Chapter 18
Waste-to-Resource (WTR) Green Supply Chain

Abstract Green supply chain has been aggressively constructed in different industrial parks around the world. The win–win benefits in both environmental and economic aspects can be achieved by implementing the waste-to-resource supply chain in the industrial park. Portfolio options of technologies for different types of waste-to-resource supply chains can be considered for achieving circular economy system. In this chapter, the strategies on implementation of waste-to-energy supply chain are proposed to overcome the challenging barriers from the aspects of technology, finance, institution, and regulation. A total of six key task forces are proposed for effectively executing the strategies. In addition, several successful lessons on waste-to-resource supply chains, such as green fuel pellet for heating supply and codigestion of organic wastes for biogas production, are provided.

18.1 Importance and Significance

The global environment and ecosystems have numerous functions including the supplies of food, clean water, and raw material for the mankind. However, human activity has impacted nearly every aspect of the environment. The adverse impacts of human activity on the environment have been known, such as follows:

- The depletion of the ozone layer,
- The destruction of various ecosystems, and
- The formation of increasingly severe weather phenomena.

In response to climate change, several key challenges of the twenty-first century have been identified, such as (1) mitigation of and adaptation to global warming; (2) protection of the population against natural hazards and disasters; and (3) optimization of food, energy and water (FEW) nexus. To prevent these destructive consequences, individuals and groups started to take concerted efforts to protect the environment in the early twentieth century. Environmental protection movement does not necessitate a slowdown of economic development. In this section, the

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concepts of sustainable development, green economy, and circular economy are provided. The definition of a green supply chain is also discussed.

18.1.1 Sustainable Development

Conventionally, the standard of excessive consumption is problematic since it necessitates a trade-off between economic development and environmental sustainability. However, this trade-off approach becomes unnecessary within the framework of a sustainable development goal. The goals of the sustainable development were originally established at the Earth Summit in 1992. It has been further defined by the World Commission on Environment and Development [1]: a sustainable development should be:

> … development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The three pillars of sustainability include sustainable economy, sustainable environment, and sustainable society. Figure 18.1 shows the three pillars and their key elements for achieving a sustainable development goal by construction of a green supply chain. It suggests that the sustainable development goal should include economic development, environmental protection, and social equity [2].

Fig. 18.1 Conceptual diagram of three aspects for achieving a sustainable development goal

At the United Nations Conference on Sustainable Development (called Rio+20 Summit) in 2012, the green economy has been one of the main themes in the international debates on sustainable development. The achievements of the Rio+20 Summit include the following:

- "Future We Want" outcome document,
- Sustainable development goals (SDGs),
- High-level political forum on sustainable development (HLPF),
- Strengthened UNEP,
- Civil society participation and commitments,
- Green economy, and
- Passed responsibility of "Post-2015 Dev Agenda" to UNEP Governing Council and UN General Assembly.

Therefore, a green economy should be considered as an important tool, both at the global and national as well as at the corporate level, in the context of sustainable development.

18.1.2 Green Economy

As suggested by United Nations Environment Programme (UNEP), the key to sustainable development is to create a green economy. The green economy is defined as an economy system that aims at reducing both environmental risks and ecological scarcities. It should encapsulate three sectors: the industry, the people, and the government. Figure 18.2 shows the history of important international movements on green economy toward a sustainable development goal. Sustainable development without degrading the environment should reply on a green economy. Therefore, it can be achieved if fundamental changes are made to the existing supply chains of energy and material production, especially in industrial parks [3]. In contrast to prior economic regimes, the feature of green economy is the direct valuation of natural capital and ecological services as being valuable in terms of economy.

In 2009, the "Global Green New Deal" report was released by the United Nations Department of Economic and Social Affairs [4]. It addressed several existing barriers such as the difficulty to call for a global effort to "target price supports, establish policy coordination, and create an extension program to ramp up" for the use of green supply chain and renewable energy. Moreover, it provided several strategies for achieving an international green economy that involves a mixture of new policies and public investments. In addition, it specifically mentioned the importance of deploying renewable energy over simply reducing GHG emissions since [4, 5]

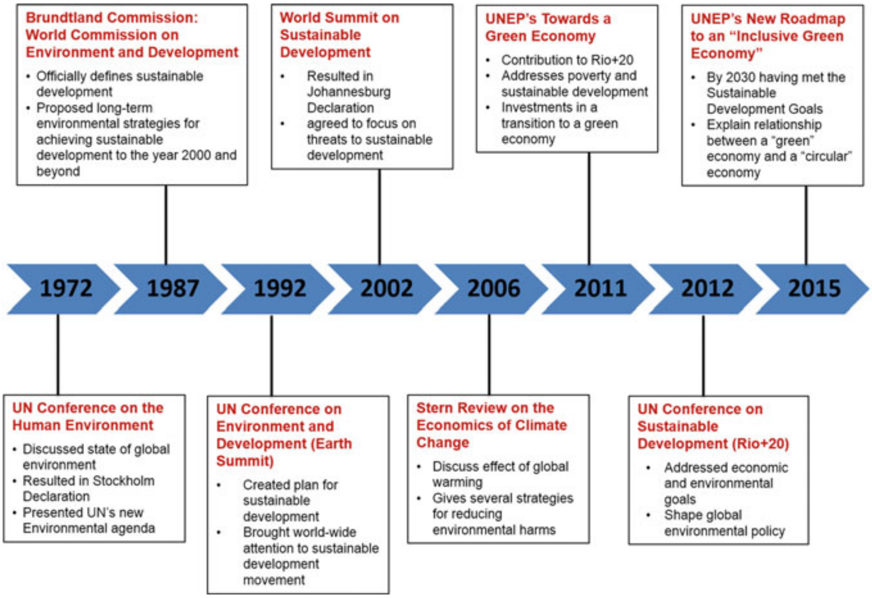

Fig. 18.2 Important international movement on the sustainable development and green economy

> energy is the key to economic development and social wellbeing, and renewable energy is the key to a future without dangerous climate change.

After that, in 2011, the necessity of a green economy, and methods for obtaining one in recent international meetings and publications were discussed. According to the definition suggested by UNEP [6], a green economy should encapsulate all industries, people, and governments, thereby resulting in

> … improving human well-being and social equity, while significantly reducing environmental risks and ecological scarcities.

In addition, a green economy should support the development of green technologies and green infrastructure that

> … reduces carbon dependency, promotes resource and energy efficiency, and lessens environmental degradation.

In 2012, the green economy became one of the main themes in the international debates on sustainable development toward the Rio+20 summit. Also, the thematic consultations of the "Post-2015 Development Agenda" include 11 areas: (1) inequalities, (2) governance, (3) growth and employment, (4) health, (5) education, (6) environmental sustainability, (7) food security and nutrition, (8) conflict and fragility, (9) population dynamics, (10) energy, and (11) water. Therefore, the green economy approach should be an effort to focus sustainable development and poverty reduction on transforming economic activities and economies.

18.1.3 Circular Economy System

The establishment of a waste-to-resource (WTR) supply chain can offer an approach to simultaneously addressing the issues of energy demand, waste management and greenhouse gas (GHG) emissions in order to achieve a circular economy system (CES). Circular economy is a generic term for an industrial economy that is producing zero waste and pollution by innovative design or intention. Therefore, it is based on the "win–win" philosophy that a prosper economy and healthy environment could be coexisted [7]. The CES is contrast to a conventional "linear economy" which is a "take, make, and dispose" model of industrial production. Figure 18.3 shows a conceptual framework of relationships between the environment and WTR supply chain for a CES. The technologies, such as fresh water production and waste production, in an industrial system should be linked together with the environment, energy and GHGs emissions to establish a business model for the CES.

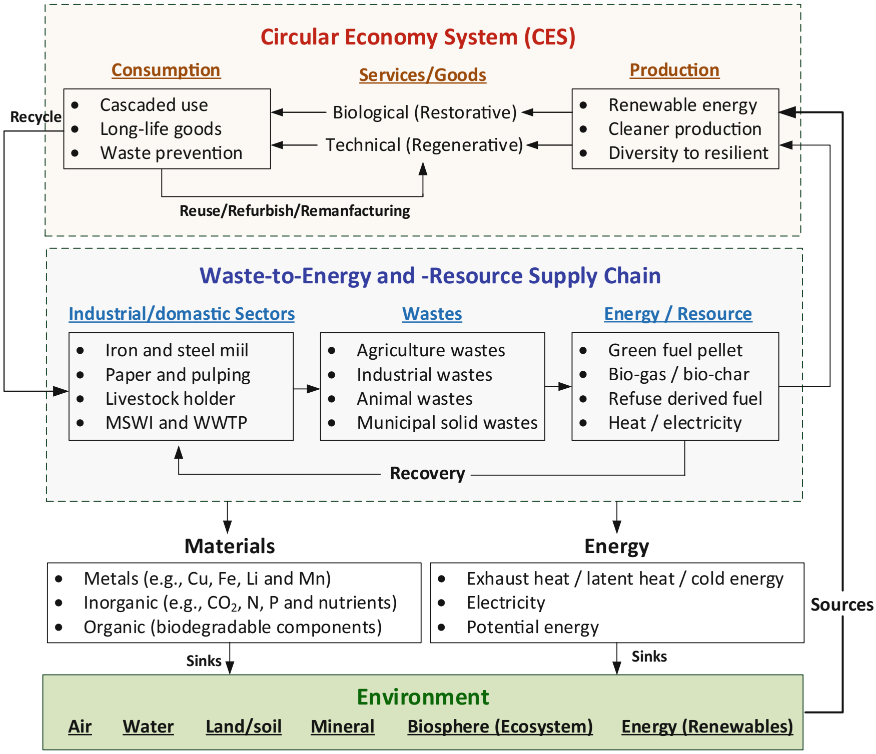

Fig. 18.3 Relationship among the environment, waste-to-energy (WTE) supply chains and circular economy system (CES)

In other words, both the industry system and the environment should be maintained as a circular relationship for facing existing environmental issues and resource scarcity. Within the CES, a closed loop of material flows including biological and technical nutrients exists:

- Biological nutrients: designed to reenter the biosphere safely.
- Technical nutrients: designed to circulate at high quality in the production system without entering the biosphere or being restorative and regenerative by design.

