Energy Policy 37 (2009) 588–596

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy technology roadmap for the next 10 years: The case of Korea

Seong Kon Lee [a,*], Gento Mogi [b], Jong Wook Kim [a]

[a] Energy Policy Research Division, Korea Institute of Energy Research,71-2 Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea
[b] Department of Technology management for innovation, Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

ARTICLE INFO

Article history:
Received 31 July 2008
Accepted 11 September 2008
Available online 20 November 2008

Keywords:
Energy technology roadmap
Energy technology policy
Energy technology forecasting

ABSTRACT

The Korea Institute of Energy Research (KIER), the only government-sponsored research institute specialized in the development of energy technology and policy, has established a long-term strategic energy technology roadmap (ETRM) for the period spanning from 2006 to 2015. Taking into account such variables as the energy environment, economic spin-off, and commercial potential, the ETRM was classified into 3 sectors, namely high oil prices, the UNFCCC, and the hydrogen economy. The ETRM not only represents a milestone in terms of the development of national energy technology in Korea, but also serves to identify the primary energy technologies which should be developed. The ETRM also supplies energy policymakers with successful R&D alternatives vis-à-vis the development of energy technologies under the current Korean energy environment.

1. Introduction

As Korea is the 10th largest energy consuming nation in the world, and the country imports 98% of its energy resources, it naturally ensues that the Korean economy is both directly and indirectly impacted by changes in oil prices. As a result, interest in the development of energy technologies has increased in Korea. Moreover, Korea has also found itself faced with the challenge of reducing greenhouse gas (GHG) emissions in response to the United Nations Framework Convention on Climate Change (UNFCCC). The importance of this task is highlighted by the fact that not only is Korea currently the 9th largest emitter of carbon dioxide in the world, but also the nation with the fastest rate of increase in terms of carbon dioxide emission. Korea also strives to become an Annex I nation by 2013. Desiring to reach the goal of generating 5% of Asia's power by 2011, the Korean government has focused on a policy of disseminating new and renewable technologies.

The Korean economy is greatly affected by rising oil prices. For example, rising oil prices occasion an increase in consumer prices, while also decreasing consumer consumption. What's more, the interest which Korea must pay rises as investment in the country drops, and Korean real wages decrease as employment in Korea shrinks. In addition, terms of trade will go steadily downhill as Korea's current account balance worsens. Another real fear is the possibility of a decrease in Korea's gross domestic product (GDP). In short, rising oil prices may very well cause the Korean economy to stagnate. The prime cost to Korean industry rises by 0.24% whenever oil prices increase by 10%. Specifically, a prime cost increase results in the cost of manufacturing petroleum and coal products, as well as nonmetallic minerals, rising by a whopping 0.36%. In other words, rising oil prices result in an increase in the prime cost for petroleum and coal products, as well as in nonmetallic minerals.

The absence of a strategic energy technology roadmap (ETRM) for the years 2006 to 2015 and Korean policymakers dire need to formulate a direction for the development of the energy technologies needed to navigate within the prevailing energy environment have spurred Korea Institute of Energy Research (KIER) to establish a long-term national ETRM for the ensuing decade that is rooted in the notions of selection and specialization. Given that the Korean economy is easily affected by oil prices, as exemplified by the fact that Korea is currently the 10th largest energy consuming nation in the world, and that the best way to solve the Korean energy environment is from a strategic standpoint, the ETRM can be regarded as a meaningful guideline through which to implement a well-focused energy technology development policy.

KIER's formulation of an ETRM and desire to provide a direction for energy policy began with an analysis of the world energy outlook in 2005 (Lee and Kim, 2005; Lee et al., 2006). The ETRM focuses on the development of energy technologies in a manner that takes into account aspects of the Korean energy environment such as economic spin-off and commercial potential. The ETRM makes it possible to identify the primary energy technologies which should be developed from a long-term

* Corresponding author. Tel.: +82 42 860 3036; fax: +82 42 860 3097.
E-mail address: sklee@kier.re.kr (S.K. Lee).

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2008.09.090

Nomenclature

APU: auxiliary power unit
DMFC: direct methanol fuel cell
ETRM: energy technology roadmap
KIER: Korea Institute of Energy Research
GDP: gross domestic product
GHG: greenhouse gas
GFRI: Government-funded research institute
KEMCO: Korea Energy Management Corporation
MKE: Ministry of Knowledge Economy
MEST: Ministry of Education, Science and Technology
PBS: project basis system
PEMFC: polymer electrolyte membrane fuel cell
PIAS: patent information analysis system
SOFC: solid oxide fuel cell
SWOT: strength, weakness, opportunity, threat
Tech: technology
TOE: ton of oil equivalent
UNFCCC: United Nations Framework Convention on Climate Change

standpoint. In addition, the ETRM also makes it possible to determine the most beneficial direction and strategy of Korean energy technology development.

