TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering
Department of Industrial Engineering and Management
Chair of Production Engineering

Zheng Zeya

Green Manufacturing framework development and implementation in industry

Supervisor: Eduard Ševtšenko

Author applies for degree of Master of Science in Engineering (M.Sc.)

Tallinn 2015

AUTHOR'S DECLARATION

I have written the Master's thesis independently.

All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's thesis is completed under the senior researcher Eduard Ševtšenko supervision.

"....." May 2015 Author ..... Signature

Master's thesis is in accordance with terms and requirements "....." May 2015

Supervisor…….....Signature. / Eduard Ševtšenko /

Accepted for defense

..... Chairman of defense commission

"....." May 2015

..... Signature

MASTER'S THESIS TASK

2014 /2015 academic year, 4 semester.

Student: Zheng Zeya, 132059.

Field of study: Industrial Engineering and Management.

Supervisor: Eduard Ševtšenko, Senior Researcher.

Master's thesis topic (English and Estonian languages):

Green Manufacturing framework development and implementation in industry

Rohelise tootmise raamistiku väljatöötamine ja rakendamine tööstuses

Tasks and timeframe for their completion:

Nr	Task description	Completion date
1	Thesis Contents created	01-03-2015
2	4R principles developed	01-04-2015
3	5 core technology developed	20-04-2015
4	Industrial implementation described	01-05-2015
5	Thesis finished with conclusion	18-05-2015

Engineering and economic problems to be solved: New framework of Green Manufacturing created. Implementations in automobile and electronic industry are detailed described with 4R principles and 5 core technologies. It created a comprehensive solution for company achieving Green Manufacturing.

Defense application submitted to deanery not later than 18.05.2015 Deadline 18.05.2015

Student: Zheng Zeya/signature/ …..…..…… date ….....……

Supervisor: Eduard Ševtšenko /signature/ …….……. date ….....……

Phone + 372 5848 0577 E-mail: zheng_zeya@163.com

CONTENT

CONTENT OF FIGURES

CONTENT OF TABLES

LIST OF ABBREVIATIONS

AQI: Air Quality Index

C.A: Activated Charcoal

CPU: Central Processing Unit

GM: General Motors

HEVs: Hybrid Electrical Vehicles

IC: Integrated Circuit

ISO: International Standardization Organization

LWTB: Laser Welding Tailored Blanks

PAM: Polyacrylamide, C_3H_5NO

PAC: Poly Aluminum Chloride

PBB: Polybrominated Biphenyls

PCB: Printed Circuit Board

PDM: Product Data Management

PFC: Prfluorocarbon

PLC: Product Life Cycle

PVC: Polyvinyl Chloride

ROHS: Restriction of the use of certain Hazardous Substances

TBBPA: Tetrabromo Bisphenol-A

WEEE: Waste Electrical and Electronic Equipment

OBJECTIVES AND TASKS

The master thesis has the following objective:

Current paper main objective is to develop a new framework of Green Manufacturing as well provides examples of implementation in industry and it will help readers better understand and apply Green Manufacturing by clearly structure and implementation examples.

The master thesis has the following tasks:

- Research and refine current knowledge hierarchy of Green Manufacturing
- Find out regularity, principle, characteristic and feasibility of Green Manufacturing
- Develop a new framework
- Present the examples of implementation of new framework
- Sum up the knowledge of Green Manufacturing

1 Introduction

Green Manufacturing, also called environmental awareness manufacturing, environment oriented manufacturing and so on. It is a comprehensive consideration of environmental impact and resource utilization efficiency of modern manufacturing model. The aim of Green Manufacturing is to the minimum negative impact on the environment and maximum resource utilization from product design, manufacturing, packaging, transportation, use and the product recycle. The ultimate goal of Green Manufacturing is to coordinate enterprise development and social benefit [1].

At the present, manufacturing industry is developing rapidly. However, it also produces a mass of garbage and resource consumption. Nowadays, the idea of sustainability and green is very popular. Green Manufacturing is the problem that every manufacturer must be taken into account. However in fact, many manufacturing company would not like to apply green manufacturing also not able to apply it. The reasons are mainly because those companies misunderstand green manufacturing and lack of green manufacturing technologies. So author will analysis it and develop a new framework to make readers better understand green manufacturing and learn more practical experience about green manufacturing [2, 32].

The new framework of Green Manufacturing includes 4R principles and five core technologies. The implementation of this new framework will also be present in automobile and electronics industry. This thesis has significance for the author himself due to the Chinese government has planned to decrease the environmental problem by applying Green Manufacturing in full-scale [3].

The first step of Green Manufacturing is green design. It requires the consideration of environmental effects during the design process. For example, recoverability, the difficulty of manufacturing, the green level of used material. An enterprise also needs to apply some

advanced production systems to reduce waste, defective and improve production efficiency. Maintenance service can prolong product life. It is better to be considered during the product design process. After green design, green production should be considerate. Company should use new technologies to reduce resource consumption and waste of emission. Green package requires producer use appropriate package to achieve sustainability by design and material selection. When a product is going to break, it is facing green recycle. Scraped product should transform into reusable resources at final. Green remanufacturing technology helps company to recover the scraped products back to the ones close to new products [2].

Green Manufacturing is a big concept. Companies that would like to apply green manufacturing needs theoretical direct as well as specific technology. The origin, status quo and future trends of Green Manufacturing to are given in Chapter 2. Regularity, principle, characteristic and feasibility of Green Manufacturing are integrated in Chapter 3. Specific technologies and experience are described in Chapter 4. Summary is in the Chapter 5. Now the journey to green manufacturing begins.

2 Background information of Green Manufacturing

With the exasperation of the environment, the populace becomes more and more concerned about such problem. It is the ultimate goal of balancing manufacturing and ecosystem to realize the globalization of Green Manufacturing. Actually, Green Manufacturing is not a brand new idea put forward during the past few years. Dated back to the commencement of Industrial Revolution, some scholars immediately found several negative effects that manufacturing had on the environment. In the recent years, more and more corporations have put Green Manufacturing into a vital strategic location [1].

2.1 The origin of the Green Manufacturing

From the end of the 17th century to the beginning of the 18th century, with the invention of the steam engine, the industrial age occurs in human's society. Versus with the agricultural society, Industrial society created incomparable productivity. The new knowledge, new technology and new product created by the industrial age enormously have decreased the death rate and increased the human life. It has achieved a world's population rapid expansion. The industrialized society also has built a new pattern of lifestyle and consumption. People do not satisfy the basic material demands anymore and constantly pursue more abundant material and spiritual enjoyment. Those all depend on the fast consumption of resources and energy. Especially, the consumption of fossil resources and other non-renewable resources caused the large emission of the pollutant. It not only leads to the rapid depletion of natural resources but also results in the deterioration of the ecological environment [1, 5].

At the present, more than 80 countries including 1.5 billion people face the problem of lacking fresh water. 26 countries with 300 million people among them are in the trouble of completely lacking fresh water. It was predicted that there would be 3 billion people lacking fresh water, and more than 500 main rivers would be exhausted. What is more,

acid rain pollution causes the reduction of forest area, greenhouse effect causes the global warming, ozone layer depletion causes the ultraviolet light damage and garbage rapid increase causes the pollution of land and underground water. Currently, people also start to aware the AQI (Air Quality Index). Damage caused by air pollution and air particulate matter continuously raises people's attention [4].

All these problems start from the industrial revolution which is the beginning of the manufacturing industry. In the 1960s, systematic researches on the relationship between human society and natural world revealed the serious conflict between human and nature. In 1962, American biologist Carson published *Silent Spring*. It presented a shocking case to tell the harm of using large pesticide. Human starts to be aware of the negative effects of industrialization. In 1972, UNHEC (United Nations Conference on the Human Environment) announced *Declaration on the Human Environment.* It requires human to protect the environment when developing and utilizing it [4].

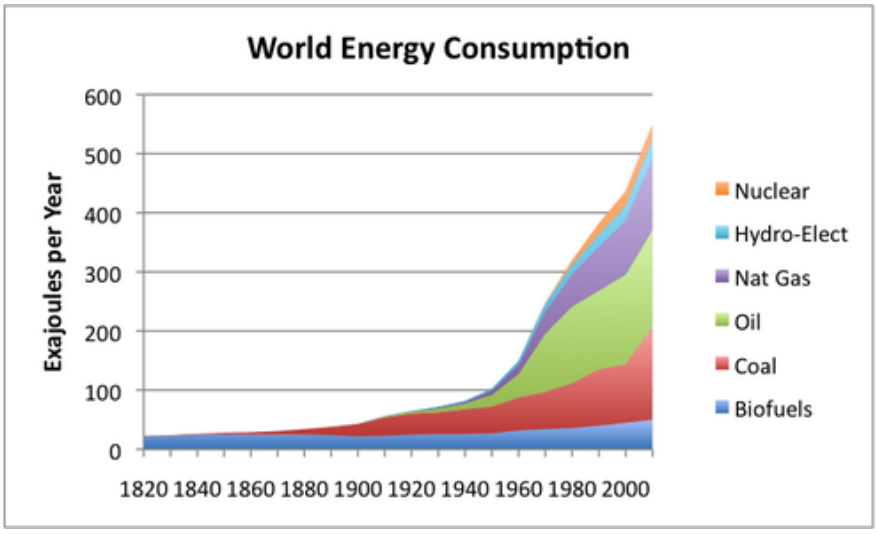

Figure 1, World Energy Consumption, 1 Exa = 1 x 20^{15} [4]

Figure 1 illustrates the world energy consumption rapid increase after 1850s. It also shows the energy resources used out by human within 100 years have exceeded the sum of all energy consumption of all previous time. Most of energy resources are coal, oil and natural gas [4].

Held in Johannesburg in 2002, the World Summit on Sustainable Development approved the "*World Summit on Sustainable Development Plan of Implementation*" by the United Nations. The plan identified that development is still the common theme for mankind and further present that economic, social and environment are integral three pillars of sustainable development [6].

Manufacturing, involving a series of industries of national economy such as mechanism, electronic, chemistry, food, war industrial, etc., is the pillar industry of creating human's wealth, the foundation of social material and spiritual civilization, and the process that energies turn into industrial products and consumer goods that can be used by people, during when, however, it produces some wastes. Since such wastes are a part of manufacturing resources that have not been used, they are also called waste resources [2].

By virtue of the depth and breadth of the manufacturing system, in the whole, it lays a profound influence on the environment. That is, on one hand, manufacturing, the pillar industry, helps human to accumulate wealth; on the other, it is one of the chief sources of environmental pollution nowadays. Therefore, aiming at solving the urgent environmental problem, it is one of the significant research direction is to minimize the resources consumption and pollution during the production. Here comes a new concept called "Green Manufacturing" which is considered as an inevitable way to reach modern enterprises. In the light of the researches carried out by experts from different countries, Green Manufacturing is one of the fundamental methods to put the environmental pollution to an end, which is a key way to control the source of pollution. Essentially, it illustrates the strategy of sustainable development in modern manufacturing of human society [2].

2.2 Nowadays situation of Green Manufacturing

Internationally, studies on Green Manufacturing can be looked back into the 1980s. Nevertheless, it was “Green Manufacturing” published by Society of Manufacturing Engineers (SME) in 1996 that systematically raised the conception, connotation, and basic ideas of Green Manufacturing, after which it released “Trends of Green Manufacturing” in 1998 to give further introduction of the significance of Green Manufacturing as well as some relative problems [7, 8].

During the past couple of years, around the environmental problems of manufacturing system or manufacturing process, a series of concepts and patterns of manufacturing, which can be approximately divided into four layers, have been put forward [7].

The first layer, which is the bottom, is environmentally neutral manufacturing, where there is a neither negative nor positive effect on the current environment or in other words, it is neutral [2].

As for the second layer, including cleaner production, cleaner technology, green production, etc., refers to the manufacturing patterns which not only do no harm to the environment, but are also beneficial to the current environment. However, such Green reveals only in the manufacturing processes instead of the other processes in the product life cycle such as product design, product usage, along with recycle disposal [2].

When it comes to the third layer, it refers to Green Manufacturing, cleaner manufacturing, environmentally conscious manufacturing, and so on, where the Green exists all through the PLC, manufacturing or production processes, product design, product usage, and recycle disposal included [2].

Last and also the highest, the fourth layer contains environmentally conscious manufacturing and environmentally conscientious manufacturing, which not only is green in the whole PLC, but also attaches importance in the balance between the development of products together with other manufacturing systems and the environment and ecosystem, reaching a sustainable developing system [2].

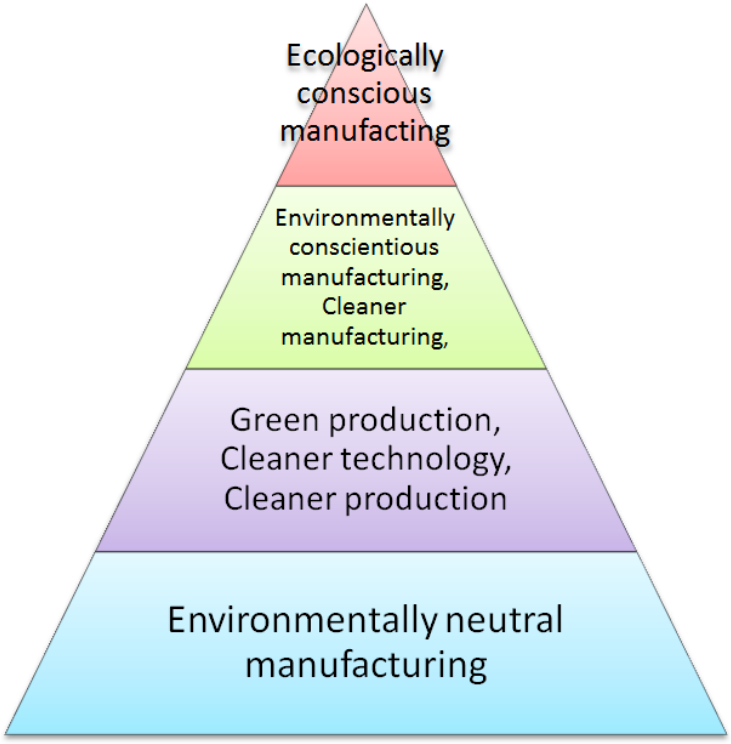

Figure 2, the four layers of the Green in manufacturing [2]

Green Manufacturing Implementations of Some Multinational Corporations

Siemens Corporation (Germany)

Carry Out Green Manufacturing Goals

- Establish environmental management system in all factories
- Set up Interior Audit System
- Strengthen environmentally coordinate product design, and integrate environmental protection to every field of manufacturing
- Preferentially select suppliers with Environmental Management System Certification

Specific Measures to Implement Green Manufacturing

- Improve the materials and the machining processes
- Produce unleaded and chloride-free products
- Design environmentally friendly products on the base of cost reduction
- Recycle and reuse obsolete electronic products
- Normatively implement ISO14001
- Assess PLC

Problems Faced with Green Manufacturing

- Resulted from the high consumption of the products, the marketing expansion will lead to exponential increment of energy consumption
- Update of software brings about early obsolete of hardware, resulted in more environmental pollution

Toyota Motor (Japan)

Carry Out Green Manufacturing Goals

- Improve the environment of all sub-factories, and reduce the consumption of energy and resources
- Not only apply Green Manufacturing in the processes, but also put it into commercial industry
- Remain in the leading position in developing engines and techniques with cleaner fuel that satisfy the requirements of environmental protection laws and regulations

Specific Measures to Implement Green Manufacturing

- Establish purchasing standards for 450 suppliers
- Attach high importance to painting in the processes
- Make some progress in the reduction and elimination of rubbish and wastes
- Decline The 7 Wastes in the processes
- Establish interior criteria for the wastes and pollutants

Problems Faced with Green Manufacturing

- Require further implementation of Green Manufacturing to remain the leading position in cleaner fuel and engine techniques
- Globalize the interior standards of the enterprise

Ford (USA)

Carry Out Green Manufacturing Goals

- Promulgate and implement the "Triple bottom line" policy that the corporation strategically services for economy, environment, and society
- Globally obtain the authentication of ISO14001

Specific Measures to Implement Green Manufacturing

- Reduce the energy consumption of motor manufacturing
- Develop the technique of motor production with light materials, and decrease the energy consumption during the use of motors
- Set up a new group for PLC, and do research on analyzing PLC and its effects on environment
- Make the products more recyclable, and put recyclable materials in the products

Problems Faced with Green Manufacturing

- How to establish a unified system among all the facilities as well as keeping each of them independent and unique

Hitachi Corporation (Japan)

Carry Out Green Manufacturing Goals

- All branch companies are required to be authenticated by ISO14001
- Reduce 10% meaningless energy consumption and 20% wastes annually

Specific Measures to Implement Green Manufacturing

- Study on unleaded weld
- Research on assessment of recycling so as to proffer product designers with an instrument of evaluating the recyclability of the products
- Hold reverse engineering seminars, and study on information interaction system

Problems Faced with Green Manufacturing

- Build up an environmental-oriented standard for all fields [2]

2.3 Analysis of Green Manufacturing implementation

From the above status analysis and corporation practice, we can learn that, the implementation of Green Manufacturing has been paid great attention to by experts and scholars, where some measures have been taken into effect. Though literatures on Green Manufacturing are theoretically focused on key issues including the implementation mechanism as well as the information support system, and empirically delivered quantitative researchers on some data in surveys, when it comes to status quo all over the world, there are still plenty of difficulties in Green Manufacturing [9].