Several reports have studied the role of CES, especially in the developing countries, in establishing a supply chain of services and/or goods using indicator mechanism [8, 9]. The CES is based on the "5R principles" to decouple the economic growth from environmental degradation and build a resource-saving society:

- Reduction,
- Reuse,
- Recycling,
- Recovery of energy, and
- Reclamation of land.

Recycling and waste reduction can coexist in a community where energy is generated through WTR supply chain. In addition, the uses of innovative technologies can improve the value of organizations and supply chains while reducing the environmental degradation and resource depletion caused by their economic growth. Under this vision, it is expected to allow policy makers to understand emerging new techniques, thereby implementing energy policy, introducing green technology, attracting the interest of the public, and utilizing appropriate evaluation tools.

18.1.4 Green Supply Chain

Green supply chain comprises the concept of a waste-to-energy and/or waste-to-resource supply to achieve sustainable development. In recent years, international organizations such as the United Nations Environment Programme (UNEP) have moved to promote a movement toward sustainable development. Since the diverse stream of human waste creates problems when landfill space becomes limited and chemical leachate spills into the environment, WTR supply chain is a feasible method of green material production that revolves two of humanities' environmental issues, i.e., the landfilling and the natural resource conservation, with one process. It is noted that communities with efforts of green supply chain have higher waste recycling ratios than the national average [10]. In other words, there is an urgent need to develop and implement the green technologies into the existing facilities, especially in the developing countries.

The composition and amount of the solid wastes from a municipality and/or industry depend on the level of economic and social developments, energy sources, cultural norms, and geographical conditions (location, climate). For instance, municipal solid wastes (MSW) include commercial waste, medical waste, construction waste, and household waste. Typically, the MSW can be broadly categorized as organic, paper, plastic, glass, metals, and others (such as textiles, leather, rubber, multilaminates, e-waste, appliances, ash, and other inert materials). These solid wastes are usually non-biodegradable and take a long time to transform into natural compounds [11].

18.2 Barriers and Challenges

Typically, barriers from the below aspects could be encountered while implementing the green supply chain:

- Regulatory barrier,
- Institutional barrier,
- Financial barrier, and
- Technological barrier.

These barriers are hard to be distinctly separated because, for instance, policies (or regulations) often act on more than one barrier simultaneously. Similarly, this is especially true for the institutional and financial barriers as they can habitually be closely related.

18.2.1 Regulatory Aspect

Figure 18.4 shows the pyramid of regulatory framework at different levels. Regulatory barriers encompass unclear national vision (corresponding to policy), goal (corresponding to strategy), objective (corresponding to program), target (corresponding to project), and indicator (corresponding to plan).

Political issues, for instance as a consequence to an outdated infrastructure, could act as obstacles to creating an effective green economy. These are the challenges in appropriate policy formulation and government authority allocation. Therefore, regulatory barriers often prevent institutions from efficiently developing technology and processes that are crucial for the green supply chains.

18.2.1.1 Strict Laws and Regulations

Overly strict laws and regulations would prevent development and implementation of green technology. In the financial sector, strict laws may deter investors or

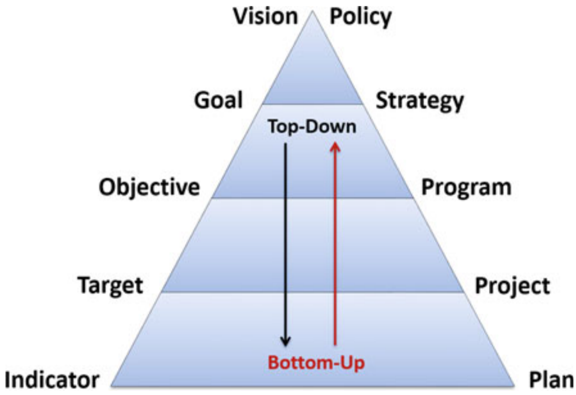

Fig. 18.4 Pyramid of regulatory framework at different levels

insurers from developing green supply chains [6]. In addition, a long time to receive permits and complete the proper procedures for developing and implementing green technology is one of the main impediment factors in the expansion of green supply chain. For instance, in France, it may take as long as eighty months to obtain the proper permits [12].

18.2.1.2 Lack of Efficient Governance and Available Information

Authorities have to identify the waste management needs and energy demands of a community while considering an available budget. Prior to project commencement, the biggest obstacle that almost all involved parties possess is the lack of information. According to the findings from various analysis methods such as analytical hierarchy analysis [13] and stakeholder interviews [14, 15], the needs of informing stakeholders about currently available technology were sometimes neglected.

18.2.1.3 Intellectual Property (IP) Constrains

Policy makers should emphasize the uses of best available technologies (BAT) to ensure environmental safety and facility efficiency. However, making the spread of technology depends on the certain groups controlling the information. Laws regulating intellectual property (IP) rights constrain the share of information among the industries since the laws determine the groups who can control the relevant information and technology. This would lead to a slowdown in technology transformation [16]. As a result, Committee of African Heads of State and Government on Climate Change (CAHOSCC) has called for the removal of restrictions on IP rights to allow African countries to develop clean energy and green infrastructure [17].

18.2.1.4 Approval in the Use of Wastes

In some circumstances, companies may experience obstacles in obtaining governmental approvals to use alternative materials and/or fuels from the recovered and/or recycled wastes. If a by-product is classified as a controlled waste (such as fly ash), strict procedures in transportation and cumbersome documentation are obliged for implementation. Although the by-product synergies appear techno-economically feasible with a positive sustainability, practical implementation has been halted due to the uncertainties of the legislative framework, especially with regard to the final responsibility for the approved reuse options and community concern.

18.2.2 Institutional Aspect

Institutional barriers are pervasive when it comes to creating the green supply chains. Typically, the institutions in play include the (1) enacting authority for policy and regulation, (2) distribution market, (3) project investors, and (4) local community.

18.2.2.1 Lack of Awareness

Decisions should be made with clear awareness of the public risks and economic benefits regarding the financial and technology support. A lack of awareness will lead to misplaced public perception, thereby hindering the progress of policy implementation. Similarly, another major barrier of establishing green supply chains is the lack of awareness of customers about the benefits of green products. Without the demands of green products from customers, the company and/or industry will not replace old technology for innovative green product. As a result, an information exchange platform among the government, industry, and customers should play a crucial role to achieve a successful green supply chain.

18.2.2.2 Unclear Ownerships

For the waste-to-energy supply chain, a critical issue pertaining to the efficiency of supply chain is the ownership of district energy system (DES) center, such as municipal solid waste incinerator (MSWI) plants. The shift of plant ownership and operation from government to a private would generally increase efficiency. Therefore, policy makers should take this into account when deciding the ownerships, operation, and management of the plants [18].

18.2.2.3 Lack of Partnerships

Different motives from political and financial ones could lead to endorsements on opposite sides of a movement. For policy makers, when drafting policy for assisting in the creation of green supply chains, it is difficult to propose a common goal and strategy. Even for people holding similar beliefs and values in a single country, there is also difficulty agreeing on a common direction. For the entire globe to agree on a unified strategy would be more difficult since there are more cultural differences and varying levels of development across continents [17]. This struggle plagues not only the public sector but also the private sector for agreeing on green supply chain strategies.

In addition, the implementation of a climate change strategy is not straightforward or uncontroversial. For instance, South Korea announced its "Four Major Rivers Restoration Project" in 2009 as part of its Green New Deal policy. The ultimate goals of the Four Major Rivers Restoration Project were to (1) combat water scarcity, (2) improve water quality, (3) implement flood control measures, and (4) restore the rivers' ecosystems. However, the opposition decried the project, claiming that it would cause habitat loss, flooding, and a contamination of the water supply. The opposite side argued that their position would benefit the environment while the other would harm it [19].

18.2.2.4 Outdated Infrastructure

An outdated infrastructure, pervasive in both developed and developing countries, would act as obstacles to moving toward construction of green supply chains and creating an effective green economy. Similarly, in the developing countries, without the basic infrastructure such as roads and communication networks, it is difficult to transfer and implement green technologies. As a result, the restructuring of outdated infrastructure is necessary for efficient development and implementation of green supply chains toward green economy. However, governments and/or business may be hesitant to take on such a task since restructuring old infrastructure would require a large input of time and may involve significant costs.

