	0.104
			(0.627)		(0.671)	(0.533)	(0.545)
Constant	-1.328	2.487***	3.833**	-2.154	3.480*	-1.410	-2.078
	(1.608)	(0.464)	(1.284)	(1.450)	(1.429)	(2.037)	(1.923)
N	34	34	34	34	34	34	34
Prob>F	0.000***	0.009**	0.088+	0.000***	0.080+	0.003**	0.001**
R2	0.404	0.264	0.193	0.565	0.284	0.455	0.566

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.14 Labor Productivity Models in 1990 (SIC 29: Petroleum and Coal Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.750***			0.776***		0.817***	0.838***
	(0.097)			(0.111)		(0.111)	(0.125)
Emp	-0.774***			-0.795***		-0.840***	-0.856***
	(0.118)			(0.131)		(0.125)	(0.141)
Spec		-0.032		-0.119	-0.357		0.128
		(0.509)		(0.301)	(0.750)		(0.421)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-0.435		-0.014	0.196		-0.317
		(0.680)		(0.389)	(0.941)		(0.535)
Cluster			0.146		0.185	0.373	0.304
			(0.425)		(0.512)	(0.241)	(0.288)
Metro			-0.599		-1.209	-0.039	0.528
			(0.592)		(1.593)	(0.371)	(0.950)
Reg			0.864		0.752	-0.065	-0.089
			(1.081)		(1.244)	(0.608)	(0.699)
Constant	6.234***	5.097***	4.754**	6.291***	5.461*	6.162***	5.671***
	(0.303)	(0.192)	(1.314)	(0.341)	(2.214)	(0.825)	(1.304)
N	27	25	27	25	25	27	25
Prob>F	0.000***	0.700	0.433	0.000***	0.850	0.000***	0.000***
R2	0.716	0.032	0.110	0.719	0.093	0.754	0.753

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.15 Pollution Intensity Models in 1990 (SIC 29: Petroleum and Coal Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	1.337*			1.072+		0.870	0.560
	(0.540)			(0.594)		(0.634)	(0.688)
Emp	-1.254			-0.917		-0.814	-0.387
	(0.734)			(0.803)		(0.816)	(0.882)
Spec		-0.780		-1.029	-2.945*		-2.641
		(1.148)		(1.136)	(1.347)		(1.561)
Div		0.000		0.000	0.000		0.000
		(0.000)		(0.000)	(0.000)		(0.000)
Asize		-2.440		-2.100	0.029		-0.644
		(1.537)		(1.462)	(1.657)		(1.913)
Cluster			-2.377*		-2.308*	-1.824	-1.934
			(1.071)		(1.029)	(1.369)	(1.373)
Metro			-0.234		-4.378	0.017	-2.981
			(1.322)		(2.887)	(1.660)	(3.565)
Reg			1.344		-0.594	0.148	-1.142
			(2.512)		(2.573)	(2.851)	(2.979)
Constant	3.780+	2.340***	3.201	2.919	9.315*	4.478	8.026
	(1.808)	(0.482)	(3.013)	(1.976)	(4.353)	(4.311)	(5.513)
N	19	21	22	18	21	19	18
Prob>F	0.031*	0.261	0.019*	0.124	0.031*	0.089+	0.164
R2	0.351	0.139	0.417	0.406	0.530	0.486	0.577

+ p<.10, * p<.05, ** p<.01, *** p<.001

3.5.3.4 SIC 32: Stone, Clay, Glass, and Concrete Products

Results from labor productivity models are offered in Table 3.16 and in Table 3.18. Plant-level features, sales and employment, are all statistically significant in all models in 1990 and in 2000. Like the former industries, sales variable is positive and employment is negative. No other variable is significant in 2000. The average size of neighboring plants is negative and statistically significant in all models in 1990, while the variable is only statistically significant at $p<0.10$ in the full model. In other words, concentration of smaller plants boosts productivity. That reflects this industry's industrial structure favoring small plants. Specialization is positive and statistically significant in the PLT-LOC model, and metropolitan location and Levinson's index are both negative and statistically significant at $p<0.10$ in the PLT-REG model.

Pollution intensity models are summarized in Table 3.17 and in Table 3.19. In 1990, cluster is positive and statistically significant in the PLT-REG and the full model. Employment is negative and statistically significant at $p<0.10$ in the PLT-REG alone. In 2000, cluster is negative and statistically significant in the LOC-REG and the full model, and specialization is positive and statistically significant in all models. In lowering pollution intensity, localization economies worked primarily at the county level and at the multi-county level in 2000. On the other hand, industrial specialization heightened pollution intensity of plants in 1990. Literal interpretation of the results suggests that clusters were against sustainability in 1990, but for sustainability in 2000. Environmental policies in the 1990s might cause the change (Vig & Kraft, 2006). Expansion of industrial clusters between 1990 and 2000, shown in 3.4, is another potential explanation. There is also a possibility that small sample size in 1990 compromises the results.

Table 3.16 Labor Productivity Models in 2000 (SIC 32: Stone, Clay, Glass, and Concrete Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.629***			0.640***		0.627***	0.635***
	(0.072)			(0.076)		(0.074)	(0.078)
Emp	-0.602***			-0.607***		-0.597***	-0.601***
	(0.069)			(0.072)		(0.071)	(0.074)
Spec		-0.051		-0.146	-0.034		-0.133
		(0.215)		(0.150)	(0.223)		(0.158)
Div		0.236		-0.360	0.388		-0.306
		(0.650)		(0.460)	(0.669)		(0.479)
Asize		-0.276		-0.063	-0.315		-0.082
		(0.221)		(0.156)	(0.229)		(0.164)
Cluster			0.009		-0.037	-0.001	-0.012
			(0.159)		(0.163)	(0.115)	(0.119)
Metro			-0.089		-0.112	-0.036	-0.025
			(0.174)		(0.184)	(0.123)	(0.131)
Reg			0.119		0.138	0.073	0.060
			(0.149)		(0.154)	(0.105)	(0.109)
Constant	5.534***	4.287***	4.165***	5.541***	4.225***	5.453***	5.477***
	(0.237)	(0.077)	(0.236)	(0.241)	(0.253)	(0.303)	(0.316)
N	78	77	78	77	77	78	77
Prob>F	0.000***	0.594	0.801	0.000***	0.743	0.000***	0.000***
R2	0.528	0.025	0.013	0.539	0.048	0.532	0.542

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.17 Pollution Intensity Models in 2000 (SIC 32: Stone, Clay, Glass, and Concrete Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	-0.244			-0.337		-0.396	-0.588
	(0.472)			(0.445)		(0.478)	(0.442)
Emp	-0.218			-0.122		-0.254	-0.110
	(0.420)			(0.393)		(0.420)	(0.382)
Spec		-2.342**		-2.209**	-2.480**		-2.309**
		(0.813)		(0.826)	(0.835)		(0.826)
Div		2.415		2.925	2.541		3.529
		(2.336)		(2.406)	(2.379)		(2.409)
Asize		-0.903		-0.803	-1.122		-1.125
		(0.796)		(0.816)	(0.821)		(0.822)
Cluster			-0.957		-1.199+	-1.384+	-1.666*
			(0.673)		(0.621)	(0.715)	(0.654)
Metro			0.374		0.119	0.463	0.118
			(0.726)		(0.672)	(0.746)	(0.683)
Reg			-0.230		-0.477	-0.384	-0.582
			(0.629)		(0.595)	(0.631)	(0.588)
Constant	4.244**	2.757***	2.677**	4.417**	3.698***	5.512**	6.393***
	(1.484)	(0.299)	(0.942)	(1.369)	(0.895)	(1.814)	(1.645)
N	63	66	66	63	66	63	63
Prob>F	0.293	0.004**	0.567	0.010*	0.008**	0.288	0.005**
R2	0.040	0.193	0.032	0.227	0.249	0.101	0.323

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.18 Labor Productivity Models in 1990 (SIC 32: Stone, Clay, Glass, and Concrete Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.587***			0.572***		0.627***	0.594***
	(0.093)			(0.090)		(0.087)	(0.091)
Emp	-0.631***			-0.592***		-0.679***	-0.625***
	(0.085)			(0.085)		(0.082)	(0.089)
Spec		0.398		0.415*	0.447		0.278
		(0.305)		(0.200)	(0.362)		(0.233)
Div		0.011		-0.380	-0.030		-0.229
		(0.563)		(0.376)	(0.605)		(0.389)
Asize		-0.807**		-0.430*	-0.819**		-0.327+
		(0.255)		(0.177)	(0.270)		(0.188)
Cluster			-0.158		-0.192	0.024	-0.003
			(0.235)		(0.218)	(0.140)	(0.141)
Metro			0.031		0.198	-0.315+	-0.167
			(0.255)		(0.267)	(0.156)	(0.180)
Reg			-0.422		-0.294	-0.423+	-0.376
			(0.407)		(0.378)	(0.239)	(0.240)
Constant	5.549***	4.011***	4.401***	5.416***	4.229***	6.313***	6.006***
	(0.243)	(0.094)	(0.429)	(0.235)	(0.414)	(0.352)	(0.387)
N	39	39	39	39	39	39	39
Prob>F	0.000***	0.030*	0.683	0.000***	0.123	0.000***	0.000***
R2	0.604	0.223	0.041	0.686	0.256	0.689	0.721

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.19 Pollution Intensity Models in 1990 (SIC 32: Stone, Clay, Glass, and Concrete Products)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.193			-0.127		0.332	0.123
	(0.609)			(0.629)		(0.561)	(0.593)
Emp	-0.696			-0.352		-0.914+	-0.725
	(0.555)			(0.587)		(0.522)	(0.572)
Spec		-2.336		-1.547	-2.602		-1.660
		(1.656)		(1.627)	(1.743)		(1.701)
Div		2.626		2.999	3.306		3.153
		(2.702)		(2.563)	(2.795)		(2.474)
Asize		-0.309		-1.200	-0.283		-0.598
		(0.942)		(1.270)	(0.941)		(1.254)
Cluster			1.565+		1.405	2.813**	2.616**
			(0.918)		(0.921)	(0.890)	(0.896)
Metro			-0.916		-1.551	-1.279	-1.829
			(1.010)		(1.102)	(1.016)	(1.144)
Reg			-0.718		-0.623	0.015	0.129
			(1.711)		(1.716)	(1.522)	(1.526)
Constant	5.156**	2.626***	3.282+	4.532**	3.854*	5.659*	5.818*
	(1.569)	(0.415)	(1.753)	(1.605)	(1.789)	(2.240)	(2.467)
N	38	46	47	38	46	38	38
Prob>F	0.147	0.314	0.366	0.153	0.332	0.024*	0.043*
R2	0.104	0.080	0.070	0.214	0.155	0.321	0.395

+ p<.10, * p<.05, ** p<.01, *** p<.001

3.5.3.5 SIC 33: Primary Metal Industries

Labor productivity models in Primary Metal Industries (SIC 33) are summarized in Table 3.20 and in Table 3.22. Dominance of plant-level features is clear in the industry. Only sales and employment are statistically significant in all models in 1990 and in 2000. Signs of variables are as expected: sales variable is positive and employment variable is negative.

Results from pollution intensity models are presented in Table 3.21 and in Table 3.23. No statistically significant variable is observed in 1990. Plant-level features show the same trends in labor productivity models. In this industry, both sales and employment are statistically significant in all models in 2000, and directions of variables are same as in labor productivity models. Local-level factors show no significant impacts, while regional-level factors have their presence in pollution intensity models. Cluster is negative and statistically significant at $p<0.05$ in all models. Metropolitan location is also negative but only statistically significant at $p<0.10$. Plants in spatial clusters and in metropolitan areas tend to have lower pollution intensity, so more environmentally friendly in 2000.

Overall, labor productivity models and pollution intensity models of selective pollution-intensive industries in this section suggest that plant-level features were essential in increasing labor productivity of larger plants, and localization economies became rather significant in decreasing pollution intensity between 1990 and 2000. In the next section, general findings from the regression analysis, as well as from the ESDA, and their policy implications will be summarized.

Table 3.20 Labor Productivity Models in 2000 (SIC 33: Primary Metal Industries)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.746***			0.748***		0.747***	0.749***
	(0.028)			(0.029)		(0.029)	(0.029)
Emp	-0.767***			-0.768***		-0.768***	-0.769***
	(0.029)			(0.029)		(0.029)	(0.029)
Spec		0.062		-0.002	0.073		-0.001
		(0.065)		(0.039)	(0.068)		(0.041)
Div		0.293		-0.103	0.229		-0.103
		(0.457)		(0.273)	(0.460)		(0.276)
Asize		0.119		-0.025	0.096		-0.025
		(0.088)		(0.053)	(0.091)		(0.055)
Cluster			0.105		0.095	-0.013	-0.013
			(0.083)		(0.084)	(0.050)	(0.051)
Metro			0.083		0.084	-0.005	0.003
			(0.096)		(0.103)	(0.057)	(0.062)
Reg			-0.002		-0.005	0.006	0.007
			(0.077)		(0.077)	(0.046)	(0.046)
Constant	6.070***	4.604***	4.512***	6.067***	4.495***	6.080***	6.069***
	(0.100)	(0.044)	(0.133)	(0.101)	(0.141)	(0.128)	(0.132)
N	439	439	439	439	439	439	439
Prob>F	0.000***	0.387	0.286	0.000***	0.390	0.000***	0.000***
R2	0.648	0.007	0.009	0.649	0.014	0.648	0.649

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.21 Pollution Intensity Models in 2000 (SIC 33: Primary Metal Industries)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.528***			0.511**		0.570***	0.543***
	(0.155)			(0.158)		(0.153)	(0.156)
Emp	-0.396*			-0.389*		-0.479**	-0.469**
	(0.159)			(0.160)		(0.159)	(0.159)
Spec		0.219		0.205	0.147		0.129
		(0.209)		(0.209)	(0.216)		(0.215)
Div		1.401		1.121	1.781		1.553
		(1.386)		(1.374)	(1.382)		(1.365)
Asize		0.144		-0.002	0.284		0.158
		(0.275)		(0.278)	(0.280)		(0.281)
Cluster			-0.589*		-0.594*	-0.627*	-0.639*
			(0.269)		(0.271)	(0.269)	(0.272)
Metro			-0.424		-0.501	-0.539+	-0.577+
			(0.305)		(0.332)	(0.305)	(0.331)
Reg			0.012		-0.002	-0.001	-0.009
			(0.245)		(0.245)	(0.242)	(0.243)
Constant	2.877***	2.564***	3.221***	2.829***	3.262***	3.879***	3.930***
	(0.550)	(0.143)	(0.419)	(0.556)	(0.448)	(0.680)	(0.698)
N	377	382	382	377	382	377	377
Prob>F	0.003**	0.530	0.012*	0.024*	0.028*	0.000***	0.001***
R2	0.030	0.006	0.029	0.034	0.037	0.065	0.070

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.22 Labor Productivity Models in 1990 (SIC 33: Primary Metal Industries)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.768***			0.773***		0.764***	0.768***
	(0.037)			(0.037)		(0.037)	(0.038)
Emp	-0.753***			-0.761***		-0.751***	-0.759***
	(0.040)			(0.041)		(0.041)	(0.042)
Spec		0.083		0.004	0.111		0.008
		(0.109)		(0.063)	(0.121)		(0.070)
Div		-0.412		-0.073	-0.358		-0.075
		(0.465)		(0.271)	(0.486)		(0.285)
Asize		-0.139		0.070	-0.120		0.079
		(0.147)		(0.085)	(0.147)		(0.086)
Cluster			0.112		0.074	0.045	0.054
			(0.114)		(0.121)	(0.066)	(0.070)
Metro			0.034		0.112	0.037	0.039
			(0.137)		(0.152)	(0.080)	(0.089)
Reg			0.594+		0.564+	0.149	0.200
			(0.318)		(0.335)	(0.186)	(0.195)
Constant	5.802***	4.181***	3.554***	5.825***	3.499***	5.607***	5.575***
	(0.126)	(0.064)	(0.349)	(0.132)	(0.372)	(0.234)	(0.247)
N	214	213	214	213	213	214	213
Prob>F	0.000***	0.472	0.245	0.000***	0.399	0.000***	0.000***
R2	0.676	0.012	0.020	0.678	0.029	0.678	0.681

+ p<.10, * p<.05, ** p<.01, *** p<.001

Table 3.23 Pollution Intensity Models in 1990 (SIC 33: Primary Metal Industries)

	PLT Model	LOC Model	REG Model	PLT_LOC Model	LOC_REG Model	PLT_REG Model	FULL Model
Sale	0.234			0.216		0.189	0.188
	(0.206)			(0.209)		(0.208)	(0.212)
Emp	-0.233			-0.217		-0.210	-0.197
	(0.226)			(0.232)		(0.229)	(0.234)
Spec		-0.189		-0.390	-0.221		-0.385
		(0.335)		(0.370)	(0.371)		(0.414)
Div		-0.293		-0.204	0.010		0.068
		(1.458)		(1.496)	(1.536)		(1.578)
Asize		-0.314		-0.296	-0.291		-0.240
		(0.433)		(0.496)	(0.442)		(0.501)
Cluster			0.102		0.095	0.113	0.174
			(0.339)		(0.364)	(0.377)	(0.401)
Metro			-0.077		-0.152	0.177	0.004
			(0.426)		(0.469)	(0.456)	(0.514)
Reg			1.007		0.731	1.570	1.254
			(0.952)		(0.997)	(1.029)	(1.079)
Constant	3.441***	2.998***	1.969+	3.525***	2.370*	1.721	2.191
	(0.720)	(0.194)	(1.051)	(0.757)	(1.116)	(1.331)	(1.405)
N	197	234	235	196	234	197	196
Prob>F	0.520	0.831	0.751	0.760	0.955	0.592	0.851
R2	0.007	0.004	0.005	0.014	0.007	0.019	0.021

+ p<.10, * p<.05, ** p<.01, *** p<.001

3.6 Summary of Findings

Results from labor productivity regression models are summarized in Table 3.24, and results from pollution intensity models in Table 3.25. Three general tendencies are identified. First, labor productivity of plants appears to be mostly driven by factors related to internal economies of scale at the plant level, while pollution intensity of plants seems to be more sensitive to location-specific factors. Sales and employment variables are statistically significant, and the directions of signs remain same in all models of labor productivity in 1990 and in 2000. Directions of sales and employment variables are as expected. Since labor productivity means a ratio of plant's sales to its employment, larger sales with less employment generate higher labor productivity. In the partial models without plant-level variables, other variables generally do not turn out to be statistically significant.

Even at the local level, the variable of the average size of neighboring plants, which is a measure of locally dominant internal economies of scale, has impacts on labor productivity in some models in 1990 and in 2000. Generally, average plant size in those industries shrunk from 1990 to 2000. In other words, there were forces to enable smaller units to be more prevalent in the market. Plants with larger surrounding plants in a same industry seemed to lose their advantages between 1990 and 2000 in Paper and the Allied Products (SIC 26) and Chemicals and Allied Products (SIC 28). Advantages of smaller surrounding plants were lost in Stone, Clay, Glass, and Concrete Products (SIC 32), which is the only industry that grew in employment and the number of plants during the decade. Overall, it is fair to say that internal scale economies are an important factor for labor productivity of those large production units in pollution-intensive industries.

Table 3.24 Regression Results from Labor Productivity Models

	2000					1990				
Variable	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33
Sale	(+)*	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Emp	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)
Spec			[+]**							
Div										
Asize	(−)					(+)	(+)		(−)	
Cluster		(−)	[−]							
Metro									[−]	
Reg		(−)							[−]	

Table 3.25 Regression Results from Pollution Intensity Models

	2000					1990				
Variable	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33	SIC 26	SIC 28	SIC 29	SIC 32	SIC 33
Sale			(+)		(+)	[+]		[+]		
Emp		(−)			(−)	(−)	(−)		[−]	
Spec			(−)	(−)		(−)	(+)	[−]		
Div		(+)								
Asize			(−)							
Cluster		(−)		(−)	(−)		(−)	[−]	(+)	
Metro			[−]		(−)		(+)			
Reg										

* **( )** both the variable and its full model are statistically significant

** **[ ]** the variable and at least one partial model are statistically significant

Second, pollution intensity of plants appears to be responsive to factors related to agglomeration economies, specifically those of localization economies. Diversity variable to estimate urbanization economies is not statistically significant in the whole set of models in labor productivity and in pollution intensity, except a pollution intensive model in Chemicals and Allied Products (SIC 28) industry, even in which the variable heighten, not lower, the pollution intensity. On the other hand, specialization and cluster variables reduce pollution intensity in 4 out of 5 industries in 2000, while results in 1990 are somewhat unclear. Possibly, it is because the TRI data in 1990 are somewhat unreliable (Gerde & Logsdon, 2001). However, environmental policies during the 1990s should have influenced the differences between 1990 and 2000, too (Vig & Kraft, 2006). The influence of variables related to localization economies suggests that environmental managements and policies mainly worked at the intra-industry level in the selected pollution-intensive industries.

Third, plant's location within metropolitan area or within environmentally stringent states has no significant impacts on labor productivity or pollution intensity except for a few industries. Except in the part models, metropolitan location is only statistically significant and negative in the pollution intensity model for Primary Metal Industries (SIC 33) in 2000, and positive in the pollution intensity model for Chemicals and Allied Products (SIC 28) in 1990. State's environmental stringency is only statistically significant in the labor productivity model for Chemicals and Allied Products (SIC 28).

Combination of the findings from the regression analysis with those of the ESDA reveals another aspect of eco-industrial development in the industrial context. In the

ESDA of selected pollution-intensive industries, spatial clusters of counties in different industries share a group of major cities as their centers on the sea of counties of higher LQ. That suggest that while localization economies are influential in promoting greener plants, major cities and their neighboring counties can be promising locations for them. Diversity in cities offers economies of opportunity and scope, but the very size of major city also provides economies of scale at the industry level. Many major cities have been industrial clusters and have contained a variety of industrial districts in diverse industries (Braczyk, et al., 1998; Bresnahan & Gambardella, 2004b; Castells & Hall, 1994; Cooke & Schwartz, 2007; Rutten & Boekema, 2007; Scott, 1988a, 1988b, 1993). As former studies in the industrial symbiosis literature suggest, cities might be right locations for eco-industrial developments (Desrochers, 2002a). In practice, however, the findings from this chapter suggest that it is desirable to organize eco-industrial developments at the intra-industry level in the industrial context to take advantages of the presence of positive impacts of localization economies on environmental performance within major cities in the U.S.

This chapter examines this dissertation's hypothesis one (spatial forms) and two (contextual factors) in the industrial context, stated in 2.7, and findings from analyses support both hypotheses. First, there are quantifiable factors of plants and of locations influencing environmental performance and locational behavior of individual plant. Through series of regression models of labor productivity and pollution intensity in the five most pollution-intensive industries in the U.S., I found that internal economies of scale are a key factor in conditioning large production plants' labor productivity, while localization economies are influential in conditioning their environmental performance.

In other words, greener plants as potential anchor tenants gain their labor productivity by their own scale economies, but their environmental excellence by their locations of industrial specialization at the county or multi-county level. Second, in that sense, greener plants in a pollution intensive industry tend to be located in existing spatial clusters of the industry, which typically contain a group of major cities as their centers.

Those findings also support the relevancy of the anchor tenants approach in a mature industrial system. Identified localization economies' positive influence on environmental performance of plants implies that at least intra-industry relationships among firms in an industry are essential to manage environmental concerns at the level of individual plant, typically in existing spatial clusters. Regarding that the whole analysis has been done at the 2-digit SIC level, we may find the importance of inter-industry relationships between 3- or 4-digit SIC industries within a 2-digit SIC industry, which is the main idea of 'related variety' (Frenken, et al., 2007) needed to be tested in the future. In addition, diversity, urbanization economies, and inter-industry relationships might be more important among small- and medium-sized economic units, but that is not just the case for large production units in the pollution-intensive industries analyzed here.

Chapter 4. Eco-Industrial Development in the Post-Industrial Context

4.1 Introduction

Findings from Chapter 3 support the spatial forms hypothesis and the contextual factors hypothesis of this dissertation in the industrial context. The same hypotheses in the post-industrial context are examined in this chapter. Changing industrial structures in developed economies have highlighted offices and commercial buildings as key economic units for the service sector, as plants and facilities are for the manufacturing sector. Namely, eco-industrial development in the post-industrial context should start from greening offices and commercial buildings. Although data on the performances of offices and commercial buildings are not publicly available, greener buildings among them can be identified with proper eco-labeling schemes in the building industry. Then, the impacts of different locational factors on greener economic units can be estimated.

This chapter begins with a section scrutinizing the common concept of the service sector as a clean part of the economy to illustrate its significant environmental impacts, and the necessity of green buildings for the sector as an eco-industrial development strategy. A series of descriptive analysis of changing spatial patterns of green building projects in the U.S. will be followed. Then, the diffusion speed and the size of green building projects will be modeled in two interrelated analyses on county-level panel data of green building projects in the U.S. from 2000 to 2005. Finally, findings from the chapter will be summarized.

4.2 Greening Post-industrial Economy with Green Buildings

4.2.1 Green Buildings in the Post-Industrial Economy

Since the 1970s, the post-industrial economy has been one of the most influential lines of thought in the economic development literature, in which the service sector dominates its economic structure (Bell, 1973; Gershuny & Miles, 1983). Theorization of post-industrial economy has prevailed, based on the fact that service industries in the industrialized countries have grown rapidly. For example, service industries were responsible for over 50 percent of the Gross Domestic Products (GDP) in the earlier 1960s, and more than two-thirds in 2007 in the U.S.[24] From the information age literature, through world city hypothesis, to the recent creative class debate, key economic development theories have been indebted to the concept of post-industrial economy, in a sense that they conceptualized and found new emerging groups and industries in the service sector (Castells, 1989, 1996, 2001; Florida, 2002; Friedmann, 1986; Sassen, 1991).

However, the conceptualization of industrialized economies as post-industrial, post-material economies has imposed an unexpected by-product perception on the service sector: service sector as an environmentally friendly one. Angel (2000, p. 613) summarized the trend, as such:

> As service sectors replaced agriculture and mining, and then manufacturing, as the dominant sources of employment within advanced industrial economies, and as knowledge and technology-intensive industries became the leading-edge of high value-added industrialization, so the relation of advanced industrial

24 Service industries are conventionally defined as industries except agriculture, forestry, fishing, mining, manufacturing, construction, and government. That is the reason why service industries are sometimes referred as a 'residual' sector (Illeris, 1996). GDP-by-industry data were retrieved from the Bureau of Economic Analysis (BEA).

> economies to nature became further attenuated during the twentieth century in a discourse of post-industrial, post-material, economies.

As service industries, especially knowledge and technology-intensive industries, are regarded as dematerialized parts of industrialized economies, they are also considered cleaner parts of industrialized economies leaving little impacts on nature. The transformation of economies from manufacturing-based to service-based ones is commonly equated to the resurgence of environmental values and the following improvement of the quality of life, in the name of environmental Kuznets curve (Kahn, 2006). Post-industrial, service economies seem to be cleaner than industrial economies.

However, this view is largely ungrounded. Post-industrial economy does not necessarily more environmentally friendly one. While service sector itself produces smaller environmental emissions, wastes, and energy use per dollar of output, it still has significant impacts on overall U.S. emissions, wastes, and energy consumption. The share of service sector has become the largest one of the U.S. GDP, and the sector's indirect effects from its supply chains on the environment are even larger (Rosenblum, et al., 2000; Suh, 2006). Nevertheless, the role of service sector played in climate change and global warming has been largely ignored. For example, there are no regular statistics, data, and reports of the environmental impacts of service industries available in the U.S., while it has been more than three decades since Bell (1973) defined the U.S. as 'post-industrial society' dominated by the service sector.

Service industries deal with more or less dematerialized and intangible parts of the economy, but they do not exist in vacuum. As Sassen (1997) argues, no firm, no enterprise can exist virtually. Even the most post-material firm still needs materialized places to perform its economic activities, which consume materials and energy. Commercial buildings and offices are those places. Offices are to service sector what plants are to manufacturing sector. As the U.S. economy has changed from industrial to post-industrial one, energy consumption in manufacturing plants and industrial buildings has decreased and that in commercial offices and buildings has increased. Similar trends are observed in greenhouse gas emissions.

Energy consumption of commercial buildings, especially in electricity, has grown significantly. From 1980 to 2005, the share of commercial buildings in the U.S. primary energy consumption grew from 14 to 18 percent, and that in the U.S. electricity consumption from 27 to 35 percent. During the same time period, the share of industrial buildings in total primary energy consumption declined from 39 to 38 percent, and that in total electricity consumption from 41 to 32 percent, while the share of residential buildings in total primary energy consumption increased from 20 to 22 percent, and that in total electricity consumption from 34 to 37 percent (U.S. Department of Energy, 2007).

Likewise, the environmental impacts of commercial buildings have grown faster in the U.S. Carbon dioxide emissions from primary energy consumption of commercial buildings were responsible for only 3.9 percent in 2005, but if the carbon dioxide emissions from energy consumption in the electronic power sector in proportion to the commercial building sector's share of total electricity retail sales were added, the share became 17.8 percent. From 1980 to 2005, carbon dioxide emissions of commercial sector, in which emissions from electricity consumption of the sector was included, increased by 63.3 percent, whose growth rate was bigger than industrial (-6.2 percent), residential (37.8 percent) and transportation (43.3 percent) sectors. Even in absolute numbers, annual emissions from commercial sector increased by 412.9 million metric tons of carbon dioxide, which is the second largest increase only to transportation sector (600 million metric tons), and the largest one among the whole building sectors (Energy Information Administration, 2007).

In sum, the impacts of service sector on nature may be less than those of manufacturing sector, but far from small or negligent. Commercial buildings and offices are locations where service industries consume energy and materials, and generate environmental burdens. As service industries are growing, environmental consequences of those buildings are increasing. The perception of 'clean' service sector prevents us from keeping and tracking environmental performance of service industries. There is no equivalent to the Toxics Release Inventory in service sector. Therefore, eco-industrial development in post-industrial context should be probed differently from that in industrial context.

History shows a way. At the dawn of the geography of services, researchers began to analyze the geography of offices first (Goddard, 1975; Gottman, 1983). City networks, theoretically rooted in the central place theory (Christaller & Baskin, 1966; Lösch, 1954), have been utilized to analyze the geography of services and of offices, and the tradition has found a new field of world city networks recently, which ranks world cities based on the global distribution of advanced services and corporate headquarters and their linkages (Taylor, 2004).

Office clustering at world cities seems to be discrepant from recent interests in the sprawl of offices and advanced services, representatively in the name of 'edgeless cities'

(Lang, 2003). However, they are not necessarily contradictory, since more advanced, sophisticated functions tend to be concentrated in cities, and more general, routinized ones are inclined to be decentralized from cities. Service industries are no exceptions. In fact, one of the very first comprehensive office distribution studies in the U.S. already found both centralization and decentralization trends of financial services in Manhattan in the earlier 1970s (Armstrong & New York Regional Plan Association, 1972). In addition, urban concentration of producer and business services had been a major geographical issue in the 1990s (Daniels, 1993; Illeris, 1996), and as those industries become mature, their decentralization has been observed recently (M. K. Nelson, 2003).

Cities, especially big cities, are not only birth places of new functions and industries, but of new types of spaces in which they are occupied. For example, skyscrapers have become most clearly visible as a representative landscape of post-industrial economy in global cities around the world. Recently, one of the most visible countermoves to global environmental concerns has been manifested in the same global cities in the form of green designs in corporate architecture (Olds, 2001; Presas, 2005). Along with the introduction of urban green buildings, the trend in green building practices has been shifted from the low-tech, ecocentric approach to the high-tech, technocentric approach (Gauzin-Müller, 2002; Gram-Hanssen & Jensen, 2005; Guy & Farmer, 2001; Guy & Osborn, 2001). In other words, urban green building projects could take advantage of clean-tech innovations and state-of-the-art ecological designs to mitigate their environmental burdens, relatively free from historic methods of bioclimatic adaptation to the local environment (Olgyay & Olgyay, 1963).

As individual green building practices were accumulated, common principles were required to be distilled from best practices as a form of standards, which construct the shared definition of green building and meet the increasing demands of green building in the market. In the late 1990s and the earlier 2000s, several voluntary green building rating systems emerged around the world, mostly from industrialized cities, regions and countries in post-industrial era. Among them, the green building movement in the U.S. has distinguished itself by its popularity and pervasiveness, and has been developing its distinctive green building rating systems, which are now used internationally, as well as domestically. The propagation of the green building rating systems ushered the green building movement into mainstream recently (Lockwood, 2006; Thompson, 2003). Practically, the rating systems provide an operational definition of green building and considerably reliable data on the diffusion of green building projects in the U.S. for the first time in history. In the next section, this U.S. green building rating systems are introduced with an operational definition of green building.

4.2.2 Green Building as Eco-industrial Development in the U.S.

What are green buildings? Green buildings are buildings "designed, constructed, and operated to boost environmental, economic, healthy, and productive performance over the conventional building" (U.S. Green Building Council, 2003, p. 4). The Office of the Federal Environmental Executive provides more detailed definition of green buildings as "the practice of 1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and 2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal – the complete building life cycle" (Office of the Federal Environmental Executive, 2004, p. 8). Those definitions of green building reflect not only common perceptions on green building but also institutional processes to design and construct green buildings in the U.S.

The recent diffusion of green buildings in the U.S. has been impressive. Since 2000, 'green building' has become a familiar word to the public, and municipalities and governmental agencies at various levels, as well as private developers, have entered into this new territory. Arguably but reasonably, green buildings have finally become mainstream (Lockwood, 2006). While green buildings have drawn significant attention from both academics and practitioners, most of existing works are limited in their focuses on individual green building projects and their potential benefits, such as case studies, cost-benefit analyses or life-cycle assessments (Gissen & National Building Museum, 2002; Matthiessen & Morris, 2004, 2007; Scheuer, Keoleian, & Reppe, 2003). On the contrary, external factors and conditions may enable and facilitate green building projects at the local level have not been systematically tested. Other than studies on the direct environmental benefits of green building might not be top priorities for architects, developers, and related practitioners at first. However, the rapid growth of green buildings in the U.S. has changed the situations, and has been revealing the necessity for the research on enabling factors that transform the potential benefits of green buildings into reality in urban planning.

Current dominance of the term 'green building' in the U.S. is not a coincidence. In fact, green building is one of many titles to call environmentally friendly buildings internationally, such as sustainable architecture, low-impact building, and ecological construction (Birkeland, 2002; Gissen & National Building Museum, 2002; Kibert, et al., 2002). The term 'green building' has been popularized in the U.S., since an U.S. non-profit organization, established for environmentally friendly construction, selected the term as its trademark, and most successfully promote its objectives by establishing and spreading green building rating systems. While there are other individual cases of sustainable architecture and rating systems working at different scales[25], it is simply unfeasible to define and identify green buildings in the U.S. without the organization, since its rating systems have become a *de facto* green building standards in the U.S. to discern whether a building is sustainable or not.

The U.S. Green Building Council (USGBC) was established in 1993 as a non-profit organization, and ever since has pursued its commitment to promote green building development. The very first goal of the USGBC was the creation of its own green building rating systems (Building Design & Construction, 2003). After testing various existing rating systems, the USGBC approved the first green building rating system under the name of the Leadership in Energy and Environmental Design (LEED) in 1998. The LEED® Green Building Rating Systems™ is 'a voluntary standards and certification program that defines high-performance green buildings' (U.S. Green Building Council, 2006b). Since its official release in 2000, the LEED quickly has become a *de-facto* standard for green building in the U.S. among other rating systems and the niche for green buildings has grown to $7 billion worth market annually (U.S. Green Building

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25 For example, the Building Research Establishment Environmental Assessment Method (BREEAM) has been used in the UK, since its establishment in 1990. Canada has led an international effort, called the Green Building Challenge. Even in the US, in addition to federal programs such as Energy Star for Homes, there are cities and communities that have run their own green building programs, such as Austin, Texas, which initiated its program in 1990 (Pitts, 2004). For a more detailed introduction to rating systems and assessment tools, see Lerario and Maiellaro (2001). The National Association of Home Builders summarized a group of local green building programs in the U.S., including Austin, Texas (National Association of Home Builders, 2006).

Council, 2006a, 2006b). The growth of the LEED has accompanied with that of the USGBC. The number of the USGBC members has increased more than ten-fold since 2000, and now the USGBC encompass over 7,000 organizations, including firms, governmental agencies, and non-profit organizations.

The LEED-NC (New Construction) is the first rating system launched in 1998, released in 2000 with 12 pilot projects, which covers the new building design and construction or major renovations process. Since then the USGBC has expanded its LEED rating systems into more specified areas, including LEED for Existing Buildings, Commercial Interiors, Cores and Shell Development, and more recently for Homes, for Schools, Retail, Healthcare and for Neighborhood Development (U.S. Green Building Council, 2006b, 2006c).

The LEED rating systems adopted the checklist approach based on the performance levels (U.S. Green Building Council, 2006f). To be certified, a green building project should go through three steps of certification process: project registration, technical support and building certification. Fees are required in both registration and certification steps, based on square footage. Achievements of green practices in the checklist will obtain credits in six categories, including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process. All LEED systems consist of prerequisites, core credits, and innovation credits. After all prerequisites are fulfilled, four levels of LEED rating – Certified, Silver, Gold, and Platinum – are determined by the performance level scored by credits achieved. Innovation credits are literally extra credits for innovative practices.

From the very first time, USGBC fully recognized that the realization of green building practices continuously requires new environmental innovations, and eco-labeling scheme should reflect this dynamic and evolutionary character of the industry. As a result, the LEED has built-in procedures to revise and transform itself, driven by consensus through USGBC member committees (U.S. Green Building Council, 2006d). Each LEED rating system is on the continuous track of evolution, and updated when available. For example, the oldest LEED rating system, LEED-NC is now version 2.2, which was released in 2005.

As an eco-label, the LEED has built up its brand power solid, as well as necessary credentials in the U.S. Most of all, LEED projects has grown impressively since the introduction of 12 initial pilot projects under the LEED-NC version 1.0 in 2000. From 2001 to 2005, the number of certified LEED-NC projects and the number of registered projects have been almost doubled annually. Positive impacts of LEED projects on the environment, however, are hardly expected to be realized at the macro scale yet, since there are only about 1,750 LEED certified and 14,400 LEED registered projects (and about 1,240 LEED-NC certified and 8,300 registered projects) as of September, 2008 (U.S. Green Building Council, 2008a). In spite of their better energy efficient and environmentally friendly capacity, green buildings are still short in numbers to influence the general trend of energy consumption in building industry. In general, green buildings are currently functioning as environmental innovations in their initial stage of diffusion process.

The shift from the initial stage to the latter stages in innovation diffusion is far from an autonomous process, and possibly need to set up new strategies based on proper understanding of current situations (G. A. Moore, 1991). It is certain that the adoption of green buildings is a function of internal dynamics. However, internal dynamics alone may be not enough to bring best practices. Nevertheless, the green building research has concentrated on internal dynamics, mostly on case studies of green building development in various settings. The USGBC itself has been dedicated to collect and share key green building case studies. On the contrary, external factors influencing the location of green buildings have been neglected in the research.

Local and regional policy initiatives for green buildings, as well as new strategies of the USGBC, have been introduced recently. However, the effectiveness of those policies and strategies has barely been investigated and supported by past patterns of green building diffusion. Although green buildings can be beneficial for any municipality pursuing urban sustainability, they may not be for every municipality for now. Some municipalities can take advantage of their given environments as resources to attract green building projects, but there are other municipalities that have to overcome their environments by building capacity to attract green buildings in their jurisdictions. Namely, favorable or hostile environments for green buildings do exist. Modeling the diffusion of the LEED green building projects is needed in this respect.

4.3 Modeling the Diffusion and Growth of Green Building Projects in the U.S.

4.3.1 Data to Model the Diffusion and Growth of Green Building Projects

Datasets for two closely related events in certifying green buildings are constructed: registered LEED-NC projects and certified LEED-NC buildings. As mentioned in 4.2.2, green buildings are certified by the USGBC through three steps of certification process: project registration, technical support and building certification. A specific building project should be registered first to be evaluated, and eventually certified as a green building through evaluation. In that sense, registered projects are proxies for future demands of green buildings, and certified buildings are those of realized demands. For the green building certification process, the Council manages databases of registered projects and certified buildings. A variety of LEED certifications are now available, but the oldest one is the LEED for New Construction, which has been offered since 2000 and focuses on commercial buildings and offices (U.S. Green Building Council, 2006c).