Awareness of Green Manufacturing

It is of great importance for the society to be aware of the significance of Green Manufacturing in order to realize it. There is no denying that Green Manufacturing can be easily accepted and supported by the populace, the government, and non-profit organizations. Nevertheless, the subject of Green Manufacturing, enterprises, play the key role in the process of consciousness which is long and lasting [10].

In developing countries, take China as an epitome, the majority of the enterprises took no consideration of Green Manufacturing with little concerns about resources consumption and environmental discharge. Plenty of the corporations regarded Green Manufacturing as

a burden of environmental protection that would not bring any effectiveness, or even bring some troubles. In reality, even some of those corporations authenticated by ISO 14001 Environmental Management System, whose ultimate goal is to simply reach the requirements of the environment department, have not be aware of the value of Green Manufacturing.

However, some enterprises suffer direct economic loss for the shortage of resources, the worsen environmental pollution, and the continuously increasing green trade barrier. For instance, the two instructions of EU, ROHS (Restriction of the use of certain Hazardous Substances) and WEEE (Waste Electrical and Electronic Equipment), challenge the export of mechanical and electrical products from China. In this case, the industries affected by green trade barriers start to find out solutions to gradually carry our Green Manufacturing while those unaffected corporations are still indifferent in Green Manufacturing. On the contrast, a group of leading companies in the world have regarded Green Manufacturing as one of the prior developing strategies, where many transnational enterprises have set specific strategic goals for Green Manufacturing, striving to be the green leaders and establish green criteria for the whole industry. Obviously, the awareness of Green Manufacturing is the key issue in its implementation. Green Manufacturing set up good images for a corporation, forming a green brand and promoting its competitiveness in the market, which will eventually create more profits [10].

Cost and benefit problem

Cost is one of the inevitable problems faced with Green Manufacturing since the development of green products as well as the application of new Green Manufacturing techniques need some costs without instant benefits, therefore, some corporations may consider it unprofitable, which to some extent restricts the implementation of Green Manufacturing.

Actually, if new techniques that help cut down the consumption of energy and resources are taken into step, the costs will be decreased directly, which increases economic benefits

in a short time. From the perspective of long-run, once consumers become more favor of green products, which transforms environmental effectiveness into marketing benefits, the economic profits of a company will also increase. Similar to other advanced manufacturing patterns, the implementation of Green Manufacturing seems to cost much at first, but it brings long-term benefits. Thus, it is of necessity for a corporation to make both ends meet and reasonably plan for the implementation of Green Manufacturing. No wonder nowadays, almost all the leaders of Green Manufacturing are international magnate companies.

Technical problem

Technical problem is the key issue of the implementation of Green Manufacturing. Up to now, Green Manufacturing techniques are not thorough enough because the critical idea of Green Manufacturing is the specific Green Manufacturing engineering while most of the extant researches are focused on the exploration of theories, conceptions, and linking framework, that is, such studies haven't been deep into the practice of industrial productions, especially lacking green techniques for every certain industries [31].

Aiming at further implementation of Green Manufacturing, the problem of green techniques have to be solved without question, two aspects of which can be taken into account: on one hand, corporations can reinforce the development of green techniques, or they can cooperate with some organizations such as high schools and research institutes; on the other hand, mature green techniques should be put into effects more deeply [31].

Problem of policies, regulations and industrial standard

The implementation of Green Manufacturing in corporations should be dependent on the guidance of the market as well as laws, regulations, financial policies, and standard specifications which are compulsory. Take automobile industry as an exemplar, green mobiles like HEVs and electromobiles have been rapidly developed in the US while in China, it is developed at a slower pace, resulted from the fact that, so far, when it comes to automobile industry in China, the reduction of costs is still taken in the first place by virtue of lacking relative preferential policies to raise the enthusiasm of the corporations. Another

epitome comes to the remanufacturing of automobiles, which is now well developed in Europe and America but still developed slowly in China, for the laws in China ban private enterprises from recycling wasted mobiles. Therefore, the implementation of Green Manufacturing requires the coordinate supports from laws and regulations, financial policies, together with normal standards [2].

3 Theoretical research of Green Manufacturing

Traditional manufacturing goes as a format of “Take, Produce & Waste”, during which all kinds of sources are consumed until drying up. However, in the light of Green Manufacturing, resources should be reused or even reused for more than one time, resulting in the forever use of resources. Moreover, manufacturing generates some new waste that can never be “digested” by the nature, which cause some negative effects on people and society eventually. That is, Green Manufacturing reconsiders the production industry from the perspective of resources and pollutants. In this chapter, Green Manufacturing will be theoretically introduced [14].

3.1 4R principles of Green Manufacturing

The core ideas of Green Manufacturing refer to the realization of “4R” Theory, that is, Reduce, Reuse, Recycle, and Remanufacturing.

Reduce requires to decrease the consumption of resources including energies as well as the emission of wastes, which may help to cut down the environmental burden, resulting in doing less harm to people’s health.

Reuse requires reusing the products or components, aiming at prolonging the life of the products to reduce the waste.

Recycle requires the products to be able to transform into reusable resources instead of rubbish that cannot be used any longer. There are two ways of recycle, one of which is recycle at the same level which refers that the waste can be recycled to produce the same kind of new products, the other is secondary recycle where the wastes are transferred into raw materials of other products.

Remanufacturing is an approach to recover the dragged products back to the ones close to new products after a series of processes including dismantle, cleaning, examination, renewal, repair, and equipment.

Reproduce is an approach to recover the scraped products back to the ones close to mew products after a series of processes including dismantle, cleaning, examination, renewal, repair, and equipment.

Figure 3, 4R principle of Green Manufacturing

But when it comes to the practice of realizing the “4R” Theories, relative techniques are required. In the chapter 3.2, the technical framework of Green Manufacturing will be introduced [11, 12].

3.2 Five core technologies of Green Manufacturing

Green Manufacturing is a technique whose framework contains five main aspects: Green Design Technology, Green Production Technology, Green Packaging Technology, Green Recycle Technology and Technique of Green remanufacturing

Technique of green design is also known as environmentally-oriented design, sustainable design, ecological design, etc., which means to produce some products whose PLC are designed with comprehensive consideration of the effects on the resources and the environment as well as the function, quality, developing period of the product, the optimization of relevant design factors in order to reach the standards of "4R" Theory in Green Manufacturing. Methods of such technique are involved with green choice of materials, materially-economical design, energy-economical design, environmentally-friendly design, pleasant-product design, detachable design, recyclable design and remanufacturable design [2, 13].

Green Design Technology	
Green choice of materials	New material, Hrmless material, Recyclable material, Remanufacturable maetrial, etc.
Materially-economical design	Component bearing capacity optimization, Cross-sectional shape optimization design, lightweight design, etc.
Energy-economical design	Low energy consumption product design, Process design for energy saving, Manufacturing environment for energy saving design, transportation energy saving, etc.
Environmental friendly design	Noise reduction design, Avoid the use of hazardous substances, Avoid to produce harmful substances, etc.
Pleasant product design	Security reliability design, Operability design, Comfort design, Health Design
Detachable design	Mdular design, Reduce the material types, Reduce the amount of fasteners design, Surface easy to grab design, etc.
Recyclable design	Product recyclability design, Components and parts recyclability design, material recyclability design, energy recyclability design, etc.
Remanufacturable design	Remanufacturing modeling, Remanufacturing process, Remanufacturing forecasts, Remanufacturing test and evaluation, etc.

Table 1, Theoretical framework of Green Design Technology

Green Production Technology, also known as technique of green production, means to manufacture with advanced production techniques or optimal technologies for traditional

manufacturing so as to improve the current situation of resource consumption along with environmental pollution, to cut down the use of resources and energies, to reduce the emission and wastes, and to ensure the security and health of the workers. There are 3 types of techniques and approaches: new green technology, improvement of traditional green technology, together with optimal technology of manufacturing, where new green technology can be classified as energy-economical technologies, material-economical technologies, technologies with respectively less solid, liquid and gas residues, epitomes including dry cutting technology,cold-air cooling cutting technology, and so on. When it come to the green promotion of traditional technologies, it can be realized by means of saving energies and/or materials, improving efficiency, cutting down noises and/or emissions. Optimal technology of Green Manufacturing contains the ideas like optimization of process route, choices of technical selection, optimization of process parameters, etc.

Green Production Technology	
New green technology	Energy-saving technique, Material-saving technique, less solid waste technique, less liquid waste technique, less air waste technique, etc.
Improvement of traditional green technology	Energy-saving improvement, Material-saving improvement, Noise reducing Improvement, Emission reduction improvement, etc.
Optimal technology of manufacturing	optimization of process route, choices of technical selection, optimization of process parameters, etc.

Table 2, Theoretical framework of Green Production Technology

Technique of green packaging refers to suitable packaging that is reusable, recyclable, degradable or decay with no harm to both human beings and the environment during the whole PLC, including: (1) Reduction i.e., to minimize the resources used for packaging while meeting the criteria of protection, convenience and sales; (2) Reusablity or reproducilibity, i.e., the packages can be reproduced into other products or can be

destructed to generate the heat; (3) Degradability and compostability, i.e., not to become forever rubbish but to improve the quality of soils; (4) Harmlessness to living beings, i.e., to exclude or control the safe quantity of poisonous elements, halogen, and heavy metals [15].

Green Package Technology	
Green packaging design technology	New material, Harmless material, Recyclable material, Remanufacturable material, etc.
Green Packaging materials selection Technology	Component bearing capacity optimization, Cross-sectional shape optimization design, lightweight design, etc.
Green package recycling technology	Package recycling, Packaging overall reuse, Packaging components reuse, Packaging components remanufacturing, Packaging material regeneration, Packaging material degradation, etc.

Table 3, Theoretical framework of Green Package Technology

Techniques of green recycle mainly contains the processes of product recycle, dismantle, cleaning, examination, reuse, regeneration cycling, etc. If a product is not recycled after its PLC, there's no denying that it will lead to a waste of resources as well as environmental pollution. Therefore, green recycle is a systematic problem that has to be comprehensively considered from the beginning of the product design, along with consideration of systematic classification. In the light of such technique, green recycle techniques can be divided into several groups concerning of the techniques of the dragged products including recyclability analysis and assessment technique, green dismantle, green cleaning, green material classification, and reserved logistics management [17, 20].

Green Recycle Technology	
Analysis and evaluation of recycling	Recycling scheme design, environmental evaluation of recycling process, economical evaluation of recycling process, etc.
Green disassembly technology of worn-out product	Modular classification of worn-out product, analysis technics of disassembly, disassembly sequence optimization , technique of disassembling method and tool selection, disassembly cost analysis, etc.
Green cleaing of worn-out product	Green cleaning scheme, green cleaning technique, green cleaning process, green cleaning detection, etc.
Material recycle and separation	Material separation, material sorting, remanufacturing technique, etc.
Reverse logistic technology	Reverse logistic net design tehnique, reverse logistic inventory technique, reverse logistic optimization and control technique, etc.

Table 4, Theoretical framework of Green Recycle Technology

Techniques of green remanufacturing is a resource reusable technique that makes the dragged products recover to those whose property is similar to that of new products after a series of dismantle, cleaning, examination, renewable, and equipment. Two aspects reveal the environmental friendliness. To begin with, remanufacturing realizes the reusability of a group of components, indirectly resulting in the prolong of the PLC and the reduction of the quantity of the wastes, and therefore, it helps to cut down the environmental burden. Secondly, it takes full advantage of resources, decreases the demand of raw resources, which benefits the environment through the processes of the production of raw materials and new products.

Green Remanufacturing Technology	
Remanufacturing system design technology	Worn-out product performance evaluation technique, Remanufacturing process design, Remanufacturing equipment design, Remanufacturing factory layout design, etc.
Remanufacturing method technology	Combined surface technique, blank rapid prototyping technique, Nano coating technique, Emergency rapid maintenance technique, etc.
Remanufacturing quality control techniques	Blank quality test technique, remanufacturing product quality test technique, remanufacturing product evaluation, etc.
Remanufacturing produciton planning and control	Remanufacturing production plannning, remanufacturing production dispatch, remanufacturing inventory management and control, etc.

Table 5, Theoretical framework of Green Remanufacturing Technology

When implementing the Green Manufacturing 4R principle and five core technology is the necessary factor. Some other related research and knowledge will also be introduced in the Chapter 3.3.

3.3 Six characteristics of Green Manufacturing

Green Manufacturing owns some characteristics that should be taken into account ahead of time, which may do a favor for us to know more about it together with some relative implementations.

Globalization of Green Manufacturing

The manufacturing influences on the environment are always surpassing the restriction of regions and areas. For example, the furniture industry of China tunnels the jungles of South-East Asia; the air of the US contains some particle pollutants from other countries; insecticides are found in North Pole; the ozone hole affects all human beings. Such phenomena demonstrate that it is of necessity to protect our Earth.

The publication of the ISO14000 Series Standards provided a favorable foundation for the globalization of Green Manufacturing. Even though, some of the standards need further improvements while some need to be studied and posited. With the development of the global market, the marketing competition of green products will also be globalized. Some economies require the import goods to pass the green authentications with green symbols and others set some “Green Trade Barriers” in accord with the purpose of protecting domestic environment, where extremely strict environmental criteria are imposed to limit the international products from entering into the market. Additionally, some enterprises request their suppliers in the supply chain to pass the ISO14000 Series Standards. All these illustrate the characteristic of Green Manufacturing globalization.

The 21st century is the age of information technology, where manufacturing industry can corporate, share knowledge along with information, optimize production resources, and realize E-manufacturing via information and network techniques. The globalization of the supply chain as well as the increasing number of multinational corporations shows it is necessary to view from the perspective of the world when it comes to the realization of Green Manufacturing [16].

Socialization of Green Manufacturing

Researches and implementations of the Green Manufacturing ca not be realized without the efforts and participation of the whole society, where the establishment of Green Manufacturing needs the support of the society.

The first issue that is involved in the social supporting system is legislation and political regulations. At present, laws and political regulations concerning to this have not been able to deliver beneficial supports for Green Manufacturing, with the fact of the inadequency of punishments for the adverse activities. The problem of legislation has been attached more and more importance to currently.

Next comes to the issue of the formulation of economic policies by the government which can lead the way pf the green-manufacturing-oriented market mechanism of economy. For instance, to set up some effective price policies with some economic means to strictly control the resources which are non-renewable or renewable but may do effects on the environment if over-exploited (like woods and trees) would make people have no choice but to cut down the use of them and further more, to develop the substitute ones. Another example appears in the severe problem of exhaust gases of vehicles in urban areas, where governments can examine the emission level of every single automobile during its annual examination, and thus overcharge the ones with higher emission levels. In this way, chances are that the sales of vehicles with high emission will reduce, resulted from the strong demand on the production of green cars. Aiming at effectively implementation of Green Manufacturing, enterprises ought to consider the disposal of the products after their PLC, which may establish a new relationship among corporations, products, and users. An epitome occurs when someone suggest the recycle of main products such as automobiles, refrigerators, air conditioners, etc., where users only purchase the right to use while the corporations have the ownership with the responsibility of the disposal [16].

Both the issue of the legislation, political regulations, as well as economic policies about Green Manufacturing and that of the required new relationship between enterprises, products, and users are quite complicated problems containing a great deal of relevant technical problems which need further researching to formulate the social supporting system for Green Manufacturing. All these are critical elements for studies on Green Manufacturing in the future [16].