18.2.3 Financial Aspect

For a green supply chain, financial barriers may be embodied by (1) high-capital start-up costs for equipment, (2) inaccurate electricity prices, and (3) pipeline and/or grid interconnection costs. Moreover, the marketplace includes the major challenges of competition with established forms of energy production and appropriate allocation of energy subsidies. In this section, the financial barriers including insufficient incentive, inappropriate allocations of energy subsidies, and inaccurate prices for energy and electricity are illustrated.

18.2.3.1 Insufficient Incentive

Financial incentive for a particular industry and its associated businesses to invest in green technology may not be available at the beginning stage. This may be attributed to a variety of reasons: first, the cost of green technology may be a hard burden, especially in the developing countries and their industries. The high upfront cost of establishing green supply chains may deter institutions from making such a green transition. In the developing countries, the upfront cost may serve as an even greater barrier since they have fewer funds to invest in green technology. As a result, these countries typically continue to be burdened with outdated infrastructures and technologies without sufficient incentive. Second, the payback period for implementing green supply chains, generally between five to ten years, is too long for businesses due to people's natural propensity for risk aversion [6, 20, 21]. Thus, the benefits of green supply chains may not be apparent or immediate enough to incentivize a business, or even the government.

18.2.3.2 Inappropriate Allocations of Energy Subsidies

Subsidies are measures that reduce costs for consumers and producers: (1) keep prices for consumers below market levels, or (2) for producers above market levels. Subsidies are typically provided by the governments to fund popular and mature forms of supply for energy or products. The forms of subsidies include the following:

- Direct regulation and transfers,
- Preferential tax exemptions and rebates,
- Price controls,
- Trade restrictions,
- Public funding, and
- Limits on market access.

However, the material and energy supply industries (such as petroleum and nuclear power) typically obtained a market advantage over other relatively newer industries. In the USA, about half of the government expenditures on energy are from subsidies [22]. Subsidies spread government benefits unevenly and discourage consumers from seeking cleaner alternatives. This also is highly related to the financial and institutional barriers. Eliminations of these subsidies will significantly improve competition in the energy industry and eliminate the unfair advantage given to the nuclear and fossil fuel technologies. Thus, the government should play a central role in the development of new energy industries and green supply chain.

18.2.3.3 Inaccurate Prices for Energy and Electricity

In some countries and their industries, renewable energy prices might be too expensive to be a viable energy option. Research indicated that population with a living budget of even US$10 per day (much higher than the US$1.25 per day that 1.4 billion people in the developing countries) cannot afford renewable energy [4]. As a result, without any policy changes to make renewable energy affordable, these people are forced to use less desirable energy options. Even if the relevant policy is available, there is no guarantee that the developing countries will be able to support these policies. For instance, a major strategy in establishing green supply chain is using subsidies to promote growth in green industries. However, in the least developed and developing countries, governments may not have enough budgets to subsidize to an effective level due to the current high cost of renewable energy and sustainable materials [4].

18.2.4 Technological Aspect

The institutional, regulatory, and financial barriers would further exacerbate technological barriers by preventing the creation of innovative technology. In this section, the technological barriers, including (1) inefficient performance of technology, (2) lack access to green technology, and (3) lack of implementing green practices such as demonstration projects, are illustrated.

18.2.4.1 Inefficient Performance

In particular, in the individual industries and/or power plants, technology barriers often come in the form of implementing the most efficient and environmentally friendly type of technology. For example, for district energy system (DES), certain steam generators used in the incinerator exhibit slow start-up and poor efficiency, thereby generating huge amounts of wastes [23]. This could be overcome by disseminating the state-of-the-art information of innovative technology, and providing appropriate subsidies to the industries.

18.2.4.2 Lack Access to Green Technology

The green technologies can improve efficiency of resource uses and reduce environmental pollutions, leading to a better environment management system toward a green economy [21, 24]. However, local industries and enterprises, especially in the developing countries, still rely on conventional technology and lack access to green technology. Moreover, technological barriers are typically related to the financial and institutional barriers such as resistance of organization to technology advancement adoption due to technological transfer.

18.2.4.3 Lack of Implementing Green Practices and Demonstration Plans

Lack of implementation of innovative green practices and demonstration plans is an important barrier to implement efficient green supply chains. Innovative green practices, such as energy conservation, and reusing and recycling of materials, are essential to achieve a green economy. The innovative green practices are associated with the explicitness of green practices, accumulation of knowledge, organizational encouragement, and quality of human resources. Also, finding appropriate sites for demonstration plans should be a crucial task force to optimize the engineering performance (e.g., overall energy efficiency) and maximize the environmental and economic benefits. For example, district energy systems (DES) should be constructed nearby customers within the region. In constructing eco-industrial parks (EIPs), the steel mill, petrochemical, paper and pulping mill, and cement industries play important roles because of their unique features by utilizing a huge amount of energy and generating a great amount of wastes [25].

18.3 Strategies on Building Green Supply Chain

The barriers, challenges, and strategies for attaining an international green economy have been proposed by many reports, such as the Global Green New Deal [4]. As presented in Table 18.1, the most challenging barriers and strategies for constructing green supply chains are summarized. For instance, eliminations of the unfair subsidies can improve competition in the innovative green industry since unevenly spread of government benefits would discourage consumers from seeking cleaner alternatives and encourage overconsumption of resources.

To overcome the aforementioned barriers in different aspects, it suggests that an effective green supply chain for a green economy should include the following eight key task forces:

- Command and control,
- Economic instruments,
- Information platform,
- Technical assistance,
- Research and development,
- Public and private partnership,
- International collaboration, and
- Environmental education.

For instance, through effective command and control, and environmental education, the National policies could be properly executed under a clear government responsibility. Similarly, the use of command and control, economic instruments, and information platform could internalize the externalities and improve the social

Table 18.1 Potential barriers and overcome strategies for constructing green supply chains

Categories	Barriers and challenges	Strategies
Regulatory	• Loose regulatory laws for green technology allows for greater development and effective implementation • Existing loose environmental regulations and exclusion of CO_2 as regulated pollutants • Long time required for reviewing environmental impact assessment	• Shorten authorization procedures for developing and implementing green technology • New pollutant-targeted regulations (e.g., carbon tax and mandatory energy audits) • Shorter authorization procedures for developing and implementing green technology
Institutional	• Different focuses and concerns between central and local governments • Low level of Bureau of Energy and Environmental Protection Administration in government hierarchy • Information availability of industries due to confidentiality and commercial issues	• Development of networking among central and local governments • Upgrade as Environment and Resource Department • Establishment of networking platform for information exchanges
Financial	• Lack of fund and resource for construction of green supply chain • Low price for utility resources discourages recycling and relatively low costs for waste disposal • Distance between companies inhibits synergies	• Providing economic incentives (e.g., price support, guarantee loans) • Implementation of feed-in tariff (FITs) for green technologies and waste reuse and recycling • Subsidies on development of piping network for renewable energy and district heating and cooling system
Technological	• Lack of own technologies and manufacturing for key components • Existing low energy and material efficiency technologies • Availability of reliable green technologies	• Integration of best available technologies for innovation • Research and development for clean and green technologies • Developments of demonstration plans for providing opportunities for new synergies

acceptance in cooperation with a sound public–private partnership. On the other hand, to achieve the vision and goals, research and development should be enforced with sufficient economic supports using appropriate economic instruments. At the same time, a comprehensive performance evaluation (CPE) program should be established with the support of research and development, technical assistance and international collaboration to assess the performance of green supply chains and promote the environmental education.

To effectively deploy the green supply chains, policy mechanisms can tackle multiple barriers from the aspects of regulatory, institution, finance, and technology at once. In this section, the most important strategies on implementing green supply chains for a green economy, including (1) implementation of National sustainable policy; (2) establishment of government responsibility; (3) provision of economic incentives and price supports; (4) internalization of externalities, social acceptance and investor mobilization; (5) integration of best available technologies for innovation; and (6) development of comprehensive performance evaluation program, are illustrated.

18.3.1 Implementation of National Sustainable Policy

The goal of sustainable economic development is to ensure the daily needs of the people while maximizing the net benefits of economic activities. However, in most developing countries, predominant emphasis was given to achieving rapid economic growth and prioritizing industrial development. Since no countries can be forced to participate in international regulation, two strategies are suggested to make the regulation more globally acceptable:

- Involvement of a regulation context and
- Implementation of green industries by technology-forcing, guaranteed market and economies of scale

On the other hand, to meet the major prerequisite of pursuing sustainable development, the National sustainable policy should be implemented at both the central and local governments. Two important task forces, i.e., (1) establishment of clear visions and missions on sustainable development and (2) promotion of green technology at private sectors and industries, are illustrated as follows.

