Green Energy and Technology

Takeshi Yao *Editor*

Zero-Carbon Energy Kyoto 2012

Special Edition of the Joint Symposium "Energy Science in the Age of Global Warming" of the Kyoto University Global COE Program and the JGSEE/CEE-KMUTT

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Preface

The Fourth International Symposium of the Global COE (Center of Excellence), titled “Zero-Carbon Energy, Kyoto 2012,” was held jointly with the Joint Graduate School of Energy and Environment/Center of Excellence on Energy Technology and Environment (JGSEE/CEE) at King Mongkut’s University of Technology, Thonburi (KMUTT) in Bangkok, Thailand, on May 22–23, 2012, succeeding the International Symposium “Zero-Carbon Energy, Kyoto 2009” at Kyoto University Clock Tower, “Zero-Carbon Energy, Kyoto 2010” at Kyoto University Obaku Plaza, and “Zero-Carbon Energy, Kyoto 2011” at Suwon, Korea. This 2012 symposium provided an opportunity for researchers to present their scenarios and their advanced research works. Many important lectures and discussions by invited speakers and members of the Global COE, as well as interesting presentations by students of the GCOE Unit for Energy Science Education, were given. This book is a compilation of the lectures and presentations.

This is the final year of the 5-year Global COE Program “Energy Science in the Age of Global Warming—Toward a CO2 Zero-Emission Energy System” of the Ministry of Education, Culture, Sports, Science and Technology of Japan. The program has aimed to establish an international education and research platform to foster educators, researchers, and policy makers who can develop technologies and propose policies for establishing a scenario for a CO2 zero-emission society no longer dependent on fossil fuels by the year 2100. Since 2008, four departments of Kyoto University—the Graduate School of Energy Science, the Institute of Advanced Energy, the Department of Nuclear Engineering, and the Research Reactor Institute—have joined together and have been engaged in the management of the Global COE Program.

The Global COE has established the GCOE Unit for Energy Science Education at its center and has placed the Scenario Planning Group, the Advanced Research Cluster, and the Evaluation around the Unit forming mutual associations. The Scenario Planning Group has set out CO2 zero-emission technology roadmaps and established CO2 zero-emission scenarios, with analyses from the standpoints of social values and human behavior. The group has set up the Committee of

Energy Scenario and Strategy Study to cooperate with the government and industries on energy and environmental issues. The Advanced Research Cluster, as an education platform based on research, has promoted a socio-economic study of energy, a study of new technologies for solar energy and biomass energy, and research for advanced nuclear energy following the road map established by the Scenario Planning Group. The Cluster has set up the Joint Committee of Scenario Planning and Advanced Research in order to enhance cooperation between the Scenario Planning Group and the Advanced Research Cluster.

At the GCOE Unit for Energy Science Education, the students have planned and conducted interdisciplinary group research containing both the social and human sciences as well as the natural sciences toward the goal of CO2 zero emission at the initiative of the students themselves. The students have acquired the ability to survey the whole energy system through participation in scenario planning and interaction with researchers from other fields and have applied it to their own research. This approach is the major feature of the cultivation of human resources. The Global COE has been striving to foster young researchers who will be able to employ their skills and knowledge with a broad international perspective and expertise in their fields of study in order to respond to the needs of society in terms of diverse energy and environmental problems.

In order to transmit the achievements of this platform to the public, the Global COE has posted information on a web site and has published annual reports, quarterly newsletters, books, and self-inspection and evaluation reports. It has also hosted domestic and international symposiums and the GCOE industry-government-academia collaboration symposium and citizen lectures, and has co-hosted related meetings both domestically and internationally.

Securing energy and conservation of the environment are the most important issues for the sustainable development of human beings. The energy problem cannot be simply labeled a technological one, as it is also deeply involved with social and economic elements. It is necessary to establish low carbon-energy science as an interdisciplinary field, bringing together the social and human sciences and the natural sciences.

Takeshi Yao
Program Leader
Global COE “Energy Science in the Age of Global Warming
—Toward a CO_2 Zero-emission Energy System”

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Part I
Scenario Planning and Socio-economic Energy Research

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Invited Paper

Challenges of Nuclear Safety to Sustainable Development of Chinese Nuclear Energy in Post-Fukushima Era

Zhiwei Zhou

Abstract Sustainable development of Chinese economy in twenty-first century will mainly rely on self-supply of clean energy with indigenous natural resources. The burden of current coal-dominant energy mix and the stress on reduction of CO_2 emission due to energy consumptions has led nuclear power to be an indispensable choice for further growth of Chinese electricity generation capacity. This paper describes the challenges nuclear safety issues in post-Fukushima era related to the development of nuclear industry of China. Three major challenges that China's nuclear energy market is facing are addressed, which include: safety standards, speed of NPP construction, and advanced technologies. This study emphasizes that China should implement sustainable energy development policy and pay great attention to advanced nuclear technologies with passive and inherent safety in future.