Integration of Green Manufacturing

Green Manufacturing is such a complex systematic engineering problem that it closely relates to the whole processes of the PLC along with all aspects of operations in enterprises, which focuses more on systematic and integrating techniques. Therefore, relevant issues of it need considering from the perspective of systematization as well as integration in order to put it into effects.

The characteristic of integration in Green Manufacturing includes that of products, technologies, and material selections, that of the demand of users and the use of products, and that within the system of Green Manufacturing. Once there was a scholar who established and put forward a systematic frame for green integrating production that contains 6 sub-systems namely, information management system, green design system, manufacturing process system, quality warranty system, material and energy resource system, and environmental assessment system. The integration of Green Manufacturing will also be a significant field of research in the coming day [16].

Concurrence of Green Manufacturing

Green Concurrent Engineering may become an effective pattern for the development of green products while the green design will still be the key issue of Green Manufacturing. An important trend goes as a combination between them which may lead to a new pattern of the design and development of products.

Green Concurrent Engineering, which is a new approach of green product design and development at present, is a systematic pattern of integration and concurrence of the product design and its PLC, where the employees in the developing department are required to take all factors through the whole PLC ranging from concepts to formulation to disposal of the product into accounts, including quality, costs, plans, requests from the users, environmental effects, consumption of resources, and so on [16].

Intelligentization of Green Manufacturing

The technology of artificial intelligence and intelligent manufacturing plays an indispensable role in studied on Green Manufacturing. The new goal system consists of decision goal system of Green Manufacturing, TQCS (Time, Quality, Cost, and Service), E (Environment), and R (Resource). Since ordinary mathematical methods may get trouble in optimal problems with multiple goals, artificial intelligence and intelligent manufacturing have the potential to be the edge tools of Green Manufacturing.

Artificial intelligence based on knowledge system, fuzzy system, neutral network techniques can help realize the analyses and optimization with multiple goal systems, and find out the relationship among product design, material consumption, and disposed wastes that will be applied to compare the effects of the design and manufacturing of different products on the environment. Besides, artificial intelligent techniques are also needed in green product assessment [16].

Industrialization of Green Manufacturing

The implementation of Green Manufacturing accelerates the establishment of a series of new industries, the well-known disposal and recycles industry and two other ones deserving special attention included. One of them is green product industry. With the continuously study, design, and development of all kinds of green products, they may take the place of the traditional ones resulting in great resource consumption and environmental influences, which assures the sustaining booming of Green Manufacturing. The other is the implementation of software or auxiliary industry of Green Manufacturing. Tools and software products, such as Computer Aided Green Product Design System, Green process planning system, Green Manufacturing decision-making system, product life cycle assessment system, ISO 14000 International Standard System, and corporation environment assessment system, are required when an enterprise implements Green Manufacturing [16].

Though Green Manufacturing may shrink some industries with heavy pollution or even put them to an end, it brings a group of new industries that would provide more employment opportunities at the same time.

3.4 Reverse logistics and ecological industry

Traditional manufacturing industries can be described as “forward logistics”, beginning with the development of resources and ended with the disposal of resources, where resources will be consumed to dry up. Nevertheless, the ecological environment contains forever recycle and conversion of resources and energies. For example, in the natural recycle of “Producer-Consumer-Decomposer-Producer”, the wastes in ever period is the resources of the next. In such recycle pattern, the resources will never run out, where the resources involved are defined as renewable resources. As the great consumption of natural resources and emission of pollution, people have be aware that such recycle may be used in manufacturing industry. Thus, reverse logistics and ecological industry are studied and developed [23, 31].

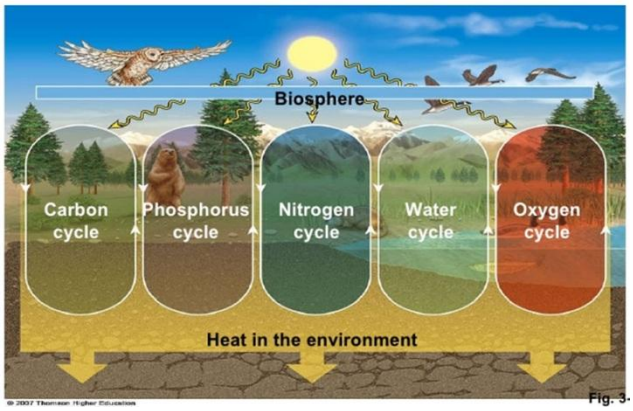

Figure 4, Mass and energy cycle in the nature system [20]

The concept of reverse logistics was first posited by an American scholar, Stock, when he handed in a report to Council of Logistics Management (CLM) that has been renamed as “Council of Supply Chain Management Professionals (CSCMP)”. In the report, the referred reversed logistics meant the implementation and control processes of the plan on the high efficient and low cost currency of raw materials, inventories, final products, and consumption information. With the study and development for years, reversed logistics has been classified into general one and narrow one. The former refers to a series of economy activities concerning with material reusability, resource savings, and environmental

protection while the later one is the recycle and disposal processes of products in manufacturing and sales with various recycle patterns [23, 31].

Reverse logistics will help more manufacturing industries to get resources in a recycled way, which will also reduce the new resources obtained from the nature. Common reverse logistics include return of goods, product recall, repair, renewal, and reuse. Obviously, in reverse logistics, products converge from low levels and separated distribution to high levels and concentrated distribution. For instance, when it comes to vehicles recalls, thousands of vehicles are going back from consumers to maintenance points or factories. For each automobile, the geographical locations and conditions are different. Furthermore, automobiles are such complicated in structure that even when two cars are in the same motorcycle type, the inner components are not exactly the same. As a result, reverse logistics is more complex and more unpredictable than forward logistics, which should be established on the basis of larger product database and supply chain database. Therefore, it is a tough challenge for the development of the whole supply chain industry.

When it comes to ecology industry concerning Green Manufacturing, in the nature, all the excreta and secreta are the food of some other organism while in economic system of human, the production and consumption chain generates a series of waste that people fail to take good use of and thus dispose away. Similar to the natural system, the waste created from human's activities can be regarded as a kind of sub-product which can be reused in a certain ecosystem. In this way, the waste of a factory can be the "food" of another.

The most typical exemplar is the eco-industry park of Kalundborg, Denmark, located 100km to the west of Copenhagen and called as the epitome of Eco-Industry Park, still works effectively. The participants in this system include power stations, refineries, pharmaceutical factories, gypsum factories, sulphuric acid plants, and several cement plants. Within an eco-industry park, one factory make good use of the sub-products of others' processes as the raw or substitute materials of its own, which sets up a harmonious

but complex win-win relationship whose ecological structure and logistics is shown in the Figure 5.

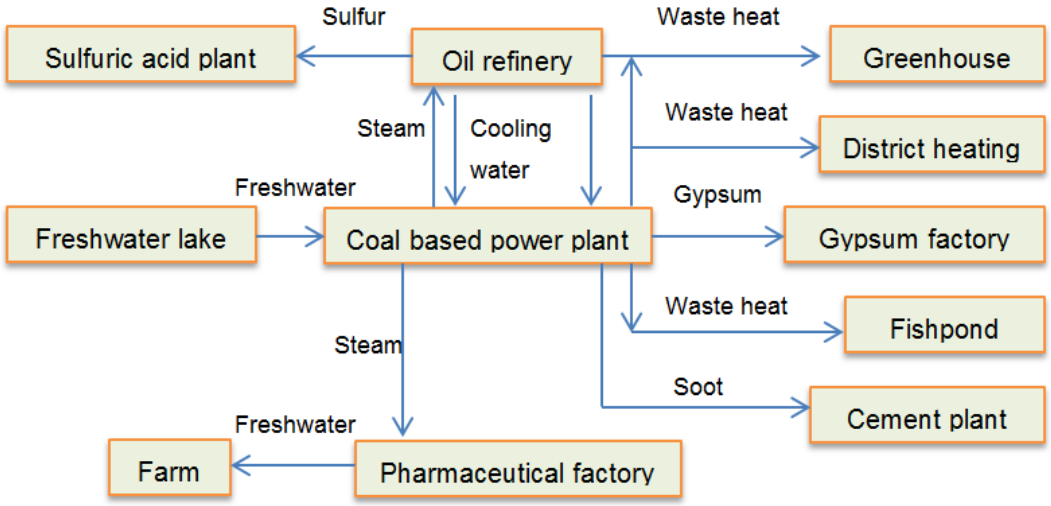

Figure 5, Structure of eco-industry park of Kalundborg [2]

In the recent years, the increasing number of researches on reversed logistics and ecological industry is the symbol of the more valuable green ideas of manufacturing, where green thinking is revealed from the perspective of supply chain in reserved logistics. More importantly, reversed logistics and ecological industry are not concepts paralleled to Green Manufacturing. In this paper, Green Manufacturing is a large and general concept contained reversed logistics and ecological industry. In the light of the four principles of Green Manufacturing in section 3.1, reversed logistics attaches special importance to principles of Recycle and Remanufacturing, where goods are made full use and recycle instead of destroyed or thrown away, while eco-industry park demonstrates principles of Reduce and Reuse, where pollutants and waste are effectively reused as a kind of products. Apparently, in practice, 4R principles of Green Manufacturing are not the factor to be illustrated equally in Green Manufacturing, but be considered in all processes [23].

3.5 Green Manufacturing and Lean Thinking

Lean Thinking, developed from Toyota Motor, Japan, mainly reforms in fields including systematic structure, human resource organization, processing, demand and supply of

market, etc., which can be more adaptable to the continuous changes in demands of the users as well as minimizing all useless things in all processes to reach the best effect of the production field containing supply and marketing. The core of Lean Thinking is the reduction of waste. Green Manufacturing is a modern pattern comprehensively taken environmental influences and resource efficiency into accounts, whose goals is the minimization of the negative effects on the environment and maximization of resource efficiency in the whole PLC processes of design, manufacturing, package, transportation, use, and disposal [24, 33].

First, the idea of people first should be insisted in. Lean Thinking regards the employees as the most significant manufacturing resource, takes the consistency of employees and enterprise benefits, as well as lifelong employment and education, and maximizes the personal ability and group intelligence of the employees. Meanwhile, Green Manufacturing attaches the importance to the health and safety of the product users and producers, along with the responsibility of the ecosystem humans are in, which also interprets the idea of people first.

Secondly, both Lean Thinking and Green Manufacturing require group work and cooperation. Lean Thinking takes teamwork as the main approach of corporation employee organization, where employees become generalists, take more responsibility, and take part in decisions and management. As for Green Manufacturing, the development group, consisting of product designers, decision makers, environmental analysis experts, and technical engineers, together with the consideration of environmental friendliness ranging from the selection of materials of raw materials, intermediate products, and suppliers to every periods in PLC, that is, product manufacturing, equipment, transportation, sales, use, maintenance, dismantle, reuse, burn and bury, requests wide cooperation of the employees.

Thirdly, both Lean Thinking and Green Manufacturing start with “Customer demand”. Lean Thinking of product development begins with “Driven by customer demand”, and shortens the development time collaterally to respond to the market demand in the shortest

time. Green Manufacturing also stands on customer demand, where collateral design are delivered in from the perspective of PLC aspects such as product structure, material selection, product environmentality, and product resource, leading to the concurrent development so as to satisfy the customers.

Fourthly, both Lean Thinking and Green Manufacturing focus on harmoniousness with the environment. Lean Thinking regards harmonious exterior environment as the standard to cope with the correlationship between corporations and customers as well as corporations and their partners, while Green Manufacturing cannot be employed without the supply chain, which also concentrates on harmonious between exterior environment and users.

Fifthly, both Lean Thinking and Green Manufacturing pursue for cost reduction and economy benefits. The goal of Lean Thinking is to increase the total profits of the whole company, where "minimization of costs in the corporation" is its basic goal. As for Green Manufacturing, during each process, the effects of the products on people and environment should be considered and minimized, the use rate of resources should be improved, the costs of resources and raw materials should be decreased, and the economy benefits as well as the ability of sustainable development should be promoted.

Sixthly, both Lean Thinking and Green Manufacturing reveal the idea of integration. Lean Thinking is guided by systematics that the systematic effectiveness is higher than that of the sum of each part. As for Green Manufacturing, the minimization of the costs in the whole PLC from "cradle to tomb" also runs for the systematic idea of the maximization of benefits.

Above all, Lean Thinking and Green Manufacturing are similar in many ways [24].

4 Analysis of Green Manufacturing practice

The practice of Green Manufacturing is specific to a certain industry because although the core of Green Manufacturing is the same, unique techniques should be taken into step in various processes in diverse works. Here come several typical patterns of green production.

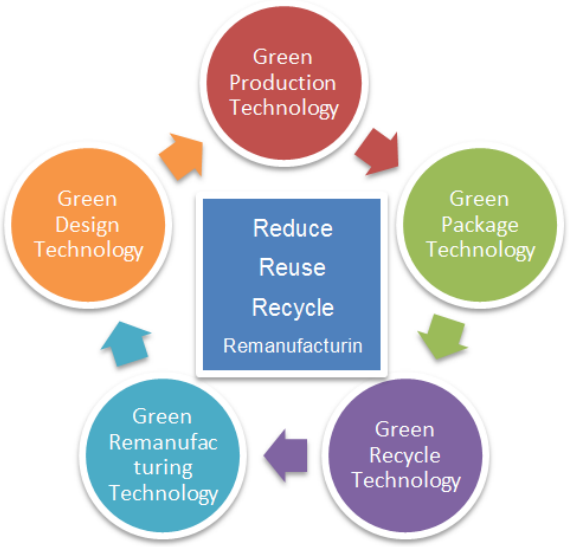

Figure 6, 4R principle and five core technology framework

In this chapter, automobile industry and electronic industry will be analyzed with 4R principle and five core technologies.

4.1 Green Manufacturing application in Automobile Industry

Vehicle industry, the epitome of the industry, contains almost all other industries like mechanism, casting, chemical industry, energy, electron, rubber, and leather. In other words, the level of vehicle industry in a country can represent as the whole level of industry, whose specialty and significance makes all advanced manufacturing technology will first introduced to it, for example, lean production, six sigma, etc. Thus, Green Manufacturing in vehicle industry plays a vital role in sustainable development. The

similarities of Leaning Thinking and Green Manufacturing are the strong foundation of Green Manufacturing in vehicle industry.

According to the theories in chapter 3, in this section, Green Manufacturing in vehicle industry will be described and analyzed from five core techniques, where 4R is the basic principle to be considered through all techniques.

4.1.1 Overview

Nowadays, vehicle industry has become an indispensably vital one in modern construction, which plays a significant role in national economy. Nevertheless, since traditional vehicle industry is based on the great consumption of resources and energy, with the increasing number of automobile manufactured, a great deal of energy and steels are used while the continuously increment of disposed vehicles leads to severe pollution in lands, air, and water. Faced with the pressure of the environment as well as the shortage of resources, aiming at long-term development, it is of great importance to reuse resources and energy in the premise of the continuously sustainable industrial development.

Products and production are two main ways of the negative effects of vehicle industry on the environment, where the former one can be reduced by means of cutting down the emission and energy consumption, which can be classified into green design, green production, and green package in the five core techniques, while the later one can be minimized through equipment and dismantle design and reuse, which is also known as green recycle and Green Manufacturing.

At present, processing techniques without waste are encouraged in EU and the US, where new environmentally friendly materials are widely used. The most well-known automobile factories actively put Green Manufacturing into studies and practice and regularly publish their reports on resources and the environment to show their achievements to the public.

Special techniques of Green Manufacturing are popular in vehicle industry. For instance, Austenitic-Bainite Ductile Iron has taken the place of Hardened Steel to produce Vehicle Rear Axles Spiral Bevel Gear in automobile corporations such as GM, which cuts down 50% of the energy consumption and 40% of the costs. Apart from this, Chevrolet has developed a new kind of automobile engine to face recycle and reuse, which 43% of the engine can be directly dismantled and the majority of components can be reused.

To study on Green Manufacturing of vehicle industry, the whole PLC and processes of automobile manufacturing should be known at the beginning. The whole PLC is shown in the Figure 7, including investigation and feedback on the market demands, development and design of products, manufacturing resource organization, manufacturing resource delivery, component manufacturing, product equipment, product sales, product maintenance and service, product disposal, product recycle, dismantle, component reuse, remanufacturing, and material regeneration.

