Distribution and research fronts of international energy technology

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31 May 2008

Abstract

In this article, we draw countries co-citation networks of international energy technology research. The co-citation network is first derived using graph-theoretical approaches as implemented in CiteSpace. We retrieved the documents by topic word “energy technolog*” between 1987 to 2006 which is published by article type in English from web of science which contains SCI and SSCI database index. Based the cluster information, we analysis the distribution and the research fronts of international energy technology.

1. Introduction

Social development and the progress of scien tific technology have brought the problems of resources and the environment. The rapid economic development will inevitably cause the huge demand of the international comm. unity for natural resources, especially for the energy. Energy problem has become the focus of attention of the world today, and countries are actively exploring the means and strategies of the development of energy. The "Interna tional Energy Outlook" report which U.S. Energy Department released pointed out that in 2025 global energy consumption will grow rapidly, especially in developing countries, energy demand will be increase rapidly with the rapid development of economic.

The report predicts that in 2025, global energy consumption will increase 54% than that in 2007, of which the industrial countries in energy consumption will be at an annual average growth rate of 1.2 %. And including China and India, developing Asia's energy demand will double the current of the world's energy demand growth rate of 40 percent growth in the developing countries and 70 percent.However, the mining of coal on the planet can only maintain 200 years or more, while oil and natural gas can only maintain 50. This situation not only brings the growth of world's energy demand and expansion of the international energy market, but also causes fierce competition in the energy buyer's market and the prices of oil and natural gas rise substantially. Now in face of the reduction of major applications of non-renewable resources, many countries, especially developed countries have a sense of the energy crisis. Energy short ages and environmental pollution problems have become increasingly prominent, and have become two main issues of sustainable development in international economic and social. Energy competition between countries has converted to the competition of the energy technology.

In this article, we make a visual analysis for the database index between 1997 and 2006 in the field of energy technology by using the interna tional forefront visual applicable software CiteSpace, and draw countries co-citation net works of international energy technology

H. Kretschmer & F. Havemann (Eds.): Proceedings of WIS 2008, Berlin
Fourth International Conference on Webometrics, Informetrics and Scientometrics & Ninth COLLNET Meeting
Humboldt-Universität zu Berlin, Institute for Library and Information Science (IBI)

research. And based on the related property value of the co-citation networks node and with the co-citation networks map, we analysis the distribution and the research fronts of international energy technology.

2. Research Methods and Data

2.1 Research Methods

CiteSpace information visual software is a powerful software tools that have been develop ed for the research of Information Visualization by Doctor Chaomei Chen in College of Infor mation Science and Technology, U.S. Drexel University. By using the Document data in the field of energy technology in SCI and SSCI database of ISI, CiteSpace software can draw countries co-citation networks, make a cluster analysis for the related properties of the network node, and explore the international regional distribution in the field of energy technology.

Tabl structure with country co-citation map

1-year slices	c	cc	ccv	space	nodes	links
1997-1997	2	2	0.20	102	15	20
1998-1998	2	2	0.20	82	15	19
1999-1999	2	2	0.20	88	11	4
2000-2000	2	2	0.20	118	30	55
2001-2001	2	2	0.20	112	18	16
2002-2002	3	3	0.20	127	18	25
2003-2003	3	3	0.20	137	14	16
2004-2004	3	3	0.20	134	19	27
2005-2005	3	3	0.20	121	14	14
2006-2006	4	3	0.20	147	15	4

At the same time, the software also provides burst detection ， which pick up the burst terms those are at a high rate of change in frequency and those frequencies often grows fast from a large number of commonly used words mainly through the inspection of the frequency distribution of the time，to analyze the frontier areas of science and the trends (Chen C), by the frequency change in trend, not just the high and low frequency. In the countries co-citation networks generated by the software, the countries Rings which are made up by the rings of different sizes and different colors present the frequency and the year and in which the countries (nodes) were cited, and the connections of different colors present the total years between the nodes which were cited. The " burst terms " Words can show the frontier and development trends in the field of the international energy research.