The use of technology roadmaps (TRM) as a means of providing support for technological development strategies has gained in popularity over the last few years. TRM have been developed for various sectors ranging from academics to industry. Such TRM have been characterized as both forecasts of future technology and plans thereto Kappel (2001). TRM were first developed by Motorola over 20 years ago Harrell et al. (1996). About 200 famous companies, including SEMATECH, Lucent technologies, Lockheed Martin, Motorola, and Phillips, now use TRM for the strategic management of technology (Willyard and McCless, 1997; Rinne, 2004).

The main purpose of this research is to supply Korean decision makers and policymakers with insight into the direction which the country's strategic energy technology development should take. The construction of the ETRM for the ensuing decade was based on 3 major sectors, high oil prices, the UNFCCC, and the hydrogen economy. Such a plan is necessitated by the fact that Korea is currently not only the 10th largest energy consuming nation in the world, but also dependent on imports for 98% of its energy resources. Moreover, Korea is also the 9th largest emitter of carbon dioxide in the world, and the nation with the fastest rate of increase in such emissions. To this end, as energy technology development represents one of the best alternatives in terms of Korea's ability to cope during the upcoming decade, this research focuses on this particular aspect. To counter high oil prices, this study undertook the task of identifying and developing energy efficiency improvement technologies and alternative fuel technologies for petroleum. Meanwhile, renewable energy technologies and GHG control technologies were selected as the means to meet the standards of the UNFCCC. Finally, new energy and fuel cell technologies were identified as the key elements in terms of the construction of a hydrogen economy capable of resolving the problems Korea faces with regards to its energy environment. This study focuses on the development of energy technology, which is regarded the key to achieve a breakthrough where Korea's energy environment is concerned.

The ETRM includes the core energy technologies that should be developed during the upcoming decade. The ETRM also introduces successful energy R&D guidelines and alternatives. Moreover, through the analysis and assessment of energy technologies, it also facilitates the efficient distribution of energy resources and contributes to the efficient formulation of technological development strategies.

The remainder of this paper is structured as follows. In Section 2, the methodology, which consists of an execution flow chart, technology analysis, and capacity analysis, is introduced. Section 3 revolves around the results garnered, and a discussion thereof. Finally, the conclusions reached in this paper are presented in Section 4.

2. Methodology

2.1. Execution flow chart

The execution flow chart used to formulate the ETRM for the ensuing decade is composed of 3 stages. The ETRM execution flow chart can be seen in Fig. 1. During the 1st stage, a list of the energy technologies developed in Korea is compiled. As this research focuses on energy efficiency improvement, renewable energy and GHG, new energy, and fuel cell technologies, nuclear energy technologies were not included in this list. These energy technologies were clustered in accordance with 3 major technical sectors, namely high oil prices, the UNFCCC, and the hydrogen economy. The 2nd stage consists of an analysis of the various technologies based on factors such as economic spin-off, commercial potential, and patents and rights. The patent information analysis system (PIAS) developed by the Korean Intellectual Property Office was used to analyze the patents and rights related to individual energy technologies. During the 3rd stage, the present state of Korean energy technology development, centering on the KIER, was analyzed from the standpoint of the present state of R&D, present state of Korean patents, and policy linkages. Finally, during the 4th stage, the ETRM was constructed by selecting core technologies, and the ETRM was provided to the decision makers within the Ministry of Education, Science

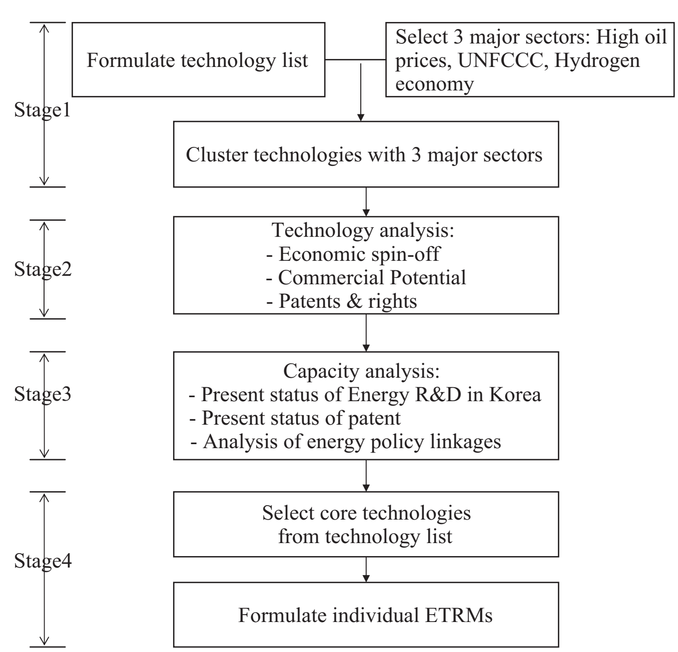

Fig. 1. Execution flow chart.

and Technology (MEST), Ministry of Knowledge Economy (MKE), and the Korea Energy Management Corporation (KEMCO).