For modeling the relationship between green building projects and their local environment, it is necessary to aggregate individual data at a certain geographical level. As the smallest administrative units of social, economic, and geographic data, congruently covering the whole continent U.S., the county is chosen as a spatial unit of analysis to analyze eco-industrial development in the post-industrial context, as in the industrial context (Isserman & Westervelt, 2006). I aggregate available data of the LEED-NC certified buildings and registered projects from the USGBC at the county level in each year to identify in which year and county those projects and buildings occurred. Cumulative numbers of the certified buildings and the registered projects of all the counties in the continental U.S. between 2000 and 2005 are calculated. Since the registration records were not designed for spatial data, and were voluntarily collected with optional confidentiality rights of project developers, the original data sets have to be filtered down to clean up void or inaccurate records. Even aggregation at the county level is quite a challenge.

County datasets for independent variables in the later analyses in this chapter are collected and prepared from various sources. Demographic data are mainly retrieved from the Census Bureau. Economic data come from the Bureau of Labor Statistics (BLS), the Bureau of Economic Analysis (BEA), the Energy Information Administration (EIA) as well as the Census Bureau. Governmental data are from the League of Conservation Voters (LCV) and local and regional public policy records for green buildings compiled by the USGBC. Geographic data are provided from the US Department of Agriculture (USDA). Due to the limitation of available data, not all U.S. counties are included in the models. Specifically, counties in Alaska, Hawaii, and Washington, D.C. have been omitted. Necessary measures and indices for the analyses are calculated from original datasets, and included as variables in the final dataset. Description for each variable and its related hypothesis will be introduced later in the analyses to model the diffusion of green buildings.

4.3.2 Analyses to Model the Diffusion and Growth of Green Building Projects

The diffusion of green buildings has not been a constant process. There have been fast sites and slow sites. The very difference in the adoption of green buildings at the local level has stimulated many environmentally conscious municipalities to establish initiatives for green building in their jurisdictions (U.S. Green Building Council, 2006e). However, the initiatives have not guaranteed the success of local green building projects so far. There are other factors that have impacts on green building adoption at the local level. A one-size-fits-all green building does not exist. A feasible project at a county can be a complete failure at another county, since no green building project can stand alone; it should interact with its social, economic, and political environments, as well as natural and physical ones. Technical and financial perfection of a green building project can be always challenged and even canceled by economic downturn, blighted neighborhood, or developmental mindset sharing no room for environmental concerns. In that sense, the identification of relevant factors influencing local adoption of green building can be desirable not only to understand the diffusion of green building projects better, but also to probe effective policy options beneficial to both green building builders and local policy makers. Most of all, if green buildings are intended not just for the development of islands of sustainability, but for the sustainable transformation of the built environment, the mechanism behind the diffusion of green buildings in the U.S. should be probed as an example of eco-industrial development in the post-industrial context.

Methods used for the analyses of manufacturing plants in Chapter 3 cannot be repeatedly applied to the green building analyses, since there are no publicly available real estate data for commercial buildings or offices, so it is almost impossible to discern the overall distribution of commercial buildings and compare it to that of green buildings. However, the county-level LEED-NC project data between 2000 and 2005 allows me to model the diffusion of green buildings with more advanced techniques, since different from the TRI data, which have been collected from different firms annually, the LEED-

NC project data can be parsed into panel datasets at the county level. County-level data from various sources are not always comprehensive and coherent, there are missing data in final panel datasets, and that makes the datasets unbalanced panels (Wooldridge, 2002), which limit diffusion models available.

For example, spatial panel models look promising with those county-year panels (Elhorst, 2003). However, spatial panel models turned out to be not working with the unbalanced panels here in a few reasons. First, there are no clear ways to deal with missing data in spatial-temporal models. Missing data handling with the maximum likelihood method in spatial econometrics has not been followed up since the late 1980s (Griffith, Bennett, & Haining, 1989; R.P. Haining, Griffith, & Bennett, 1989), and available packages such as LeSage's Spatial Econometrics Toolbox for Matlab and R-project have some problems in dealing with unbalanced panels. Although it is possible to use the instrumental variable method to estimate coefficients (Kelejian, Prucha, & Yuzeforich, 2004; Kelejian & Robinson, 1993), the method is also not free from missing value problem. Second, some standard spatial panel models are simply not working properly with unbalanced panels of large number of spatial units and small number of temporal durations, since the standard spatialtemporal-lag model with temporally and spatially lagged dependent variables has been developed more fit to balanced panel data of small spatial units and large temporal durations (Franzese & Hays, 2007, 2008). Third, the impacts of time-invariant and rarely changing factors, other than time and space, cannot be properly estimated with these panel models (Plümper & Troeger, 2007). The county-level panel datasets of the LEED-NC projects consist of more than 3,000 county-wide data for 6 years, but not many county-level data show significant changes during the period. As a result, the impacts of theoretically important variables tend to be underestimated. Test runs with the spatialtemporal-lag model proved that spatial and temporal lags tend to consume explanatory power of other factors. Fewer spatial units or longer temporal durations may make the model work, but with these specific panels, it is necessary to take different approaches to serve the purpose.

Three inter-related analyses will be performed to test hypotheses of spatial forms and of contextual factors, refined in Chapter 2. First, descriptive statistics of green building distribution will be covered to probe spatial patterns of the LEED-NC green building projects. As mentioned, the distribution of commercial buildings in the U.S. is not tractable with publicly available data, so it is not possible to overlay and compare the distribution of green building projects to that of commercial buildings. However, it is possible to test the hypothesis of the urban dominance of green buildings. Although general offices are decentralizing, newly-built premium offices still tend to concentrate in big cities (Girardet, 2004; Lang, 2003; Lang, Sanchez, & LeFurgy, 2006; Presas, 2005). Since green buildings are a new type of office, an environmental innovation, it is reasonable to assume that green buildings started to concentrate in cities, then have been diffused into neighboring suburbs and rural areas. General growth trends of green buildings in urban, suburban, and rural settings will be analyzed. Then, clusters of green buildings will be interpolated on density surfaces with the inverse distance weighting to depict the geographical distribution of green building projects with reference to the urban-rural continuum.

Second, locational factors that make a county adopt green building projects faster will be investigated. Green building projects has not been diffused equally or simultaneously. To measure the changing diffusion patterns of green building projects, it is necessary to find the right model to tract diffusion processes. Event history analysis has been used to follow the diffusion of events quantitatively. Since event history analysis can model not only the event, but also the duration time until event, it can be used to probe both whether and how fast events occur (Box-Steffensmeier & Jones, 2004). Diffusion and innovation models in policy research has a solid tradition in modeling diffusion with event history analysis (F. S. Berry & Berry, 2007). Demographic, economic, governmental, and geographic factors influence the adoption and diffusion of green building projects will be selected and included in the analysis.

Third, I will probe whether the same factors enabling faster adoption of green building projects also attract more projects. Early adopters may take first-mover advantages and develop new green buildings with experiments and innovations, but a group of 'fast second' (Markides & Geroski, 2005) can grow bigger by using their size to collect former best practices and create a niche market for green buildings. In other words, factors promoting the speed of green building adoption do not necessarily influence the number of green buildings in the same way. Panel data analysis, which is used to study the characteristics of fixed units over time (Baltagi, 2005; Wooldridge, 2002), can be applied to the county-level dataset of the LEED-NC projects to probe the influence of the same factors on the amount of green building projects over time. The following chapter will be organized in the suggesting order of analyses.

4.4 Clusters of the LEED Green Building Projects

4.4.1 Urban Dominance of Green Building Projects

Green building development in the USGBC started its LEED green building rating systems. This eco-labeling scheme has become as a *de facto* standard in the building industry, and builders and municipalities around the U.S. have created their green buildings based on their interpretations of this performance-based approach. Due to its importance and pervasiveness in the U.S., the LEED green building projects are selected for the analysis. As mentioned, the LEED provides a group of different rating systems. The LEED-NC is chosen for the research, since it is the oldest rating system by the USGBC, started in 2000 and designed mainly for commercial buildings and offices. The LEED green building project database for the LEED-NC was obtained by direct request to the USGBC and complemented with its online database. Green building registration data has been collected by the USGBC, including location records of certified buildings and registered projects. Since the registration database was not designed and collected as a spatial dataset, and some of the LEED projects asked to make their locational data confidential, the LEED database has considerable quality problems and need to be cleaned. Overall, about 7 percent of total records have to be removed though the process of aggregating the LEED project records at the county level.

The LEED projects, then, are sorted by the degree of urbanization. The LEED projects are classified into urban, suburban, and rural categories according to the 1999 definition of Metropolitan Statistical Areas (MSAs) from the Census Bureau. Following conventions in urban studies, central cities are classified as urban, counties in metropolitan areas but not central cities as suburban, and counties out of metropolitan areas as rural (Isserman, 2005).

Along with the further analysis at the latter sections of this chapter, the distribution of the LEED green building projects by the degree of urbanization is graphed from 2000 to 2005. Two sets of graphs are created: the distribution of the LEED certified buildings, and that of the registered projects. The certified buildings are consequences of the decisions of the past, and the registered projects reflect the current and future trends in the distribution of the green building projects. Changing distribution trends ordered by the degree of urbanization can be identified with those graphs.

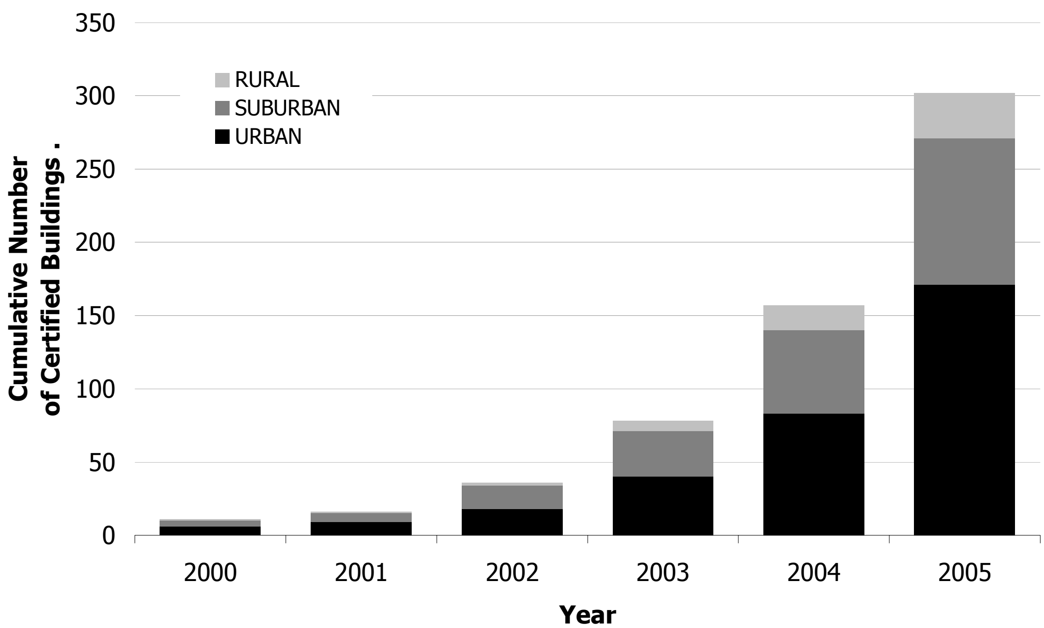

Figure 4.1 Cumulative Number of the LEED-NC Certified Buildings in Urban, Suburban, and Rural Counties

Figure 4.1 shows cumulative number of the LEED-NC certified buildings in urban, suburban, and rural counties. It also demonstrates the increasing supremacy of urban counties in green building construction. The number of certified buildings has rapidly grown from 11 in 2000 to 302 in 2005. Since 2003, the share of certified buildings in rural counties has maintained around 9 to 10 percent. The share in urban counties was the lowest in 2002, 50.0%, then grew back to 56.6% in 2005. On the contrary, suburban share has declined from 44.4% in 2002 to 33.1% in 2005. Cities have attracted more green buildings faster. It seems natural since office demands, especially those for special offices like green buildings, tend to be concentrated in big cities.

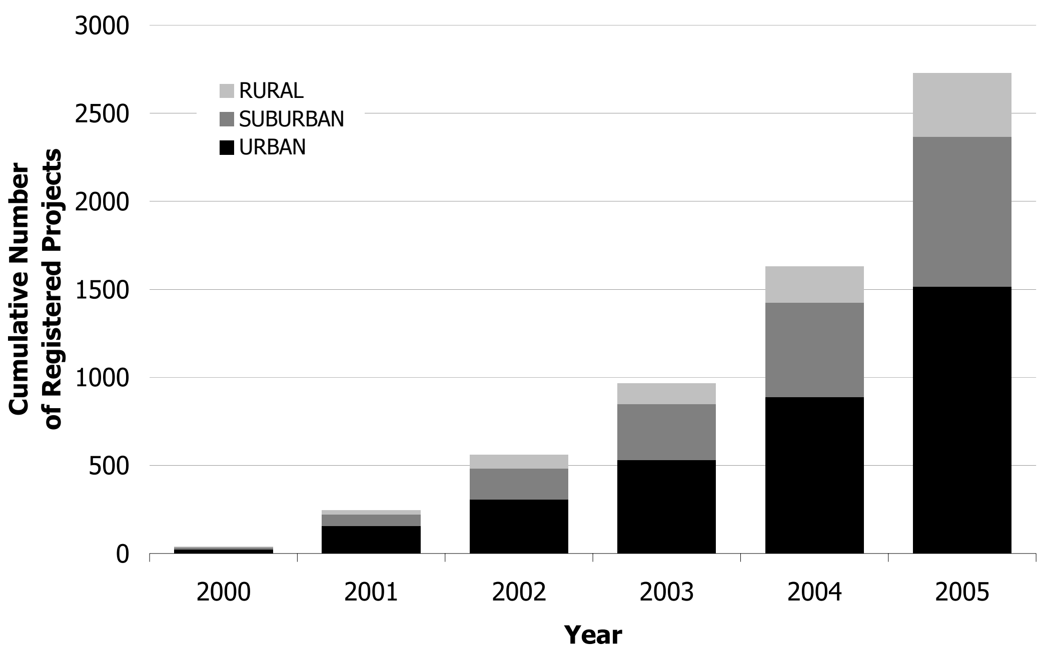

Figure 4.2 Cumulative Number of the LEED-NC Registered Projects
in Urban, Suburban, and Rural Counties

The trend in the distribution of the certified buildings is similar to that of the LEED-NC registered projects. Cumulative number of the LEED-NC registered projects has grown from mere 40 in 2000 to 2729 in 2005. As presented in Figure 4.2., the dominancy of urban counties in the number of green building projects has been continued. Urban share of the registered projects has been around 55 percent since 2002. The share of the registered projects in suburban counties has been stuck around 32 percent, and rural share around 13 percent. Overall, rural counties attract slightly more percentage of registered projects, but each share by the degree of urbanization in the LEED-NC registered projects is quite similar to that in the certified buildings. Considering the distribution of registered projects reflects future demands of green buildings, it is fair to say that the current supremacy of urban counties in green building development will be continued at least for a few years.

4.4.2 Locations of the Clusters of Green Building Projects

Cities – urban counties – are where green building projects cluster. However, which cities and urban counties make bigger clusters? 3-dimensional density surface is a useful visualization to present high-density clusters of green building projects. Density surfaces for the LEED-NC certified buildings and the registered projects are interpolated with the inverse distance weighting in Fig 4.3 and Fig 4.4, respectively. Since the green building data are aggregated at the county level, the centroids of counties are used to generate density surfaces.

As a complementary measure, spatial clusters of green building projects are identified with the local Moran's *I* (Anselin, 1995), which is a spatial statistic used to discern local clusters of pollution-intensive industries in 3.4. Spatial clusters of the LEED-NC certified buildings are depicted in Figure 4.5, and of registered projects in Figure 4.6.

Although the distributions of the LEED-NC certified buildings and registered projects show similar patterns, there are also significant differences between the realized demand of certified buildings and the future demand of registered projects. It is noticeable that peaks and spatial clusters share roughly same locations. In 2005, the LEED-NC certified buildings are mainly located in counties with major historical cities on each side of the continental U.S. On the west side, Los Angeles county in California, Multnomah county in Oregon, and King county in Washington have higher peaks. Those counties are top three among counties with the certified building; King county where Seattle is located was the top rank with 17 certified buildings in the number of the certified buildings in the U.S., Los Angeles county and Multnomah county where Portland is located ranked at the second place with 12 buildings each. On the east side, the majority of certified buildings are roughly in the Rust Belt between New York and Chicago, although Fulton county in Georgia showed the highest number of 11 certified buildings on the east side, in which Atlanta is placed. Alleghery county in Pennsylvania is the next with 10 buildings, where Pittsburgh is located. A group of counties with major cities follows, such as Cook county with Chicago in Illinois, Kent county with Grand Rapids in Michigan, and Middlesex county with Cambridge and near Boston in Massachusetts.

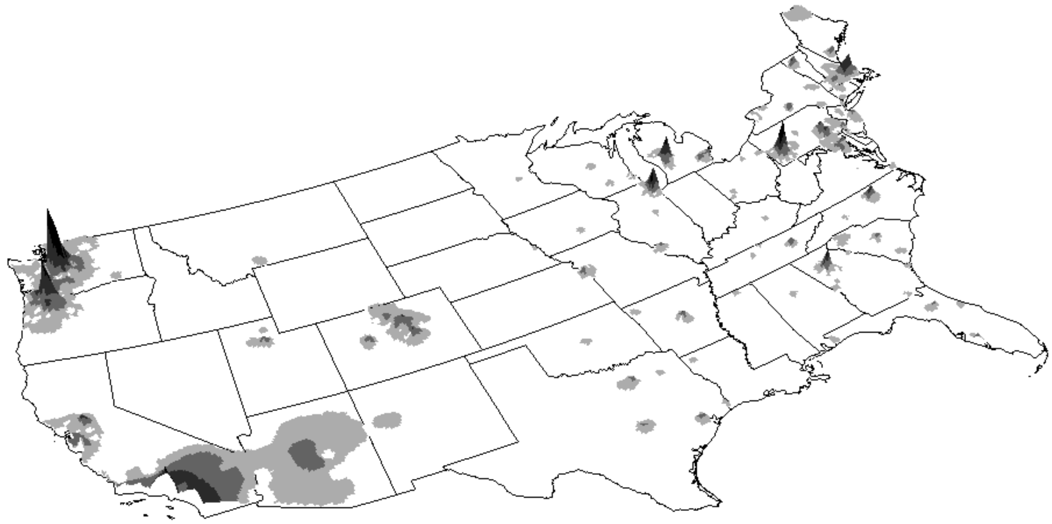

Figure 4.3 Distribution of the LEED Certified Buildings in 2005
(Interpolated with the Inverse Distance Weighting)

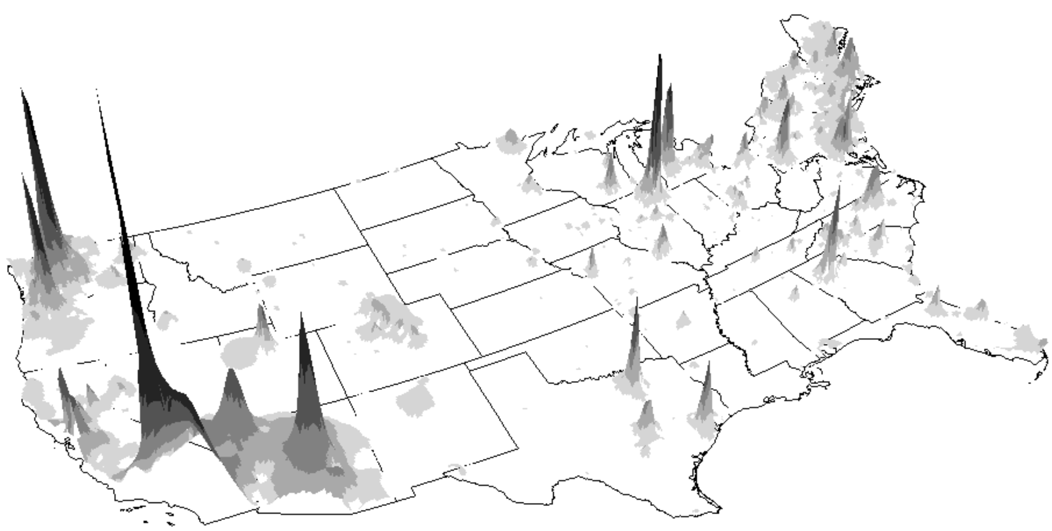

Figure 4.4 Distribution of the LEED Registered Projects in 2005
(Interpolated with the Inverse Distance Weighting)

Figure 4.5 Spatial Clusters of Counties of the LEED Certified Buildings in 2005 (LISA High-High Spatial Clusters)

Figure 4.6 Spatial Clusters of Counties of the LEED Registered Projects in 2005 (LISA High-High Spatial Clusters)

While counties with smaller number of green buildings are scattered around the U.S., the Mountain States and the Central United States do not have many counties with green buildings. The LEED certified buildings in those States tend to be located in major cities, including Salt Lake city in Utah; Denver in Colorado; and Phoenix in Arizona. Except Fulton county in Georgia and Durham county in North Carolina, the American South also has only a limited number of counties with green buildings.

The distribution of the LEED registered projects reflects the past trend of green building construction, and reveals the future demands of green buildings. The distribution shows a similar distribution of the certified buildings, but major actors in initiating registered projects are somewhat different from those in building certified buildings. Still, most green building projects are found on the West and the East sides of the U.S. A leap of Los Angeles county is the most significant feature in the distribution of the LEED registered projects in 2005. Los Angeles county recorded almost 100 registered projects. San Diego county and Alameda county with San Francisco were ranked eight and twelfth respectively. Maricopa county with Phoenix in Arizona had almost 40 projects, ranked in sixth place, and Clark county with Las Vegas in Nevada also had about 20 projects. In spite of relatively smaller presence in numbers, Seattle and Portland still showed higher peaks than most of the counties in the U.S. King county with Seattle, which had the most certified buildings in 2005, was ranked third in registered projects with 49 projects, and Multnomah county with Portland ranked fifth with 39 projects. Along with those counties, isolated counties of higher registered green building projects sprung out on the West, including Salt Lake city county in Utah and Denver county in Colorado.

On the East side, Chicago showed the most significant increase in green building demands. Cook county with Chicago had slightly more than 50 registered projects, ranked in second place. Near Chicago, Kent county where Grand Rapids located had 30 projects. Fulton county containing Atlanta, which had the most certified buildings on the East side, took the second place with 42 projects. Alleghery county, which was the second in certified buildings in 2005, had 23 projects, mainly in Pittsburgh. Like on the West side, a group of isolated clusters of the LEED registered projects existed around the major cities in BosWash. The Central United States did not have many LEED registered projects, but three moderate peaks were located in Texas, around Dallas, Houston, and Austin. Smaller peaks could be observed across the U.S., and the frequency of those events was more often than those of certified buildings.

The distributions of the LEED green building projects show a few, but significant trends. First, in each case, the distribution of the LEED is uneven. Not always, but more frequently, the LEED green buildings prefer to be located in major historical cities on the each side of the U.S. Second, islands of the LEED certified buildings and registered projects have been growing, again, around major historical cities, often around state capitals. Third, the distribution of registered projects shows much sophisticated patterns and covers more cities and counties across the U.S. than that of certified buildings. In other words, the future demands for green buildings were much greater than the revealed demands in 2005. Finally, it is worth mentioning that major cities within spatial clusters of the LEED-NC certified buildings and registered projects are largely overlapped with common centers of spatial clusters in pollution-intensive industries in Chapter 3.

4.4.3 Changing Patterns in the Growth of Green Building Projects

Cities prevail in the adoption and diffusion of green building projects, and a group of cities have stepped up as centers of spatial clusters of the LEED-NC certified buildings and registered projects. As more and more suburban and rural counties take part in green building diffusion process, however, growth patterns of green building projects start to show signs of change. By comparing earlier and later distributions of the LEED-NC certified buildings and registered projects with identified green building clusters, those signs can be investigated. The LEED-NC dataset contains data from 2000 to 2005. I divided the whole period into two 3-year periods, and compare distributions of green building projects at the end of each 3-year period – in 2002 and in 2005. Maps are created with the dataset recoded in 1, if a county has any green building project, or in 0, otherwise. On the 2005 maps, counties in local clusters of green building projects, identified by local Moran statistics in Figure 4.5 and in Figure 4.6, are juxtaposed to facilitate the comparisons between pairs of maps. Figure 4.7 shows the distribution of counties that had the LEED-NC certified buildings in 2002, and Figure 4.8 shows the same map in 2005 with a layer of local clusters of certified buildings. Figure 4.9 presents a distribution map of counties that had the LEED-NC registered buildings in 2002, and Figure 4.10 is the same map in 2005 with a layer of spatial clusters of registered buildings.

Comparisons between the maps show three distinctive trends. First, the distribution of registered projects has not been differentiated much from that of certified buildings. Second, spatial clusters of green building projects tend to be formed around the early adopters. Third, newly entered counties are likely to be near existing spatial clusters.

Figure 4.7 Counties that Had the LEED-NC Certified Buildings in 2002

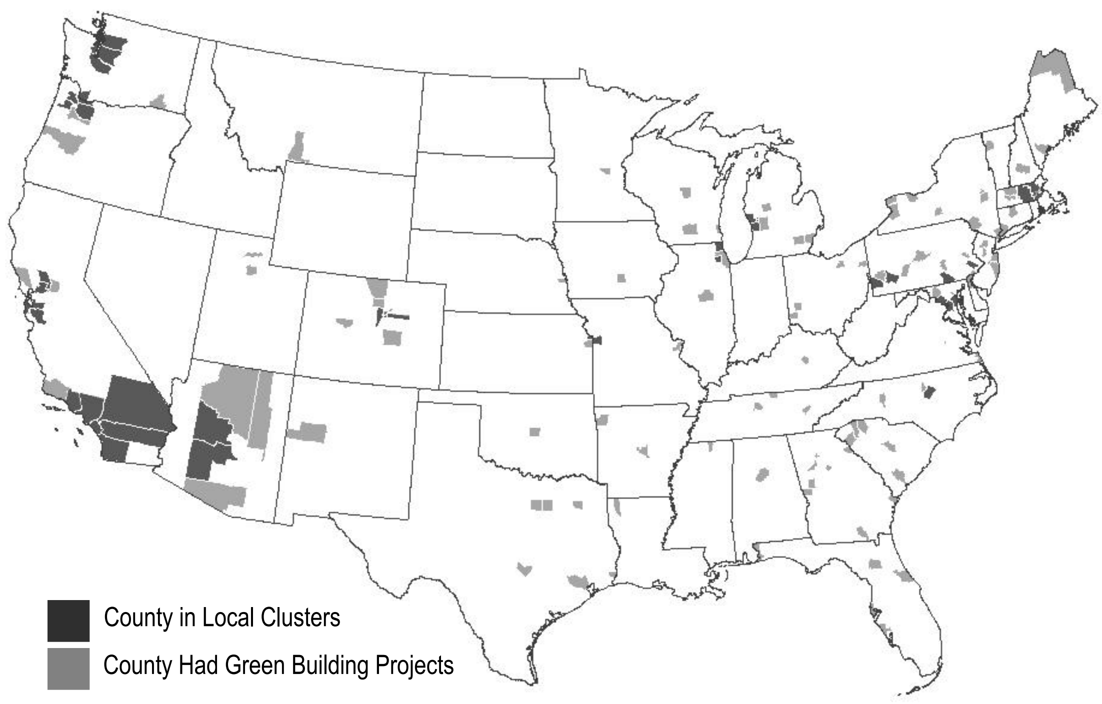

Figure 4.8 Counties that Had the LEED-NC Certified Buildings in 2005
(Mapped with Spatil Clusters of the Certified Buildings)

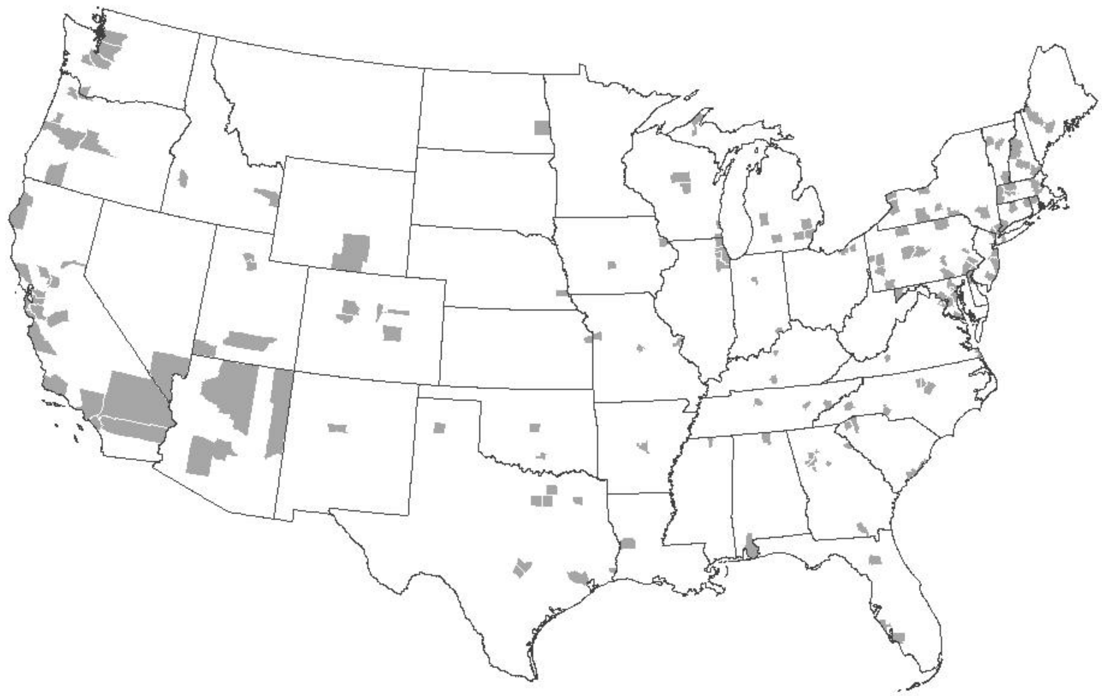

Figure 4.9 Counties that had the LEED-NC registered projects in 2002

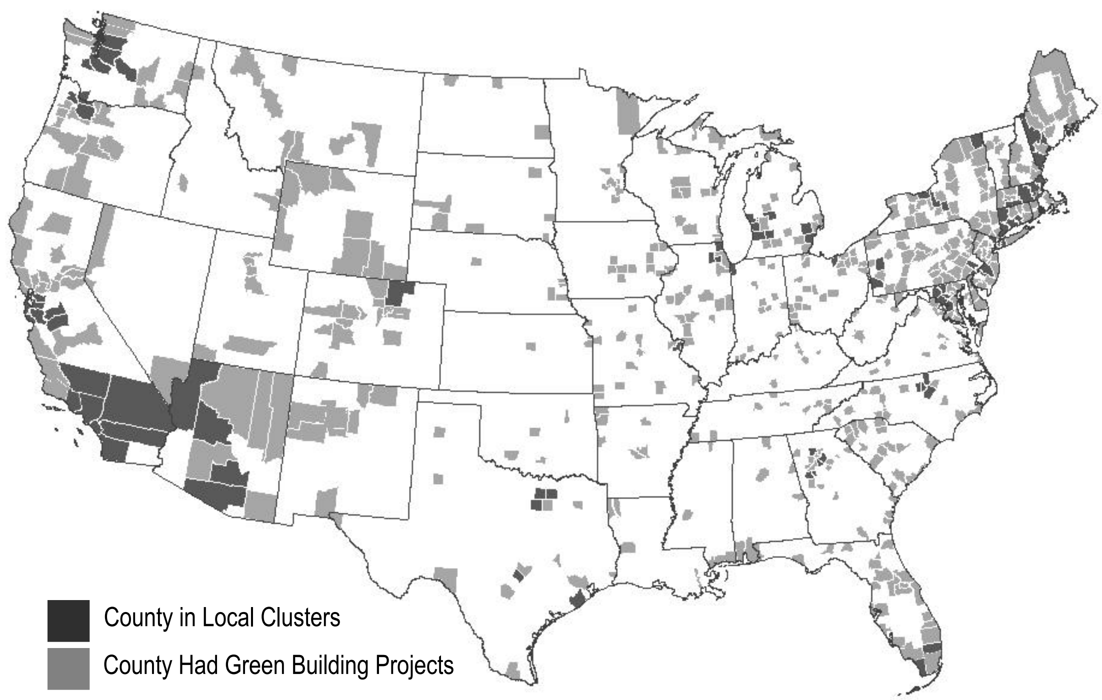

Figure 4.10 Counties that Had the LEED-NC Registered Projects in 2005
(Mapped with Spatial Clusters of the Registered Projects)

Similar distributions of the LEED-NC certified buildings and registered buildings and cluster genesis around earlier adopters are already observed in 4.4.2., but the above maps show those trends more clearly. Third trend that counties that initiated green building projects later tend to be near existing clusters, is a new one. The trend implies that spatial clusters of green building projects have been growing, and extended into suburban counties near clusters. The very growth of spatial clusters located in major cities may change the supremacy of urban counties, and offer more opportunities for suburban and rural counties to have more green building projects in the near future. However, this observation is needed to be tested with more formalized data and methods later, like other findings from the descriptive analysis in 4.4.

4.5 Diffusion of Green Building Projects

4.5.1 Event History Analysis (EHA) to Model the Diffusion of Green Building Projects

To analyze the diffusion of the LEED green building projects in the U.S., I modify and use a series of event history analysis models that state policy innovation studies have used and refined since the early 90s (F. S. Berry & Berry, 2007). While the same modeling techniques can be applicable to both state policy innovations and green buildings, types and drivers of them are obviously different. In the state policy diffusion literature, states are regarded as the actors adopting policy innovations, so political characteristics of individual states are key concerns in the literature, since states are administrative and political entities formulating various policies, often under the guidance of the federal government (Walker, 1969).

The diffusion of green buildings in the U.S., arguably, has been led by local socio-economic drivers. Green building has been a bottom-up process, a movement in the U.S. (Building Design & Construction, 2003) The USGBC, a national organization enabling and promoting green building practices across the nation, resulted from the movement, although the establishment of the organization later dramatically accelerated the diffusion process.[26] Public policies for green building at the state level have been established and increased, but many local policy initiatives for green buildings preceded them (U.S. Green Building Council, 2006e). To grasp more local characteristics, I choose the county as a geographical unit of analysis, since the county is the smallest geographical and administrative unit that covers the continental U.S. congruently, and many annual social and economic data are available for (Isserman, 2005). While event history analysis has mainly used at the state-level innovation diffusion modeling in political science and public policy, there are studies applying the technique to adoptions of policies by administrative units other than the U.S. states. Many of them focus on policy diffusions among nations (Brooks, 2005; Meseguer, 2004; Simmons, 2000; Simmons & Elkins, 2004). Applications of event history analysis to local or regional units are difficult to find. Hoyman and Weinberg (2006), Jeong (2006), and Jun (2007) are rare exceptions. Within author's knowledge, no study has ever covered counties in more than one U.S. State.[27]

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26 Even before the LEED green building rating systems, several local and regional green building programs existed (National Association of Home Builders, 2002). At the initial stage of the development of the LEED, the USGBC tried to learn from some of those programs, like a program in Austin, Texas, initiated in 1989 (Building Design & Construction, 2003).

27 At the county level, strategic interaction models based on spatial econometrics are dominant. Brueckner (2003) and Revelli (2005) provide comprehensive overviews of strategic interaction models in various topics, including tax, welfare, and yardstick competition. The review of Brunnermeier and Levinson (2004) focuses on environmental regulatory competition and its impacts on industrial location, and includes several examples of strategic interaction models. Explicit specification of spatial dependence is

Generally, event history analysis addresses 'events' meaning transitions from one state to another state (Box-Steffensmeier & Jones, 2004). Different from logistic regression, event history analysis models cope with not only the transition, but also the duration time until transition. Therefore, event history analysis can be used to model both whether and how fast events occur.

Discrete event history analysis has been the most popular technique to analyze state policy innovation since Berry and Berry (1990), and recent studies in this field have employed important specification refinements to mitigate its limitations, such as the assumption of duration independence (Beck, Katz, & Tucker, 1998; Buckley & Westerland, 2004). Although those refinements for the discrete event history model are reasonable, they are not necessarily best solutions for model's inborn limitations. In that sense, the Cox proportional hazard model can be a promising alternative (B. S. Jones & Branton, 2005). The Cox model is a robust model providing reasonable estimates of regression coefficient and hazard rates based on given datasets, especially when we do not know the true form of the correct model specification (Allison, 1984; Box-Steffensmeier & Jones, 2004; Cox, 1972).

The Cox proportional hazard model is defined as follows:

$$h_i\left(t\right) = h_0\left(t\right)\exp\left(\beta'\mathbf{x}\right)$$

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clear advantage of these models, and the increasing application of spatial discrete choice models and spatial panel models makes those models more attractive to innovation studies (Garrett, Wagner, & Wheelock, 2005; Konisky, 2007; Rincke, 2007). However, these spatial models are more appropriate to model the possibility of adoption, and not to the possibility of adoption at a given period or hazard ratio, which can be properly managed in event history models.

Here, $h_0(t)$ is the baseline hazard function and $\beta'\mathbf{x}$ are the independent variables and regression parameters. As far as the proportional hazards assumption holds, the baseline hazard function can be left unspecified, and be taken any form that given data suggest (B. S. Jones & Branton, 2005). Since the duration times are parameterized by a set of independent variables in the exponential part of the equation without the distributional assumptions of the hazard function, the Cox model is often referred to as a semi-parametric model (Box-Steffensmeier & Jones, 2004). Although the Cox model has not been used much in geography and urban planning except Jeong (2006) and Jun (2007), it can be instrumental to study genuine issues in both fields that analyze diffusion of new policies or phenomena, such as the adoption of zoning, of specific ordinances, of public housing or of green buildings for a given duration.

The way of dealing with duration dependence in each model exemplifies the difference between two models. The discrete event history model requires the assumption of duration independence, which assumes that an event is not affected by the previous events. In the innovation studies, however, this assumption is likely to be violated (Buckley & Westerland, 2004). The key reason that the discrete event history model need to include a time variable to cope with duration dependence is that it is analogous to an exponential model, established on the assumption of the flat baseline hazard rate invariant over time (B. S. Jones & Branton, 2005). In contrast, the Cox model does not need to specify the form of the baseline hazard function, since the hazard rate in the Cox model can be different over time, and is still parameterized as a function of given independent variables (Box-Steffensmeier & Jones, 2004). Therefore, the duration dependence does not need to be specified separately as an independent variable; it is incorporated in the model as a form of baseline hazard rate. If there are not enough previous works to determine any specific form of the baseline hazard rate for a given issue, the Cox model can be a reasonable and strategic choice for the event history modeling of the issue.

Another advantage of the Cox model is that it can be effectively modified to use repeated events that cannot be easily managed with the discrete event history models using logit or probit (Box-Steffensmeier & Christopher, 2002; B. S. Jones & Branton, 2005). Event history models for repeated events can address key questions in the innovation studies, which single-event models cannot. Most of all, repeated events models can probe the presence of event dependence; they can control for the possibility that units that have had an event are likely to have more or less of such events (Box-Steffensmeier, De Boef, & Joyce, 2007). Several modifications of the standard Cox model for repeated events have been suggested (P. K. Andersen & Gill, 1982; Prentice, Williams, & Peterson, 1981; Wei, Lin, & Weissfeld, 1989). Modifications are mainly different from each other in how they define risk sets at each event, so the choice of a specific modification for the repeated data depends on the nature of a given research and data (Box-Steffensmeier & Christopher, 2002; Box-Steffensmeier & Jones, 2004).