2.2 Sources of Data and Processing

In this paper, the data used in the Quantitative Analysis come from the Web of Science, which is the searchable database portal of the U.S. scientific and technical information by the intelligence (ISI) of the Science Citation Index (SCI) and Social Science Citation Index (SSCI). Each data record includes the main author of the documentation, title, abstract and referen ces.

Generally speaking, the data file which Cite Space entered is the format of the output of ISI, that is the documents and data format downloaded from the Web of Science. And different from other similar information visual software, CiteSpace itself can make a direct conversion of data format stored on the net, and there is no need to make a related matrix conversion of the original downloaded documents data (Chen C).

We retrieved the documents by topic word “energy technology” between 1997 and 2006 which is published by article type in English. There are 885 documents record that contain 29355 citations in total.In the Quantitative Analysis, 1 year as the unit, set up "Time Scaling" the value of 1, divide the 10 years from 1997 to 2006 into 10 sessions. At the same time, set the threshold to be(2.2.20), (3.3.20), (4.3.20). Sub-time data processing mainly considers the following two aspects: First, CiteSpace software use the "sub-rule strategy" principle in the process of design and operation, and the Sub-time data processing will help to improve its speed and accuracy . The second is the Sub-time data processing will help to identify the prominent turning point of

the subject evolution and the dynamic trend of the subject frontier.

Run the downloaded data through the software CiteSpace, choose "country" that is countries co-citation network analysis ,and we can get the reginal distribution of the research of the international energy technology and the co citation network map of forefront of hot situation. There are totally 104 nodes, 199 links and 513 bursts words in the map.

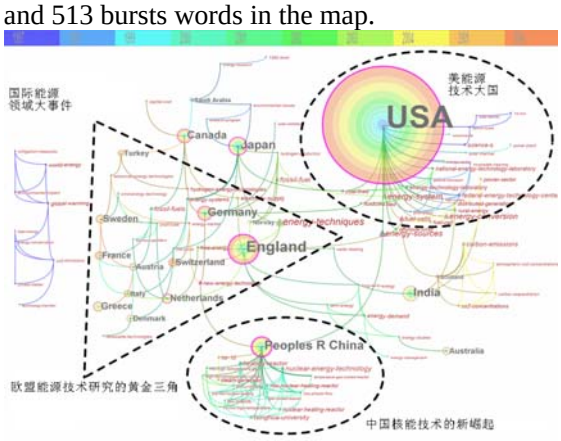

Fig 1 countries co-citation network of energy techn ology research

3. Results

From the countries co-citation network, it's distinct that there are three core regions of energy technology research on the globe: the first is USA and it's energy technology research in the highest flight; the second one is EU and it's golden triangle of energy technology research ; the third one is China and it's emergency in energy technology research of nuclear energy.

3.1 USA and it's energy technology research in the highest flight

From the co-citation network, we can see that USA locates the core position and leads the research fronts of energy technology. In the network, the United States has more co citations with other countries, and the node is far bigger than other countries', so it shows that the United States is in the higher frequency of citation in the field of energy technology research. From the centre of node, the centre of the United States in the co-citation network is also the biggest node, and it shows that the United States is on the core position in the field of energy technology. Through the statistical data by the CiteSpace software, we made a histogram which could be more intuitive to see that either in the Frequency or the Centrality, United States is far ahead of other countries, and it shows that the leadership and status of the United States in the field of international energy technologies research.

