The Implementation of Green Jobs Activities

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The Implementation of Green Jobs Activities

- Green Jobs Study in Energy Intensive Industries in Asia

Part 1: Review of Job Changes and Skill Needs

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List of Acronyms

AHSS	Advanced High Strength Steel
AISI	American Iron and Steel Institute
ALC	Autoclaved Lightweight Concrete
APL	Annealing and Pickling Line
ASR	Automobile Shredder Residue
BAT	Best Available Technology
BCT	Bulk Cement Trailer
BF	Blast Furnace
BF-TGR	Blast Furnace Top Gas Recycling
BOF	Basic Oxygen Furnace
CCS	CO2 Capture and Storage
CDM	Clean Development Mechanism
CDQ	Coke Dry Quenching
CMS	Continuous Monitoring System
COG	Coke Oven Gas
COURSE50	Cool Earth 50
CP	Complex Phase
CSI	Cement Sustainability Initiative
CSIRO	Common Scientific and Industrial Research Organisation
DME	Dimethyl Ether
DP	Dual Phase
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EOR	Enhanced Oil Recovery
FINEX	Fine Particle Extraction
FOG	Finex Off Gas
GHG	Green House Gas
HISMELT	High-Intensity Smelting
HMR	Hot Metal Ratio
IEA	International Energy Agency
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
LDG	Linze Donawitz Gas
LNG	Liquefied Natural Gas
MOE	Molten Oxide Electrolysis
NSP	New Suspension Preheater

OPC	Ordinary Portland Cement
PCI	Pulverized Coal Injection
PSA	Pressure Swing Adsorption
R&D	Research and Development
SL/RN	Stelco-Lurgi/Republic Steel-National Lead
SP	Suspension Preheater
TMS	Telemetry System
TRIP	TRansformation Induced Plasticity
TRM	Technology Road Map
TRT	Top gas pressure Recovery Turbine
TWB	Tailor Welded Blank
TWIP	Twinning Induced Plasticity
ULCOS	Ultra-Low CO2 Steelmaking
USPTO	United States Patents and Trademark Office
WBCSD	World Business Council for Sustainable Development
WSA	World Steel Association

【Summary】

This study will forecast the future skills demand and present the direction for future workforce cultivation on a global level in response to spreading green technology in steel and cement industries. Each country can refer to the direction for future workforce cultivation presented in this study by considering current status of industry, technology and workforce of own country. Meanwhile, the analysis methodology presented in this study can help to plan the direction for future workforce cultivation in response to greening of other energy intensive industries and general manufacturing.

This study seeks job change and workforce cultivation in response to greening and energy reduction in steel and cement industries which are considered to be the energy intensive sector. For that, the following technology categories will be focused.

(1) Alternative fuels and resources by industry

(2) Energy efficiency processes by industry

(3) Recycling by industry

(4) Environmentally friendly product by industry

(5) Carbon Capture and Storage

(6) Environmental monitoring systems

Among these, carbon capturing and environmental monitoring are not limited to steel and cement industries. Therefore, carbon capturing and environmental monitoring will be analyzed as separate categories, while alternative fuels and resources, energy efficiency processes, recycling and environmentally friendly products will be reviewed by steel industry and cement industry.

First of all, this study will forecast what are the skills to be required newly according to the technology outlook based on TRM by IEA scenarios, and how the skills composition ratio will change. And then, the changes on related jobs and skills demand according to technology area diagnostics that newly had appeared in the participation of related technology experts, job analysis experts and training & education experts will be deduced. Finally, on the basis of the outlook on this skills and job changes, the direction for education & training will be presented.

Outlook on skills & job changes according to difficulty and differentiation is presented below.

x The Implementation of Green Jobs Activities

Difficulty (R&D dependency)	Low	Differentiation with related technology	High
High	- Relatively high R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Relatively high R&D dependency - Medium differentiation from existing relate technology	- Relatively high R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement
	- Medium R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Medium R&D dependency - Medium differentiation from existing relate technology	- Medium R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement
Low	- Relatively low R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Relatively low R&D dependency - Medium differentiation from existing relate technology	- Relatively low R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement

According to difficulty by technology and differentiation from existing technology, steel and cement industries' technologies of alternative fuels and resources, energy efficiency processes, recycling, environmentally friendly product, and carbon capture/storage and environmental monitoring were divided into ' Technology area with high new R&D workforce demand', ' Technologies with high demand for new engineer & technician workforce', ' Technologies with expected greening of existing R&D workforce' and ' Technologies with greening of existing engineer & technician workforce '.

- Technology area with high new R&D workforce demand: area with more focus on R&D rather than commercialization at current level such as CCS related technology
- Technologies with high demand for new engineer & technician workforce: alternative fuel, eco-friendly post-treatment, carbon monitoring, etc.
- Technologies with expected greening of existing R&D workforce: Area with greening deployment by developing current technology level such as energy efficiency, eco-friendly post-treatment and eco-friendly product
- . Technologies with greening of existing engineer & technician workforce: area with greening deployment through applying technology on existing process such as energy efficiency and eco-friendly product.

Education & training direction is presented as below according to difficulty by technology and differentiation from existing technology.

1. Steel Industry

1.1. Technology area with high new R&D workforce demand

It is the area with focus on R&D at current level rather than commercialization including hydrogen fuel(hydrogen production), coal chemistry and light weigh t material for structure, which has nature of eco-friendly original-base technology. This area requires comprehensive consideration such as international carbon emission regulation and economic situation until reaching realization and commercialization. R&D workforce for related technologies should be cultivated through related research projects in university. Not only the engineering departments including material, metal, chemical and mechanical engineering, which are directly related to steel industry, but also the fundamental science departments including physics, chemistry and biology should plan cultivating elite workforce along with long-term research development plan.

1.2. Technologies with high demand for new engineer & technician workforce

This area attracts the most attention in relation with greening of steel industry including waste resource utilization like waste plastic, biomass and high temperature dust collection. This technology area contains currently emerging or being realized technologies such as alternative fuel and eco-friendly post-processing, for which active workforce cultivation is required. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally highly related with steel industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening steel subject in related departments and to promote improving curriculum, while government level support is also necessary.

1.3. Technologies with expected greening of existing R&D workforce

This is the area in which greening is being contrived by improving current technology level including energy efficiency, eco-friendly post-processing and eco-friendly products. Rather than separate workforce cultivation plans, expanding research development opportunities, to which existing researchers can participate, is required. But government supervising on the researches that should be implemented on enterprise level, is not advisable, while entrepreneurs need to guide research developments into vitalization. For government, vitalizing on-offline forum that delivers related info of researchers in private companies systematically and promptly is expected.

1.4. Technologies with greening of existing engineer & technician workforce

In relation with the greening of steel industry, this area is the most focused area along with the technology area for high demand on new engineer & technician workforce. The technologies in this area try greening through applying technology from energy efficiency and eco-friendly products on existing process, for which retaining of present workforce is important. To induce flexible response to fast technological development, not only training & education but also rearranging related certificates is required. For fruitful outcome of training and education, analysing job changes according to the proceeding of greening, and systematizing of education & training are also necessary. By combining green technology distribution chart, which was arranged by difficulty of technology and differentiation from existing technology, and outlook on job demand change, the outlook on new job creation and greening of existing jobs is presented along with the direction for education & training.

2. Cement Industry

2.1. Technology area with high new R&D workforce demand

It is the area with focus on R&D at current level rather than commercialization including heat resource utilizing technology of ASR and city waste source materializing by burning technology, which has nature of eco-friendly original-base technology. To reach realization and commercialization, comprehensive consideration on international carbon emission regulation and economic situation is required as well as significant amount of time and investment. R&D workforce for the technology should be cultivated from related research projects of university. Not only the engineering departments including material, chemical and mechanical engineering, which are directly related to cement industry, but also the fundamental science departments including physics, chemistry and biology as well as environmental engineering should be the target of cultivating elite workforce along with long-term research development plan.

2.2. Technologies with high demand for new engineer & technician workforce

This area attracts the most attention in relation with greening of cement industry including biomass. This technology area contains currently emerging or being realized technologies such as alternative fuel and eco-friendly post-processing, for which active workforce cultivation is required. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally highly related with cement industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening cement subjects in related departments and to promote improving curriculum, while government level support is also necessary.

2.3. Technologies with expected greening of existing R&D workforce

This is the area in which greening is being contrived by improving current technology level including energy efficiency, eco-friendly post-processing and eco-friendly products. Oxyfuel technology, eco-cement and dust detoxification technology are included. Rather than separate workforce cultivation plans, expanding research development opportunities, to which existing researchers can participate, is required. But government supervising on the researches that should be implemented on enterprise level, is not advisable, while entrepreneurs need to guide research developments into vitalization. For government, vitalizing on-offline forum that delivers related info of researchers in private companies systematically and promptly is expected.

2.4. Technologies with greening of existing engineer & technician workforce:

In relation with the greening of cement industry, this area is the most focused area as the technology area for high demand on new engineer & technician workforce along with re-education/training of existing workforce. The technologies in this area try greening through applying technology from energy efficiency and eco-friendly products on existing process, in which steel slag utilization technology as an alternative fuel of limestone, high efficiency cooler, waste heat generation and chloride by-pass system are included. To induce flexible response to fast technological development, not only training & education but also rearranging related certificates is required. For fruitful outcome of training and education, analysing job changes according to the proceeding of greening, and systematizing of education & training are also necessary.

3. Carbon capture/storage and carbon monitoring

3.1. Technology area with high new R&D workforce demand

CCS related technologies, belong to here of which have focus on R&D instead of commercialization on current technology level. While CCS related technologies have high difficulty on current technology level, geographic situation in storage aspect after capturing carbon became a very big limitation. This area requires comprehensive consideration such as international carbon emission regulation and economic situation until reaching realization and commercialization. R&D workforce for related technologies should be cultivated through related research projects in university. It is not limited to steel and cement industries, and a long-term research development plan on the fundamental science areas such as physics, chemistry and biology rather than traditional material, metal, chemical and mechanical engineering, is considered to be more important.

3.2. Technologies with high demand for new engineer & technician workforce

Carbon monitoring belongs to here, which should get attention first than CCS. While it's importance has already recognized, active workforce cultivation should be implemented for the area during realization. It is not limited to steel and cement industries, and a long-term research development plan on the fundamental science areas such as physics, chemistry and biology rather than traditional material, metal, chemical and mechanical engineering, is considered to be more important. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally not limited with steel industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening convergence subjects in related departments and to promote improving curriculum, while government level support is also necessary.

Chapter 1. Development of a Systematic Approach

1.1. Research Method & Utilization

Ongoing technological development brings corresponding change on the demand of work force such as replacing existing work force, skills change and new skilled-work demand. During the ages of slow technological change, experts can be trained through many years' experience in the field, but with complicated technological changes, training expert work force separate from field training is required. As technological changes being advanced quickly, current work force training is just responding to current or past demand of work force. Because of the existence of time lag from work force training term, they respond late to changing technological demand. For work force training which responds to technological changes, it is necessary to respond to future technological demand, not to current technological demand.

Also in work force training in response to green technology, a response to commercializing of individual green technology and its time for application is requested. This study tries to provide information on work force training according to the advent of and transition to green skills. While the current target for analysis is steel and cement industries, this study tries to support smooth response to the demand changes of work force according to the advent of green jobs and greening of existing jobs. It will examine technological changes by technology area(with focus on eco-friendly manufacturing process, alternative energy and improving energy efficiency, and carbon capturing) and the skill demand change according to that.

This study tries to seek the job change and workforce cultivation from greening and energy cut of steel and cement industries, which were considered as the energy intensive sector. For that, it will focus on the technology categories in the below.

(1) Alternative fuels and resources

(2) Energy efficiency processes

(3) Recycling

(4) Environmentally friendly goods (product)

(5) Carbon Capture and Storage

(6) Environmental monitoring systems

Among these, carbon capturing and environmental monitoring are not limited to steel and cement industries. Therefore, carbon capturing and environmental monitoring will be analyzed as separate categories, while alternative fuels and resources, energy efficiency processes, recycling and environmentally friendly products will be reviewed by steel industry and cement industry.

This study will examine how many of what level manpower is requested until the time of individual green technology's commercialization, and furthermore present recruiting new work force as recruiting method and the relative importance of retraining/reeducation of existing related work force. By responding to the demand of green skill efficiently and successfully on the basis of this, creating and spreading green jobs can be expedited, and development of green industry and continuous growth of national economy can be planned. Such study will be helpful to get flexible measure for the changes in government, labor union and workers, employers and education & training organizations in response to green growth.

This study starts from overall technology development scenario of IEA for green technology development trend. IEA had presented several scenarios for carbon emission level up to 2050 on global level along with the goals for energy reduction and carbon emission restriction by time and sub-industry. This study prepared technology items in detailed technology areas and the content & level of necessary workforce, in other words, skills demand by detailed technology, on the basis of the outlook on technology change according to energy reduction and carbon emission restriction goals by time and sub-industry from TRM based on IEA scenarios. By forecasting what is the newly required skill (knowledge and dexterity) according to the technology demand outlook and how the skills composition ratio has changed, the changes on related jobs will be deduced. And also the changes on related jobs and skills demand according to technology area diagnostics that newly appeared by the participation of related experts in technology, job analysis and education & training will be deduced. Finally, the direction for education & training based on such skills change and job change will be presented.