Keywords Advanced nuclear technology • Chinese nuclear policy • Fukushima accident • Nuclear safety • Sustainable development

1 Introduction

The time span of next 15–20 years is a crucial period for China to develop prosperous economy and to establish harmonic society in all aspects benefiting its well over 1 billion people. Energy is one of the most important material conditions. The bottle-neck burdens from energy resources and environmental protection will be the major limits for fulfilling the criteria of a modern harmonic and prosperous society.

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To realize harmonic between man and nature is the up-most ambition of human-being. The rich culture embedded in China's long lasting civilization of more than 3,000 years has always been reflecting the thoughts of "harmonic combination between man and nature" from numerous great ideologists, politicians and scientists. The modern industrial technology based on western scientific civilization also pursues the philosophy of sustainable development. Nowadays, more than 400 nuclear power plants are producing safely and reliably about 14% of total electricity used by human being without emission of greenhouse gas CO_2 [1]. This is a great achievement made by nuclear energy technology which originated from the middle of the twentieth century.

Although many challenges have resulted in a valley in projecting nuclear power plants under construction worldwide in the previous two decades, nuclear energy so far is still a competitive alternative option to substitute fossil energy in massive scale for generating electricity in predictable near future. The major trend in last a few years in the world for new-built nuclear power plants (NPP) projects before Fukushima accident showed a strong indication of the renaissance of nuclear energy. According to the forecast from the prestigious research institutions [2], the potential market for nuclear power plants in China is in the scale of 240–400 GWe. However, current total generation capacity of nuclear power plants (NPPs) of China is only about 11 GWe. Now, China has played the leading role to accelerate the worldwide nuclear renaissance and 28 units of NPP are under construction. Unfortunately, the Fukushima accident induced by the devastating tsunami after a beyond design basis earthquake may have some setback impacts to the development of global nuclear energy industry. The global statistic poll has shown that the public support rate for continuing nuclear energy still remains high, although it drops in comparison to the situation before Fukushima accident. So far, China's policy to effectively develop nuclear energy on the basis of safety first principle has not changed. It will be foreseeable that the potential Chinese market for new units of NPPs will still remain very attractive to both international and domestic vendors and equipment suppliers.

2 Challenges in China's Energy Security and Nuclear Safety

2.1 China's Energy Consumption and Supply

The primary energy consumption of China since 2006 has been listed in Table 1. The data shown in table one indicates that China has become the largest energy consuming country in the world since 2009, although the level of the primary energy consumption per capita in China (~2.5 tce) is still very low compared to the world rich countries, such as USA (~8 tce), Japan (~4 tce). However, the total energy production of China has almost matched up the energy consumption in

Table 1 Total energy consumption of China since 2006

Year	Total consumption (billion tce)
2006	2.46
2007	2.65
2008	2.8
2009	3.06
2010	3.25
2011	3.48
2020 (forecast)	~4.0 (coal share >60%)

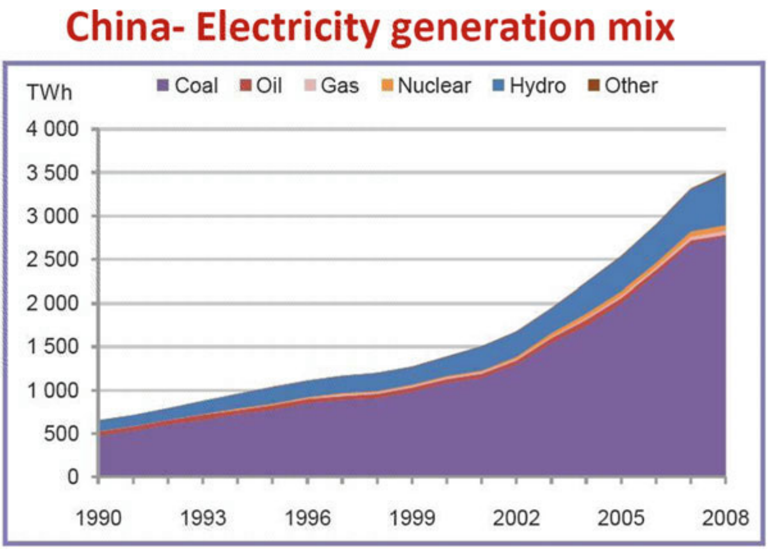

Fig. 1 China's electricity generation mix

China and therefore China is also the largest energy producer. The main contributors of energy sources so far in China are the coal (~70%) and hydro-power (~16%). Thus, the room for developing new energy, such as wind, solar, biomass and other types of renewable energy, and as well nuclear energy, remains very large (see Figs. 1 and 2).

