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Takeshi Yao *Editor*

Zero-Carbon Energy Kyoto 2011

Special Edition of Jointed Symposium of Kyoto University Global COE "Energy Science in the Age of Global Warming" and Ajou University BK21

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Editor
Takeshi Yao
Program Leader
Professor of the Graduate School of Energy Science
Kyoto University
Steering Committee of GCOE Unit for Energy Science Education
Yoshida-honmachi, Sakyo-ku
Kyoto 606-8501, Japan
gcoe-office@energy.kyoto-u.ac.jp

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Preface

The Great East Japan Earthquake with a magnitude of 9.0 hit east Japan and brought about an unprecedented disaster on March 11, 2011. The tsunami that followed caused great damage. The Fukushima Dai'ichi Nuclear Plant lost all electric power and lapsed into an uncontrollable state. The nuclear plant accident has had a major impact on the energy strategy of Japan and the world. Approach to the energy issue is becoming more and more important.

Since 2008, four departments of Kyoto University, Japan—the Graduate School of Energy Science, the Institute of Advanced Energy, the Department of Nuclear Engineering, and the Research Reactor Institute—have joined forces, and with the participation of the Research Unit for comprehensive activities on local area survivability, they have been engaged in a program entitled "Energy Science in the Age of Global Warming—Toward a CO2 Zero-Emission Energy System" as the Global Center of Excellence (COE) Program of the Ministry of Education, Culture, Sports, Science and Technology of Japan, with the support of university faculty members. This program aims 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 toward a CO2 zero-emission society no longer dependent on fossil fuels by the year 2100.

The Global COE is fully in action. The Scenario Planning Group is setting out a CO2 zero-emission technology roadmap and establishing a CO2 zero-emission scenario based on analyses from the standpoints of social values and human behavior. The Advanced Research Cluster is promoting a socio-economic study of energy, a study of new technologies for renewable energies, and research for advanced nuclear energy by following the roadmap established by the Scenario Planning Group. At the GCOE Unit for Energy Science Education, the students are planning and conducting interdisciplinary group research on their own initiative, combining social and human science with natural science, and working toward CO2 zero emission. At the same time, the students are acquiring the skills to survey the whole energy system by participating in scenario planning and through interaction with researchers from other fields, and are applying the experience to their own research. The Global COE is striving to foster young researchers who will be able to employ their skills, knowledge, and expertise in their field of study, along with a broad international perspective, to respond to the needs of society in terms of energy and the environment.

The Global COE, in order to transmit the achievements of this platform to the public, posts information on a website, publishes annual reports, quarterly newsletters, books, self-inspection and evaluation reports, hosts domestic and international symposiums and activity reports on meetings, hosts an industry–government–academia collaboration symposium and citizen lectures, and co-hosts related meetings both domestically and internationally.

The Third International Symposium of the Global COE titled "Zero-Carbon Energy, Kyoto 2011" was held jointly with the BK21 Program of Ajou University at Suwon, Korea, August 18–19, 2011, succeeding the International Symposium "Zero-Carbon Energy, Kyoto 2009" at Kyoto University Clock Tower and "Zero-Carbon Energy, Kyoto 2010" at Kyoto University Oubaku Plaza. The international cooperation made the discussions more meaningful and the information exchange more dynamic. Many important lectures and discussions by invited speakers and members of the Global COE, and interesting presentations by students of the GCOE Unit for Energy Science Education, were given. This book is a compilation of the lectures and presentations.

It is very important to promote a wide range of studies in order to cope with the complex and delicate energy and environment problems. The Global COE continues to promote the establishment of a "Low-carbon Energy science," as an interdisciplinary field integrating social science and human science with the natural sciences, for securing energy and conserving the environment, which are the most important issues for the sustainable development of human beings.

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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Potential of Drastic Improvement of Energy Efficiency in Japan

Seiji Ikkatai and Haruki Tsuchiya

Abstract This research has estimated the potential of drastic improvement of energy efficiency in Japan by classifying the end use services such as transport, food, heating and cooling, power, access to information and lighting. We made tables of potential improvement factors on each fields and has quantified the improvement potential in Japan by 2050. The improvement potential by using existing technology is 31.6% and the improving potential by using the future technology based on theoretical efficiency limit by referring a research result of Cullen and Allwood of Cambridge University is 74.8%.

Introduction of effective policy measures to improve energy efficiency not only for industry sector but for household and commercial sector etc. should be explored more.

Keywords Drastic improvement of energy efficiency • End use services • Existing technology • Future technology • Theoretical efficiency limits

1 Introduction

After the huge earthquake and the accident of nuclear power plant in Eastern Japan, the management of energy supply and demand has become more and more crucial issue in Japan towards the low carbon society. Drastic improvement of energy efficiency of the various sectors including industry, transportation and

S. Ikkatai (✉)
Center for the Promotion of Interdisciplinary Education and Study, Kyoto University, Yoshida-Honmachi Kyoto, Japan
e-mail: ikkatai.seiji.3u@kyoto-u.ac.jp

H. Tsuchiya
Research Institute for Systems Technology, 1-1-5 Higashi-Nihonbashi, Tokyo, Japan

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household etc. could be an effective measure to reduce energy usage and reduce environmental pressure without deteriorating people's satisfaction on energy.