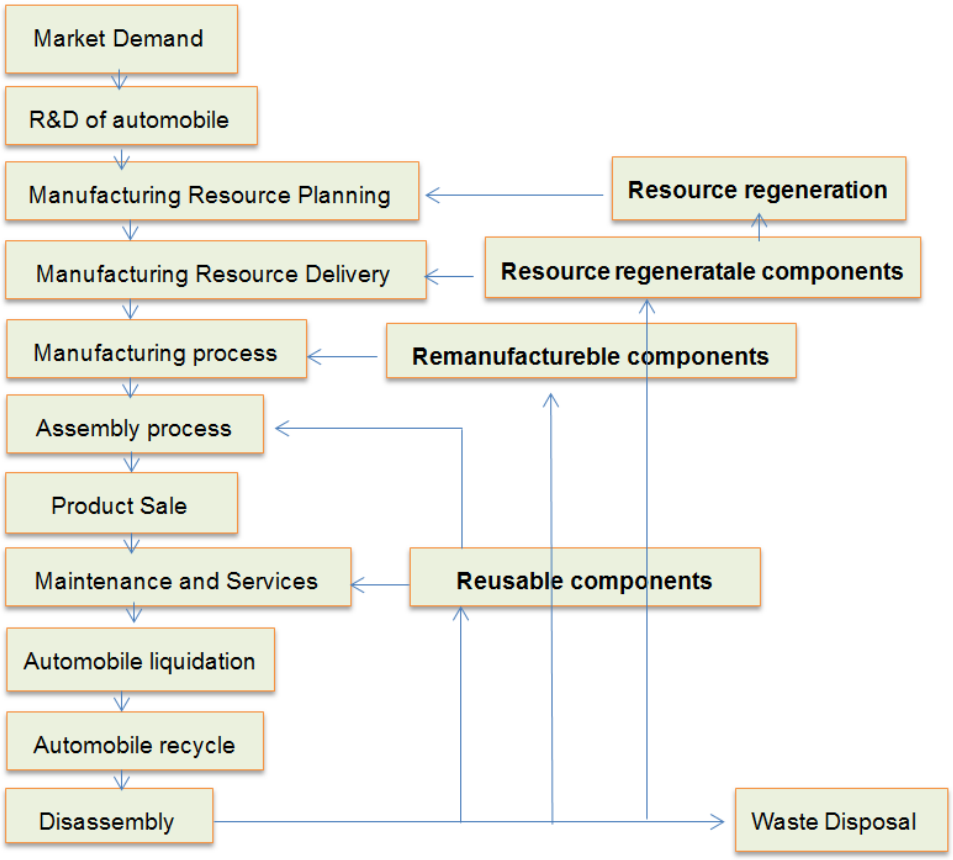

Figure 7, Product life cycle of automobile Green Manufacturing [26]

With the background of new Green Manufacturing, a new challenge the vehicle industry faces at the moment is how to organize the whole PLC so as to satisfy the requirements of costs, resources, and the environment in Green Manufacturing. In the following sections, Green Manufacturing in vehicle industry will be introduced in five aspects, respectively, green design, Green Manufacturing, green package, green recycle, and green remanufacturing.

4.1.2 Green design

Green design is the beginning of Green Manufacturing. Vehicle manufacturing formulates its certain design demands by collecting external demand information and green design engineering of automobiles. In the light of these demands, the design department can roughly decide the design conception, during when cross-department virtual organization is employed to investigate and match the manufacturing ability of the corporation so that green design product schemes and automobile product models can be formed. On the basis of automobile product models, the design department can do plans on the product, such as the whole scheme, automobile structural design, raw material selection, manufacturing techniques, package design, automobile disposal scheme, etc. Such processes are finished with the support of the green design repository of automobiles, PDM and emulational assessment system. In accord with the comparison of the conclusion and scheme of the emulational assessment system, the qualified models can be taken into the next progress of the PLC, manufacturing process, otherwise the models need corrections.

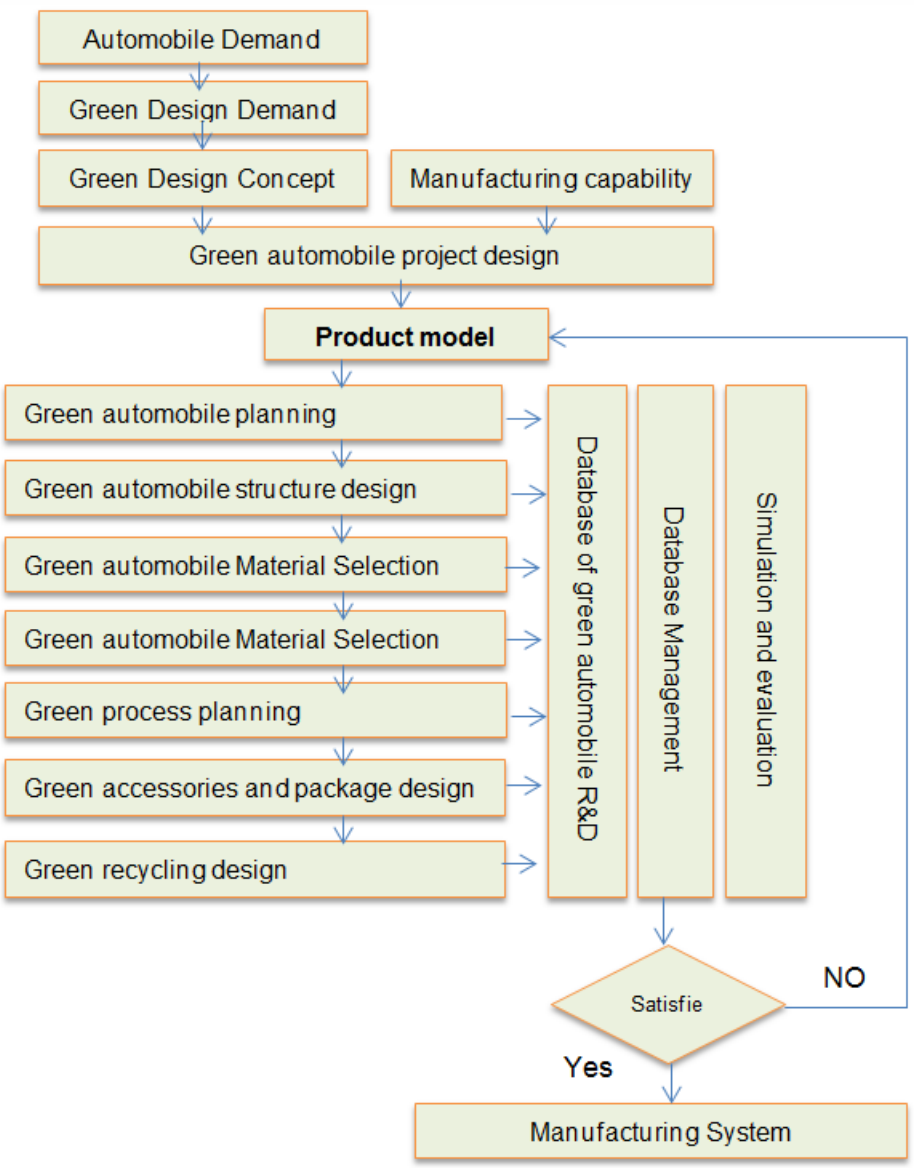

Figure 8, Green design in automobile industry

Three aspects are valued in this pattern. First comes to the trigger of green design as well as intrinsic and extrinsic demanding information where from the perspective of the objects of information source, it refers to external customers and dealers of a corporation or internal marketing department and customer service department; from the perspective of the way delivered information, it can be either direct feedbacks such as calling center and emails, or indirect ones such as information from profiles of the company. Secondly, green design repository and database are regarded as green design strategies to enter into green design system of a corporation. Green design repository is to introduce green factors into

processing, including using green materials, employing harmless methods, delivering clean techniques, reducing chemical emission, cutting down energy consumption, and designing for easy dismantle, which supports green design. Third comes to green design assessment and feedback system, containing assessment and feedback of models and simulation, along with application feedbacks of data statistics and data mining. Such feedback information helps the design organizations modify and improve the design schemes.

4.1.3 Green production

Automobile production owns a large and complicated system. In this section, automobile green production is described with the focus on component production along with equipment processes, which is considered with the technical application of the 4R principles of Green Manufacturing, including four processes, namely, stamping, welding assembly, coating, and final assembly. This section pays attention to the above processes as well as their involving problems of resource consumption and the environment, where relevant solutions are put forward.

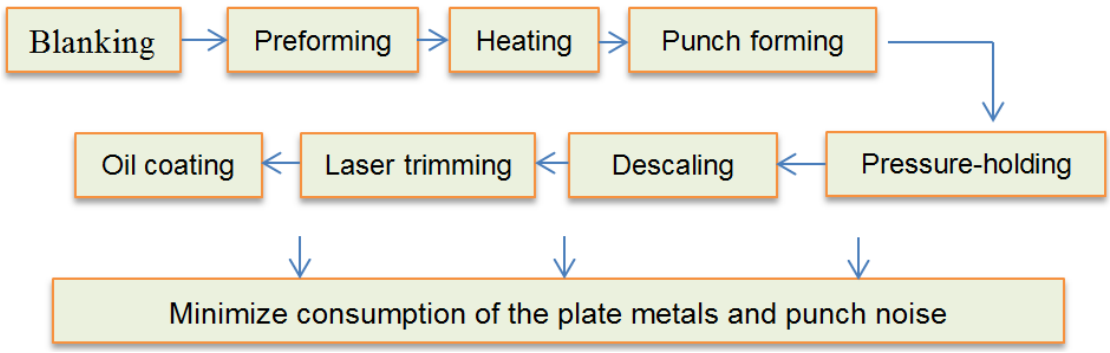

Figure 9, Process and problem of Stamping [18] [26]

The stamping process goes with banking, preforming, heating, punch forming, pressure-holding, descaling, laser trimming, and oil coating, where plate metals are processed with dies to produce components like automobile bodies, shells, chassis, during which problems may come as the consumption of plate metals as well as noises.

The application of new materials and new techniques, the optimization of the plate metal materials, and the recycle of the remaining materials are the solution to the problem of the consumption of the plate metals. Examples of new materials and techniques are laser welding tailored blanks (LWTB) and aluminum alloy materials while those of material optimization and remaining material recycling follow with the minimization of the remained during pressure-holding according to the size of the plate metals, the automatic generation of blanking, the collection of the remaining of the plate metals by vehicle factories, and the recycle and melting directly by suppliers.

The noises of pressure workshop can be solved in two ways, initiative one and passive one. The former one is to control from the resource, that is, to employ equipment with low noise, while the latter one is to minimize the effects of noises during its delivery. The initiative way is complex with difficulties but the highest cost performance. For instance, to replace punching machine with hydraulic pressure will greatly reduce the noises. The passive approaches mainly include absorbing, reduction, insulation, and attenuating with silencers, acoustical ceilings and walls, sound insulation cover, screen, and shock absorber.

The process of welding assembly mainly contains the consist of baseplate, side body, front side panel, longitudinal beam, frame assembly, car body, car door, front shroud, and black door, where auto transportation system within each step and the car bodies with completed wielding are delivered to coating workshop by transportation line. All the six assemblies of the engine, transmission, vehicle axle, car frame, car body, and carriage are involved in the process. The solution to decrease the resource consumption of the wielding process is to employ efficient and energy-conserved wielding equipment such as MIG and MAG, advanced wielding techniques such as electric resistance welding, arc welding, friction welding, laser welding, braze welding, advanced transportation equipment like laser automated leading system, and energy suppliers (eg. to deliver multiple cooling exchange with cooling towers). The environmental problems in wielding process concentrate on the recycle and clean of the welding fumes, the adjusted sealing treatment of noise during examination, and the equipment of noise elimination device.

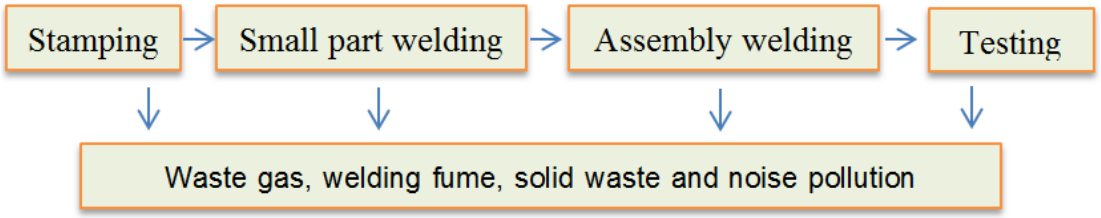

Figure 10, Process and problem of welding [18] [26]

The coating process consists of pretreatment, electrophoresis, electrophoresis drying oven, electrophoretic polishing, sealant, PVC coating, sealant oven, floating coat, floating coat oven, finishing coat, and finishing coat oven. Between different steps pf processing, hanging chains are used for transportation while lifts are used for connection. The main environmental problem in this process is the generated large amount of liquid waste, which is the key issue of green improvement. Such liquids should be dealt with a series of chemical reactions such as acid-alkali neutralization, coagulation, precipitation, and dephosphorization, after which reaches the hazardous substances management as well as the recycle of water.

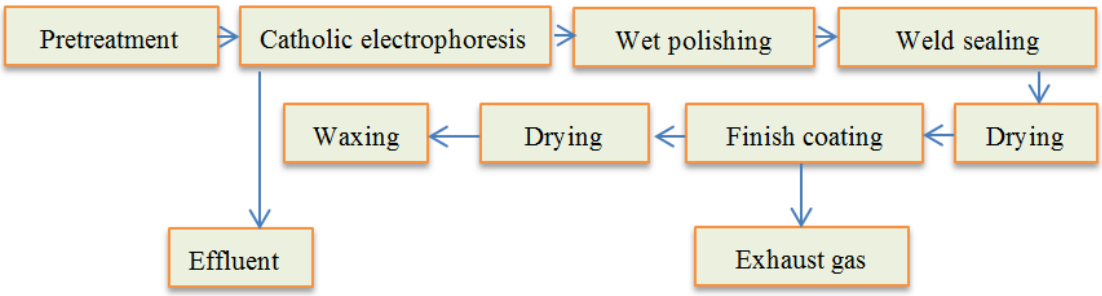

Figure 11, Process and problem of coating [18] [26]

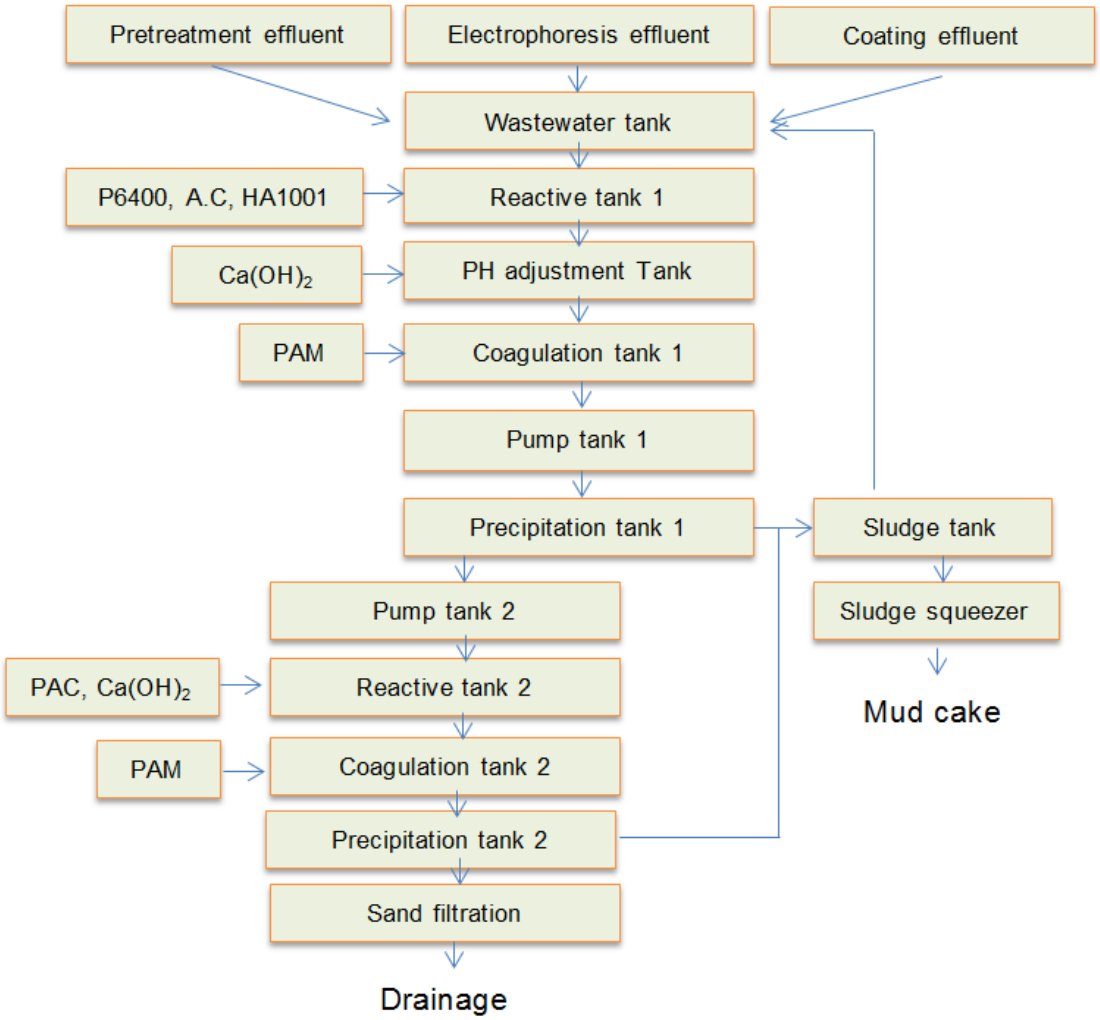

Figure 12, Green circulation processing flow of Coating Effluent [18] [26]

The final assembly process is the last process of automobile production, storage and transportation line, trim assembly line, chassis assembly line, final assembly line, final inspection line, instrument board assembly line, and car door assembly line included. Green improvements in this process contain polluted water purification, rainfall test for water recycle in the assembly shop, off-gas generated from static speed measurement test going through ventilator, along with recycle of packages and solid residues during assembly.