[Table 1.1] List of participated experts to the study

Affiliated organization	Title	Role
University	Professor	Technology analysis participation, job analysis consultation, education course development consultation
University	Professor	Technology analysis participation, job analysis consultation, education course development consultation
University	Professor	Technology analysis consultation, job analysis participation, education course development consultation
Research institute	Researcher	Industry analysis participation, technology analysis consultation, education course development consultation
Research institute	Researcher	Industry analysis participation, technology analysis participation, education course development participation
Research institute	Researcher	Technology analysis consultation, job analysis participation, education course development participation
Research institute	Researcher	Technology analysis consultation, job analysis participation, education course development participation
Research institute	Researcher	Analysis methodology participation, job analysis participation, education course development consultation
Research institute	Section chief	Technology analysis consultation, job analysis consultation, education course development consultation
Private company	Director	Technology analysis consultation, job analysis consultation, education course development consultation
Private company	Section chief	Technology analysis consultation, job analysis consultation, education course development consultation
Private company	Dept. chief	Technology analysis consultation, job analysis consultation, education course development consultation
Related association	Team leader	Technology analysis consultation, job analysis consultation, education course development consultation
Related association	Team leader	Technology analysis consultation, job analysis consultation, education course development consultation

The interpretation and utilization of technology items by detailed technology and skills demand presented in the 1st part of this study requires significant caution. As mentioned above, the foundation of this outlook came from the IEA's technology outlook according to energy reduction and carbon emission restriction goals by time up to 2050 on global level. While it has a strong intention on global level, it could be an unrealistic technology outlook that does not fit to market competition situation in the aspects of rising cost and cost pressure for individual country and enterprise. Furthermore, because of the nature of industry as equipment industry & key industry, it cannot be related to equipment-facility replacement in reality, even though the presented technological changes try to energy reduction and carbon emission restriction. Or a part of technology that has been realized in individual country or enterprise could be considered as a future technology in this study. The skills demand in the 1st part of this study also had predicted future skill changes on a kind of upper bound level based on technology outlook of IEA scenarios. Therefore, the changes on job ability (skills demand) in response to future technology change of relevant region (country) could be different from the reference point, as future technology demand differs by region (country). This study is an analysis on general tendency at global level.

Meanwhile, tracing the technology change, skills demand change and education & training item on regional detailed level would be the research items of the sister research, the 2nd part of this research. This research then will be the reference item. The technology items and skills demand presented in this study is an outlook on a general level of tendency. In order to reflect this study on reality or discuss this study's appropriateness to reality, more strict analysis on current carbon emission restriction level and facility-equipment investment plan should precede beforehand. Based on that, the analysis of this study on technology items and skills demand should go under significant level of adjustment. In regional (by country) future skills demand change outlook, the advent point of future technology demand as a reference point should be adjusted by future technology demand of relevant region (country) as well as the future skill level change of relevant region (country).

1.2. Future Technological Needs

To analyze the demand on future technologies[1], it will review future demand on skills and their possibility for realization in 2020's, and provide mid-long term direction for corresponding related work force training and basic information for detailed items of work force training. Detailed future skills demand and work force training will focus on short period (up to 2020's) but technology outlook had mid-long term technology outlook carried out in the aspect of increasing suitability of mid-long term direction search for work force training. Analysis on technology will be implemented through participation of experts in relevant technology along with utilizing related documents and data. For newly established technology analysis beside of existing data will go through cross reviewing by related experts.

1.2.1. Current Status and Issues

To analyze current status, detailed areas will be deduced first.(e.g. in the case of alternative fuel, the detailed areas of currently used fuel will be deduced and for the case of energy efficiency improvement processes, the major processes would be considered as detailed areas. Other special items should be determined at the discretion of the specialists). Subsequently it will analyze the current status per detailed area by utilizing Historical fact data and then document outline of detailed needs of future society per detailed area. Based on this, technology status per area and needs adaptability of future world will be put together as well as evaluation on matching/mismatching per individual area.

[Table 1.2] Status of ooo area - actions to meet needs

Detailed area	Status summary	2030 future world needs	Evaluation on the needs adaptability of the future world by current status	Reasons of mismatching
Area A	In relation with detailed area, brief documentation on keyword including outline, trend and major characteristics with a weight on currently applied product and technology	2030 future world needs : Quantify the needs of future world in relation with detailed area	Mismatching ⇔ Matching ①②③④⑤	Brief documentation on keyword
Area B	Brief documentation on keyword	Brief documentation on keyword		Brief documentation on keyword
Area C	Brief documentation on keyword	Brief documentation on keyword		Brief documentation on keyword
Total	Brief documentation on keyword	Brief documentation on keyword		Brief documentation on keyword

1 The future technologies considered by this study do not designate all the future technologies in steel and cement industries. It is limited to the technology areas with high relation to greening and energy reduction of steel and cement industries.

1.2.2. Identification and Analysis of Alternative Technologies in Future

Present alternative technology by area which corresponds to future world needs along with corresponding matching (a kind of reason for selection). If there is newly developed area, introduce that one too.

□ Completeness analysis

[Table 1.3] Alternative technology by area

Detailed area	Alternative technology name	Concept (overview)	Future world needs adaptability of alternative plan	Matching reason
Area A	1	Brief documentation on keyword	Mismatching ↔Matching ① ② ③ ④ ⑤	Brief documentation on keyword
	2		Mismatching ↔Matching ① ② ③ ④ ⑤	
Area B	3		Mismatching ↔Matching ① ② ③ ④ ⑤	
	4		Mismatching ↔Matching ① ② ③ ④ ⑤	
New area M	5		Mismatching ↔Matching ① ② ③ ④ ⑤	
New area N	6		Mismatching ↔Matching ① ② ③ ④ ⑤	
	7		Mismatching ↔Matching ① ② ③ ④ ⑤	

By presented alternative technology, write down current status, skills demand analysis, completeness analysis, technological obstacle, time of technology realization and technology characteristics.

□ Overview and Status

Write the basic contents of the alternative technology. It is acceptable to combine with the technological demand analysis.

□ Technological demand analysis

Write down the response from and applicability to market along with the reasons for the alternative technology. Contents are similar to the future world needs, matching reasons in the above table. Clearly describe the distinction between 2020 and 2030 demand.

□ Analysis on completeness

Show the current development stage of the corresponding technology from one of the following options: ①Basic research stage, ②Experiment stage, ③Prototype stage, ④Production, ⑤Mass production and commercialization. Present the reason for the stage selection by referring to the following table.

[Table 1.4] Entire Industry Evaluation index by TRL stage (Example)

Classification	Stage	TRL Definition	Industry area							
			Machine / Robot	Material	Electronic and Electric	Information and Communi-cation	S/W	Fiber and Chemistry	Polymer Ceramic	Bio
Basic Research Stage	1	Basic test	Scientific research stage (basic level papers and research)				Basic theory / experiment	Scientific research stage (Basic level papers and research)		Application principle
	2	Establish concept	Basic principle is converted to application technology development (level of application papers and patents)				Establish concept with practical purpose, including ideas and papers	Basic principle is converted to application technology development (level of application papers and patents)		Exploration / refining
Experiment stage	3	Basic performance verification	Modeling / design	Material synthesis / culture	Modeling / design	Modeling / design	SW modeling (analysis / design)	Material synthesis/ culture	Material synthesis/ culture	Effectiveness research
Experiment stage	4	Component / system performance verification	Core component technology	Optimum mix ratio	Core component technology	Core component technology	Research prototype implementation	Optimum mix ratio	Optimum mix ratio	Core component technology
Prototype stage	5	Component / system prototype manufacturing	Secure manufacturing technology	Process optimization	Secure manufacturing technology	Secure manufacturing technology	Sub system development (analysis / design / implementation)	Process optimization	Process optimization	Process optimization (separation, culture)
Prototype stage	6	Prototype performance evaluation	Prototype performance	Prototype performance	Prototype performance	Prototype performance	Sub system test / check effectiveness	Prototype performance	Prototype performance	Pharmaceutical formulation Pre-clinical trial
Production stage	7	Prototype reliability evaluation	Reliability evaluation	Reliability evaluation	Reliability evaluation	Reliability evaluation	System integration / verification	Reliability evaluation	Reliability evaluation	Clinical trial (phase 1,2)
	8	Prototype certification	KS/ISO certification	KS/ISO certification	KS/ISO certification	KS/ISO certification	System test/verification (in real environment)	Stability certification and permit	KS/ISO certification	Clinical trial (phase 3)
Mass production	9	Commercialization	-	-	-	-	Commercialization	-	-	KFDA approval

□ Technological Barrier

Present obstacles to remove for commercialization in the future, the parts that are impossible to develop with current technology and way to secure economic efficiency.

□ Draw the time to realize the technology

Select the expected time frame for the commercialization and mass production of the corresponding technology from one of the following 4 options:

①Five years later, around 2015, ②10 years later, around 2020, ③15 years later, around 2025, ④Around 2030, ⑤After 2030

※ Provide a brief explanation for the reason in connection with the removal of technical obstacles and technology demand analysis.

□ New/Disruptive Technology Identification

Determine whether the corresponding technology is sustainable or new/disruptive technology, and provide a foundation for the judgement.

1.2.3. Technology Road Map for Future Skills Demand

For the detailed technologies of green technology areas, the completion time point of technology development, where commercialization is possible, will be presented. “Alternative fuels and resources”, “energy efficiency processes”, “recycling” and “environmentally friendly products” will be carried out by dividing steel industry and cement industry, while “Carbon Capture and Storage” and “environmental monitoring systems” will be carried out separately. This dividing follows that IEA scenarios and the target goal on global level for realization of carbon reduction goal. Each country can be different from the technology map presented by this study depending on the difference in the environment of industry and technology and facility investment plan of enterprises.

1.3. Future Skills Needs and Job Change

To analyze future skills demand, the outlook on new green job creation possibility by technology, skills demand change according to technological change, and outlook on job(work) change are necessary. On the basis of this future skills demand analysis, the information on the range, level, related major and curriculum of related work force training was prepared.

1.3.1. Skills Demand Change

The meaning of 'skill' in this study is a comprehensive competence, including knowledge and dexterity. Job change refers to changes of knowledge and dexterity requirements for the corresponding technology due to changes to related technologies and the corresponding changes of work functions. Occupational change refers to the advent of new jobs and/or reduction/extinction of existing jobs due to changes in related technologies and work functions.

Outlook for job change by period can be deduced through outlook on skills demand change derived from the technology change outlook by time in a sense that the components of the competence which defines the job are knowledge and dexterity. It will interpret patent sub-classification (IPC) of related patent by technology as a required skill and focus on changes on composition rate of required skills according to technology outlook by time.

In order to compare skills demand, the detailed technologies expected from 'alternative fuels and resources', 'energy efficiency processes', 'recycling', 'environmentally friendly products', 'Carbon Capture and Storage', and 'environmental monitoring systems' in steel and cement industries were mapped on a 2 dimensional space according to the degree of difficulty by technology and similarity to existing technology. The necessity of technology deduced from each technology analysis and its estimated time for realization along with characteristics of technology and necessary resources were studied through discussion between related technology information analysis experts and job analysis experts and consultation with related technology experts and field experts.

[Table 1.5] Green technology chart by difficulty and differentiation

	Low	Differentiation with existing similar technology	High
High	Technology Ⅰ : High difficulty, Low differentiation with existing technology	Technology Ⅱ : High difficulty, Medium differentiation with existing technology	Technology Ⅲ : High difficulty, High differentiation with existing technology
Difficulty (R&D dependability)	Technology Ⅳ : Medium difficulty, Low differentiation with existing technology	Technology Ⅴ : Medium difficulty, Medium differentiation with existing technology	Technology Ⅵ : Medium difficulty, High differentiation with existing technology
Low	Technology Ⅶ : Low difficulty, Low differentiation with existing technology	Technology Ⅷ : Low difficulty, Medium differentiation with existing technology	Technology Ⅸ : Low difficulty, High differentiation with existing technology

On the basis of this Green technology chart by difficulty and differentiation, each cell's new or existing work force demands per job (R&D, Engineer, Technician work forces) can be determined. This job demand change outlook is the source for the outlook on new green job creation and greening of existing jobs. This will also be determined through discussion between related technology information analysis experts and job analysis experts and consultation with related technology experts and field experts.

[Table 1.6] Necessity of new/existing workforce and the level of necessary workforce in response to technology distribution

Difficulty (R&D dependency) \ Differentiation with related technology	Low		High
High	- Relatively high R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Relatively high R&D dependency - Medium differentiation from existing relate technology	- Relatively high R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement
	- Medium R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Medium R&D dependency - Medium differentiation from existing relate technology	- Medium R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement
Low	- Relatively low R&D dependency - No big differentiation from existing relate technology & high possibility of utilization from existing related workforce	- Relatively low R&D dependency - Medium differentiation from existing relate technology	- Relatively low R&D dependency - Big differentiation from existing relate technology & high importance on new workforce supplement

Supplementing workforce is for the demand on new workforce and possibility to utilize existing workforce. As higher the differentiation with existing related technology, the lower the possibility to utilize existing workforce, and higher the necessity for supplementing new workforce. If the necessity for supplementing new workforce is high, new job creation ratio will be high. If utilizing existing workforce is high, greening of existing job would be important. On the basis of such analysis system, detailed technologies can be arranged by difficulty of technology and differentiation from existing technology. Based on that, the possibility of new job creation according to workforce composition change by technology can be reviewed.

[Table 1.7] Outlook on new job creation

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low	High
High	Area with greening of existing jobs with focus on R&D workforce	Area with new job creation with focus on R&D workforce
Low	Area with greening of existing jobs with focus on engineer & technician workforce	Area with new job creation with focus on engineer & technician workforce

According to that, ‘area with new job creation centered on R&D workforce’, ‘area with new job creation centered on engineer & technician workforce, ‘area with greening of existing jobs centered on R&D workforce’ and ‘area with greening of existing jobs centered on engineer & technician workforce’ were presented. Expected job changes from steel and cement industries in response to the technology outlook of ‘Alternative fuels and resources, ‘energy efficiency processes, ‘recycling’ and ‘environmentally friendly `products, and expected job changes in response to the technology outlook on 'Carbon Capture and Storage' and 'environmental monitoring systems' will be presented.

1.3.2. Proposal for Education and Training Course by Technology

In order to develop education/training courses according to the job changes expected in steel and cement industry, and job changes from 'Carbon Capture and Storage' and 'environmental monitoring systems', the information on necessary size and plan by work force level (new workforce supplement VS. reeducation/training of existing workforce), necessary knowledge/dexterity, and related department is required. Basic information for developing education/training courses by individual technology can be described as below by comprehending technology analysis and skills demand analysis which were done earlier. This information can be considered as a suggestion for education/training course by technology but for detailed application, an adjustment for each country's workforce status, education/training status and technology level is necessary.