This research has estimated the potential of drastic improvement of energy efficiency in Japan by classifying the end use services such as transport, food, heating and cooling, power, access to information and lighting. We made tables of potential improvement factors on each fields and has quantified the improvement potential in Japan by 2050. The improvement potential by using the future technology has been estimated based on theoretical efficiency limit by referring a research result of Jurian Allwood of Cambridge University.

2 Improvement of Overall Energy Efficiency

2.1 Factors on Improvement of Energy Efficiency

Energy efficiency Improvement is combination of Energy device efficiency, social system efficiency and lifestyle efficiency (Fig. 1). Energy device efficiency is known to be improved more than twice with existing technologies, for example, hybrid cars. Sometimes they are called BAT (Best Available Technology). If social system efficiency and lifestyle efficiency are improved, the overall energy efficiency will be much higher.

2.2 Improvement of Energy Efficiency with Existing Technology

We made several tables by classifying the end use services such as access to information, transportation, lighting, heating and cooling, etc. in industry, household, commercial and transport sector.

For example, the improvement of energy efficiency to obtain information with existing technology is shown in Table 1. Electronic devices are more efficient for communication than paper communication. Resource efficiency will be improved by electronic technology as much information on paper is read only once. Energy efficiency will be 60 times for newspaper and 37 times for paper book when substituted by electronic devices.

Another example is "hybrid car" which has engine, electric motor and battery. The millage is 35 km/gas.l (catalogue) and 20–22 km/gas.l (real) which are twice efficient than ordinal car 10–12 km/gas.l (1,500 cc). New infrastructure is not necessary compared with hydrogen fuel cell vehicle. Now, plug-in hybrid is emerging. Electricity is supplied for it at home with larger battery added.

"Eco-drive" is an existing soft technology which is a driving method of cars can affect fuel consumption. It is a driving method with moderate acceleration and braking, keeping constant speed, using engine brake, no idling and no necessary baggage in trunk room. It saves 10–20% of fuel consumption. A construction company saved 30% of truck fuels by eco-drive in Japan (CSR report 2001).

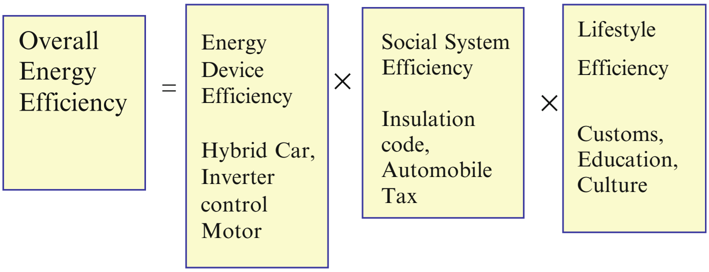


Fig. 1 Improvement of overall energy efficiency

Table 1 Energy efficiency to obtain information

Information	Substitute	Base	Energy/base (kcal)	Electronics (kcal)	Ratio	Use pattern
Book	Electronic book	1 copy	5,403	148	37	8 h to read
Magazine	Electronic Book	1 copy	3,782	55	68	3 h to read
News paper	Electronic news	1 copy	2,231	37	60	1 h for 2 person
Leaflet	Electronic news	1 day	9,950	37	269	1 h for 2 person
CD	Music download	1 copy	800	24	33	PC for 10 min
Post mail	E-mail	1 mail	269	24	11	PC for 10 min

Energy efficiency ratios are calculated for electronic devices compared with conventional methods to obtain information

Truck cargo companies are introducing eco-drive because it can save insurance cost as it affects drivers to drive carefully and to decrease accidents.

Another example is a "car-sharing" which is an easy rent-a-car system with reservation by internet and card systems. It changes people's habitat of driving and decrease car use by nearly 80% reportedly. This means that the rest of transport demand goes to public transportation. It will affect that car production. The habitat of car possession may turn to the habitat of using car.

Efficiency improvement potential factors in transport with existing technology is shown in Table 2 and the total efficiency improvement potential by using existing best available technologies in transport sector in 2050 is shown in Table 3.

2.3 Improvement of Energy Efficiency with Future Technology

Estimating improvement of energy efficiency with future technology is not an easy work because it is difficult to know when and which technology will be developed in the future. Also, it is difficult to predict people's future lifestyle and accepted social systems so on. But still it is beneficial for us to estimate the potential of energy efficiency improvement in the future because it could reduce the difficulty to reduce