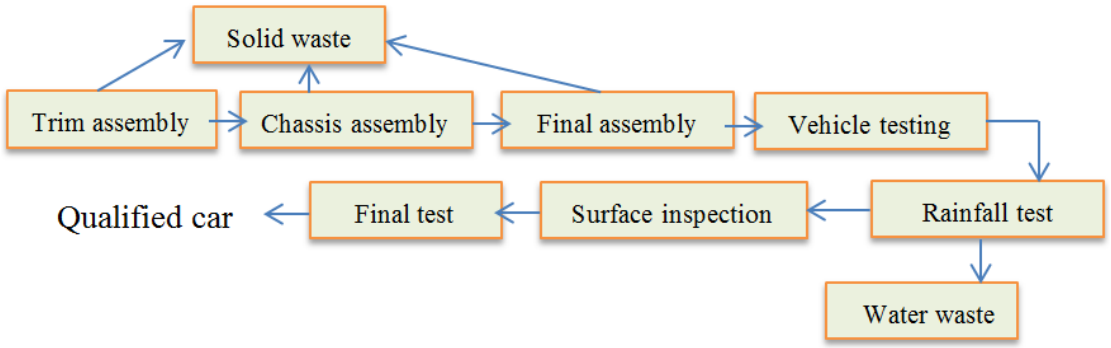

Figure 13, Process and problem of assembling [18] [26]

Green Manufacturing involved in automobile production and equipment is an extremely complicated system engineering issue. In this section, such issue is discussed from technical perspective, considering processes like introduction of advanced energy-conserved environmentally-friendly equipment, improvement of the green production technology, optimization of the decision-making system, harmless ended processes along with recycle, and reduction of energy consumption as well as negative impacts on the environment.

4.1.4 Green package

Automobile products are special in green package since they have little package other than protective films on their surface during transportation although they are bulky merchandises, resulting in insignificant green package problem of automobiles themselves. However, with the purchasing, transporting, repairing, and changing of components during vehicle production, where parts are a kind of product, it is indispensable of some package for transportation. Such package contains paper boxes, wooden boxes, planks, plastic models, and iron frames, which needs green package to reduce the negative influences on the environment for the great quantity.

In the light of the severity, green package in automobile industry can be classified into three groups: plastic films during transportation of the whole vehicles, packing boxes of the small parts, and metal frames of the large parts.

Due to the small amount as well as the low recycling efficiency of plastic films for transportation, their common disposal is to be torn down after the arrival of the automobiles and thrown away as household garbage. According to the green package principle, the manufacturers can use films that are as thin as possible with the premise of their wearproof requirement, and also sign some hints on plastic garbage classification.

A bill of material for a vehicle is complex with a large number of components. Furthermore, since the great deal of components are not produced in the same factory, manufacturers at every level need to package their products in order not to damage them during transportation, where plastic bags, cystosepiments, paperboards, and plastic model bases are used to fix the components. By virtue of the number of components, the amount of packages is large as well. Usually, parts suppliers purchase new packages year by year while part buyers press and break up the packages after using the components and deliver them to waste recycle corporations, which, however, results in a kind of waste without selection because plenty of packages of B2B products are reusable. One of the feasible solutions is to establish reversed logistics in the supply chain, where the purchasers should try to maintain the packages of components and redeliver to the suppliers while the suppliers reuse them until they cannot be used any longer. Green package requires to use as many recycled and degradable materials as possible when it comes to the packages for components. For exemplar, to replace cystosepiments with corrugated paper made of recycled paper.

Some large parts of automobiles need to be fixed by iron frames during their transportation, where for suppliers, iron frames are disposable despite of their reusability. This always happens in transnational transportation by virtue of the fussy processes and expensive costs. Therefore, it is of great importance for governments to come to consensus through

cooperation and employ new management. For example, in 2013, Shenzhen Customs of China creatively put forward a new approach of "Pre-declare, Post-cancel after verification" faced with the difficulty of recycling metal package exported by BYD Automobile, which realized the convenient clearance of the packages such as iron frames of BYD Automobile.

4.1.5 Green recycle

Traditional automobile recycle focuses on the recycle of raw material, multicomponents of the scrapped, with the method of destructive disassembly, leading to low reusable value since the dismantled components are simply separated and gathered without efficient separation, where materials with high reusable value like aluminum and magnesium are wasted while other materials that are not easy to be disposed, such as plastic, rubber, and waste oil, are optionally piled, dumped, and burned, resulting in severe pollution of the soil and water resource. It often occurs in under-developed areas. There was a time when a series of environmental problems took place in China owing to the behindhand recycle techniques that caused the inefficient use of resources, low profits of recycle, along with the unbalanced development of industries. Nevertheless, green recycle benefits from recycle and reduces the harm to the environment by means of the disassembly technology and the maximization of the management [27].

An automobile is an assembly with thousands of components which are made of different materials. Thus, simple melting down has little to do with green recycle of scrapped vehicles which requests scientific approaches to dismantle them and deal with them respectively.

The green recycle process in vehicle industry contains acquisition, disassembly, cleanout, test, and reutilization, where disassembly process plays a vital role. In the US, automobile dismantle has been a large industry with totally approximately 15,000 corporations that disassemble the components from the vehicles, sell the valuable parts to automobile

manufacturers for correction and renovation, and then reuse them. When the valuable parts are dismantles, the car frames will be smashed in pulverizers, after which magnetic separation is delivered to separate the steels.

The disassembly process of green recycle is very significant, whose recycle value can be illustrated only after scientific disassembly with the premises of the reuse, remanufacturing, and regeneration of the component materials. In this section, green recycle of the vehicle industry will be introduced from the perspective of dismantle and material recycle. Maintenance and renewal of components belong to remanufacturing, which will be discussed in section 4.1.6 [27].

There are 3 kinds of disassembles: Complete Disassembly, Partial Disassembly, and Target Disassembly.

1) Complete Disassembly refers to thoroughly dismantle a product into every single component, which is often used in theoretical researches instead of practical applications.

2) Partial Disassembly refers to dismantle part of the components of a product, usually out of the consideration of economy. When dismantling a certain component, if the recycle value of the remained components is less than the dismantle costs, we regard it valueless to continue dismantling as recycled material; or when the remained components are in the same materials, we stop dismantling and recycle them as an integer. This method is widely used in practical application.

3) Target Disassembly refers to the dismantle between or within certain components, mainly out of the consideration of reuse or environmental factors. For example, during the using period of a product, when a component of it is out of work and need dismantling for repair or abandon while other parts or components may still be valuable for reuse or renew; or when the disposal of a part or component does great harm to the environment, they

should be considered as target components to be disassembled. This approach is also widely used in practice.

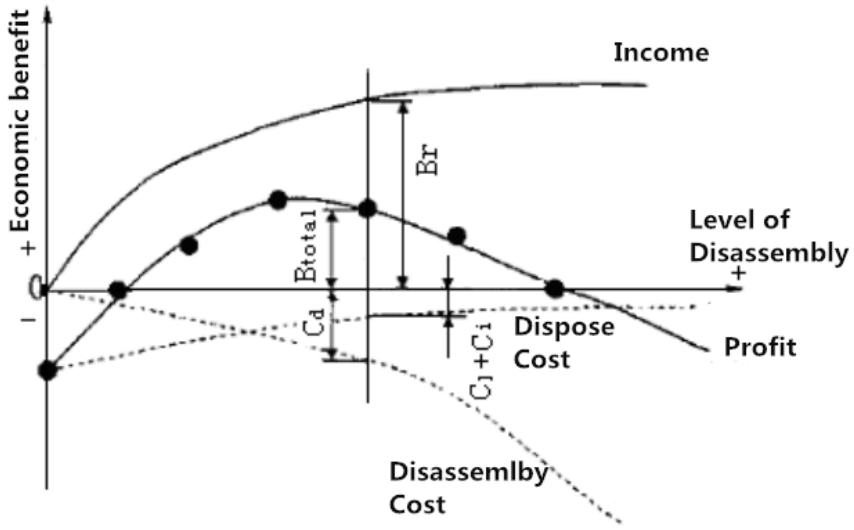

Figure 14, Economic evaluation of disassembly [27]

Decisions of disassembly level depend on economic evaluation. With the increasing steps, the number of obtained and recyclable components goes up, resulting in the climbing profits of dismantle and recycle while the cost of landfill is decreasing. Nonetheless, for the components difficult to be separated, the recycle profits are low, following with low economic value. Therefore, in comparison of the recycle profits and dismantle costs, when the economic effect reduces, the dismantle process should be stopped.

To begin with the economic effects of product disassembly, it is necessary to take high recycled value as well as easily dismantled components and equipment when products are scrapped into accounts with the premise of non-effect on the functions during the design, aiming at less steps of dismantle along with less connection for the convenience of disassembly, which is one of the requirements of green design. Here as we can see, every process in Green Manufacturing has close relationship to each other, which reveals the integration of Green Manufacturing.

The recycle at part and component levels makes great contributions to Green Manufacturing in automobile industry but with some difficulties in implementation. In developed countries like the US, components of vehicles are reused as long as they are not expired or damaged. In Japan, 30% of the components of scrapped cars are reused while 50% are recycled as raw materials. In Germany, the recycle rate even reaches 90%. On the contrary, it is illegal to recycle parts and components in China, where only raw materials can be recycled, resulted from the immature component recycled market, or even, the behindhand remanufacturing techniques in automobile recycled industry. Green Manufacturing is of necessity so as to maximize Green Manufacturing in automobile industry [27].

4.1.6 Green remanufacturing

Remanufacturing is an industrial process that scrapped products is restored to be as the new ones. In this section, the key component of vehicles, engine, is shown to illustrate the techniques and processes of green remanufacturing in the automobile industry.

When it comes to scrapped engines, the traditional approach is to melt them down, which can only obtain the value of raw materials, as low as 3% value of them, while remanufacturing makes 85% of their value into recycle, resulting in much longer PLC, energy conservation, reduction of environmental pollution, together with significant economic and social effects.

A remanufactured engine takes an old engine as workblank, employed special techniques and equipment in accord with strict technical requirements in industrialization. Such process first cleans, tests, processes, and changes the delicate parts of the old engine, equips it and tests the whole engine including functions such as power, torque, fuel consumption, emission, etc., after which only when it reaches the standards of the new can be packaged and produced. Compared with overhaul, remanufacturing of an engine shows

great advantages, including high quality, high performance, a large amount, and compatibility. Moreover, with the shorter time and quite the same costs as overhaul, it has high cost performance since the price is only 50-60% of a new engine.

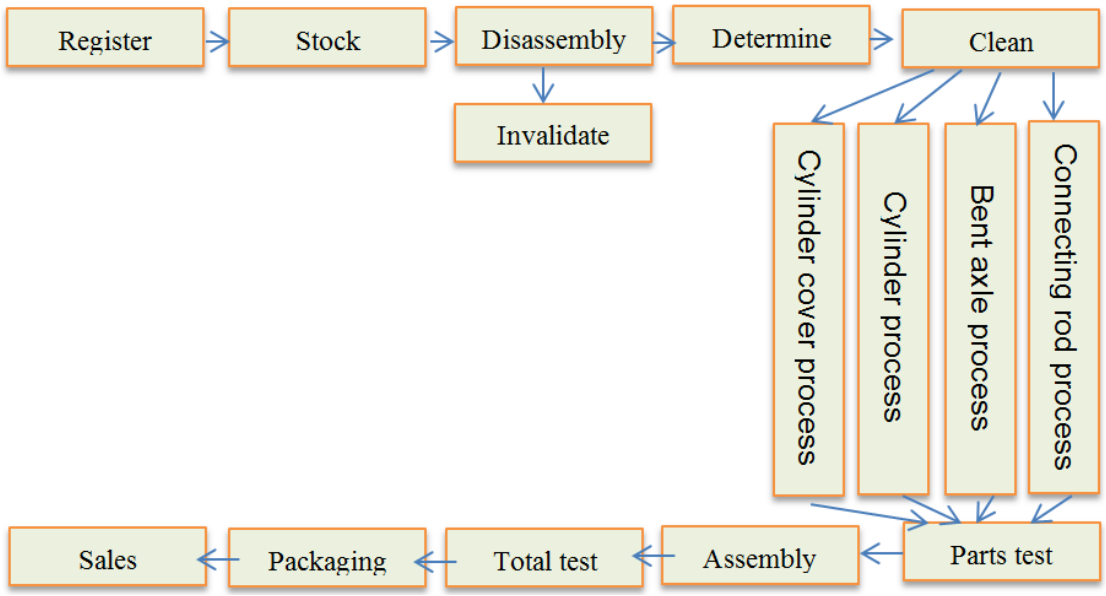

Figure 15, Process flow of engine remanufacturing [27]

Engine remanufacturing employs the work of assembly line, where all processing steps and examinations are strictly according to the standards of those for the new engines, and all main components are specially processed by expert equipment with high accuracy. The main wear parts, such as bearings, pistons, and gasket, are all replaced with the referred authentic accessories, after which every single engine is requested to pass strict professional detection. Thus, no matter when it comes to performance or lifetime, a remanufactured engine is comparable with a new one, with the same quality warranty and after-sale service system. There are 4 steps of engine remanufacturing, respectively, disassembly, cleaning, repair, and reassembly.

Disassembly of engine remanufacturing

Disassembly is the premise of remanufacturing, without which efficient recycle cannot be discussed, let alone remanufacturing. Generally, there are two kinds of disassembles: to dismantle a product into every single component, that is, to dismantle from top to bottom;

and to dismantle selectively in the light of the final situation of the product. With the concerning of thorough cleaning, testing, and repairing during remanufacturing, the products should be exhaustively disassembled.

Disassembly is not simply the reversed process of equipment, which is much tougher by virtue of corrosion and greasy dirt in scrapped products that may lead to low rates of dismantle. Thus, several issues should be considered as for disassembly: (1) know the structure, technical requirements, and features of an engine before dismantling, aiming at avoiding rude disassembly that may damage the components; (2) try to use apropos and specialized tools and be delivered by experts; (3) well prepare before dismantling, especially double check some special parts and components such as the mating number of mating parts and installation position of parts before manufacturing and equipment; (4) classify the disassembled components and prepare for their further cleaning and repairing.

Cleaning of engine remanufacturing

Cleaning refers to clear out liquid and solid pollutants on the surface in order to reach a certain level of cleanliness, whose processes is a complex physical and chemical interaction among cleaning agent, pollutants, and workpiece surfaces. Such processes not only involve with the property, type, and adhesion level of the pollutants, but also involve the physicochemical property, cleaning performance, work piece material, condition of surface of the cleaning agent, as well as other conditions of cleaning such as temperature, pressure, additional ultrasonic vibration mechanical force, and so on.