This study not only compiles a list of Korean energy technologies, but also sets up the first ever 10-year strategic ETRM. This ETRM illustrates the path which those in charge of the development of energy technologies should take given the Korean energy environment.

2.2. Technology analysis

Fig. 2 shows the sectors of technologies. Technology analysis takes economic spin-off, commercial potential, and patents and right. Technology analysis chart divides energy technologies into 3 sectors depending on economic spin-off and commercial potential. Energy technologies analyzed with economic spin-off and commercial potential are divided into 2 sectors, which are core tech and basic tech. Core tech is included between sectorI and sectorII. Basic tech is placed on between sectorII and sectorIII.

Economic spin-off is the reduction quantity of TOE/yr or CO_2/yr and is composed of 5 scales from very low to very high in Table 1. Commercial potential is also composed of 5 scales from very high to very low in Table 2. For example, lighting technology is composed of three technologies, semiconductor lighting resource, new lighting resources, and lighting system. Semiconductor lighting resource lies between very high and high on the axis of economic spin-off. And also is placed in the medium level on the axis of commercialization possibility.

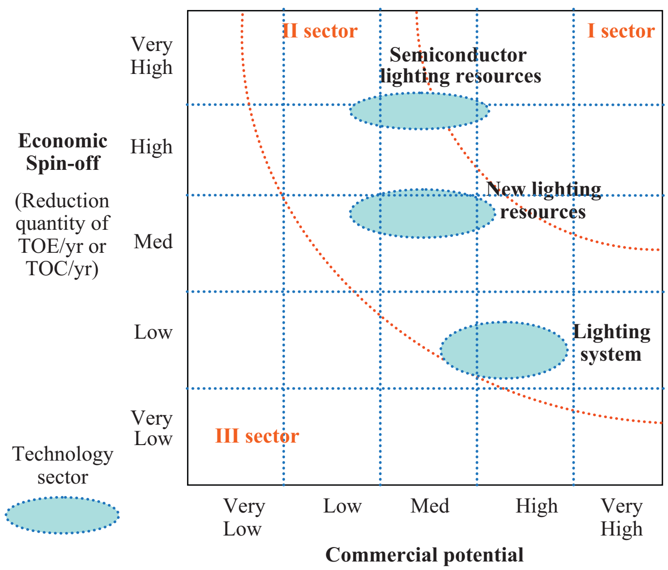

Fig. 2. Technology analysis chart.

2.3. Capacity analysis of Korean energy technology development

The analysis of Korean energy technology development capacity consists of 3 stages: the present state of R&D, present state of patents, and analysis of policy linkages. Here, Korea's energy technology development capacity is regarded as equating the KIER technology development capacity. This is because KIER is, with the notable exception of the nuclear sector, the only government-sponsored energy technology development institute. Thus, as the technology capacity of KIER is regarded as a fair benchmark of the present status of Korean energy technology development, the energy technology capacity of KIER was therefore analyzed.

In the present state of R&D stage, changes in the energy paradigm were considered, and a strengths, weaknesses, opportunities, and threats (SWOT) analysis of Korean energy technology development was conducted. In the present state of Korean patents stage, Korean patents and the status thereof were analyzed using PIAS. Thereafter, energy policy linkages within

Table 1
Economic spin-off

Section	Very low	Low	Medium	High	Very high
Reduction quantity of TOE/yr	<10,000	10,000–50,000	50,000–1,000,000	1,000,000–2,000,000	>2,000,000
Reduction quantity of CO_2/yr	<10,000	10,000–50,000	50,000–1,000,000	1,000,000–5,000,000	>5,000,000

Table 2
Commercial potential

Section	Contents
Very high	Technology spread phase: acquiring core patents and commercialization and spread in 3 yrs
High	Commercialization phase: acquiring core patents and commercialization in 3–5 yrs
Medium	Phase of acquiring core patents and commercialization based on market and technology maturity
Low	Technology development phase: need for developing component technology without commercialization
Very low	Technology quickening period phase: level of building concepts of new technology

Table 3
Change of energy paradigm

Section	Previous paradigm	Condition change	New paradigm
Energy environment	Secure energy demand and supply	Int'l environment regulation upgrade	Sustainable development
Energy policy	Government initiated market operation	Globalization and privatization	Liberalized market function
Foreign relation	Closed system	Northeast asian region rising, South-North Korea cooperation progress	Open system
Technology development	Development of domestic demand technology	Limitless market cooperation era	3rd/4th generation technology development

the ETRM were analyzed. Table 3 displays the changes in the energy paradigm.