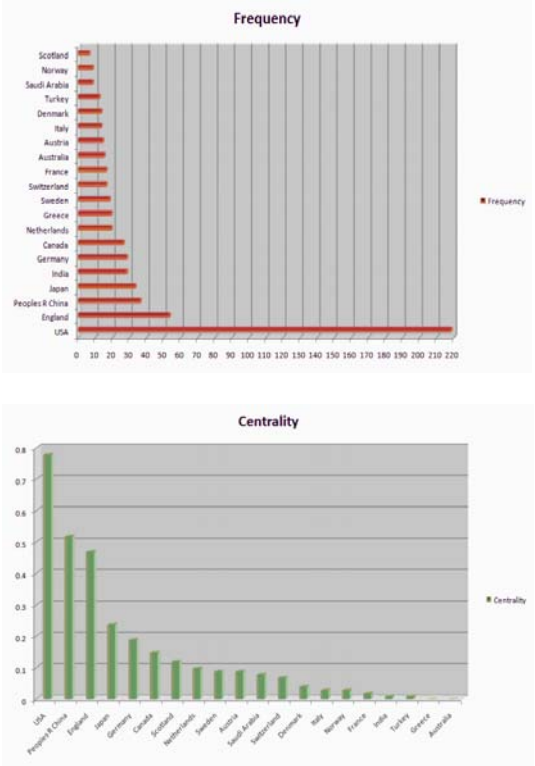

Fig 2 citation frequency and centrality in the network of countries distribution

Based on energy technology countries co-citation network, in order to more clearly detect the distribution of the co-citation countries, we use CiteSpace visual software with google earth software to draw the specific distribution of the United States main areas of energy technology research and the United States and co-citations with other countries (Figure 3).

At the same time, we combine burst terms for further analysis. Make the higher central burst terms for example: fuel-cells and coal-fired. What the fuel-cells refers is that hydrogen and oxygen produce electricity through chemical reactions, and the only by-product is water. The

electricity is clean and durable, just like inputting the current to the car. The United States as early as 2004 on the allocation of energy has already pulled 321 millions for clean coal technology research and pulled 273 millions to develop the hydrogen fuel-cells which was used by cars and small generators for the research of the project.

Fig 3 Distribution of U.S. energy technology research

The United States attaches great importance to clean coal power generation technology, and treats it as the commanding heights of future energy technologies. Governments, enterprises and research institutions actively organize all the related technology research and develop ment. Clean coal technology development which began in the 1980s, is the new gene ration of coal processing methods, and it can take full advantage of the abundant coal resources in the circumstances that it improves energy efficiency and reduces air pollution. In order to better develop clean coal technology, the U.S. Department of Energy (US DOE) in 2003 proposed the project of future power plant, in which government departments and the private sector and international organizations needed to invest 1 billion U.S. dollars, in five years to complete the designing and building a zero-emissions coal-based power plants, and in 10 years in operation. The future coal power plant will translate the coal form the energy which damage the environment into useful energy, and is an important step to the non-polluting energy. The future power plant technology can improve the efficiency of coal-fired power plant to 60 percents or higher, almost the two times of traditional coal-fired power plant efficiency. As a big coal produ ction and consumption country, 90 percents of American coal is used for power generation, and the coal-fired electricity power accounts for more than 55 percents of the entire United States electricity power. Therefore, U.S. plans in 10 years to pull 2 billion dollars to promote the development of clean coal technology and to develop an "American clean coal power generation plan", which is aimed to reduce the emissions of sulfur, nitrogen and mercury by coal-fired plant to 70 % to 2018.What the study report of World Energy Committee indicates, the main countries of coal consumption, in the next several years, the synthesis gas, liquid and hydrogen extracted from the coal will be an important and long-term energy supply sources. It is estimated that by 2030, about 72 percent of global electricity generation will use clean coal technologies.

At the same time, "the National Energy Technology Laboratory "and "Federal Energy Technology Center " and other bust terms, indicate that the investment of United States in the field of energy technology country is very large. The USA Department of Energy (DOE) and Harvard University is the U.S. energy technology research base. Solid oxide fuel cell (SOFC) is one of the several fuel cells supported by the Department of Energy (DOE), because of its greater commercial potential. The specific application of SOFC is helpful to production, such as industrial or laws of the central power station. The advantage of SOFC is that it could use fossil fuel to produce hydrogen, and provide geothermal energy for industrial under the high temperature (1500 ° F). The new 10 years goal of U.S. Department of Energy (DOE) is to reduce investment costs to 400 U.S. dollars per kilowatt, and improve efficiency by 60% to 70%(Y Jiang).