Methods of cleaning

(1) In engine remanufacturing, metal components like cylinder covers, cylinders, bent axles, and connecting rods are retained. Therefore, banking is the first step to clean away the dirt such as greasy filth.

(2) Cleaning with high pressure abrasive blasting employs high pressure airflow to generate high pressure water, after which high pressure water with white corundum are

delivered for cleaning. Considering the fact that common tap water can be used without heating and that white corundum can be used from time to time, it has little effect on the environment with low costs, which can easily realize mechanized work.

(3) Clear out the white corundum and dirt from the surface of the components.

(4) Cleaning with ultrasonic wave requires the transformation in transducer from high frequent electrical oscillation signals in ultrasonic wave reactor into high frequent mechanical vibration (i.e. ultrasonic wave), after which ultrasonic wave radiates to the cleanout fluid through cleaning tanks and delivers the high energy to the dirt of the component surface, leading to the dissociation and dispersion of the dirt.

(5) Wash the remained cleaning agent and dirt.

(6)Drying

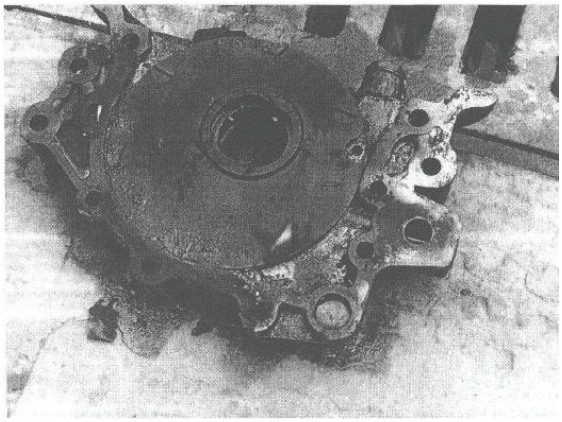

Figure 16, Engine cover before cleaning [27]

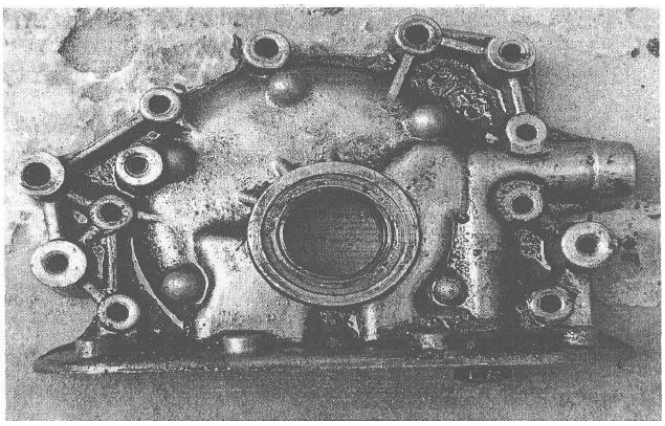

Figure 17, Engine cover after burning [27]

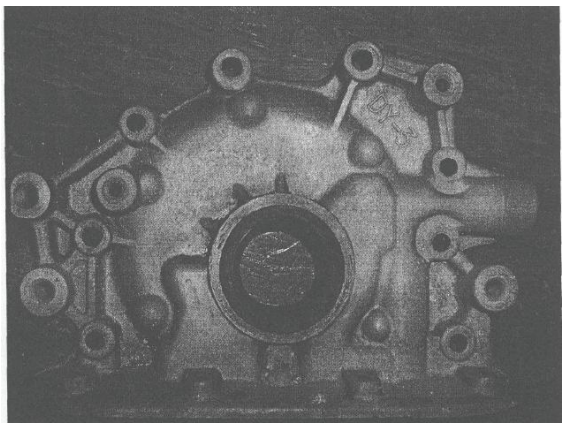

Figure 18, Engine cover after blast cleaning [27]

In comparison of the pictures, we can clearly know that through the above processes, the cleaning can be employed smoothly with significant effects, simple operation, short time, but little environmental pollution. After the cleaning, electronic gauges, advanced inspection tools, and advanced measuring machine can be used to measure the cylinder barrels, crankshaft holes, Camshaft Holes, tappet holes, diameter of crankshaft, symmetrical degree, as well as the gear open width.

Repairing of engine remanufacturing

Remanufacturing is the reuse of components with remanufacturing forming technology to restore them and meet the requirements of quality and performance, coming out with new products. In other words, the new products contain some old components that has been used and remanufactured. With the little effects on the environment, high efficiency of

resource use, minimized costs but high performance satisfaction, such approach realizes the goals of high quality, high efficiency, safety, reliability, energy conservation, and material conservation, where new materials and techniques are employed to restore or promote the performance and functions of the products, for example, surface technology, bonding technique, Blank forming technology, and Lathe processing technology.

Reassembly of engine remanufacturing

Reassembly is a process to equip the remanufactured components with the remanufactured products, where small amounts of assemble lines are employed with the same electric tools and Reassembly as the new products. After the equipment, all the remanufactured products are required to be examined or experimented to ensure their quality and performance.

The 100% test rate of the remanufactured products makes such engines more reliable than the new ones with sampling tests. Besides, compared with those only repaired, the remanufactured ones owns much higher quality [27].

Remanufacturing of engines prolongs the PLC, saves energies, and reduces environmental pollution so that it shows great economic and social effects, which is regarded as the most economical way of restoring.

4.2 Green Manufacturing application in Electronic Industry

Since 1990, the rapid development of electronic information techniques has brought the increment of electronic products while such products keep updating at a high speed with a life cycle of only one to three years, even the manufacturing machines become completely obsolete every five to ten years. Electronic products take up a great deal of resources as well as generating some poisonous and harmful wastes during their production. What is worse, they turn into e-wastes after their using period, which do harm to the environment,

especially when it comes to water resource. To control the environmental pollution from electronic products, it is a must to implement Green Manufacturing in this work [29].

4.2.1 Overview

The production of electronic products leads not only to something harmful for both environment and people's health, but also to a severe waste of resources. Some statistics show that, for a single workstation, even if it consumes no more than 30g silicon chip, over 4kg sodium hydroxide and 14kg other chemical pharmaceutics are needed for the neutralization of the effluent; 20kg waste materials come following 1.8g printing circuit board. Apart from this, the increasing number of electronic products and the curtail of PLC result in a surprisingly high learies of such products. At first, plenty of noble metals in chips and circuit boards, including gold, palladium, copper, and lead, made them attractive for their recyclability in economy, but with the less noble metals resulted from the updated electronic products, the economic advantage of recycling has gradually declined. Hazardous chemicals contained in the obsolete and scrapped products, such as Mercury (Hg), Cadmium (Cd), Hexavalent Chromium (Cr(VI)), Polybrominated Biphenyls (PBB), and Polybrominated Diphenyl Ethers (PBDE), lay a severe negative effect on the environment [2, 31].

Electronic industry is an industrial category of the production of electronic products, all kinds of electronic components, instruments, radio and television equipment, communication equipment like radar and base station, and smart end equipment such as computers, mobile phones, along with tablet PC, included. The PLC of an electronic product starts with electron components, after equipment, usage, and obsolescence, and ends with its dismantle together with recycling

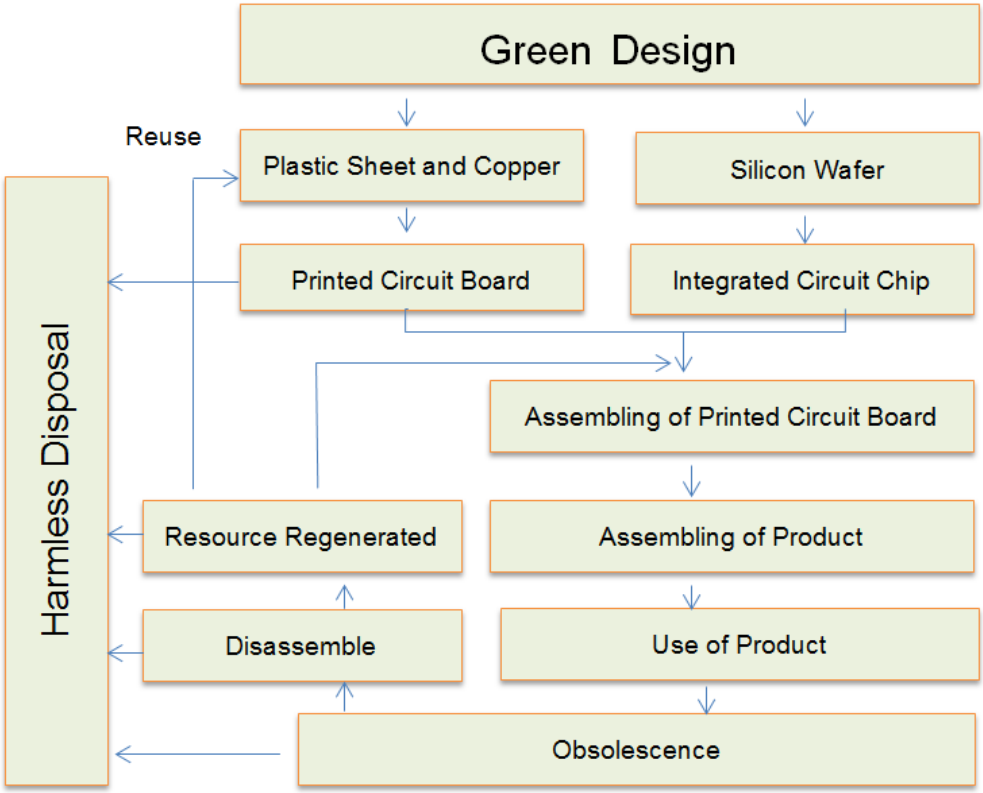

Figure 19, Product Life Cycle of electronic product Green Manufacturing [2]

During the whole PLC of an electronic product, the manufacturing of electron components is the most polluting link with the emission of harmful gas, effluents, and solid waste. Harmful gas, Perfluorocarbon (PFC), including CF_4, C_3F_6, and C_2F_6, mainly come from the production of circuit boards, which directly do harm to the health of the producers and lead to greenhouse effect that warmer the global temperature. Wasted liquids like electroplating effluent, organic wastewater, and cleaning agent also cause some contamination. To our surprise, the great deal of solid waste may even reach at a weight more than thousands of times of that of a chip during the manufacturing of circuit boards.

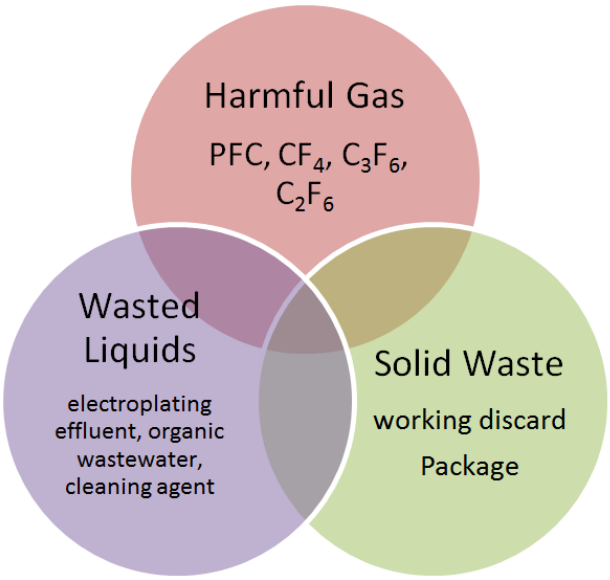

Figure 20, Three mainly wastes in the manufacturing of electron components

Green Manufacturing of electronic products focuses on three aspects: green design, green production, and resource regeneration of scrapped products. All these will be discussed in details as follows.

4.2.2 Green design

The requirements of green design of electronic products contain short developing period, top quality, high customer satisfaction, low costs, low consumption of energies, and less poisonous materials as well as effluents, that is, there are three principles of green design, also called 3Rs, Reduce, Removable, and Recyclable.

Minimization of design requires the products to be smaller in size, which can reduce the consumption of energy, water, and chemical materials and also cut down the harmful emission to the environment during the manufacturing. Besides, such products would consume less in use. In spite of the fact that nowadays, it only make use of 1% energy compared to 20 years ago to produce a product with 1MB data storage, with the development of science and technology, consumers set higher expectations for

performance of the products. Therefore, it is of necessity for more integrative function along with minimum size of electronic products.

Integrated Circuits Technology integrates different kinds of electrical components and circuit boards, which significantly reduce the size of circuit boards. Surface Mount Technology directly embeds electrical components into circuit boards, with a reduction of weldment, higher quality, and less pollution. The size of chips keeps getting smaller, approaching to physics limitation, where the latest quantum' computers chip technology, breaking through the limitation of computer chips, has been proved in experiments, which may bring to another revolution of the new computer chip generation.

Aiming at decrease the flammability of the electronic products, Brominated Flame-Retardants are always added to the plastic, including shells of goods along with electrical components, and circuit boards themselves. Take a computer as an instance, there are Brominated Flame-Retardants in its printed circuit board, components like linkers, plastic shell and cables, most of which are lipid soluble so that they would accumulate in human's body. In the light of some studies, Brominated Flame-Retardants are needed to avoid flash burning of plastic and prolong the time of fire spreading. Among various Brominated Flame-Retardants, some are extremely venomous. In order to make the products more recyclable, it is beneficial for corporations of plastic production to take Tetrabromo Bisphenol-A (TBBPA) which is authenticated internationally as Flame-Retardants, and reduce the range of plastic in use [28].

Details that should be considered in green design of electronic products	
1, Design details of recycling:	Use recyclable materials. When it comes to components heavier than 100g, use single material. Do not use materials in special colors unless necessary. Identify materials. Use secondary materials. Instruct for battery recycling
2, Design details of reducing hazardous substance	Avoid using poisonous chemical materials like heavy metals such as Pb, Cd, Hg, Se, Ba, etc. Do not use coating with heavy material. Decrease the use of PVC plastics.
3, Design details of prolong product life	Warrant the quality of the products. Guarantee the warranty period of the products. Design modularization that is possible to be expanded in functions and upgraded in products.
4, Design details of easy dismantle	Avoid the fusion between various materials. Use the design of mortise and tenon which will be able to be dismantled with simple tools to cut down the use of screws. Realize the detachability of modules.
5, Design details of energy saving	Equip the products with sleep and standby mode. Restrict the energy consumption during Standby. Design products of low power operation. Limit the maximum of output power.

Table 6, Details that should be considered in green design of electronic products [2]

4.2.3 Green production

Three main steps of the production of electronic products are chip production, PCB production, and PCB assembly, each of which contains a series of processes. In this section, ordinary processes and main pollution factors are first illustrated, after which the green of production processes is introduced [22].

Green production of electronic products focuses on green measures in resource consumption and environmental emission, whose specific processes and resource consumption of the three steps are introduced as follows [21, 22].

Integrated circuit / chip production

Chip production, based on silicon wafer, contains three steps: first, to make integrated circuits on the silicon wafer; then, to separate the silicon wafer into single integrated circuits, that is, chips; and finally, encapsulate the chips. These are all employed in manufacturing workshops [22].

The production of integrated circuits can be summarized as four processes. First, oxidate the surface of the silicon slice; secondly, cover breaker mask on the oxidated silicon slice and remove the oxidized layer of the breaker; third, implant the atoms into certain areas with Ion bombardment method and lead them to appropriate depths through diffusion effect; finally, remove other oxides. Repeat the above steps for several times to formulate high conduction bands and low conduction bands, after which multiple plane crystal valves are created. The conjunctions of the external junction points of chips and transistors depend on the metal conducting layers with deposition patterning. Various metal conducting layers are separated by insulating materials. The generation of the metal layers and the insulating layers is similar with that of the crystal valves. The generation of integrated circuits may repeat the steps for hundreds of times [22].

After the above generation of integrated circuits, the silicon slices should be separated into single ones (or chips) before their encapsulations, most of which are ceramic encapsulation or plastic encapsulation. Such process includes Silicon wafer thinning, silicon wafer cutting, die bonding, bonding, encapsulation, pre-curing, electroplating, printing, post-curing, trimming, pipe arrangement, and testing.