Fig. 3 shows the results of the SWOT analysis, a method generally used in management science to analyze the present state of a project and to identify measures to address this present state, of Korean energy technology development. In terms of strengths, this study identified the international increases in demand for energy and for environment technology occasioned by

Strength

2005 : Increase in international demand for energy/environment tech occasioned by the quest for energy security, high oil prices and the UNFCCC

2015 : Need to develop high-efficiency and GHG tech as a result of the rapid increase in the demand for alternative fuels, acceleration of the hydrogen economy and the UNFCCC/ Kyoto Protocol

Weakness

2005 : Growingly open and competitive nature of the global R&D market, advanced nations' monopoly of leading core technologies, and increases in their R&D budgets for the development of new technology

2015 : More extensive competition in World R&D market, transfer from public tech to private tech, possibility of developing nuclear fusion energy tech

Opportunity

2005 : Role of the hub bringing together a wide array of research areas and human resources, ability to erect a national network of research resources and of the demanders of technology

2015 : Top five institute in the global energy field, core role in technology development and policy, achievement of status as an internationally renowned institute through international cooperation

Threat

2005 : Current identity crisis marring government-funded research institute (GFRI), The existence of a project basis system (PBS) greatly hampering government-funded research institutes' ability to conduct their research where selection and specification is concerned, problems related to performance and human resources aspects of the research management system

2015 : Restructuring of GFRI role, unstable employment conditions occasioned by advent of limitless competition era

Fig. 3. SWOT analysis of Korean energy technology development based on KIER.

Strength

- Need to enhance energy security related policies, and to improve KIER'sreputation as a supplier of energy technology
- Improvement of KIER'sinternational competitiveness where energy technology development is concerned

Weakness

- Establishment of a center of excellence system capable of addressing the task of restructuring GFRI (Government funded research institutes)
- Creation of a synergy effect where human resources are concerned through the planning of large-scale projects
- Need to strengthen GFRI roles during the reestablishment process

Measures

Opportunity

- Develop high efficiency technologies and new and renewable energy technologies capable of helping to overcome the depletion of resources
- Strengthen the development of hydrogen fuel cell technologies where the hydrogen economy is concerned
- Develop GHG (Greenhouse gas) low emission technology with regards to the UNFCCC

Threat

- Develop energy technologies in cooperation with the business sector
- Select and specialize in world leading core energy technologies

Fig. 4. Measures of SWOT analysis.

the growing focus on energy security, high oil prices, and the UNFCCC in 2005. Meanwhile, the growingly open and competitive nature of the global R&D market was identified as the main weakness. Other weaknesses included the fact that advanced nations' monopoly of leading core technologies has increased and that their R&D budgets for the development of new technology have also increased. The most significant opportunity identified was the fact that KIER, which represents the only government-sponsored research institute in terms of the development of energy technologies in Korea, can play the role of a hub bringing together a wide array of research areas and human resources. Moreover, KIER has the ability to erect a national network of research resources and of the demanders of technology. In terms of threats, this study identified the current identity crisis marring government-funded research institutes. The existence of a project basis system (PBS) has greatly hampered government-funded research institutes' ability to conduct their research where selection and specification is concerned. In addition, several problems were also identified in terms of the research management system where performance is concerned.

Fig. 4 shows the measures to be taken in response to the SWOT analysis, as well as the scaling ratio used to apply weights to the various factors. In terms of strengths, this study identified the need to enhance energy security related policies, and to improve KIER's reputation as a supplier of energy tech. Moreover, international competitiveness should also be enhanced when it comes to the development of energy technologies. From the standpoint of weaknesses, this study focuses on the need for KIER to establish a center of excellence system capable of addressing the task of restructuring Government-funded research institutes

Table 4
Classification of high oil prices

High-level	Mid-level	Low-level	Core technologies
Technologies against high oil prices	Efficiency energy improvement technologies	Building energy tech	Lighting tech
			Air-conditioning tech
			Building envelope tech
			Building system tech
		Industrial energy tech	Common utilities tech
			Waste heat tech
			Petroleum refinery and fine chemical
		Transportation tech	Automobile tech
	Synfuel	Coal	Direct utilization tech
			Conversion utilization tech
		Non-conventional fuels	Direct utilization tech
			Conversion utilization tech
		Biomass	Direct utilization tech
			Conversion utilization tech

Table 5
Classification of the UNFCCC

High-level	Mid-level	Low-level	Core technologies
Technologies against the UNFCCC	Renewable energy Tech	Solar	Solar tech tech
		energy	Photovoltaic tech
		Wind power energy	Wind power tech
		Geothermal and small hydropower energy	Geothermal energy tech
			Small hydropower energy tech
		New and renewable energy resources	Management and assessment system of new and renewable energy resources
	GHG Control	Capture tech	Post-combustion CO_2 capture tech
			Pre-combustion CO_2 capture tech
			Oxy-fuel combustion tech
			Non-CO_2 capture tech