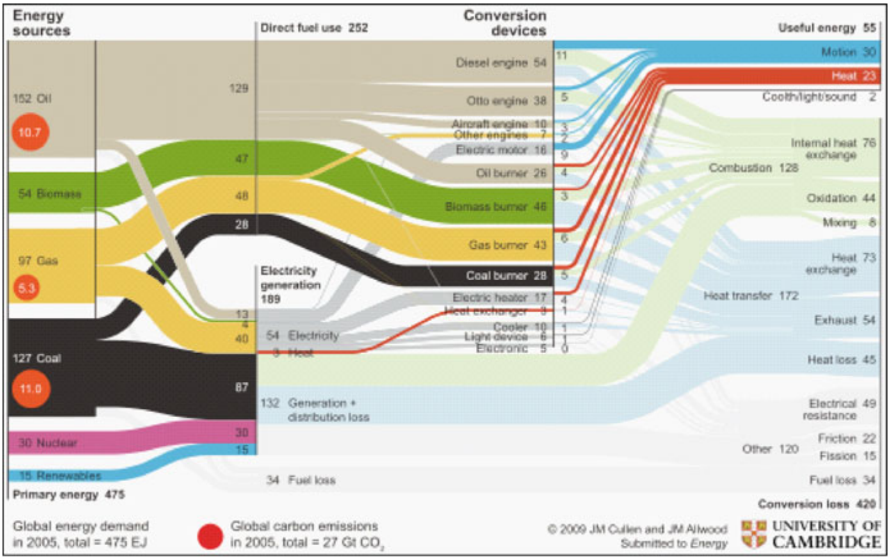
Table 2 Efficiency improvement in transport sector

Means	Efficiency improvement	Ratio
Car navigation system	2.4% fuel saving reportedly	0.977
Eco drive	15% saving fuel economy	0.850
Down sizing lighter body	20% better fuel economy	0.833
Hybrid vehicle	Twice fuel economy	0.500
Plug-in-hybrid	2.37 times fuel economy	0.422
Electric vehicle	2.9 times fuel economy	0.345
Fuel cell vehicle	2.26 times fuel economy	0.444
Solar assist car	1.25 times fuel economy	0.800
Bicycle to electric bicycle	70 times efficiency improvement	0.014
Car to railways	12 times efficiency improvement	0.083
Car to bus	3 times efficiency improvement	0.333
Shinkansen to TV conference	16.7 times efficiency improvement	0.060
Aircraft to Shinkansen	12 times efficiency improvement	0.083
Aircraft to TV conference	83.3 times efficiency improvement	0.012

Table 3 Efficiency improvement in transport sector

Scenario 1	2050 efficiency improvement by BAT				
End use energy consumption				Data 2008 10,000 TOE	
	Energy	Efficiency improvement			Result
End use	10000 TOE		Reduce ratio	Ratio	10000 TOE
Transport					
Passenger	5,475			0.345	1,890
Automobile	4,542	Electric vehicle, Plug-in-hybrid, Fuel	−71%	0.286	1,299
Business use	138	Electric vehicle, Plug-in-hybrid, Fuel	−71%	0.286	39
Bus	145	Electric bus, fuel cell Bus	−10%	0.9	131
Railways	191	Efficiency improvement of power tra	−72%	0.28	53
Marine	16	Energy saving design and drive	−20%	0.8	13
Air	443	Energy saving design and drive	−20%	0.8	354
Cargo	2,945			0.731	2,152
Truck	2,502	efficient × reduce execess food + Pay	70% × 94%	0.66	1,651
Railways	191	Efficiency improvement of power tra	−10%	0.9	172
Marine	374	Energy saving design and drive	−20%	0.8	299
Air	55	Energy saving design and drive	−46%	0.54	30

Reducing potentials from present level are to 34% in passenger sector and to 73% in cargo sector around 2050. (Data 2008)



The study by Allwood and others at Cambridge University by excergy efficiency and engineering models shows only 11 per cent of global energy consumption is used effectively and the rest is wasted.

Fig. 2 Efficiency limit of global Energy flow. (Cullen and Allwood, 2010)

the greenhouse gas emission by replacing conventional energies such as fossil fuel energies and nuclear energies by renewable energies.

In this field, there is little studies, but Cullen and Allwood of Cambridge University challenged it 2010. They estimated the efficiency limit of global energy flow (Fig. 2). The point of his study is as follows.

1. Excergy model is used for energy conversion process. Electricity generation, thermal energy use from high temperature to low temperature heat etc.
2. Engineering models are used for energy end use. Heating and cooling at home, electric appliances, automobile etc.
3. Focus on ultimate recycle of material resources. Improvement of design process of steel, copper and aluminum so on
4. 3R (reduce, reuse and, recycle). Reuse is most favorable. If recycle process include melting process then the loss will increase.
5. Estimate of efficiency improvement in industrial activities. Multi stage use of thermal energy, efficient use of mechanical power through electronic devices, Efficient operation of fluid machineries etc.