Two assumptions are particularly relevant to choose a specific modification for a research: whether the baseline hazards should be different across events and whether the sequence of events should be preserved (Box-Steffensmeier & Jones, 2004). The adoption of green buildings at a given administrative unit is a typical case of repeated events, since green buildings can be built in the unit over and over again. Certainly, there are reasons to believe that the earlier adoption of green building in a given county is distinctive to the latter adoptions. Many early green buildings were introduced as pilots or demonstrative projects to enlighten the general public and encourage further green building development, often initiated by the entrepreneurs and the public entities. Those earlier projects were supposed to construct green buildings by finding and organizing available actors and resources. As the niche markets for green building were growing, however, more general developers, subcontractors, and customers participated in. Accumulation and transfer of knowledge and know-how, expansion of existing actors and resources, and public policy initiatives for green buildings set a different stage for the latter green buildings. Recurrent appearance of green building may represent the embeddedness of necessary mechanisms to facilitate and promote green building construction, which were not readily available because of their cumulative nature. Then, it is reasonable to assume that repeated cases of green buildings in a given county have different logics from the adoption of the first green building in the county. The initial adoption may be considered a threshold, while the following adoptions are likely to become easier to be built. Therefore, the hazard rate for each event sequence is expected to be different from each other, and the order of sequences should be preserved.

The conditional gap time model offers the most applicable option for this kind of research. This model assumes that an observation becomes at risk for an event, after all the previous events have happened (Prentice, et al., 1981). Along with the assumption, the gap time, the duration since the prior event, and event strata, the ordering sequences of events, is set for each event. Then, a Cox model stratified on event strata can be estimated, where the baseline hazard may differ by event sequence, but the parameters remain the same across the repeated events (Box-Steffensmeier & Christopher, 2002; B.

S. Jones & Branton, 2005). To account for repeatability of events within observations, robust estimation method is generally used for the model estimation (Lin & Wei, 1989). In this chapter, both single-event and repeated-events models will be used to model the adoption and re-adoption of green building projects.

4.5.2 Descriptions of the Variables for the EHA

The unit of analysis is a county-year, and the dependent variable is whether a county has an event, such as a registered project or a certified building, in a given year. For each county-year, a dichotomous variable is created, which is 1 at the year of an event or events, and 0 otherwise. Events across counties are grouped in event strata, respectively. The time since the last event is set for each event.

Table 4.1 Frequency of the LEED-NC Buildings and Projects in Each Strata

	Certified Buildings		Registered Projects	
Strata	Frequency	Percent	Frequency	Percent
1	150	69.8	589	50.3
2	43	20.0	277	23.7
3	15	7.0	164	14.0
4	6	2.8	90	7.7
5	1	0.5	38	3.2
6	0	0.0	12	1.0
Total	215	100.0	1,170	100.0

The higher strata tends to have small number of events that is susceptible to bring biased results, and is also the case for the research as presented in Table 4.1. Three approaches to address the problem of low frequency in higher strata have been suggested (Box-Steffensmeier & Jones, 2004). Instead of just acknowledging the unstable results or truncating the higher strata, I combine the higher level strata into one. Considering the frequency of events for each strata in Table 4.1, grouping strata 3 and higher would be reasonable for the certified buildings, and 4 and higher for the registered projects.

Independent variables are constructed to probe determinants of the diffusion of LEED registered projects and certified buildings. Each observation is a county-year along with its associated values for independent variables. In this data setting, the incorporation of time-dependent independent variables that change in value over time is rather straightforward (B. S. Jones & Branton, 2005). The values of time-dependent variables can be changed and included for every county-year, while time-independent variables never changes in value across the duration of analysis. The availability of independent variables confines the duration of analysis from 2000 to 2005. A mixture of time-varying and time-independent variables is used for the research, and independent variables are classified into four associated types: demographic, economic, governmental, and geographic.

Demographic factors

Population and population density from the U.S. Census Bureau are two control variables that have been used to capture the size and density of local economy in the environmental regulatory competition literature (Fredriksson, et al., 2004; Fredriksson & Millimet, 2002a, 2002b). Bigger local economies make enough rooms for niche markets that may not be feasible in smaller ones, so green buildings as a niche market of construction industry are more likely to be located at populated areas. Higher population density of a county implies that the county is a densely developed area with a considerate amount of the built environment.

As a measure of race diversity, the index of dispersion is used (Lieberson, 1969). As the index is closer to 1, the level of diversity becomes higher. Diversity is often considered a proxy of tolerance, of an inclination to accept differences and innovations (Florida, 2002). If that argument stands, green buildings may be found in counties of higher race diversity faster. Median age is included as another demographic characteristic that may facilitate the adoption of LEED green buildings, while it is not necessarily clear whether counties with lower median age or with higher median age implement green buildings sooner. However, younger counties may have more office workers and may be more flexible to adopt new type of development like green buildings. Data for both of these variables are also from the Census Bureau.

Positive correlation between higher education and pro-environmental behavior is a well-known relationship (Kahn, 2006). County-level data of the percentage of people over 25 who have bachelor's degree from the 2000 Census are used. Counties with more highly educated people are expected to be more environmentally friendly, and more inclined to start green building projects earlier.

Economic factors

The LEED-NC is a green building rating system for new construction, specifically for new commercial buildings and offices, not likely for new homes.[28] Although offices are sprawling along with the sprawl of residential areas (Lang, 2003; Lang, et al., 2006), office location largely depends on location of jobs demanding office space. Employment growth can be used as a proxy of workplace demands, since the job increase requires

28 The LEED for Homes, a rating system dedicated to green home design and construction, started its pilot programs in 2005, and officially launched at the end of 2007.

more workplace. However, a classic trade-off between development and the environment makes it difficult to foresee the direction of this condition's influence. Employment growth may increase the demands for more commercial buildings, but it does not guarantee the construction of green offices. Simply put, developers in booming counties may not have enough motivation, or even lesser motivation than other counties, to go green in their development projects. I construct an independent variable of 2-year employment growth rate for each county to test these conflicting interests with county-level employment data available at the Bureau of Labor Statistics (BLS).

To control for overall economic condition, per capita income and employment rate are included. Per capita income data are drawn from the Bureau of Economic Analysis (BEA). Employment rate (or employment-population ratio) is calculated along with the definition of the BLS, which is the ratio of the employed to the total civilian noninstitutionalized population 16 years of age and over. This variable is estimated with county-level employment data from the BLS, and population estimates from the Census Bureau.[29] It is a capacity argument that a vibrant local economy is more capable of starting new, green initiatives than a depressed one. Thus, higher income and employment may heighten the possibility of adoption of green building projects. On the contrary, higher income may mean upscale, residential neighborhoods that do not necessarily embrace – or rather dodge – green office development projects.

Energy price is total energy average price in the commercial sector, measured in dollars per million BTU. Energy price is locally different, since it is determined by locally available resources and historical decisions in policy and management (Andrews,

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29 Employment rate does not have underestimation problem related to discouraged workers who are not part of the labor force, which is an innate weakness of unemployment rate in regional economic analysis.

2000). Since county-level energy price data are unavailable, total energy price data at the state level from the Energy Information Administration (EIA) would be used with one-year lag.[30] On the one hand, energy efficiency has always been considered a major advantage of green building in practice. Then, the higher the local energy price is, the stronger the attraction of green buildings becomes, and the faster the adoption is, at least theoretically. On the other hand, offices in general may prefer places of lower energy price, which are at least partly determined by geographical distributions of natural resources. Sign of this variable is hard to be predetermined.

Governmental factors

Local government budgetary condition can be a key factor, since significant share of green building projects has been filled with and supported by governmental initiatives (U.S. Green Building Council, 2006a). Interest on general debt measures the amount paid for use of borrowed money, which can be used as a proxy of state and local investments for public projects, utilities, and infrastructure.[31] Since the governance structure between state government and its local governments is different across the U.S., budgetary condition of a county should be matched with that of the State in which the county is located. I constructed a measure of governmental indebtedness variable by calculating both numbers of the interest on general debt per capita of a given county and of its state,

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30 The only exception is the EIA-861, Annual Electric Utility Report, which compiles electric sales and revenue data of electric utilities in the U.S. With these files, locations of electric utilities can be identified at the county level. Then, by calculating revenue per sales as a proxy of electricity price for each utility, and averaging them for each county, rough estimates of electricity price at the county level can be obtained. Due to the data reliability issue, I chose to use state data of total energy average price in the commercial sector.

31 Interest on general debt per capita can be considered a measure of local fiscal distress. For example, Wyly, Glickman and Lahr (1998) use this variable as one of 20 urban stress indicators to calculate single standardized distress scores for cities in 1990. In other words, this variable can mean both fiscal stress of a locality and its capability to endure it for the future.

and summarize them at the county level, using data from the 1997 and the 2002 Census of Government. Higher governmental indebtedness may enable future public projects of – or related to – green buildings.

Many local and regional governments in the U.S. have introduced public policy incentives for LEED green buildings (U.S. Green Building Council, 2006e). Counties can be political actors for those incentives, but states can also initiate green building programs influencing counties within them, and cities within counties can start citywide green building programs. I integrate those initiatives at the county level, and build a two-year lagged dummy variable for regulatory benefits promoting green buildings, coded 1 when a county is under the impacts of green building incentives in a given year and 0 otherwise. The presence of green building initiatives is expected to accelerate green building adoption.

The role of government is not limited to encourage green building projects. Government has been a key customer of the USGBC. Although the private sector has increased its share in green building projects, the LEED-NC green building projects of government ownership are still a major part of total projects (Building Design & Construction, 2003; U.S. Green Building Council, 2007a). Namely, government is a motivated enabler and enlightened consumer in the green building market. In that sense, the larger share of government employment in a local economy may accelerate the adoption of green building projects. The percent of government employment at the county level is calculated from the BEA data.

Environmental policy inclination of a given county can be a desirable control variable, but environmental stringency is almost impossible to be measured and operated at the county level with publicly available data. Even at the state level, it is still not entirely feasible to build objective time-series measures because of the limitation of available data. Alternatively, researchers have used annual scores of voting behavior on environmental issues by elected state representatives, published by the League of Conservation Voters (LCV) (Auffhammer & Steinhauser, 2007; Kahn, 2007; Sigman, 2003). The annual LCV score for each state represents a percentage measure of pro-environmental votes on environmental legislations by state representatives in the House and in the Senate. The LCV House scores are preferred here, because the House scores are usually included more individual legislators' data and more sensitive to changes of environmental sentiments of a given state (Sigman, 2005). Higher LCV score for a given state reflect pro-environmental preference of the state. Counties within environmentally conscious states are expected to be more favorable – at least more sensitive – to the earlier adoption of the LEED green buildings.

Geographic factors

Natural amenities attract people, jobs, and ultimately places for them, and concerns about natural amenities can be found in the overall LEED certification process. For example, the LEED checklist recommends building locations near water and open spaces (U.S. Green Building Council, 2006c). In addition, many pilot and demonstrative green buildings tended to choose locations of natural amenities strategically. The USDA's natural amenities measures that integrate climate, topography, and water area data at the county level to capture the benefits of natural amenities using principal component analysis are included to check this argument (McGranahan, 1999). Higher natural amenities measure means that benefits from natural amenities are greater. Offices in general, and green buildings in particular, may be prone to be sited in locations of higher natural amenities measure earlier.

It has been a convention to use the U.S. metropolitan statistical areas (MSAs) to discern the urban and the rural, and central cities to separate cities from the suburbs in urban and regional studies (Isserman, 2005). Two dummy variables are created to estimate the impacts of different degrees of urbanization in the U.S. using the definition of the 1999 MSAs. City dummy variable is coded 1 when a central city is seated in a given county and 0 otherwise. If a central city is across multiple counties, one or two major counties within the boundary of the central city are selected. Suburb dummy variable is coded 1 when a county is within MSAs, but does not embrace any central city and 0 otherwise. Rural counties out of MSAs are not included in the analysis, so become a baseline for comparison.

Generally, it is fair to say that big cities have reasonable advantages over suburbs, and the descriptive analyses of the diffusion of green building projects support the argument. For example, the USGBC has organized information workshops and other teaching sessions about the LEED-accredited professional program across central cities (U.S. Green Building Council, 2006b). It is worth mentioning that larger cities generally recruit bigger amount of green buildings, but it is a different question whether those cities attract green buildings sooner. Smaller cities and suburbs with environmentally conscious atmosphere may move faster, and many earlier green buildings were heading toward economically depressed areas as demonstrative projects. Economic advantages of big cities may be compromised by political agendas across different scales of governance.

In state policy innovation studies, the influence of a state's neighbors to the state has been typically measured by the number or proportion of neighboring states adopting policy innovations (F. S. Berry & Berry, 2007).[32] Similar logic can be applied to the case of green buildings. If actors in a county benchmark more from green building cases in their neighboring counties than in all the other counties, this variable will be positive. Groups of green buildings in neighboring counties may have bigger impacts on actors who have potential to build their own LEED-NC buildings than a single demonstrative green building project somewhere distant. Therefore, I construct measures of the influence of a county's neighboring projects by calculating the average cases of total certified buildings and registered projects of neighboring counties. The presence of a national organization, the USGBC, and its unifying rating systems may lower the expectation of this contagious diffusion mechanism, while it is still reasonable to investigate whether the mechanism work at the local level.

Due to the limitation of available data, not all U.S. counties are included in the models. Specifically, counties in Alaska, Hawaii, and Washington, D.C. have been totally omitted. Variables for population, population density, and income have been log-transformed for better fits.

32 Another common approach to measure neighboring influence is to construct a variable by calculating the number or proportion of geographical units that have events in predefined groups of them, i.e. states in census regions (M. D. Allen, Pettus, & Haider-Markel, 2004; Andrews, 2000; McLendon, Deaton, & Hearn, 2007).

4.5.3 Results from the EHA

Results of the single-event and repeated events Cox models for LEED certified buildings and registered projects are summarized in Table 4.2. Overall, all four models are statistically significant at $p<0.001$, according to their Wald chi-square statistics. Results are reported in coefficients with standard errors. The number of events for each model is given under each model. First column (S-CP) is the results from the single-event EHA model for the LEED-NC certified buildings, and the second column (R-CP) is the repeated-events model for the certified buildings. The third column (S-RP) is the results from the single-event EHA model for the registered projects, and the last column (R-RP) is the repeated-events model for the registered projects.

For the Cox proportional hazards model, the independent variables are parameterized in terms of the hazard rate (Box-Steffensmeier & Jones, 2004). Therefore, a positive coefficient implies that the hazard is increasing, so the survival time, the time until an event happens, is decreasing. Namely, the adoption of green building projects becomes faster as a function of an independent variable, if the variable is positive. A negative coefficient indicates that the survival time is increasing, and the adoption tends to be slower. Generally all four models show significant similarities, while there are subtle but key differences.

First, the results of demographic factors discern two important factors enabling the adoption of green building projects. Population and higher education are positive and statistically significant at $p<0.001$ in all four models. Namely, green building projects tend to show early and repetitive appearance in populated counties with higher share of well-educated people. Population density, diversity and median age are not statistically significant, but median age in the single-event model for certified buildings is an exception, which is positive and statistically significant at $p<0.05$. That suggests that higher median age actually facilitate the adoption of LEED certified buildings, which is not applicable to the repeated-events model result. The initial hypothesis of advantages of younger counties is not supported.

Second, the results of economic factors show conflicting interests in green building development. Notably, personal income variable has statistically significant, negative effects in all four models, which indicates that counties of higher income tend to adopt green building projects slower, even after the first introduction of green building.

The general perception of conflicting relationship between economy and the environment, which makes the ‘luxurious green office’ sound oxymoronic, may hinder the initiation of green building projects in high-income counties. It is also probable that counties of high income may be dominated by residential units, so they are sort of reluctant to adopt new development projects in general. Two-year employment growth rate variables are negative for all, and statistically significant except the repeated-events EHA model for the registered projects. That means local growth in employment also tends to make the adoption of green buildings slower. The argument that development pressure could offer some room for green buildings does not stand here. Rather, the result supports the arguments that growth blinds counties to environmental concerns; development pressure tends to deter the earlier development of green buildings.

Table 4.2 Single-Event and Repeated-Events EHA Models for the LEED-NC Certified Buildings and Registered Projects

	S_CP Model	R_CP Model	S_RP Model	R_RP Model
Population	1.17***	0.84***	0.99***	0.76***
	(0.15)	(0.12)	(0.10)	(0.06)
Population Density	-0.12	-0.16	0.08	-0.01
	(0.12)	(0.10)	(0.07)	(0.05)
Racial Diversity	0.37	1.24	-0.36	-0.51
	(0.94)	(0.78)	(0.40)	(0.33)
Median Age	0.04	0.03	0.04*	0.02
	(0.04)	(0.03)	(0.02)	(0.01)
Higher Education	0.08***	0.08***	0.07***	0.06***
	(0.02)	(0.01)	(0.01)	(0.01)
Income	-2.48**	-1.69*	-2.06***	-1.20***
	(0.79)	(0.66)	(0.49)	(0.32)
Employment Rate	1.40	-0.86	2.45*	0.97
	(1.98)	(1.75)	(1.05)	(0.90)
2yr Emp. Growth Rate	-11.22***	-8.03***	-4.28**	-1.65
	(1.75)	(1.88)	(1.32)	(0.89)
Energy Price	-0.13***	-0.11***	-0.11***	-0.05**
	(0.03)	(0.03)	(0.02)	(0.02)
Gov. Indebtedness	0.44	0.56**	0.30*	0.29**
	(0.26)	(0.21)	(0.12)	(0.09)
Gov. Employment	0.03	0.01	0.03***	0.01*
	(0.02)	(0.01)	(0.01)	(0.01)
LCV House Score	1.07*	1.03*	1.69***	1.07***
	(0.50)	(0.45)	(0.28)	(0.19)
Green Building Policy	0.09	-0.01	0.06	-0.09
	(0.23)	(0.22)	(0.16)	(0.10)
Natural Amenities	0.13***	0.09**	0.15***	0.08***
	(0.04)	(0.03)	(0.02)	(0.02)
Cities	0.53	0.94**	0.04	0.31*
	(0.35)	(0.32)	(0.16)	(0.15)
Suburbs	0.13	0.54	-0.09	0.10
	(0.42)	(0.38)	(0.17)	(0.15)
Neighbor CPs	0.45*	0.35		
	(0.20)	(0.23)		
Neighbor RPs			-0.13*	-0.02
			(0.06)	(0.02)
N	18431	18641	17442	18641
Log-Likelihood	-1035.85	-1310.31	-4422.71	-7694.18
Chi2	0.000***	0.000***	0.000***	0.000***

* p<.05, ** p<.01, *** p<.001

Employment rate variable is positive and statistically significant in the single-event model for the registered projects. Different from certified buildings, registered projects as future demands tend to be present earlier in locations with higher employment rate, or economically viable locations.

The variable of energy price in the commercial sector is negative and statistically significant in all four models. That means that regions of higher energy price are slower in the adoption and re-adoption of green building projects. The presumed benefits from the energy efficiency of green building seem not to be distinctively attractive to regions of higher energy price. This result is quite unexpected and there is no clear theoretical explanation. In a certain market, especially during the initial stage of diffusion, the adoption cost of energy-efficient technologies, such as green buildings, may suppress the demands of those technologies originated from higher energy price for a while (Jaffe, Newell, & Stavins, 2001), so if the construction costs of green buildings are distinctively higher in regions of higher energy price, the negative relationship between energy price and the pace of green building adoption may be explained. However, it is a new hypothesis for future research that should be tested with data of regional variations in construction costs in general and those of green buildings in specific.

Third, the results of governmental factors reveal the role of government in the adoption of green buildings. Governmental indebtedness shows statistically significant and positive results except the single-event EHA model for certified buildings. County governments can be key patrons for local green building practice, and their healthy fiscal conditions are supposedly helpful for new green building projects. Although it does not statistically support the first introduction of the certified buildings, it makes the adoption of the registered projects and the recurrent adoption of both certified buildings and registered projects faster.

The independent variable of government employment is positive for all, but only statistically significant for the LEED-NC registered projects. Counties of bigger share of government employment demand more green buildings in the future, but did not in the past. Partly, it is because the green building movement in governments has shifted its focus on pilots and demonstrative projects to the focus on everyday office buildings for governmental workers lately. Government has become more of a consumer.

While a variety of public policies for green buildings have been established at different scales of governments, no evidence of statistical significance of those policies on green building practices has been detected from the analysis. On the contrary, the LCV house score variable is positive and statistically significant for all four models. The positive sign of the variable indicates that pro-environmental sentiment invites green building projects sooner. Public policies for green buildings may result from given local environmental atmosphere, so they may not necessarily accelerate or promote additional green building projects. Historical development of pro-environmental consciousness tends to shadow the impacts of green building initiatives. Until 2004, the share of counties under the umbrella of any type of public policy for green building was less than 8 percent. Even after the enactment of those policies, it takes time to implement them, since green building policies should go through necessary processes to make them compatible to existing rules and specifications before implementation. The LEED-NC program did not officially go public until 2000 and most of the policies for encouraging the program were created after 2001. Therefore, it is reasonable to say that the power of those policies did not initiate an earlier start in green building development.

Finally, geographic factors imply that natural amenities offer favorable conditions for green buildings. Natural amenities variable is the only geographic factor that is statistically significant for all four models. As expected, natural amenities tend to be along with green building projects. City and suburb variables generally show no impacts. City and suburb areas are not significantly faster than rural areas in green building development. Only in the repeated-events models, city variable turns out to be statistically significant and positive. It seems that central cities were major locations where the LEED green building projects occur repeatedly, while more suburban and rural counties build their own capacities to manage multiple green projects. Past and future demands of green building projects show similar patterns, so it is possible to say that the dominance of central cities will not be vanished quickly in the near future.

Proximity variable is statistically significant only in the single-event models. That may be because the current LEED certified buildings result from earlier registered projects. The growth of the LEED projects has been along with that of the USGBC. Before the USGBC set up its national network, it was likely that the diffusion of green building practices was following the contagious diffusion pattern. For example, to make up for the lack of necessary information on green buildings, earlier projects tend to be demonstrative. The neighboring counties could take advantage of their proximity to those projects to obtain not readily available or transferable information. Then, the construction of a green building in a given county tended to nullify the necessity of visiting existing projects in neighboring counties. That fits the non-effect result of this variable in the repeated-events model for certified buildings. The completion of its national network with regional charters and the accumulation of information of best practices have diluted the impacts of neighboring projects. Results from the models for registered projects partly support this argument. Proximity effects for those models are not positive, and the effect in the single-event model of repeated projects is statistically significant. Overall, the growth of national organization appears to have cancelled the initial proximity effects.

The presence of event dependence, a condition where the possibility that subsequent events a unit has are related to whether previous events have happened, is assumed in many parts of model interpretation (Box-Steffensmeier & De Boef, 2006; Box-Steffensmeier, et al., 2007). The conditional gap time model used in this analysis stratifies on event strata, and enables to probe whether event dependence exists by comparing the baseline hazard functions by event strata. If the cumulative hazard curves for each stratum are distinctive, that suggests that event dependence is present. Figure 4.11 graphs the cumulative hazard curves by event strata of the certified buildings, and Figure 4.12 graphs by event strata of the registered projects. Both graphs show that the cumulative hazards vary by event strata. More specifically, the cumulative hazard curve of the latter strata becomes steep, that is, risks for the adoption of further green building projects rise over time; the likelihood of having a first green building project is the lowest, and after the first project, the likelihoods of having second and further projects are getting higher. Eventually, this tendency slows down, as shown in Figure 4.12, where the risk of adoption of the registered project is stalled after the third event occurs.

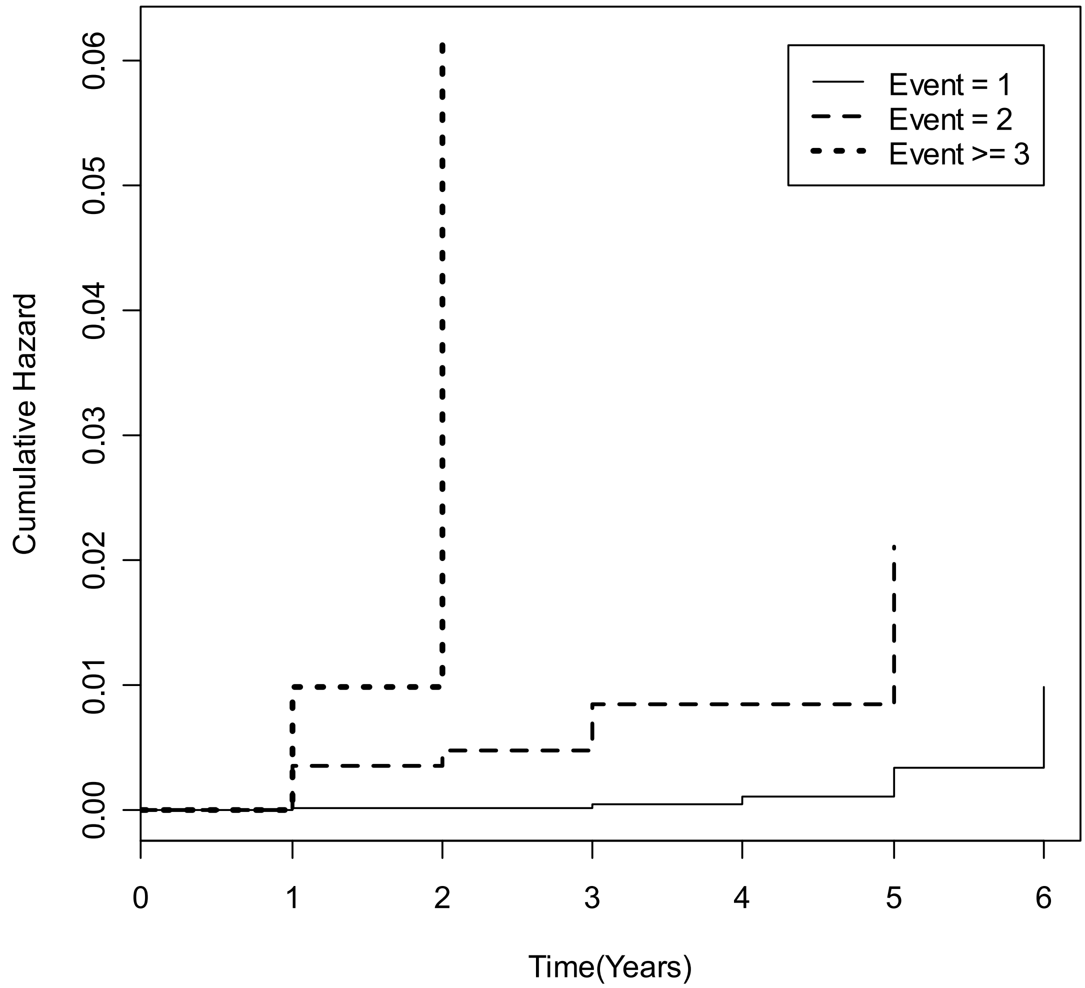

Figure 4.11 Cumulative Hazards for the Repeated-Events Model for Certified Buildings

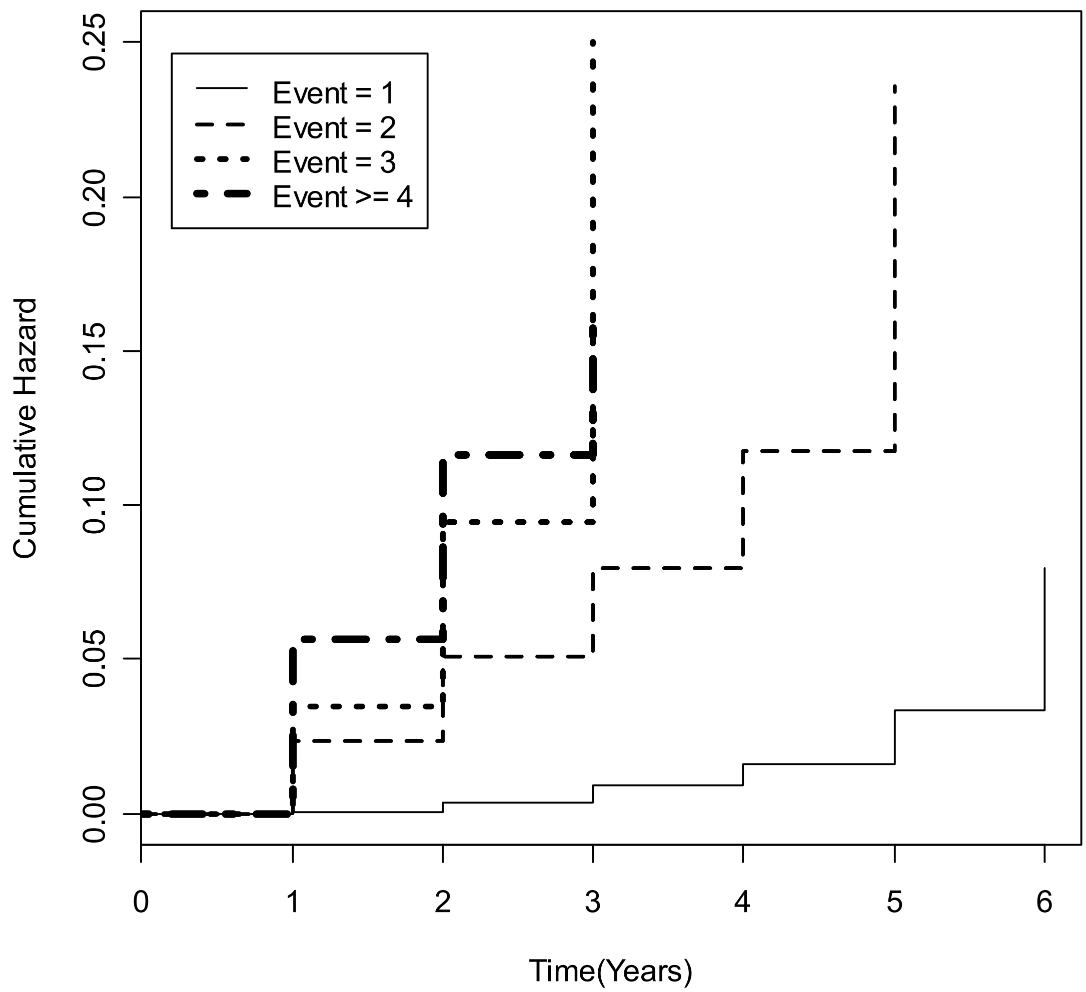

Figure 4.12 Cumulative Hazards for the Repeated-Events Model for Registered Projects

The presence of event dependence stresses the importance of history. Cumulative hazard curves that plot the amount of risk of the adoption of green building projects accumulated are analogous to the well-known S-shape curve of innovation diffusion (Geroski, 2000; Rogers, 1983). The rather flat shape of cumulative hazards of the first adoption cases in certified buildings and registered projects suggests that the adoption of green building projects is still at their initial stage. Cumulative hazards of the further strata imply that the first green building project tends to be the most difficult one to occur, but after that, the occurrence of further projects is likely to be facilitated. During the diffusion period, the costs of construction of green buildings are expected to fall, since counties and their actors can build their capacities to handle green building projects through their learning experiences, and widespread adoption of green buildings facilitates producers and suppliers to provide crucial materials and facilities for green building by achieving scale economies collectively.[33] The later, shaper cumulative hazard curves imply that those learning and scale economies have been working, specifically in counties adopting green building projects earlier.

In this section, the impacts of contextual factors on the diffusion speed of green building projects are examined. In the perspective of urban planning, the next logical step is to examine whether factors encouraging earlier adoption of green building projects in a specific county are also encouraging the sizable growth in the county. With the same contextual factors, the changing size of green building projects within the U.S. counties will be tested in the next section.

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33 In that sense, the LEED has provided a series of indirect network effects, in which adoption itself does not offer benefits to other members, but the increasing adoption makes that specific market more attractive to actors in related markets, from engineering firms to facility suppliers (Farrell & Klemperer, 2003).

4.6 Growth of Green Building Projects

4.6.1 Panel Data Analysis to Model the Growth of Green Building Projects

LEED green building project data aggregated at the county level are typical time-series-cross-section (TSCS) data, or pooled data, which consist of repeated observations on the same fixed units over the same time periods (Beck, 2001; Beck & Katz, 2001; D. P. Green, Kim, & Yoon, 2001). TSCS data make a specific type of the panel data, since they are not sampled. However, general panel econometric methods along with proper conditions and specifications can be applied to TSCS data (Plümper, Troeger, & Manow, 2005).

Traditional approach to this kind of data was to perform the ordinary least square (OLS) on pooled TSCS data (Baltagi, 2005). The pooled OLS is a straight-forward approach, but it simply ignores the nature of the panel data. By disregarding distinction between observations in space and time, the pooled OLS generate a complicated error process which is hardly practical in the panel analysis.

Two panel data estimators, which allow for heterogeneity across time and space by including the intercept terms of the relationship, are tested (Baltagi, 2005; Wooldridge, 2002). The fixed-effects (FE) estimator means by the OLS on the deviations from the means of each cross-section unit or time period. Strengths and weaknesses of the FE model are well probed, but still on debate (Beck, 2001; Beck & Katz, 2001; D. P. Green, et al., 2001; Plümper, et al., 2005). Among other pros and cons of the FE model, the emphasis should be on the most serious limitation coming from the very nature of the green building dataset which includes many time-invariant and nearly time-invariant variables of theoretical interests. Since the FE estimator depends on the variation within each unit or time period, time-invariant variables which have no within variation by definition cannot be measured, and the estimation of the effect of variables of little within variance becomes inefficient (Plümper & Troeger, 2007).

The random-effects (RE) estimator specifies the unit effect as a random draw that is not correlated with the independent variables and the error term, so it enables to estimate time-invariant variables, which is not possible in the FE model (Baltagi, 2005; Wooldridge, 2002). It is potentially desirable to the analysis, since many variables of interests in the analysis are time-invariant by nature or by construction. However, the RE model provides consistent results only if the orthogonality assumption that the random-effects term is uncorrelated with the independent variables is not violated. If the assumption is violated, the RE estimator is no longer consistent. A Hausman test, comparing common coefficient estimates of the FE and RE models, is used to test the null hypothesis that the orthogonality assumption required for the RE estimator is valid (Hausman, 1978). The result rejects the null hypothesis at the 0.001 significant level, so the RE estimator is not valid for the analysis.

The reject of the FE and RE models suggests that a panel estimator can estimate time-invariant and rarely changing variables is required for the proper analysis of the given dataset. The fixed effect vector decomposition procedure (FEVD) is an alternative to estimate those variables (Plümper & Troeger, 2007). The FEVD proceeds in three stages to estimate parameters in panel data models with unit effects. First, a FE model is estimated to obtain the unit effects with the time-variant variables. Second, the estimated unit effects are regressed on the time-invariant variables to decompose the unit effects into the explained part and the unexplained part, i.e. an error term. Third, a full model is estimated by pooled OLS with the time-invariant variables and the error term obtained from the second stage. Necessary correction procedures of the standard errors against heteroskedasticity and serial correlation can be applied at the third stage. While the FEVD is a relatively new estimator, its straightforward approach addressing the problem of time-invariant and rarely changing variables in the FE model has appealed to empirical researchers recently (Alonso & Ruiz-Rufino, 2007; Lago-Peñas & Ventelou, 2006; Plümper & Neumayer, 2006). Through a series of Monte Carlo simulations, Plümper and Troeger (2007) compare the FEVD model with other estimators, including the pooled OLS, FE and RE, and show that the FEVD keeps providing reliable estimates in various specifications. If time-invariant and rarely changing variables are of interests, and the unit effects cannot be ignored theoretically, the FEVD is a logical choice for the model specification.

Rarely changing variables had better be estimated with the FEVD in two conditions. First, if heterogeneity among units is not observed, or the random-effect term is not correlated with the regressors, other estimators, such as pooled OLS or RE models, are suitable. The structure of the given data supports the application of the FEVD, since homogeneity among the U.S. counties is simply improbable. Second, if the within variance of a variables is very low, the FEVD provides more efficient and reliable estimates. No clear rules or tests are offered for identifying rarely changing variables from others. However, Plümper and Troeger (2007) suggest that if the b/w ratio, calculated by dividing the between standard deviation of a variable by the within standard deviation, exceeds at least 2.8, the FEVD should be the right procedure for the variable.

The suggested value is applied as a threshold to identify rarely changing variables for the panel data analysis in this section.

In the FEVD models, rarely changing variables with the b/w ratio higher than 2.8 are population, population density, racial diversity, median age, income, and LCV House score, while higher education, natural amenities, cities, and suburbs variables are time-invariant. Eta is the residuals from the regression of the unit effects on the observed time-invariant and rarely changing variables. It represents the unexplained part of the estimated unit effects (Plümper & Troeger, 2007).

Heteroskedasticity is expected to be present, when an analysis deals with units of different sizes and characteristics. The diffusion pattern of the LEED green building projects analyzed in the former sections implies the existence of heteroskedasticity, and the results for the White and Breusch-Pagan tests show the evidence of heteroskedasticity (Breusch & Pagan, 1979; White, 1980). Serial correlation test suggested by Wooldridge (2002) is applied to the specified model. Although the specification with the LEED certified buildings does not show the evidence of serial correlation, the specification with the LEED registered projects rejects the null hypothesis of no serial correlation at the significant level of 0.001. Since the structure of the data shows the presence of heteroskedasticity and serial correlation, the standard error correction procedures should be included in the FEVD procedure. The robust Sandwich estimator with the Prais-Winsten transformation is applied for the correction of standard errors (Baltagi, 2005; Huber, 1967; Wooldridge, 2002). Pooled OLS analyses are added for comparison.

4.6.2 Descriptions of the Variables for the Panel Data Analysis

Dependent variable is the amount of the LEED-NC green building projects in each county at a given year. Two sets of dependent variables are constructed: the amount of certified buildings at the county level is used as a proxy of realized demands for green building and that of registered projects as a proxy of future demand. Same set of independent variables involved in modeling the diffusion of the LEED-NC certified buildings and registered projects are used for the panel analysis. Definitions of independent variables and four categories of demographic, economic, governmental, and geographic factors remain unchanged. The duration of analysis is also same as the period between 2000 and 2005, due to the limitation of available public data. However, hypothesis related to each independent variable is required to be redefined and rephrased fit to the purpose of panel data analysis.

Demographic factors

Population and population density controls the size and density of a region respectively. More populated and denser counties may have big enough capacities to embrace more green buildings. Diversity and younger median age can be regarded as proxies of tolerance to green building projects. If that is the case, more green buildings may be found in counties of more diverse and/or of younger counties. Counties of higher education are assumed to prefer pro-environmental projects, and to attract more green building projects.

Economic factors

Per capita income and employment rate are included to test whether better economic conditions promote green building projects. Higher income and employment rate may enable more green building projects. Employment growth is used as a proxy of office workplace demands. Although employment growth does not guarantee the construction of green offices, the increasing amount of overall office building stock may allow a group of commercial building projects to be greener. Higher energy price can attract more green buildings which are claimed to be more energy-efficient and to save energy-related costs in the long run.

Governmental factors

Local governments have been major actors in green building practice. Then, the size of governmental activities may stimulate the growth of green building projects. Increase in government indebtedness may mean that more public investments are in the future and possibly initiate more green building projects. Higher share of local government employment may facilitate the local development of green buildings. Higher LCV house score as a measure of pro-environmental atmosphere at the state level can encourage the local growth of green building projects. The presence of public policies for green building can provide practical solutions to green building projects, and bring more projects into reality.

Geographic factors

It seems reasonable to assume that higher level of natural amenities may go along with more green building projects. However, the urban prevalence of green building projects unraveled in descriptive analysis may conflict and nullify this assumption. Urban counties do have more green buildings than rural counties as a baseline for comparison, while it is not clear whether suburban counties have more than rural counties, since more suburban counties have green building projects, but some rural countries have more green buildings than most of suburban counties. Finally, if a county is neighbored with counties of more-than-average green building projects, the county could have a chance to have more green building projects than other counties. Spatial proximity allows counties to learn from each green building project, and build and share accessible sources of necessary goods and services to construct green buildings over the years. Emerging clusters of green building project in descriptive analysis in 4.3.2 support this hypothesis.