The general principle of energy policy of China is to insist on self-reliance to ensure energy security. The current status is that self-supply occupies about 94% share of Chinese total energy market and the net imported energy shares only 6% of total demand of Chinese energy market. The major part of the imported energy has been crude oil and natural gas, and the uranium import may also increase in near future. It is projected that the above proportional ratio of Chinese energy consumption and supply will not significantly change in the decade to come.

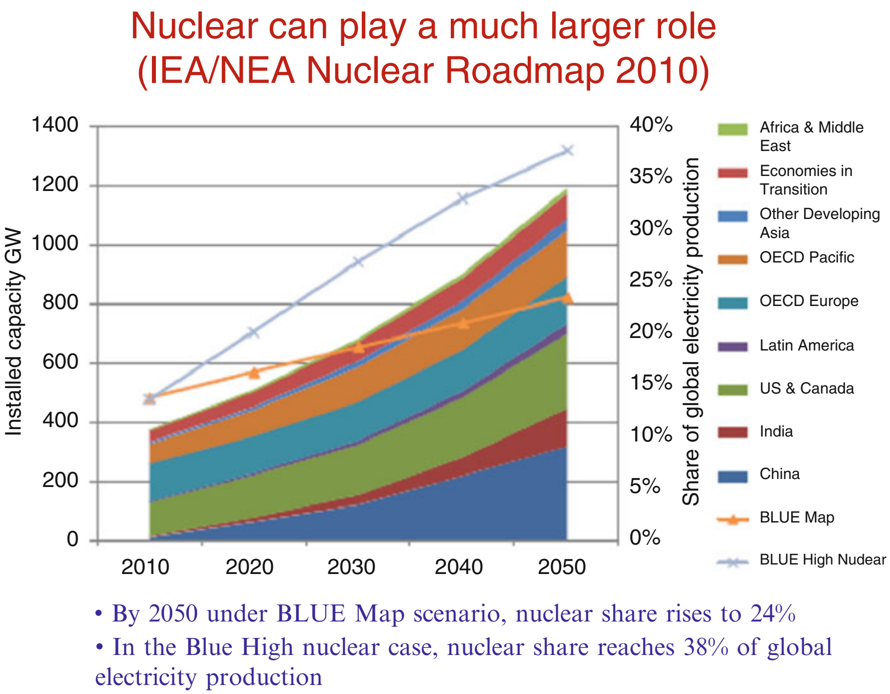

Fig. 2 Potential role of nuclear generation capacity

2.2 Current Status of China's Nuclear Power Plants

Nuclear power plants in commercial operation in China and their operational performances are listed in Table 2, indicating all NPPs of China in commercial operation are very reliable.

Nuclear power plants under construction in China and the type of their reactors are listed in Table 3, in which total of 28 units include various types of PWRs and modular high temperature reactors and cover GEN-II+, GEN-III and GEN-III+ reactors. Table 3 has also shown that Chinese nuclear fleet is experiencing transition from GEN-II+ to more advanced GEN-III or plus technologies. Safety has always been emphasized as the priority of the new-built NPPs.

Figure 3 indicates the distribution of existing and planned NPPs sites in China. The future trend is to expand NPP constructions in a number of inland sites. From the global experience, the inland NPP sites are significantly more than the coastal sites because it is much easier to find the low population density sites which are satisfy the criteria of building NPPs in the vast inland area.

China is a continental country, the remote northern and north-east areas along the border to Mongolia and Russia may be suitable for building new inland NPPs, by taking into account the easy distance for transmitting electricity to the industrial

Table 2 Operational performance of Chinese nuclear power plants

NPP name	Type of reactor	Capacity factor	Load factor
Qinshan	PWR 300 MWe, GEN-II	96.39%	95.58%
Daya Bay	U-1 PWR 900 MWe, GEN-II+	99.78%	99.60%
	U-2 PWR 900 MWe, GEN-II+	86.20%	86.39%
Qinshan-II	U-1 PWR 600 MWe, GEN-II+	85.35%	87.41%
	U-2 PWR 600 MWe, GEN-II+	85.21%	87.00%
Lingao	U-1 PWR 1 GWe, GEN-II+	92.11%	90.72%
	U-2 PWR 1 GWe, GEN-II+	85.24%	84.57%
Qinshan-III	U-1 CAN 650 MWe, GEN-II	91.21%	93.52%
	U-2 CAN 650 MWe, GEN-II	87.32%	89.25%
Tianwan	U-1 VVER 1 GWe, GEN-II+	70.97%	74.76%
	U-2 VVER 1 GWe, GEN-II+	81.20%	85.47%
Lingao-II[a]	U-1PWR 1 GWe, GEN-II+	n/a	n/a
	U-2 PWR 1 GWe, GEN-II+	n/a	n/a
Qinshan-II[a]	U-3,4 PWR 600 MWe, GEN-II+	n/a	n/a
	Average factor	87.36%	88.57%

[a]NPPs start to operate in 2010, the operation data are not available for a year based average