The typical project of the national research and development of U.S. fuel cell and hydrogen is the "Hydrogen fuel cell technology and the corresponding infrastructure development pro jectts" (HFCIT: Hydrogen , Fuel Cells & Infrastructure Technologies Program) imple mented by the Energy-saving and new energy

development(EERE)of the U.S. Department of Energy (DOE). This is very similar to Japan's New Energy Development Organization (NEDO), and they are both in the purposes of developing new energy and actively planning to implement the new energy into practice. On January 28, 2003, U.S. President George W. Bush issued hydrogen fuel cell development program (HFI: Hydrogen Fuel Initiative)which total is over 1.2 billion U.S. dollars. HFCIT development project constitutes the core of the plan. And in the similarity, the so called FCVT(Freedom CAR and Vehicle Techn ologies) implemented by the energy-saving and new energy development Bureau of the U.S. Department of Energy develop projects through joint, and make the HFI and a part of the FCVT merger and form a new development model, which we known as Freedom CAR and Hydrogen Fuel Initiative.

Hydrogen fuel cell technology development has become one of the important direction of the 21st century new energy technology develop ment. The United States, Japan and Europe are all trying to further intensify efforts to occupy high ground of a new generation of energy, and the development of vehicle dynamic and dis persed fuel cells showed intense competition.

3.2 EU and it's golden triangle of energy technology research

From the co-citation network, thirteen countries of EU form a golden triangle as their distri bution (except for Scotland). It presents that EU have the similarity and relationship in energy technology research(finger 3). In order to more directly observe why the above-mentioned 12 countries gathered in the "triangle", we find the EU map, mark the 12 EU countries of the "triangle" on the map, do color fading to the remaining countries, and then we find that these 12 EU countries have high similarity in the region, and also have the same "triangular" characteristics on the area. At the same time, to do a comparative analysis through energy technologies research between the EU countries on the google earth with other countries' co citation situation and the energy technology research "Golden Triangle" on the EU map.