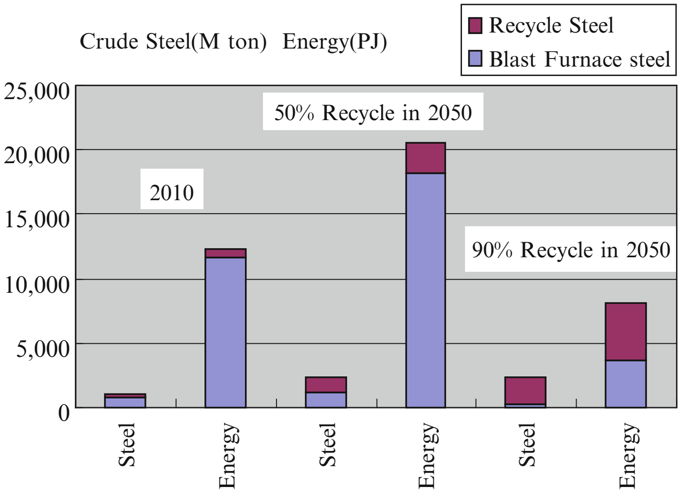


Fig. 3 Production of crude steel in 2050

Table 4 Compound (Cullen and Allwood)

	ε f(%)	ε e(%)	ε d(%)	ε c(%)	100-ε c
End use equipment	Fuel transform efficiency	Efficiency of power generation and transmission	End use device efficiency	Compound efficiency	Reducing potential (%)
Aircraft engine	93	100	27	25	75
Diesel engine	93	100	21	20	80
Other engines	92	78	25	18	82
Electric motor	93	32	56	17	83
Gasoline engine	93	100	12	12	88
Coal burner	90	100	19	17	83
Oil burner	93	100	15	14	86
Gas burner	91	100	13	12	88
Electric heater	93	32	24	7	93
Lighting	93	34	12	4	96
Air conditioner	93	33	7	2	98
Electronic device	93	32	6	2	98

ε c(%) = ε f(%) × ε e(%) × ε d(%)

Regarding the point 3 above, for example, the case of production of steel is shown at Fig. 3. Crude steel demand in 2050 is estimated 2,400M ton. If recycle rate increases to 50%, energy demand would be depressed but still exceeds the energy consumption in 2010. If the rate increases to 90%, energy demand will decrease absolute terms.

Compound efficiency is calculated by multiplied with fuel transformation, electricity generation and transmission, and end use device efficiency (Table 4).

Limit of energy efficiency of Automobile, for example, is calculated by three factors; rolling resistance, aerodynamic drag, and acceleration resistance (Fig. 4).

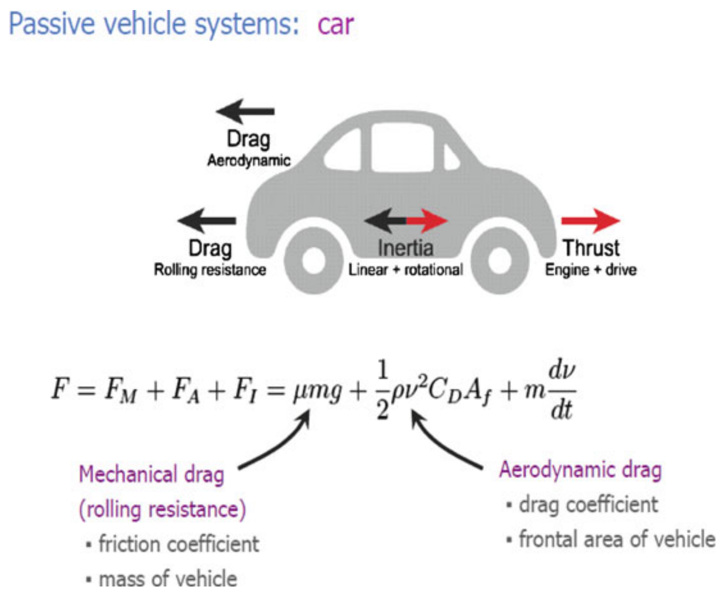


Fig. 4 Limit of energy efficiency of automobiles

Table 5 Realistic limit of energy efficiency

End use	Points of design	Saving potential
Home heating and cooling	Insulation wall, insulation glass, mass of room	100%
Hot water	Use only when necessary, heat recovery, lower temperature	80%
Appliances	Refrigerator, freezer, dish washer, cloth dryer	67%
Lighting	Task lighting	95%
Factory furnace	Loss from wall, ventilation loss, thermal mass	62%
Steam system	Loss from wall, distribution loss, thermal mass	66%
Power systems	Pump, material processing, compressed air, Fan, etc.	59%

Saving potential is estimated by engineering model of energy end use. (Cullen and Alwood, 2010)

By using engineering model, weight can be reduced to 300 kg from 1,300 kg, rolling resistance can be reduced to 0.001 from 0.015, aerodynamic drag coefficient can be reduced to 0.1 from 0.4 and front projected area can be reduced to 1.5 from 2 m^2. The total energy reducing potential is 91%.

The result is understandable, because Toyota released plug-in hybrid 1/X for the 40th Tokyo motor show in 2007. The body size of 1/X is length 3,900 $\times$ width 1,620 $\times$ height 1,410 mm, wheel base is 2,600 mm. CFRP (Carbon Fiber Reinforced Plastic) is applied. The room space is the same as hybrid car Prius. Weight is 1/3 of Prius 420 kg.