Table 3 NPPs under construction in China

Contractor	Site location	Type of reactor	Units and power
SNPTC	Sanmen, Zejiang	AP1000, GEN-III	2 × 1000 MWe
	Haiyang, Shandong	AP1000, GEN-III	2 × 1000 MWe
CGNPC	Taisan, Guangdong	EPR, GEN-II+	2 × 1700 MWe
	Hongyanhe, Liaoning	CPR1000, GEN-II+	4 × 1000 MWe
	Ningde, Fujian	CPR1000, GEN-II+	4 × 1000 MWe
	Yangjiang, Guangdong	CPR1000, GEN-II+	3 × 1000 MWe
	Fangchenggang, Guangdong	CPR1000, GEN-II+	2 × 1000 MWe
CNNC	Fuqing, Fujian	M310+, GEN-II+	3 × 1000 MWe
	Fangjiashan, Zejiang	M310+, GEN-II+	2 × 1000 MWe
	Changjiang, Hainan	CNP600, GEN-II+	2 × 600 MWe
Huaneng	Shidaowan, Shandong	HTR-PM, GEN-III+	2 × 100 MWe

and commercial prosperous flat and coastal zones in north-east provinces and municipals. Other inland areas in central and south-west provinces are also possible to find suitable inland sites for NPP if the domestic economic boost reaches these areas.

2.3 China's Nuclear Safety Regulatory Body

China has established a legal system to regulate and oversight nuclear safety. The safety standards developed by International Atomic Energy Agency (IAEA) have been adopted as the backbone in Chinese nuclear safety regulation system.

Fig. 3 Existing and planned sites of China's NPP

Meanwhile, a professional team has also been established for performing safety assessment and inspection to nuclear power plants and the other civil nuclear facilities. The Ministry of Environmental Protection (MEP) and the National Nuclear Safety Administration (NNSA) under MEP have strengthened regional offices which are located at Beijing, Shanghai, Shenzhen, Chengdu, Dalian and Lanzhou. As the technical support centers, Nuclear and Radiation Safety Center, Radiation Monitoring Center, Mechanical Equipment Reliability Center, Suzhou Safety Center and Beijing Nuclear Safety Review Center have played vital roles in nuclear safety assessment. Among them, Nuclear and Radiation Safety Center are of full responsibility to carry out safety assessment for NPP license. Figure 4 displays the institutional structure of the NNSA.

The main measures for safety regulatory body of China to ensure NPP safety include: adopting the "safety first" policy firmly; enhancing the legislation and regulation on nuclear safety; ensuring nuclear safety to the new projects; strengthening nuclear supervision and surveillance; establishing high standards for civil nuclear-grade equipments; increasing government funding for supervision staff; enhancing nuclear emergency readiness and training; implementing periodic safety review and experience feedback; applying probability safety assessment (PSA) and strengthening scientific research on severe accident management; enhancing international cooperation in the field of nuclear safety; and advocating the information publicizing and encouraging public participation positively.

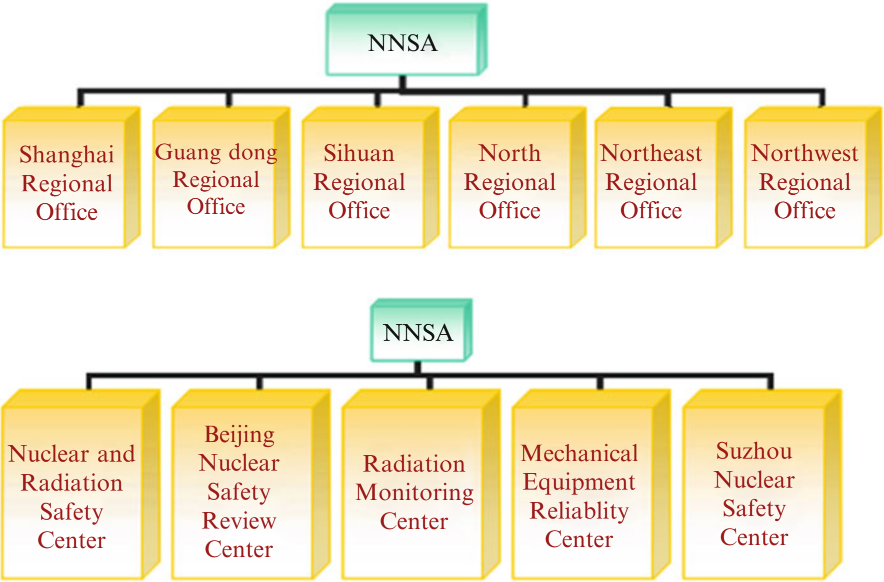

Fig. 4 Institutional structure of NNSA

2.4 Post-Fukushima Actions

Since March 11 when the Fukushima-I NPP was struck by the earthquake and the following 14 m high tsunami [3, 4], Chinese government has paid great attention to the evolving of the Fukushima accident. When the accident became a severe accident with hydrogen explosions, Chinese government immediately took a firm decision to assess the safety status of all NPPs both in operation and in construction, and to suspend all applications for constructing new nuclear power plants temporarily. The following major actions have been implemented: (1) an expert group has been assigned to complete specified nuclear safety inspection to all NPPs in operation to evaluate the safety status. If any one could not meet the safety requirements, it should be shutdown for further evaluation; (2) all NPPs under constructions has been inspected by the expert task force to ensure new NPP construction to fulfill safety requirements and high quality standards; (3) all NPPs planned to construct must adopt advanced safety standards; (4) all new applications for new NPP projects have been temporarily suspended until the new nuclear safety plan (up to 2020) be approved.