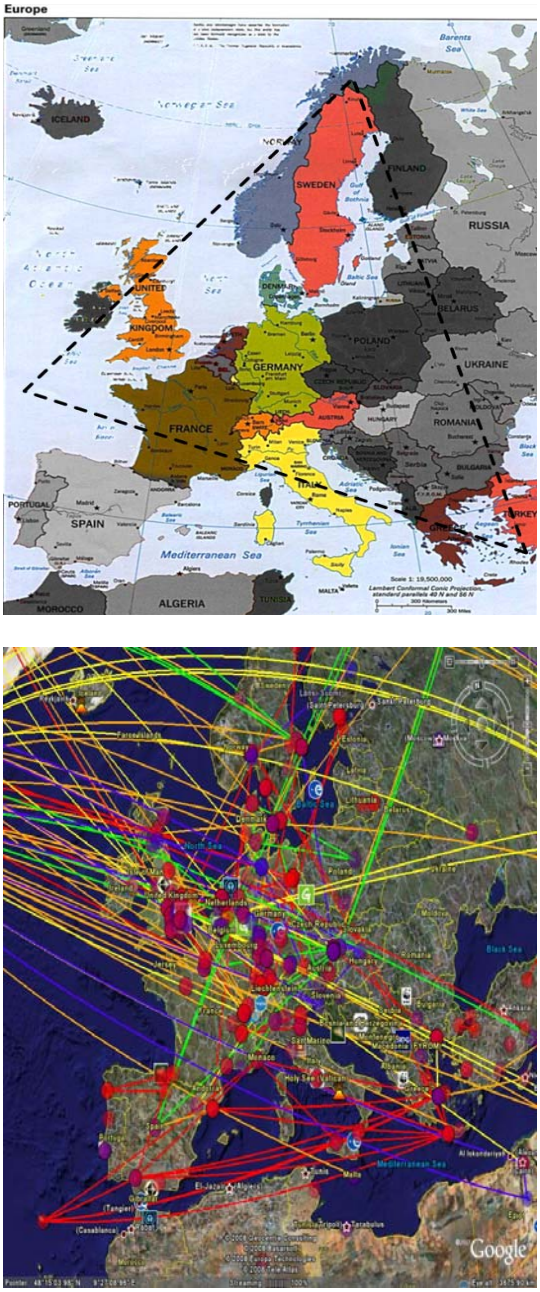

Fig.4 EU golden triangle in energy technology research and Google Earth

In the "triangle" of the countries co-citation network ,further analyse the burst words related to 12 co-citation countries, such as renewable technologies, new-energy-technology and so on. Either the frequency or centre, England and Germany are significantly higher than that of other EU countries, which indicates that both of them invest more and technical level is higher

in the field of the EU energy technology research. Why Germany is closely linked to hydrogen-energy-technologies, hydrogen produ ction is that German technology in the develop ment of hydrogen fuel aircraft and automobile sector is world leading.

EU renewable energy development has made great achievements, and EU is the world re newable energy development leader. EU began to develop renewable energy from the 1980s. Since the 1992 <Framework Convention on Climate Change>and in 1997 the<Kyoto Protocol>signed, the pace of development acc elerated, surpassing the United States as the world's renewable energy development leader.

By the end of 2005, all EU member states wind power installed capacity to 40.9 million kW, five years ahead of schedule to achieve the EU in 1997's "By the year 2010 wind power capacity of 40 million kW" ,and in 2006 make a new increase of 7.7 million kW than that in 2005. Except for the eliminated wind power unit, at the end of 2006 the EU wind power installed capacity reached 48.55 million kW, accounting for over 65 percents of the global power generation capacity. Of the 10 biggest world wind power installed capacity countries, the EU member states account for seven of the world's 10 wind power equipment manu facturers, eight in the EU. The EU is also make great progress in solar photovoltaic, biomass energy use and other aspects. Its new solar photovoltaic power generation capacity in 2005 was over Japan and became the fastest-growing areas, particularly Germany, in 2006 New Photovoltaic power generation capacity was close to 1 million kW, accounted for 1 / 3 of the world's new capacity. In 2003 by the British-led, initiating the formation of the "Renewable Energy and Energy Efficiency Partnership Scheme"; in 2005 by the Italian-led, initiating the formation of the "Global Health Material can Partner Program ";by the German-led, initiating the formation of the " 21st Century Renewable Energy Policy Network ", initiated a number of multilateral mechanisms for cooperation, actively promoting the global re newable energy development.

Germany, in 2004 through the Bonn "World Re newable Energy Congress", pulled the re newable energy development into a new stage. Through recent years stimulating policy and concrete action, the European Union has become the world's development of renewable energy leader surpassing the United States and Japan. In 1997, the EU issued a White Paper on the development of renewable energy, developed the magnificent goal to 2010 the renewable energy consumption would account for 12 percents of the EU's total energy consumption, in 2050 renewable energy would achieve 50 percents of the energy formation throughout the EU countries. In 2001, the EU Council of Ministers presented a common position on the use of renewable energy power generation command, requiring to 2010 EU countries' renewable energy consumption ac count for 12 percents in its total energy con sumption, and in its electricity consump tion ,the ratio reach 22.1 percents of the total control objectives; later, the EU's member countries in accordance with the instructions, developed a national renewable energy or renewable energy power generation develop ment goals, and put into practice, and achieved significant results(JF Li). As the countries around the world gradual unification on the issue of climate change awareness and the concerns of the energy supply security, the European Union since 2005 has began to re-evaluate the importance of renewable energy development. Based on the rapid growth of the renewable energy in the past, it raised new ideas, new goals and new actions accelerating the pace of alternative energy. New ideas are: the develop ment of renewable energy will be in a transition from supplement energy to alternative sources of energy. In January 10, 2007 announcement of the new energy development goals putting forward a new goal: By 2020, renewable energy will account for 20% of the energy structure of the EU 27 member countries, and will meet at least 10 percents of the trans portation fuel demand.