4.6.3 Results from the Panel Data Analysis

Results of the panel data analysis of the LEED certified buildings and registered projects are summarized in Table 4.3. Overall, all four models are statistically significant at $p<0.001$. Results are reported in coefficients with standard errors in parenthesis. The number of events for each model is given under each model. First column (CP_OLS) is the results from the pooled OLS model, and the second column (CP_FEVD) is the FEVD model for the LEED-NC certified buildings. The third column (RP_OLS) is the results from the pooled OLS model, and the last column (RP_FEVD) is the FEVD model for the registered projects. FEVD models are my main interests. Top three counties of the highest number of the LEED certified buildings and registered projects – Los Angeles county in California; King county in Washington; Fulton county in Georgia – are removed as outliers.

Panel models of certified buildings and registered projects show similar trends. It seems that trends in the growth of certified buildings as revealed demands have been repeated and reinforced in those in the growth of registered projects as future demands. First, all demographic factors in both FEVD models are positive and statistically significant. Population and population density have significant impacts on the growths of the LEED-NC certified buildings and registered projects. That means that green building projects have grown mainly in densely populated areas. Counties of highly educated people also attract more green building projects, which support the linkage between higher education and pro-environmentalism. Higher racial diversity as a proxy of tolerance brings more green building projects, while older – not younger – counties tend to get more projects. The assumed relationship between young people and green building adoption is discarded, as in the EHA in 4.5. Higher racial diversity and median age are typical characteristics of larger cities which have larger amount of working age population, and the LEED-NC green buildings for commercial buildings and offices may be lured by the size of working age population.

Second, results from economic factors show the importance of regional economic capacity. Higher income and higher 2-year employment growth rate are positive and statistically significant in both FEVD models. Growing wealthier counties may have enough capacity to initiate and build more green building projects.

Table 4.3 LEED-NC Certified Buildings and Registered Projects
: Panel Data Analysis, 2000-05 (w/o Los Angeles, CA / King, WA / Fulton, GA)

	CP_OLS Model	CP_FEVD Model	RP_OLS Model	RP_FEVD Model
Population	0.0098**	0.0102***	0.0990***	0.1131***
	(0.0030)	(0.0000)	(0.0268)	(0.0007)
Population Density	0.0015	0.0005***	0.0091	0.0069***
	(0.0019)	(0.0000)	(0.0146)	(0.0007)
Racial Diversity	0.0284**	0.0267***	0.2000**	0.1998***
	(0.0103)	(0.0000)	(0.0675)	(0.0022)
Median Age	0.0013**	0.0012***	0.0089***	0.0106***
	(0.0004)	(0.0000)	(0.0024)	(0.0002)
Higher Education	0.0013***	0.0014***	0.0099***	0.0117***
	(0.0004)	(0.0000)	(0.0019)	(0.0002)
Income	0.0076	0.0283***	0.1543*	0.2738***
	(0.0094)	(0.0002)	(0.0750)	(0.0112)
Employment Rate	0.0089	-0.0201***	0.0968	-0.0108
	(0.0199)	(0.0002)	(0.1299)	(0.0134)
2yr Emp. Growth Rate	-0.0250*	0.0278***	-0.1803**	0.1099***
	(0.0108)	(0.0002)	(0.0683)	(0.0128)
Energy Price	-0.0010	0.0008***	-0.0033	0.0097
	(0.0011)	(0.0001)	(0.0070)	(0.0052)
Gov. Indebtedness	0.0001	0.0033***	0.0078	0.0272***
	(0.0021)	(0.0000)	(0.0119)	(0.0008)
Gov. Employment	0.0004*	0.0005***	0.0040***	0.0048***
	(0.0002)	(0.0000)	(0.0011)	(0.0000)
LCV House Score	-0.0135	-0.0108***	-0.1855**	-0.2078***
	(0.0085)	(0.0001)	(0.0647)	(0.0037)
Green Building Policy	0.0610**	0.0328***	0.5206***	0.3358***
	(0.0187)	(0.0005)	(0.1367)	(0.0430)
Natural Amenities	0.0006	-0.0003***	0.0055	-0.0001
	(0.0011)	(0.0000)	(0.0065)	(0.0002)
Cities	0.0191**	0.0219***	0.1410***	0.1709***
	(0.0060)	(0.0000)	(0.0350)	(0.0015)
Suburbs	-0.0216***	-0.0254***	-0.2031***	-0.2563***
	(0.0045)	(0.0000)	(0.0325)	(0.0010)
Neighbor CPs	0.2473***	0.2600***		
	(0.0534)	(0.0012)		
Neighbor RPs			0.1940***	0.2158***
			(0.0367)	(0.0082)
Eta		0.8396***		0.7495***
		(0.0004)		(0.0038)
Constant	-0.2477*	-0.4780***	-3.1658***	-4.7626***
	(0.1004)	(0.0014)	(0.7657)	(0.0941)
N	18623	12413	18623	12413
Prob>F	0.000***	0.000***	0.000***	0.000***
R2	0.081	0.376	0.198	0.651

* p<.05, ** p<.01, *** p<.001

In the FEVD model of the LEED-NC certified buildings, two more factors are statistically significant; employment rate is negative, and energy price is positive. Although the signs of those variables are not changed, they are not statistically significant in the FEVD model of the registered projects. In other words, those trends have faded out. Green buildings have become prevalent, and are no more limitedly attractive to places of lower employment rate or of higher energy price.

Third, governmental factors show that governments matter in stimulating green building projects. All variables are statistically significant in both FEVD models. Higher government indebtedness and higher share of government employment in local economy promote more green building projects. The presence of green building policy helps counties to increase their stock of the LEED-NC certified buildings and registered projects. Negative sign of the LCV house score is unexpected. Possibly, it is because pro-environmental atmosphere may conflict the fast growth of green building projects. Otherwise, green building policies as results from local environmental consciousness may cancel out the impact of the LCV house score.

Finally, results from geographic factors underline the role of cities and their neighbors in the diffusion of green building projects. Cities, suburbs, and neighbor green building projects are all statistically significant in both FEVD models. Urban counties tend to have more green building projects than rural counties as a baseline, while suburban counties tend to have less. Certainly more suburban counties have green building projects, but the result suggest that the number of green building projects in suburban counties is likely to be less than that in rural counties. With the urban-suburban-rural distinction, proximity to counties of more green building projects matters. Higher number of green building projects in neighboring counties increases the number of projects in the county within those neighboring ones. The impact of natural amenities is negative in both FEVD models but only statistically significant in the model of the certified buildings. It seems that dominance of cities in green building initiatives conflicts the benefits of natural amenities. However, the influence of this factor is also fading in the FEVD model of the registered projects, since the LEED becomes more universal rating systems which are relatively free from physical and bioregional locations.

4.7 Summary of Findings

The individual county's adoption and re-adoption of green building projects have generated the collective patterns of green building diffusion in the U.S. While the USGBC has nurtured and coordinated efforts to provide learning and scale economies for green buildings and has guided the overall pattern of the diffusion of the LEED-NC green building, the unique social and natural conditions and the capacity building processes of a county are vital to determine the diffusion speed and size of green buildings across counties in the U.S. Since the LEED certification is awarded through the evaluation process after registration, the current distribution of the LEED certified buildings reflect past demands for green buildings realized, and the distribution of the registered projects reflect future demands yet to be realized. In this chapter, the diffusion of the LEED-NC green building projects is investigated in three intertwined analyses with the LEED certified buildings and registered projects.

A series of descriptive analysis of the distribution of the LEED-NC green building projects in the U.S. is performed. With a typology of urban, suburban, and rural counties, the growth of the LEED-NC certified buildings and registered projects is charted. Then, clusters of the certified buildings and registered projects are identified with spatial statistics techniques. Both analyses show the urban dominance of green building projects. Green buildings have increased in suburban and rural counties, too. However, urban counties have been growing faster in the construction of certified buildings and registered projects, in existing and future demands for green building in the .U.S. Among green building clusters, larger cities are ranked higher in the amount of green building projects. Not all high-ranked larger cities were innovators or early adopters in the diffusion of green building, but many of them are 'fast seconds' (Markides & Geroski, 2005) to use their existing advantages to overtake first movers in green building movement.

Diffusion speed and size of green building projects are modeled in two interrelated analyses with a same set of factors conceived. The diffusion of green building projects is investigated with the single-event and repeated-events EHA models for the LEED certified buildings and registered projects, while the growth of green building projects is probed with the FEVD panel data models for both certified buildings and registered projects. Both analyses are designed to be compared with each other to understand different impacts of each factor. Each factor can influence the diffusion speed and size of green building projects differently. For example, higher personal income in a county may hinder the faster adoption at first, but ultimately increase the amount of green building projects. Understanding different impacts of factors on the diffusion speed and size help us to distill policy implications out of those models and analyses. Findings from the EHA analysis and the FEVD panel data analysis are presented in 4.4.3 and in 4.5.3 respectively. Table 4.4 summarizes results from models in both analyses for comparison, which are presented in Table 4.2 and in Table 4.3. Table 4.4 contains signs of statistically significant factors in two sets of three models. First set includes models of the LEED-NC certified buildings, and second set includes for those of the registered projects. In each set, first column is from the single-event EHA model, second one from the repeated-events model, and third one from the FEVD model. In other words, first two columns model the diffusion speed, and the last column the size of green building projects.

Among demographic factors, population and the share of highly educated people are two variables increasing the diffusion speed and size of the LEED-NC certified buildings and registered projects. Higher population density, racial diversity, and median age variables are associated with the bigger amount of local green building projects, but barely their faster adoption. Median age variable in the single-event EHA model of registered buildings is an exception influencing the diffusion speed.

Economic factors show mixed results. Economic vitality tends to make the diffusion slower, but to make the amount of local green building projects bigger. Higher income, 2-year employment growth rate, and energy price are correlated with the slower diffusion speed, but the faster size of green building projects. The impact of energy price fades out in the panel data analysis of registered projects. Higher employment rate appears to shrink the amount of the LEED-NC certified buildings, but accelerate the earlier adoption of registered projects.

Table 4.4 Factors Conditioning the Diffusion Speed and the Size of the LEED-NC Certified Buildings and Registered Projects

	Certified Buildings			Registered Projects		
	Speed		Size	Speed		Size
	Single	Repeated	Amount	Single	Repeated	Amount
Population	+	+	+	+	+	+
Population Density			+			+
Racial Diversity			+			+
Median Age			+	+		+
Higher Education	+	+	+	+	+	+
Income	-	-	+	-	-	+
Employment Rate			-	+		
2yr Emp. Growth Rate	-	-	+	-		+
Energy Price	-	-	+	-	-	
Gov. Indebtedness		+	+	+	+	+
Gov. Employment			+	+	+	+
LCV House Score	+	+	-	+	+	-
Green Building Policy			+			+
Natural Amenities	+	+	-	+	+	
Cities		+	+		+	+
Suburbs			-			-
Neighbor Projects	+		+	-		+

* The sign of each factor is presented only if the factor is statistically significant
* In the 'speed' column, '+' means faster and '-' means slower adoption
* In the 'size' column, '+' means more and '-' means less amount

Results from governmental factors demonstrate that governments have supported green building movement. Higher government indebtedness promotes the earlier and recurrent adoption and the larger amount of green building projects, except in the EHA model of certified buildings. Higher share of government employment increases the overall stock of the LEED-NC certified buildings and registered projects, but only stimulate the earlier adoption of registered projects. Those variables do not particularly accelerate the diffusion of certified buildings. Possibly, that is because governments came later in the whole green building movement, but became key actors with their given resources. Other two variables support this argument. Pro-environmental political atmosphere represented by the LCV House score tends to accelerate the initial and repeated adoption of the LEED certified buildings and registered projects, but to lower the amount of green building projects. On the contrary, public policy initiatives for green buildings do not illustrate any evidence to influence the rate of green building diffusion yet, but increase the stock of green building projects significantly. Local environmental consciousness brings speedy adoption, but holds back from substantial construction of green buildings. Public policies for green building are likely to come late out of local environmentally friendly atmosphere, but help to attract more local green building projects.

Findings from geographic factors illustrate that the man-made environments condition the diffusion speed and the size of green building projects more than natural environment does. Natural amenities contribute to the initial and recurrent adoption of the LEED-NC certified buildings and registered projects, but barely fuel the boom of green building projects. Cities move faster in the repeated adoption of certified buildings and registered projects, so tend to have more green buildings and projects. On the contrary, suburbs stay behind, and fall short of green building projects. This trend may be changed in the near future, since counties with higher number of green building projects in neighboring counties continues to open new green building projects. As expected in 4.3.3, more and more suburb counties are participating in building the LEED-NC certified buildings and registered projects, and sprawling from urban counties into suburban counties. If the trend continues, suburbs near cities will have more green buildings sooner or later, and eventually mitigate the current urban dominance of the LEED-NC certified buildings and registered projects.

In addition to those findings, it is worth mentioning that event dependence in the repeated-events EHA models are illustrated with distinct cumulative hazard curves of certified projects and registered buildings in Figure 4.11 and 4.12. That means that threshold effect is present in green building development; the first adoption cases are less likely to happen, but the recurrent adoption of green building projects tends to be facilitated after the initial case.

This dissertation's hypothesis one (spatial forms) and hypothesis two (contextual factors) in the post-industrial context are investigated in this chapter. Findings from the chapter support both hypotheses in the post-industrial context, as they were supported in the industrial context in Chapter 3. First, all analyses in this chapter reveal urban dominance in the location of the LEED-NC green building projects. Descriptive analysis shows the on-going ascendancy of urban counties in attracting green building projects, despite the increasing number of new green building projects in suburban and rural counties. Models of the EHA reveals that central cities are where the recurrent adoption of the LEED certified buildings and of registered projects happens faster and models of the panel data analysis presents that central cities are where the number of those green buildings and projects grows faster. Green buildings tend to cluster in central cities, while the growth of spatial clusters around those central cities into surrounding suburban counties may change the trend in the future. It is notable that a group of central cities as centers of spatial clusters of counties in green building projects are similar to those in pollution-intensive industries in Chapter 3.

Second, a group of locational factors influence the location behavior of green building projects as eco-industrial development. Demographic factors, mainly population and higher education, tend to promote faster adoption and larger amount of green building projects. Economic factors are likely to deter the introduction, but increase the size of green building projects. Governmental factors show the active role of governments in green building development. Geographic factors support the dominance of cities in green building development and the benefits of proximity to neighboring green building projects. The LEED certified buildings as revealed demands show similar trends to those of registered projects as future demands.

Findings from this chapter offer some policy implications for green building development. The presence of positive event dependence, which means that the existence of former case tends to bring more latter cases, in the diffusion of green building projects suggests that supporting the initial adoption of green building projects can be a reasonable policy option for government. Public policies for green buildings do not necessarily accelerate earlier adoption of green buildings, but they do increase the number of green buildings at the county level. As revealed in findings, governments have been both major enablers and customers in green building development. Local governments may set incentives and initiatives for private green building projects, or start their own green buildings as demonstrative projects. Then, public policies for green buildings can be used more effectively to expand experiences from those pilots into general green building practices in both public and private sectors.

The overall findings supporting the benefits of urban counties in green building development do not suggest that actors in counties of relatively less resources should be discouraged. It suggests that they need to know their situations properly, and try to offset their disadvantages with their own capacity building processes. It is impossible to create favorable environments for green buildings for every county, but it is feasible to generate local initiatives for more effective mechanisms with currently available non-local information and knowledge networks and local communities of institutions and organizations. A series of efforts to build local guidelines and concordances for green buildings with the LEED and existing local building codes and specifications and to drive cooperative green building projects with other governmental or non-profit organizations and private contractors are exemplary practices in this direction.

This dynamic local capacity building processes with local communities of practice and non-local information networks generates distinctive local characteristics which are not easily measurable and transferable, but can be crucial in achieving successful eco-industrial development. Although this issue is brought here at the end of the chapter for eco-industrial development in the post-industrial context, it is also true in the industrial context. The issue is exactly the main focus of this dissertation's hypothesis three (institutional fabrics) that will be tested in the next chapter. Because of the issue's qualitative nature, it is necessary to use proper qualitative research methods to analyze and compare different local institutional structures for eco-industrial developments. Case studies of three on-going eco-industrial development cases in the industrial context and post-industrial context will be conducted with an eco-industrial development typology developed in Chapter 2 and interpreted with general findings from Chapter 3 and 4.

Chapter 5. Eco-Industrial Development in Practice

5.1 Introduction

This chapter performs three case studies of on-going eco-industrial developments in the U.S. Two strategic pathways of eco-industrial development, based on the typology developed in Appendix, are used to frame eco-industrial development cases. The catalyst pathway, in which nascent local industrial systems are supposed to be stimulated and transformed more sustainably by an eco-industrial development, is examined with the Rutgers EcoComplex case in Southern New Jersey. The symbiote pathway, in which mature local industrial systems enable an eco-industrial development to take advantage of its local industrial systems in creating eco-industrial loops inside those systems, is probed with the Regional By-Product Synergy (BPS) networks of Kansas City and of Chicago in the industrial context, and with the green building practices at Battery Park City in Manhattan in the post-industrial context.

The institutional fabrics of those cases are investigated with a focus on the interactions between local and non-local anchor tenants in initiating, nurturing, maintaining, and replicating eco-industrial developments. Data for each case study have been gathered from a series of archival research, interviews with key informants from selected eco-industrial developments, and site visits. Individual case studies of the EcoComplex, the Regional BPS projects, and the Battery Park City will follow in sequence, and overall findings from case studies will be evaluated at the end of this Chapter.

5.2 Taking Eco-Industrial Developments Practically

5.2.1 Past and Present Eco-Industrial Development Projects in the U.S.

Eco-industrial development is rare in the U.S. Nevertheless, it is possible to identify some distinctive eco-industrial developments in the recent U.S. history within the last two decades. Gibbs *et al.* (2005) identified 35 eco-industrial developments in the U.S. and 26 in Europe via the internet and a literature search. Almost half of identified eco-industrial developments in the U.S. came from the emblematic eco-industrial park (EIP) initiative in the early 1990s. The President's Council on Sustainable Development (PCSD) with the U.S. Environmental Protection Agency (EPA) initiated a pilot project of 15 eco-industrial parks in the U.S. and in Canada in 1994 (President's Council on Sustainable Development, 1997).

The U.S. experience of eco-industrial park initiative has been compared with experiences in Canada (Côté & Cohen-Rosenthal, 1998), in Netherlands (Heeres, et al., 2004), in Europe (David Gibbs, et al., 2005; David Gibbs & Deutz, 2007), and around the world (Hardy & Graedel, 2002). Now, only one of the original 15 eco-industrial parks – Londonderry, New Hampshire – still retains its environmental goal, but suffers from a tough energy and financial situation, and five of EIPs never emerged (Chertow, 2007). Hence, it was fair for Ehrenfeld to say that "all of the master-planning approaches to industrial symbioses in the U.S. have failed" (Betts, 2005). Overall results suggested that the failure of earlier EIPs in the U.S. came from their veiled focus on local and regional economic development over environmental concerns (Deutz & Gibbs, 2004; Heeres, et al., 2004). Table 5.1 summarizes the status of the original PCSD EIPs, except a Canadian case of the Burnside

Table 5.1 Status of Eco-Industrial Park (EIP) Projects in the U.S. President's Council on Sustainable Development (PCSD)

Name	Location	Category (2002-2004)	Category (2005-2006) Chertow (2007)
Fairfield Ecological Industrial Park	Baltimore, MD	Operational	Open with changed concept
Brownsville Eco-Industrial Park	Brownsville, TX	Attempted	Regional exchange concept failed
Riverside Eco-Industrial Park	Burlington, VT	Pre-operational	Open with changed concept
Port of Cape Charles Sustainable Technlogies Industrial Park	Cape Charles, VA	Operational	Closed
Civano Industrial Eco-Park	Tucson, AZ	Attempted	Never emerged
The Volunteer Site	Chattanooga, TN	Attempted	Never emerged, open as traditional industrial park
East Bay Eco-Industrial Park	Alameda County, CA	Planned	Planned, changed concept
Green Institute Eco-Industrial Park	Minneapolis, MN	Operational	Open as sustainable development project
Plattsburgh Eco-Industrial Park	Plattsburgh, NY	Attempted	Open as standard industrial park
Raymond Green Eco-Industrial Park	Raymond, WA	Attempted	Never emerged
Skagit County Environmental Industrial Park	Skagit County, WA	Attempted	Never emerged
Shady Side Eco-Business Park	Shady Side, MD	Attempted	Never emerged
Stoneyfield Londonderry Eco-Industrial Park	Londonderry, NH	Pre-operational	Open, but status uncertain
Trenton Eco-Industrial Complex	Trenton, NJ	Attempted	Never emerged

Source: U.S. President's Council on Sustainable Development (1997), Gibbs *at al.* (2005) and Chertow (2007)

* ranges from sites that failed in the planning stages to ones that are not fully operational but have abandoned the 'eco' and/or 'industrial' themes

** includes both existing industrial parks developing 'green' practices and new EIPs that are under construction and/or recruiting tenants

Eco-Industrial Park. Some projects have changed their names throughout the development process. For instance, former Green Institute Eco-Industrial Park is now Philips Eco-Enterprise Center (Krause & Brinkema, 2003). For a coherent comparison between two different categories of status (Chertow, 2007; David Gibbs, et al., 2005), all the projects' names are taken from the PCSD (1997).

Gibbs *et al.* (2005), certainly, did not cover all eco-industrial developments in the U.S. Sometimes, eco-industrial developments cease to exist, or simply stop working as eco-industrial development, like Triangle J Council of Government's Industrial Ecosystems Project in North Carolina (Freid, 2007; Kincaid & Overcash, 2001). Many newer eco-industrial developments are not involved in their list. After the PCSD's EIP initiative, EIPs tended to be developed individually. It is only a recent phenomenon that a group of eco-industrial developments share a common development framework and maintain communication networks among them in multiple locations.

Regional By-Product Synergy (BPS) Networks guided by the U.S. Business Council for Sustainable Development (USBCSD), a not-for-profit organization, are representative examples of those eco-industrial developments.[34] While the earlier BPS projects were initiated in the earlier 1990s, most of regional BPS projects were initiated only within a few years back. Table 5.2 illustrates a list of regional BPS projects in the U.S. Except first five projects in the table, other nine BPS projects are in their early development stage. BPS projects which are not necessarily regional or established are excluded.

34 A brief history and case studies of regional BPS projects in the U.S. will be introduced in 5.5.

Table 5.2 Status of Regional By-Product Synergy (BPS) Projects

Name	Location	Category
North Texas BPS Project	Around Dallas, TX	Completed
New Jersey BPS Project (Mid-Atlantic BPS Project)	NJ, NY, PA, MD	Completed
Gulf Coast BPS Project	Around Houston, TX	Completed
Kansas City Regional BPS Project	Kansas City, MO	On-going
Chicago Waste to Profit Network	Chicago, IL	On-going
Central Ohio BPS Project	Columbus, OH	On-going
Boston BPS Project	Boston, MA	On-going
Pacific Northwest BPS Project	Seattle, WA	On-going
Mobile BPS Project	Mobile, AL	On-going
Milwaukee BPS Project	Milwaukee, WI	On-going
Southeast Michigan BPS Project	Around Grand Rapids, MA	On-going
SF Bay BPS Project	San Francisco, CA	On-going
Denver BPS Project	Denver, CO	On-going
Fort Bragg BPS Project	Fort Bragg, NC	On-going

Source: Wagger and Lawson (2005), USBCSD (2008a), and WBCSD (2008)

BPS projects are different from the earlier EIPs, mostly in their organizing principles. PCSD's EIPs were likely to bring in new development projects to create new eco-industrial parks to attract new economic units, while regional BPS projects tend to organize eco-industrial networks among existing economic actors promoting local green businesses. Therefore, regional BPS networks need to be located in mature industrial systems full of economic units of different types and sizes. The 1996 EIPs were relatively free from this condition, and some of them found their locations in nascent local industrial systems.

Locations of those projects support this observation. Although it is not feasible to perform any statistical analysis with current data on EIPs and regional BPS networks, it is possible to compare the spatial distributions of those two series of eco-industrial development. Figure 5.1 shows locations of the original PCSD's EIP projects and Figure 5.2 shows locations of the current regional BPS projects. It is clear that sometimes the 1996 EIP and regional BPS projects share similar locations, but regional BPS projects are more likely to be initiated around major cities.

It is also noticeable that cities in which regional BPS networks are located are likely to be centers of spatial clusters of selected pollution-intensive industries in Chapter 3 and of green building projects in Chapter 4, including Portland in Washington, San Francisco in California, Dallas in Texas, Chicago in Illinois, Boston in Massachusetts and so on. That may be mainly because major cities are favorable environments for those projects. The fact that those cities are earlier adopters of eco-industrial developments implies that a certain social, cultural, political, and institutional atmosphere encouraging eco-industrial developments may exist locally in those identified cities.

In contrast, eco-industrial developments in the post-industrial context have not been analyzed much in the U.S. While there is recent interest in green building practices as eco-industrial developments in the post-industrial context (Earth Pledge Foundation., 2000; Smith, 2003), it is fair to say that there has been a lack of comprehensive quantitative and qualitative studies of eco-industrial development on this matter. I contribute to this issue by presenting a brief history of the U.S. green building movement and findings from spatial forms and contextual factors of the LEED-NC green building projects as eco-industrial developments in Chapter 4 of this dissertation.

Figure 5.1 Locations of the Original 1996 Eco-Industrial Parks (EIPs)

Figure 5.2 Locations of the Regional By-Product Synergy (BPS) Projects

5.2.2 Eco-Industrial Developments as Catalysts and as Symbiotes

Based on the typology of eco-industrial development in the Appendix, two strategic pathways for eco-industrial development are developed to identify demonstrative cases for case studies. Those strategic pathways are ways which respect the power of surrounding industrial environments, and find desirable strategies to introduce eco-industrial developments in those environments. An eco-industrial development can be a catalyst for local eco-industrial development in a nascent local industrial system, while an eco-industrial development can be a symbiote to find its eco-industrial niche in a mature local industrial system. Nascent industrial systems typically represent under-developed, under-industrialized areas lacking in pre-existing businesses, institutional networks and physical infrastructure and utilities, particularly in rural areas, or ‘greenfields’ (Lambert & Boons, 2002). On the other hand, mature industrial systems are fully developed, industrialized areas with plentiful economic actors, business facilities, and industry infrastructure. Representative examples of the mature system are typically cities, industrial clusters, or ‘brownfields’ (Lambert & Boons, 2002). This chapter assesses the feasibility and effectiveness of those pathways with typical cases.

Since probing institutional fabrics emerged in response to conditions of different local industrial systems is the focus of case study, relationships among different institutional anchor tenants that enable eco-industrial developments in each case are primary concerns in this chapter. An institutional anchor tenant typically offers “the system with education, information, social and economic infrastructure, a decision-making forum, institutional and political support etc.” (Burström & Korhonen, 2001, p. 41). Different from physical anchor tenants which are typically bound to local flows of material and energy, institutional anchor tenants do not have to be local, at least permanently. By definition, institutional anchor tenants are centers of information and knowledge, of learning and expertise, and there are ways in which those services can be delivered beyond local boundaries. Emergence of national and international consultant and service firms in the era of digital globalization has facilitated those non-local human and business communications (B. Andersen, 2000; Sassen, 2002; Wood, 2002). However, this non-local aspect of institutional anchor tenants has been strangely overlooked in the literature on industrial symbiosis, in which many academics and experts have provided expertise and consultancy services in environmental management for eco-industrial developments, often internationally.

New ideas and concepts of eco-industrial development are commonly introduced and diffused by non-local institutions and organizations, but organized and realized through local interactions between local and non-local businesses, institutions, and organizations. By identifying different types of institutional anchor tenants, defined in Chapter 2, and illustrating relationships between them, it becomes possible to simplify, demonstrate, and compare different institutional fabrics that promote and duplicate on-going eco-industrial development cases.

The maturity of a local industrial system and the proper choice of strategic eco-industrial development pathway in that system are influential in constructing local institutional fabrics. The catalyst pathway of eco-industrial development in a nascent environment has a common root with incubators, industrial parks, and growth centers in the economic development literature, in which spillover effects of newly established economic entities to its neighboring regions are assumed, so successful cases are typically benchmarked by cloning those entities in other needed locations (Castells & Hall, 1994; Hansen, 1972; Lewis, 2003). Standardization of former successful experiences by setting up and applying a common platform to different locations are a common practice. In this pathway, non-local institutional anchor tenants can distill experiences from single or multiple local institutional anchor tenants and develop a modular platform of local institutional anchor tenant for future eco-industrial developments – modular anchor.

The symbiote pathway in a mature environment may also exploit the modular anchor approach. However it may not be an efficient option, since it is probable that a mature local industrial system already has potential local institutional anchor tenants for eco-industrial development. Instead of establishing new modular anchor, those local anchors may initiate eco-industrial projects with non-local anchors and acquire and learn necessary information and knowledge to nurture, manage, and transform those projects into full-fledged eco-industrial developments. Projects are 'temporal systems' with 'institutional termination' (Lundin & Söderholm, 1995). From initiation to termination of an eco-industrial project, non-local institutional anchor tenants that have former experiences with eco-industrial developments can participate in the project as temporary anchors that lead local face-to-face meetings and forums to steer the overall pathway of the eco-industrial project, in close connection to local institutional anchor tenants. After the project, local anchors take over the work of temporary anchors and continue to pursue their local eco-industrial development, while temporary anchors return to non-local anchors with new know-how and experiences from the former project that enable them to continue their works. Sometimes, those non-local institutional anchor tenants maintain their connections to local institutional anchor tenants of former eco-industrial projects and manage interregional business and knowledge networks that facilitate regular and occasional meetings among previous and would-be local anchors.

Another means of non-local anchor's involvement in local eco-industrial development is to set up standardized procedures that allow local anchors to perform their own eco-industrial developments with minimal administrative and technical assistance in person. Codes, standards, specifications, and eco-labels are typical examples of this approach. However, those codes and standards cannot fully nullify impacts of local interactions, mainly because they should be continuously updated and upgraded to meet changing market demands with practical know-how and technical innovations originated from creative local interpretations of them (Ben-Joseph, 2005; Ben-Joseph & Szold, 2005; Rubik & Frankl, 2005). In fact, many of those codes and standards have been created or inspired by original local experiences and practices (A. Banerjee & Solomon, 2003; S. A. Moore & Engstrom, 2005). Therefore, as programs of codes and standards for eco-industrial development grow, those non-local institutional anchor tenants of the programs tend to establish local chapters or branches as subsidiary anchor tenants to communicate with local anchors and to organize local forums of enlightenment and education more efficiently.

Those three types of non-local anchors' local presence are closely linked to different replication mechanisms of successful eco-industrial development. Throughout the case studies, I examine strengths and weaknesses of those different interactions between local and non-local anchors in initiating, managing, and reproducing eco-industrial development in different local settings of maturity.

5.3 Conducting Case Studies of On-Going Eco-Industrial Developments

The objective of case studies is to gather detailed information on institutional fabrics built on different local and non-local actors in selected eco-industrial developments. Case studies are an important part of my dissertation, because while quantitative analyses in Chapter 3 and 4 can illustrate existing spatial patterns and frame local factors for and against eco-industrial developments, local reactions to those conditions can be different from case to case, so local institutional fabrics need to be examined through qualitative research methods. A case study is a proper way to investigate the origin and evolution of those local institutional structures (Yin, 1994).

Cases of eco-industrial development were selected by three interrelated criteria, considering limited time and resources. First, key cases of eco-industrial developments in the U.S. were identified through a literature review and Internet search. Less established or less accessible cases of eco-industrial development were excluded. Second, strategic pathways of catalyst and of symbiote, identified by the typology of eco-industrial development in the Appendix, were applied to select representative cases of eco-industrial development fit to the typology. The distinction between mature and nascent local industrial systems was typically instrumental in selecting cases, and findings in Chapter 3 in the industrial context and in Chapter 4 in the post-industrial context helped frame potential locations of eco-industrial developments in the U.S. Third, whether evolutionary or reproductive mechanisms for future eco-industrial developments exist was considered. Isolated, accidental cases of eco-industrial developments were disqualified for case studies in this chapter.

Three cases of eco-industrial developments were identified by selection process: the Rutgers EcoComplex in Southern New Jersey, the BPS projects in Kansas City and in Chicago, and green building practices at Battery Park City in Manhattan. Table 5.3 summarizes cases by selection criteria.

Table 5.3 Cases of Eco-Industrial Development by Selection Criteria

Pathway	Context	Case	Documentation	Replication
Catalyst	Industrial / Post-Industrial	The Rutgers EcoComplex	Literature: • Goldstein (2004) • Rovins (2005) • Linky *et al.* (2005) Website: • EcoComplex (2008)	Platform: Modular Anchor
Symbiote	Industrial	Kansas City Regional BPS Initiative	Literature: • Forward and Mangan (1999) • Bossilikov *et al.* (2005) Website: • US BCSD (2008a) • WBCSD (2008)	Project: Temporary Anchor
		Chicago Waste-to-Profit Network		
	Post-Industrial	Battery Park City	Literature: • Thompson (2003) • BPCA (2003) Website: • BPCA (2008)	Code: Subsidiary Anchor

The Rutgers EcoComplex as a part of the New Jersey Agricultural Experiment Station (NJAES) followed the original path of the NJAES as an R&D and information and knowledge dissemination center in under-developed areas, and attempted a modular approach of duplicating its eco-industrial system of landfills and greenhouse facilities by developing a general eco-industrial platform in Puerto Rico and other locations. The EcoComplex is a typical case of the catalyst pathway, in which the EcoComplex is planned to boost local industrial systems both economically and environmentally.

Two representative cases of the symbiote pathway are identified. In the industrial context, the regional BPS networks share a temporary anchor tenant, the U.S. Business Council for Sustainable Development (USBCSD), in initiating their projects, and later the UCBCSD functions as a non-local institutional anchor tenant managing an information and knowledge network among multiple regional BPS networks to enable those projects to share their eco-industrial development practices and experiences. In the post-industrial context, high-rise green building practices at Battery Park City in Manhattan have been driven by a strong local institutional anchor tenant, the Battery Park City Authority (BPCA), and have been spread into similar green high-rise projects in Manhattan, in close relationship with the New York Chapter as a subsidiary anchor of the U.S. Green Building Council (USGBC), a non-local institutional anchor tenant, through the LEED rating systems as *de-facto* green building codes and standards in the U.S. Later, the USGBC appeared in the local scene by founding a local chapter to identify and nurture local communities of practice.

Data collection for case studies include several methods for each case, such as archival research with documents and reports of each project's historical, technical and financial data, semi-structured interviews with key informants, and on-site visits of relevant eco-industrial development projects (Yin, 1994). Documents analyzed include annual and ordinary reports, fact sheets, and websites of related companies, organizations and institutions, and relevant newspaper and magazine articles. Confidential interviews with directors, managers, practitioners, and champions of eco-industrial developments, were performed with an interview protocol developed and refined in the pilot study of the Rutgers EcoComplex case in 2005 (Rubin & Rubin, 2005). Generally, interviews were conducted, while I visited case study sites from the later 2006 to the earlier 2007. Follow-up contacts were performed to collect additional documents and materials on request after on-site visits. The individual case study for each project includes data from all three data collection efforts listed above. An overall evaluation of case studies was developed with an overview and cross-comparison of eco-industrial developments.

Key informants of each case were contacted again in the late 2008 by phone and by email to confirm and update the current status of each case. Responded information of personal communication or of additional documentation was reflected in the final revision of the chapter.

5.4 Environmental Research Center with Landfills: Rutgers EcoComplex

5.4.1 Rutgers EcoComplex and Its Demonstration Greenhouse

The Rutgers EcoComplex and the Burlington County Resource Recovery Complex (BCRRC) is located in the Burlington County, New Jersey, as shown in Figure 5.3. The site covers 522 acre (2.11 million m^2), and includes a medium-size landfill with two landfill cells of roughly 50 acres (200,000 m^2) respectively. One was operated from 1989 to 1999 and closed, and another is active, and operated as a bioreactor landfill (Hull, Krogmann, & Strom, 2005). The BCRRC also contains a biosolids composting facility, a wood recycling facility, the Rutgers EcoComplex as a research and extension center, and its demonstration greenhouse. The landfill and the greenhouse compose a working eco-industrial system, which is modularized and potentially transferable to other sites with landfills.

The master plan of the BCRRC was established in the late 1970s. From the very start, the main concern of planning the Complex was the co-location of the landfill and the waste treatment and recycling facilities (Goldstein, 2004). However, the co-location process has never been exactly premeditated. Although it does not explicitly use any specific scheme or model, the BCRRC has been developed along with the strategy analogous to the anchor tenant model in industrial symbiosis (Chertow, 2000; Korhonen, 2001a; Korhonen & Snäkin, 2001). The landfill was the key physical anchor tenant in the development of the Park, and the later facilities have been sited at least partly along with their compatibility to the existing links and networks at the Complex.

The use of the landfill gas, mainly methane, is the most promising path to retrieve energy from the landfill. Since the collection of the landfill gas is mandatory in the U.S. but the New Jersey State regulations prohibit the market sale and use of the methane on site, it was necessary to find innovative applications to use collected landfill gas (Linky, et al., 2005). In the mean time, Robert Shinn, a former Burlington County legislator and a state legislator at that time, had a chance to learn about a single cluster hydroponic tomato production system developed by Rutgers, the State University of New Jersey. Researchers at Rutgers had tested the production system in a greenhouse on campus, and tried to find a site for a full greenhouse possibly near a power plant to use waste heat from the plant. The state legislator connected the Rutgers and the Burlington

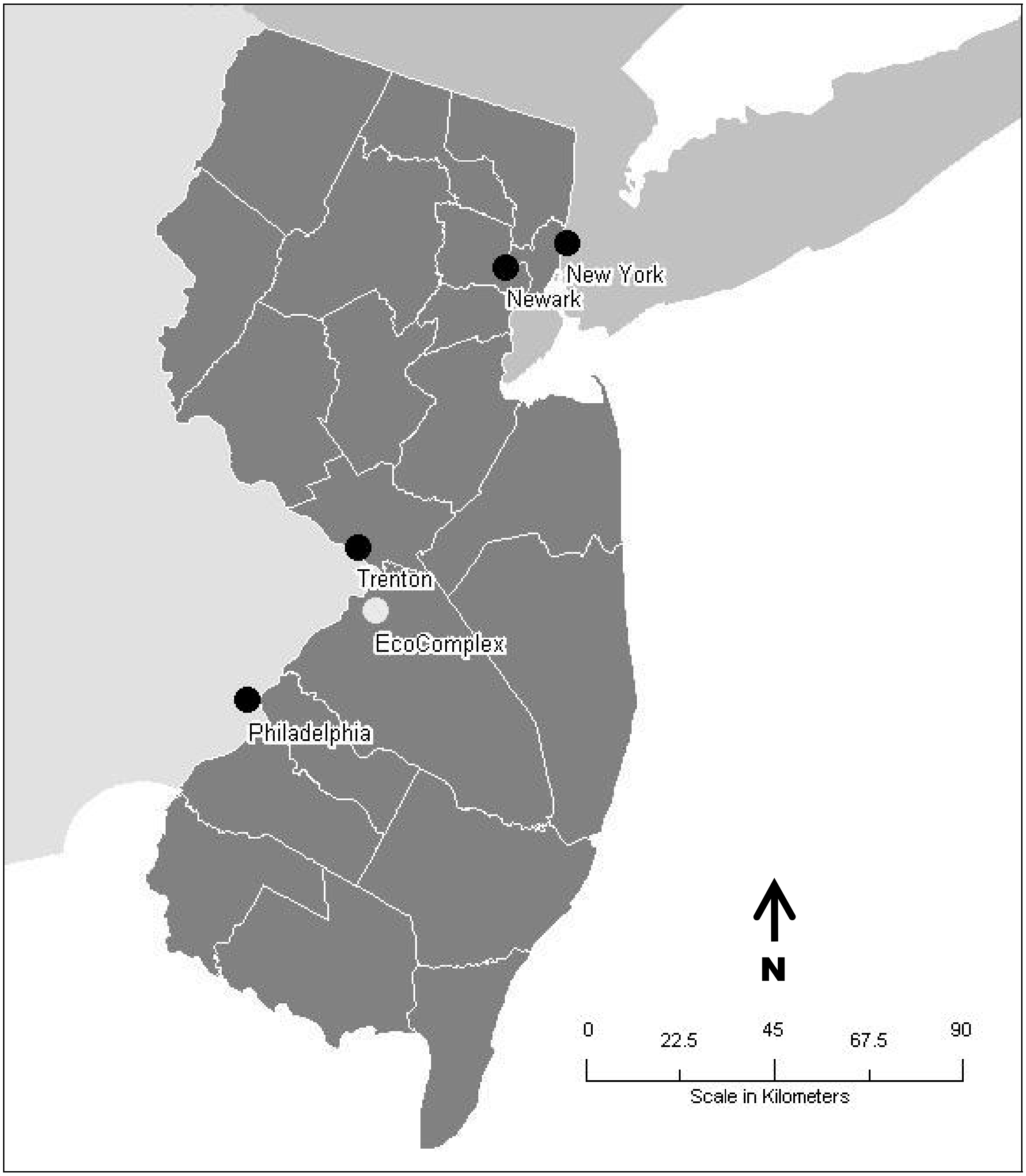

Figure 5.3 Location of the Rutgers EcoComplex and the Burlington County Resource Recovery Complex (BCRRC)

County, searching for a synergetic relationship with Rutgers to develop the future research and education potential of the Complex. The Burlington County Board of

Freeholders agreed to build a demonstration greenhouse on the BCRRC with funds from landfill tipping fees (Goldstein, 2004).