18.3.1.1 Establishment of Clear Visions and Missions on Sustainable Development

A policy with uncertain goals can result in the negative consequences of a collapsed project. Therefore, well-defined goals and measures are important to make projects feasible. Figure 18.5 illustrates the visions, goals, and strategies of building green supply chains toward a green economy. Governments should put efforts on promoting the development of green industries, cleaner production, and green consumption [26]. Also, the government should place much greater emphasis upon achieving both economic development and environment protection. In addition, the industries themselves should pursue a more balanced economic development, where raising quality takes precedence over expanding quantity. In seeking to satisfy the basic living needs, people should also abide by the moral imperative to coexist and coprosper with other forms of life to maintain the biological diversity [2].

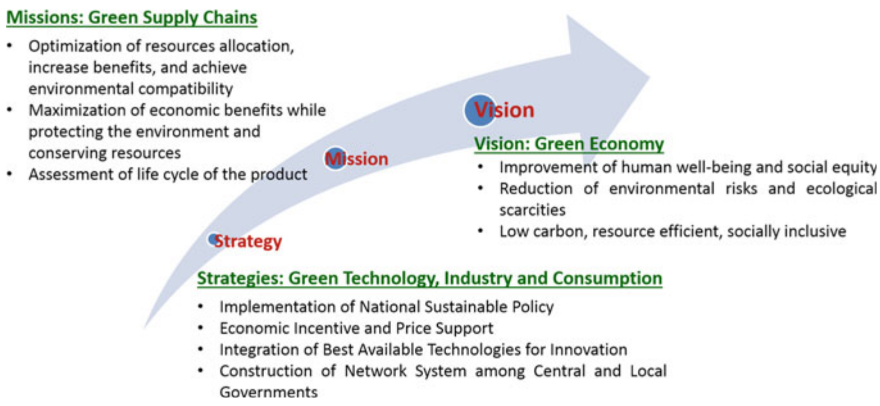

Fig. 18.5 Visions, missions and strategies of a green economy toward sustainable development

Comprehensiveness, consistency, and flexibility must be maintained to obtain success in the policy enforcement. A comprehensive policy should incorporate insight into a wide range of disciplines and account for externalities. Also, a policy needs to be formulated with precautions to handle changes in the political and economic situation. Clear goals and evaluation measures can ensure the consistency of a policy. For policy makers, the concept of consistency is needed to make changes as minimal and as infrequent as possible. A constantly shifting policy would lead to reluctant investors and limited progress during production. Furthermore, in the past, policies were given favorably to the categorical labels, such as financial policy, administrative policy, or social policy. Nowadays, the integrated policy should encompass measures formulated with a multidisciplinary approach. This could be the successful way to accomplish effective green supply chain while paying attention to the multitude of actors in play.

18.3.1.2 Promotion of Green Technology at Private Sectors and Industries

A successful green supply chain among plants can demonstrate its environmental and economic benefits [27]. Development of a sustainable economy seeks to preserve the gains from industrial capitals, including man-made capital, natural capital, and human capital. For the private sectors and industries, the concept of eco-industrial park (EIP) is imperative to facilitate the development of innovative products and green services for upgrading industrial technologies. With a view to promote the marketability of regenerated products, the promotion of green supply chains in industrial parks helps firms to publicize the sale of such products, promote green purchasing, and develop marketing channels for green products. Appropriate policies should be established to foster industrial symbiosis, thereby accelerating the development of green technologies for effectively material reuse and waste recycling [28, 29].

18.3.2 Establishment of Government Responsibility

Mostly, the government is the entity that brings all stakeholders, such as energy companies and the local communities, together through policy formulation. To overcome different barriers in an organized way, a national government would often create a department and equip it with the proper authority. Depending on the scale of the program, a governing body can range from a local government to an international organization (such as the European Union). In the following part, the main responsibilities of government, such as (1) appropriate policy with effective governance, (2) cultivation of green market and enterprise culture, and (3) involvement of stakeholders in policy-making system, are illustrated.

18.3.2.1 Appropriate Policy with Effective Governance

An appropriate policy with governance at both the city and national levels must be adopted to overcome financial, technical, and social barriers. Governance should be steered to direct cities' significant resources of physical, human, natural, and intellectual capital toward a green economy [30]. In the context of green supply chain, actions including agenda in policy development, formulation, adoption, and evaluation should be implemented to reduce the amount of GHG emissions and wastes while generating green products in a profitable manner.

On the other hand, to produce a shift to environmentally cleaner forms of renewable energy, several government measures can be implemented including the following:

- Demand-side management,
- Eliminating conventional subsidies,
- Pricing electricity more accurately,
- Enacting a national feed-in tariff (FIT) mechanism,
- Taxes on pollution, and
- Energy service companies (ESCO).

Municipal authorities can lower costs by linking public investment with the ESCO. The ESCO can establish special funds, credit lines loan guarantee programs, market transformations, and/or grants to address barriers in investments. Several full-scale ESCO models have been established in the developed countries, such as North America. However, no successful ESCO model was found in the developing countries, which might be attributed to the lack of legal and financial policies in place to enforce complex contracts [31].

18.3.2.2 Cultivation of Green Market and Enterprise Culture

It is not appropriate for governments to take on official pricing strategies or policy measures for institutional green transition. Rather, the unofficial measures could be equally effective. As shown in Fig. 18.6, the governments can assist in cultivating green enterprise culture and market environments of green consumption, and encouraging green technological innovation. By publicizing green consumption through publicity, schools, and media outlets, it is possible to widely spread the green knowledge to consumers and push businesses to a greener production. Therefore, environmental education on green economy and green supply chain should be critically promoted.

The ultimate goal of the investment and policy changes is to create a "virtuous cycle." It is noted that all subsidies could be removed in the following decade without hindering the development of green supply chains and a green economy [4]. An initial series of investment and policy changes would facilitate industrial scaling-up, expand markets for green products, and accelerate growth rates in cleaner production. Finally, technological improvements will further accelerate industrial scaling-up.

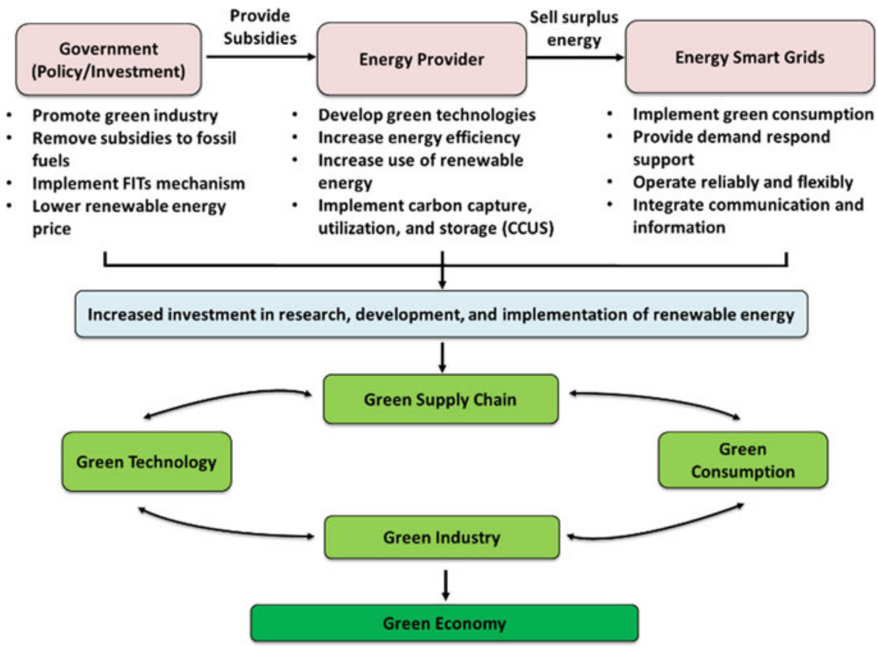

Fig. 18.6 Schematic diagram of price support and governance in cities for building green supply chains toward a green economy. Reprinted by permission from Macmillan Publishers Ltd: Ref. [32], copyright 2015

18.3.2.3 Involvement of Stakeholders in Policy-Making System

The development and implementation of a green supply chain generally involve different stakeholders, such as the owners of plants, a governing body (or competent authorities of plants), local government, industrial sectors, energy supply/distribution companies, communities, and citizens. Social familiarity because of common cultures and trusts among the stakeholders is considered as the vital factor for minimizing the risks and uncertainties of failure. A central governing body (such as the competent authorities of industrial park) should link up all the stakeholders to provide information on regulatory and financial support [29, 33]. Describing and outreaching policy information along with the coordinating collective actions are imperative for a long-term mutually beneficial success among the newly developed projects [34]. An efficient strategic decision-making system for green supply chains should include the following [23]:

- Supply and demand contracts;
- Network configuration such as sourcing, location and capacity of energy production facilities, locations of storage facilities, and network design;
- Ensuring sustainability.

On the other hand, policy makers should identify the specific concerns and issues and even recognize the need for intervention when the market fails [35]. Therefore, appropriate policy measures should be used to ensure compatibility and viability of a project. In some cases, a policy just needs to simply overcome a few local barriers rather than enacting large overbearing financial mechanisms.