Table 6 Efficiency improvement in household and commercial sector

Scenario 2	2050 Efficiency improvement to Limit					Data 2008	
End use energy consumption						10000 TOF	
	Energy	Fuel		Electricity			Result
End use	10000TOE	10000TOE	Efficiency (%)	10000TOE	Efficiency (%)	Compound Effiency (%)	10000TOE
Household	5,265					0.224	1,181
Cooling	113	0		113	7	0.070	8
Heating	1,280	1,113	15	167	24	0.162	207
Hot water	1,553	1,376	13	177	24	0.143	221
Cooking	428	325	13	103	24	0.157	67
Power	996			996	56	0.560	558
Lighting	996			996	12	0.120	120
Commercial	4,192					0.237	994
Cooling	505	294	15	211	7	0.117	59
Heating	644	586	15	58	24	0.158	102
Hot water	622	597	13	25	24	0.134	84
Cooking	373	333	13	40	24	0.142	53
Power	1,024			1024	56	0.560	573
Lighting	1,024			1024	12	0.120	123

Realistic limit of energy efficiency is calculated by using excergy model and engineering model for end use services shown in Table 5. For example, saving potential of home heating and cooling is 100%. It means home heating and cooling can be controlled only with heat from the sun and the resident him/herself.

Table 6 shows the efficiency improvement of household and commercial sector by future technology in Japan using Cullen and Allwood's research method. Reducing potentials from present level are to 22% in household and to 24% in commercial sector around 2050.

Efficiency Improvement by future technology of transport sector and other sectors in Japan by 2050 are also calculated.

3 Conclusion

Based on the research above, we studied two scenarios of energy saving potential end use energy around 2050. Scenario 1 is applying BAT and adding compound efficiency improvement (decreasing excess food, paper alternative). Scenario 2 is calculated ultimate energy efficiency limit of end use energy referring works of excergy and engineering model by Cullen and Allwood.

Energy reducing potential at end use of scenario 1 is to 68.4% of present level, and that of scenario 2 is to 25.2% of present level

The energy consumption of household depends on lifestyles, and differs sometimes twice even for the same constituent. Lifestyle changed drastically in the last 50 years by automobiles, TV, mobile phones, internet and so on by using relatively cheap energy cost to save time. Also, industrial sector uses more and more energy to produce goods and services. In order to change these trends, there is wide range of policies such as tax, cap and trade, efficiency labeling etc. Introduction of effective policy measures to improve energy efficiency should be explored more.

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Feasibility of Natural Gas Supply from Russia to Korea

Ekaterina Zelenovskaya

Abstract In this paper author calculates the price of gas for the planned gas supply project from Russia to Korea. That price includes: the gas production cost in the prospective gas fields in Russian East regions, gas pipeline transportation cost across Russia to the Pacific coast, and further gas transportation by gas pipeline through the Korean Peninsula or transportation of gas by tankers as liquefied natural gas (LNG), to the Korean consumers. It also includes the minimum expected rates of return on capital by investor (hurdle rates).

Our calculations show that the estimated prices of Russian gas in Korea in constant 2010 US dollars during the period of the possible contract from 2017 to 2041 could be as follows: for PNG (pipeline natural gas) 12.91 \$/MBtu (468 \$/1,000 m^3), and for LNG 13.22 \$/MBtu (479 \$/1,000 m^3), which is rather competitive under the projected oil price between 18.37 and 25.79 \$/MBtu or 106 and 150 \$ per barrel of crude oil for the same period of time. This suggests that supplying Russian natural gas to Korea is cost effective in either PNG or LNG form.

Keywords Energy cooperation • Gas pipeline • Gas supply cost • Korea • LNG • Northeast Asia

1 Introduction

For substantial strengthening of climate policy actions and since fossil fuels will remain the dominant sources of primary energy in the next decades, natural gas, having the lowest carbon emissions content per unit of energy relative to coal and oil, will play a key role in the energy policies worldwide [1]. The demand for gas

E. Zelenovskaya
Institute of Energy Systems and Climate Change (IECC), Ajou University, San 5, Woncheon-dong, Yeongtong-gu, Suwon 443-749, Republic of Korea
e-mail: katyshali@gmail.com

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has consequently significantly increased, especially in the Asia Pacific Region. China and India see the most rapid rates of gas share increase in their primary energy mix. At the same time Korea, Japan, and Taiwan heavily rely on liquefied natural gas (LNG) imports for their gas supplies from Malaysia, Brunei, Indonesia, Australia and the Middle East. On the other hand, Russian Eastern Siberia (RES) and Far East (RFE) regions (which are also part of the NEA) are rich with natural gas, oil and coal and considerably closer to the NEA consumers than the other gas producers. For instance, a possible onshore pipeline route from Russian port Vladivostok to South Korean port Samchuck is about 980 km and offshore it is 690 km, respectively, while the distances between Korea and its other LNG suppliers are 4,140 km—from the closest producer—Brunei, and 13,800 km—from the farthest supplier—Qatar.