The business opportunities from the construction of the greenhouse at the BCRRC led to the idea of building a research and development center at the site, and the establishment of the Rutgers EcoComplex was a tipping point of the relationship between the BCRRC and Rutgers. In 1996, the 46,000-sq. ft. (4,273.5 m^2) greenhouse opened in the BCRRC. The initial demonstration greenhouse was designed by the Bioresource Engineering Department of Cook College, Rutgers University, but there have been many changes to make the system more sophisticated and productive. The current system at the BCRRC is summarized in Figure 5.4.

The landfill gas is used to heat the greenhouse. Four 30 kW Capstone microturbines, installed in 2002, generate electricity and heat to be used in the greenhouse. Wasted heat from the turbines is used to desalinate water in general and to heat the greenhouse during the winter. Hydroponic vegetable production, mostly tomato, is the major part of the greenhouse, which is combined with the aquaponics system to breed tilapia, installed and linked to the vegetable production system in 2003 (Levinsky, 2007). Wastewater from the tanks is recycled to fertilize hydroponic vegetables. Through this fertilization process which removed nutrients from the wastewater, the water becomes clean enough to be reused in the aquaculture tanks. Inedible biomass from the vegetables and the sludge from the filtered effluent out of the wasted water from the

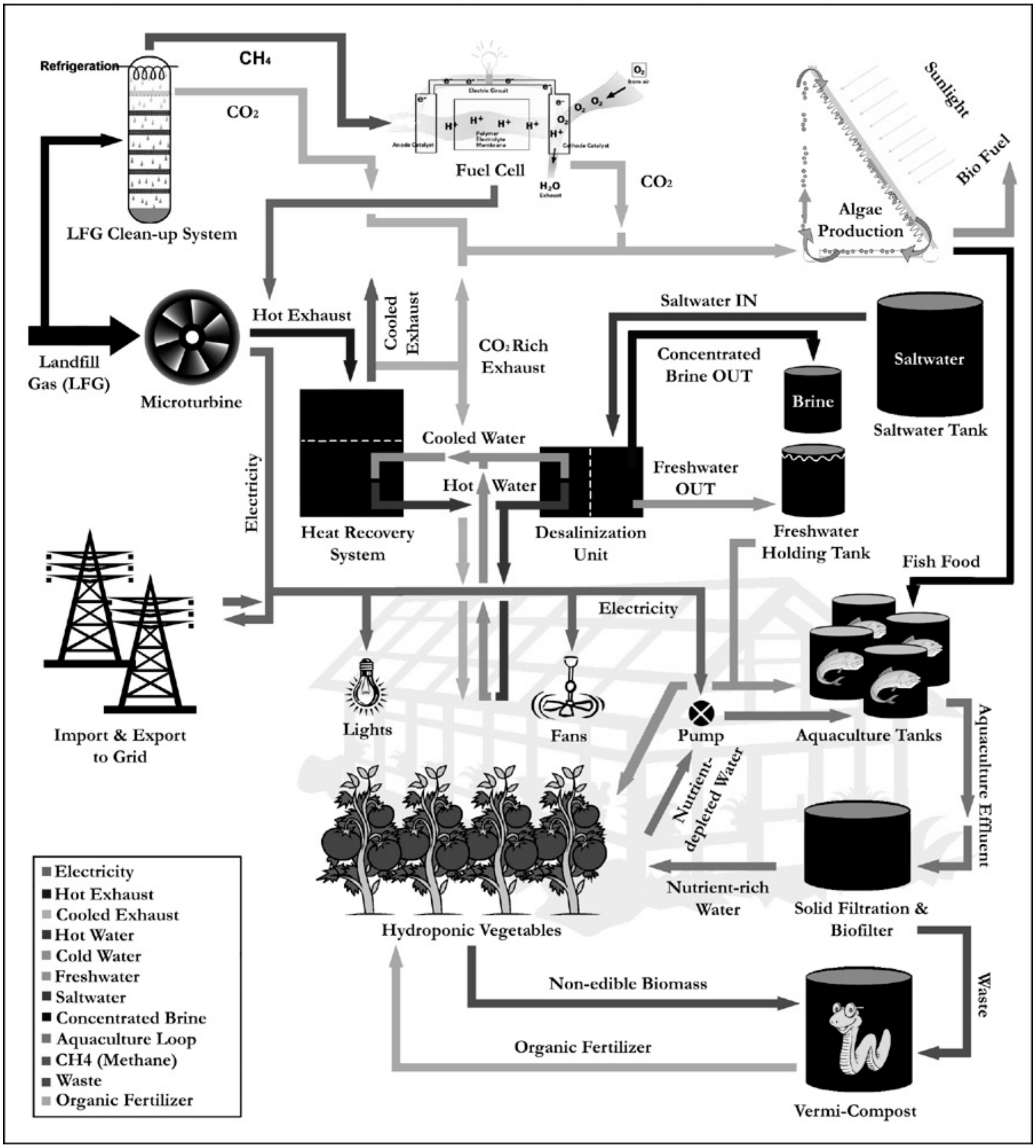

Figure 5.4 Material and Energy Flows of the Demonstrative Greenhouse at the Burlington County Resource Recovery Complex (BCRRC)
Source: Rutgers EcoComplex (2008)

tanks are applied to the vermi-compost process, composting with worms, to produce organic fertilizers. Other alternative energy production systems have been tested or are being tested on site, including a fuel cell with the landfill gas clean-up system, an anaerobic digester, and biofuel production through algal bioreactor.

The Rutgers EcoComplex originally started as a virtual research center to operate and manage the greenhouse, when the greenhouse opened in 1996. However, it was in 2001 that the current 32,000-sq. ft. (3,000 m^2) EcoComplex facility opened. The EcoComplex is a joint venture between Rutgers' NJAES, Stevens Institute of Technology and The Burlington County Board of Chosen Freeholders. Total construction cost of the EcoComplex was $6 million, of which $5 million originated from the State Higher Education Facility Trust Fund and $1 million from Burlington County (James, 2001).

As the birth of the EcoComplex as a joint venture implies, the Rutgers EcoComplex embraced multi-faceted goals and functions from the start. As an extension of the NJAES, it should take roles of research and education on site. Rutgers University is the oldest land-grant university, and has the third oldest Agricultural Experiment Station at the Cook College in Rutgers (New Jersey Agricultural Experiment Station, 1973, 1993). In addition, as 'the nation's first statewide environmental research/technology development center' (Hujber, 2001), the EcoComplex positioned itself as a business incubator for environmental technology entrepreneurs, providing state-of-the-art technical services and seedbeds for piloting potential technologies. Since the Burlington County is only allowed to use its tax-free bonds limitedly to build and manage the landfill and waste treatment facilities, the Rutgers EcoComplex has dealt with all private sector activities (Goldstein, 2004).

Economic development is a naturally induced goal for the concept of business incubator and the neighboring local industrial systems of the Rutgers EcoComplex. The location of the EcoComplex and the BCRRC is at the southern part of New Jersey, which is a relatively under-developed area in New Jersey. As illustrated in Figure 5.5, the initial business plan for the EcoComplex explicitly presented an economic development vision that has the EcoComplex developed from a virtual research center to a full-fetched eco-industrial park (Rutgers EcoComplex, 2006). However, the scheduled steps of economic development from the original economic development plan have been delayed. According to the plan, Phase I started in 1996, when the greenhouse opened. Phase II was practically completed with the establishment of the Rutgers EcoComplex in 2001. Since then, the recruitment of entrepreneurs and the development of green businesses has been one of the key goals of the EcoComplex. The current situation of the EcoComplex suggests that Phase III is still in progress.

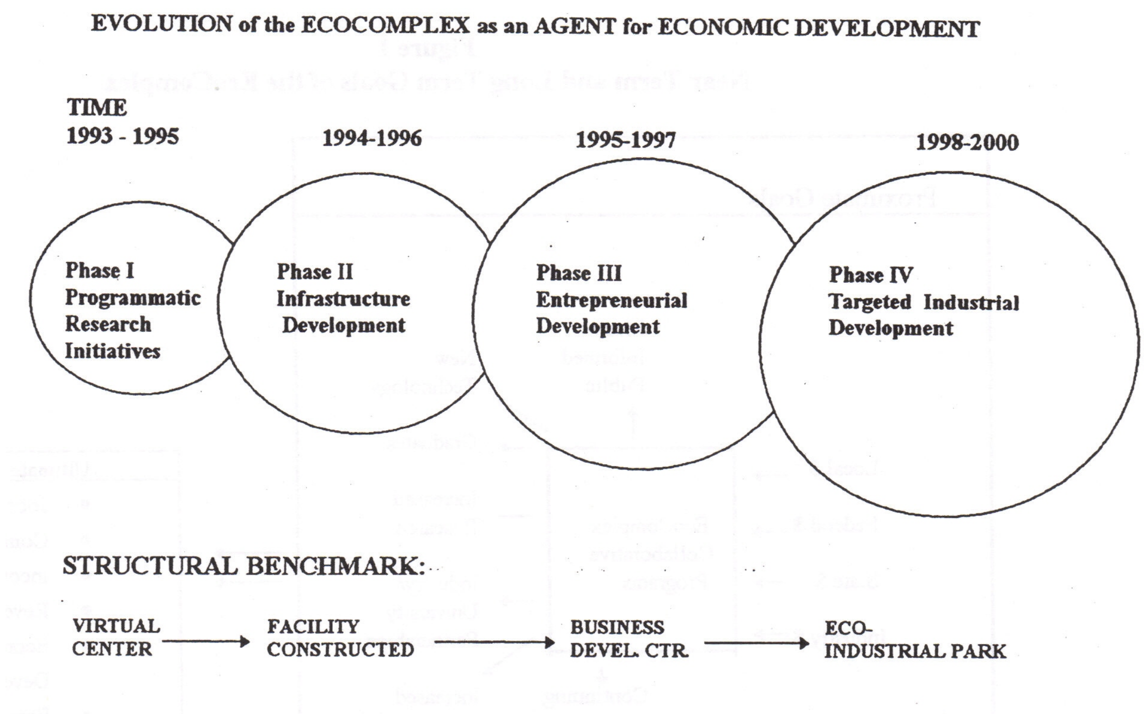

Figure 5.5 Evolution of the Rutgers EcoComplex
Source: Rutgers EcoComplex (2006)

The delayed transition to the Phase IV might be because of the overall decline of environmental industries in the late 1990s. Venture capital investments to the environmental industries peaked in 1991 and diminished after then in the 1990s. In the fourth quarter of 1999, PriceWaterhouse Coopers stopped tracking the environmental industry and reclassified the industry as a part of 'Industrial' category (Diefendorf, 2000). Government overview of the geographical distribution and growth of environmental industry in the U.S. was also discontinued about at that time (Office of Environmental Technologies Industries, 2001). The environmental industry seemed to be stalled, or to have reached its earlier mature stage in the late 1990s (Diener & Terkla, 2000). It was a rather recent phenomenon that the old environmental industry came back with a new vision of clean and green tech industry (Esty & Winston, 2006; Pernick & Wilder, 2007). In this novel vision for green industry, the EcoComplex and the BCRRC are looking for the development of green business that might be enough to launch a fully functioning eco-industrial development in the near future.

Nevertheless, there are several considerable barriers to achieving the original goal of the EcoComplex. The EcoComplex has been suffering from the lack of local firms and institutions to cooperate with. As a proposition, the EcoComplex was located in a nascent local industrial system where an eco-industrial growth center encourages the system to be further developed both environmentally and economically. However, the history of the EcoComplex indicates that the recruiting of new actors to a nascent business environment has been tricky. As a business incubator, the EcoComplex has supported and is supporting more than 10 start-ups, but incubated firms in their post-incubation period have not been located near the EcoComplex.[35] There are three graduates from the Rutgers EcoComplex (Rutgers EcoComplex, 2008). Acrion Technologies, specialized in landfill gas clean-up and utilization, went back to its hometown, Cleveland, OH. Hydroglobe, an environmental technology firm with metal removal patents and technologies from water, was acquired by Graver Technologies in 2004, and is now located in Glasgow, DE. Finally, Terracycle, producing organic fertilizers, repellents, and composters from worm waste products, has moved to Trenton, NJ.

It is not unexpected that those firms have moved to other mature industrial systems of bigger market demands, more intermediate suppliers, and better knowledge connections, rather than stay near the EcoComplex. The real challenge here is whether and how much the EcoComplex could have leveraged its relatively weak industrial conditions with its capabilities and resources and attracted new firms in the vicinity. One of the main functions of the Rutgers EcoComplex is public outreach as part of the NJAES, so the EcoComplex is equipped with auditorium, atriums, and conference rooms, holds and recruits events, meetings, and conferences of local and regional academic, business, industrial, and governmental groups to make connections to those groups (Specca, 2005, 2006). However, those networking efforts have not necessarily increased business opportunities and cooperation projects, and the BCRCC and the EcoComplex do not have explicit plans to retain incubated firms or recruit new firms at the BCRCC (Simkins, 2007). In that sense, "the missing link is central coordination between government, academia, business and nonprofits" (Fitzgerald, 2008) in economic development at the Rutgers EcoComplex and the BCRRC.

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35 Currently, 8 start-ups and firms reside at the Rutgers EcoComplex or utilize facilities of the EcoComplex: Garden State Ethanol, MicroDysis, Internet Creations, Four Seasons Orchids, Ocean of Know, Carbozyme, U.S. Biomass, and Human Nature.

This current situation of the Rutgers EcoComplex and the BCRCC claims that the market coordination is not an operating mechanism of this eco-industrial development yet. An annual budget of about $6 - 700,000 is required to manage and operate the EcoComplex and its greenhouse (Cooper, 2006; Specca, 2006). Although there are strategic plans to expand independent funding sources in office leases, event holdings, controlled agriculture, and laboratory works in environmental technologies, the main funding of the Rutgers EcoComplex has been and still is state and federal funds and grants, in close relationships to the NJAES and Rutgers University. For example, the New Jersey State Legislature provides support in the amount of $500,000 permanent annual funding for the Rutgers EcoComplex through the NJAES budget (New Jersey Department of Agriculture, 2008). It might be true that the potential of the Rutgers EcoComplex is not yet to be fully realized in the market, but then it is also true that the duration of investment return in this eco-industrial development is typically very slow, so sources of long-term funding should be secured until the development really takes off and begins to be paid off eventually.

Overall, the Rutgers EcoComplex has not necessarily worked well as a catalyst to its nascent local industrial system. While it has achieved an impressive eco-industrial system between its greenhouse and the BCRRC’s landfills, its lack of vital coordination among available local stakeholders, and its dependency on public funding have been key barriers to becoming a self-sustaining eco-industrial development. However, the EcoComplex is still pursuing its full potential in the market vigorously, so the final judgment about the development should be withheld for a few more years at least.

5.4.2 The CaribELATE Project in Puerto Rico

Despite its innate limitations, the case of the Rutgers EcoComplex and the BCRRC has shown some possibilities of replication, and a few attempts to transplant the existing system to other locations have occurred. At least, two non-local institutional networks have been related to the BCRRC since the late 1990s, which have enough capacities to learn from the case, and to disseminate and initiate similar projects elsewhere: the Agricultural Experiment Station and the Environmental Protection Agency (EPA). Both networks cover the whole U.S. and have regional associations. The Rutgers EcoComplex is a part of the NJAES, and the US EPA has provided a series of grants to demonstrate and evaluate technologies currently used at the BCRRC site (Goldstein, 2004; Rovins, 2005). As the landfills, the EcoComplex, and its greenhouse became a working eco-industrial system, the concept of transferring the system to some other locations of proper conditions, such as the presence of a landfill, has been developed in the interaction among actors working at the Rutgers EcoComplex and the BCRRC.

EPA seemed to be more motivated in replicating the system at the BCRRC, and the attempt of transplanting the landfill-greenhouse eco-industrial system was first organized within its regional reach. New Jersey was included in EPA Region 2 with New York, Puerto Rico and the U.S. Virgin Islands. Harry Janes, founding director of the Rutgers EcoComplex and professor in the Department of Plant Biology and Plant Pathology at Rutgers, and Edward Linky, senior energy policy advisor at the US EPA in New York City, pushed for the transfer of the system to either Puerto Rico or the Virgin Islands, and ultimately started a project in Puerto Rico under the name of the Caribbean

Environmental Laboratory for the Advancement of Technological Entrepreneurship (CaribELATE) in 2004 (Linky, et al., 2005). The ELATE is formally defined as:

> a technology development, technology demonstration, research, teaching and outreach laboratory which forms innovative partnerships among academia, government and industry to develop ecologically sustainable and economically viable strategies and goals for addressing environmental issues and concerns. (Janes & Rakocy, 2006)

Puerto Rico drew attention, mainly because it is an island economy of high energy costs and lack of land for landfills. Harry Janes and Edward Linky contacted potential stakeholders in public and private sectors, and found that the 'market transformation' of the demonstrative system of the Rutgers EcoComplex could be desirable for promoting the project (Linky, et al., 2005). They first organized a consortium of academic institutions to steer the CaribELATE with a series of grants from the EPA, throughout 20-month period of networking with various public agencies. Five institutions signed a memorandum of understanding: Rutgers, the State University of New Jersey; the University of the Virgin Islands; the University of Puerto Rico; Universidad Metropolitana, Universidad del Este, and Universidad del Turabo. For several months, the steering consortium distilled core concepts and principles from the Rutgers EcoComplex experience and developed a set of criteria and plans for the CaribELATE, as granted by the EPA and Rutgers University.

Rutgers University earned an EPA grant to evaluate landfill sites in Puerto Rico and select an adequate one for the CaribELATE (Linky & Janes, 2006b; Linky, et al., 2005). Out of final four candidates, the San Juan site and the Carolina site got the most attention. While the San Juan site had the biggest landfill in Puerto Rico and the support of the Mayor, the distance between the landfill and its recycling system was too far to install physical connections between them within the project budget. Hence, the Carolina site of collection and recycling facilities on site was ultimately selected (Rust, 2004). After the selection of the site for the CaribELATE, the steering consortium began to organize potential eco-industrial systems by recruiting industrial partners seemingly compatible to the eco-industrial system at the Rutgers EcoComplex and the BCRRC.

The connection between the Rutgers EcoComplex and the CaribELATE is clear in their industrial partners (Linky & Janes, 2006a; Linky, et al., 2005). The pilot project of Acrion Technologies with the Mack Truck at the BCRRC, which used cleaned-up liquefied natural gas from the landfill as fuel for trucks, gave considerable leverage in generating a new project at Puerto Rico, so Acrion Technologies became one of the first industrial partners for the CaribELATE. Terracycle, which was incubated in the EcoComplex, and Greenfuel Technology, which ran a demonstrative algal bioreactor system at the BCRRC, were partners, too. The Puerto Rico Electric Power Company (PREPA), the electric utility for the Commonwealth of Puerto Rico, became an affiliate to CaribELATE with the use of the MARKAL (MARKet Allocation) model that integrates management of material and energy flows. Biocatalyst manufacturer, Bio-Organic Catalyst was also involved in as an industrial partner.

Although the CaribELATE successfully demonstrated a landfill-gas clean-up system, greenhouse with aquaponics facilities, and biofuel production with those industrial partners (Janes & Rakocy, 2006), the perceived 18-month eco-industrial project might not be sufficient to generate enough local buzz for the initiation and operation of a full-scale eco-industrial development. The CaribELATE was stalled by dire financial conditions in Puerto Rico after its initial phase. Jones and Linky learned the lessons from the CaribELATE experience, and tried to find potential sites to apply the advanced ELATE platform for, including the New York and the North Texas areas (Linky, 2007; Linky & Janes, 2006b).

Originally, the CaribELATE was developed as a modular institutional anchor that can be sited and replicated as 'a collaboration between entrepreneurial minded academic researchers with industrial partners, and a host municipality that provides the landfill site' (Linky, et al., 2005, p. 34). The transferability of the ELATE as an entire or partial platform, however, has not been proved yet. Although Linky *et al.* (2005) argued that relatively low capital requirements for the realization of the ELATE can be instrumental to reproduce the ELATE in other municipalities with sizable landfills, as the experiences of the EcoComplex and its greenhouse illustrate in the last section, it will be problematic to secure long-term funding to manage and operate the ELATE based on industrial synergies and business opportunities among private companies and to transform the initial eco-industrial project into a full-fledged eco-industrial development.

Furthermore, industrial partners of the CaribELATE were not actually local firms. Except the PREPA, those industrial partners tended to be temporarily joined for the project from outside of Puerto Rico, demonstrating their green technologies and anticipating future benefits when the eco-industrial development would go into the black. Linky and Janes recalled that if they had included local solid waste treatment company operating the landfill in the project from the first time, the CaribELATE might have had different results (Linky & Janes, 2006b). Since Puerto Rico has a lot of potential local industrial partners, sources of substantial wasted materials and energy in upstream, like in heavy industries and in pharmaceutical companies (Chertow & Lombardi, 2005; Deschenes & Chertow, 2004), the limited inclusion of local partners downstream is somewhat distressing. Transformation of a modular anchor to an established local institutional anchor seems to require time long enough to build local communities and networks between academics, governmental agencies, and businesses, and to keep continuous revenues from either public or private funding to sustain the maturity of the modular anchor. Overall, the CaribELATE experience revealed the possibilities and limitations of the catalyst pathway of eco-industrial development more clearly than that of the Rutgers EcoComplex. The results from those cases will be summarized and evaluated in the next section.

5.4.3 Results from the Rutgers EcoComplex Case

The Rutgers EcoComplex case is fit to the pathway of eco-industrial development as a catalyst that represents the transformation of a local industrial system from a nascent to a mature state by establishing a strong eco-industrial development in the system. The Rutgers EcoComplex at the BCRRC was planned to motivate the sustainable development of the relatively under-developed Southern New Jersey by demonstrating environmental innovations and technologies on site, recruiting new start-ups with its incubation and greenhouse facilities, and providing state-of-the-art environmental technology information and knowledge for New Jersey and neighboring States. The Rutgers EcoComplex has been enabled by its unique institutional fabric represented by the interactions between local and non-local institutional anchor tenants of the Rutgers EcoComplex Case, diagramed in Figure 5.6.

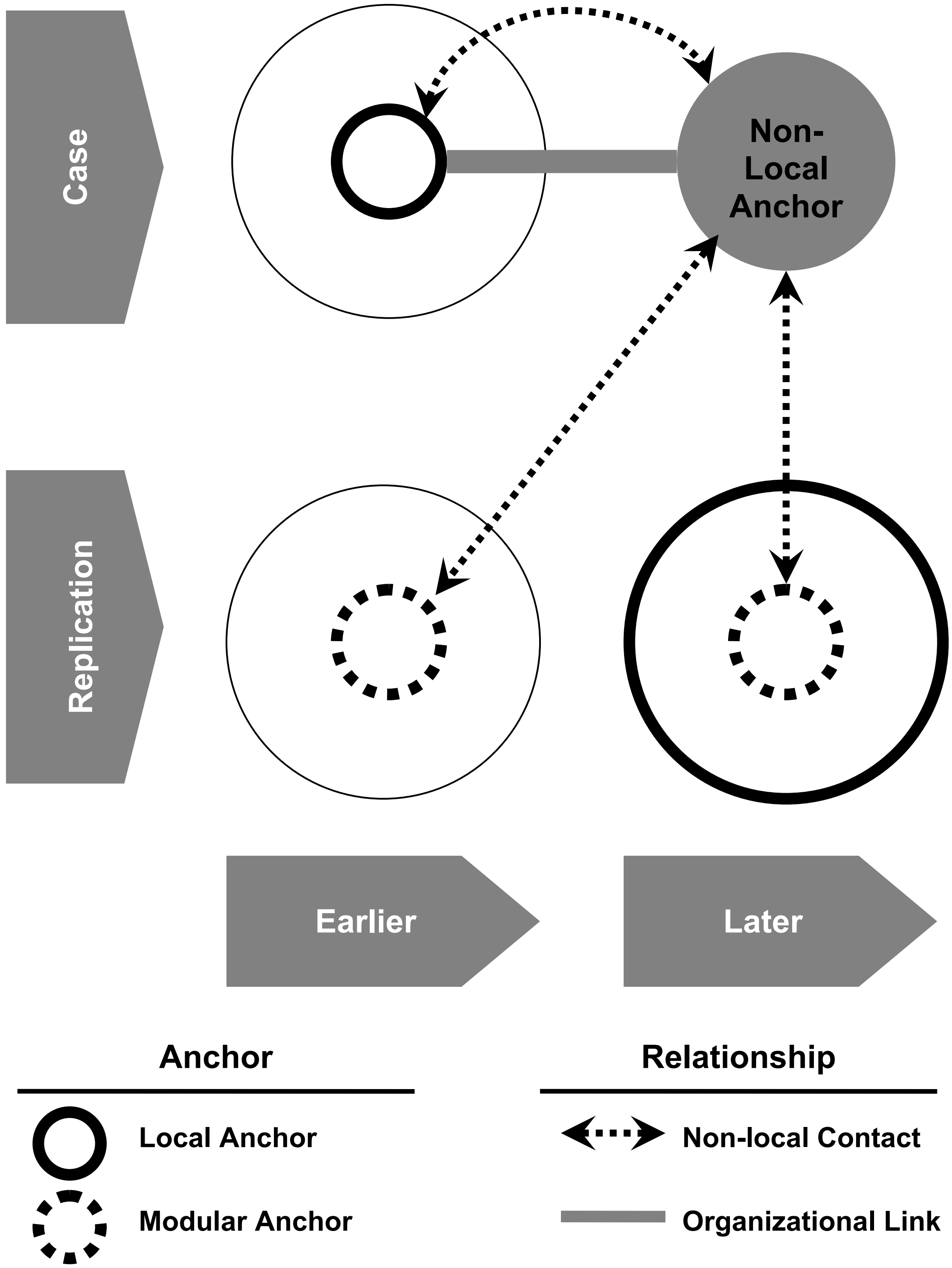

Figure 5.6 Institutional Relationships among Different Anchors in the Rutgers EcoComplex Case
* Thick (thin) outer circle means mature (nascent) local industrial systems.

Non-local institutional anchor tenants have been essential in creating and operating the Rutgers EcoComplex. Rutgers University and the NJAES have been major enablers of the EcoComplex which is an organizational part of the NJAES. Major state funding has been available through the revenue of the NJAES, and information and knowledge flows have been originated from those non-local anchors by sharing their research and human resources with the EcoComplex. EPA Region 2 also has worked as a key non-local anchor to offer a significant amount of grants and networking opportunities for the development of the Rutgers EcoComplex. Facilitators like the state legislator at that time played their parts of work, too.

Local anchor tenants on site have been developing their local capabilities. Landfills of the BCRRC are regarded as physical anchor tenants that provide necessary waste reuse and recycling flows for the eco-industrial system of the EcoComplex and its demonstrative greenhouse. As local institutional anchors, the BC RRC and its owner the Burlington County secured the current site and the initiation investment for the Rutgers EcoComplex, in concordance with Rutgers University and EPA. Most of all, the Rutgers EcoComplex has attempted to establish itself as a major local institutional anchor for future eco-industrial development of its local industrial system. Despite its impressive activities in the R&D, environmental technology education, and business incubation, the EcoComplex may need to develop a more focused coordination among various local and non-local actors, including academics, governmental agencies, businesses, and non-profit organizations, to secure a more balanced financial base between private and public funding sources, and to ultimately become an influential local anchor of sustainable industrial development.

Replication of the Rutgers EcoComplex experience has been formulated by setting up a general platform of eco-industrial development. The ELATE is a concept of a modular anchor of eco-industrial development, which consists of a research and development center, its greenhouse facilities, and municipal landfills at its site. Members of non-local anchors of the EcoComplex case tried to transplant this concept of the modular anchor to a different soil in Puerto Rico, with support from local anchors, mainly from the Carolina municipality with its landfill and waste treatment facilities. The CaribELATE successfully initiated an eco-industrial project, but could not generate enough inertia to push the project into a fully functional eco-industrial development because of its limitation in networking with industrial partners locally and securing long-term funding for future development due to the financial mayhem in Puerto Rico. The CaribELATE case suggests that it may be feasible to reproduce and even improve an engineered eco-industrial system in a different location, but it is difficult to replicate institutional fabrics that enable the system as a sustaining eco-industrial development. For example, the organizational support of the NJAES through its connections to the New Jersey State and the national AES program has been a key element to sustain the activities of the Rutgers EcoComplex, but the CaribELATE did not obtain similar non-local contacts or develop an alternative model or strategy to sustain its long-term existence.

In sum, the Rutgers EcoComplex case shows a typical scene of the catalyst pathway. Supposed positive impacts of a strong eco-industrial development to its nascent local industrial systems are generally required to be nurtured for a long period of time with continuous supports from local and non-local anchors. The general platform of the modular anchor of eco-industrial development might be helpful to reduce the costs of project initiation by providing a standardized physical and institutional framework of eco-industrial development. However, still the operation and maintenance of the development requires time-consuming capability and trust building processes with influential local and non-local anchors and long-term funding sources to assist those processes in progressing safe and sound. Hence, significant governmental intervention seems to be necessary for eco-industrial development in this pathway, at least until the development takes off, since the rate of return from this type of eco-industrial development is likely to be delayed. For the private investor, it might be difficult to be attracted to this type of eco-industrial development unless there are other benefits, such as promising business opportunities among former members of the development, or policy options like relocation incentives or incubation privileges. Most of all, to achieve the eco-industrial transformation of existing local industrial systems, it is essential to create well-coordinated local interfaces among local actors continuously and between local and non-local actors continually to expand the role of located eco-industrial development in generating local green business opportunities in various industrial processes and products, which is only implicitly available at the Rutgers EcoComplex case.

There are on-going cases of similar eco-industrial development centered on landfills and waste reuse and recycling, but in more mature industrial settings. For example, Catawba County's EcoComplex project in North Carolina does not only benchmark the title of the Rutgers project, but also its main concepts and plans, including a future research facility of the Appalachian State University with its greenhouse, the Blackburn Resource Recovery facility, the landfill gas to energy electricity generating facility, and the overall project's commitment to economic development (Batten, 2008; Catawba County, 2007). The EcoComplex in Catawba County is also following the same catalyst pathway of the Rutgers EcoComplex so far, but this project's reach seems to be a little bit longer than that of the Rutgers EcoComplex. Lumber manufacturer Gregory Wood Products and pallet manufacturer Pallet One have agreed to move in the EcoComplex, and the sludge processing facility, the composting amendment facility, and the wood-fired steam production plant will be added to the Complex.

Another comparable but distinctive eco-industrial development has taken shape in Columbus, OH. The Center for Resilience, the U.S. Business Council for Sustainable Development (USBCSD), the Solid Waste Authority of Central Ohio (SWACO), the Ohio BioProducts Innovation Center (OBIC), the Ohio EPA, the City of Columbus, and other groups have developed an eco-industrial network with the Franklin County Landfill (Center for Resilience, 2008). In 2008, the Central Ohio By-Product Synergy Project is officially launched. The Rutgers EcoComplex has some influence to this project. For example, the SWACO developed a Green Energy Center which converts landfill gas to Compressed Natural Gas (CNG) with the landfill gas clean-up system developed by the Acrion Technologies, a graduate from the EcoComplex (Edwards and Kelcey, 2005; Rovins, 2006). The combination of landfill sites and R&D business incubator at the Rutgers EcoComplex was a key inspiration for the Central Ohio project.

However, the Columbus project has positioned itself differently from the Rutgers EcoComplex from the start. In 2007, the project attracted more than 75 manufacturing and service firms, non-governmental organizations, and government agencies to find business opportunities by setting up new exchanges with formerly wasted material and energy flows. During the summer of 2008, 15 to 20 participant firms share their data of available resources to identify economically and technically feasible eco-industrial processes among them, locally championed by the Center for Resilience at Ohio State University, and non-locally communicated with the USBCSD and its former eco-industrial developments (Center for Resilience, 2008; U.S. Business Council for Sustainable Development, 2008b). Simply put, the Central Ohio project is taking a different pathway of eco-industrial development as a symbiote, taking advantage of its local industrial systems, to aim at sustainable local economic development. It also relies on a different kind of existing non-local network: it is one of the regional By-Product Synergy (BPS) networks, which are a series of eco-industrial developments that have evolved to promote this strategic pathway as a symbiote since the 1990s in the North America and currently guided by the USBCSD in the U.S. In the next section, I will investigate the case of regional BPS projects focused on two of the oldest cases in Kansas City and in Chicago, and the role of the USBCSD as a temporary and non-local institutional anchor tenant.

5.5 Regional By-Product Synergy Networks: Kansas City and Chicago

5.5.1 A Brief History of By-Product Synergy in the U.S.

By-Product Synergy (BPS) is originally defined as ‘the synergy among diverse industries, agriculture and communities resulting in profitable conversion of by-products and wastes to resources promoting sustainability’ (The Business Council for Sustainable Development - Gulf of Mexico, 1997). In a recent review of BPS projects, Mangan and Olivetti (2008, p. 1) offered a more operational definition of the BPS:

> The matching of under-valued waste or by-product streams from one facility with potential users at another facility to create new revenues or savings with potential social and environmental benefits… The process brings clusters of facilities together to create closed-loop systems in which one facility's wastes become another's raw materials.

As the definition shows, the BPS projects have close relationships to the field of industrial ecology and industrial symbiosis (Mangan & Olivetti, 2008; World Business Council for Sustainable Development, 2008). It is fair to say that BPS projects have been the most recent and significant movement of eco-industrial development in the industrial context in the U.S. since the PCSD's EIP initiatives in 1996. However, different from EIPs, "BPS networks do not depend upon co-locating industries, but rather taking advantage of existing ones in heavily industrialized areas" (Mangan & Olivetti, 2008, p. 1). In other words, the BPS focuses on the generation of an eco-industrial network in a mature industrial system.

The USBCSD's BPS methodology is centered on the establishment of a forum where firms, institutions, governmental entities, and municipalities sit down together to encourage interactions, to collect information for potential by-product synergies, and to implement promising synergies in the near future (Mangan & Olivetti, 2008; World Business Council for Sustainable Development, 2008). Shared information among participants is secured by an agreement that covers issues of deliverables, confidentiality, and intellectual property rights. The USBCSD leads a regional BPS project as a facilitator and enabler, typically teaming with a local institutional anchor tenant as a coordinator. After the regional BPS project, typically of 12 months duration, the local anchor takes over the USBCSD's role in leading and managing the BPS and the USBCSD functions as a non-local institutional anchor tenant that facilitates inter-regional communications between other regional BPS projects and offers state-of-the-art information and knowledge on eco-industrial development. Funding for BPS projects becomes available from participants' membership fees and governmental grants to initiate and manage those projects. Government entities can also offer technical and learning assistance and ensure that relevant public policies and regulations are available and in place, while private participants of various types and sizes can generate a working eco-industrial network spontaneously with the support, not a mandate, from government (Mangan, 2006; Mangan & Olivetti, 2008).

The origin of the BPS dates back to the early 1990s. In 1992, the Business Council for Sustainable Development of Latin America was first initiated among business leaders influenced by the United Nation Conference on Environment and Development in Rio de Janeiro, and the Business Council for Sustainable Development for the Gulf of Mexico (BCSD-GM) of American and Mexican companies was found as one of the seventeen regional non-profit organizations of the World Business Council for Sustainable Development (WBCSD) to promote sustainable industrial development in 1993, which is the predecessor of the USBCSD.

In the early 1990s, a prototype BPS project was generated between two firms in Texas. Chaparral Steel, a steel product manufacturer, and Texas Industries, a construction materials manufacturer and parent company of the Chaparral Steel have pursued BPS applications led by company president, Gordon Forward (Forward & Mangan, 1999). Under the motto of 'zero waste, 100 percent product', managers of two jointly-owned neighboring companies searched for potential synergies previously unknown thorough a series of meetings. They discovered a group of operable synergies, including the

CemStar, a patented process of using steel slag to produce high-quality Portland cement, which reduced overall energy consumption by 10-15%., CO_2 emissions by 10%, NO_x emissions by 25-45%, but increase production by 5-15%.

Forward brought his experience from the Chaparral Steel BPS to the BCSD-GM, and Andrew Mangan, executive director of the BCSD-GM at that time, became an early adopter and evangelist in initiate and running a series of BPS projects in North America throughout the latter half of the 1990s. In 1997, the BCSD-GM launched a BPS project around the Mexican seaport of Tempico, with 21 major local firms, mainly in the chemical and petrochemical industries (Mackenzie, 2002). Mangan and his colleagues guided the projects with essential leadership from local businessman Eduardo Prieto, found 29 instant synergies out of a set of 68 potential synergies that had been identified, and pursued 13 demonstrative synergies. Throughout this demonstration project, a sequential model of four-step processes developed, which has become the general BPS model of the USBCSD: awareness raising – data collection – analysis – implementation (World Business Council for Sustainable Development, 2008).

The success of the Tempico BPS project encouraged Mangan and his colleagues at the BCSD-GM to create a venture to commercialize the BPS process. In 1998, Mangan established Applied Sustainability LLC. in Austin, Texas, and Forward joined the venture as chairman. For the next two years, Applied Sustainability performed BPS projects successfully in Alberta, Canada in 1999, North Texas, US, and Montreal, Canada in 2000 (Mackenzie, 2002). However, the limited funds of a start up company were not enough to maintain multiple BPS projects with longer pay-off periods due to economic, regulatory, technical, and organizational barriers. In 2002, the venture was officially dissolved, but the BPS practice was championed again by the newly organized the USBCSD with Mangan.

The last project of Applied Sustainability in New Jersey, however, deserves more attention, since it could be regarded as the first real attempt of a regional BPS project to work with state and local governments (Mackenzie, 2002; Wagger & Lawson, 2005). In the late 2001, Applied Sustainability and CH2M HILL, a Colorado-based engineering consultancy, initiated a regional BPS project in New Jersey, championed by Robert Shinn, the Commissioner of the New Jersey Department of Environmental Protection (NJDEP). To secure governmental support for the BPS project, Applied Sustainability and CH2M HILL got NJDEP verification of the BPS process by the New Jersey Corporation for Advanced Technology (NJCAT) (New Jersey Corporation for Advanced Technology, 2001). This verification enabled wider participation of firms, not only in New Jersey, but also in Pennsylvania, and later in New York and Maryland. As a result, the Mid-Atlantic BPS Project was formally established in 2002, with 3 Dow Chemical plants in New Jersey and Pennsylvania, and 12 New Jersey companies. Although this regional BPS network identified more than 80 synergy opportunities in solids, aggregates, semisolids, process water, gas and land, this BPS project did not generate any implemented synergy among participants prior to its completion in 2004 (Wagger & Lawson, 2005).