Poisonous chemical preparations are used in the above generating process while such process ought to reach high level of the production environment, resulting in great deal of water, energy, and chemicals consumed to clean the wafers and ensure the cleanness of the manufacturing atmosphere. Apart from this, processes such as thinning, scribing, die bonding, bonding, encapsulation, and pre-curing are requested to be delivered in super

clean work shops where a great amount of ultrapure water is used for cleaning, following with some other wastes.

PCB production

PCB production is the stage for the connection between integrated circuits and other components. Generally, integrated circuits are made of glass-fiber reinforced epoxy resin. By virtue of the inflammability of plastic, fire retardant are added in the plastic while some related laws and regulations have banned the use of some Brominated fire retardants like ROHS. Compared with the production of chips, the generation of PBC, whose production can be classified into the production of baseboards and that of the arrangement of wires, does not require so high level of the production environment.

The production of a baseboard involves drilling, electroplating, multilayer PCB stitching, and trepanning. At present, most boards in PCB are multilayer boards, where before bonding, drilling should be employed while Plated-Through-Hole technology is delivered on metal treatment and electroplating to connect between the layers. The plating bath used for Plated-Through-Hole demands a great deal of water and chemicals. Pressing needs high pressure, with insulating layers added into different layers to fix them. Mounting holes are drilled in the circuits, during which processes such as drilling, cutting, and conditioning may generate a number of wastes.

The production of arrangement of wires is to depose the coppers on the circuit boards in accord with the designed patterns, remove the redundanceand coat soldering tin for the subsequent connection of the components. The decomposed copper wires are much thicker than those on the circuit boards, whose typical width is 1-2mm. In this process, plenty of electroplating effluent and cleaning agent are generated.

PCB assembly

PCB assembly is the composition of PCB, integrated circuits, and other components like cells, large-power resistors, capacitors, and Oscillators. To begin with, wield the packaged

chips and tinned-coating copper wires on a board, then fixedly wield some components with lead perforation, and finally clean the circuit board, through which they can join the connector to connect with the external environment. Tin-lead solders and cleaning agents are used in wielding while leaded solders, which may lead to severe environmental pollution, have been banned form WEEE and ROHS published by EU.

Green measures

Green optimal techniques are used to improve some current production technology from the perspective of resources and the environment. The production of chips and PCB needs to be washed from time to time, resulting in the consumption of water that overweights the quality of the products. Thus, techniques of recycled water can be delivered to reduce the consumption of water. Meanwhile, the cleaning of circuit boards after equipment can be blew and swept by compressed air.

Since the production of electronic products is high efficient with low material consumption, totally, the energy consumption in this industry is not high. However, most of the energy is consumed to filter the air in the workshops, resulted from the high cleanliness standard of the production environment. Thus, to promote the performance of air filter equipments plays an important role in energy conservation.

Though the absolute amount of materials is small in electronic production, there are copious types of them, some of which are poisonous and harmful. Harmful etching agents and other chemicals are used in a series of steps in the electronic production, like Copper Electroplating and Brominated flame-retardant in the production of PCB,tin-lead solders in packaging, as well as different cleaning agents for all cleaning steps. As for soldering, the solutions are to implement lead-free soldering, along with putting lead-free solders such as tin-silver solders and tin-copper solders in high-temperature regions, tin-zinc solders in mid-temperature regions, and tin-bismuth solders in low-temperature regions [29].

4.2.4 Green package

Functions of both protection and convenient transportation as well as attraction and informalization are required in the package of electronic products. According to the 4R principles, the size of package should be as small as possible while the design should reach some criteria of reusing. Also, recyclable and degraded materials are encouraged to be used.

Nowadays, problems involving with packaging are mainly over packaging or poor packaging, the former of which refers to the overuse and large packages in order to appeal to the customers while the latter concerns with the defect of package design without comprehensive consideration of the uncertainties during transportation, causing the damage of the products.

Green improvements in packages of electronic products come with green package materials and design. Green package materials such as reclaimed board can be used as external package while corrugated paper and crepe paper can take the place of Expandable Polyethylene to strengthen the damping capacity of the package. As for green package design, measures such as reduction of the types of package boxes, usage of standard paper boxes, employment of materials without veneer, heavy metals, or volatile solvent, and delivery of water-based ink printing can be considered.

4.2.5 Green recycle

To recycle scrapped circuit boards is to recycle the inner metal and nonmetal materials. Generally speaking, scraped circuit boards contain 30% of plastics, 30% of indifferent oxide, and 40% metals that can be divided into ordinary ones including 20% Bronze, 8% Iron, 2% Nickel, 4% Tin as well as 2% Zinc, and heavy ones accounting for approximately 1%, 0.1% Gold, 0.2% Silver, along with 0.005% Palladium included. Such metals can be

reused with high economic value while the relatively low-valued plastic can also be reused as coating, pavement, or padding for plastic production [29].

Currently, there are 3 major ways to remanufacture circuit boards. The first one comes physically mechanical approach, containing a series of processes such as powder process and sorting, which is widely used in Japan, the US, Germany, Russia, etc. The second method is chemical solvent method, acid pickling, exfoliation, displacement, precipitation, electrolysis included. As for the last one, it is called incineration pyrolysis, where thermo metallurgy, direct incineration, Prevent oxidizing roasting, and pyrolysis are taken into step.

Physical method

The technical principle of physically mechanical approach is pretreatment, crushing, sorting, and smelt. More specifically, to begin with, the scrapped circuit boards are sorted and the components are dismantled ahead of time. Then, during multiple stage crushing, the circuit boards and components are crushed into powder mixture of metals and nonmetals, which will be powder concentrate after multi-step separation. Finally, they will be smelted and purified into demanded materials.

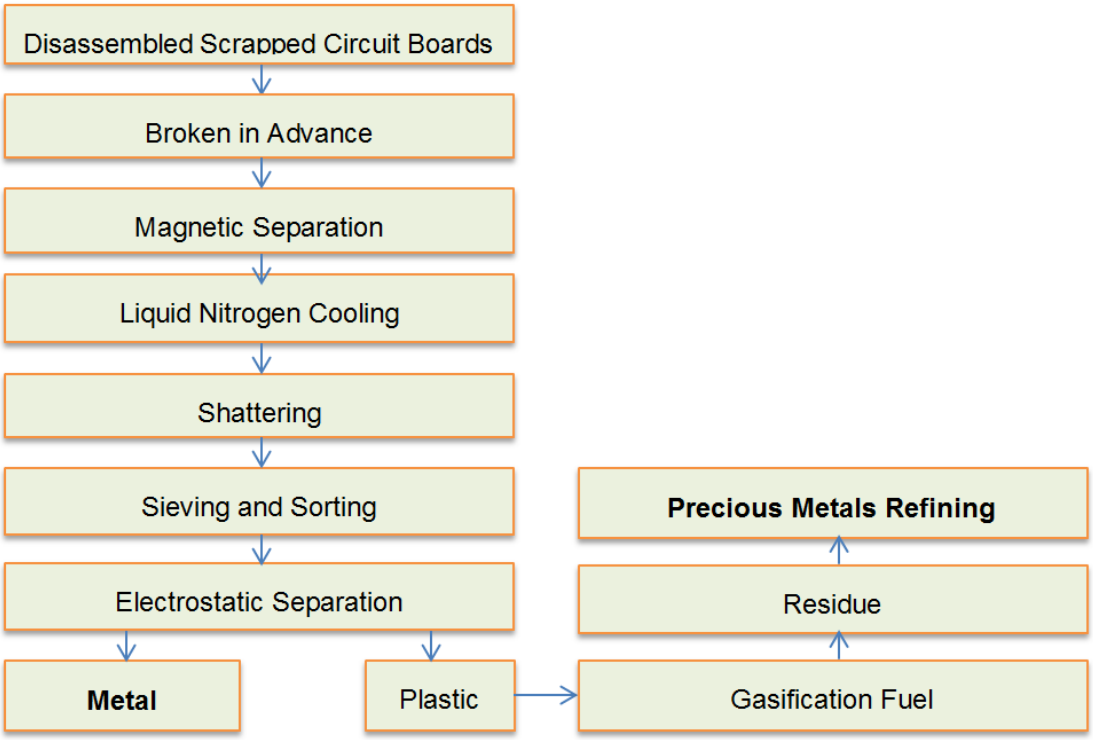

Figure 21, Process Routing of Physical Method

Considering the complexity of circuit boards, a great deal of powders generated during the crushing, emission of harmful gases, and oxidation by virtue of continuous crushing, technique of freeze grinding at low temperature is employed in some researches. However, such approach is not ideal because it needs expensive equipment, consumes plenty of liquid nitrogen as well as energies, and also do harm to the environment. Other researches make efforts in cooling with and reducing dust with water during the crushing, which leads to the waste and pollution of water.

Physically mechanical approach is most widely used today, with advantages such as low costs, mature techniques, along with simple manipulation. Nevertheless, the final products are merely concentrate of metals and nonmetals that should be purified before reusing with a low recycle rate.

Chemical approach

Chemical approach is another method widely delivered for recycling, where strong acids and oxidants are used to dissolve metals in circuit boards into compounds, after which reducing agents help to obtain metals. In general industries, strong oxidants like strong Nitric Acid, Vitriol, and Aqua Regia are employed to dissolve scrapped circuit boards, where metals come into compounds while nonmetals come into waste residual. With the help of various reducing agents, heavy metals such as gold, silver, and palladium will be accessed. Additionally, waste acid with high concentration of cupric ions can be used to recycle copper sulfate or electrolytic copper.

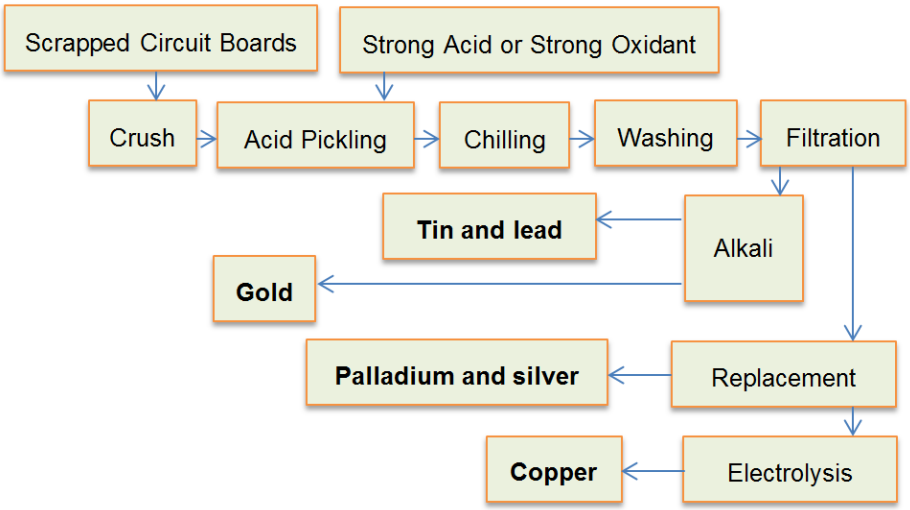

Figure 22, Chemical approach process of electronics remanufacturing

Although such method can approach to relatively pure metal products, it will lead to environmental pollution by virtue of the effluents and waste residue it produces. As a result, nowadays it is seldom employed, mainly delivered in some informal recycle companies, which generate great pollution on the environment.

Incineration and pyrolysis

Incineration refers to the process of sufficient burning of waste printed circuit boards with adequate oxygen supply, after which the waste residues are powered and purified. The general method is shown as the following Figure 22. The main idea goes that the old

circuit boards are powered and delivered into the incinerator in which their resin is broken down, leaving metal and glass fiber that will be powered and delivered to recycle in metal smelting plants. Resulted from the high consumption and great pollution of the approach, as well as the oxidizable material with low recycle rate, it is not widely used either.

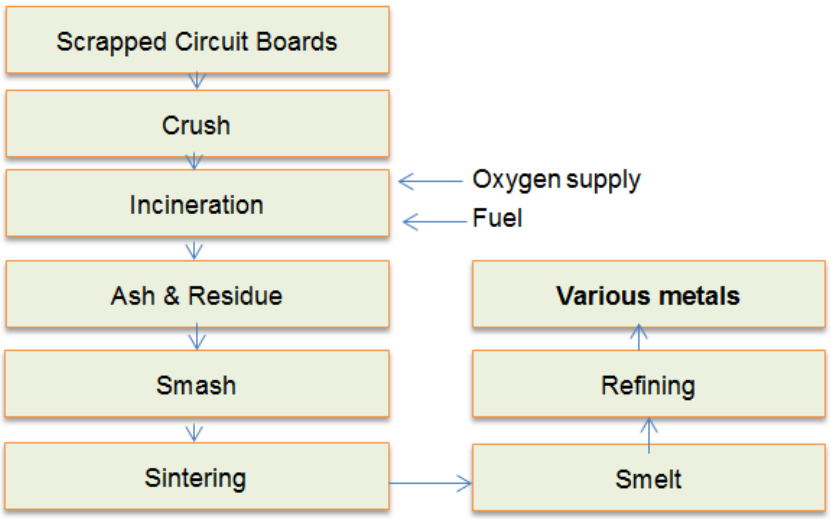

Figure 23, Incineration method of electronic remanufacturing

Pyrolysis method means to anaerobically heat the waste printed circuit boards up to a certain temperature that makes them smelt, after which the generated gases, liquid oil, scorched solid are recycled. The processes of this approach are shown in Figure 23. To begin with, the components are dismantled from the circuit boards, followed by smashing of the circuit boards. Then, such products are delivered into the pyrolysis reaction, where resin material of the circuit boards are thermally decomposed into low molecular weight mass at a certain temperature with inert gases. Then, such mass will come into pyrolysis oil and gas in the condensation reactor while metal and glass fiber remain unchanged, left in the reactor as waste solid which can be recycles through simple physics approaches.

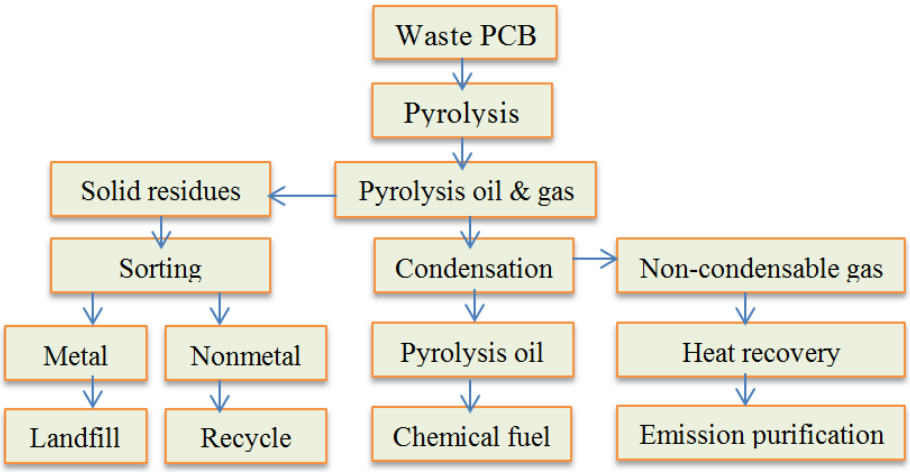

Figure 24, Pyrolysis method of electronic remanufacturing

The main pyrolysis gases of circuit boards include CO_2, CO, HBr, aliphatic hydrocarbon, and aromatic hydrocarbon which are valuable. Pyrolysis oil, with the similar property as crude, can be used as fuel oil or be exacted as chemical materials. The waste solid residues of pyrolysis can be reused after grinding into metal and nonmetal power enriched products.

4.2.6 Green remanufacturing

At present, research on remanufacturing technology of scrapped electronic products has been one of the global hot issues. There are two main ways to remanufacture wasted circuit boards, one of which is to remanufacture the components and the other is to remanufacture the materials. However, when it comes to the reparation and remanufacturing of scrapped electronic products, or the dismantle and degrade use of components and parts, it is not so popular, resulted from the fact that there are plenty different electronic products while recycling of components only occurs in a small scale. Up to now, resource of electronic products still focuses on recycling materials. Scrapped electronic products include obsolete circuit boards, cables, CPU and memory chips, where circuit boards are the majority [32].

If we want to remanufacture the components, we have to dismantle the scrapped circuit boards and keep them as intact as possible. However, by virtue of the small size and high

accuracy of components, it is of necessity to normalize the heating and reasonably separation processes. Dismantle of printed circuit boards has little to do with environmental problems so that it is one of the preferred approaches to recycle circuit boards. Despite a series of techniques of repairing as well as dismantling circuit boards, it is not effective in real industrial applications.