[Table 1.8] Basic information for developing education/training courses by technology

Area of technology	Technology Ⅰ		
Definition	Definition of technology Ⅰ		
Estimated time of realization	Year		
New work force (Training)	R&D	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related department & major	Necessary major of new work force
	Engineer	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related department & major	Necessary major of new work force
	Technician	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related department & major	Necessary major of new work force
Existing work force (Reeducation)	R&D	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related job	Related existing research part or job
	Engineer	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related job	Related existing research part or job
	Technician	Demand	Write down reinforcement size
		Necessary knowledge, dexterity	Necessary knowledge and dexterity for development and operation of each technology
		Related job	Related existing research part or job

Chapter 2. Future Technological Needs

2.1. Diffusion of Green Technology[2]

2.1.1. Greening of Manufacturing Industry in general

Currently, manufacturing industries across the world consume about 1/3 of total energy and contribute to 40% of total CO_2 emissions (IEA, 2009: 24). While global efforts to reduce carbon emissions are urgently needed, the International Energy Agency presents two scenarios related to carbon emissions (IEA, 2009: 32).

- Baseline scenario: CO_2 emission volume continues to increase at the current rate (as of 2006). By 2050, CO_2 emissions will be increased by 130% and oil consumption by 70%.

- Act scenario: CO_2 emission volume is to maintain current level until 2050 and the plans to meet the demands are presented.

- BLUE scenario: CO_2 emission volume is reduced to less than 50% of current level by 2050, and the plans to meet the demands are presented.

Baseline Scenario and BLUE Scenario are evaluated as appropriate to current situation among them (IEA, 2009: 32). Because the energy consumption for these scenarios is divided into low-demand and high-demand, there are 4 scenarios to be presented[3]. In order to achieve the BLUE scenario in high-demand, more carbon emission reduction is required than in low-demand.

- (Low-Demand) Baseline Scenario

- (High-Demand) Baseline Scenario

- (Low-Demand) BLUE Scenario

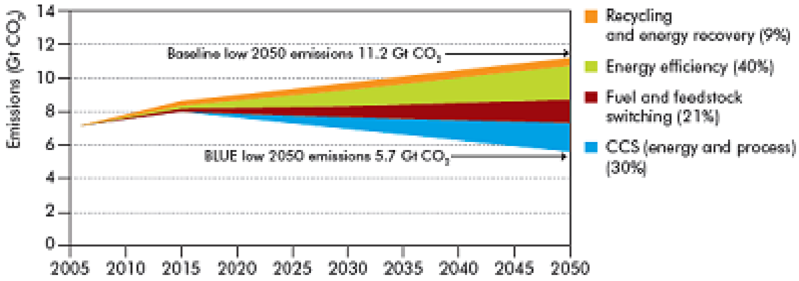
- (High-Demand) BLUE Scenario

The direct CO_2 emission by manufacturing industries should be reduced by 21% from current level in order to achieve the total CO_2 emission volume in 2050 at the half of 2005 level (BLUE scenario). Using electricity is considered as an indirect CO_2 emission.

Not only applying existing technologies, but new technologies including energy efficiency improvement, alternative energy source development, recycling, and carbon capture and storage are necessary. International Energy Agency estimated the reduction of CO_2 emissions from manufacturing industries by technology as outlined in <Figure 2.1>.

2 This section was exerted from 2009 IEA report.
3 Where a specific mention of demand is listed below, it is based on ‘Low-Demand’.

<Figure 2.1> CO_2 emissions reducing technology from 2006 to 2050 by industry



Source: IEA, (2009:39)

■ The estimated reduction of direct CO_2 emission by industry in 2050 based on the low-BLUE scenario and the high-BLUE scenario is 37-38% compared to 2006 and 62-67% compared to the baseline of 2050 in the case of the steel industry.

[Table 2.1] Direct emission reduction by sector in BLUE low-and high-demand scenarios in 2050

Reference	2006 (%)	2006 (%)	Baseline low 2050 (%)	Baseline high 2050 (%)
Iron and steel	-37	-38	-62	-67
Cement	-18	-18	-34	-45
Chemicals and petrochemicals	0	-4	-50	-58
Pulp and paper	-47	-46	-71	-77
Aluminum	122	121	-8	-32
Total	-21	-21	-49	-56

Source: IEA, (2009:40)

The CO_2 emissions reduction is essential especially for the five energy intensive industries of steel, cement, chemical-engineering, paper, and aluminum, where their contribution to total direct CO_2 emissions is 75%[4]. The low-demand and high-demand figures in the BLUE scenario represent a difference of 20% (=15% to 40%) in carbon emission reduction levels for the five aforementioned industries.

The additional investment under the BLUE scenario over the baseline scenario until 2050 is around 2-2.5 trillion USD. While they contribute to most of CO_2 emission in manufacturing, the investment for CO_2 emission reduction across all manufacturing industries under the same scenario is 6% of the total investment for CO_2 emission reduction made by all industries[5].

4 Steel (29%), cement (25%), chemical (17%), paper (3%), and aluminum (1%)

5 The investment of each manufacturing industry is increased by 10-15% compared to the baseline scenario, whereas investment by the cement industry is increased by 50% compared to the baseline scenario.

[Table 2.2] Technology requirements by industry

Iron and steel	Cement	Chemicals	Pulp and paper	Aluminum
Application of current best available technologies Including CHP, efficient motor and steam systems, waste heat recovery and recycling				
Fuel and feedstock switching				
DRI, charcoal and waste plastics injection	Alternative fuels, clinker substitutes	Biomass feedstocks	Increased biomass	
New technologies				
Smelt reduction		Membranes	Lignin removal	Wetted drained cathodes
Electrification (MOE)		New olefin processes	Black liquor gasification	Inert anodes
Hydrogen		Process intensification	Biomass gasification	Carbothermic reduction
CCS for blast furnaces	CCS post-combustion	CCS for ammonia	CCS for black liquor gasification	
CCS for DRI	CCS oxyfuel	CCS for large scale CHP		
CCS for smelt reduction	CCS pre-combustion	CCS for ethylene		

Source: IEA (2009:45)

2.1.2. Greening of Steel Industry

2.1.2.1. Overview

Global steel production has been growing at an unprecedented rate in the last decade, largely driven by economic development in China. This growth has slowed recently, but it is expected to resurrect by the increased demand of crude steel by 85% to 122% between 2006 and 2050.

The energy efficiency potential, based on today's best available technologies, is about 20%. Replacement of small-scale blast furnaces is the single most important task. Recycling of residual gases and waste heat is also important as well as improvement of other existing technologies. On the assumption of using the most energy-intensive carbon-emission method, estimating the outlook for the demand on 'from ore to steel production' displayed that the emissions will be increased from 840 tons in 2006 to 1440-1740 tons by 2050 in Baseline Scenario, and for the BLUE Scenario, it will be increased by 1060-1290 tons by 2050[6]. CO_2 emissions from the iron and steel sector need more reduction in the BLUE Scenario compared to the Baseline Scenario. Given that the demand for steel will only increase, this requires CO_2 intensity (CO_2/t crude steel) to be reduced by a factor of almost one-fourth of current levels. To achieve this, the cost will be around USD 200/t CO_2. Also through new energy-efficient technologies being developed and applied, the rate of using coal for hot metal making is estimated to be reduced to 8 to 15% of current level. They could also capture from 40 to 70% of CO_2 emissions without major process adjustments, but with additional process steps. Fuel conversion also can help to reduce CO_2 emissions. A switch from blast furnaces to gas-based direct reduced iron (DRI), a solid iron product, and the increased use of biomass (including charcoal), chemical byproduct (plastic waste), and CO2-free electricity are also useful. Carbon capture and storage (CCS) will be an important option for reducing CO_2 emissions in the iron and steel sector. Because this technology still remains commercially unavailable, there is an urgent need to introduce CCS on a commercial scale for various iron and steel processes.

6 Baseline Scenario and BLUE Scenario are regarding the total carbon emission level. At the BLUE Scenario to halve global carbon emissions from 2006 levels by 2050, carbon emission of individual industry can be increased. It is expected that the carbon emissions would be still increased in the iron and steel sector even in the Baseline scenario.

Total additional investments into the iron and steel sector under the BLUE scenarios would amount to between USD 300 billion and USD 400 billion by 2050, about 17% higher than the levels of investment implicit in the Baseline scenarios. These additional investments will be lowered by cutting down fossil fuel costs.

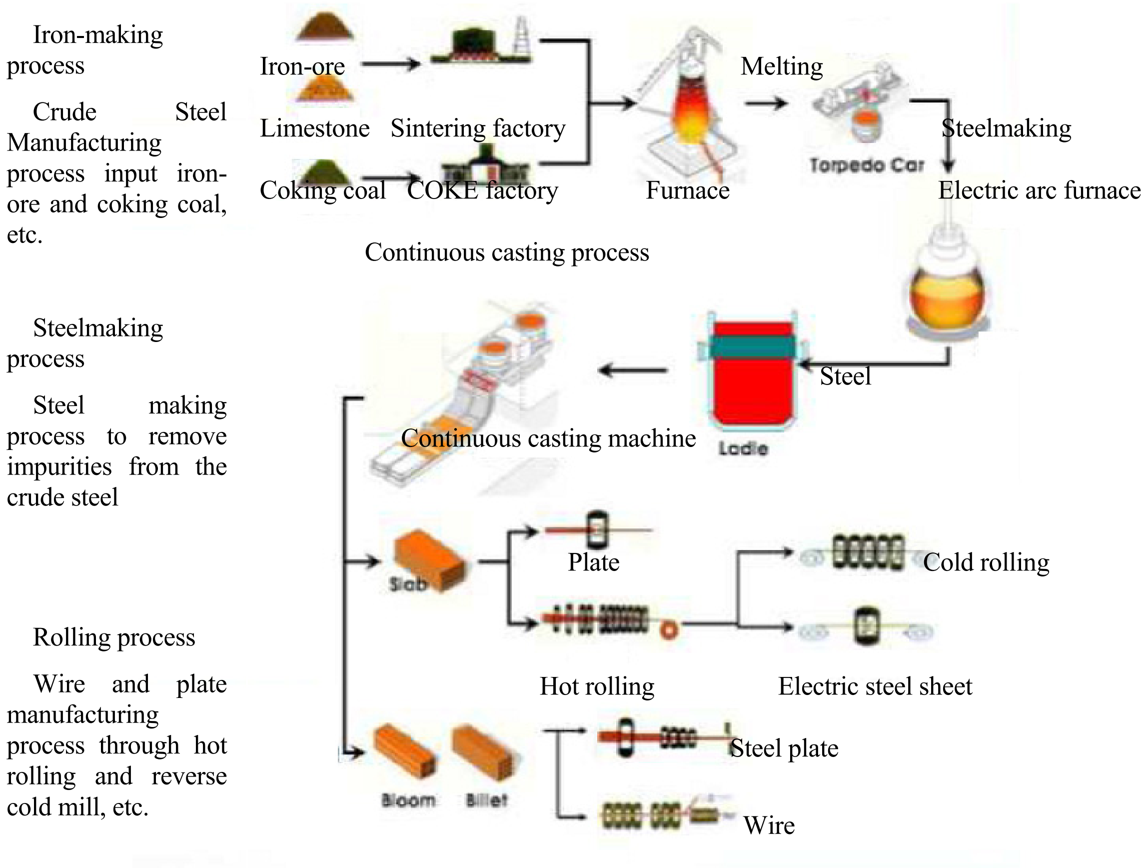
2.1.2.2. Steelmaking Process

Manufacturing process of steel products divided into three; Blast Furnace, which refines 70-100% of iron ore with scrap metal, scrap/EAF [electric arc furnace] method, based on scrap for the iron input and DRI [Direct Reduced Iron]/EAF. The two methods of Blast Furnace and Electric Arc Furnace will be reviewed briefly.

2.1.2.2.1. Blast Furnace Process

The blast furnace process is a steelmaking method using traditional iron-making. Iron ore and coke are used as the heat source and reductant. Through iron-making and steelmaking, steel products are manufactured. The manufacturing process is illustrated as follows.

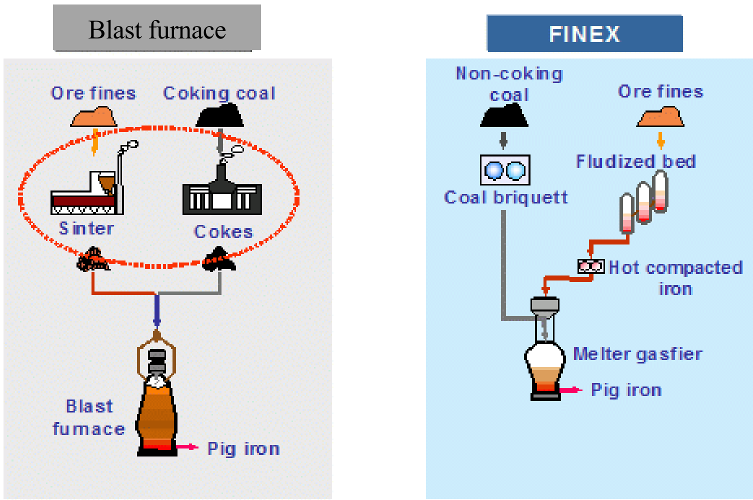
<Figure 2.2> Manufacturing process of blast furnaces



: POSCO

On the other hand, recent POSCO FINEX method can be a transformed or developed iron-making process, and the differences are shown as below compared with the traditional blast furnace process.