18.3.3 Provision of Economic Incentives and Price Supports

Renewable energy plays an inevitable role in a circular industrial economy. In many countries, however, the price of renewable energy is much too high for it to be a viable option of green energy. This is likely due to excess subsidies that lower the prices of fossil fuels so that they are much cheaper than the cost of the renewable energy. These issues can be solved by simply removing those uneven subsidies to allow the international market to determine the price of fossil fuels. It is estimated that eliminating fossil fuel subsidies would reduce global GHG emissions by 6% and increase GDP by 0.1% [36].

Beyond policy in the form of price supports, a series of policy changes will bolster the price supports to be effective. This assistance of pricing strategies would solve the institutional and financial barriers in the developing countries. To create a cost-effective green certificate market, many economic incentives and price support tools can be used, such as (1) feed-in tariff (FIT) mechanism, (2) emission trading scheme, and (3) tax exemptions and rebates.

18.3.3.1 Feed-in Tariff Mechanism

To decrease the price of renewable energy, the primary method suggested by the "Global Green New Deal" report is to provide price supports through a "feed-in tariff (FIT)" mechanism. The FIT mechanism can increase investment in developing renewable energy, thereby increasing the installed capacity of renewable energy. Aside from that, the FIT can offer several benefits including the following [22]:

- Ensuring a stable investment stream for project developers,
- Suppliers getting paid immediately,
- Quickly expanding renewable power, and
- Providing a predictable industry to produce new high-paying jobs.

The FIT mechanism forces electric utilities to purchase renewable power in a nearby service area at a fixed price above market rates for a specific period of time. Germany is one of the greatest success countries for implementing FIT around the world. Its FIT covers the costs of electricity grid interconnection and metering by spreading it across all electricity customers, and then slowly declining the tariff over time.

18.3.3.2 Carbon Pricing System

Aside from the FIT mechanism, the most widely used tool should be the carbon pricing system. Carbon pricing system is to put a cost on the negative externalities generated by non-green technology and makes using those technologies undesirable. Therefore, it could spur on the research and development of green technologies. Normally, carbon pricing system can take the form of a trading scheme or a tax on emissions wherein the right to certain levels of GHG emissions is traded.

1. Emission Trading Scheme (ETS)
   The implementation of the emission trading scheme (ETS) is based on the "cap and trade" principle, where a maximum (cap) is set on the total amount of GHG that can be emitted by all participating installations. "Allowances (or permission)" for GHG emissions will be allocated for free or auctioned off by the authorities and subsequently can be traded among all the participants. Under the "measurable, reportable, and verifiable (MRV)" principle, installations must monitor and report their GHG emissions. After verifying their GHG emissions by third party, installations should hand in enough allowances to authorities to cover their GHG emissions. If emission exceeds the permission, a company must purchase allowances from other participants. Conversely, a company having well performance on emission reduction can sell its leftover credits. The European Union Emissions Trading System (EU-ETS), launched in 2005, was the first large-scale ETS for GHG emissions in the world. However, an issue

with the emission trading is that it lowers the net emissions of an industry but could increase the emissions at a single site [37]. This individual issue should be considered by the policy presiding over that single facility.

2. Tax Exemptions and Rebates
Tax exemptions and rebates can be implemented in many forms, such as fuel taxes and land development taxes. Carbon taxes can provide large fiscal revenues while lowering carbon emissions by putting a price on pollution emission [38]. Taxes on pollution account for externalities that have traditionally remained unpaid for. Due to the rising price of carbon emissions worldwide, companies would be forced to adopt cleaner technologies. Moreover, a company with overtaxed from pollution costs may be forced to reevaluate its overall efficiency on the use of energy and materials.

18.3.3.3 Other Measures

To promote the renewable energy, electricity can be priced more accurately by other measures:

- Abolishment of "price ceilings": This would allow electricity rates to reflect current market prices instead of fueling excessive consumption, inhibiting investment, and undervaluing energy efficiency.
- Elimination of "declining block-rate pricing (i.e., the per unit price of energy decreases as the energy consumption increases, which is offered to large-scale energy consumers)": this would promote energy efficiency and reduce the consumption of electricity.
- Reflection of "time use (i.e., how the electricity usage varies throughout the day)" in electricity bills: This would adjust customers' consumption with respect to peak and off-peak consumption hours. A consumer will buy electricity in a more efficient manner [22].

18.3.4 Internalization of Externalities, Social Acceptance, and Investor Mobilization

Global environmental issues can be classified into three parts: (1) pollution, (2) biodiversity, and (3) trade-related. Global public environmental issues, such as GHG emissions and ozone depletion, should be addressed by collective actions and binding agreements to avoid "free-rider" problems. With a view to improve social welfare, the concept of environmental externalities, social acceptance, and investor mobilization are introduced in this section.

18.3.4.1 Internalization of Externalities

There are two types of environmental market failure: (1) environmental externalities and (2) environmental degradation. Externalities can cause divergence between social cost (or benefits) and private costs (or benefits). Externalities arise when certain actions of a producer or a consumer have unintended external effects on others. In general, negative externalities (such as pollution) arise when a producer imposes cost on other producers and/or consumers, where the imposer is not charged. Mostly, the probability of human exposure to pollution such as solid residues and wastewater can be effectively mitigated through proper operating procedures. However, airborne emissions are typically no longer controllable once they are released. There has been consensus among public health officials that airborne pollutants from incineration would lead to premature mortality. Airborne emissions comprise a large number of substances that are environmental persistence, long half-life, and inherent toxicity. Even at a low level, they would exhibit severe impacts on environment, ecosystem quality, and human health [39]. As a result, facilities should deploy up-to-date green technologies with appropriate flue gas controls to reduce airborne emissions.

18.3.4.2 Social Acceptance

Since a community is made up of a spectrum of different viewpoints, it cannot be treated as a collective whole. People with different viewpoints may react differently to certain political decisions and scientific information. As a result, these variances should be considered in the decision-making process to complement the policy measures. In general, "cultural theory" can be applied as a heuristic tool to evaluate the public opinions and acceptance on a certain issue. It is noted that even when the information is available to the public, certain factions will remain skeptical about the need to implement green technologies [40]. A study indicated that local attitudes were surprisingly in favor of green supply chains. However, the development of green supply chains was still limited due to the absence of public information, insufficient technology information, incomplete legal framework, and inadequate political decision [41].

18.3.4.3 Investor Mobilization

Prior to green facility installation, investor behavior and mobilization can be evaluated by several factors. Two of the most important parameters affecting the decision making of stakeholders are as follows:

- Awareness of investor [42] and
- Payback period [43].

1. Awareness
   For investors and stakeholders, awareness is the amount of information regarding a certain technology and its associated market [44]. It should be established through the understanding of governance, objectives, targets, business models, technical knowledge, risks, and rewards [45]. Making investors aware of the costs and benefits of a successful green supply chain is a tipping point since lack of awareness could result in a market failure. In particular, in the developing countries, there is lack of consensus on green practices such as promotion of energy efficiency.
2. Payback Period
   Payback period refers to the period of time required to recoup the investments or to reach the break-even point. It is correlated to the probability of an investment being made [46], e.g., a shorter payback time will yield a higher probability of investment. Interestingly, a larger number of recommendations in a preliminary assessment means more work for stakeholders further down the road, thereby leading to a negative influence on the probability of implementation. The neglect of the stakeholders in following through with recommendations can be attributed to a lack of economic incentives.

18.3.5 Integration of Best Available Technologies for Innovation

Technological barriers require comprehensive and integrated strategies that include solutions from the institutional, regulatory, and financial aspects. Simple technologies are available with limited resources, which should make significant improvements in economic efficiency, resource use, and human well-being [30]. The complexity of various technologies for green supply chains, however, may hinder the formation of green supply chains. It thus suggests that the innovation centers should adapt the relevant knowledge to localize the experience on implementation of green technologies. The technology knowledge should be available to policy makers, investors, and communities to support national institutions and serve as a link to international experts and knowledge base.

For optimization of WTE supply chain, several approaches such as bioethanol supply model [47], taxonomy criterion [48], mathematical programming [49], and multiobjective decision making [50] have been employed. Integration of best available technologies (BAT) for innovation can provide opportunities of green technologies and products. With consideration to the life cycle of the production process, the recycling-based technologies should be implemented in industrial parks. In industrial manufacturing processes, the integrated approaches include the following [28, 33]:

- Waste-to-resource and -energy technologies;
- Energy conservation technologies, such as waste heat recovery;
- Cleaner productions for energy, water, and materials;
- Energy-efficient and water-efficient technologies; and
- Carbon capture and utilization (CCU) technologies.

Several important technologies for the constructions of green supply chains are illustrated as follows.

18.3.5.1 Waste-to-Energy (WTE) Technologies

The biosolids from the wastewater treatment plant can be converted to biogas for electricity and heat. Biosolids gasification has been receiving the most attention as viable options for waste-to-energy (WTE), which is capable of providing a clean and manageable process with the possibility of net energy gains [51]. The WTE technologies can convert the biobased wastes into a form of biobased chemicals or energy, which can be used for heating and energy supplies of a district. For building the WTE supply chains, the commonly used technologies used in industrial park are as follows:

- Green fuel pellet [52],
- Bioheating [53],
- Combustion [54] or incineration [55],
- Gasification [51, 56], and
- Anaerobic codigestion [57].