There are two main methods of components dismantling from circuit boards, one of which is specific while the other is integral. When it comes to the former one, specific components on the circuit board need to be selected and checked the linkage, after which they will be removed. As for the later one, with the heating of a whole circuit board, all the components will be disordered and moved away, which is more efficient but also easier to damage the components. Meanwhile, resulted from another demanded process of classifying the components, it increases time and costs.

5 Conclusion

Firstly, companies have to know the Green Manufacturing before they implement it. Chapter 2 tells the origin, status quo and future trends of Green Manufacturing to give readers a whole scene. According to the research and analysis, a new framework of Green Manufacturing has been developed in chapter 3. It contains 4R principles: Reduce, Reuse, Recycle, as well as Remanufacturing and five core technologies: Green Design Technology, Green Production Technology, Green Packaging Technology, Green Recycle Technology along with Technique of Green remanufacturing.

Green Manufacturing is not only a theory but also a technology. Readers can clearly find what will happen with its applications in the in Chapter 4 of this thesis. The patterns of Green Manufacturing are different when applied to different industries. Two representative industries, Automobile Industry and Electronic Industry, are chosen to show the implementation of Green Manufacturing. According to the new framework, the author presents the green design, green production, green package, green recycle and green remanufacturing in both automobile industry and electronics industry. Each part is in the light of 4R principles.

The reason why to select automobile industry and electronics industry is that they are so popular nowadays with huge productivity. Those two industries also have huge influences on other industries. For example, Lean Production developed in Toyota Company's car production now becomes the epitome of almost every industry. Electronic industry is also considered as the most potential industry. Many countries have put it into a national strategy level. The number of electronic products has been supposed over the number of human and it is still increasing at fast speed. So the significance of implementing Green Manufacturing in those two industries is great.

In the automobile industry, most Green Manufacturing problems happen in production (especially painting) and remanufacturing stage. So the contents of the two chapters are also larger than others. That such different industries have various Green Manufacturing implementations also reflects that automobile industry has very practical method and technology in remanufacturing while electronic industry has only practical method and technology in recycle. Compared with automobile industry, due to the size difference, electronic industry is better at the reuse of material level.

The framework and technology presented in this thesis has very high commonality, for example, a tea bag manufacturer may start to apply Green Manufacturing. This thesis will help to increase the decision makers' Green Manufacturing awareness. It will also guide them to think about Green Manufacturing in Reduce, Reuse, Recycle, and Remanufacturing. Maybe they will find methods of reducing and reusing package. Chapter 4.2.4 gives readers the suggestion to use water-soluble ink and standard size package. After this the mark and certification of Green Manufacturing will also help the company improve their reputation. In addition, this company could also reach and apply Green Manufacturing by using lean thinking and reverse logistic. This makes the long-term development of Green Manufacturing divide into short terms and easy achieved stages.

Another example is that 3M Company starts the strategy of Sustainability since 1975. It is actually a kind of Green Manufacturing strategy. In the past 40 years, 3M Company has kept the sustainability idea in all company processes and put it in a vital important position. According to company's annual report, people are able to believe that applying Green Manufacturing finally results in abundant profits [30].

In the future, government in many countries will set high budgets for pollutant discharge. Using Green Manufacturing is the key for companies to keep survival and this article will help those companies a lot.

Form the above, the objective of this thesis is fulfilled. The examples in Chapter 3 fully displayed the developed framework and demonstrated the feasibility of this frame work. This developed framework has very clear structure and features. This advantage does not only attractive for readers but also very benefit for them. In addition, Green Manufacturing is a topic related to sustainability, environmental protection and pollution abatement; it also generally spread the green awareness among readers.

Tasks of this thesis are also fulfilled well.

- ✓ Research and refine current knowledge hierarchy of Green Manufacturing
- ✓ Find out regularity, principle, characteristic and feasibility of Green Manufacturing
- ✓ Develop a new framework
- ✓ Present the examples of implementation of new framework
- ✓ Sum up the knowledge of Green Manufacturing

Author completes lots of research and study of Green Manufacturing so that the entire of Green Manufacturing can be described precisely. Regularity, principle, characteristic and feasibility of Green Manufacturing are demonstrated in Chapter 3. Author integrates them into 4R principles, 5 core technologies, Reverse logistics and Lean thinking and so on. New framework is developed with 4R principles and 5 core technology. The advantage of this framework performance in that company would like apply Green Manufacturing can improve it from green design to green remanufacturing. It is also a cycle, easy control and never ends. If we could say the theoretical knowledge guided by chapter 3, then practical guide is shown at chapter 4. Abundant practical experience in two typical industries, Automobile and Electronic industry, are shown in chapter 4. Readers can easily find appropriate suggestion for their own Green Manufacturing improvement. Finally, all that knowledge is summed up in conclusion chapter.

There are three main purpose of this thesis. Firstly this thesis can help people from educational organization know green manufacturing clearly by this new framework and

structure. Secondly, this thesis can help people from industrial field to implement their own green manufacturing by the particular examples. Thirdly, this thesis increases the interests of the author himself and may make him to practice green manufacturing in the future. Nowadays, many engineering students have courses about green manufacturing in university. Author believes that green manufacturing will becomes more and more important in the future.

Kokkuvõte

Selle magistritöö esimene ja teine peatükk annavad lugejale taustteavet rohelise tootmise kohta, käsitledes muu hulgas selle algupära, tänapäevast olukorda ja tuleviku trende. Kolmandas peatükis tutvustab autor uut raamistikku, mis on valminud tema uurimistöö ja õpingute tulemusena. See uus raamistik hõlmab 4 R-i põhimõtet – inglise keeles Reduce, Reuse, Recycle, Remanufacturing ehk vähendamine, taaskasutamine, taaskäitlemine, taastootmine – ning rohelise tootmise viite põhilist tehnoloogiat – rohelise disaini tehnoloogia, rohelise tootmise tehnoloogia, rohelise pakendamise tehnoloogia, rohelise taaskäitlemise tehnoloogia ja rohelise taastootmise tehnoloogia.

Suurem osa tänapäeva teadlaste uurimistöid rohelise tootmise kohta on üksnes teoreetilised või käsitlevad seoses rohelise tootmisega vaid mõnda üksikut edusammu mingis konkreetses valdkonnas. Selle magistritöö autor pani kokku need kaks erisugust uurimistöö liiki ja töötas välja uue raamistiku, milleks on 4 R-i põhimõtte ning viis põhilist tehnoloogiat. Õigupoolest saaks seda raamistikku rakendada igas tööstusvaldkonnas. Kui mõni ettevõte tahab püüelda rohelise tootmise poole, siis võib see magistritöö aidata ettevõttel teha vastavaid edusamme eelmainitud nelja põhimõtte abil, milleks on vähendamine, taaskasutamine, taaskäitlemine ja taastootmine. Igast tehnoloogiast räägib lähemalt peatükk 3.2. Seal leidub palju soovitusi ja meeldetuletusi rohelise disaini tehnoloogia, rohelise tootmise tehnoloogia, rohelise pakendamise tehnoloogia, rohelise taaskäitlemise tehnoloogia ja rohelise taastootmise tehnoloogia kohta.

Neljas peatükk on selle töö kõige tähtsam osa. Autor kirjutab selles raamistikust, mille ta on välja töötanud, kahe näite varal. Autotööstus ja elektroonikatööstus on väga tavalised tööstused, mis on omavahel tihedalt põimunud. Lugeja võib tutvuda konkreetsete näidetega ning saada innustust hakata ise rohelise tootmisega tegelema. Kummaski näites on detailselt kirjeldatud rohelise disaini tehnoloogiat, rohelise tootmise tehnoloogiat, rohelise pakendamise tehnoloogiat, rohelise taaskäitlemise tehnoloogiat ja rohelise taastootmise

tehnoloogiat. Väiksed ettevõtted võivad neljandast peatükist leida kahtlemata sobiva meetodi, millest malli võtta.

Käesoleval magistritööl on kolm peamist eesmärki. Esiteks võib see magistritöö aidata haridustöötajatel selgelt mõista rohelise tootmise olemust tänu siin kirjeldatud uuele raamistikule ja struktuurile. Teiseks võivad see magistritöö ja selles toodud konkreetsed näited aidata tööstusvaldkonna inimestel minna üle rohelisele tootmisele. Kolmandaks, see magistritöö on pakkunud autorile endale suurt huvi ja võib ajendada teda tulevikus rohelise tootmisega tegelema. Tänapäeval läbivad paljud inseneriteadusi õppivad üliõpilased rohelise tootmise alaseid kursusi. Autor usub, et roheline tootmine muutub tulevikus üha olulisemaks.

ACKNOWLEDGMENTS

First and foremost, I would like to show my greatest thanks to my supervisor Senior Researcher Eduard Ševtšenko. I could not finish this thesis without his help and guide. I also felt strong encouragement and motivation by his support. It is very pleasure to write thesis under his supervision.

I would like to show my great thanks to those teachers and friends who also helped me a lot.

General steering: Krist Karjust
Schedule steering: Moonika Asu
Theoretical direction: Tatyana Karaulova
Formatting guide: Jevgeni Baklanov
Kokkuvõte translation: Oliver Juhtver
Language tutoring: Cai Wanqing
Thesis material collection: Sun Zhenyu
Support and encouragement: Gao Lulu, Huang Shengxian, Chen Zhaowei, Li Zongchen, Jarno, Hanna, Imbi, Xu Jingyao, Han Yu, Diu Diu and Zheng Zeya

References

[1] Association for Manufacturing Excellence, 2007. Green Manufacturing: Case Studies in Lean and Sustainability. Productivity Press. ISBN 9781563273896 - CAT# PP7389.

[2] C. Li, Green Manufacturing operation mode and its implementation method. Science Press pp.

[3] Chinese government specialized planning. Green Manufacturing technology development. *Available from:* *http://www.most.gov.cn/tztg/201204/W020120424330209534599.pdf* Accessed: 2015-05-20.

[4] Treehugger, 2015. World Energy Use over the Last 200 Years. *Available from:* *http://www.treehugger.com/fossil-fuels/world-energy-use-over-last-200-years-graphs.html* Accessed: 2015-05-20.

[5] Ecology, 2015. The Ecological Impact of the Industrial Revolution. *Available from:*http://www.ecology.com/2011/09/18/ecological-impact-industrial-revolution/ Accessed: 2015-05-20.

[6] World Summit on Sustainable Development, 2002. World Summit on Sustainable Development Plan of Implementation. *Available from:* *http://www.earthsummit2002.org/* Accessed: 2015-05-20.

[7] Q. J, L. Li, 2012. Research on Green Manufacturing Model for Circular Economy. Applied Mechanics and Materials pp.201-202.

[8] SME 2015, About SME. *Available from:* *http://www.sme.org/about-sme/* Accessed: 2015-05-20.

[9] J. Y. Huang, H. Y. Zhu, "Analysis of Implementation the Key Technologies of Green Manufacturing", Applied Mechanics and Materials, Vols 522-524, pp. 787-790, Feb. 2014

[10] R. Dandu, 2009. Sustainability conference. Bringing Awareness on Sustainable Green Manufacturing. K-State at Salina

[11] J. Patten, D. Meade, M. A. Johnson and M. Barcelona, 2010. Green Manufacturing Initiative and Green Manufacturing Industrial Consortium, ppt. Western Michigan University, Green Manufacturing Research Center

[12] C. A. Rusinko "Green manufacturing: An evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes", IEEE Trans. Eng. Managem., vol. 54, no. 3, pp.445 -454 2007

[13] Green Car Design, 2015. Interview with Takeshi Tanabe. *Available from: http://www.greencardesign.com/site/interviews/interview-takeshi-tanabe* Accessed: 2015-05-20.

[14] Y. Zhang, Research on Development & Application of Information Resources of Green Manufacturing Enterprise. IEEE

[15] Ikea packaging, 2015. National geographic megafactories - ikea full documentary. *Available from: https://www.youtube.com/watch?v=ghlwmvyiTE4* Accessed: 2015-05-20.

[16] Anonymity, 2008. Research and analysis of green manufacturing technology. *Available from:* http://www.doc88.com/p-9941678582370.html Accessed: 2015-05-20.

[17] Sharing Net, 2015. How far are we from green manufacturing. *Available from:* http://www.vsharing.com/k/PLM/2008-7/612540.html Accessed: 2015-05-20.

[18] Car painting process, 2015. National Geographic - Nissan GTR. *Available from: https://www.youtube.com/watch?v=cTTRlRSwGe8* Accessed: 2015-05-20.

[19] K. Balan, 2008. Introduction to Green Manufacturing. The Green Issue Insights from a Machine Manufacturer. Wheelabrator Group

[20] Slideshre, 2015. Ecological cycles. *Available from: http://www.slideshare.net/mccracken/ecological-cycles* Accessed: 2015-05-20.

[21] How the integrated circuit is made, 2006. NHK tv station report. *Available from: https://www.youtube.com/watch?v=usPZ5e6mGaQ&list=PLRTr0hPqPk_xkAUNF9KC5er8e7wduwgMn&index=2* Accessed: 2015-05-20.

[22] How the AMD CPU is made, 2011. Documentary film. *Available from: https://www.youtube.com/watch?v=wOuYLq6vfLE&index=1&list=PLRTr0hPqPk_xkAUNF9KC5er8e7wduwgMn* Accessed: 2015-05-20.

[23] L. Huang. 2015. The research of reverse logistic based on the green manufacturing. Xidian University. Master Thesis. *Available from:* *http://doc.mbalib.com/view/0888a2fd62a379020e26c0eabec6f1e5.html* Accessed: 2015-05-20.

[24] G. Bergmiller, P. McWright, 2009. Lean Manufacturers' Transcendence to Green Manufacturing. Proceedings of the Industrial Engineering Research Conference. May 30 – June 3, Miami, FL.

[25] X. Wang, 2010. Standardized management and comprehensive assessment in green manufacturing enterprise. *Available from:* *http://www.doc88.com/p-4022253436666.html* Accessed: 2015-05-20.

[26] Y. Wang, F. Liu, Q. Wang, J, Yin. 2008. Green Manufacturing Mode for automotive manufacturers and its key technologies. Chongqing University.

[27] H. Guo, 2008. The research of key technology about recycling and remanufacturing in parts of End-of-Life Vehicle. A Thesis Submitted to Chongqing University in Partial Fulfillment of the Requirement for the degree of Master of Engineering. College of Mechanical Engineering Chongqing University.

[28] Flame Retardants. DG Environment Video 2000, cited by AEA technology, January 2001. *Available from:* http://www.guokr.com/article/439186/ Accessed: 2015-05-20.

[29] J. Li, B. Tian, T. Liu, H Liu, X. Wen, Shun'ichi Honda. Status quo of e-waste management in mainland China[J]. Journal of Material Cycles and Waste Management . 2006

[30] 3M sustainability, 2015. 3M 2015 annual report. *Available from:* *http://www.3m.com/3M/en_US/sustainability-us/* Accessed: 2015-05-20.

[31] E Shevtshenko, Y Wang, 2009. Decision support under uncertainties based on robust Bayesian networks in reverse logistics management. International Journal of Computer Applications in Technology 36 (3), 247-258, 2009. *Available from:* *http://scholar.google.se/citations?view_op=view_citation&hl=en&user=ZHKPr1sAAAAJ&citation_for_view=ZHKPr1sAAAAJ:u5HHmVD_uO8C* Accessed: 2015-05-20.

[32] E Shevtshenko, V Bashkite, M Maleki, Y Wang. Sustainable design of material handling equipment: a win-win approach for manufacturers and customers. Mechanics 18 (5), 561-568 *Available from:* *http://scholar.google.se/citations?view_op=view_citation&hl=en&user=ZHKPr1sAAAAJ&citation_for_view=ZHKPr1sAAAAJ:IjCSPb-OGe4C* Accessed: 2015-05-20

[33] V Bashkite, T Karaulova. Integration of Green thinking into Lean fundamentals by Theory of Inventive Problems-Solving tools. DAAAM International, Vienna, Austria, EU, 345-350. *Available from: http://scholar.google.se/citations?view_op=view_citation&hl=en&user=o7GvKiYAAAAJ&citation_for_view=o7GvKiYAAAAJ:ufrVoPGSRksC* Accessed: 2015-05-20