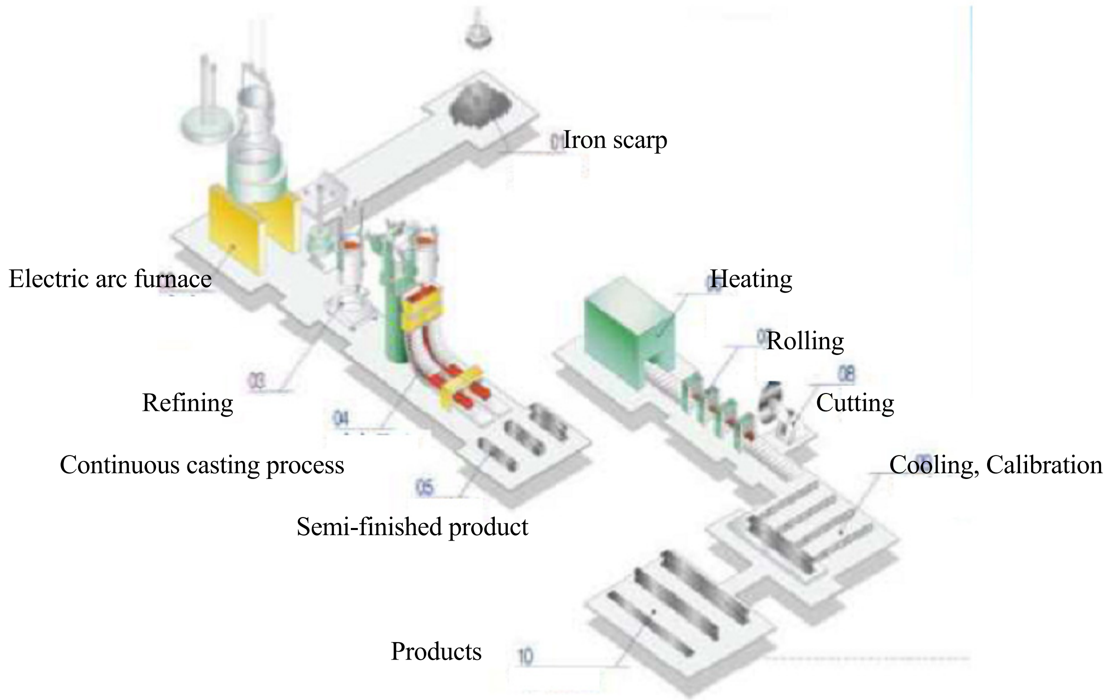
<Figure 2.3> Blast Furnace and FINEX



2.1.2.2.2. Electric Arc Furnace process

Steel is manufactured using iron scrap as a raw material with heat transmission (major steel products are steel bars, shape steel, and reinforced steel, etc.), and steelmaking using nuclear power, which is expected to expand in the future, is an extension of the electric arc furnace process.

<Figure 2.4> Manufacturing process of the electric arc furnace process

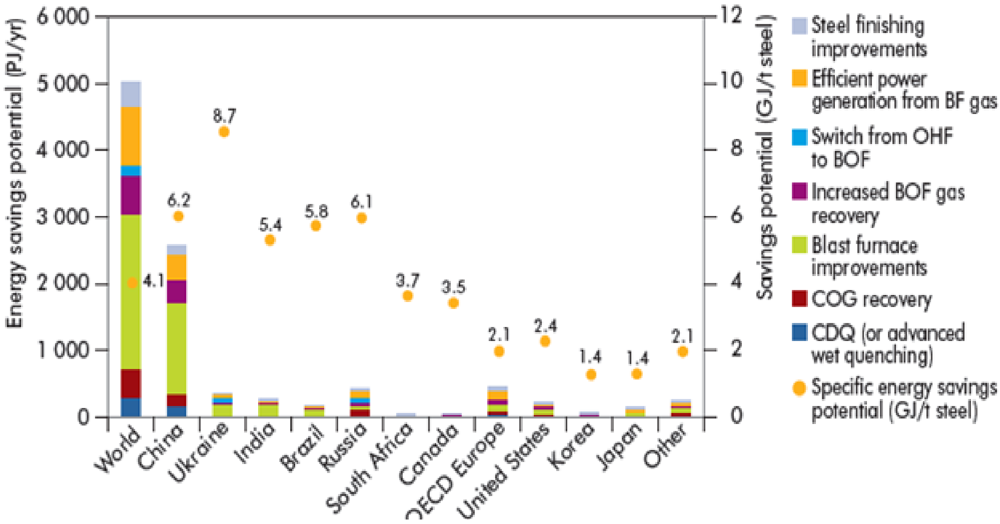


2.1.2.3. The Greening of Iron and Steel Industry

Although the energy and carbon emission reductions based on existing technology should be planned in accordance with a switch to the electric arc furnace process that results in energy and carbon emission reductions compared to blast furnace, the potential is limited to around 20% of total reductions required.

Because the increase in energy demand according to production doubling between 2006 and 2050 is considerably less, there should be significant technological innovations for reduction in energy demand and carbon emissions.

<Figure 2.5> Energy savings potential in 2006, based on best available technology



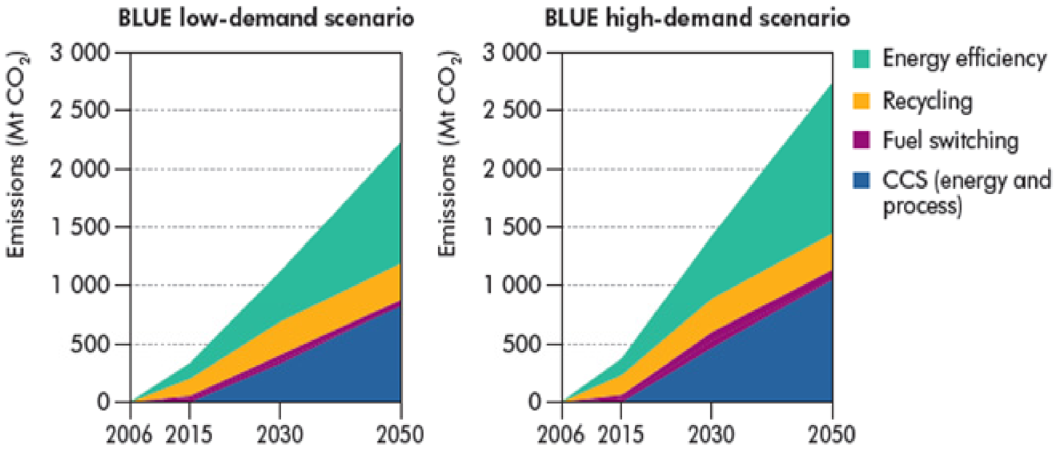
Source: IEA (2009:54)

There are five ongoing representative technology developments according to Ultra-Low CO_2 Steelmaking (ULCOS); the new carbon-based smelting reduction process, new types of reactors, new blast-furnace processes, the use of biomass, and CO_2 capture[7].

Under the BLUE Scenario, energy efficiency and recycling dominate at the initial stage up until 2015 to achieve CO2 emission reduction goal. From 2015 onward, fuel switching and carbon capture are scheduled to play a more important role; specifically up to 37-38% for CCS and up to 11-14% for recycling. Energy efficiency and recycling are already taking an important part as seen under the BLUE scenario.

7 48 European companies and organizations from 15 European countries have participated.

<Figure 2.6> CO_2 Emission reduction of Baseline Scenario from 2006 to 2050



Source: IEA (2009:62)

2.1.2.4. Trend in Major Green Technology Development

2.1.2.4.1. New Coal-based processes

In the smelting reduction processes, there are two kinds of processes; FINEX of POSCO and HIsmelt (high-intensity smelting). Coal-based direct reduced iron (DRI) includes Stelco-Lurgi/Republic Steel-National Lead (SL/RN) process, FASTMELT and ITmk3®.

2.1.2.4.2. Fuel switching

The use of fossil fuels that have low carbon intensity, alternative fuels (including waste), and biomass fuels are increasing. Since the cost of alternative fuels will be increased as the cost of CO_2 increases, considerations must be made for changes in facilities and processes according to the use of alternative fuels. There are three kind of fuel switching; Gas-based DRI – MIDREX, use of coal and use of waste plastic.

2.1.2.4.3. Electricity-based steel-making

There are three methods in electricity-based steel-making; molten oxide electrolysis (MOE), plasma injection, and the use of hydrogen.

2.1.2.4.4. Carbon Capture and Storage (CCS)[8]

Additionally, there are more diverse technologies. The representative technologies are carbon capture and storage, post-combustion capture technology and Oxyfuel technology. Carbon capture and storage is a process in which CO_2 is captured as it is emitted, compressed to a liquid, and then transported in pipelines to be permanently stored. Social consensus is necessary in transport and storage.

Post-combustion capture technologies: Since CO_2 is captured at the end-of-pipe mechanisms that would not require fundamental changes in the process, and so could become available for existing facilities (Chemical absorption: Carbonate looping, an adsorption process in which calcium oxide is put into contact with the combustion gas containing CO_2 to produce calcium carbonate). It is expected to be commercially available after 2020.)

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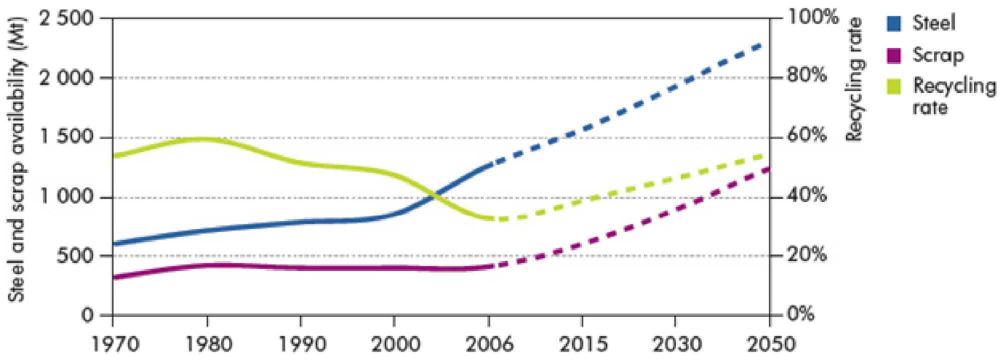
8 There are many discussions on the realization point and application possibility of carbon capture and storage. Especially for carbon storage, not only the technological matter, but also geographical situation makes it impossible to introduce. Under the circumstance of impossible carbon storage, carbon capturing is also not being able to be introduced even though it is possible technologically. The realization possibility and time presented in the study is the outlook of IEA, and can have totally different opinion depending on the circumstances of each country or enterprise.

Oxyfuel technology: Using oxygen instead of air in kilns would result in a comparatively purer CO_2 stream. It will be commercially available after 2050.

2.1.2.4.5. Material Flow and Material Flow Optimization

For material savings and energy efficiency improvement, new plants need to apply existing most advanced technologies in consideration of operational efficiency, and improve to highly efficient facilities by considering economy additionally for existing facilities[9].

<Figure 2.7> Steel scrap availability and recycling rate of BLUE scenario from 1970 to 2050



Source: IEA (2009:72)

2.1.2.4.6. Product Innovation

Product innovation is divided into 4 sectors of corrosion-resistant steels, high-strength low-alloy steels, improved heat resistance and efficient electrical steels.

2.1.3. Greening of Cement Industry

2.1.3.1. Overview

As cement production is a major source of CO_2 emissions, total direct CO_2 emissions from cement production amounted to 1.9Gt CO_2 in 2006, with around 0.8Gt CO_2 emitted from combustion and 1.1Gt CO_2 from process emissions. As the cement industry is energy intensive industry, its final energy intensity rate including electricity is from 2.9GJ/t to 4.7GJ/t and the necessary energy per ton in clinker is from 3.2 GJ/t to 4.5GJ/t.

The cement industry has made significant strides in reducing energy consumption. With China reducing its thermal energy intensity since 1990, energy consumption has been reduced to 1/4. Coal accounts for around 60% of the fuel burned in cement clinker and around 1EJ electricity was used in 2006. The thermal consumption of BAT(Best Available Technology) and clinker was reduced down by 27% (2.3 EJ). The CO_2 savings from the use of alternative fuels including BAT and clinker substitute, is equal to 510Mt CO_2.

To reduce CO_2 emissions from the cement industry by 2050 to below today's levels and maintain projected growth in demand, new technology is necessary. Under the BLUE scenario, in order to reduce the cement industry's CO_2 emissions in 2050 to 18%, which is below 2006 level, efficient consumption of energy, alternative fuels and clinker substitute, and applying modified CO_2 capture technologies are required.

9 Facility investment improvement is conservative due to the nature of the industry. Retrofits on a large scale are currently limited due to high investment costs

Especially, CCS is an essential component in achieving the BLUE scenario outcomes by reducing CO2 emission from 0.5Gt to 1.0 Gt a year until 2050.

Applying CCS can reduce the cost of between USD 40/t CO_2 and 170/t CO_2. In a long-term perspective, new low-carbon cements might become available but much remains to be done to prove and deploy these technologies effectively.

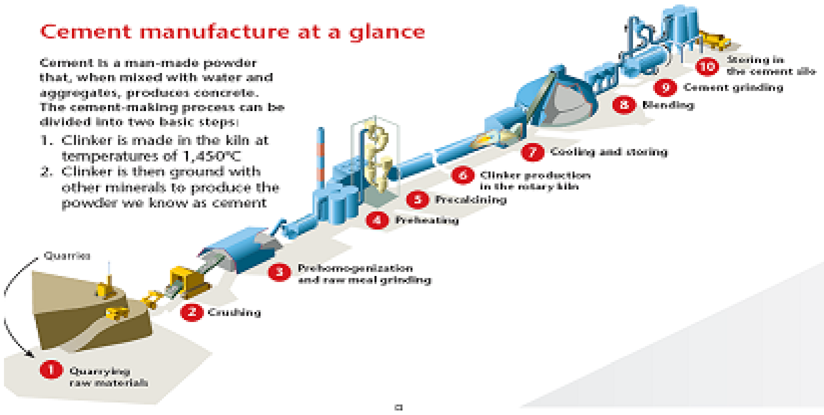
The Cement Sustainability Initiative (CSI) project, “Getting the Numbers Right”, launched by the World Business Council for Sustainable Development (WBCSD), has collected energy and CO_2 data with over 70% from Annex 1 countries and 20% from non-Annex 1 countries. This kind of data collection should be done continuously and the development spirit for low-carbon cement should be encouraged.

2.1.3.2. Cement Manufacturing Process

Cement is a man-made powder making concrete by mixing water and aggregates. The cement-making process can be divided into two basic steps: 1. Clinker is made in the kiln at temperatures of 1,450°C, 2. Clinker is then ground with other minerals to produce the powder we know as cement.