Table 6
Classification of the hydrogen economy

High-level	Mid-level	Low-level	Core technologies
Technologies for the hydrogen economy	Hydrogen tech	Hydrogen production	Natural gas hydrogen production tech
			Thermochemical hydrogen production tech
			Water electrolyzer hydrogen production tech
		Hydrogen separation and storage	Solid state storage tech high purity hydrogen production tech
	Fuel cell tech	PEMFC	Portable fuel cell
			Fuel cell vehicle
			System for home and commerce
		DMFC	Micro-fuel cell
			Fuel cell for laptop
			Portable fuel cell
		SOFC	Fuel cell for power generation
			Fuel cell for home and APU

(GFRI). Furthermore, it should also focus on creating a synergy effect where human resources are concerned through the planning of large-scale projects. In addition, the need to strengthen GFRI roles during the reestablishment process was also highlighted. From the standpoint of opportunities, KIER needs to develop high-efficiency technologies and new and renewable energy

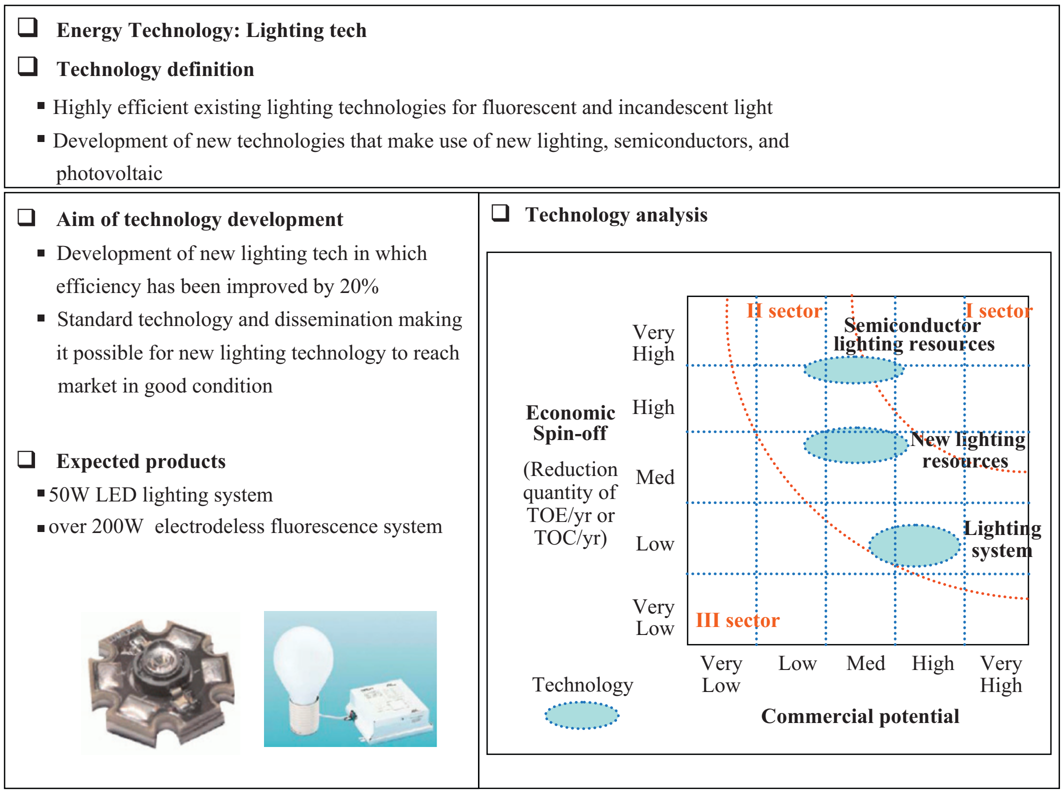

Fig. 5. TRM sample (1): lighting technology.