Nevertheless, this project inspired and enabled Dow Chemical to initiate a new BPS project organized between Dow Chemical's largest integrated site, the Texas Operations facility and its neighboring facilities at the Gulf Coast in 2003 (Lee, 2003). The Gulf Coast BPS project was planned as an internal Dow Chemical BPS project to be extended to other nearby chemical, petroleum refining, and electronics facilities. Synergies just among Dow Chemical's facilities in the project could divert 155 million pounds of formerly wasted materials, reduce 108 million pounds of CO_2 emissions, and save 900,000 MMBtu worth of energy and 15 million dollars annually (World Business Council for Sustainable Development, 2008).

After the Gulf Coast BPS project, multiple regional BPS projects have sprung out all over the U.S. (U.S. Business Council for Sustainable Development, 2008a). The Kansas Regional BPS Initiative, launched in 2004 and Chicago Waste-to-Profit Network in 2006, founded in 2006, are two earlier cases. However, as shown in Table 5.2, a group of regional BPS projects have been organized or are being organized in and around Seattle in Washington, San Francisco in California, Denver in Colorado, Mobile in Alabama, Milwaukee in Wisconsin, Grand Rapids and Detroit in Michigan, Columbus in Ohio, Boston in Massachusetts, and Fort Bragg in North Carolina. In addition, there are other cities and municipalities in earlier stages of organizing regional BPS networks. The emergence of multiple eco-industrial developments has endowed the USBCSD with another key role lately. Since 2006, the US BCSD has managed bi-annual meetings to share experiences from multiple regional BPS projects and to offer business opportunities among current and future members of the US BCSD (Mangan, 2006).

BPS as an eco-industrial development framework has developed some distinctive features from other eco-industrial developments in the U.S. history. First, the BPS methodology has been refined through the evolution from green-twinning projects between two facilities to regional BPS networks. Throughout its own history, the USBCSD has found a position of consultancy with know-how and experience accumulated from former projects. As a temporary anchor tenant, the USBCSD enables and facilitates regional BPS projects, and after the completion of those projects, the USBCSD takes a role of non-local institutional anchor tenant to encourage further communications between other on-going BPS projects. This business model appears to be more sustainable than the start-up model of Applied Sustainability, directing and managing actual projects, in the late 1990s.

Second, the BPS aims to identify and implement by-product synergies that neither the public nor the private can do on their own. Since the very beginning, the BPS has emphasized deliberations between businesses and regulators to generate a favorable atmosphere for eco-industrial developments (Forward & Mangan, 1999; The Business Council for Sustainable Development - Gulf of Mexico, 1997). This approach is a good fit to the third way in environment policy which recognizes that neither market nor government is enough to redress environmental concerns and incorporates deliberative sessions into policy making process (Angel, 2000; Bruijn & Norberg-Bohm, 2005). In the next two sections, two recent regional BPS projects in Kansas City and in Chicago will be introduced to posit institutional fabrics in which those interactions occur.

5.5.2 Kansas City Regional By-Product Synergy (BPS) Initiative

The Kansas City Regional BPS Initiative resulted from an event sponsored by the Environmental Excellence Business Network (EEBN), a program and an affiliate of the Bridging the Gap (BTG) in Kansas City. BTG is a not-for-profit organization that started in 1992 'to encourage local and global awareness of our interconnectedness and to develop this understanding through community education and action' and soon became a local hub for a variety of environmental activities (Bridging The Gap, 2006a). The EEBN, a local network of business people and environmental professionals, has shared their commitment to environmental excellence, since its establishment in 1998. The EEBN held an event to invite Andy Mangan, executive director of the USBCSD, to bring in the BPS concept to the Kansas City metropolitan area in 2002, and the event resulted in a significant enough local repercussion to initiate a regional BPS project among local communities of business, institution, and organization.

BTG started as an organizer of Kansas City's first volunteer-staffed recycling center, and manages five recycling centers in Kansas City (Bridging The Gap, 2008). The Mid-America Regional Council Solid Waste Management District (MARC SWMD), located in Kansas City, has built favorable relationships to BTG thorough several waste management projects, such as voluntary recycling centers. MARC SWMD supported BTG to organize a team of local institutions and organization, such as the Elements Division of BNIM Architects, Franklin Associates, with a non-local anchor, the USBCSD. The team tested and confirmed the feasibility of regional BPS network together in 2003 (Mangan, et al., 2003). As a result, the Kansas City Regional BPS Initiative was officially launched in 2004 as a yearlong project. The EEBN recruited 11 fee-paying members for the initiative, and EPA Region 7, Environmental Improvement Energy Resources Authourity (EIERA) and MARC SWMD offered financial support. During the first year, the team identified 29 commercially promising synergies among participants in the near future out of 50 potential synergies, which possibly divert about 30,000 tons of waste from municipal solid waste landfills annually (Bridging The Gap, 2005). Since the first year, the BTG took over the job from the USBCSD, and has pursued those identified synergies. Although there have been some fluctuations, about a dozen firms have participated in the initiative, with key participants, including Hallmark Cards, Harley-Davidson Motor Company, Cook Composites and Polymers (CCP), Lafarge Corporation Cement Group, and Missouri Organic Recycling, as well as City of Kansas City and Johnson County, KS (Bridging The Gap, 2006b; R. Gordon, 2008).

Waste diversion has been the most outstanding field in the Kansas City Regional BPS Initiative. Among earlier identified synergies, food waste composting, erosion control products, in-place pipe re-lining, and off-spec resin use have been pursued primarily (Bridging The Gap, 2006b). For example, CCP has tested a potential synergy to coat concrete floors and walls with off-spec resins. Missouri Organic Recycling composts food waste collected at Hallmark Cards, Whole Foods Market, and the Jackson County Department of Corrections Jail in Kansas City. This synergy of food waste composting has diverted 346 tons of food waste from the landfill, and reduced 145 tons of CO_2 emissions annually (Bridging The Gap, 2007).

Food waste composting is a typical example of 'low hanging fruit' for the BPS project. In the feasibility study of Kansas City Regional BPS Initiative, the team developed a classification to prioritize identified synergies, shown in Figure 5.5 (Mangan, et al., 2003). 'Low hanging fruits' represent synergies that are expected to have high economic benefits and low technical difficulties, so it is reasonable to pursue those synergies first to acquire 'swift trust' (Meyerson, Weick, & Kramer, 1996) and fast results among members and accumulate necessary trusts and capacities enabling more complicated synergies later. In practice, even 'low hanging fruit' synergies sometimes turned out to be more difficult to be attained than originally perceived. In the Kansas City case, a Hallmark employer recalled that it had taken a whole year to officially participate in the food waste composting by completing administrative procedures with internal directors and teams (Robson, 2006).

Economic Benefit	High	**A** Low hanging fruit High Interest	**B** High Risk & High Return
	Low	**C** Easy to Find In-House Low Interest	**D** Not of Interest
		Easy	Hard
		Technical Difficulty	

Figure 5.7 Market Segmentation on Technical and Economic Barriers
Source: Mangan *et al.* (2003)

The shift from ‘low hanging fruit’ synergies to more sophisticated ones (B in Figure 5.6) has been followed. Most recent and significant example is Lafarge’s new alternate solid fuels facility in Sugar Creek, a suburban city of Kansas City, opened in 2007 (City Clerk of Sugar Creek, 2008). This 22,000-sq-ft energy recovery facility, built with $7-million investment, processes by-products and wastes from manufacturing firms around Kansas City into fuel consumed at the Lafarge Sugar Creek cement plant. Non-hazardous, non-reusable wastes, including cellulose, plastic, rubber, and textiles, are used to recover energy. This new program complements the plant’s landfill gas recovery projects that use methane generated from two closed landfills since 2005.[36] According to BTG and Lafarge, the facility is expected to divert 50,000 tons of industrial by-products

36 Lafarge’s Sugar Creek cement plant is an ISO certified plant that also received Energy Star in 2006 and in 2007. Until January 2008, the plant is one of only eleven Energy Star cement plants in the U.S. (Systech Environmental Corporation, 2008).

from landfills, replace 50,000 tons of coal, and reduce 33,758 tons of CO_2 emissions annually (Bridging The Gap, 2007).

Recently, the Kansas City Regional BPS Initiative took another step, trying to expand the scale and scope of the program and replace its name with the Missouri-Kansas (Mo-Kan) Regional BPS (R. Gordon, 2008). Currently, its interaction with the USBCSD is minimal. BTG uses its position as a local hub for environmental flows, and plans to expand the BPS project with more local actors in the wider metropolitan area of Kansas City. To actively recruit new members, BTG started a new member track in which new members learn the BPS and identify potential synergies with former members within 90 days. BTG aims to recruit 25 new members in 2009 and ultimately over 100 members in the near future. It is noticeable that the BPS attempts to actively create markets for the BPS by strong technical drivers, as well as by the recruitment of new members. It seems that original synergies have been already tested and planned to be implemented, and more sophisticated synergies are able to be pursued now with advanced technical assistance on the ground of trust and capacities built from former activities in the project.

5.5.3 Chicago Waste-to-Profit Network

In 2005, the Chicago Manufacturing Center (CMC) began its collaboration with the USBCSD to create the regional BPS project in Chicago. CMC is a not-for-profit organization, like BTG in Kansas City, which was formed in 1994 as a modernization center for small and medium-sized manufacturers, and sponsored through the Manufacturing Extension Partnership (MEP) under the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) (Chicago Manufacturing Center, 2008). The City of Chicago intensified its environmental drive at that time. Richard Daley, the mayor of the City of Chicago since 1989, unveiled Environmental Action Agenda in 2005 (Chicago Department of Environment, 2008a, 2008b). As a part of the Agenda, the Department of Environment for the City of Chicago was looking for proper industrial processes for sustainable manufacturing. It was natural that the partnership between the CMC and the USBCSD earned sponsorships from EPA Region 5 and the City of Chicago to develop a regional eco-industrial network through the BPS methodology.

Chicago Waste-to-Profit Network (WTPN) was officially launched in 2006, championed by Mayor Daley. The City of Chicago and the CMC led the Recycling Expansion and Modernization Program of the State of Illinois' Department of Commerce and Economic Opportunity, the NIST's MEP, and EPA's Great Cities Program to invest in the project (Chicago Waste to Profit Network, 2007). World Business Chicago and Waste Management Resource Center joined as project partners with the CMC, the US BCSD, and the City of Chicago. Since 2005, WTPN also has been working with the National Industrial Symbiosis Programme (NISP) in the U.K., which encourages governments and industries to pursue the benefits of industrial symbiosis with its vast by-product synergy experience and cases across the U.K. About 80 companies have been involved in the network, have identified more than 100 synergies, and have implemented 50 synergies (Mangan & Olivetti, 2008). It is worth mentioning that two major members in the Kansas City Regional BPS Initiative, CCP and Lafarge, have been actively involved in the Chicago project from the start, as founding members.

WTPN uses a hybrid model that incorporates two different networks to promote synergies among participants (Chicago Waste to Profit Network, 2007; Mangan & Olivetti, 2008). The innovation network is a fee-paying network for long-term collaboration, designed for 10-25 organizations. This network composes a core team in WTPN, which have signed an agreement of confidentiality and intellectual property issues to secure safer interaction and collaboration among participants, based on the USBCSD's process. Community networks are designed to include 30-60 small- and medium-sized companies into the WTPN without costs, and to introduce the BPS as business opportunities to them. It is possible to manage multiple community networks at once, and to transform them into innovation networks to pursue long-term partnerships in finding and implementing synergies, if necessary. The community network is intrigued by the experiences of the NISP in the U.K.: participants provide basic information on potential by-product inputs and outputs, and the project team assesses collected information technically and suggests the synergy opportunities for the network. Project partners, mainly the CMC and the USBCSD, have worked as facilitators in the innovation networks, and as organizers in community networks, and the WTPN technical team bridges those networks.

There is another key organizing element in the Chicago case. Due to the large number of participants in diverse industries, the WTPN introduced a series of affinity groups by different types of potential synergies (Chicago Waste to Profit Network, 2007; Mangan & Olivetti, 2008). At first, five affinity groups of chemicals, metals, construction and building materials, bio-materials, and food waste were organized thorough brainstorming sessions, but later bio-materials and food waste affinity groups were merged into organics affinity group. Each group consists of about 10-15 members of companies, local institutions and governmental organizations, and a member can participate in multiple affinity groups. Those affinity groups focus more on practical solutions and synergy implementations, while the overarching network steers overall directions of the project for the future.

Successful cases of by-product synergy have come out of those structured networks (Wan, 2007, 2008). For example, Engineered Glass Products and Gilasi/Innerglow Surfaces have diverted 50 tons of glass cullet from landfills and been developing a new line of green building materials that can divert up to 900 tons annually. Curb Appeal Materials, Baxter Healthcare, Sherwin Williams, CCP, Department of Fleet Management, and Chicago Center for Green Technology were teamed to put plastic parking blocks made out of unrecyclable plastics to practical use, which can replace concrete parking blocks. 15 tons of wasted plastics were diverted from landfills by mid 2008, and spin-off projects that can divert over 50 tons more annually are in process. Smurfit Stone Recycling has worked with Christy Webber Landscaping and Cloverhill Bakery and has diverted more than 2,000 tons of plastic and packaging wastes annually. Finally, Abbott Laboratories diverted 20k tons of industrial bleach (sodium hypochlorite) from the public sewer system to create cleaner process water for AcelorMittal Steel. As a result, the WTPN has switched about 22,118 tons of landfill wastes, saved over 4 million dollars, reduced CO_2 emissions by approximately 42,600 tons, created $300,000 new revenues and retained 17 jobs in its pilot year (Chicago Manufacturing Center, 2008; Gess, 2008; Wan, 2008). The WTPN expects to double those outputs in 2008, with new $70,000 public/private investments, and 4 recruited businesses.

The WTPN plans to expand the Chicago network significantly (Wan, 2008). Recently, the WTPN received funding from the State of Illinois Recycling Expansion Modernization (REM) program to create more regional networks in Illinois. Rockford, Peoria, and Carbondale were designated nodes, and Rockford Innovation and Community Networks were launched in the late 2008. The WTPN also attempts to broaden its coverage to a statewide BPS network, and to even 10 state Midwest region (EPA Regions 5 and 7) as Midwest Regional BPS Network with the NISP's Core Resource for Industrial Symbiosis Practitioners (CRISP) database that the CMC has adopted to assist community networks. The USBCSD has been involved in other regional BPS projects in the Midwest region – For example, Milwaukee and Southeast Michigan – so the partnership between the WTPN, the USBCSD, and those regional BPS projects is expected to be continued and even intensified.

5.5.4 Results from the Regional By-Product Synergy Networks Case

Overall, the regional BPS projects case is representative of the symbiote pathway in the industrial context, in which mature local industrial systems enable an eco-industrial development to create closed loops by offering given physical and institutional networks within those systems. The BPS methodology has its own preference of locations in mature industrial systems, developed through its evolutionary path, since it needs former actors and networks to create new regional eco-industrial networks (Mangan & Olivetti, 2008). In practice, the regional BPS projects tend to be located in and around major cities, as illustrated in Table 5.2 and Figure 5.2. Case studies of two recent regional BPS projects are not exceptions. Those projects are located in Kansas City and Chicago, which have large and diverse manufacturing bases. The BPS methodology characteristically generates new, long-lasting institutional networks promoting local eco-industrial developments out of existing physical and institutional anchors through instrumental eco-industrial projects for a limited period of time. In the process, the interface between local and non-local anchors is temporarily compact at the site during the project, and becomes distant out of the site after the project. In Figure 5.8, the diagram of institutional relationships between local and non-local institutional anchors illustrates these dynamic institutional fabrics in the Regional BPS networks case.

The USBCSD as a non-local institutional anchor tenant has been a crucial actor in the development, implementation, and marketing of the BPS methodology and network since the late 1990s. In the earlier 2000s, Applied Sustainability, the former entity of the USBCSD, tried an approach, similar to that of the EcoComplex, which initiated and managed eco-industrial developments in mature local industrial systems. However, after its closure due to the BPS projects' longer investment return time, the newly established USBCSD has re-positioned itself as a consultant agency: It works as a temporary institutional anchor for local BPS projects of a time limit, typically one year, and maintains non-local contacts to former projects and developments later. Capabilities and trust that have been built through projects at different locations enable the USBCSD to cooperate with other key non-local anchors, including EPA and the WBCSD, as well as local institutional anchors, usually local governments and not-for-profit organizations.

Local physical anchor tenants are recruited and identified throughout a series of meetings and forums in the local BPS processes. In the Kansas City case, BTG identifies

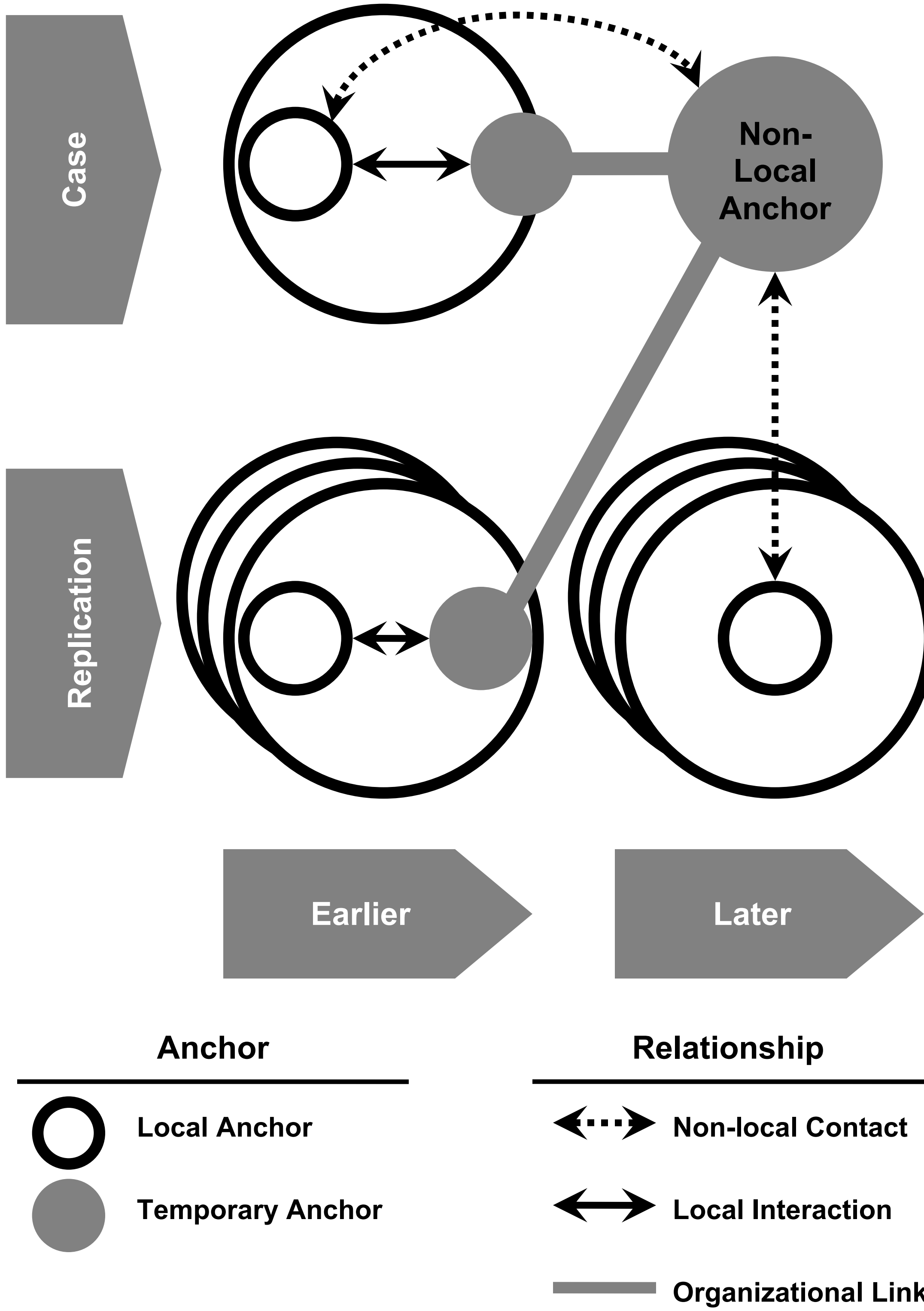

Figure 5.8 Institutional Relationships among Different Anchors in the Regional BPS Networks Case
* Thick outer circle means mature local industrial systems.

the two most significant beneficiaries in the regional BPS network. Missouri Organic Recycling is a typical case of ‘scavengers and decomposers’ (Geng & Côté, 2002) that offer waste treatment and recycling services, while Lafarge, a construction material group, works as a major physical anchor tenant (Chertow, 2000; Korhonen & Snäkin, 2001). Plants in pollution-intensive industries, identified in Chapter 3, participate in the project as key anchors, including Lafarge (Concrete), Hallmark (Paper), and CCP (Chemicals). It is worth mentioning that practitioners in the Kansas City project called those physical anchor tenants ‘syncers’ or ‘sinkers’, since those anchors are ultimate sinks of waste and by-products in the project, in sync with most of other participants (Gromacki, 2006; Silva, 2006). In the Chicago WTPN, Lafarge and CCP also joined the project, in part motivated by their experiences in Kansas City. Including those companies, four affinity groups of chemicals, metals, construction and building materials, and organics operate in the Chicago case. As the names of those groups imply, key anchors in each affinity group, such as Mittal Steel (Metal), Engineered Glass Products (Glass) and Akzo Nobel (Chemicals) are likely to be in pollution-intensive industries, too. Waste treatment and recycling companies like Curb Appeal and Smurfit Stone Recycling are also members of the WTPN.

The pre-existence of local institutional anchor tenants is a crucial ingredient in the implementation of the BPS methodology, since local anchors would offer an instant interface to existing local institutional networks at first and take over the leading role of the temporary anchor after the project. By BTG, a local anchor of not-for-profit organization, the Kansas City Regional BPS Initiative has been stimulated by its EEBN program with local businesses and organizations, facilitated with its established links to local and regional governmental agencies of waste treatment, and managed and improved during the aftermath of the project. CMC has played a similar role as BTG in the Chicago WTPN, while the support of the City of Chicago with the local champion of the Chicago Mayor has been notably significant in the establishment and operation of WTPN. Membership fees, as well as available grants from governmental agencies, have successfully supported the initiation and operation of several regional BPS networks. Mostly, expectations for current and future business opportunities among local members of the networks enable the regional BPS networks to sustain their existence and further development.

As a replication strategy, the USBCSD's dynamic approach of shifting between a temporary anchor for a local eco-industrial project for a limited time period and a non-local anchor for multiple locations of eco-industrial development has built momentous accomplishments. As shown in Table 5.2 and Figure 5.2, the USBCSD is now handling a series of regional BPS projects of different developmental stages across the U.S. Heightened environmental concerns of local and regional governments by rising oil prices in the mid 2000s have facilitated new regional BPS projects in major cities, such as Chicago (Mangan, 2006). Regular meetings among current BPS projects, related actors, and future participants held by the USBCSD were originated from the recent development of multiple eco-industrial projects and developments, and have enriched the USBCSD's pool of know-how and expertise in this field and expanded green business opportunities among members and participants of different origins and locations simultaneously. The development of non-local institutional anchors to encourage eco-industrial development in different locations appears to be feasible and doable, if the

USBCSD's activities for the last decades are considered a successful alternative policy option. In fact, the USBCSD is not the only case of reproducing eco-industrial development in multiple locations.

One notable example is the NISP in the U.K., officially launched as the first national-scale eco-industrial development project in 2005 (Mirata, 2004; Scott Wilson Business Consultancy, 2007). Through the WBCSD, which is a parent organization of the USBCSD, the NISP has learned and incorporated experiences of earlier EIP and BPS projects in the U.S. However, different from the U.S. cases, mainly based on temporary consultancy and local membership, the NISP is a national network of 12 regional offices, partly funded by the Department for Environment, Food and Rural Affairs' (Defra) Business Resource Efficiency and Waste (BREW) Programme derived from Landfill Tax. Since its establishment, the NISP recruited more than 8,000 participant firms of different sizes in all kinds of industries nationwide (World Business Council for Sustainable Development, 2008), and for the last two years the Programme has:

- Diverted more than 2.2 million tons of business waste from landfill
- Saved 4.8 million tons of virgin material
- Saved 2.5 million tons of potable water
- Created 490 new jobs and safeguarded 768 jobs
- Reduced carbon emissions by 2.1 million tons
- Reduced carbon emissions by 2.1 million tons
- Generated £ 104 million in new sales for members
- Saved members £ 81 million

Successful performance of the NISP now creates inverse feedback loops to the BPS projects in the U.S. The NISP has been a key non-local partner of the Chicago project from the start. For example, Chicago WTPN shared lessons from the NISP with the USBCSD, and organized a series of forums of middle- and small-sized firms with advanced performance measurement schemes, including CO_2 reduction in relation to the Chicago Climate Exchange (CCX). The concept and implementation of community networks among middle- and small-sized firms in the Chicago case is a direct result from those efforts. Setting up temporal eco-industrial projects with a capable non-local anchor to create local buzz on eco-industrial projects in advance and re-organize effective and favorable local institutional fabrics for future eco-industrial developments seem to be a feasible policy option, but not the only option. Obviously, there are other ways in which eco-industrial developments can be motivated. A promising option of green codes and standards, originally developed in the post-industrial context, but also suitable in the industrial context, will be investigated in the next section with an eco-industrial development case at Battery Park City in Manhattan.

5.6 Green Skyscrapers in a Global City: Battery Park City and Its Neighbors

5.6.1 Battery Park City's Green Building Practices

Battery Park City is located at the southern end of Manhattan in the vicinity of Wall Street. This site of high rise buildings and public parks was an engineered site from the beginning. It was built on a landfill site reclaimed from the Hudson River. This new land was literally a *tabula rasa*, a man-made site waiting for artificial landscape. Since then, this 92-acre landfill site has been a hotspot of real estate activity in the New York City (Uhlfelder, 1995). While there has been a significant debate about the design, development process, and characteristics of Battery Park City in urban planning (Fainstein, 2001; D. L. A. Gordon, 1997; Kohn, 2004; Schuman & Sclar, 1996), sustainable practices of Battery Park City have never been the center of the debate.

However, the evolution of design concepts and practices of Battery Park City has converged into a green neighborhood with 32 acres of organically maintained open space and a group of the LEED certified green high-rise buildings.

In 1966, Governor Nelson Rockefeller and New York City Mayor John Lindsay proposed the Lower Manhattan Plan for waterfront revitalization (Fainstein, 2001; D. L. A. Gordon, 1997). The major drive of the plan was the recognition of potential threats and opportunities resulting from the fact that New York had moved from an industrial to a post-industrial economy (Kohn, 2004). The emerging financial industry appeared to be a promising economic engine of Manhattan. The Lower Manhattan Plan of 1966 suggested that the financial district should be filled out soon, and proposed a waterfront urban-renewal development along the pier line from the Brooklyn Bridge to Battery Park (Boyer, 1996). The same year, the Port Authority announced the creation of a landfill area along the piers on the Hudson River with the ground dug from the site of the World Trade Center, proposed in 1964 (Darton, 1999). Later, the landfill site became the 92 acre foundation for Battery Park City, completed in 1976. That site had been the last big landfill in Manhattan. Although Manhattan had grown from its initial land size by more than 3,000 acres since the 18th century, the Clear Water Act of 1972 practically prevented further landfills that could pollute the Hudson River (Gastil, 2002; Willlis, 2002).

In 1968, the Battery Park City Authority (BPCA) was established as a public authority by the State of New York to lead, execute and manage the project on the land owned by the city (D. L. A. Gordon, 1997).[37] Approved in 1969, the original master plan

37 Public authorities are, in a more formal definition, public benefit corporations, which "provide government or quasi-government functions which cannot easily be carried out by traditional government departments… particularly when long-term financing is required or businesslike activities conducted" (K. M. Henderson, 2006, p. 226).

was full of visions of mega-structure. However, it never had a chance to be implemented because of a recession stimulated by oil shocks, a fiscal crisis in New York City in the 1970s, and a default of federal support for subsidized housing in the Nixon administration (Kohn, 2004). In 1979, ownership of the land was transferred to the BPCA by a memorandum of understanding between city and state officials (Uhlfelder, 1995). The same year, a new master plan developed by Cooper & Eckstut was approved by BPCA. Along with a revitalizing office market, this more traditional plan, which reflected old grids and looks of Manhattan and parcel divisions familiar to developers, attracted 30 developers in 1980 (Alexander Cooper Associates, 1979; Fainstein, 2001; Kohn, 2004). Although the recession during the 1980s slowed down the development process, Battery Park City has grown continuously and is regarded as one of the most successful planned urban communities in the 1990s.

Battery Park City's green practices predate its innovative green building projects. Parks and gardens, which cover one-third of Battery Park City and have been operated organically since the late 1980s, are areas of environmentally friendly practices. The entity that led this organic maintenance is the Battery Park City Parks Conservancy (BPCPC), a non-profit organization for maintaining and operating the 36 acres of parks within Battery Park City, which was originally established in 1988 so as not to encumber the limited resources available for New York City parks. Ever since, the BPCPC has practiced organic maintenance without the use of pesticides or inorganic fertilizers (Urban, 2004a, 2004b).[38] Parks at Battery Park City produces its compost on site from cuttings and wood chips, manure from a police department, and leftovers from local

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38 In part, this impressive performance results from a relatively substantial budget for the Parks of Battery Park City. The annual budget for horticultural maintenance in Battery Park City is $1.5 million, which represents approximately 25 percent of the total maintenance budget of the BPCPC (Urban, 2004a).

stores. More than $12,000 is spent for soil tests to probe the biological and chemical condition of the soil annually (Urban, 2004a). Staff decides the needs of the soil based on the test results and suit them with necessary treatments.

The main reason for organic maintenance came from the nature of parks in Battery Park City: they are public parks and designed for heavy public use. Therefore, the priority should be on the safety of parks, as well as their appearance, and the preference for non-toxic gardens and parks was a logical choice for the BPCPC in that context. The initial skepticism of BPCA has been dissolved over the years, with the success of organic maintenance of Battery Park City parks (N. Cohen, 2004). It is fair to say that at least in part those green practices in Battery Park City have influenced the introduction of green buildings.

Environmental leadership for Battery Park City came with BPCA's initiation of major real estate development in the late 1990s. Timothy Carey, the Chief Executive Officer of BPCA, proposed a new vision for sustainable development of Battery Park City, with Governor George Pataki and BPCA Chairman James Gill at that time (Battery Park City Authority, 2003). In 1999, Carey organized a team of experts to develop a set of green building guidelines following the emerging LEED rating systems, and publicized the Residential Environmental Guidelines or so-called 'green' guidelines for Battery Park City. He thought that the large scale of real estate development might be instrumental in pushing the market to better environmental performance (Aridas, 2004). The guidelines have been a tool to pursue the environmental excellence of high-rise buildings thorough the market mechanism.

In 2000, BPCA released a request for proposal (RFP) in which developers provided BPCA a monetary bid for ground lease and a design concept meeting the green guidelines. Many members of the BPCA and real estate industry in the NYC were very skeptical about the RFP process promoting green skyscrapers in Battery Park City (Carey, 2006). However, more than two dozen developers attended the RFP meeting, and nine of them submitted proposals. The Albanese Organization, Inc was selected to develop the Solaire, the first comprehensive green residential high-rise building in the U.S. However, after 5 months of construction, the Solaire project was halted because of the 9/11 attacks and their aftermath on Battery Park City in 2001. The economic feasibility of the whole project was questioned afterward, and the whole project was at stake until early 2002, when the Congress approved the alternative financing by the Liberty Bonds program (Battery Park City Authority, 2003). The construction of the Solaire was resumed in late 2002, and completed in 2003. Erasing all the initial apprehensions, the Solaire was quickly occupied, even needed a waiting list (Kuchment, 2008; Neuman, 2006).

BPCA had been an ultimate local institutional anchor throughout the construction of the Solaire as a distinctive urban eco-industrial development. Since it was the first attempt to build an urban green skyscraper, there were many issues and limitations to be solved at the project for the first time. BPCA as a public benefit corporation of quasi-governmental functions has clear benefits in cooperating and negotiating with city, state, and federal agencies and governments, as well as labor unions, to facilitate the progress of the Solaire project. For example, some new technologies applied to the Solaire conflicted with existing codes fit to older technologies, and BPCA managed to acquire waivers for those technologies under a section of the New York City Charter, that was never a simple task for any developer or professional firm involved in the project (Carey, 2006; Clerico, 2006).

BPCA, teamed with the Albanese Organization, drew helpful assistance from State and Federal agencies. During the evaluation of design and construction options of the Solaire, the New York State Energy Research and Development Authority (NYSERDA) offered technical and financial incentives to assess the environmental performance of design alternatives. At the same time, the US DOE with the Natural Resource Defense Council provided potential design options and necessary technical assistance on the performance modeling with the DOE-2, the agency's building energy evaluation program (Aridas, 2004). It was also BPCA that led the resolution of the financial and institutional havoc after the 9/11 in a close relationship with governmental agencies and financial institutions. The Solaire resulted from those efforts of BPCA that kept its commitment to eco-industrial development during the initiation and development of the Solaire.

The Solaire as the first LEED gold-certified green skyscraper of a 27-story and 293-unit building has many green features, such as centralized HVAC (heat, ventilating, and air conditioning) system with air filtration and seasonal humidity adjustment, photovoltaics, on-site wastewater treatment and stormwater reuse systems, Energy Star fixtures and appliances, the use of recycled materials, and a rooftop garden at the 19^{th} floor and a green roof on the 27^{th} floor (Battery Park City Authority, 2003). Some of those features are for indoor air quality, including the circulation of filtered air with the

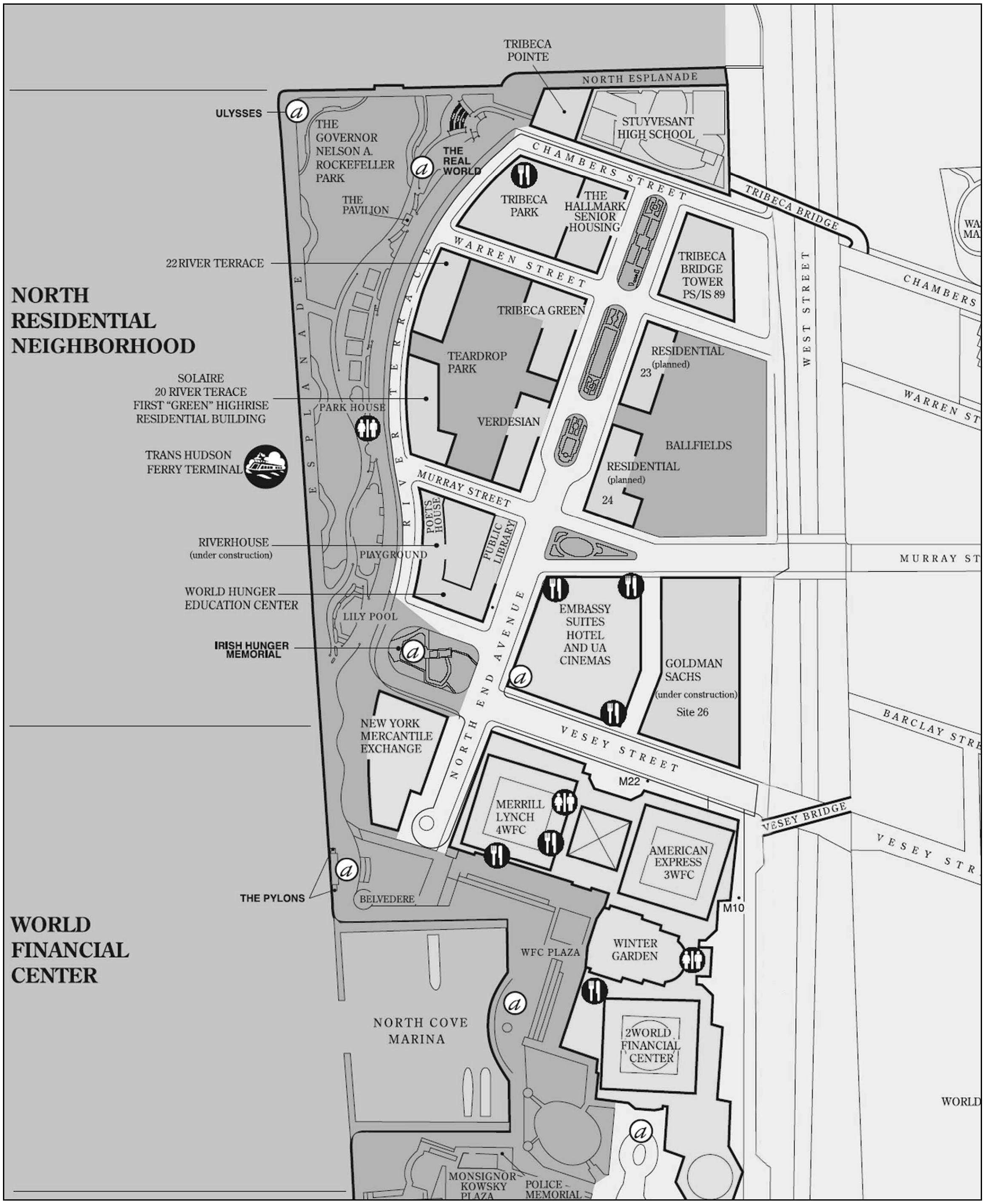

Figure 5.9 Map of Battery Park City I
Source: BPCA (2008)

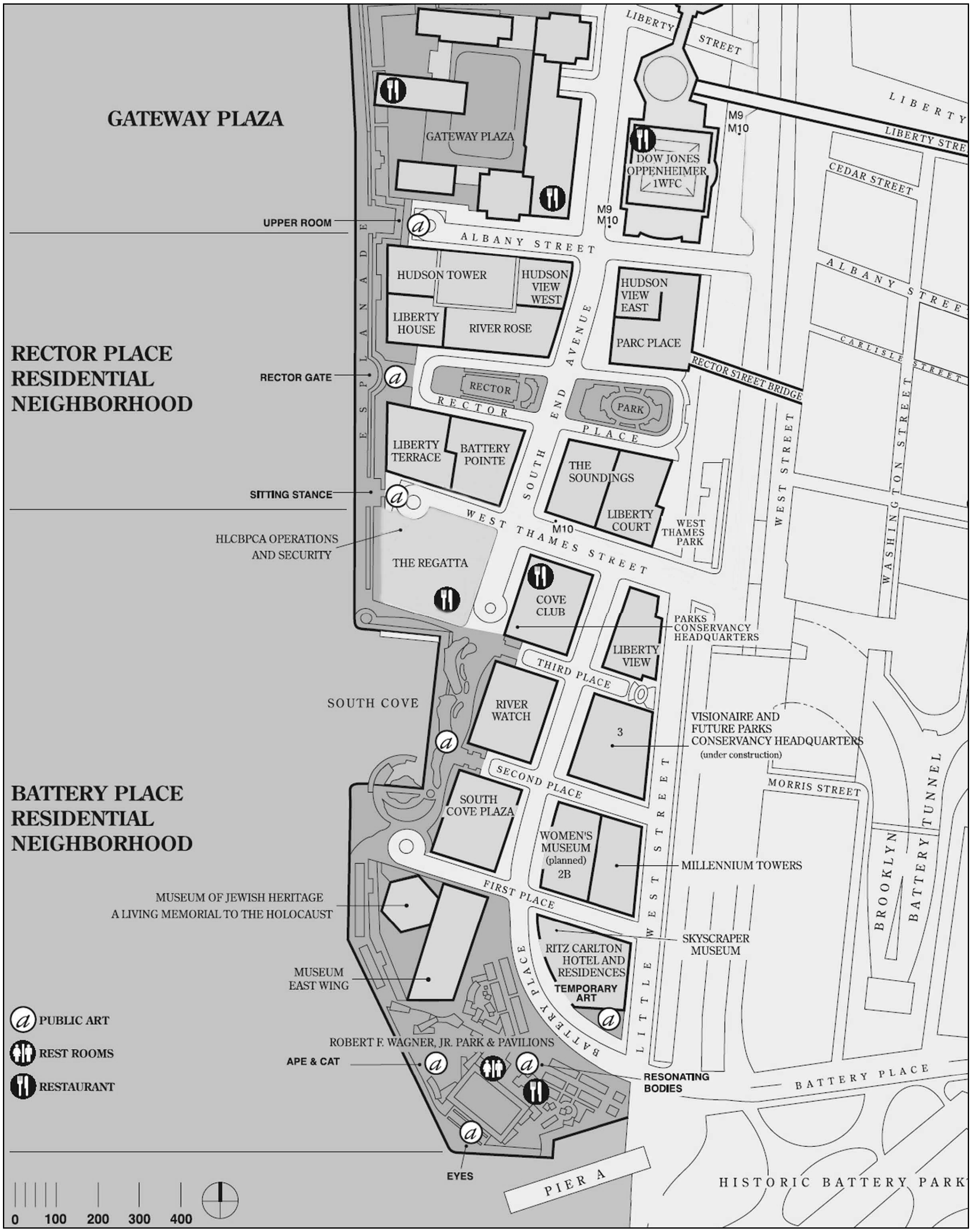

Figure 5.10 Map of Battery Park City II

Source: BPCA (2008)

use of products that minimizes V.O.C.'s (volatile organic compounds), while reduction in energy and water consumption is a key factor in green building construction. The Solaire uses 35 percent less energy than New York State Energy Code requirements, reduces summer peak demand by 65%, and generates 5% of the building's base electrical load by on-site photovoltaics. Water reuse systems of the Solaire enable the building to consume 50% less portable water than a traditional building of similar size on the whole. As an urban skyscraper, the Solaire takes advantage of well-equipped grids of energy and water in the mature industrial systems of large cities, but lessens its impacts on public utilities by its environmentally friendly features. This 'low-impact' approach to the urban infrastructure, as well as to the environment, is what makes urban green buildings unusual recently, and the water and wastewater reuse systems at the Solaire and their interactions with existing parks, physical infrastructure, and local governmental agencies are an exemplary case of this approach.