Cement manufacturing process is divided into ten specific steps:

<Figure 2.8> 10 steps in Cement Manufacturing Process



The first step is quarrying raw materials, naturally occurring calcareous deposits such as limestone, marl, or chalk that provide calcium carbonate ($CaCO_3$) and are extracted from quarries, often located close to the cement plant. Very small amounts of “corrective” materials such as iron ore, clay, or silica may be needed to provide extra iron oxide (Fe_2O_3), alumina (Al_2O_3), and silica (SiO_2) to adapt the chemical composition of the raw mix to the process and product requirements.

The second step is crushing, where the raw material is broken into 10cm pieces, twice divided by the primary/secondary processes.

The third step is homogenization and raw meal grinding, which is homogenization that takes place in which different raw materials are mixed evenly, and the crushed pieces are then milled together to produce the “raw material”.

The fourth step is preheating, wherein the raw meal is passed through a preheater. The raw material comes into contact with swirling hot kiln exhaust gases. In these heat exchanges, the necessary chemical reactions occur faster and more efficiently.

The fifth step is precalcining, the decomposition process of limestone to lime that takes place in the precalciner), which is a combustion chamber at the bottom of the preheater above the kiln. Here, the chemical decomposition of limestone typically emits 60-65% of total CO_2 emissions, and the fuel combustion generates the rest. In terms of fuel consumption, 65% occurs in the precalciner.

The sixth step is clinker production in the rotary kiln, when the precalcined meal then enters the kiln, and the fuel is fired directly into the kiln to reach temperatures of up to 1,450°C. As the kiln rotates, about 3-5 times per minute, the material slides and tumbles down through progressively hotter zones towards the flame. The intense heat causes chemical and physical reactions that partially melt the meal into clinker.

The seventh step is cooling and storing from the kiln, where the hot clinker falls onto a grate cooler where it is cooled by incoming combustion air.

The eighth step is blending, where the clinker is mixed with other mineral components. If significant amounts of slag, fly ash, limestone, or other materials are used to replace clinker, the resultant product is called "blended cement".

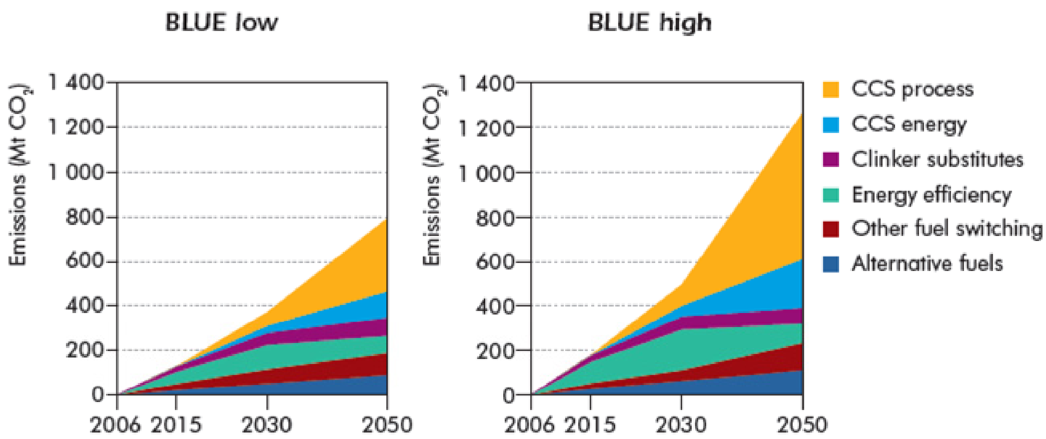
The ninth step is cement grinding, where the cooled clinker and gypsum mixture is ground into a grey powder, Ordinary Portland Cement (OPC), or ground with other mineral components to make blended cement.

The tenth step is storing, where the final product is homogenized and stored in cement silos and then dispatched to either a packing station or shipped out using BCT.

2.1.3.3. The Greening of the Cement Industry

For carbon emission reduction in the cement industry, energy efficiency and fuel switching is important in the short term, however, carbon capture and storage (CCS) is considered a core need in the long term.

<Figure 2.9> CO_2 emissions reduction of Baseline from 2006 to 2050



[Table 2.3] Cement Roadmap Indicators

Cement Roadmap Indicators							
		2012	2015	2020	2025	2030	2050
Heat source unit (GJ/T-clinker)		3.9	3.8	3.5~3.7	3.4-3.6	3.3-3.4	3.2
Replacement ratio of alternative fuel (1)		5-10%	10-12%	12-15%	15-20%	23-24%	37%
Ratio of clinker/cement		77%	76%	74%	73.5%	73%	71%
CCS	Number of pilot plants	2	3				
CCS	Number of demonstration plants		2	6			
CCS	Number of commercial plants				10-15	50-70	200-400
CCS	Capture and storage volume (Mt)	0.1	0.4	5-10	20-35	100-160	490-920
Basic unit of CO_2 ($t\text{-}CO_2/t\text{-cement}$) (2)		0.75	0.66	0.62	0.59	0.56	0.42

Note: (1) assumes 25 to 30 Mtoe of alternative fuel use in 2015 and 50 to 60 Mtoe in 2030, and excludes energy from CCS and electricity use, (2) includes reduction from CCS
Source: IEA, 2009: 24

2.1.3.4. Trend of Major Green Technology Development

2.1.3.4.1. Thermal and Electric Efficiency

When building new cement plants, manufacturers incorporate the most recently developed technologies, which are also typically the most energy efficient. Therefore, new kilns are comparatively energy efficient. More efficient technologies generally provide a cost advantage to manufacturer through lower energy costs, so efficiency does increase gradually according to building new plants and upgrading of old facilities.

Mostly, the heat efficiency of plants is defined by the initial design. However, after installation, to maximize efficiency, the efficiency on machine operation should be increased. This operating efficiency is different from the technologies. Even though it is difficult to precisely measure, it is significantly important in terms of CO_2 emission and energy management.

Recently, dry manufacturing facility with attached preheaters and precalciners has shown the latest technologies.

- **Limits to Efficiency Improvement**

There are five limitations to the implementation of greening technology. First, a significant decrease in source power unit will only be achieved through major retrofits. These have high investment costs, and are therefore currently limited.

Second, strengthened environmental requirements can increase power consumption (e.g., dust emission limits require more power for dust separation regardless of the technology applied).

Third, the demand for high performance cement, which requires very fine grinding and uses significantly more power than low-performing cement, is high.

Forth, it is generally accepted that CCS is the key to reducing CO_2 emissions, but has been estimated to increase power consumption by 50-120% at the plant level (power for air separation, stripping, purification, CO_2 compression, etc.).

Lastly, other reduction methods can collide with energy efficiency improvement. For example, clinker substitutes such as slag and fly ash reduce CO_2 emissions in the clinker production process, but generally require more energy for grinding cement finely.

- **R&D Needs and Goal**

The fluidized bed is a promising technology to improve thermal efficiency and is widely used in some other industries. It has yet to prove its suitability at a large scale in the cement industry. Other breakthrough technologies that could lead to a significantly higher thermal or electric efficiency are not envisaged. Therefore, it is vital to ensure that new plants are fitted with the most efficient technologies at the time, and are then operated and maintained efficiently.

2.1.3.4.2. Alternative Fuel Use

There are five typical alternative fuel used by the cement industry; pre-treated industrial and household solid waste (domestic waste), discarded tires, recycled oil, plastics, textiles, and paper residue and biomass including agricultural residue like animal meal, logs, wood chips, recycled wood and paper, rice husk, sawdust, sewage sludge and biomass crops.

- Limits to Alternative Fuel Use

There are four known limitations. First, waste management legislation significantly impacts availability. Higher fuel substitution only takes place if local or regional waste legislation prohibits land-filling or dedicated incineration, and allows for controlled waste collection and the appropriate treatment of alternative fuels. Second, local waste collection networks must be adequate. Third, alternative fuel costs are likely to increase with higher CO_2 costs. It may then become increasingly difficult for the cement industry to source significant quantities of biomass at acceptable prices. This roadmap assumes it will be economically viable for the cement industry to use alternative fuels until 2030, when prices will reach about 30% of conventional fuel costs, increasing to 70% by 2050. Lastly, the level of social acceptance of waste fuel usage in cement plants can strongly affect local uptake. People are often concerned about harmful emissions from alternative fuel use, even though emission levels from well-managed cement plants are the same with or without the use of alternative fuels.

- R&D Needs and Goals

Suitable materials that could be used as alternative fuels must be identified and classified. R&D related the processing and use of such fuels need to be shared to enable widespread expertise in using high and stable volumes of alternative fuels.

- Regional aspect

The detailed analysis of GNR data show that 20% of cement plants in Europe are utilizing alternative fuels (15% of fossil fuels, 5% of biomass) while North America, Japan, Australia and New Zealand uses 11% (mostly fossil fuels) and South America 10% of alternative fuels (6% of fossil fuels, 4% of biomass). In Asia, the alternative rate reached 4% by 2006. The utilizing of alternative fuel is as yet insignificant in Africa, the Middle East, and the Commonwealth of Independent States.

2.1.3.4.3. Clinker Substitution

Clinker is the main component in most types of cement. When ground and mixed with 4-5% gypsum, it reacts with water and hardens. Other mineral components also have these hydraulic properties when ground and mixed with clinker and gypsum, notably ground blast furnace slag (a by-product of the iron or steel industry), fly ash (a residue from coal-fired power stations), and natural volcanic materials. These can be used to partially substitute clinker in cement, thereby reducing the volumes of clinker used, and, subsequently, the process, fuel, and power-related CO_2 emissions associated with clinker production.

- Limits to Clinker Substitution

There are five known limitations; the low regional availability of clinker-substituting materials, increasing prices of substitution materials, low properties of substitution materials and low applied use of cement, irregular national standards for Ordinary Portland Cement and composite cements, and low awareness and acceptance of composite cements by construction contractors and customers.

- R&D Needs and Goals

Documented assessment on substitution material properties is needed to understand and communicate which substitutes are the best for which intended applications. For example, cement standards allow up to 95% blast furnace slag in some cement. However, this has low early-stage strength. These cements are only suitable for very special applications, which has the possibility in doubt. It would be valuable to develop and cross-reference roadmaps for different industries that are linked to the cement industry by the production of clinker substitutes. This will enable better forecasting of the effects of mitigation technologies in one industry in terms of the impact of mitigation potential in other industries.

2.1.3.4.4. Carbon Capture and Storage:

Burn and capture technology can be implemented in the existing kilns as well as new kilns, because CO_2 is captured at the last exit and there is no need to change the basic flow of the calcination process.

Oxyfuel technology enables the capture of relatively purer CO_2 by using oxygen instead of air in the kilns. This technology requires more research to understand all potential effects in the clinker calcination process. Currently, oxyfuel technology is being validated in many small-scale power plants, and the results will be useful in cement kilns in the future.

- Limits to Implementation

There are four limits. First, political support such as governmental incentives, funding for research, long-term liabilities and the use of CCS as a component of a comprehensive climate change strategy is superficial. Second, property owner cooperation in obtaining the necessary permits and approvals for CO_2 transportation and storage sites is necessary.

Third, local residents' informed approval of proposed CCS projects in their communities is needed.

Fourth, expanded efforts by government and industry to educate and inform the public and key stakeholders about CCS are required.

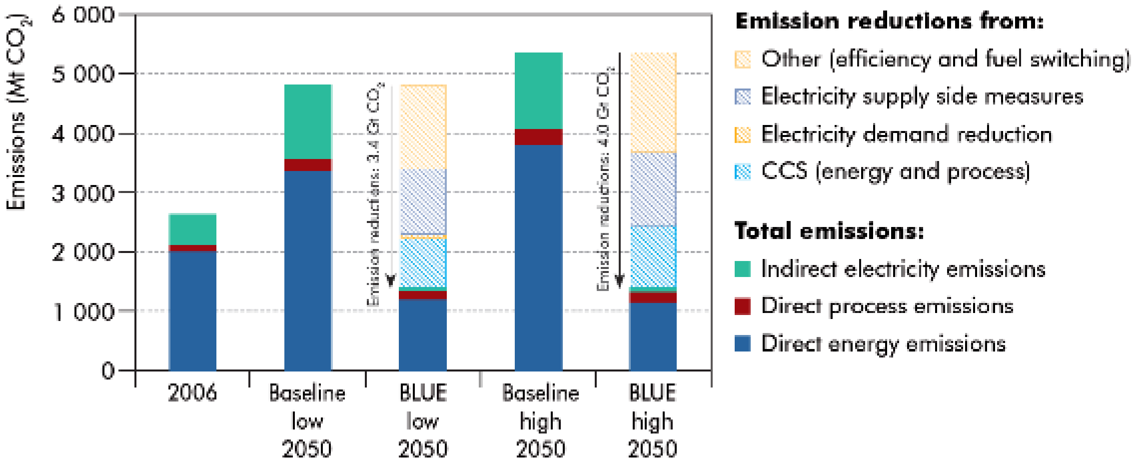
- R&D Needs and Goals

CCS measures for the cement industry are being discussed, but to date only a few feasibility studies have been carried out and no results from pilot or industrial-scale trials at cement kilns are available. Oxyfuel technology, in particular, needs further extensive development to bring CCS technologies to commercial scale in the industry.

2.2. Green Technological Needs in Steel Industry

The figure shows direct and indirect CO_2 emissions from iron and steel in the Baseline. Total direct and indirect emissions in the BLUE scenarios will fall by 47% from 2.6 Gt CO_2 in 2006 to 1.4 Gt CO_2 in 2050. The near-decarbonization by utilizing electricity will play a major role in achieving these emissions reductions. Over 30% of the direct and indirect emissions reduction amounts in the BLUE scenarios will come from the power generation sector. By 2050, about one-quarter of the CO_2 emissions will be reduced. Additional reductions will come from energy efficiency, alternative energy, and technology usage.