By using the proper technologies, different types of biomass can be converted into various types of bioenergy products, such as biogas, biofuel, and biochar. The suitable feedstock for the WTE supply chain includes the following:

- Agriculture and forestry wastes,
- Energy crops,
- Domestic and household wastes,
- Animal residues, and
- Industrial residues.

As shown in Fig. 18.7, the WTE techniques can be divided into four categories: physical, thermal, chemical, and biological methods. As suggested by USEPA [56], there is significant interest around the globe in developing this technology to commercial scale based on the quantity of research data pertaining to sludge gasification. However, the pulp and paper mill sludge may not be a suitable candidate for gasification due to the high moisture and mineral contents, resulting in low energy values and uneconomical even for a full-scale operation [56].

In this section, the commonly used processes in the WTE supply chains, including green fuel pellet, combustion, gasification, and anaerobic digestion processes, are briefly illustrated.

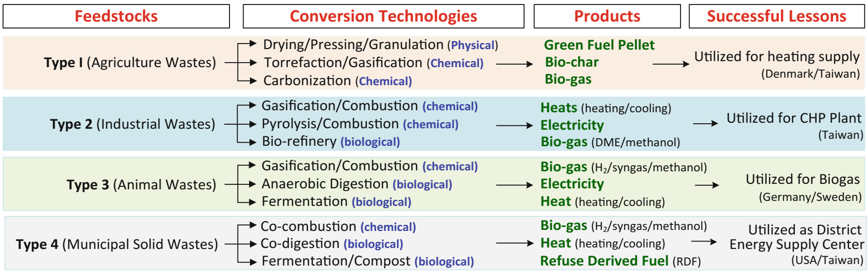

Fig. 18.7 Waste-to-energy (WTE) supply chain for bioenergy utilization. Reprinted by permission from Macmillan Publishers Ltd: ref. [3], copyright 2015

1. Green Fuel Pellet

Green pellet fuels are biofuels made from compressed organic matter of biomass. They are considered as environmentally friendly fuels due to their lower sulfur content and lower pollutant emission than heavy fuel oil in the course of combustion. Wood pellet fuels are the most common type of pellet fuels, generally made from compacted sawdust and related industrial wastes such as lumber, furniture, and construction wastes. The advantages of using green pellet fuels as alternative sources of heating and power include as follows:

- Substantial increase in low heating value (LHV) compared with green chips.
- Reduction in transportation costs.
- Simplified transportation and handling.
- Reduction of biological activity and stable storing.
- Homogeneous manageable fuel for power plants.

According to the life cycle assessment, the energy consumption of wood pellet production was mainly on the manufacturing process ($\sim$71%), followed by its transportation ($\sim$23%) [58]. On the other hand, the solid residues generated from wood pellet combustion (such as bottom ashes) can be used as farmland fertilizers and soil conditioners due to the high contents of calcium, potassium, magnesium, and phosphorus [3, 52]. Another pellet fuel produced by the physical method is called refuse-derived fuel (RDF). The RDF is made from materials that have been sorted out of municipal solid waste streams to exclude non-combustible materials such as glass and metals.

2. Combustion

Combustion is referred as a thermal treatment or an incineration (in the case of municipal solid wastes treatment). The commonly used combustion technologies can be categorized into

- Pile combustion,
- Stoker combustion,

- Suspension combustion, and
- Fluidized-bed combustion.

Combustion involves heating under excess oxygen to completely oxidize the organic part of input stream. It can make use of the chemically bounded energy in solid wastes. After combustion, the volume of solid waste can be reduced, and its contained hazardous materials can be destroyed. The outputs of the combustion processes include exhaust (flue) gases, fly and bottom ashes, wastewater, and energy (in terms of heats). In the exhaust gas, complex elements and compounds can be found: such as N_2, CO, CO_2, NO_x, SO_x, polychlorinated di-benzodioxine, furan, methane, ammonia, hydrochloric acid, and hydrogen fluoride [59]. The emissions of air pollutants could be reduced by various methods such as follows:

- Modifying fuel composition,
- Modifying moisture content of fuel,
- Modifying particle size of fuel, and
- Improving construction chamber shape and incineration application.

Prior to combustion, input solid wastes are often physically altered to increase energy efficiency and decrease emissions. Since the moisture content in municipal solid waste directly affects the efficiency of combustion, the solid waste stream is often processed to ensure an optimal level of moisture content.

3. Gasification

Conventionally, the treatments for biosolids, such as paper and pulp mill sludge and municipal sewage sludge, were landfill, incineration, or land application. Aside from combustion, the sludge can be sent to a gasification process to generate biogas. Gasification can convert organic part of input stream into methane (CH_4), syngas (CO and H_2), and CO_2. It typically can be achieved by reacting the materials at high temperatures (e.g., >700 °C) with a controlled amount of combination of steam, oxygen, and/or nitrogen. The advantages of gasification for sludge treatment include [56]:

- Higher value of versatile end products.
- Availability of the feedstock.
- High efficiency of gasification system.
- Low costs for syngas conversion process.

Appropriate pretreatments on sludge are required if the gasification process is applied. For example, the appropriate moisture content in sludge should be typically between 10 and 20%, which is much lower than those in raw sludge, i.e., 40–99%. After gasification, the syngas, if purified and cleaned, can be further converted to liquid fuels via a catalytic Fischer-Tropsch (FT) process. The produced liquid fuels can be applied in various applications [56] such as follows:

- Feed into an internal combustion engine as transport fuels,
- Feed into generator for electricity production,

- Combusted for heat recovery,
- Used in fuel cell applications, and
- Production of a variety of chemicals.

4. Anaerobic (co-)digestion

Anaerobic digestion is a series of biological processes where microorganisms break down biodegradable components in the absence of oxygen. It is a versatile technology by which a renewable energy in the form of biogas can be produced in the course of microbial decomposition of biosolids. As a result, it can significantly reduce the costs for treating wastes and pollution. After anaerobic digestion, the reacted residues have a fairly homogeneous content with respect to major nutrients such as sodium, phosphate, and potassium, which is beneficial to using as a fertilizer.

Anaerobic digestion of a certain biomass (such as manure) as a sole substrate might not be profitable because of low biogas production and some exploitation problems. To overcome this barrier, codigestion of various complimentary feedstocks has been developed and implemented as a good engineering practice (GEP). The codigestion process could avoid the probabilities of ammonia and lipids from inhibiting the process due to a better nutritional balance [52, 61]. For stable anaerobic digestion operation, the carbon-to-nitrogen (C/N) ratio should range between 20 and 30. In this case, the anaerobic codigestion of municipal sewage sludge with swine manure and poultry manure can achieve a high biogas yield of 400 dm^3 per kg VS [60].

18.3.5.2 Waste Heat Recovery

The heat recovery in the incineration or manufacturing processes not only enhances the use of district heating but also reduces the energy consumption with a better valorization of the waste. The exhaust (waste) heat can be classified into various levels:

- High quality: higher than 500 °C,
- Medium quality: 250–500 °C, and
- Low quality: lower than 250 °C.

The process waste heat could be further utilized to generate electricity and/or steam by various technologies, such as heat exchanger, adsorption chiller, transcritical CO_2 heat pump, refrigeration cycles, and organic Rankine cycle (ORC).

1. Multiple Energy Production System

For waste heat recovery, several mature technologies regarding multiple energy production system can be used in district energy supply [61, 62]:

- Combined heat and power (CHP): known as "cogeneration" and
- Combined cooling, heating and power (CCHP): known as "tri-generation."

By utilizing exhaust heat, both CHP and CCHP boost system efficiency and decrease CO_2 emissions. The principles of CHP and CCHP are similar since they derive energy from a single source. CHP utilizes a heat engine and/or power station to simultaneously generate electricity and available heat. In CHP, the high-temperature heat or steam first drives a gas or steam turbine-powered generator, and then, the resulting low-temperature exhaust heat is used for water or space heating. The moderate temperatures of outlet steam after the CHP process were typically at 100–180 °C, which can be used by the adsorption chillers, and/or refrigerators for cooling demand such as air conditioner. It is noted that a well-designed CHP system could offer an energy efficiency of over 80% [54, 61].

The main difference between CHP and CCHP is that, for CCHP, cooling is one of the desired end products for the customers. Cooling can be generated by a heat pump or absorption chiller using the exhaust heat from process or heat delivered to buildings. Moreover, a great advantage of deploying CCHP systems for energy supply is the flexibility of the system. For instance, in winter, the CCHP can be seen as CHP since there is no demand for air-conditioning in building.

2. Organic Rankine Cycle (ORC) System

Organic Rankine cycle (ORC) power facility has been recently used for exhaust (waste) heat recovery from the flue gas in various industrial processes because of its simplicity, reliability, low maintenance, and easy remote monitoring [63]. The ORC facility can effectively extract low- to medium-grade thermal heat (typically at temperatures of 66 − 260 °C) in the flue gas for power generation [64–66]. Moreover, it can be operated at low pressures (less than 1380 kPa or 200 psig) [63]. To evaluate the thermodynamic and economic performances, the thermal efficiency and net power output index are frequently used, respectively [67]. In the ORC, the R245fa has been commonly used as the organic working fluid because of its relatively high latent heat of gasification and heat exchange efficiency, and relatively low environmental impacts on ozone depletion and GHG emissions [64]. The boiling point and specific heat of R245fa are 15.1 °C at 1 atm and 0.9369 kJ/(kg·°C) at 30 °C, respectively. The density of R245fa at 30 °C is about 1324.6 kg/m^3.