For example, BPCA and the Albanese Organization have linked material and energy flows between Tear Drop Park and surrounding buildings, including the Solaire, located at the same block in the North Residential Neighborhood at Battery Park City, as illustrated in Figure 5.8. The Solaire has a water reuse system that treats wastewater from the building sewer to supply nonpotable water for toilet, and cooling tower makeup, and to irrigate neighboring Tear Drop Park. The idea of the irrigation of Tear Drop Park from the Solaire's water reuse system came from BPCA (Carey, 2006; Huxley, 2006). For BPCA that managed parks with the BPCPC and led green building practices with the Albanese Organization, it might be natural to connect the building and the park. The Albanese Organization's next project near Tear Drop Park, The Verdesian, also has similar system for landscape irrigation, and is equipped with heliostats which are giant mirrors to capture and redirect sunlight to Tear Drop Park (Sheftell, 2008; Williams, 2005).

In addition, a governmental agency reacted to the Solaire's water reuse system, and started an incentive program for similar systems in the New York area. Water reuse systems are in the grey area of urban water management: the Safe Drinking Water Act and the Clean Water Act are not applicable to the systems, since water reuse systems do not release potable water and discharges. Therefore, the water reuse systems are handled as independent appliances by the Department of Health, without the need of special permits in New York (Clerico, 2007). In 2004, the New York City Department of Environmental Protection (NYC DEP) promulgated the Comprehensive Water Reuse Program which provides a 25% reduction in water and wastewater fees for buildings that incorporate a water reuse system that reduces the water consumption of minimum 25% by comparison to a base building that utilizes the average water consumption of 69 gallons per capita per day, as defined by the NYC DEP (Clerico, 2005, 2007). Even though the Solaire achieves a higher water use reduction, the incentive stays at 25% of the water and wastewater fees. In the U.S., the Solaire represented the first case that direct nonpotable water reuse is incorporated in a residential high-rise building, and NYC DEP's Comprehensive Water Reuse Program was the first such incentive program. This example of incentive on building's reduced burden on city's physical infrastructure clearly reflects the basic assumption of the low-impact approach in current urban green building development, and shows how urban green building can be fit into existing physical infrastructure of major cities with proper institutional coordination.

Beyond BPCA's leadership in residential green high-rise buildings, BPCA sought to bring the same leadership to office development, and issued the Commercial / Institutional Environmental Guidelines in 2002 (Battery Park City Authority, 2002). Experiences from residential green high-rise buildings are reflected to the Commercial / Institutional Environmental Guidelines, and BPCA expected to educate and influence the building industry with its green design visions and strategies, as the Residential Environmental Guidelines did. Goldman Sachs New World Headquarters, being built at the last commercial site in Battery Park City, was supposed to be the first building to be constructed along with the Guidelines, but the company decided to focus on the pursuit of the LEED gold certification (Kaplan, 2006). Nevertheless, the green practices of Battery Park City have stimulated the overall real estate industry all over the New York area, and pushed green offices and commercial high-rise buildings, as well as residential towers, to be developed around New York City in the last few years. In the next section, the evolution of the local institutional fabric that has enabled and facilitated green residential and commercial building developments in Manhattan will be probed.

5.6.2 'Green Towers for New York'

At first glance, it seems odd to match New York with the term 'sustainability'. The very size of the city embraces and magnifies all the visible environmental concerns in our society, and prevents us from thinking of New York as a favorable place for eco-industrial development. However, arguably, New York City maintains its extremely compact and energy-efficient form on a per capita basis with its skyscrapers and public transportation (Hsu, 2006; Owen, 2004). As the largest city in the U.S. with the largest municipal government in the U.S., New York also has enough capacity to innovate at the city level (Hsu, 2006). Although that might be an unintended consequence of the interactive relationships between human endeavor and the natural environment, the history and context of New York City has been influential for green practices in the City. It is not just a coincidence that the green building movement has been substantiated in New York City in the form of green high-rises or 'green towers' (Skyscraper Museum, 2006). New York City, with Chicago, has been an American city of skyscrapers. For several decades, high-rise buildings became a key part of the second nature of New York City. Probably no other place in the world was more qualified than Manhattan as a site for a green skyscraper.

4 Times Square is referred to and marketed as the first commercial high-rise building project that adopted environmentally responsible design, such as renewable building materials, energy-efficient lighting, solar panels and fuel cells, and higher air-quality (Earth Day New York, 1998). Located at Broadway and 42nd Street, this 48-story office was opened in 1997, before the USGBC released its first LEED rating system in 2000. The Durst Organization developed this office building, under the leadership of president Douglas Durst, with Fox & Fowle Architects (now FXFowle Architects), using a whole-building approach considering the maximum efficiency of systems of the building as a whole. The office also incorporated density-alleviating features, such as setbacks, and double façades to harmonize it with its neighborhood. Although the initial cost of the building was more expensive than others, mainly because of the pioneer's difficulties, the building was maintained with about 15% less operating costs, expected to achieve total cost savings in the long run (Earth Day New York, 1998).

The attention to 4 Times Square did not solely come from its environmentally friendly features: this office building was also a major economic success. 4 Time Square was the first skyscraper constructed in Manhattan since 1992 (Makagon, 2004). As a key building of the 42nd Street Development Plan, which has attracted about $4 billion in private funds to an underdeveloped area near Times Square since the 1920s, it had one of the biggest shares of total investment (Sagalyn, 2001). With significant assistance from the Giuliani administration, including city tax breaks, Condé Nast Publications decided to move into the building and that decision gave this building a major breakthrough in its success and the nickname of the Condé Nast Building. 4 Times Square became the biggest building and one of the most profitable projects for the Durst Organization at that time, fully leased within four months after the opening (Bianco, 2004).

The presence of 4 Times Square as a prototype green skyscraper has been quite an inspiration for the building industry in New York, but might not be contagious enough to generate the momentum to begin a series of green towers in Manhattan. It was mainly because the know-how created from the construction of 4 Times Square remained within the development team of involved architects, developers, and contractors, and turned out to be difficult to be transferred without proper frameworks. The Battery Park City experience has changed this situation. BPCA found a standardized scheme with the USGBC's LEED green building rating systems, and opened a practical way in which experiences from different green building projects can be documented, assessed, and transferred using those systems. In that sense, the Solaire was a criteria setter for the green building industry in New York, as well as a key example of successful green high-rise building. If 4 Times Square illustrated what to do, the Solaire detailed how to do green skyscrapers for interested developers. Since the earlier 2000s, green high-rise building has been no more an ideal case, but a realistic option in New York.

Since the meeting between the USGBC and BPCA in the late 1990s at the annual American Institute of Architects (AIA) conference, the USGBC has worked as a major non-local institutional anchor that offers reliable *de facto* green building codes and standards over the New York areas (Carey, 2006; Kaplan, 2006). However, the establishment of New York Chapter of the USGBC in 2002 as a local subsidiary anchor was instrumental to diffuse rather limited experiences of 4 Times Square and the Solaire to the overall New York area, and accelerate the initiation and construction of multiple green skyscrapers in New York (U.S. Green Building Council, 2008c).

It was in 2002 that a handful of the first local chapters were founded, when the USGBC began its Emerging Green Builders (EGB) program for students and young professionals dedicated to become and recruit future green building leaders at the first annual Greenbuild International Conference and Expo held by the USGBC (U.S. Green Building Council, 2004, 2007b). Since then, about 80 local chapters and affiliates of the USGBC have been established, and the USGBC's New York Chapter is one of the first local chapters aiming to share local green building strategies and best practices and to provide local education and business opportunities. Most of all, the local chapter as subsidiary anchor quickly became a facilitator in organizing local communities of practice in green building builders, developers, and experts who were originally isolated in individual green building project teams, but began to communicate each other through activities of the New York Chapter. The chapter also enabled the USGBC to disseminate its agendas and strategies, as well as newest

Table 5.4 Green Towers in Manhattan

Building	Stories	Completion	Client / Developer	Architect	Development Manager	Construction Manager	LEED Rating
Hearst Tower	46	2006	The Hearst Corporation	Foster & Partners – Norman Foster Principal; Adamson Associates	Tishman Speyer Properties	Turner Construction Company	Gole
The New York Times Building	52	2006	The New York Times Company	Renzo Piano Building Workship, Renzo Piano; RXFowle Architects, PC; Gensler	Forest City Ratner Companies; ING Real Estate; The New York Times Company	AMEC: Core & Shell, Turner Construction Company, Times Company Interiors.	-
Bank of America Tower at One Bryan Park	54	Expected 2008/2009	One Bryant Park, LLC, a Joint Venture of Bank of America and The Durst Organization	Cook+Fox Architexts, LLP; Richard A. Cook, Partner; Robert F Fox Jr., Partner; Adamson Associates	The Durst Organization	Thishman Construction Corporation	Expected Platinum
Goldman Sachs New World Headquarters [PBC]	43	Expected 2009/2010	Goldman Sachs	Pei Cobb Freed & Partners; Adamson Associates	Tishman Speyer Properties	Tishman Construction Corporation	Expected Gold
7 World Trade Center	52	2006	Silverstein Properties, Inc.	Skidmore, Owings & Merrill LLP	Silverstein Properties, Inc.	Tishman Construction Corporation	Gold (LEED-CS)
Freedom Tower	84	Expected 2011	Silverstein Properties, Inc.	Skidmore, Owings & Merrill LLP	World Trade Center Properties, LLC; an affiliate of Silverstein Properties, Inc.	Tishman Construction Corporation	Pending
The Memorial Sloan-Kettering Cancer Research Center (MSKCC)	25	2006	Memoerial Sloan-Kettering Cancer Center	Skidmore, Owings & Merrill LLP in association with Zimmer Gunsel Frasca Partnership	-	-	Pending

Building	Stories	Completion	Client / Developer	Architect	Development Manager	Construction Manager	LEED Rating
The Solaire [BPC]	27	2003	Albanese Organization	Pelli Clarke Pelli Architects; SLCE Architects	Albanese Organization	Turner Construction Company	Gold
TriBeCa Green [BPC]	24	2005	The Related Companies, LP; MacFarlane Partners	Robert A.M. Stern Architexts; Ismael Leyva Architexts	The Related Companies, LP; MacFarlane Partners	Bovis Lend Lease, LMB Inc.	Gold
The Verdesian [BPC]	24	2006	Albanese Organization	Pelli Clarke Pelli Architects; Schuman Leichtenstein Clamon Efron	Albanese Organization	Turner Construction Company	Platinum
One River Terrace (Riverhouse) [BPC]	31	2007	The Sheldrake Organization	Polshek Partnership Architects; Ismael Leyva Architects	The Sheldrake Organization	Plaza Construction Corporation	Expected Gold
Millennium Terrace (Millennium Towers) [BPC]	35	2006	Millennium Partners	Handel Architects, LLP	Millennium Partners	Gotham Greenwich Construction Company, LLC	Gold
The Helena	38	2005	The Durst Organization; Rose Associates, Inc.	FXFowle Architects, PC	The Durst Organization; Rose Associates, Inc.	Kreisler Borg Florman General Construction Company, Inc.	Gold
West 31st Street (Epic)	58	2005	The Durst Organization; Sidney Fetner Associates	FXFowle Architects, PC; Schuman Lichtenstein Clamon Efron	The Durst Organization; Sidney Fetner Associates	Gotham Construction Company, LLC	Silver
The Mosaic (Archistone Clinton)	24	2007	The Dermot Companies	FXFowle Architects, PC; Gordon Kipping, H. Thomas O'Hara	The Dermot Companies	Bovis Lend Lease, LMB Inc.	Expected Silver

Source: Skyscraper Museum (2006) and USGBC (2008c)

* Changed building titles are presented in parenthesis and the titles of buildings in Battery Park City are tagged with [BPC] sign

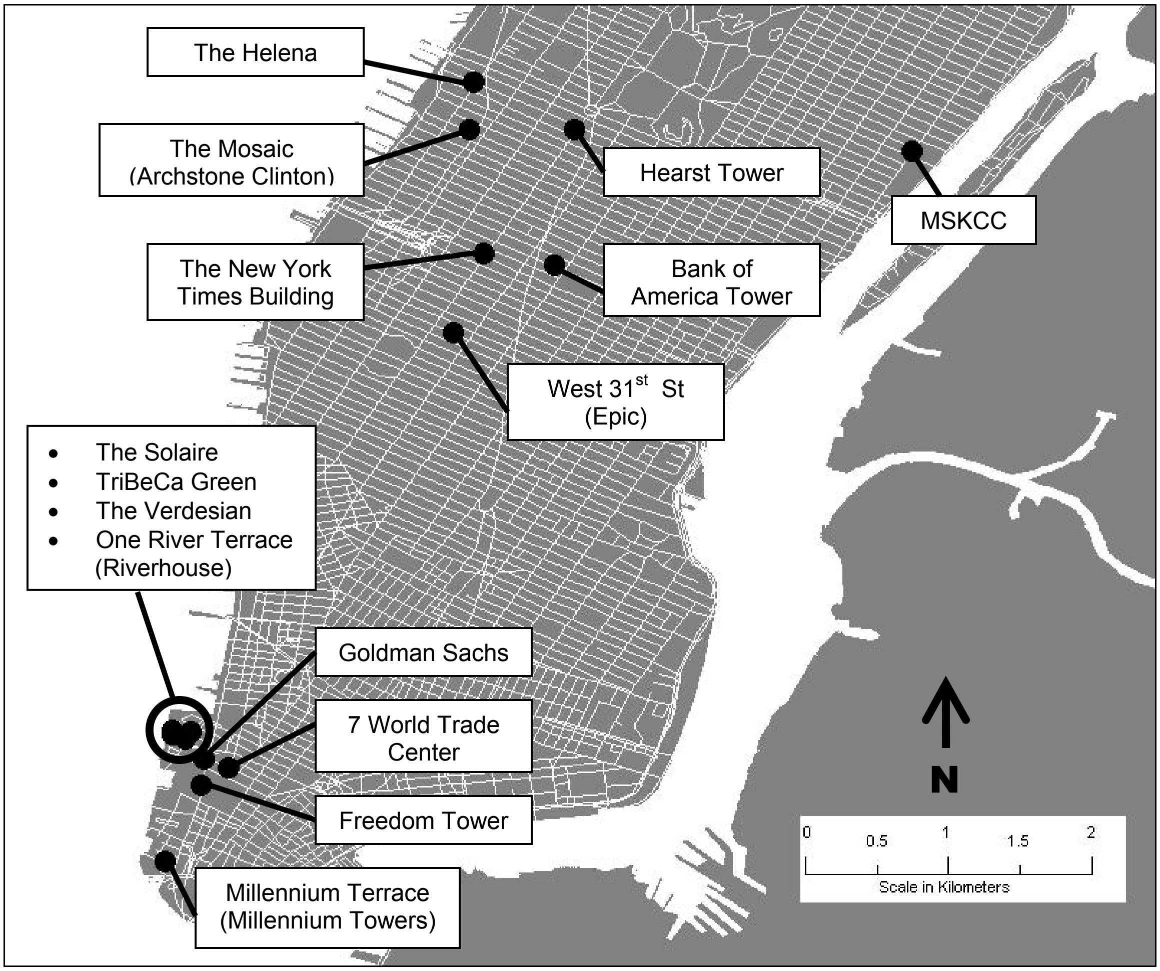

Figure 5.11 Sites of Green Towers in Manhattan
Source: Skyscraper Museum (2006) and USGBC (2008c)

information and knowledge, more intimately, and collect and learn practical expertise and know-how from one of the most active U.S. real estate markets more easily. Building trust and capabilities among local green builders and advocates beyond the boundaries of individual practices have been the key contribution of the New York Chapter to the local green building industry. As a promising market of potentially huge demands for green buildings, New York was perceived as one of the most desirable places to begin and manage a subsidiary anchor at that time, and the perception has proven itself noteworthy.

For the last few years, green skyscrapers have become an obvious real estate trend in New York City, driven by both clients and developers (Gross, 2007; Pogrebin, 2006b). A New York Times article described the perceived imperative of green high-rise buildings in the real estate industry in Manhattan, as such:

> Most of the new apartment buildings by big-name architects are meeting LEED standards, whether or not they actually seek certification. Projects that do not pursue certification (among them, the new tower being built by The New York Times Company) are subject to a skeptical reception. (Pogrebin, 2006a)

The Skyscraper Museum's 2006 exhibition, 'Green Towers in New York' identified 15 sustainable skyscrapers recently completed or under construction and introduced their construction teams in Manhattan, as presented in Table 5.6 (Skyscraper Museum, 2006).[39] The first seven buildings in Table 5.6 are commercial offices, and the rest eight are residential high-rise buildings. Sites of completed or planned green skyscrapers in Manhattan illustrated in Figure 5.10. It shows that about half of them are located in or near Battery Park City. Except the New York Times Building and the Freedom Tower, all buildings have sought or been seeking the LEED certification explicitly. Obviously, experiences of residential green high-rise buildings in Battery Park City have influenced more recent green tower projects in Manhattan and helped to expand the reach of the local green building industry into the revival of commercial green high-rise offices after 4 Times Square, such as the Hearst Building and 7 World Trade Center (Pogrebin, 2006a).

It is noticeable that a group of clients, developers, architects, and construction companies have been repeatedly involved in green skyscraper projects in Manhattan. Firms and companies in the construction industry particularly rely on previous records of

39 Neuman (2006) and Gross (2007) introduced some other on-going green building projects in Manhattan.

successful construction projects in selecting their partners. As a result, they also tend to work with proven partners in former joint projects over and over again. For example, the Durst Organization has worked two residential green high-rise buildings – The Helena and Epic – with the FXFowles Architects who designed 4 Times Square. Similarly, green towers in Battery Park City, especially driven by the Albanese Organization, tended to work with an architectural firm, Pei Cobb Freed & Partners. Local and regional construction companies, like Turner, Tishman, and Gotham, have been built their reputations in the construction of green high-rise buildings in New York City. Most of those local and regional actors have become members of the USGBC's New York Chapter, and relatively new green building developers, including the Related Companies, Millennium Partners, and the Dermot Companies could take advantage of the established local networks of builders, architects, and construction companies with previous practices of green high-rise building.

Expanding markets for green buildings result in the growth of various suppliers and contractors ranging from environmentally friendly products and construction materials to green design and environmental services and continue to reduce costs of green building development. A series of residential green skyscrapers in Battery Park City by the Albanese Corporation illustrate this market transformation. When the Solaire was being built by the Albanese Corporation, lots of construction materials and equipment had to be custom-made to be qualified for the LEED requirements and the BPCA's Residential Environmental Guidelines, and the Corporation spent an extra 17 to 20 percent of construction costs for green building features, which brought the LEED Gold certification to the Solaire (Aridas, 2004; Battery Park City Authority, 2003). The

Albanese Corporation's next project, the Verdesian acquired the first LEED Platinum certification as a residential green skyscraper with 15 percent of investment premium for green building features in 2006. The most recent project, the Visionaire was completed with only 5 percent additional investment in 2008 (Kuchment, 2008; Sheftell, 2008). In addition, except savings in operation and maintenance, those buildings' rents are about 8 to 9 percent higher than comparable traditional buildings. It is no more a surprise that green skyscrapers have become a legitimate business opportunity for a bunch of enlightened developers in Manhattan.

City and state governments have encouraged the trend by setting local green guidelines and offering public policies for green buildings. The New York City Department of Design and Construction (DDC) established the Office of Sustainable Design (OSD) in 1997 (Hsu, 2006). The OSD released DDC's High Performance Building Guidelines in 1999 and High Performance Infrastructure Guidelines in 2005. With BPCA's 1999 Residential Environmental Guidelines and 2002 Commercial / Institutional Environmental Guidelines, those guidelines have offered helpful references for local developers and general construction contractors involved in green building projects. In 2000, the New York State legislature passed the Green Building Tax Credit under which developers who build green buildings in accordance with requirements based on the LEED would be able to take a tax credit against a portion of additional costs for green features, and the next year, New York Governor Pataki issued an Executive Order to encourage state building projects to acquire LEED certification (Earth Day New York, 2001). The Green Building Tax Credit program has finished its first period, and the second five-year period, which started in 2005, is in action after updating requirements in accordance with other codes and standards, such as the 2002 NYS Energy Construction Conservation Code, the 2003 NYS Uniform Fire Protection and Building Code and LEED-NC version 2.2 (New York State Department of Environmental Conservation, 2006). In 2005, Mayor Michael Bloomberg enacted Local Law 86, which mandates that new public buildings should be designed to achieve the LEED silver certification, and requires that major renovations should consider the reduction of water and energy consumption (Hsu, 2006).[40] With all those public policies for green buildings, New York City has become a more favorable place in developing green buildings.

It is clear, though, that green skyscrapers in New York City are not a viable and feasible option of eco-industrial development for most of other cities and communities. However, this limitation can be a huge opportunity for world class cities that have active real estate markets and innovative capabilities inviting tryouts and experiments (Presas, 2005). As analyzed in Chapter 4, the LEED-NC green buildings have been clustered in major cities and their neighboring counties. Green skyscrapers are a new form of eco-industrial development grown out of trials and errors in those environments, and their contribution to the overall green building movement can be found in institutional processes and new technologies enabled in their developments, transferrable to much smaller green building projects through the non-local networks of the USGBC and its growing local chapters as subsidiary anchors. This perceived diffusion process, however, has not been proven, and is needed to be tested in the near future.

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40 Governments can take a role of code- or standard-setter in environmental public policy, like Energy Star, or create green niche markets using their large purchasing power. In the case of green building, governments accepted the LEED as a de-facto standard, and became a key buyer. In 2006, federal, state and local governments owned 46% of total LEED projects (U.S. Green Building Council, 2006b).

5.6.3 Results from the Battery Park City Case

The Battery Park City case is another distinctive case of the symbiote pathway, in which an eco-industrial development establishes itself as a sustainable part indebted to its mature local industrial systems abundant of physical and institutional networks, and ultimately brings some structural eco-industrial changes to its systems. Overall, green buildings tend to be located in and near big cities, as shown in 4.4. That is partly because recent green buildings tend to take advantage of well-equipped urban physical and institutional infrastructure, instead of building self-sustaining structures in more nascent settings. 4 Times Square, a prototype green office tower, predates the recent trend of green skyscrapers in Manhattan, mainly pioneered by a series of development of residential green high-rise buildings in Battery Park City. This trend of urban green towers results from vibrant institutional interactions between local and non-local anchors involved in green building developments in Manhattan. Figure 5.12 illustrates these interactions schematically.

As a strong local institutional anchor tenant that owns and manages the Battery Park City and has significant power of coordination and negotiation on governmental agencies, BPCA has triggered an impressive green leadership in eco-industrial development at Battery Park City. BPCA brought the USGBC’s LEED green building rating systems at the New York scene, and has led developers to observe the Residential and Commercial / Institutional Environmental Guidelines in creating green high-rise buildings in Battery Park City. Pioneers’ difficulties of developers have been mitigated by the very scale of green skyscrapers and the learning experiences from repeated construction of them, as well as the Authority’s resourceful supports.

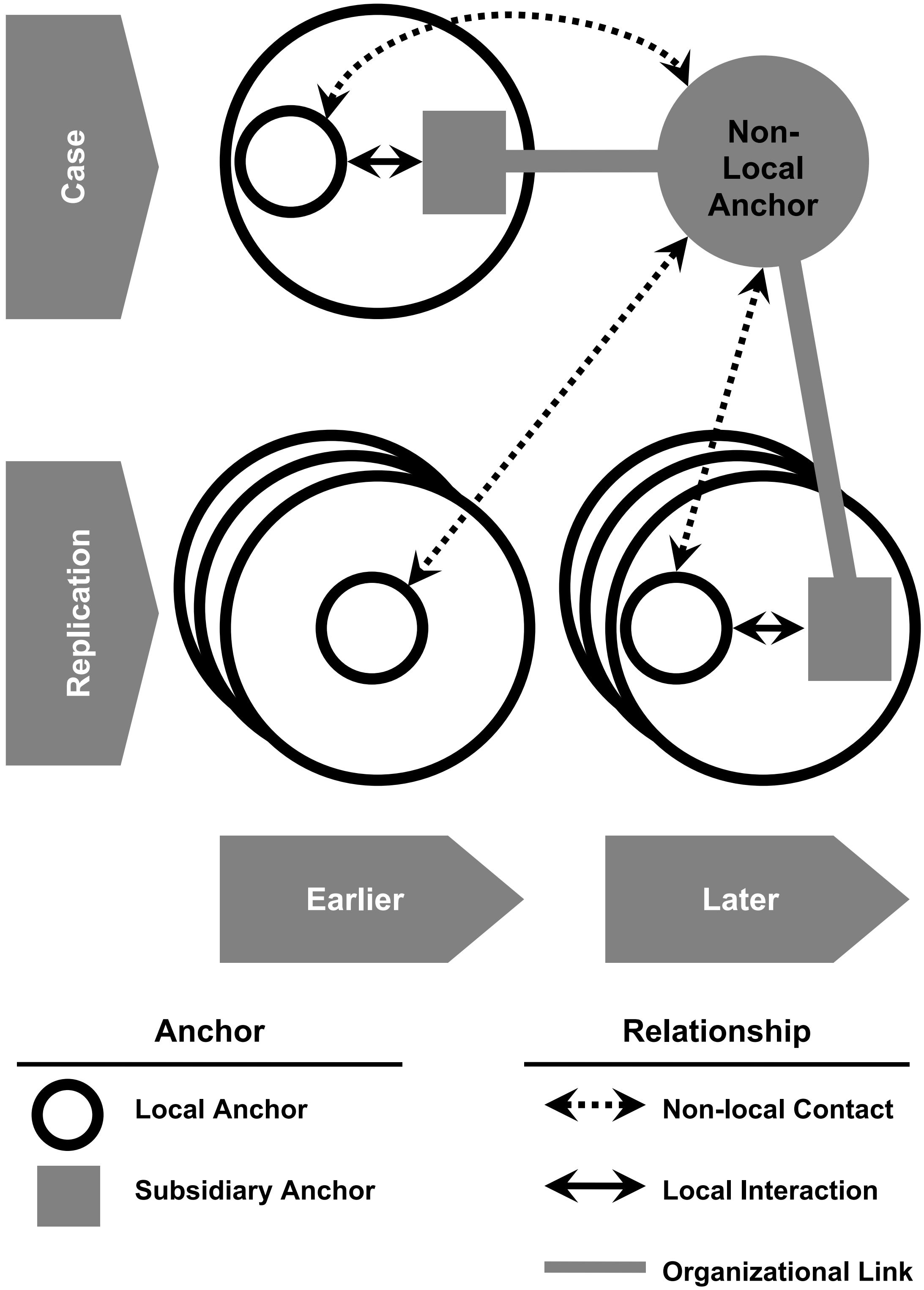

Figure 5.12 Institutional Relationships among Different Anchors in the Battery Park City Case

* Thick outer circle means mature local industrial systems.

It is fair to say that New York City was prepared for accepting the consequences of the Battery Park City experience willingly. Traditionally, New York, especially Manhattan, has been a skyscraper capital of the North America in competition with Chicago, and one of the most active real estate markets in the U.S., full of local developers, contractors, and builders. As a global city, New York City has sophisticated and resilient grids of infrastructure and public utilities that have been built, operated, and improved for decades. In the late 1990s and the earlier 2000s, developers understood prospective benefits of green high-rise building after both economic and environmental achievements of 4 Times Square, and the city government was willing to encourage green building construction by establishing the OSD that released High Performance Building Guidelines and High Performance Infrastructure Guidelines for better eco-industrial development in New York City. Existing institutional networks and physical infrastructure of Manhattan have allowed the Battery Park City experience to be accepted and varied in Manhattan in the last decade.

The USGBC has been a key non-local institutional anchor in the Battery Park City case. While the local presence of the USGBC was not minimal at first, the Council has maintained close contacts with BPCA since the late 1990s. BPCA's guidelines are locally customized versions of the LEED green building rating systems which evaluates and certifies whether a constructed high-rise building in Battery Park City is a green building. Despite being a non-profit, non-governmental organization, the USGBC has successfully positioned its LEED rating systems as *de facto* codes and standards of green building in the U.S., as described in 4.2. The public acknowledgement of the LEED has enabled the USGBC to promote green building projects in various locations more easily in the distant, since standardized procedures of registration, evaluation, and certification through LEED can minimize direct contacts between the USGBC and the directors and managers of local green building projects who want to attain the green building certification as a visible and marketable form of eco-label.

The growth of the national green building market by the diffusion of LEED, however, has forced the USGBC to pursue its local presence as well in spite of standardized LEED certification processes, since at first local green building experts and contractors were required to be identified and motivated collectively by education and communication, and later a huge pool of best practices and know-how that are valuable but not easily accessible from a distance should be intimately and systematically collected and redistributed from different locations. The USGBC's solution to this matter was to create local chapters as subsidiary anchors in major cities and communities of economic vitality and heightened environmental concerns. About 80 local chapters and affiliates of the USGBC have been developed, and these organization links have been key local actors in promoting green building practices. New York was not an exception. The establishment of USGBC New York Chapter in 2002 was instrumental in expanding and replicating the green building practices of Battery Park City in Manhattan, as illustrated in Table 5.6 and in Figure 5.11.

Green skyscraper practices at Battery Park City and in Manhattan are now being diffused to other major cities through institutional networks centered on the USGBC. For example, the Related Companies builds a residential green tower, 340 on the Park, near the Millennium Park in Chicago, based on its development experiences of a green high-rise residential building, TriBeCa Green at Battery Park City and a mixed-used building, Time Warner Center at Columbus Circle in Manhattan (Skyscraper Museum, 2006). Chicago also has an architectural history of skyscrapers, and has been a major player in green building development with its local chapter founded when New York Chapter was established. Similar to the BPCA's guidelines, the City of Chicago has developed its own citywide Chicago Standard, based on the LEED rating system as a part of its overall Chicago Climate Plan (City of Chicago, 2006). Chicago Sears Tower and Merchandise Mart which recently attained the LEED-EB (Existing Buildings) certification, and two LEED-NC certified green high-rise offices – 111 South Wacker and One South Dearborn – are recent examples of Chicago's green building drive (Wenzel & Wenzel, 2007).

The combination of non-local codes and local chapters seems to be an effective strategy to reproduce and diffuse best practices from a location to other locations, not only in the post-industrial context, but also in the industrial context. Although fully-blown cases of this type have not been identified in the industrial context, some meaningful programs of this eco-industrial development are in progress. For example, the USBCSD, introduced in 5.5, has had plans to establish local chapters and affiliates as subsidiary anchors since it had multiple regional BPS projects across the U.S. simultaneously (Mangan, 2006; Silva, 2006). One of the first affiliates is the Ohio Business Council for Sustainable Development (BCSD) which was established as a statewide BCSD with the launch of the Central Ohio By-Product Synergy Project in 2008, as briefly introduced at the end of 5.5 (Center for Resilience, 2008). The USBCSD's attempt to establish local chapters and affiliates seems to share similar causes with the USGBC: the motivation of locally available stakeholders and the facilitated communication among local actors and between local and non-local anchors.

Another comparable example can be found in Devens, MA, an individual eco-industrial development, which turned an old military base into an eco-industrial park (Ecology and Environment, 1997). Devens is a unique experience in eco-industrial development in the U.S., since it has several key aspects of eco-industrial development in the site, including green building, eco-industrial park, and smart growth.[41] Since the earlier 2000s, Devens has attempted to balance its eco-industrial park with the LEED green buildings (Hollander & Lowitt, 2000; Williamson, 2001). Devens Enterprise Commission (DEC) encourages members of the park to introduce the LEED certification with the Green Building Incentive Program which grant 15 percent of unified permit fee when the LEED green building projects in the park are certified. Devens also has plans to transform old buildings into green ones with the LEED-EB (Existing Buildings) and ultimately the whole eco-industrial park into a green neighborhood with the LEED-ND (Neighborhood Development) (Lowitt, 2007).

However, the most distinctive feature of Devens is its own eco-label of green codes and standards, the EcoStar environmental achievement and branding program, launched in 2005, which is roughly an equivalent to the LEED in the industrial context (Devens Enterprise Commission, 2008a, 2008b). This practice of the EcoStar program appears to be very similar to the earlier movement of local green building standards before LEED (National Association of Home Builders, 2002). Until now, the EcoStar program is applied within the Devens eco-industrial park, but has got significant attentions from industrial ecologists and environmental policy makers recently. While it is too early to evaluate results from all the innovative eco-industrial programs and

41 Devens is a winner of the 2006 Environmental Award from Mass Audubon & Worchester Business Journal, the 2007 Massachusetts Smart Growth / Smart Energy Award, and the 2008 EPA Merit Award.

projects in Devens, the recipe of codes and local eco-industrial practices led and driven by the DEC, a local institutional anchor managing the Devens Regional Enterprise Zone, appears to be promising. Lessons from the Battery Park City case in connection to the USGBC can be beneficial to refine and enhance those similar eco-industrial development approaches in the industrial context. In the last section, findings from three on-going eco-industrial development cases will be summarized to compare their results and distill lessons from their benefits and limitations for future eco-industrial developments and policy implications for them.

5.7 Summary of Findings

In this Chapter, the hypothesis three (institutional fabrics) of this dissertation is examined with three on-going eco-industrial development cases in the U.S.A. The Rutgers EcoComplex, Regional BPS Projects in Kansas City and in Chicago, and the Battery Park City's green skyscrapers are identified and analyzed as vital cases of eco-industrial development. Findings from case studies uncover three different institutional fabrics of local and non-local institutional anchor tenants enabling eco-industrial developments in action in different locations and contexts. Institutional fabrics in each case are represented with the interactions among local and non-local anchors, and unique replication strategies of those institutional fabrics in each case are also originated from those local and non-local interactions, as schematically illustrated in Figure 5.6, 5.8, and 5.12. Table 5.5 summarizes those anchors and strategies in three cases with references of related burgeoning eco-industrial practices and programs briefly introduced at the end of each case study.

Table 5.5 Summary of Key Local, Non-local Anchors and Replication Strategies in Case Studies

Pathway	Context	Case	Local Anchor	Non-local Anchor	Replication Method	Replication Strategy	References
Catalyst	Industrial / Post-Industrial	The Rutgers EcoComplex	The Rutgers EcoComplex	Rutgers / NJAES (New Jersey Agricultural Experiment Station)	Platform : ELATE (Environmental Laboratory for the Advancement of Technological Entrepreneurship)	Modular Anchor : CaribELATE Project	• EcoComplex at Catawba Councy, NC • Regional BPS Project at Columbus, OH
Symbiote	Industrial	Kansas City Regional BPS (By-Product Synergy) Initiative	BTG (Bridging the Gap)	USBCSD (US Business Council for Sustainable Development)	Project : Regional BPS Project	Temporary Anchor : USBCSD in Regional BPS Projects	• NISP (National Industrial Symbiosis Program), UK
		Chicago Waste-to-Profit Network	CMC (Chicago Manufacturing Center)				
	Post-Industrial	Battery Park City	BPCA (Battery Park City Authority)	USGBC (US Green Building Council)	Code : The LEED Rating Systems	Subsidiary Anchor : USBCC New York Chapter	• Chicago's Green Skyscrapers • Ohio BCSD • EcoStar Program at Devens, MA

Overall, these case studies support the hypothesis three (institutional fabrics) in two ways. First, collective capacity building processes to generate local institutional fabrics are necessary to enable designed or engineered solutions and networks of eco-industrial development to come true. Replication strategies in case studies are typically focused on how to create local institutional fabrics effectively in different locational contexts. In general, making an eco-industrial development takes time, so it should be backed up with solid institutional fabrics making the eco-industrial development survive and work. Second, local and non-local institutional anchor tenants need to interact with each other to establish concrete institutional fabrics for specific eco-industrial developments. In the case studies, neither local anchors nor non-local anchors solely led eco-industrial developments to be successful. Joint pathways that emerged from the interactions among local and non-local anchors have been crucial in initiating and managing viable eco-industrial developments. While there may be a lot of achievable institutional fabrics enabling various eco-industrial developments, three on-going institutional fabrics in three case studies are identified and closely examined in this chapter.

Findings from case studies favor the symbiote pathway over the catalyst pathway in the U.S. The catalyst pathway was represented by the Rutgers EcoComplex case, in which the EcoComplex is sited in Southern New Jersey, a relatively less-developed area in New Jersey, to stimulate economic development of the surrounding region as an environmental technology research center and business incubator. While the Rutgers EcoComplex has been created and managed successfully since the early 2000s, the EcoComplex has had limited impacts on its nascent local industrial system that lacks local institutions and businesses essential to regional economic development. In its current stage, the Rutgers EcoComplex is like an island of eco-industrial development and is required to strengthen its capacities and to develop well-built local and non-local institutional networks possibly supporting economic development in the future. That takes a significant amount of time and money, and most of all requires institutional leaderships constant and strong enough to tolerate the whole process of local eco-industrial development. It might be a feasible but not necessarily efficient or prompt option for eco-industrial development. The stalled attempt of the transplantation of the Rutgers EcoComplex experience in the CaribELATE illustrates the rather higher financial and institutional requirements of this pathway.

The symbiote pathway is tested in the Regional BPS Networks case and the Battery Park City case. Both cases generate eco-industrial developments that take advantage of existing institutional and physical networks in mature local industrial systems, particularly in major traditional cities. Regional BPS networks in Kansas City and in Chicago as well as in a group of major cities across the U.S. have created and managed eco-industrial developments to reuse and recycle wasted materials and energy to and from local businesses and institutions collectively. Battery Park City provided a concrete physical and institutional infrastructure under the strong local leadership of BPCA to generate green high-rise buildings on site. Since both cases have organized institutional networks from existing local and non-local anchors necessary for eco-industrial developments, instead of creating new facilities or institutional anchors, the financial and institutional requirements of those cases are relatively lower, and allow those cases to be replicated in different locations rather suitably. It seems a reasonable and strategic choice for emerging eco-industrial development projects to rely on developed industrial systems, rather than to develop new local systems.