It has been clear that "Safety first, quality assurance, advanced technology, sustainable development" become the main policy to future NPP projects. However, the policy to develop nuclear energy efficiently based on "safety first" principle still remain unchanged.

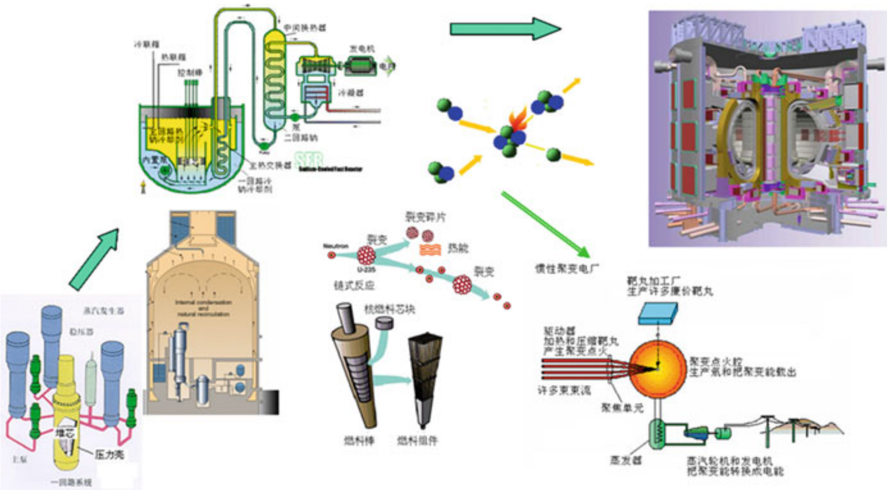

Fig. 5 China's main strategy towards sustainable development of nuclear energy

2.5 Future Development Strategy of China's Nuclear Energy

The sustainable development of Chinese economy will still rely on cheap, clean, low carbon and reliable energy source [5]. No matter we like it or not, nuclear energy is still the only alternative to substitute the fossil energy in massive scale. However, with the implementing of advanced safety standards, more advanced NPP technologies, may become the backbone of China's future NPP industry. The consensus on the main strategy to develop China's sustainable nuclear energy has been achieved in China's nuclear community, and the roadmap can be briefed as "PWR-FBR-Fusion (Pressurized Water Reactor – Fast Breeder Reactor – Fusion reactor)" as shown in Fig. 5.

It is clear that in the near future before the economical fast breed reactors and fusion reactors are attainable, the GEN-III PWRs will play the major role. Two types of GEN-III PWRs currently in construction in China, namely the EPR with active safety characteristics and the AP1000 with passive safety features, are illustrated in Figs. 6 and 7. The generation III PWR has at least one order higher safety standard evaluated by core damage frequency (CDF $< 10^{-5}$/a) and large radioactive release frequency (LRF $< 10^{-6}$/a) than generation II PWR. Especially, the passively safe PWR-AP1000 has achieved very low CDF ($<10^{-6}$/a) and LRF ($<10^{-7}$/a).

3 Security of NPPs and Other Nuclear Facilities in China

Security of NPP in China has been addressed in order to prevent any NPP from sabotage. In the aspect of the physical protection to NPPs, the emphasis has focused on entrance control, protection with armed police; regarding the issue of