Moreover, Korea has a growing gas industry that is heavily dependent on imports and relies almost exclusively on importing gas in liquefied form. LNG imports account for nearly all of the Korean gas supply. Due to the high dependence on LNG imports from the Middle East producers (51% of the total LNG import) and unexpected disruption of gas supply from Indonesia such as the shutdown of the Arun LNG plant for several months [2], diversification of the Korean gas import sources became a very important matter for Korea, and one of the preferable sources of alternative gas supply is Russia [3].

At the same time, Russia seeks to increase its presence in Asian markets [4], but the high cost of development of Greenfield gas deposits in RES and RFE regions and its associated long-distance transportation to the Asian gas markets made the supply of Russian gas to Korea economically inefficient [3]. The economics is becoming more favourable in the last decade because of the rapid increasing in oil prices and correspondingly in the gas prices.[1] This makes gas production from the difficultly-accessible deposits in the RES and RFE regions more practical and also very attractive for sustainable development of the Russian Eastern part and for Northeast Asia as a whole.

This study developed the methodology for enabling the calculation of the minimum prices of gas supply from the RES and RFE regions to Korea. Specifically it determines the price of gas supply from the Chayanda oil and gas condensate field (OGCF) in the Republic of Sakha (RES) together with the gas from Sakhalin III gas fields offshore of Sakhalin Island (RFE), with gas transportation by pipelines across Russia to the Pacific coast (port Vladivostok) and further gas transportation from Vladivostok to South Korean consumers, by tankers as LNG, or, alternatively, by a land pipeline through the Korean Peninsula.

While there are several publications analysing the economic feasibility of Russian gas supply to Korea [5, 6], including feasibility studies conducted by companies such as UKOS (Russia), BP (UK), Kogas (Korea) jointly with the government of Sakha Republic (RES) that worked in eastern Russian gas projects,

[1] Since in all Korean long-term gas supply contracts the gas price is still linked to the oil price by the price formula.

the question of the Russian gas supply cost for Korea still remains open because of two reasons. First, because the previous works examined the different sources and therefore routes of gas supply to Korea [5] which are resulting in different level of final gas price. For example such as the gas supply from Kovykta field near Irkutsk city (RES) by 4,100 km gas pipeline to northeast China and Korea [3, 5]. Second, because the past studies were conducted under different economic assumptions of the gas supply projects, such as different levels of taxation, different field development schemes (production sharing agreements, concessions etc.), as well as for different inflation and discount rates. The previous studies also employed the assessment of the economic feasibility of the project mostly by the Net Present Value (NPV) criteria. This criterion, however, do not show to the buyer the economic merit of the project. From the gas buyer point of view, the project is feasible and desirable if the price of gas by the planning project is equal or lower than the projected gas market price. In this connection, in this study author employed the assessment of the economic feasibility of the project by slight different methodology which allows calculating the minimum acceptable price of gas at which the project could already proceed. Taking into account all differences with the previous studies mentioned above, our study on the gas supply from Cahyanda and Sakhalin III gas fields with its consequent transportation to Pacific coast and then directly to Korea is unique in the literature on Russian gas supply to Korea and important for assessing the feasibility of the Russian-Korean gas supply project under the current economic conditions.

To define the possible minimum price of Russian gas supplied to Korea: DES[2] (Samchuck[3]) we calculate the total price of gas supply which includes the gas production cost in the prospective gas fields (Chayanda and Sakhalin III), gas pipeline transportation cost across Russia to the Pacific coast, the gas transportation cost from the Pacific coast by LNG tankers and alternatively by gas pipeline through the Korean Peninsula (PNG transportation), as well as the minimum rates of return by capital in each element of gas supply chain (gas production, transportation, liquefaction).

To determine the optimal parameters (diameter and working pressure) of trunk gas pipelines the author employed computational methods of fluid dynamics. constituting thereby a bottom-up cost estimation to make pre-engineering estimates of gas production, pipeline and LNG transportation costs. This analysis is integrated with a cost–benefit and breakeven analysis of all gas supply related projects, such as production, transportation, gas liquefaction projects.

[2] Delivered Ex Ship (named port) -where goods are delivered ex ship, the passing of risk does not occur until the ship has arrived at the named port of destination and the goods made available for unloading to the buyer. The seller pays the freight and insurance costs. Costs for unloading the goods and any duties, taxes, etc.. . . are for the Buyer [15].

[3] The marine port, planning LNG terminal at the North-East cost of the Republic of Korea.

2 Planning Russian–Korean Natural Gas Supply Project: General Information

This section provides some general information about the possible Russian-Korean natural gas supply project and its background.

2.1 Russian–Korean Natural Gas Supply Project: Background

Korea's interest in the Russian gas supply dates back to the late 1980s. Since that time, the Russian Eastern Siberia and Far East regions had been considered as a potential base for gas supply to Korea. During the Soviet era and the first decade after the breakup of the Soviet union in 1991, all gas export projects to Asian markets have however failed to progress because of a mixture of political, commercial and institutional obstacles [3]. Since 2002 the situation changed fundamentally after the Russian Government started preparing the program for a unified system of gas production, transmission and distribution in Eastern Siberia and the Far East, taking into account the possibility of exports to China and other Pacific-Asia countries (Eastern gas program [7]). The Russian gas monopoly company JSC Gazprom was appointed by the Russian government as the program execution coordinator. Russian–Korean negotiations about the gas industry progressed since that time. On May 12, 2003 Gazprom and Korea's Kogas entered into a 5-year Agreement of Cooperation which was extended for another 5-year term in 2008. The agreement embraces a wide spectrum of issues including the study of possible ways to deliver Russian natural gas to Korea. In November 2010 the parties entered into the next stage of negotiations and signed a "road map" to export Russian gas to South Korea. According to the document deliveries of natural gas will start in 2017, and the volumes of import are planned to be as much as 10 billion cubic meters per year [4]. The duration of the planned long-term contract is expected to be 25 years.