18.3.5.3 Carbon Capture and Utilization (CCU) Technologies

The implementations of carbon capture and utilization (CCU) technologies should combat the environmental and energy issues in industries for security and sustainability. With the CCU technologies, appropriate value of carbon management mechanism is added into fossil fuel, biomass, and renewable energy. Furthermore, updates in the main infrastructures, such as road and land accessibility, water availability, solid waste disposal, and an electrical grid, should be required for construction of WTE supply chain.

18.3.6 Development of Comprehensive Performance Evaluation Program

To evaluate the performance of a green supply chain, two methods, i.e., cost–benefit analysis (CBA) and life cycle assessment (LCA), are commonly utilized. CBA can be used to estimate the costs and profits associated with a project, while LCA can quantify the environmental impacts and benefits. Aside from the CBA and LCA, several concepts are imperative to carried out a comprehensive performance evaluation (CPE) for establishing green supply chains, including determination of plan-do-check-action (PDCA) principle, key performance indicators (KPIs), and demand-side management (DSM), which are illustrated as follows.

18.3.6.1 Plan-Do-Check-Action (PDCA) Principle

Plan-do-check-action (PDCA) principle was originally suggested by Shewhart [68] and could be implemented in the design of comprehensive performance evaluation as illustrated in Fig. 18.8. Establishing commercialized (or business) models should be essential to demonstrate and evaluate the performance of innovative green technologies. For example, the incineration plant can be integrated with the steam cooking system to form a district energy supply center. Biosolid wastes from the

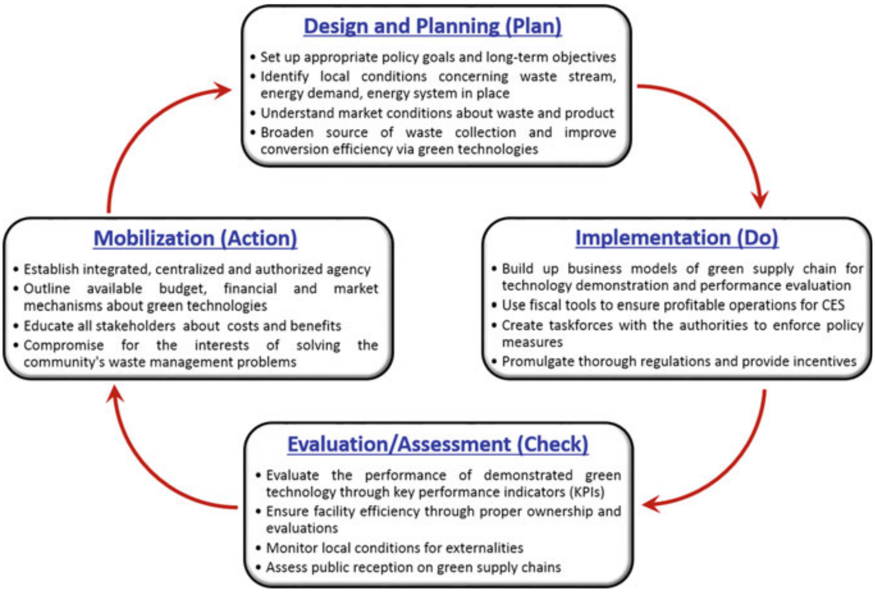

Fig. 18.8 Policy-making cycle for establishment and implementation of green supply chains

large and/or small industrial plants could be utilized as the energy source for power generation and/or heating purpose, respectively. After performance evaluations, policy makers and stakeholders can compare the operation results with their original goals and properly revise it if needed. Through revisions and amendments, a policy can be adjusted in light of new information. The above procedure is consistent with the management method of PDCA cycle.

18.3.6.2 Key Performance Indicators (KPIs)

The CPE programs are required to assess whether the policy factors are successful at achieving preset goals. Since a policy acts on a community in a multifaceted way, performance evaluations should be conducted in a diverse approach. The CPEs should be performed for at least three times: (1) before a policy is enacted to ensure proper planning, (2) during the process of implementation to ensure optimal function, and (3) after goals have been met to ensure insight into future improvements. For the CPE, key performance indicators (KPIs) must be established for evaluating the progress toward the implementation of green supply chains. The KPIs are quantifiable measures of an institution's ability to accomplish their set goals. As suggested by UNEP, three primary areas act as the most beneficial KPIs when measuring various aspects of green economies [1]:

- Indicators of resource efficiency (engineering aspect),
- Economic transformation (economic aspect), and
- Human progress and well-being (social aspect).

Table 18.2 summarizes the themes and KPIs for establishing green supply chains from environmental, economic, and social aspects. For instance, the KPIs in the environmental aspect measure resource efficiency of a green supply chain. Because the scales of land areas and companies for various industrial parks are quite different, the performance of each industrial park should be compared via annual production of energy or economic values as the basis, e.g., carbon intensity (i.e., CO_2 emission/energy production) and energy intensity (i.e., energy/GDP).

For the economic aspect, the economic transformation indicators often assign a monetary value to the cost and profits of greening strategies, including investments, jobs, and industrial growth. The levels of investments made in green activities can be compared with that in environmentally harmful activities. Moreover, economic performance of green supply chains can be measured by the growths of goods, services, and jobs in green activities [69].

For the social aspect, human progress, community development, and well-being indicators are suitable for gauging the performance of green supply chains since they consider if the economic development goal of sustainable development is fulfilled. However, when available data is sufficient, the indicators are often seen as

Table 18.2 Themes and key performance indicators (KPIs) from environmental, economic, and social aspects

Aspects	Themes	Indicators
Environmental	Pollution prevention and control (per unit output value increase)	Air pollutant emissions such as VOCs, NO_x, SO_2, and particles
		Wastewater discharge
		COD emissions
		Solid waste generation
		Target for CO_2 reduction
	Energy and resource consumption (per GDP)	Land consumption
		Energy consumption
		Freshwater consumption
		Chemicals consumption
	Energy and resource recycling	Energy-saving efficiency
		Ratio of reclaimed industrial wastewater
		Water consumption per unit output value
		Material consumption per unit output value
		Waste recycling ratio per unit output value
	Environmental planning and management	Averaged pollution standard index (PSI)
		Ratio of green land
		Green building indicators
		Environmental management system (EMS)
		Sustainable material management (SMM) system
Economic	Cost reduction and clean production	Measures for promoting pollution prevention and resource recovery
		Cost reduction of CO_2 emission control by waste recycling
		Ratio of material shipping expense in the total output value
	Profit increase and green consumption	Gross domestic production (GDP)
		Gross industrial output value (GIOV)
		Industrial added value (IAV)
		Discounted cash flow
	Tax	Carbon tax
		Fuel tax
		Pollution tax
	Incentive and pricing support	Feed-in tariff on renewable energy (or green technology)
		Government subsidy on construction
		Credit lines loan guarantee
	Corporate image promotion and green industry	Budget/expenditure of environmental protection
		Total investment for pollution control

(continued)

Table 18.2 (continued)

Aspects	Themes	Indicators
Social	Public participation and acceptance	Number of visitors in open house events per year
		Completeness of message platform
		Publication of environmental report
		Public satisfaction of environment
		Public cognition of eco-industrial park
	Community development	Interchange plan for public transportation system
		Plan for biking and walking route
		Social familiarity
		Betweenness centralization
		Density average distance
	Fairness and justice	Green park area per capital
		Number of pleaded environmental pollution events
		Compliance with laws and regulations
	Population and health	Safety nets
		Health status

less legitimate than the key economic indicators such as GDP for making policy decisions.

18.3.6.3 Demand-Side Management (DSM)

Demand-side management (DSM), or demand-side response, programs are implemented to change the consumption pattern of consumers, such as the behavior of a household. The goal of the DSM is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times (such as nighttime and weekends). A successful DSM program should comprise marketing strategies with multiple approaches, such as follows [22]:

- Programs targeting specific audiences,
- Technical assistance for customers,
- Simple program procedures for customers to estimate potential benefits, and
- Financial incentives to attract attention and reduce initial costs.

Similarly, large-scale energy plants also should be located near their source of heat demand to maximize the overall energy efficiency [70]. Also when changes occur, the performance of a plant and its associated energy distribution network should be able to predict [35]. In catering to green supply chain, a cost–benefit analysis can provide an estimate on the direct costs of operating and maintenance and the fixed costs to optimize the design of green supply chain [10].

18.3.6.4 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is an evaluation of potential environmental impacts for a production system or service throughout its life cycle by compiling all inputs and outputs (e.g., material, energy, and pollutants). LCA was originally used in product analysis, and it recently has been widespread in analyses of pollution control facility and/or environmental engineering areas, such as follows:

- Waste management system [31, 71],
- Incineration facility [39, 72], and
- Carbon footprint in industrial park [73].