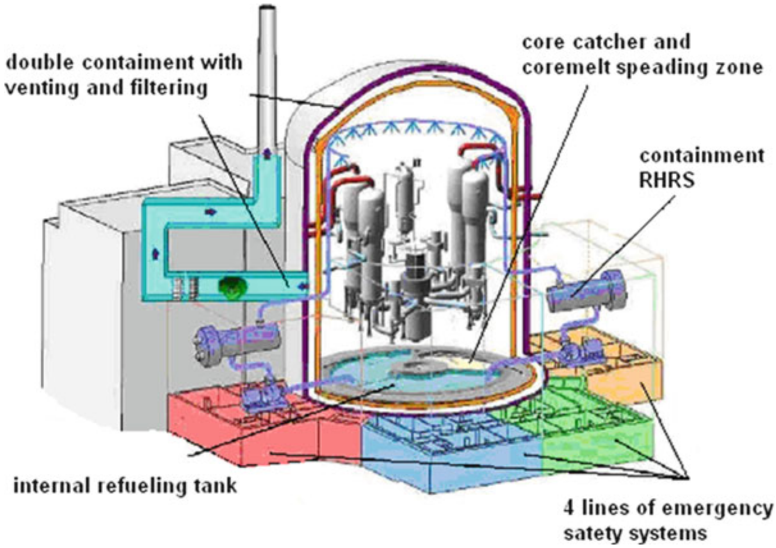

Fig. 6 EPR: GEN-III PWR NPP under construction in China

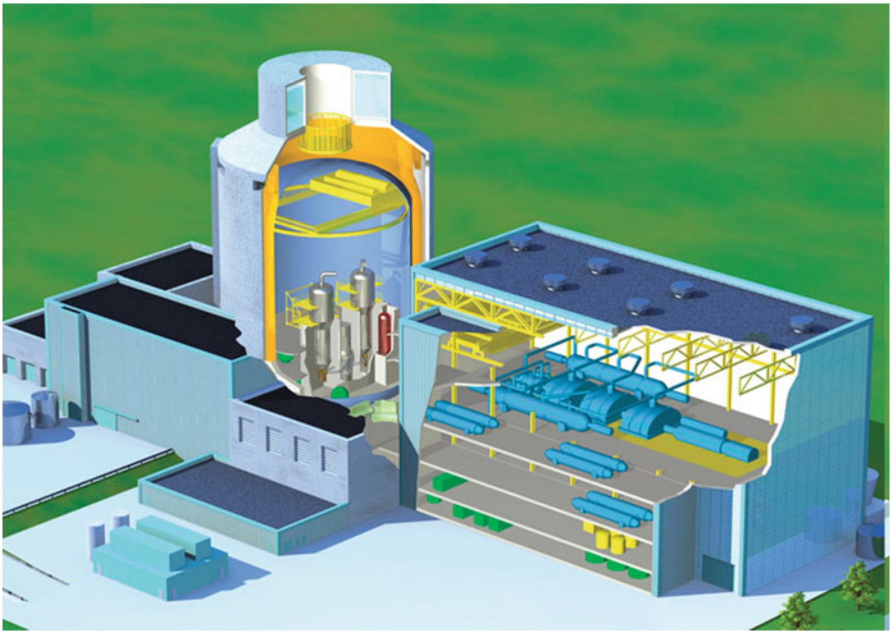

Fig. 7 AP1000: GEN-III passive safety PWR under construction in China

non-proliferation, China has enhanced its implementation of international conventions related to nuclear non-proliferation and nuclear material control. Import and export of NPP technologies are strictly controlled with license system. New and used nuclear fuels are also strictly controlled. Especially, the reprocessing, transport and storage of nuclear used fuels are also strictly controlled. IAEA safeguard for civil nuclear facilities have ensured firmly the peaceful use of nuclear technologies of China.

4 Conclusions

Nuclear safety is the most important issue for China to develop nuclear power plants and is the backbone of nuclear energy industry. The "safety first" must be put to utmost priority in expanding NPP fleet. Human being must pay sufficient respect to the objective law of the nuclear power construction based on scientific policy-making. Thus, the pace to develop nuclear power actively and stably in China in near future can return to normal track.

Acknowledgment The author were grateful for the invitation of Professor Ishihara and Dr Zhang of Kyoto University to attend the symposium and for the support of the Ministry of Education, Culture, Sports, Science and Technology of Japan via "Energy Science in the Age of Global Warming" of Global Center of Excellence (G-COE) program (J-051).

References

1. Nguyen F (2011) World energy, electricity and environment. Lecture notes on 2011 WNU one-week orientation-course, July 4–6, Beijing
2. Zhao RK, Feng YC, Xu J, Li ZN (2002) Study on sustainable strategy for developing nuclear energy in China. In: Zhao RK, Ruan KQ, Shi DH, Feng YC, Xu J (eds) Progress of the Research Works in the Energy Technology Area of the National 863 Program, Chapter 5, Section 1. Atomic Press of China, Beijing, p 309 (in Chinese)
3. World Nuclear News, First IAEA Report on Fukushima, 1 June 2011
4. IAEA website, IAEA Briefing on Fukushima Nuclear Accident, 2 June 2011
5. Wang D (2004) Future energy development and nuclear prospect of China. In: NUTHOS-6, Nara, Japan, paper PL-02, 4–8 October 2004

(ii)
Contributed Papers

An Optimization Supply Model for Crude Oil and Natural Gas in the Middle East

Hooman Farzaneh, Keiichi N. Ishihara, Nuki Agya Utama, Benjamin McLellan, and Tetsuo Tezuka