2.2 Details of the Gas Supply

The natural gas to Korea from Russia may be delivered in liquefied (as LNG) or compressed (as CNG) form, by tankers or by a land pipeline (as PNG) [4]. A possible route of the pipeline is through the Korean Peninsula.

According to the Eastern Gas Program, the sources of gas supply to Korea would be the Sakhalin III gas field offshore of Sakhalin Island (RFE) and the Chayanda oil and gas condensate field (OGCF) in the Republic of Sakha (RES). According to this program, the transportation of gas will start from the Russian fields to its Pacific coast as follows:

1. From the Sakhalin III gas fields by the recently constructed Sakhalin–Khabarovsk–Vladivostok gas transportation system (GTS)
2. From the Chayanda gas field, by a planned pipeline Yakutia-Khabarovsk with subsequent integration into the Sakhalin–Khabarovsk–Vladivostok GTS

In the Russian Pacific port Vladivostok, the gas would be pumped into the planned Trans-Korean gas pipeline, or optionally, liquefied in the planned LNG plant [8] and transported to Korea by tankers (Fig. 1). The CNG transportation which is also one of the options of international gas transportation to Korea is not included in the scope of our study due to the lack of sufficient technical and economical data on marine CNG transportation methodology and gas compression plants.

As seen from the map, the physical infrastructure of the planned gas supply system to Korea includes the following seven elements:

1. The Sakhalin III gas field
2. The Chayanda OGCF
3. The Sakhalin–Khabarovsk–Vladivostok GTS
4. The Yakutia–Khabarovsk gas pipeline
5. The liquefaction plant (optional)
6. Marine LNG transportation (optional)
7. Trans-Korean gas pipeline (optional)

A short description of each of these elements follows.

2.3 Description of the Projects

The Sakhalin III project involves the development of the Kirinskoye gas field (located 50 km offshore, at water depth around 150 m), which are the Ayashsky and East Odoptinsky blocks of Sakhalin III field. Gas reserves and resources of the Sakhalin III project are estimated at some 1.4 trillion cubic meters. The field is scheduled to become operational in 2014 [9] and the annual gas production from the field will be at the level of 28.6 billion cubic meters (bcm) [10].

The Chayanda OGCF in East Siberia in Sakha Repuplic (also known as Republic of Yakutia) is the biggest gas field in the planned Yakutsk center of gas production in Eastern Siberia.[4] The Chayandinskoye field's proved reserves consist of 1.24 trillion cubic meters of gas and 68.4 million (M) tons of oil and gas condensate [11]. Annual gas production from the field will be at the level of 31 bcm [12].

[4] According to the [7] it is planned to establish four new gas production provinces in east Siberia, namely Krasnoyarsk, Irkutsk, Sakhalin, Yakutsk gas production centers.