Environmental impacts evaluated through LCA can be associated with analysis of material and energy consumptions [74] and stakeholder involvement [14]. On the other hand, the decisions from human health risk assessment need to be supported by strong scientific evidences, and the extent of uncertainties in assessments should be carefully determined. Scenario evaluation by LCA can be used to estimate exposure levels in humans, with the consideration to the time of contact and the sources of hazardous materials. Another tool for approximating actual human exposure levels to a pollutant of interest is biomonitoring.

18.4 Implementation of WTR Green Supply Chains: Case Study

To achieve the goals of being environmentally bearable, economic viable, and social equitable, "building a green supply chain within industrial park" should be extensively promoted to make traditional industries around the world. It is noted that development of eco-industrial parks (EIPs) can simultaneously achieve the environmental protection, economic development, and social equity.

18.4.1 Eco-Industrial Parks (EIPs) as a Business Model

To meet the demands of a circular economy, eco-industrial parks (EIPs) have been extensively established in different regions, such as Australia [75], Denmark [76], Europe [12, 77], USA [34], Japan [29], Mainland China [28, 78, 79], Korea [33], and Taiwan [26, 80]. The definition of the EIPs can be found in the literature [81]:

> community of manufacturing and services companies seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water, and materials.

The EIPs are to promote energy conservation/efficiency, carbon reduction, and green production by the implementation of green supply chains. The objectives of EIPs are to

- Establish an integrated framework that embraces economic development, environmental quality, and social equity,
- Stimulate investments in the private sector, increasing employment opportunities related to resources recycling and encouraging rural and urban community developments,
- Build up a recycling-based sustainable society to achieve the goals of zero emissions,
- Manage waste reduction and reuse technologies to achieve goals of total recovery and zero waste, and
- Build recycling-based ecocities and/or ecovillages, raise resource-recycling ratios, and reduce water and energy consumptions.

To meet the objectives of EIPs, five strategies are suggested as follows:

- Policy makers should create policy for simultaneously reducing GHG emissions and improving energy efficiency.
- Action plans should increase manufacturing efficiency while seeking synergetic cooperation between all manufacturers in the industrial park.
- Creation of a cost-effective integrated green certificate market by implementation of pricing instruments, such as tax exemptions and carbon credits.
- Crucial information should be made easily accessible including the following:
  - Updated manufacturing processes,
  - Supply and demand of materials and energy,
  - Resources for assistance, and
  - Human training resources.
- Life cycle analysis (LCA) should be utilized as a structured basis for evaluating the performance of environmental impacts and benefits in EIPs.

18.4.2 Iron and Steel Industry

In the case of iron and steel industry, China Steel Corp. (CSC) in Lin-Hai Industrial Park (Kaohsiung, Taiwan) has successfully established the business model and served as the center of green supply chain since 2008. Figure 18.9 shows the schematic diagram of construction of the green supply chains in the Lin-Hai Industrial Park. Lin-Hai Industrial Park consists of a total of 482 manufacturers in the fields of mechatronics, steel manufacturing, chemical engineering, and transportation. By the end of 2012, a total of 15 green supply chains including steam, hydrogen, nitrogen, waste alkaline solution, incinerator bottom ash, and electric arc furnace dust were established. For instance, the alkaline solid wastes can be used for carbonation process to react with flue gas CO_2 to form stable carbonate precipitates [82]. Meanwhile, the physicochemical properties of the carbonated solid waste can be upgraded since the free-CaO content is eliminated, which is beneficial to the application as construction materials [25, 83]. Moreover, the alkaline

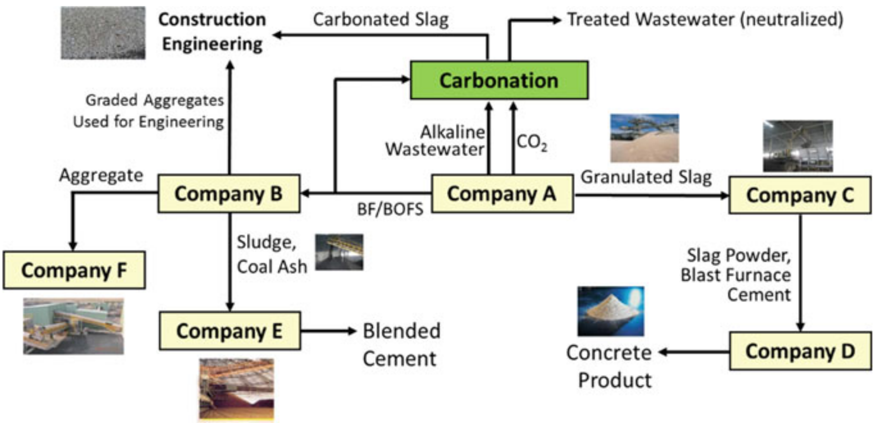

Fig. 18.9 Conceptual diagram of green supply chains in the case of alkaline solid wastes in the Lin-Hai Industrial Park (Taiwan)

wastewater, if available, can be introduced in the carbonation reaction, and the wastewater can be neutralized after reaction.

From this green supply chain model, the total amount of steam supply was estimated at about 2.5 Mt/y. As a result, the environmental benefits of steam supply include the following: (1) a CO_2 reduction of 574,000 t/y, (2) a SO_x reduction of 1830 t/y, (3) a NO_x reduction of 1270 t/y, and (4) particle matter (PM) reduction of 180 t/y. On the other hand, the total amount of recycling wastes was determined at 0.67 Mt/y, corresponding to a waste utilization ratio of 84.7%. Accordingly, the total economic profits attributed by the green supply chains was estimated to be US$ 100 million per year.

18.4.3 Petrochemical Industry

Lin-Yuan Industrial Park (Kaohsiung, Taiwan) comprises a total of 30 industries, where 27 of them are petrochemical related industries including Formosa Plastic Corp. and China Petroleum Corp. Since 1992, Formosa Plastic Corp. had been served as the district energy supply (DES) center for many companies in the industrial park. Figure 18.10 shows the schematic diagram of construction of the green supply chains in the Lin-Yuan Industrial Park. For example, the Formosa Plastic Corp. utilized the CHP technology to generate electricity and heat (i.e., steam), where four boilers with a steam capacity of 200 tons/h were installed. The exhaust heat with different qualities was used to simultaneously generate electricity, steam, and hot water. The high-quality steam ($\sim$3.5 kg/cm^2) was utilized to drive the steam turbine for electricity generation and median-quality steam supply. Similarly, the low quality steam (1 kg/cm^2) was used not only to recycle the chilled water for air-cooled heat exchanger but also generate hot gas ($\sim$105 °C) delivering

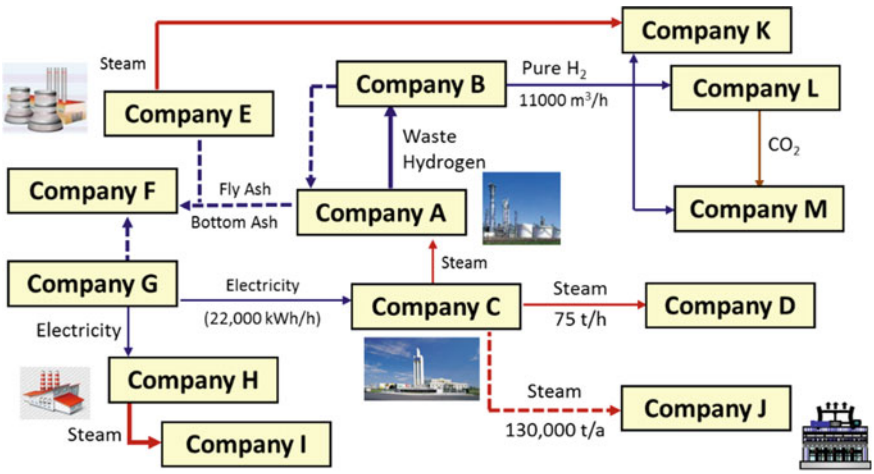

Fig. 18.10 Schematic diagram of construction of the green supply chains in the Lin-Yuan Industrial Park (Taiwan)

to another plant for high-density polyethylene (HDPE) production. With the aforementioned energy integration system, the overall heat efficiency increased up to 60.5% because of the district steam supply. Furthermore, the industry waste gas supply (such as hydrogen) was estimated at 8600 ton per year.

In this industrial park, both the rainwater and wastewater are recycled into the manufacturing process for reuse. The water recycling technologies, including the membrane bioreactor (MBR), ultrafiltration (UF) and reverse osmosis (RO) processes, can be used to purify the wastewater to the acceptable levels of turbidity (<0.2 NTU) and total suspended solid (<1 mg/L). Also the large molecules and ions in the wastewater can be removed though the RO process.

Since 2012, a total of seven green supply chains (including electricity, steam, hot water, hydrogen and bottom ash) have been established with a potential amount of 38,000 tons per year. The environmental benefits of steam supply include (1) a CO_2 reduction of 32,300 ton per year, (2) a SO_x reduction of 370 ton per year, and (3) a NO_x reduction of 160 ton per year. Accordingly, the economic profits in the Lin-Yuan Industrial Park were estimated to be US$5.3 million per year.

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