Abstract Crude oil and natural gas are major contributors to the world economy. Most of the Middle East countries are the main participants in the world energy because of their reserves, supplies and also trade markets. In this investigation, a model of optimal oil and natural gas supply has been developed for the Middle East region including main producers such as Iran, Iraq, Kuwait, Qatar, Saudi Arabia, Oman and Bahrain. To this aim, Middle East region is supposed to be organized in the form of a firm and appears in the market that oriented towards establishing an effective energy system to produce oil and gas with minimum costs subject to satisfying technical, institutional and economical constraints. The model is used to prepare a projection on oil and gas supply up to 2030. According to the results, oil production is expected to increase in the Middle East region to meet growth in consumption. It should be expected to rise by about 30 Mbbld by 2030. Also, the Middle East's share in global gas production is predicted to expand to 20% in 2030. The projection implies that the Middle East upstream and refinery capacities are likely to be sufficient to meet the demand until around 2015; thereafter expansion appears certainly.

Keywords Crude oil • Energy supply • Middle East • Natural gas • Optimization model

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1 Introduction

Oil is the most used energy source worldwide. According to recent researches, it is clear that the world will soon face a global crisis due to dwindling oil resources and a peak in production [1, 2].

The Middle East region contains the largest quantities of proven oil and gas reserves in the world. According to OPEC, the proven crude oil reserves amount to 774.6 (billion barrels oil equivalent) bboe and proven natural gas reserves up to 505.3 bboe are also located in this region [3]. The Middle East accounts for more than 800 billion barrels of oil ultimate recoverable reserves (URR) or 42% of global URR. Saudi Arabia controls the largest share of URR, with 300 billion barrels, and Iraq and Iran follow with 135 billion barrels and 130 billion barrels, respectively. Together these larger reserve holders control more than 70% of Middle East URR [4].

Middle East countries currently contribute 14% of global energy production [5]. In former decades, the share of the Middle East in world oil production varied widely. Before the first oil crisis their share was up to 44%, in the mid-1980s it decreased to about 28% [6]. Five countries (Saudi Arabia, Iran, United Arab Emirates, Iraq and Kuwait) each produce more than 2 million barrels per day, contributing by far the largest proportion of regional production. Saudi Arabia leads in terms of oil, as do Iran, Qatar, Oman and UAE in terms of natural gas.

Increasing population, higher standards of living, accelerated growth of energy-intensive industries (cement, aluminum, petrochemicals, etc.) and highly-subsidized energy prices have led Middle Eastern demand for oil and gas to almost double [7]. The strong growth in demand for water, which is met partly by seawater desalination, also has the effect of increasing energy consumption. Also, the price of energy is politically a highly sensitive issue in this region. Some countries must now begin to face the need to balance domestic energy demand against export demand for oil and natural gas and the need to increase the price of energy to levels more compatible with new cost conditions.

It can be stated that the Middle East region has been one of the major influences on global energy markets, and the future of global energy demand and supply is strictly dependent on how the reserves are managed in this region. Having considered the outlook for supply of oil and gas from these suppliers, it becomes clear that a number of challenges lie ahead. A major one relates to the significant uncertainties over how much future production will be required and how the Middle East region could be able to balance the world oil and gas demand. Moreover, alongside this concern, there are various other challenges including the emergence of oil as a financial asset; upstream costs; the technology evolves, the issue of sustainable development and the domestic energy demand.

This paper analyzes the aforesaid concern and its consequences by estimating a cumulative supply curve for conventional oil and gas in the Middle East region through the using an optimization supply model.

2 Concept of the Model

Analysis of multi-dimensional interactions of flow of energy in the Middle East Region is a complex task that necessitates the development and utilization of analytical tools [8, 9]. Development of analytical tools with high complexity is usually based on conclusions of many concepts and theories from different scientific disciplines. The economic rationality of a producer and activity of a firm has extensively been developed as a branch of microeconomics and it has been utilized for explaining the development of production technology. In this case, the Middle East region can be supposed to be organized in the form of a firm and appears in the market that is oriented towards establishing an effective energy system which may be identified as producing oil and gas with minimum total cost subject to satisfying the demand and other technical, economical and institutional constraints. This concept may be formulated as below [10]:

$$Min\ TC = \sum_i p_i F_i \tag{1}$$

Subject to:

$$f(F_1, \ldots, F_n) \geq Q \tag{2}$$

$$\sum_i F_i \leq A_i \tag{3}$$

$$F_i \geq 0 \tag{4}$$

where, TC, p_i, F_i, Q and A_i are defined sequentially as total system cost, the unit price of production factor i, production factor i, energy demand and available resources.

Application of the model is subject to the identification and estimation of the production function (Equation 2). Difficulty of obtaining an explicit form of the production function has in many cases led to an indirect solution of the model. This is usually achieved by defining total production function as a function of the parameters of the model. The production function represents a nonlinear system and it is a complex function. Empirical estimation of the complex function would be associated with considerable over or underestimations. It is, therefore, possible to segregate the Middle East energy system into incremental elements and substitute the non-linear production function with a set of interrelated equations based on the theory of system integration. Simultaneous solution of the set of equations would help identifying the function of the whole system and state of variables at different points of the system and time can be estimated. Such a formulation would enable to solve the behavioral model of the production firm explicitly. Implementation of system integration in the Middle East region may be represented by the help of the reference energy system (RES) diagram as depicted by Fig. 1.