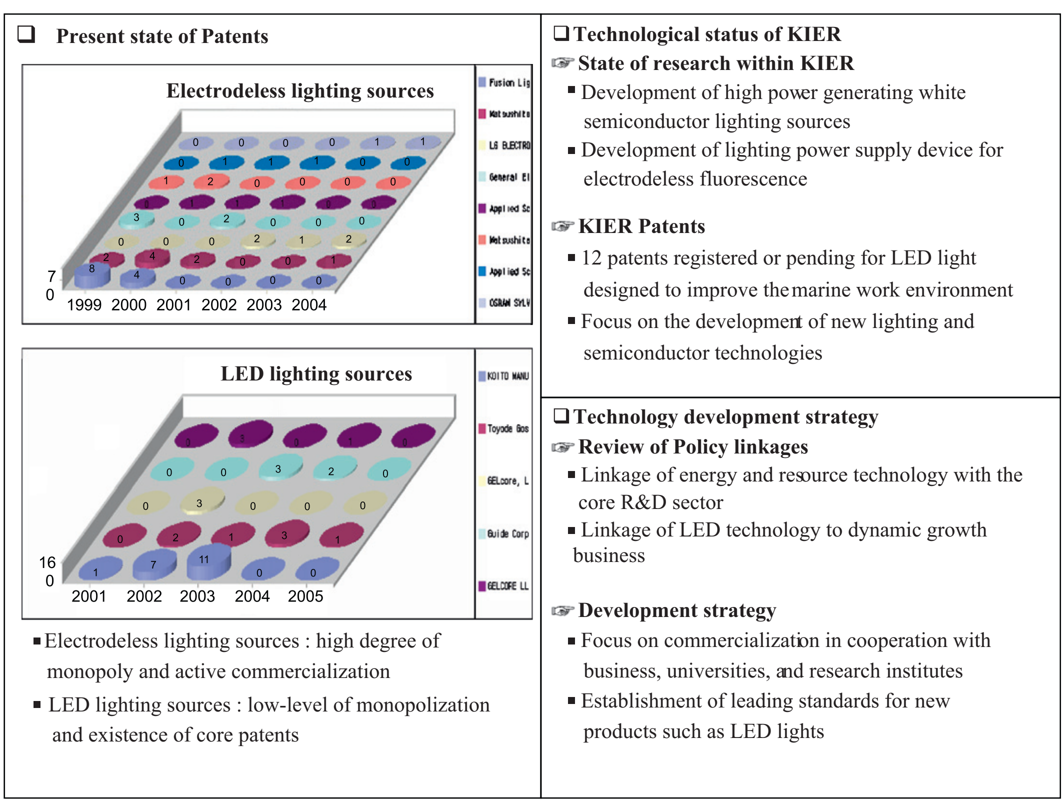

Fig. 6. TRM sample (2): lighting technology.

technologies capable of helping to overcome the depletion of resources, strengthen the development of hydrogen fuel cell technologies where the hydrogen economy is concerned, and develop GHG low emission technology with regards to the UNFCCC. Where the threats are concerned, KIER must develop energy technologies in cooperation with the business sector, and select and specialize in world leading core technologies.

3. Results and discussion

3.1. Classification of 3 major sectors

The core technologies were systematically classified in accordance with experts' opinions and by type of energy technology. The core technologies were divided into 3 major sectors, namely technologies to resolve the issue of high oil prices, meet the standards of the UNFCCC, and facilitate the advent of a hydrogen economy.

The technologies to resolve the issue of high oil prices are displayed in Table 4. Technologies to resolve the issue of high oil prices consisted of 2 mid-level technological sectors: energy efficiency improvement technologies and synfuel, and 14 energy technologies. Meanwhile, energy efficiency improvement technologies were broken down into 3 low-level sectors; namely, building energy tech, industrial energy tech, and transportation tech. Synfuel also featured 3 low-level sectors: coal, non-conventional fuels, and biomass.

The technologies to meet the standards of the UNFCCC are shown in Table 5. The technologies for the UNFCCC were divided into 2 mid-level sectors: renewable energy tech and GHG control, along with 10 energy technologies. In turn, renewable energy tech consisted of 4 low-level sectors: solar energy, wind power energy, geothermal and small hydropower energy, and new and renewable energy resources. GHG control had just 1 sector.

The technologies to facilitate the advent of a hydrogen economy are shown in Table 6. Technologies for the hydrogen economy are divided into 2 mid-level sectors: hydrogen tech and fuel cell tech, along with 12 energy technologies. Hydrogen tech could in turn be broken down into 2 low-level sectors: hydrogen production and hydrogen separation and storage. Meanwhile, fuel cell tech was divided into 3 low-level sectors: PEMFC, DMFC, and SOFC.

3.2. Energy technology roadmap

The ETRM was formulated in accordance with experts' opinions and consensus. The ETRM is composed of technology definition, aim of technology development, technology analysis, present states of patents, technological status of KIER, strategy for developing technology, a master TRM chart, and detailed TRM charts with a time framework. Fig. 5 shows a sample TRM for