The balance between local and non-local institutional anchor tenants can be different from case to case. The Rutgers EcoComplex itself was created as a local anchor in the Rutgers EcoComplex case, and has built its capabilities to stimulate local economic development over time since its establishement. Existing local not-for-profit organizations, such as BTG in Kansas City BPS Initiative and CMC in Chicago WTPN, are resourceful local anchors in organizing eco-industrial projects in close cooperation with local and non-local actors and taking over the operation and management of eco-industrial developments later in the Regional BPS Networks case. Finally, BPCA that has the ownership of Battery Park City has been the strongest local anchor among three cases, which can mobilize local builders and contractors and confer with city and state governments to construct its green skyscrapers along with its green guidelines.

The degree of involvement of non-local institutional anchor tenants in each eco-industrial development varies according to the strength of local anchors. Rutgers and NJAES have secured a significant part of the funding for the Rutgers EcoComplex and shared their human and economic resources with the EcoComplex. The USBCSD has spread the concept of BPS and guided multiple regional BPS projects across the U.S. as a key consultant and enabler. Finally, the USGBC has maintained its distant communication with BPCA and participants of green high-rise buildings in Battery Park City through its LEED certification procedures, and pursued its local interactions later by the establishment of USGBC New York Chapter as subsidiary anchor. Those dynamic interactions between local and non-local anchors, as well as growth of participating anchors, have been essential in generating capable institutional fabrics for eco-industrial development.

Replication methods and strategies coming out of those institutional fabrics reflect their evolutionary paths in different locations. The Rutgers EcoComplex experience inspired some members of the EcoComplex to create a general platform of the ELATE and to transplant the platform in different locations. The ELATE was designed as a standardized modular anchor of local physical anchor of landfills and local institutional anchor tenant of a research center and its greenhouse facilities, and was applied to Puerto Rico as an eco-industrial development project of the CaribELATE. While the CaribELATE could replicate modularized parts of the Rutgers EcoComplex, it could not successfully reconstruct local and non-local institutional networks that enable and sustain the EcoComplex or invent new networks for the CaribELATE within its project time limit. Still the ELATE has potential to be a feasible modular anchor, if it can be enhanced with the CaribELATE experience and lessons from other eco-industrial developments analyzed in this chapter. Comparable eco-industrial developments to the EcoComplex at Catawba County, NC and Central Ohio Regional BPS Project at Columbia, OH deserve more attention related to this replication method and strategy in the future.

In regional BPS projects in the industrial context, the USBCSD has been a key institutional anchor tenant of multiple BPS projects in different locations. During the period of a regional BPS project, the USBCSD is involved in the project as a temporary institutional anchor that attends local forums and meetings for institutional networking and provides adequate expertise and consultancy services acquired from former experiences. After the regional BPS project, local institutional anchor tenants take a role of managing the project and transforming it into a more established eco-industrial development, and the USBCSD moves to other BPS projects but retains its links to former local anchors and finds new interested local anchors by orchestrating occasional contacts and regular meetings. Local anchors may take a more independent route which BTG takes to widen and deepen local institutional networks in Kansas City or continue an interactive route which CMC promotes in Chicago with the USBCSD and the NISP. It is notable that not only the USBCSD increases its coverage, but also both the Kansas City BPS Initiative and the Chicago WTPN are seeking to expand their networks based on their current achievements. The impressive results from the NISP as a national industrial symbiosis organization in the U.K. give proper sanction to this approach, and the Chicago WTPN was the first case using both methods of the USBCSD and the NISP. Evolutionary path of this case can be very fruitful in the industrialized areas and countries, and needs further analysis.

The Battery Park City case in the post-industrial context unravels another operating replication method and strategy. The USGBC has created the LEED green building rating systems which are not considered *de facto* codes and standards of green building in the U.S. The strong leadership of BPCA brought the emerging reputation of the LEED as well as its standardized certification procedures in developing green residential high-rise buildings in Battery Park City, and local developers and builders aware of potential benefits of green office towers like 4 Times Square found a practical way to construct new green residential and commercial skyscrapers from the Battery Park City experience. The establishment of New York Chapter of the USGBC was timely for the emerging green building market in New York. The local chapter has invited practitioners and specialists in individual green building cases and facilitated communications and interactions between them and motivated actors in the local building industry, as well as between local actors and the USGBC. Current green towers in Manhattan result from those interactions, and similar green high-rise buildings have been designed and constructed in other major cities with local USGBC chapters, including Chicago. Although still at its earlier stage, the reproduction mixture of green codes and subsidiary anchors appears to be applicable to the industrial context, as well as to the post-industrial context. The USBCSD begins to create its local affiliates like the Ohio BCSD, and the eco-industrial development at Devens, MA generates its own green eco-label EcoStar to standardize environmental management of industrial facilities.

A few policy implications can be distilled from findings from case studies. First, the symbiote pathway can be a more effective strategy for eco-industrial development than catalyst pathway. Right now, eco-industrial development, as well as sustainable development, is not for every location. There are favorable or unfavorable locations for eco-industrial development. Results from case studies imply that industrialized areas of cities and clusters are productive locations of eco-industrial development. Quantitative analyses of eco-industrial development in Chapter 3 and 4 support the results in both industrial and post-industrial contexts, too. Hence, it might be reasonable for capable municipalities and entrepreneurs to concentrate on urban eco-industrial developments and for governmental agencies to support the smooth and swift diffusion of lessons and innovations from them to less-resourceful but enlightened pursuers of eco-industrial development through recognized non-local networks. Direct investment to a self-sustaining type of eco-industrial development in under-developed areas can be a costly and time-consuming policy option.

Second, institutionalized deliberation processes for capacity building through eco-industrial practices and projects are essential to establish solid institutional fabrics for successful eco-industrial developments in the two cases of the symbiote pathway in both the industrial and post-industrial contexts. It seems that neither local nor non-local anchors, neither private members nor government agencies done can make eco-industrial developments work. The coupling of established local institutional anchor tenants with local knowledge and reputation and non-local institutional anchor tenants with new ideas and concepts has been proven as a recipe for wearing strong institutional fabrics. As influential local or non-local institutional anchor tenants, governmental agencies can provide and find funding sources for those deliberation processes, recruit desirable local and non-local participants, and attend those deliberations as key members to coordinate existing rules and regulations with new requirements for new eco-industrial development.

Finally, material and energy exchanges in the post-industrial context can be effectively exploited in a similar way as those in the industrial context. The Battery Park City case in the post-industrial context does not show dynamic material and energy exchanges like Regional BPS Networks case in the industrial context. The wastewater treatment cascading from the Solaire to near Teardrop Park is an exceptional anecdote. However, collective efforts among economic units in both industrial and post-industrial contexts to achieve better environmental and economic performances are not unfeasible, like the reference case in Devens, MA, a hybrid eco-industrial development of green buildings in an eco-industrial park.

Material and energy exchanges between industrial and commercial buildings are also a viable option for this hybrid eco-industrial development. New York is actually a working example of these material and energy exchanges. The city has the largest distribution system of cogeneration which uses stream as a beneficial by-product of power generation to heat many New York buildings (Hsu, 2006). Similarly, the coordination between green building and industrial facilities of this type has been established at an individual green building project in Cambridge, MA. Genzyme Center, a global biotechnology firm Genzyme Coporation's 12-story new headquarter, is located near MIT. Its location on a remediated brownfield site was not only helpful for the building to earn the LEED Platinum certification but also to draw waste steam from a nearby power plant into the center's HVAC system for heating and cooling (Brown, 2004). Industrial symbiosis or by-product synergy of material and energy flows among economic units in both industrial and post-industrial contexts is a rather neglected area, but as those real cases show, the area seems to have a larger potential for future urban eco-industrial development, and policy makers can help to exploit this less explored area by creating business forums among stakeholders of both industrial facilities and commercial buildings and governmental officials and offering incentives for green codes and standards.

The next chapter is the last chapter of this dissertation and summarizes main reflections on policy implications from findings from the whole dissertation and suggests further research directions for eco-industrial development in urban planning, geography, and regional science as spatial social sciences, as well as in industrial ecology.

Chapter 6. Eco-Industrial Development for the Future

6.1 Comments and Reflections

This dissertation examines the spatial forms and contextual factors of existing greener economic units as key actors in potential eco-industrial developments, and the institutional fabrics of on-going eco-industrial developments in the industrial and in the post-industrial contexts. Hence, the dissertation probes the possibility of sustainable industrial development both environmentally and economically with the current industrial systems and evaluates the validity of eco-industrial development practices and strategies in the U.S. Overall, findings from the dissertation illustrate three main lessons for on-going and potential eco-industrial developments across the U.S.A.

First, spatial forms of eco-industrial developments tend to follow existing geographical patterns of economic units, and to cluster in and around a group of major U.S. cities in the industrial and the post-industrial contexts. Findings from the exploratory spatial data analysis (ESDA) and regression analyses in Chapter 3 illustrate that larger and greener plants in selected pollution-intensive industries tend to be located in spatial clusters of those industries which typically embrace a group of major cities. Descriptive analysis, event history analysis, and panel data analysis of green building projects in Chapter 4 show similar results in the post-industrial context. Greener offices are likely to be located in central cities and their neighboring counties, since central cities are where the recurrent adoption and the fast growth of green buildings occur. It is an unexpected finding that spatial clusters of greener plants tend to share the same centers of major cities as those of greener offices. Overall, major cities appear to have potential to be favorable environments for eco-industrial developments in both the industrial and post-industrial contexts.

Second, contextual factors have significant impacts on the environmental performance and locational behavior of greener economic units. In the industrial context, the economic performance of larger plants, measured by labor productivity, is mostly conditioned by the scale economies of those plants, while environmental performance, measured by pollution intensity, is controlled by factors of localization economies at the county and the multi-county level. The factors of urbanization economies and environmental policies generally have negligible impacts on the economic and environmental performance of plants. In the post-industrial context, however, urbanization economies seem to be working: More green buildings are attracted faster mainly by the size of population and number of highly educated persons, representing the size of market demands, and cities and their neighboring counties are likely to have more green building projects sooner. In addition, economically sound places tend to build more green buildings in spite of their initial hesitation toward green building adoption in general. An existing pro-environmental atmosphere may accelerate the adoption of green buildings, but it is governments that can boost the growth of them with green building initiatives and policies.

Third, institutional fabrics of continuing eco-industrial developments reveal the importance of balanced capacity building processes between local communities and non-local networks at the local level, which are examined through a series of individual case studies. The pre-existence of environmentally enlightened local institutions and organizations as potential institutional anchor tenants can be instrumental in initiating eco-industrial development projects, transforming them into sustaining eco-industrial developments, and managing and improving them through continuous contacts with related actors through local communities and non-local networks. The Rutgers EcoComplex was established in close relation to its academic and institutional root, the Rutgers University and its Agricultural Experiment Station (AES). Regional by-product synergy projects relied on short-term projects between local institutional anchor tenants – Bridging the Gap (BTG) at the Kansas City project and Chicago Manufacturing Center (CMC) at the Chicago project – and a temporary anchor tenant, the U.S. Business Council for Sustainable Development (USBCSD). Finally, the Battery Park City Authority (BPCA) promoted local practices for green high-rises in Manhattan using the LEED green building rating systems from the U.S. Green Building Council (USGBC) and its New York chapter as a subsidiary anchor.

In a developed country like the U.S., the strategy of eco-industrial developments as symbiotes, in which eco-industrial developments are inserted in the mature local industrial systems and take advantage of existing local communities of practice and physical infrastructure to be a greener part of those systems, appears to be more feasible than the strategy of eco-industrial developments as catalysts, in which eco-industrial developments are greener pioneers to transform and boost their nascent local industrial systems both economically and environmentally. The role of the Rutgers EcoComplex as an eco-industrial catalyst to its local economies is still in question, while regional BPS projects in Kansas City and in Chicago, and local green building practices at Battery Park

City and in Manhattan keep getting visible results that fit the concept of eco-industrial development.

Based on those findings, planning and policy implications to support future eco-industrial developments pursuing both economic vitality and environmental excellence can be distilled in the fields of economic development and sustainable development. First, findings from the analyses of spatial forms of greener plants and offices suggest that potential eco-industrial developments will be likely to follow existing spatial patterns of economic units. In both the industrial and post-industrial contexts, spatial clusters of economic units turn out to be locations of greener plants and offices in the current industrial settings in the U.S.A. In other words, major cities and their neighboring counties are likely to be favorable environments for future eco-industrial developments. On-going cases of eco-industrial development also support this argument; eco-industrial developments in mature industrial systems appear to be more successful than those in a nascent environment in the case studies. In that sense, it is more strategic to take advantage of the agglomeration economies of existing cities and clusters in initiating and nurturing potential eco-industrial developments, than to develop new eco-industrial developments from scratch. Brownfield development appears to be a better policy option than greenfield development regarding future eco-industrial development projects in a developed country like the U.S.A.

Second, identification of influential contextual factors offers us a chance to refine policy options for the promotion of eco-industrial developments. In the industrial context, localization economies, identified by spatial clusters of single industries, have positive impacts on the environmental performance of larger plants in selected pollution-intensive industries, while their economic performance is mainly conditioned by their internal economies of scale. That result suggests that industry-specific policies for eco-industrial development can be effective in current industrial settings in the U.S., since greener and larger plants in a pollution-intensive industry as potential physical anchor tenants are significantly influenced by industrial specialization, and possibly tend to interact more with other economic units in the industry, according to the results. It is important to notice that the current analyses in the dissertation are organized at the SIC 2-digit level. Within an industry at that level, intra-industry relationships among economic units of various sizes in different sub-industries at the SIC 3- and 4-digit level can support the overall enhancement of environmental performance of economic units. On-going eco-industrial developments have started to use similar insights from their own experiences. For example, the regional BPS network in Chicago developed four small sub-groups in its framework, including organics, chemicals, metals, and building and construction groups to reduce and recycle wasted materials and energy (Mangan & Olivetti, 2008). Those sub-groups take advantage of their common industrial grounds to avoid unnecessary technical and communication conflicts and to streamline eco-industrial development projects among them. Policies promoting communication and deliberation among governmental officials, firm representatives, and entrepreneurs of shared industrial mindsets can be particularly instrumental.

In the post-industrial context, findings demonstrate that governmental policies to support the diffusion of green buildings have worked significantly. Although findings from the analyses confirm that governmental initiatives and policies for green buildings can increase the LEED-NC certified buildings and registered projects in a given municipality, it is not desirable for planners and policy makers to overlook impacts of existing demographic, economic, and geographic factors of a location in searching for strong policies to promote local green building developments. A perfectly good green building policy for a location is not necessarily a good one for a different location, since different locational characteristics may amplify or hamper the effectiveness of the green building policy. Different types of green building policies and their different impacts on the adoption and growth of green building projects should be tested against influential locational factors identified in this dissertation.

Third, case studies of institutional fabrics of on-going eco-industrial developments illustrate the potential importance of non-local actors and networks in initiating eco-industrial developments, as well as of pre-existing local communities. It should be mentioned that the overall benefits of cities and clusters in pursuing eco-industrial developments identified in this dissertation do not necessarily mean that less favored locations should not start eco-industrial developments. They can offset their disadvantages through capacity building processes, with solid understandings of their positions in the current industrial settings in the U.S. It can be an effective policy option to support non-local institutional anchor tenants that collect and disseminate information and knowledge of eco-industrial developments in the U.S., so more local communities can access key information on eco-industrial developments and organize their eco-industrial development projects more easily.

In the next section, directions for future research on eco-industrial development will be summarized. I focus on several new datasets and certifications that can be useful for future studies of eco-industrial developments in the U.S., and then introduce related topics and methods to extend and surpass the findings from this dissertation.

6.2 Directions of Future Research

6.2.1 New Datasets and Certifications

Several commercial and limitedly available datasets on the economic and environmental performances of plants exist. The TRI is still the main source of environmental emission data at the plant level, but economic datasets of wider coverage can be used to increase the size of joint samples of economic and environmental performances. Dun & Bradstreet (D&B) offers commercial databases and datasets which cover economic data on smaller plants than in the D&B's Million Dollar Directories (Dun & Bradstreet, 2008). The Census Bureau provides a limited access to the Longitudinal Businesses Database (LBD) which literally covers the whole universe of U.S. manufacturing plants at the Census Research Data Centers (Jarmin & Miranda, 2002). Other related plants' environmental data, including individual records for a plant in the recent Pollution Abatement Costs and Expenditures (PACE) surveys in 1999 and in 2005, are also available at the Centers. Findings from this dissertation come from the focus on larger plants. Economic and environmental datasets of smaller plants, limitedly retrievable from the above sources, will be valuable to extend and complement results from the dissertation's focus on the larger plants as potential physical anchor tenants.

Energy Star, joint eco-label framework between US EPA and US DOE, is a significant potential data source for future research (U.S. Environmental Protection Agency & U.S. Department of Energy, 2008). Eco-label programs have widened their coverage from electronics and cars to homes, buildings, and plants. Energy Star for Buildings started in 1995 with Energy Star Qualified New Homes, but officially went public in 1999, and predated LEED for New Construction. It extended its coverage to manufacturing plants in 2006 and became Energy Star Labeled Buildings and Plants. Energy Star Labeled Buildings and Plants maintains an on-line database of certified projects with data on their locations and certification dates. Due to its later current entry, only 45 records for plants are included in Energy Star Labeled Buildings and Plants, but the program contains more than 5,600 building records in 2008. Alternatively, for plants, commercial data on firms and plants certified to International Organization for Standardization (ISO) 14001, the international environmental management standards are obtainable annually (Darnall, 2006; King, Lenox, & Terlaak, 2005). Panel data analysis and event history models in Chapter 4 can be applied to those datasets of new green certifications of plants and offices, and used to triangulate findings from the dissertation from different angles.

In addition, different datasets of eco-labeled residential units are and will be available in the near future. The Energy Star Qualified New Homes program started in 1995, and the number of the Energy Star Qualified New Homes in the U.S. is over 900,000 in 2008. The program only provides spatial data aggregated at the state level and historical data of New Homes are currently unavailable, but possibly will become available sooner or later, at least at the state level.[42] The LEED for Homes piloted in 2005, and officially started in 2008 (U.S. Green Building Council, 2008b). Since its initiation, about 500 projects with 1,000 housing units have been certified. In addition, the National Association of Home Builders (NAHB) published in the NAHB Model

42 Personal communications with the US EPA in 2006 and in 2007.

Green Home Building Guidelines in 2005, and started the NAHB Green Scoring Tool and National Green Building Certification, based on the Guidelines, in 2008 (National Association of Home Builders, 2005, 2008). New datasets from those fresh green home rating systems in coming years will enable this work to extend into residential buildings.

6.2.2 Further Topics and Methods

Findings from this dissertation support the importance of large cities and their surrounding counties in eco-industrial development across the U.S.A. The following studies, hence, should scale down quantitative and qualitative analyses in this dissertation to focus on selected metropolitan areas which have high potential to entice future eco-industrial developments. Certainly, this dissertation initially cover the issue with case studies of regional by-product synergy projects in Kansas City and in Chicago in the industrial context, and of green building projects at Battery Park City in Manhattan in the post-industrial context. However, as briefly introduced in Chapter 5, more than a dozen regional by-product synergy projects are up and running, and sharing their experiences through a non-local network among them, which has the U.S. Business Council for Sustainable Development as a hub. It would be particularly desirable to platform detailed multiple case studies with a coherent evaluation framework on those projects, possibly similar to the work of Heeres *et al.* (2004) on early eco-industrial park initiatives in the U.S. and in the Netherlands. Individual case studies on different regional by-product synergy projects, however, are also desirable.

Case studies at the level of the city and its metropolitan area is also a relevant approach to green building research, since cities across the U.S. now experiment with unique institutional solutions to promote local green building practices at the different governmental levels, in close relation to the USGBC. For instance, local-version codes for green building are emerging, which are locally customized green building guidelines, usually based on LEED. A representative case is the Chicago Standard, announced in 2004 (City of Chicago, 2006). City-driven green building initiatives and their metropolitan consequences are a timely topic in urban planning to ponder the right role of green buildings in pursuing sustainable communities and cities. In that sense, individual and multiple case studies of on-going urban green building initiatives are desirable for future research on eco-industrial development.

Quantitative researches at the metropolitan level can complement future case studies. Most of all, the intra-metropolitan distribution of greener plants and offices can be probed with the same – but advanced – methods in this dissertation. There is a solid line of research in the literature of the dynamics of urban spatial structure and land-use change (Anas, Arnott, & Small, 1998). Many studies in the literature analyze population and employment densities with census tract or census block demographic data, and identify urban and suburban centers of population and employment (Anderson & Bogart, 2001; Carlino & Chatterjee, 2002; Fujita, Thisse, & Zenou, 1997; P. Gordon, Richardson, & Wong, 1986; J. McDonald, 1987; Wheaton, 2004). Whether those centers of population and employment have different impacts on locations of greener plants and offices within different metropolitan areas is a testable and timely hypothesis, since their suburban locations and relocations start to be discernible recently. This focus also can be easily extended to studies on greener homes, identifiable with different eco-labels introduced in 6.2.1, such as the LEED for Homes.

The application of advanced methods to the datasets used in the dissertation and available in the future is a feasible option to widen our understanding of on-going eco-industrial developments in the U.S. For example, geographically weighted regression (GWR), which estimates a density surface using nearby local observation for data points with more weights given to closer observations, is considered a promising technique in spatial analysis and econometrics (Fotheringham, et al., 2002). Hedonic modeling with GWR can be fit with social, economic, geographical, and ecological variables of neighboring administrative units of economic units. From the planner's viewpoint, different policy options for eco-industrial developments deserve more attention. The comparison between mandatory and voluntary policy options for green buildings at different scales of governance can be particularly relevant to both practitioners and policy makers (May & Koski, 2007). In addition, local environmental sentiments and their relations to environmental policies for plants and offices can be surveyed and used as key variables. Those local policy options should be woven into future models to investigate which policy option is more effective.

The variety of event history models opens new possibilities for further analysis of panel data. This dissertation relies on the Cox proportional model, since it was too arbitrary to select an underlying distribution without former studies on the diffusion of green buildings. Based on the results from the dissertation, however, it becomes feasible to build parametric event history models, which are more appropriate as prediction models (Box-Steffensmeier & Jones, 2004). It is also reasonable to enhance conditional gap models used in the dissertation with the conditional frailty models, which can model not only event dependence, but also heterogeneity among counties (Box-Steffensmeier &

De Boef, 2006; Box-Steffensmeier, et al., 2007). Spatial survival analysis, which can probe stratified event history data hierarchically, is another alternative (S. Banerjee, Wall, & Carlin, 2003). Most of all, event history models with GIS seem to be the most practical and promising option to analyze and predict the urban structure change and its impacts on locations and performances of economic units at the metropolitan level over time (An & Brown, 2008). The focus on metropolitan areas forces the researcher to sacrifice some key variables used in the dissertation, but GIS can offer more localized variables common in the land use change literature, such as distance to the nearest city, major road, or open space.

Overall, three direct future studies from this dissertation are evident. First, the presence of newly available data from different sources provides clear opportunities to triangulate findings from the dissertation and to perform more focused studies at a smaller scale, most likely starting at the metropolitan scale in close relation to studies in urban structure and land use change. Data on green homes are especially valuable for researchers in urban planning in the near future. Second, multiple case studies on eco-industrial developments in different metropolitan areas are timely and doable. Third, advanced research methods in spatial econometrics, panel data analysis, and event-history analysis with GIS offer promising ways to distill more lessons from existing industrial settings desirable to potential eco-industrial developments.

Nevertheless, it is obvious that future research can be much wider and richer than I suggested here. To understand the dynamics of eco-industrial developments in the U.S., uncover their suitable roles in sustainable development and economic development, and establish appropriate plans and policies for their innovative practices in urban planning and public policy, a variety of new multidisciplinary and interdisciplinary research efforts are necessary. Those efforts are also essential to probe principles of favorable environments in nurturing eco-industrial developments from existing cases and to examine those principles in urban planning, policy making and project initiation for eco-industrial developments at different scales and locations.

Appendix: A Typology of Eco-Industrial Development

Inspired by a typology of flow management, classifying interactions between green buildings and infrastructure networks (Jensen, 2001), a typology of eco-industrial development has been developed. To illustrate different features of eco-industrial development and factors of neighboring local industrial system, two ideal dimensions are identified. One dimension of the typology represents the strength of an eco-industrial development, and another dimension represents the maturity of its neighboring local industrial system.

Weak and strong eco-industrial developments

The degree of eco-industrial development is scaled between weak approach and strong approach. Weak eco-industrial development represents a minimalistic approach in eco-industrial development, which complies only legally required environmental standards and specifications and does nothing more. Weak eco-industrial development can be equal to ordinary industrial development practice in reality. Strong eco-industrial development is at the opposite end of the scale, which voluntarily pursuits an ideal closed-loop system in the eco-industrial development by using best available technologies, and encouraging environmental innovations throughout the development process. Certification through eco-labels and green rating systems, such as Energy Star, the LEED, and ISO 14001, is a common practice to move toward stronger eco-industrial development in practice.

Nascent and mature industrial systems

The maturity of local industrial system ranges from nascent to mature stage. Nascent industrial system represents under-developed areas, developing countries, or 'greenfield' development (Lambert & Boons, 2002) without significant amount of existing firms, industries and business networks and without enough physical infrastructure and utilities. On the other hand, mature industrial system means developed areas and countries, or 'brownfield' development (Lambert & Boons, 2002) with fully developed industrial ecosystems among economic actors supported by well-developed infrastructure. Traditional urban areas are probable places of mature industrial system, either in the industrial context of the manufacturing sector or in the post-industrial context of the service sector, since cities have been centers of those functions in history (Jacobs, 1969, 1984).

By crossing these two dimensions, four types of interaction between eco-industrial developments and their local industrial systems are created and presented in Figure A.1. Each type illustrates a different interaction between eco-industrial development and its local industrial system. Description of each type is suggested in details as follows.

Weak eco-industrial development in a nascent industrial system (WN)

This type represents the lower-left quadrant in Figure A.1. It is the case of traditional industrial development without proper physical infrastructure, local industrial partners, and local environmental consensus. The enhancement of local industrial system with this interaction is unlikely, since economic units in this interaction complies minimal environmental requirements, and collective activities for the environment among economic units and other local actors are fairly limited. Isolated manufacturing plants in less populated areas, or in non-industrial areas, and back offices and branches in suburbs are typical examples of weak eco-industrial development in this type. Since the economic unit in this type is not likely to be able to utilize its own capacities and local resources to improve local environmental quality, external connections through governmental, institutional and organizational networks can be instrumental to upgrade the current environmental conditions of eco-industrial development and its local industrial system.

Weak eco-industrial development in a mature industrial system (WM)

The lower-right quadrant in Figure A.1 stands for this type. Traditional industrial development with minimum environmental specifications is in place. Mature industrial system enables an economic unit of weak eco-industrial development to pursuit collective solutions to environmental problems among nearby actors. However, that is far from an automatic process, and many traditional industrial development projects just choose to be self-contained. On the other hand, strong presence of infrastructure and public utilities in mature industrial system helps weak eco-industrial development respect minimal environmental requirements. Ordinary plants in industrial parks and offices in downtowns and office parks can be classified into this type.

Strong eco-industrial development in a nascent industrial system (SN)

The upper-left quadrant signifies this type in Figure A.1. In this case, strong eco-industrial development tends to be self-sufficient by creating its own closed-loop system of materials and energy, and maintaining its open system interface of knowledge and information with non-local institutions and organizations. Sometimes, this strong eco-industrial development brings additional infrastructure and utilities for itself into local industrial system. The self-sufficient tendency of this interaction lessens social, economic, and technical conflicts between the eco-industrial development and its industrial system, while that also means that the influence of the eco-industrial development on its industrial system is likely to be limited. More often than not, this type of eco-industrial development is initiated as a stimulus to local sustainable development, but the close interface between a strong eco-industrial development and its neighboring industrial system needs to be developed over time, and cannot be guaranteed by any means necessary, especially in an industrial system lack of economic resources and actors. Selective examples in this type are 'greenfield' eco-industrial parks (Lambert & Boons, 2002), regional R&D centers for environmental technology, and the LEED certified buildings and other demonstrative green building projects in rural areas.

Strong eco-industrial development in a mature industrial system (SM)

The upper-right quadrant in Figure A.1 represents this type and completes the typology. It is an attempt to launch a strong eco-industrial development in locations of well-developed infrastructure, of abundant actors in various firms, institutions, and organizations, and of local connections to remote connections of knowledge and information. Since strong eco-industrial development already has significant potential to be self-sustaining, the availability of those resources and opportunities from its mature industrial system may increase the possibility that the eco-industrial development serves its own purpose of sustainable industrial development. Collective actions for sustainable industrial development between the eco-industrial development and other actors in its local industrial system are plausible in this type. That also means that it is probable that social, economic, and technical conflicts between strong eco-industrial development and its mature industrial system emerge radically, which have potential to bring both torpid gridlock of disunity and bureaucracy, and dynamic mixture of inquiries and innovations at the industrial system. It is a challenge to find and build working concordances between new eco-industrial development and its old industrial system. This type contains cases of 'brownfield' eco-industrial parks (Lambert & Boons, 2002), urban and regional eco-industrial networks, and the LEED certified green buildings in central cities.

This typology is based on the presupposition that there is no full-fledged local eco-industrial system, and that is not achievable without the growth of eco-industrial development along with the maturation of its local industrial system. This presumption is at least partly indebted to the insights from the environmental Kuznets curve that hypothesizes the inverted U-shape relationship between economic growth and environmental quality (Ayres & van den Bergh, 2005; Kahn, 2006). Eco-industrial development is an offspring of industrial modernization, as much as of ecological environmentalism.

Both eco-industrial development and local industrial system do not necessarily stick to the current equilibrium points, and change each other through interactions between them, just like an analogy of niche construction in which the creation of a niche is explained by circular interactions of organisms and their environments in evolutionary biology (Odling-Smee, et al., 2003).

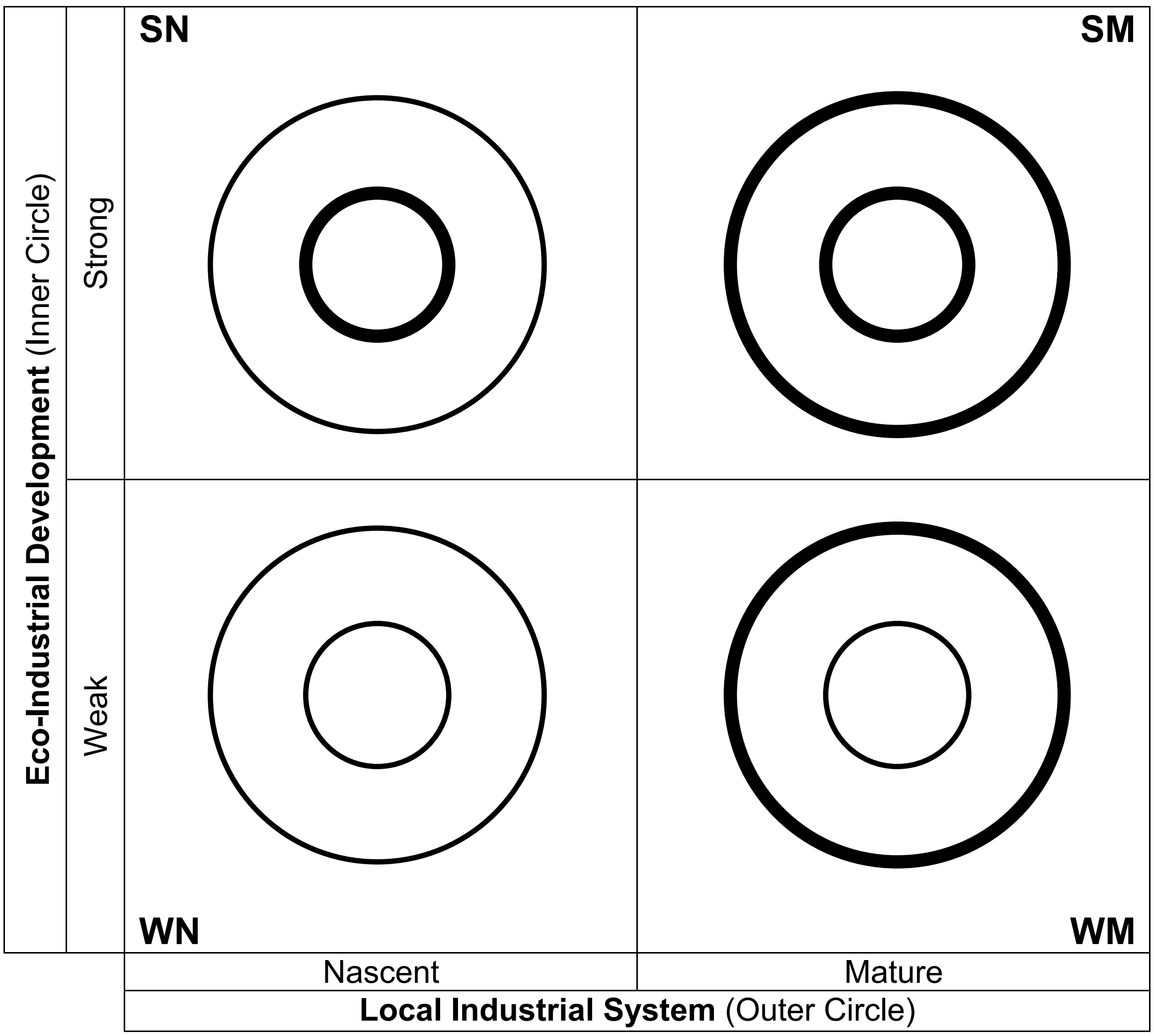

Figure A.1 A Typology of Eco-Industrial Development

Therefore, one interaction type between eco-industrial development and its local industrial system can be shifted into another type by self-organization process or by strategic intervention. However, shifts between those types do not necessarily bring advantageous results for eco-industrial development s and their local economies. To recommend promising shifts for an eco-industrial development, we should identify possible pathways from the current type of interaction between the eco-industrial development and its local industrial system to an anticipated type. In other words, we should know where we are now and where we are heading to take strategic actions. Differences in the maturity of local industrial system require different strategies in placing eco-industrial development. Instead of enlisting and describing all the possible pathways, I focus on two desirable pathways in terms of sustainable industrial development. If sustainable industrial development in an economy means an economy-wide industrial development caring both economic viability and environmental quality, strong eco-industrial development in mature industrial system (SM, upper-right) would be close to a desirable state of sustainable industrial development in Figure A.1. Then, based on the maturity of a given industrial system in which a strong eco-industrial development will be located, two strategic pathways can be identified.

Eco-industrial development as a 'catalyst'

If a given local industrial system is nascent, a strong eco-industrial development can be applied as a 'catalyst' to stimulate and ultimately transform the industrial system into a more mature and sustainable one. In Figure A.1, this pathway means a movement from WN (lower-left) through SN (upper-left) to SM (upper-right). In fact, this pathway has a deep root in the economic development literature, which is easily dated back to Perroux's (1955) work of the growth center and its trickle-down effects to neighboring areas (Hansen, 1972; Kirat & Sierra, 1998). Studies on business incubators and on academic and research anchors for local economic development are representative examples (Adams, 2005; Agrawal & Cockburn, 2003; Lewis, 2003).

Within theoretical and empirical studies in eco-industrial development, it is not difficult to find strategies, plans, and projects in the line of this pathway. Anchor tenant approach for eco-industrial parks (Chertow, 2000; Korhonen & Snäkin, 2001) reflects this pathway. At the level of local economies, eco-industrial parks in greenfields can be considered working cases of eco-industrial development following this pathway (Lambert & Boons, 2002). Pilots and demonstrative projects of green building are another case in this pathway (Building Design & Construction, 2003).

This pathway has an appeal to the developing areas, starting from scratch as 'latecomers' in economic development (Storper, Thåomadakåes, & Tsipouri, 1998), but being willing to achieve their goals without ignoring environmental concerns. Although this strategic pathway may offer a feasible and reasonable option that local governments, businesses, and entrepreneurs can afford, it is not always clear that this pathway can bring desirable results. Just like organisms and their environments in nature generally interact in an unequal manner – adaptation (Bijlsma & Loeschcke, 2005), the dominant practices in an industrial system may overwhelm and even suffocate newly located eco-industrial development.

In the U.S., most of earlier eco-industrial park projects have given up being eco-industrial parks, and become ordinary industrial parks, or simply ceased to exist

(Chertow, 2007; Heeres, et al., 2004). It is also common that many initial green building projects remains as local experiments, and fail to attract more green buildings or to change existing buildings into greener ones. Anchor tenants approach may offer a way to overcome the unequal position of organism in its environments by establishing massive sources of materials and energy, as well as of knowledge and information (Burström & Korhonen, 2001; Korhonen & Snäkin, 2001). However, building anchor tenants with additional infrastructure may not be a feasible and affordable option to many locations. Search for the right catalytic eco-industrial development in a given industrial system is a key challenge in this strategic pathway.

Eco-industrial development as a 'symbiote'

If a given industrial system is mature, a strong eco-industrial development can be slipped in as a 'symbiote' to exploit existing advantages of its neighboring mature system, potentially to convert its relation to the local industrial system into mutualistic – or at least commensal – one later, and eventually to make the whole industrial system more sustainable by completing closed loops among economic units and related institutions. Jane Jacobs once argued that every economic unit is a symbiote or 'symbiont' in the market (Jacobs, 2000), while here the pathway of eco-industrial development as a symbiote is used to capture environmental excellence, as well as economic vitality in Jacobs' terms. It is a pathway shifting from WM (lower-right) to SM (upper-right) in Figure A.1. Recent theories on industrial clusters share a similar line of thought that respects existing patterns of industrial agglomeration and customizes cluster strategies for a region along with spatial and historical patterns that the region is enclosed in (Braunerhjelm & Feldman, 2006; Martin & Sunley, 2005; Porter, 1998a). In addition, metropolis has been rediscovered as a seedbed for potential industrial clusters (Scott, 1988a). Theoretical and empirical studies in the literature of learning regions (Rutten & Boekema, 2007) and of regional innovation systems (Asheim & Gertler, 2005; Braczyk, et al., 1998) have escaped from the earlier focus of the industrial cluster research on new industrial districts and high-tech industries, and opened a series of research on the possible futures of old industrial centers and their neighbors in a variety of industries.

Eco-industrial development has its own version of this trend. Eco-industrial parks in brownfields (Lambert & Boons, 2002), and local and regional eco-industrial networks among internal and external actors (Chertow, 2000; Cohen-Rosenthal & Musnikow, 2003; Côté, et al., 2006) gain their popularity in the recent mode of eco-industrial development. Majority of green buildings find that old downtowns are enabling locations of economic and environmental sustainability, in which they don't have to be overly self-sufficient, but can take advantage of existing infrastructure and public utilities to alleviate their burdens in green building design and construction (Gissen & National Building Museum, 2002; Guy & Moore, 2005; Jensen, 2001). Although it is still at the initial stage, the introduction of regional learning and innovations systems to the industrial symbiosis literature has been started (Mirata & Emtairah, 2005).

Pathway of this kind appeals the developed areas in two significant ways. First, this pathway can offer new greener strategies and opportunities of regional economic development to declining industrial centers, losing their former growth engines. Second, it prefers the in-situ restructuring of local industrial system to take advantage of given physical and social infrastructure to the replacement of the current local industrial package with something else, like high-tech, green, or bio industries. Similar to an organism adapts to its environments, or a symbiote to its host, an eco-industrial development is designed to be fit in the existing local industrial system. Still, there is a considerable possibility that eco-industrial development in this type will lose its environmental edge, and be assimilated by its mature industrial system.

There are abortive cases of regional eco-industrial networks (Cohen-Rosenthal & Musnikow, 2003; Kincaid & Overcash, 2001; Wagger & Lawson, 2005), but regional by-product synergy projects have gained popularity recently among major cities in the U.S. (World Business Council for Sustainable Development, 2008). Urban green building projects, including the LEED certified existing buildings and green skyscrapers in big cities, are examples of this pathway (Gissen & National Building Museum, 2002; U.S. Green Building Council, 2003).

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