Level of segregation is usually determined by the ability to introduce the oil and gas producing process or different processes of energy conversion. Therefore, a set

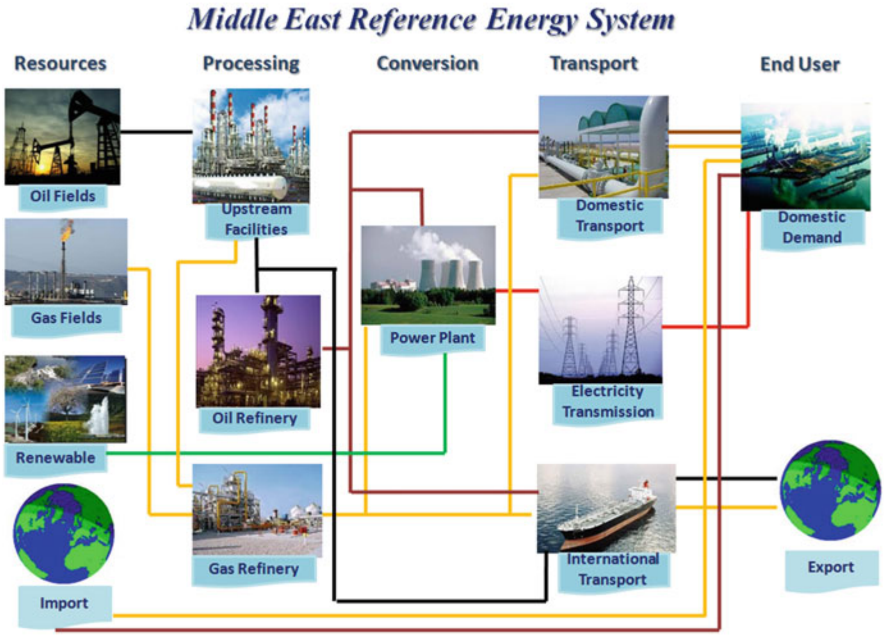

Fig. 1 Middle East region RES

of simultaneous equations would be developed that represent the laws governing the flow of energy through different sub-systems (control volumes) and levels at different operating conditions in the Middle East region. Also, defined technologies at different levels represent the functionality of each sub-system in the whole system.

2.1 Constraints of the Model

According to the Middle East RES, the following description of the energy flow constraints is given for the set of level identifiers as: U (useful energy), F (final energy after distribution), T (final energy after transmission), X (secondary energy), *A* (primary energy) and *R* (energy resources). Some of the important constraints of the model can represent through the following equations:

A) Demand constraint:
   Demand must be met. In each region (countries) the supply of crude oil, oil products and natural gas must be greater than or equal to the demand of those fuels in that region:

$$\sum_{fvlt} \eta_{fvlt} U_{fvlt} \geq U^{*}{}_{fvlt} \tag{5}$$

where, η, U^* represent efficiency and defined energy demand for energy carriers f through using technology v in each region during the load region l and time period t.

B) Availability of resources:
More resources cannot be extracted from a region than exist in that region. For each region, fuel, load and time period:

$$\sum_{rglt} R_{rglt} - \sum_{fvlt} A_{fvlt} \geq 0 \tag{6}$$

where, g is the cost grade of the energy resource.

C) Speed of resource extraction:
The percentage of available resource extracted in a given year cannot exceed a defined fraction of the remaining resources:

$$A_{fvlt} \leq \alpha \left(URR - \sum_{\tau=1}^{t-1} A_{fvl\tau} \right) \tag{7}$$

α is the percentage of remaining resource that can be extracted in a year. This constraint governs the overall shape of increasing and decreasing production of a resource, representing a peak oil curve of resource depletion.

D) Capacity constraint on production:
The production of energy carriers in each region must be less than or equal to the production capacity:

$$\frac{A_{fvlt}\varepsilon_{fvlt}}{\Delta l} \leq \sum_{\tau=1}^{t} H_{fvl\tau} PF_{fvl\tau} + \sum_{\omega=b-((PL-t))}^{b} H_{fvl\omega} PF_{fvlt} \tag{8}$$

where PF and PL are plant factor and plant life of each sub-system. H is the production capacity.

2.2 Objective Function of the Model

Costs represent the extent of allocation of factors and resources to the Middle East region. A criterion that is used for identifying an optimal point of development is minimum usage of total factors and resources. Such a criterion is the dual of economic efficiency of the Middle East region which is the maximization of profits. The cost function is the sum of the present values of capital, maintenance,