85 percents EU of primary energy supply come from fossil fuels, and renewable energy techn ology development has become the strategic choice that the EU countries substitute for

fossil fuels to solve the energy crisis and environmental protection. In the perspective of energy supply and demand, 50 percents of the EU energy demand depend on imports, so protecting the EU security of energy supply, and avoiding the economic recession triggered by the two energy supply crisis of the 1970s and 1980s is one of the EU energy strategic focus. In the consideration of the import of energy resources, the EU is either dependent on the Gulf region, or impatient to develop the Eastern European market .In the view of the imbalance between the EU internal market and regional economic and technological development, technology and equipment of the developed areas could be transferred or exported to the backward areas, which can promote the function of the internal single market, drive energy technology develop ment of backward areas, and have a positive role in promoting the entire Western European economy.

3.3 China and it's emergency in energy technology research of nuclear energy

The huge demand for energy of China's peaceful rise, makes the development of energy technologies face the dual pressures that either has to meet the demand of both economic growth and the improvement of living standards, or to reduce environmental pollution. In recent years China's energy consumption grows rapidly, and since 2004 China has become the world's second largest energy consumption country, which is over Japan, after the United States, which is over Japan, after the United States. With oil prices rising, the growing problem of climate and environment problems, and the various changes in international relations triggered by oil, the protection of national energy security has become the primary objectives of a national energy strategy and policy development ,and the diversification of energy is an important foundation to protect national energy security. In the next period of time, China's economy will maintain a higher rate of growth, and will speed up the process of urbanization. China's energy consumption will inevitably continue to grow. If China repeats the path of develop ment in the history of the developed countries experienced, in 2050 when China reached the level of moderately developed countries, per capita energy consumption standard will be 3.5 tons of oil equivalent, then China's total energy consumption will reach 5.25 billion tons of oil equivalent standards, which is equivalent to 60 percents of the world's total energy consum ption. Therefore how to meet China's energy needs will be an enormous challenge, not only for China's own energy supply, but also the world's energy supply. From co-citation net work, there is a clear big cluster with a central node "People R China" link to burst words "Tsinghua university", nuclear energy techn ology and mw nuclear heating reactor. Through google earth map, we can clearly see that China's total energy technology high co-citation research institutions have been distributed to Beijing as the center, formed a circle of high concentration of radiation, but there is fewer co citations between the countries in China's energy technology research.

Fig.5 Distribution of institutions co-citation of China's energy technology research

Nuclear energy is clear and environmental energy which can replace the fossil energy. It can provide specific power with not sulfur dioxide and dust and also carbon dioxide. So it is the necessary choice for developing nuclear energy in China and other counties.

The Chinese Government has proposed a "positive development of nuclear energy" poli cy. nuclear energy is playing an increasingly important role in the optimization of China's energy structure and diversified energy develop

ment strategy.

Nuclear energy heating is a new technology which is developed in the 1980s, and which is an economic, safe, clean heat and thus gets world wide attentions. In the energy structure, heat used for the low-temperature (such as heating, etc.),accounts for about half of the total consumption, and this portion of thermal comes from a more direct coal-fired, thus causes serious pollution to the environment. In China's energy structure, nearly 70 percents of energy is consumed in the form of heat, of which about 60 percents is the low-temperature heat below 120 ℃, so developing low-temperature heating of nuclear reactor, is very important to ease the supply tension and transportation tension, clean up the environment, reduce pollution. Nuclear heating is a promising way of using nuclear energy. Nuclear heating can be used not only by residents for the winter heating, can also be used for industrial heating. In particular, high temperature gas cooled reactor can provide high-temperature heat, can be used for the gasification of coal, iron-smelting, and other huge heat consumption industries. Since the nuclear energy can be used to heat, also can be used for refrigeration. Tsinghua University has conducted successful experiments in the five megawatt low-temperature heating reactor.