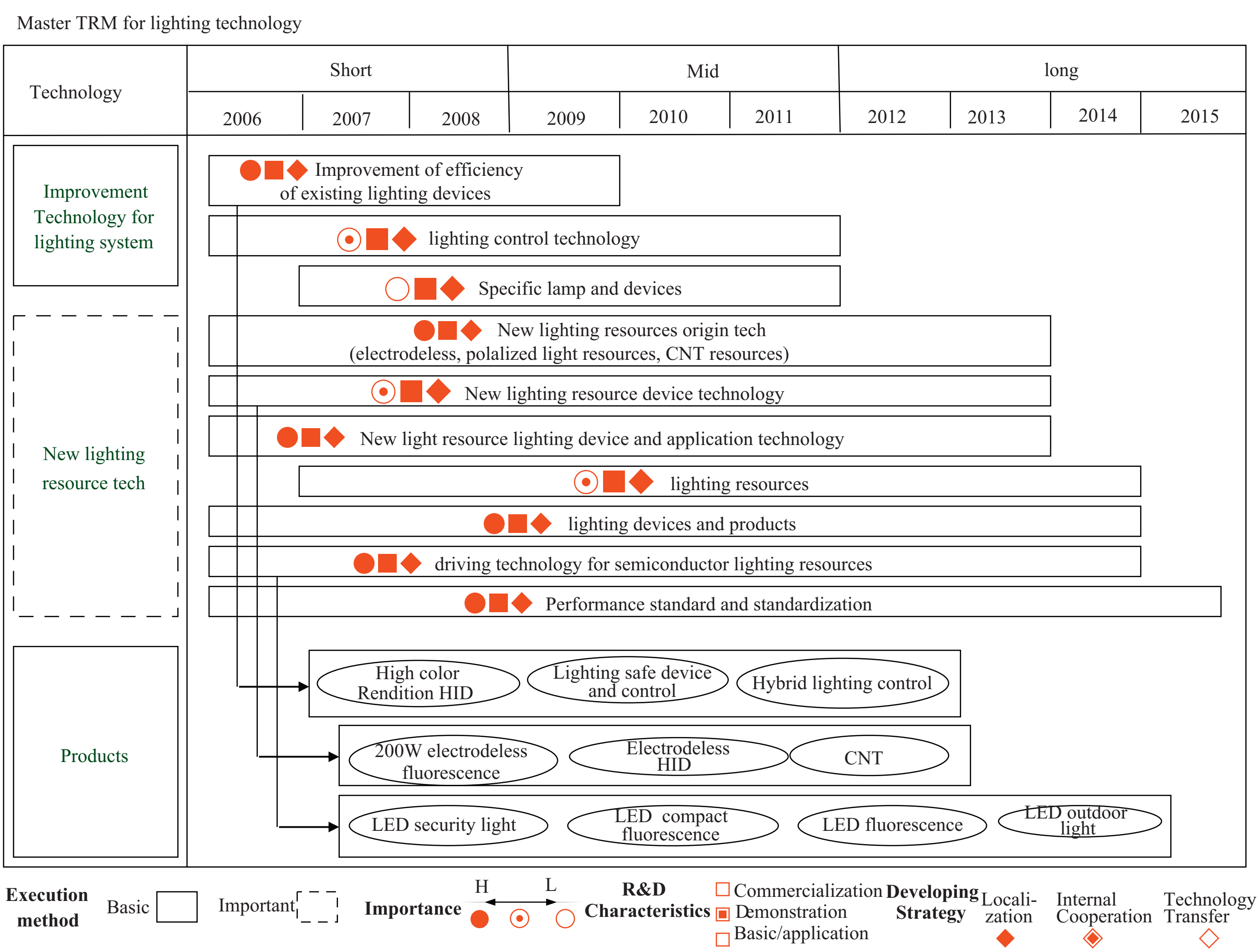

Fig. 7. Master TRM of lighting technology.