<Figure 2.10> CO_2 emissions by BLUE scenario from 2006 to 2050 in the iron and steel industry



Source: IEA (2009: 123)

2.2.1. Alternative Fuel and Source Material

2.2.1.1. Current Status and Issues

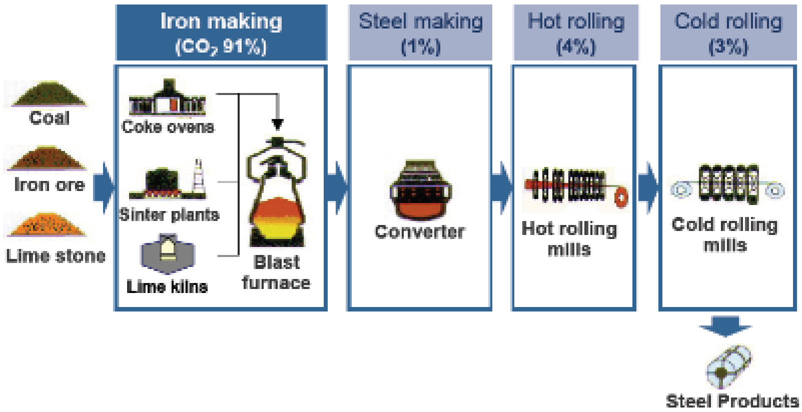
The steel industry requires energy to maintain high temperatures for the reduction of iron ore.

Currently, coal is used as the iron ore reducing agent for blast furnaces or FINEX type furnaces, and electricity is used as the energy source in electric furnaces for manufacturing steel products from iron scrap.

The major processes in the steel industry are composed of iron making process for producing pig iron, the steel making process for producing steel, hot rolling to shape the steel, and cold rolling process to control the thickness and shape of the manufactured billet or slab products.

More than 80% of the greenhouse gas CO_2 is produced in the iron making process using coal in the blast furnace based steel industry. (Refer to the data published by POSCO and WSA (World Steel Association) in Figure 2.2-2)

<Figure 2.11> CO_2 emission distribution data of POSCO



Source: POSCO and WSA

Steel industries across the world recognize the need for alternative fuel or source materials that can reduce CO2 emissions in steel making process. Various projects are underway for this purpose, such as ULCOS project by EU steel companies, COURSE 50 by Japan, AISI in the USA and CSIRO in Australia.

Research on the use of the gases generated during the steel making process and the by-products of the conversion process as alternative resources replacing petroleum is also underway.

2.2.1.1.1. Coal

2.2.1.1.1.1. Status

In the blast furnace type steel manufacturing process, coal is converted to coke in the coke oven and put into the blast furnace. Coal and iron ore are isolated in the sintering furnace, and they are then sintered and combined in the blast furnace. Some of the coal in a powder state is put into the blast furnace directly[10].

Around 720 - 750kg of coal is required to produce one ton of steel with a blast furnace, and it is generally understood that about 2 tons of CO_2 is generated per ton of steel. The FINEX method of POSCO requires similar or lower amounts of coal.

Coal is the main source of CO_2 as it contributes to 7% (as of 2004) of total CO_2 emissions across the world. The majority comes from the blast furnace processes.

The cost of coal is expected to increase due to the boom of the steel industry in China. Therefore, cost reductions can be realized by using low quality coal instead of high quality coal[11]. The amount of coke put into the blast furnace is 499kg cokes/t-pig iron, and the fixed carbon contained in the coke is defined as 444kg/t -pig iron. Carbon emissions can be reduced by 0.20t CO_2/t-pig iron, if a part of coke put into the blast furnace is supplied using the PCI (Pulverized Coal Injection) method with160kg/t-pig iron (110kg FC/t-pig iron).

2.2.1.1.1.2. Future needs in 2030

Alternative energy sources that can replace coal must be explored in the future and the proper range of applications should be determined based on the results of the research.

As a technology replacing the use of coal, hydrogen can be used as a reducing agent for reducing carbon emissions by 30% by separating CO_2 from the gas in the blast furnace backend.

Flammable waste such as scrap plastics can be used in the coke oven to reduce the use of coal and increase the use of recycled energy.

10 This technology is called PCI [pulverized coal injection].
11 This will be explained in Alternative Technologies in the “Environmentally Friendly Steel Products” section.

Charcoal can be used instead of carbonized coke from coal where biomass can be produced on a large scale.

If a part of coke is replaced by natural gas (100Nm3 NG/t-pig iron), 0.25t CO_2/t-pig iron of carbon emissions can be reduced.

If a part of coke put into the blast furnace is replaced by carbonized charcoal from biomass (210kg charcoal/t-pig iron), 0.8t CO_2/t-pig iron can be reduced. If coke were to be entirely replaced by carbonized charcoal from biomass, -0.125t CO_2/t-pig iron of CO_2 emissions can be cut. In other words, CDM (Clean Development Mechanism) is achievable.

2.2.1.1.2. Electricity

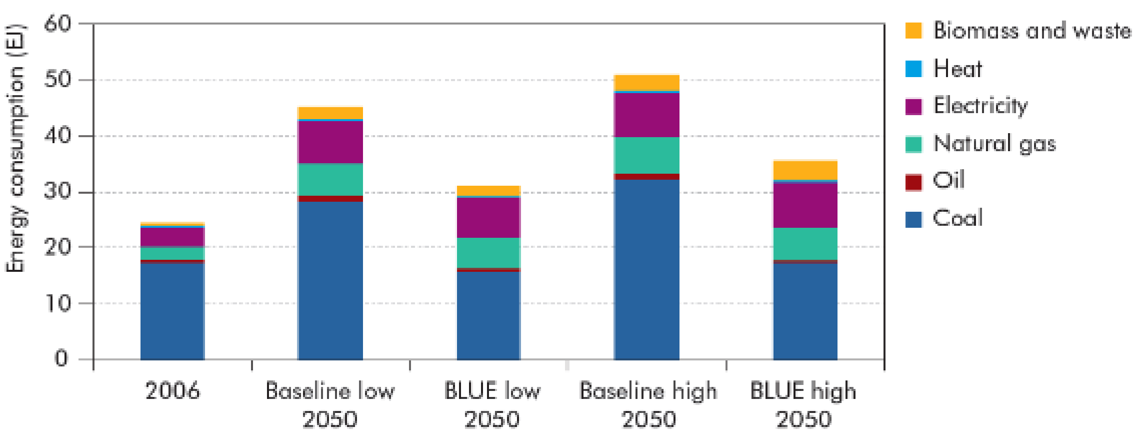
2.2.1.1.2.1. Status

Electric furnace factories that use iron scrap provide high voltage electricity, oxygen combustion and additional oxygen to EAF (Electric Arc Furnaces). The power required to operate the electric energy including the electricity required for generating oxygen is 400kWh/t-steel. Electric energy consumption has been reduced to 200-330kWh/t-pig iron using shaft furnaces and continuous operation in the years after 2000. The steel industry that uses blast furnaces also requires a large amount of electric energy to blow air to the blast furnace, compressing air in an oxygen factory, and driving the rolling motor in the rolling process.

2.2.1.1.2.2. Future needs in 2030

Electricity consumption by electric furnaces can be reduced by 3kWh, if 1Nm3 of additional oxygen is provided to produce each ton of steel. Therefore, technologies to produce both oxygen and electricity in cost effective ways must be developed.

<Figure 2.12> Final energy consumption by scenario from 2006 and 2050



Source: IEA (2009: 123)

2.2.1.2. Assessment on the current status and response to the needs

[Table 2.4] Gap between current status and future needs in the alternative fuel area

Area	Status overview	Future needs in 2030	Suitability for future needs	Reason for not fitting
1) Coal	60% of greenhouse gas emissions comes from burning coal	Conversion to clean alternative fuel	Low	Majority of CO_2 emissions is from burning coal
2) Electricity	Enormous amounts of electrical energy are used	Cost effective electricity generation technology	Relatively Low	Carbon is generated when producing electricity

2.2.1.3. Drawing and analyzing Alternative technologies in the future

2.2.1.3.1. Drawing Alternative technologies by area

[Table 2.5] Alternative technologies by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative technologies to meet future needs	Reasons for suitability
Alternative fuel	[1-A] Hydrogen	Production of hydrogen by processing and refining COG, and using hydrogen for blast furnaces	Very High	Increased productivity by using the high reduction potential of hydrogen gas
	[1-B] Waste resources such as scrap plastics	Using scrap plastics in coke production, replacing coal	High	Solid technology that can replace coal
	[1-C] Biomass	Using biomass such as wood instead of coal as a source of coke production	Very High	Fundamental solutions, land, and technology must be secured

2.2.1.3.2. Analysis on alternative technologies

2.2.1.3.2.1. Hydrogen

□ Overview and status

Hydrogen is used as a reducing agent of iron ore in blast furnaces. Hydrogen can be supplied externally or by processing and isolating hydrogen from COG produced in a coke oven.

□ Analysis on technological demand

The concept of using hydrogen as a reducing agent is to use the property of the high reduction potential of hydrogen by putting hydrogen into a blast furnace for which enormous hydrogen production is essential.

Research on the production of hydrogen at a large scale from the gases produced during the steel making processes are being conducted by the ULCOS in Europe and Cool Earth 50 in Japan, and also considered by domestic institutions. The possibility of application in the future is high[12].

□ Maturity analysis

Currently, it is in the stage of establishing the direction of research from the basic concept.

12 More explanations in "Technology to produce hydrogen from BFG" in Alternative Technology for Environmentally Friendly Backend Processes.

□ Technological Barriers

Technology to inject hydrogen into blast furnaces and the technological analysis on the reduction properties and thermo-physical properties by the amount of injected hydrogen are required.

□ Expected technology realization period

Around 2020, the concept for technological development is complete, but assessments on economic efficiency and applicability are necessary.

2.2.1.3.2.2. Waste resources such as scrap plastic

□ Overview and status

The basic concept is to use flammable scrap plastics, scrap tires, and scrap cooking oil for coke ovens to replace some of the use of coal.

NSC and JFE in Japan have already implemented this technology.

□ Analysis on technological demand

Under the BLUE scenarios, the use of plastic waste increases from less than 0.1 EJ today to between 0.6 EJ and 2.0 EJ by 2050. The demand for plastic is divided into 3 stages between now and 2050, scheduled to utilize 250 Mt to 300 Mt of plastic waste. However, there will be a fierce competition in the future.

□ Maturity analysis

Currently, it is at the practical stage in Japan. Japan utilized 0.46 Mt of waste in this way in 2005 and has set a target of one million tons by 2010 (JISF, 2008a).

□ Technological Barriers

Although continuous verification is underway for the quality of coke such as the strength of coke when waste plastics were put into coke ovens, continuous evaluation is necessary for existence problems in the trend of being replaced with low quality coal.

□ Expected technology realization period

Around 2015, initial operation may be possible in the near future, but additional technologies must be developed to extend the range of replacement.

2.2.1.3.2.3. Biomass

□ Overview and status

The concept is to use biomass, such as woods, as the source of coke in blast furnaces.

This alternative technology is considered by countries with large areas of territory, such as Brazil and Australia, as viable.

□ Analysis on technological demand

The introduction of biomass is being recognized as very useful in terms of the diversification of energy sources and carbon reductions but it has serious problems on ‘limited resources’ compared to other new energy sources.

This technology needs continuous attention and research because there could be a way to import into the countries with limited resource by converting into coke after being produced as wood in overseas.

□ Maturity analysis

The concept is complete, but it has not been applied to the steel industry on a large-scale, since this is still at the basic research stage.

□ Technological Barriers

It has limitations on the feasibility and quality of the produced coke and securing land to produce wood fundamentally.

□ Expected technology realization period

Around 2030, technical verifications on developing high quality coke production technology using biomass and wood production are necessary along with large-scale investment.

2.2.2. Energy Efficient Process

2.2.2.1. Current Status and Issues

The cost of energy related to the efficiency of the steel manufacturing process directly affects the unit cost of steel manufacturing and cost competiveness. The effects on cost competitiveness will be more significant when a CO_2 trading system is activated in the steel industry in the future.

2.2.2.1.1. Blast furnaces

2.2.2.1.1.1. Status

Various technologies have been developed to increase the energy efficiency of blast furnaces that consume the majority of the energy consumed in the steel industry, and many technologies have been commercialized, such as PCI, oxygen injection, oxygen enriched hot air, energy recovery from hot air blower and TRT (Top gas pressure Recovery Turbine) facility investment.
Currently, PCI (pulverized coal injection) and oxygen injection technologies are deployed for increasing productivity and energy efficiency. The level of PCI is currently around 200kg/t-pig iron, and it is increasing.

The current technology is to inject Oxyfuel in hot stoves that generate hot air at 1200oC with 25 - 30% oxygen content for use in blast furnaces, so as to increase productivity.

Currently along with the efforts to increase the oxygen content, the technologies to pre-heat the occurring gas (BFG, COG) and combustion air using high temperature exhaust gas from the hot stoves are also being applied.

Particles like dust are removed from the high temperature and high pressure BFG (blast furnace gas) exhausted from the top of the blast furnaces, and pressure energy is recovered by passing it through TRTs (top gas pressure recovery turbines) to generate electricity.

2.2.2.1.1.2. Future needs in 2030

Efficiency must be improved for the currently deployed technologies, such as PCI (pulverized coal injection), oxygen injection to hot stoves, and heat recovery from hot stoves.

A 25% reduction in the coke ratio and a 50% reduction of carbon emissions are expected through blast furnace top gas recycling – this technology is used to capture and remove CO_2 contained in BFG, pressurize and heat the gas mainly composed of H2/CO, and inject it back into the blast furnaces, designed to increase the temperature inside the furnaces by injecting oxygen.

POSCO has developed and deployed its own cast iron manufacturing technologies, FINEX method, which replaced the blast furnace method. Other countries have developed methods for removing the sintering process by reducing of iron ore in advance and expected to be deployed soon.

2.2.2.1.2. High temperature heat recovery

2.2.2.1.2.1. Status

When fuel and air mixture is burned in high temperature furnaces and power plants, exhaust gases are emitted through the smokestack. The energy efficiency of these thermal facilities is determined by the temperature of the exhaust gases.