The nuclear energy is mainly used for electri city generation, and it also has a wide range of applications in other areas. For example, nuclear heating, nuclear power and so on. In early 2007,"10-megawatt-high-temperature gas cooled reactor test" developed by Tsinghua University won first prize of the Chinese scientific and technological progress, and its technology applications Chinese" high tempera ture gas cooled reactor nuclear power demon stration project" has been classified as the major special in national medium and long-term science and technology development planning, which would be constructed together by the China Huaneng Group, China Nuclear Industry Group Corporation and Tsinghua University. 10-megawatt high-temperature gas cooled reactor is a crucial representative of China nuclear technology research. This is the world's first modular HTGR experimental power plant, and it presents that China is in the world leading positions in the field of new nuclear technology.

3.4 Other energy technology research in co-citation network

There are some relatively independent purple bust terms on the left of the countries co citation network, such as the "united-states", "co2-emissions", "global-warming", "environ menttal-impact", "energy-conservation" and so on, which shows that the recent global warming, carbon dioxide gas emissions, the greenhouse effect and increase the U.S. withdrawal from the Kyoto Protocol, and other incidents that have impacts of the state environmental. Energy development and environmental require ments raised more severe challenges to human. Greenhouse gases come from oil, coal and other petrochemical energy that human burn, so promoting clean energy and reducing emissions are all a same problem.

Application of clean energy, not only can reduce greenhouse gas pollution, to contribute to curbing global warming, also can reduce the economy's dependence on the petrochemical energy. This does not mean the expense of economic development. And on the opposite ,it is a wise move beneficial to people's livelihood and the long-term, sustainable development. <Kyoto Protocol>is about to expire in 2012, but the global climate change assessment report issued by scientists in early 2007 confirmed that climate warming "very likely" caused by human activities, and predicted that in this century climate change could reach the disaster Degree. Therefore, the world still faces the arduous task which makes a reduction in greenhouse gas emissions and curbs global warming trend.

Although Japan extremely short of energy, but the level of energy technology is advanced. The burst terms around the Japan in the network, such as energy-techniques and energy-systems, show that Japanese Inputs in the field of energy technology and its world's high level of energy technology.

We also notice that there is neither the big powers Russia, nor major oil Middle East

countries on the map. Because although the two countries are major energy counties, they are not big energy technology countries , and they do not show up with other energy technology countries in the co-citation network in the field of energy technology research.

4. Conclusion

Energy system is a complicated nonlinear systems, social progress and economic develop ment, scientific and technological progress and macro economic policies will have a direct impact on the efficiency of energy systems. On the contrary, energy supply and demand have a direct impact on the economic, social and environmental comprehensive development. There are mutual promoting and constraining relations between energy and economy, the environment. According to the international energy technology visual network of this paper, through analysis we can get: with its strong financial backing，The United States provides support to enhance the level of energy technology, and the U.S. energy technology has been in the forefront of the world; comprehensively promoting the EU integration process, researches are becoming closer and closer in the energy technology especially in the renewable energy technology; China as a new rise in the field of international energy technology, is at the forefront of the world in nuclear energy technology research. With rapi dly development of the world economic today, the development of the country increasingly depends on energy demand, but the energy is not inexhaustible. Only grasped the most advan ceed energy technology, we just enable our country stay ahead in the international arena.

5. Acknowledgement

This research was supported by the National Natural Science Foundation of China under Grant 70773015, 70431001, 70620140115, National Social Sciences Foundation under Grant 07CTQ008, Project of DUT under Grant DUTHS1002, Specialized Research Fund for the Doctoral Program of Higher Education under Grant 20070141059, projects of League of Social Sciences in Liaoning Province under Grant 2007lslktglx-52.

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