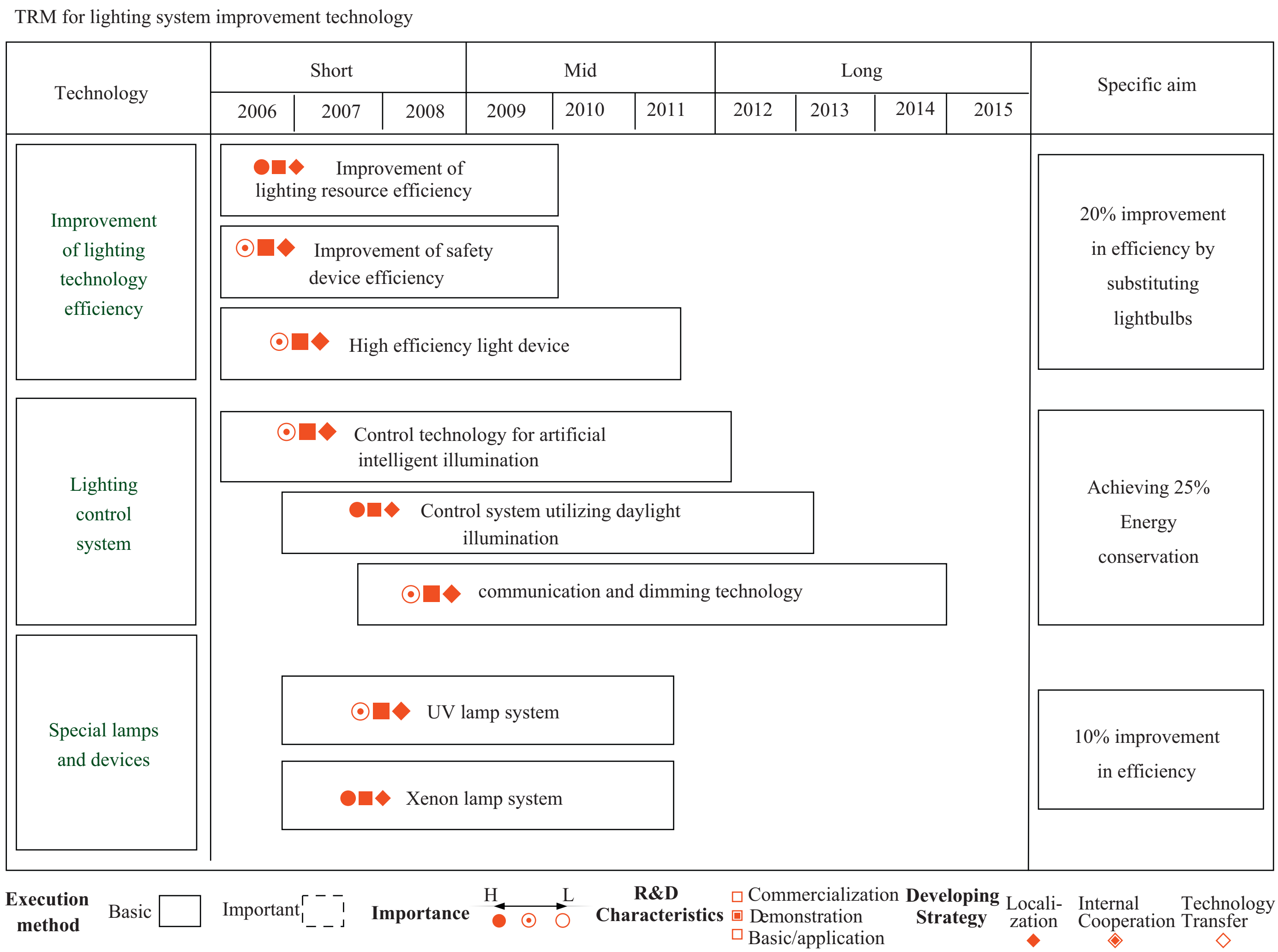

Fig. 8. TRM for improvement technology of lighting system.

lighting technology. Technology definition, aim of technology development, expected products, and technology analysis are introduced in Fig. 5. Meanwhile, Fig. 6 displays the present status of patents, the technological status of KIER, and the strategy for developing technology. Fig. 7 provides the master TRM for lighting technology, which was composed of 3 detailed technologies. Fig. 8 exhibits the TRM for lighting system improvement technology, which consists of one sub-technology of lighting technology. We established ETRMs for 37 core technologies, each of which included master and sub-TRMs.

4. Conclusions

Advanced nations have been formulating TRM as part of their efforts to improve their competitiveness amidst rapid environmental changes. Moreover, major companies have also made regular use of TRM where the strategic management of technologies is concerned.

This study constitutes a major milestone for Korean decision makers and policymakers in terms of technology development. Furthermore, this study also introduces the competitive core energy technologies whose development should be pursued through the staging of analyses of future needs and market forecasting. The ETRM enables us to strategically develop competitive high-end technologies in accordance with the development of future energy technologies.

The ETRM built in accordance with experts' opinions can also be used to optimize investment in energy technologies and R&D outcomes. The results of this study will help decision makers and policymakers to approach the issues of forecasting future technology needs, technology plans, and the outcomes of Korean energy technology R&D from a long-term standpoint.

Finally, because it was built for a specific time frame and energy technology continuously changes, the ETRM will be periodically modified. Furthermore, there is a need to apply it to disruptive energy technologies.

Acknowledgements

We wish to express our warmest gratitude to the researchers who participated in the establishment of the energy technology roadmap.

References

Harrell, S., Seidel, T., Fay, B., 1996. The national technology roadmap for semiconductors and SEMATECH future directions. Microelectronic Engineering 30, 11–15.

Kappel, TA., 2001. Perspectives on roadmaps: how organizations talk about the future. Journal of Production Innovation Management 18, 39–51.

Lee, S.K., Kim, J.W., 2005. World energy outlook and measures. KIER-A 52417, 299–354.
Lee, S.K., Yoon, Y.J., Kim, J.W., 2006. A study on making a long-term improvement in the national energy efficiency and GHG control plans by the AHP approach. Energy Policy 35, 2862–2869.
Rinne, M., 2004. Technology roadmap: infrastructure for innovation. Technological forecasting & social change 71, 67–80.
Willyard, CH., McCless, C., 1997. Motorola's technology roadmap process. Research Management 30 (5), 13–19.