Currently, the heat of the exhaust gas is recovered for steam production, air pre-heating, fuel pre-heating, and partial electricity generation, and efficiency improvement can be achieved by reducing the temperature of exhaust gas.

Examples of high temperature heat recovery in steel manufacturing factories: Coke produced in coke ovens is over 1000°C, and electricity is generated using the CDQ (coke dry quenching) facility that recovers a sensible coke heat. The high temperature waste heat recovered from the sintered iron produced from sintering furnaces can be used to generate steam or electricity, and it can also be used to generate hot water for local area heating.

The temperature of the hot gas is usually over 300°C and most of the heat is recovered, but there are many facilities that have a low heat recovery rate, due to the inefficient thermal exchange facilities and run-down facilities.

The typical unrecovered heat is the waste heat of melted slag produced by blast furnaces and converters. Cost effective technologies to recover the waste heat from the melted slag do not yet exist.

2.2.2.1.2.2. Future needs in 2030

Waste heat of over 300℃ must be recovered with a higher priority. Technologies to recover the waste heat that is difficult to recover, such as melted slag, must be developed.

2.2.2.1.3. Mid-low temperature waste heat recovery

2.2.2.1.3.1. Status

Waste heat below 300°C is not recovered due to low economic efficiency and high facility investment costs, but it is drawing attention as energy costs continue to rise. Waste heat over 200ºC is promoted to be recovered through steam generation, air pre-heating, water heating, and electricity generation.

2.2.2.1.3.2. Future needs in 2030

Mid-low temperature waste heat below 200ºC must be recovered as well to reduce carbon emissions and generate better energy efficiency. Efforts to reduce the cost of waste heat recovery are essential. Also it is possible to commercialize the technology economically for the recovery of waste heat of 100°C through electricity generation.

2.2.2.1.4. Combustion area

2.2.2.1.4.1. Status

Many types of industrial furnaces are used in the steel manufacturing process, and most of them are combustion furnaces that convert chemical energy contained in gas, oil, and coal into thermal energy. Coke ovens, sintering furnaces, hot stoves, lime kilns, and blast furnaces are used for the iron making process. The steel making process includes ladles, tundish, torpedo cars, cutting torches, and cast iron treatment furnaces. The rolling process uses the thermal facilities converting the chemical energy of fuel, including heating furnaces and annealing facilities.

The energy losses during the combustion process include the heat loss by walls, waste heat loss of exhaust gas, heat loss by incomplete combustion, and furnace cooling loss. Energy efficiency can be significantly different depending on many combustion related parameters, such as the temperature of exhaust gas from furnaces, gas leakage/air inflow, oxygen concentration control failure, furnace temperature control, and fuel/air (oxygen) flow meter failure.

As explained above, reducing the temperature of exhaust gas has the highest effect on improving energy efficiency, and intensive research and investment efforts have been made for waste heat recovery (recuperator, regenerative combustion, etc.). Oxygen concentration control and flow rate accuracy are also important considerations.

Oxyfuel technology can reduce energy consumption by 50% compared to air combustion with no heat recovery because the amount of exhaust gas is reduced to 1/4 of air combustion. The size of the exhaust duct can be reduced and the size of the furnaces can also be reduced due to the improved thermal transfer rate, with the higher temperature combustion rates.

Because over 90% of the exhaust gas using Oxyfuel technology is CO_2 and H2O, 90% of CO_2 is remained and can be captured, if H2O is condensed and removed. Therefore, Oxyfuel technology is considered as the main CO_2 capturing technology of CCS.

2.2.2.1.4.2. Future needs in 2030

Major combustion technologies in 2030 will be the previously mentioned exhaust gas temperature reduction and Oxyfuel combustion technology, which reduces exhaust gas and enables higher temperature combustion.

Therefore, Oxyfuel combustion technology, highly related to CCS, will become more common, and the unit cost of oxygen production needs to be lowered through the development of new oxygen production technologies.

2.2.2.2. Assessment of the gap between the current status and future needs

[Table 2.6] Gap between current status and future needs in the energy efficiency area

	Status overview	Future needs in 2030	Suitability for future needs	Reason for not suitable
Blast furnaces	Efficiency of high energy consumption blast furnaces must be improved.	Top gas recycling	Medium	Major carbon emissions process
High temperature heat recovery	Unrecovered waste heat such as melted slag	Development and application of heat recovery technology	High	Inefficient recovery technology
Mid-low temperature heat recovery	The majority of heat is not recovered due to a lack of economic value.	Economic value through the development of recovery technology	Low	The majority of heat is not recovered.
Combustion	Efficiency drops when combustion is not well controlled.	Conversion to Oxyfuel technology	Low	Inefficient combustion process

2.2.2.3. Drawing & analyzing Alternative technologies for the future

2.2.2.3.1. Alternative technology by area

[Table 2.7] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative technologies to meet future needs	Reasons for suitability
Blast furnaces	[2-A] Top gas recycling	Returning BFG to blast furnaces after removing CO_2	High	This technology is recognized as an efficiency improvement and generating coal use reduction.
High temperature heat recovery	[2-B] Melted slag heat recovery	Recovery of waste heat of melted slag	Very High	Recovery technology must be developed.
Mid-low temperature heat recovery	[2-C] Electricity generation technology using mid-low temperature waste heat	Technology to generate electricity using mid-low temperature waste heat around 200ºC	Very High	Essential for the improvement of energy efficiency
Combustion	[2-D] Oxyfuel technology	Technology to use oxygen instead of air for combustion	High	Technology will be developed coupled with CCS.
	[2-E] Combustion control technology	Operation control technology for optimum combustion	Medium	Technology has become mature to a certain degree and individual facility management is more important.

2.2.2.3.2. Analysis on alternative technologies

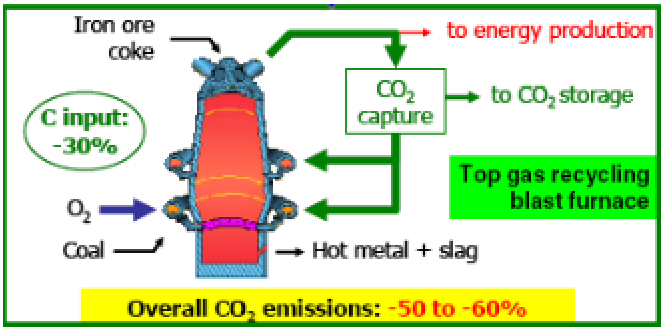
2.2.2.3.2.1. Blast furnace top gas recycling[13]

□ Overview and status

Blast furnace top gas recycling technology refers to the technologies used to capture and remove CO_2 contained in BFG generated from blast furnaces, pressurize and heat the gas mainly composed of H2/CO, and feed it back to the blast furnaces, along with oxygen for high temperature combustion as shown in <Fig 1>. Carbon consumption can be reduced by 25% and CO_2 emissions can be reduced by 50%.

13 As mentioned in CCS related discussion, there is a case that carbon capture and storage is impossible due to geographical reason of a country. In that case, Blast furnace top gas recycling is also considered as an impossible technology.

<Figure 2.13> Concept of blast furnace top gas recycling technology



□ Technological demand

The possibility of realization of this technology for carbon reduction by 2020 is high, as it is recognized as one of the technologies crucial for efficiency improvements and coal reduction.

□ Maturity

Currently, this technology is at the experiment stage. Positive results have been achieved with the testing of a 1.5t/h blast furnace of Mefos. Additional verification on operational stability and organic operation with gas plants is required.

□ Technological Barriers

Various issues related to securing CCS technologies, economic efficiency assessment and rationalizing CO_2 emissions regulations and the application of captured CO_2 must be resolved in advance, and large-scale deployment technologies must also be developed.

□ Expected technology realization period

Around 2025, a significant research period will be required for developing large-scale deployment technologies and assessment on the stability of the technology.

2.2.2.3.2.2. Melted slag sensible heat recovery technology

□ Overview and status

Iron ore, lame, or inorganic materials contained in coke are produced from blast furnaces and converter in melted states at temperatures over 1500ºC. They are currently cooled down with water due to lack of stable and economically viable recovery technology.

Around 0.2-0.3 of melted slag is produced from one ton of cast iron from blast furnaces, and the sensible heat of melted slag is 360kcal/kg, meaning that the melted slag takes 2% of the total amount of heat in the blast furnaces.

Converter slag is also produced in a melted state, but the sensible heat is not recovered. The cooled slag is reused for cement and the bed materials for road construction.

□ Technological demand

The sensible heat of melted slag is the highest unrecovered heat source in the steel manufacturing process. The application of technology to resolve this had been abandoned due to difficulties in development and a lack of economic value before 2000 in Japan, but this technology is being developed again as carbon emissions and energy efficiency issues become more serious. A small-scale facility is developed and being tested in China.

□ Maturity analysis

Melted slag sensible heat recovery technology is at the small-scale experiment stage. Research to achieve the desired level of operation stability, economic value, and the technology to utilize the heat recovered slag must be conducted.

□ Technological Barriers

Currently, slag can be used through rapid cooling, but technology to utilize the slag produced through the sensible heat recovery process in a cost effective way must be developed.

Issues in sensible heat recovery technology, economic viability assessment, and utilization of slag must be resolved first, with large-scale deployment technology also being developed.

□ Expected technology realization period

Around 2015, a period of research for large-scale deployment technology and assessment on the stability of the technology is required.

2.2.2.3.2.3. Electricity generation with waste heat

□ Overview and status

Waste heat over 200ºC is recovered through steam production, air pre-heating, water pre-heating and electricity generation, and it has a certain level of economic value.

The temperature of the exhaust gas after using the waste heat over 200ºC is below 200ºC and, currently, the use is limited due to a lack of economic value. Eventually, the technology to recover it to electricity as an efficient energy source will be required.

□ Technological demand

The technology to reduce the exhaust temperature of waste heat sources to 100 - 110ºC to prevent moisture condensation must be developed.

This is recognized as an important technology development for energy efficiency improvements and heat recovery of the exhaust gas from Oxyfuel combustion in the future.

□ Maturity

Electricity generation with waste heat is in the Prototyping stage. Actual application remains limited due to the lack of economic value, and technology to reduce installation costs is required.

□ Technological Barriers

Economically efficient turbine design and manufacturing technology, as well as thermal exchanger design/manufacturing technology must be developed.

□ Expected technology realization period

Around 2015, it is possible that some of the technologies may be complemented and commercialized if the current CO_2 reduction efforts are continued.

2.2.2.3.2.4. Oxyfuel technology

□ Overview and status

The concept is to use oxygen instead of air as an oxidizer for burning fuels. The end result is a higher flame temperature for an improved thermal transfer rate and better thermal efficiency from reduced exhaust gas because of reduced nitrogen in air.

This technology is not actively adapted because the expense of oxygen manufacturing remains a barrier.

Oxygen-enriched combustion also improves thermal efficiency, and it is used for generating hot air for blast furnaces, but the side effects are increased NOx generation due to the higher temperature of the flame.

□ Technological demand

Over 90% of the exhaust gas generated from Oxyfuel combustion contains CO_2 except moisture, with a small amount of N2 and O2. Because CO_2 can be captured at low pressure, this technology is drawing attention as one of the CO_2 capture technologies.

Oxyfuel combustion has the advantage of burning low calorific gas fuel stably, which is difficult to achieve solely using air, so it can burn the low calorific gas produced during the steel manufacturing processes. Corresponding burner technologies must be developed.

□ Maturity

Oxyfuel technology is at the small-scale experimental stage. The basic concept to connect with CO_2 capturing technology is complete and already in operation but the technical knowhow required for individual engineering technology on each furnace is important. Continuous technology development will be required because of the positive effects of carbon capturing.

□ Technological Barriers

Combustion control technology for using Oxyfuel burner with Oxyfuel combustion technology must be developed.

Furnace design and operation technology development must be accompanied by Oxyfuel technology coupled with CCS technology, and large-scale deployment technology should also be developed.

Cost effective oxygen manufacturing technologies are essential for the commercialization of Oxyfuel technology.

□ Expected technology realization period

Around 2020, economically viable carbon capturing technology for exhaust gas containing high concentration CO_2 and related Oxyfuel combustion operation control technology must be developed. More research is required for large-scale deployment and field trial technology.

2.2.2.3.2.5. Combustion control technology

□ Overview and status

Efficient combustion control technology for furnace temperature and combustion control using the burners attached to the furnace - Various technical issues, including furnace temperature and pressure setting optimization, exhaust gas oxygen content control, and pollutant control, such as NOx, remain. Combustion control technology is continuously being improved and organic coordination between the basic instrumental measurement technology of the oxygen level and furnace temperature and furnace operation pattern control technology.

□ Analysis on technological demand

There will be continuous demand for combustion control technology, since the continuous management of installed furnaces is required, and operation patterns must be changed depending on the type of combustion source and production volume.

□ Maturity

Combustion control technology is at the deployment stage. The concept was completed 10 - 20 years ago, but continuous technology development is required for practical applications. Especially, the various issues related to control logic specific to each furnace must be resolved.

□ Technological Barriers

Since the technology requirements and type of each furnace is different, proper engineering technology to establish optimized control logic and application technology is required.

If Oxyfuel technology needs to be applied, the corresponding combustion control technology should also be developed.

□ Expected technology realization period

Around 2015, the control logic and the technology to measure the parameters required for combustion control, such as temperature, pressure and concentration, can be improved in the future, which is essential for efficient operation of furnace.

2.2.3. Backend Process including Recycling

2.2.3.1. Current Status and Issues

A large amount of coal is used as the combustion source for furnaces in the steel manufacturing processes, and various gases including BFG (blast furnaces gas), COG (coke oven gas), LDG (linze donawitz gas) and FOG (finex off gas) are produced. Blast furnaces/converters produce a large amount of slag.

Since the abovementioned gases produced in the steel manufacturing process are generated from coal, sintering iron and scrap materials in furnaces, they are of a high temperature and may include foreign substances such as dust and tar. Therefore, the removal of foreign substances is essential to recover and utilize them, and currently, a wet filter is used to capture them by spraying water. High temperature heat that can be recovered otherwise is lost due to the water spray, and the water is then vaporized. Blast furnace slag, unavoidably produced by the use of coal and iron ore in the steel manufacturing process, and slag produced by converters and electric furnaces, may contain hazardous substances. Compositions of slag differ depending on the type of fuel and source materials, and granulated slag produced with rapid cooling with water and air cooled slag produced by slow cooling has a different use.