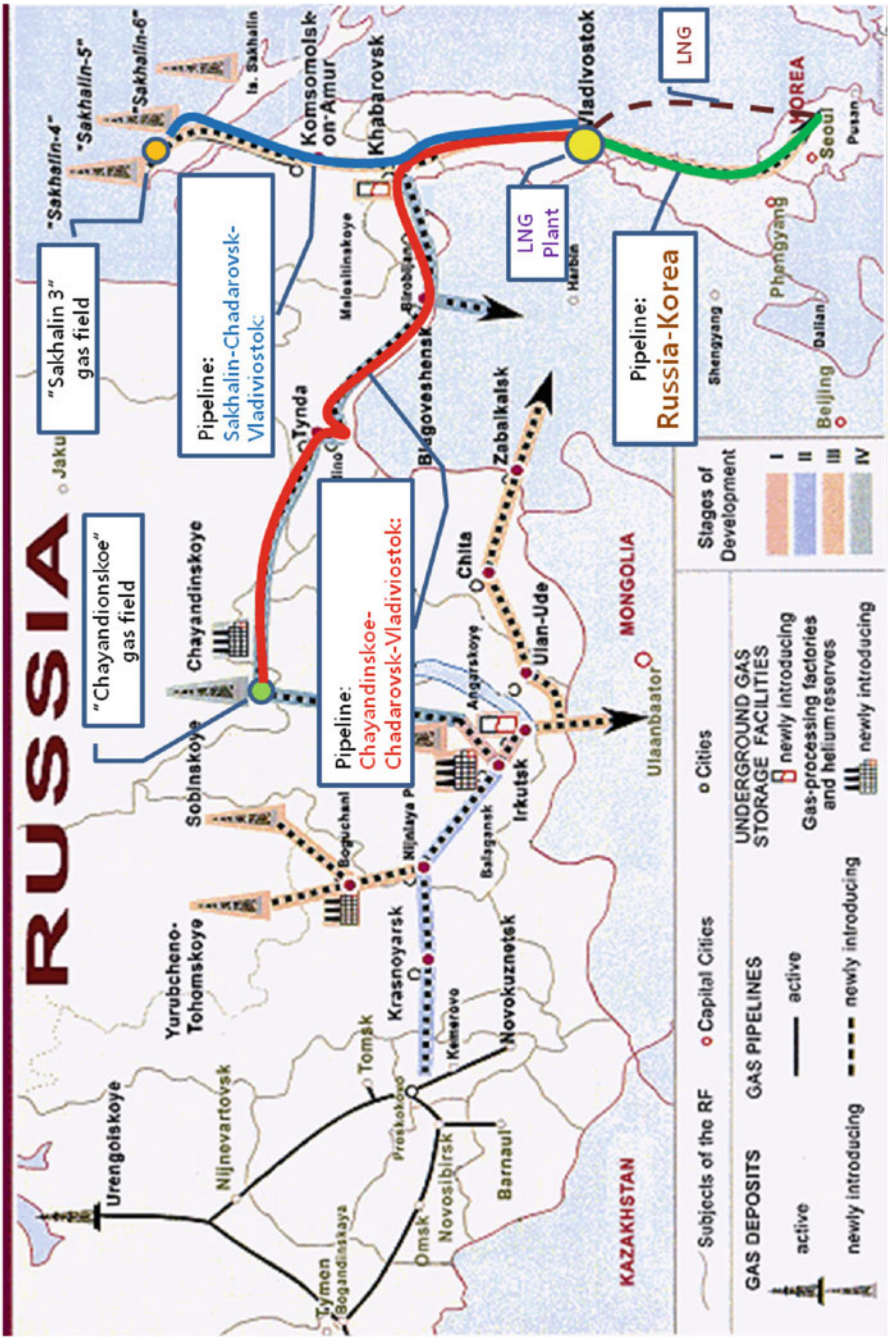

Fig. 1 The map of the possible project of gas supply from Russia to Korea

It is projected to start oil and gas production from the Chayandinskoye field in 2014 and 2016, respectively.

The Sakhalin–Khabarovsk–Vladivostok pipeline is for the transport of Sakhalin's gas to the Vladivostok port and then to the customers in the Far East countries. The total length of the Sakhalin–Khabarovsk–Vladivostok pipeline is 1,837 km. The maximal annual capacity is 31.7 bcm. The diameter of the pipeline is 1,220 mm, and the maximum rated pressure is 9.8 megapascals (MPa).

The Yakutia–Khabarovsk pipeline will start from the Chayanda OGCF in Yakutia. In Khabarovsk city, it will be connected with the Sakhalin–Khabarovsk–Vladivostok GTS. Together, the pipelines will feed a planned LNG plant that will produce LNG for export to NEA, or that will feed a Trans-Korean gas pipeline (if built). The total length of the Yakutia–Khabarovsk pipeline will be about 2,800 km and total length of pipeline from Yakytia to Pacific Ocean (port Vladivostok) is 4,383 km. The maximum annual capacity is 31.7 bcm. The diameter of the pipeline is 1,220 mm, and the maximum rated pressure is 9.8 MPa.

The LNG plant near Vladivostok will be built in the period 2015–2018, and its capacity could be 10 M tons of LNG per year. Two 5 M tons LNG trains are expected to be built. Such plans had been considered by the Board of Gazprom's Directors (as related to the development of gas processing and gas chemicals industry in eastern Russia) in February 2011.

Until our study completion time there was no technical and economic information on a planned Trans-Korean gas pipeline (Fig. 2). Consequently, the technical and economic parameters of planning this gas pipeline were determined and calculated by the author for this study. In this analysis she determined that for supplying 10 bcm of gas to Korea per year it is optimal to build the pipeline with a 1,020 mm internal diameter and operation at 5.45 MPa maximum rated pressure. The length of the pipeline from the Vladivostok port to the destination point—Korean port Samchuck, is 980 km. In the optimization analysis it was chosen to space the compressor stations 130 km apart, thus requiring eight such stations.

Correspondingly, to calculate the final gas price of Russian gas in Korea it is necessary first, to find the price of gas in each of seven elements of the gas supply chain, described above, namely the price of gas production from two fields in Russia, the price of domestic gas transmission by two pipelines, the price of consequent gas liquefaction and LNG transportation as one alternative, and of compressed gas transportation by a Trans-Korean gas pipeline as the other.

For asses the economic merit of the project, the calculated minimum acceptable price (prices—according to the different means of international transportation: LNG or PNG[5]) of Russian gas in Korea must finally be compared with the projected market price of crude oil (since currently the crude oil price serves as a reference for the LNG price in Korea) or the price of gas for the same region (NEA).

[5] Pipeline natural gas.