The blast furnace slag is produced mainly from impurities of iron ore, coke for reduction and lame, and around 300kg of slag is produced per ton of crude steel. The main compositions are silicon and calcium. Converter slag is produced by quicklime and mill scale, and about 140kg is produced per ton of crude steel.

Nonferrous slag includes FeNi slag that is produced during the smelting process of fero-nickel, which is used to produce nickel alloy and stainless steel, and copper slag produced during the smelting process of copper.

2.2.3.1.1. Value added utilization of byproduct gas

2.2.3.1.1.1. Status

Foreign substances are removed from the byproduct gas produced from the steel manufacturing process, and they are stored in a holder with constant pressure and supplied to the steel making process. They are used as fuels for power plants after being mixed with other furnaces in operation. The thermal efficiency of power plants using the byproduct gas is around 35-40%, and the combined power generation using gas turbines with a thermal efficiency of over 50% are deployed. However, there is a high level of fluctuation of the amount of byproduct gas produced at the steel manufacturing factories, and it is a challenge to use this waste in gas turbines when the pressure deviates from the tolerance range. COG contains over 50% of hydrogen and LDG contains over 60% of CO in volume ratio. These products can be utilized as high value added source materials. It is difficult to identify economically viable applications for BFG and FOG due to their compositions, and the best approach appears to burn them to generate electricity.

2.2.3.1.1.2. Future needs in 2030

Coal chemistry will be more cost competitive as the oil price rises, while coal prices rise relatively slowly in the future.

If coal chemistry becomes more active using the byproduct gas produced from steel manufacturing factories, the existing fuels supplied to furnaces and power plants must be replaced with other materials. Alternative solutions could be LNG for furnaces and power plants for electricity.

When CCS technology is commercialized, CO_2 contained in BFG and FOG can be captured and removed to produce more effective gases with higher calorific values. This is a sufficiently cost competitive process.

2.2.3.1.2. Technology to utilize slag

2.2.3.1.2.1. Status

The sulphate elution in the air-cooled slag produced from blast furnaces is over 7.5 times higher than granulated slag. Therefore, the main applications are low cost bed materials for road construction and coarse aggregates of cement, with application in high value added cement being limited.

Granulated slag can be recycled for high value added applications such as cement and ocean structure concrete due to its salt resistance properties.

Slag from blast furnaces is divided into devulcanized, dephosporized, converter and ladle slag, and they are used for aggregates for asphalt concrete and bed materials for road construction, due to its excellent abrasion resistance and hydraulic properties[14].

Converter slag is divided into oxidizing slag and reducing slag. Oxidizing slag is used for bricks or concrete and reducing slag is used for additives and fertilizers.

Slag from the steel manufacturing has the highest content of silicon, and slag with a high content of iron is reused at steel manufacturing factories. Research to recover slag with a high content of Nickel, Zinc, and Calcium is underway.

2.2.3.1.2.2. Future needs in 2030

The uses of various types of slag are different depending on their physical and chemical properties. Finding the right applications is important. The technology to recycle high function and high value added slag must be developed.

High value nonferrous metals such as nickel, zinc and calcium will be recovered and utilized in the future.

The application of aggregates for cement and road construction should be expanded in the future, and corresponding technology must be developed.

2.2.3.1.3. Dust collection technology

2.2.3.1.3.1. Status

Since solid materials such as coal and iron ore are used as fuel and source material in steel making process, large volumes of small particles, such as dust, can be generated. The method to capture and remove them is being developed to protect the environment.

Dust in BFG produced by blast furnaces and LDG produced by converters can be removed by water spray, and they can be reused as process fuel at steel manufacturing factories. Therefore, providing high moisture contents through the pipelines will generate pressure loss and cause corrosion and erosion due the condensation of water as the temperature drops.

2.2.3.1.3.2. Future needs in 2030

Technology to remove dust or foreign substances contained in high temperature emitted gas with the dry method is considered an important technology development, since high temperature heat can be recovered, the diameter of the pipelines can be reduced, and expenses required to remove the condensation inside the pipes can be reduced.

14 The application range may increase as it can suppress the harmfulness of concrete by chromium (Cr^{6+}), but the application of ladle slag is limited.

2.2.3.2. Assessment of the gap between the current status and future needs

[Table 2.8] Gap between the current status and future needs in environmentally friendly backend processing, including recycling

	Status overview	Future needs in 2030	Suitability for future needs	Reason for not suitable
Value added utilization of byproduct gas	Byproduct gas is used as a simple fuel.	High value added utilization of byproduct gas	Low	Inefficient use, and some are released to the atmosphere.
Technology to utilize slag	Used as cement or aggregates	High function and high value added slag	Medium	Recycling rate is high, but regrouping and higher efficiency is required.
Collection technology	Mostly wet collection is used	Dry collection enables high temperature heat recovery and improved energy efficiency.	Low	Wet collection is used, but is inefficient.

Drawing and analyzing alternative technologies for the future

2.2.3.2.1. Alternative technology by area

[Table 2.9] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative technologies to meet future needs	Reasons for suitability
High value added utilization of byproduct gas	[3-A] Coal chemistry	Converting byproduct gas from steel making to high value added interim chemical substances	Medium	More competitiveness is required compared to that prevailing in the petro chemistry industry.
Technology to utilize slag	[3-B] High function slag treatment technology	High added value slag utilization enhanced from current applications	High	Converting high value added products by enhancing the functions compared to general source materials for cement is required.
	[3-C] Technology to recover nonferrous metals from by-products of the steel making process	Technology to recover high value added nonferrous metals using currently scrapped by-products	Very High	High value added generation with by-products and resource recycling
Collection technology	[3-D] High temperature dry collection technology	Dry collection technology for heat recovery compared to the wet collection that reduces temperature	High	Development of heat resistant materials and high performance collection technologies are required.

2.2.3.2.2. Analysis on alternative technologies

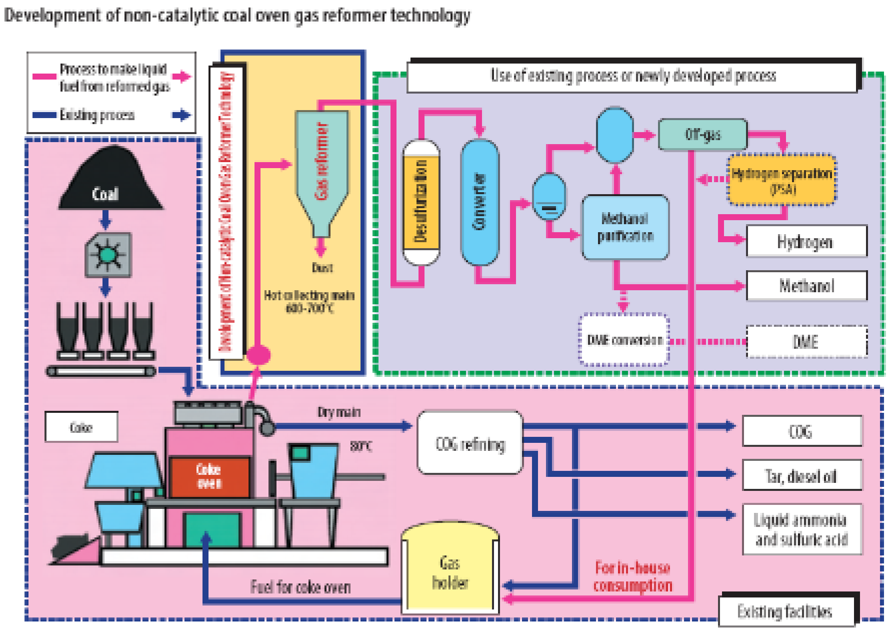
2.2.3.2.2.1. Coal chemistry

□ Overview and status

High purity carbon monoxide can be produced from LDG, where over 60% is carbon monoxide, through a separating and refining process. This can replace part of the coal used by feeding it back to the blast furnaces. It can also be used to produce interim chemical substances such as methanol.

As shown in <Fig 2.14>, interim chemical compounds including methanol and dimethyl ether (hereinafter referred to as DME) and hydrogen can be generated by passing part of the coke oven gas (COG) through a gas reactor, refiner and converter.

<Figure 2.14> Coal chemistry (interim chemical compound production process using COG)



□ Analysis on technological demand

Currently, converting enormous amounts of byproduct gas generated from the steel making process to high value added chemical products instead of using them as fuel is not competitive against the petro chemistry, but it will become competitive as oil prices rise.

□ Maturity analysis

Currently, maturity is at the basic research stage, with coal chemistry as a very old area of technology, but it is not in active use due to a lack of competitiveness against petro chemistry. New processes that can improve the competitiveness to the level observed in the petro chemistry industry remain at the basic research stage.

□ Technological Barriers

Coal chemistry is not competitive against the petro chemistry industry with existing processes.

The current issues in economic efficiency must be resolved through the development of technology to separate hydrogen and carbon monoxide from waste gas produced from the steel making process in a cost effective way, and low cost processes for producing effective chemical compounds with separated gases.

□ Expected technology realization period

Around 2025, many years will be required to establish economically viable business models from acquiring fundamental technologies of coal chemistry to establishing mass production technologies.

2.2.3.2.2.2. High performance slag treatment technology

□ Overview and status

The application with the highest economic value is cement, and it can also be used for landfill. Improving the functions of the economically viable application of slag is a major research topic.

□ Analysis on technological demand

The crude steel volume from blast furnaces and converters will be continuously increased, and the amount of slag will also increase accordingly. The development of alternative fuel to replace coal will reduces the generation of slag, but it will be of a limited range. Therefore, large-scale applications must be explored through the increase of demand in cement source materials by improving slag functions and new material development.

□ Maturity analysis

High function slag treatment technology is at the experiment stage. Finding and evaluating applications for only certain types of slag are underway.

□ Technological Barriers

As there are strict regulations on cement and aggregates, the technology to determine the mixing ratio of slag or to develop appropriate additives is necessary.

Standardization of the technologies is challenging, as there are many different types of slag and there are wide variations of compositions in the same type of slag.

□ Expected technology realization period

Around 2020, the technology to recycle slag is currently under development, and the technologies for some slag types may be realized in the near future. However, the recycling technologies for currently not recycled slag will be mature after 2020.

2.2.3.2.2.3. Technology to recover nonferrous metals from the by-products of the steel making process

□ Overview and status

This is the technology designed to recover high value nonferrous metals such as nickel and zinc contained in steel slag. Currently, the technology to recover nickel is commercialized and zinc recovery technology is soon to be commercialized.

When producing Fero-nickel (FeNi) by recycling APLAPL (Annealing & Pickling Line) slug, it can be reused in steel making processes.

□ Analysis on technological demand

Slag from the steel making process is oxidized with Si, Ca, Al, or Mg, and recovering these high value nonferrous metals has high economic value.

□ Maturity

Technology to recover nonferrous metals from the by-products of the steel making process is at the prototyping stage. Currently, the technology to recover nickel, zinc, and calcium is being commercialized.

□ Technological Barriers

The stabilization of technology is challenging, since there are large variations in the specifications of the by-products generated from the steel making process.

□ Expected technology realization period

Around 2020, as some non-ferrous metal recovery technologies in the prototyping stage are available currently, these technologies are expected to be stabilized by 2020.

2.2.3.2.2.4. Dry dust collection technology

□ Overview and status

There are many dust collection facilities designed to capture and remove particles like dust in the steel making process. Collection facilities are attached at the backend of the furnaces to capture the byproduct gas from the steel making process, and, mostly, wet technology is used, depending on the characteristics of inflammable gas. One issue in this case is the loss of waste heat due to the cooling of high temperature byproduct gas.

Dry collection technology enables capturing and removing particles at high temperature, and waste heat can be recovered and water use can be reduced because the temperature does not drop.

□ Analysis on technological demand

Dry collection technology has many years of technology development history but the research and development for dry collection technology in high temperature are slow in source material development and improving low collection efficiency. This technology can be applied to other industries when the issues are resolved.

Dry collection technology in blast furnaces enables the supply of high temperature BFG (Blast Furnace Gas) to TRT (top gas pressure recovery turbine) so as to improve efficiency by 20-30%.

□ Maturity

Dry collection technology is at the prototyping stage. Technology has been developed to a certain level of maturity at the lab scale, but the application to large-scale facilities and performance evaluations has not yet been implemented.

□ Technological Barriers

Materials that can withstand high temperatures must be developed, and the plan to improve efficiency, currently less than wet types, must be prepared. Since the pressure drops significantly when improve collection efficiency, technology to compensate this must be developed.

□ Expected technology realization period

Around 2015, currently, the technology is quite mature, and commercialization of the technology is expected in the near future through the prototyping, field trial, and performance evaluation processes.

2.2.4. Environment-friendly Steel Products

2.2.4.1. Current Status and Issues

Environmentally friendly steel products refer to steel products that are manufactured through environmentally friendly processes and that have environmentally friendly elements and use after production.

The major environmental factors are low HMR (hot metal ratio), low coal ratio, low carbon emissions and super light material development.

Indirect carbon emission reduction effects can be achieved if light materials with the same strength are applied to car to increase the fuel efficiency. Currently, many research efforts are being conducted to make lighter products, and some of them are already commercialized.

TWB (tailor-welded-blank) and hydro-forming products are steel products developed for cars for better fuel efficiency and reducing pollution gas emissions. They have been commercialized recently, and their applications are being extended. TWB steel products for cars is expected to reduce the weight by 10% and improve fuel efficiency and reduce exhaust gas, as well as reduce manufacturing costs by around 10% as a secondary effect.

2.2.4.1.1. Vehicle Materials

2.2.4.1.1.1. Status

AHSS (advanced high strength steel) includes DP (dual phase), TRIP, CP (complex phase) and martensite as shown in <Figure 2.15>, and, currently, development is complete and products are commercialized.

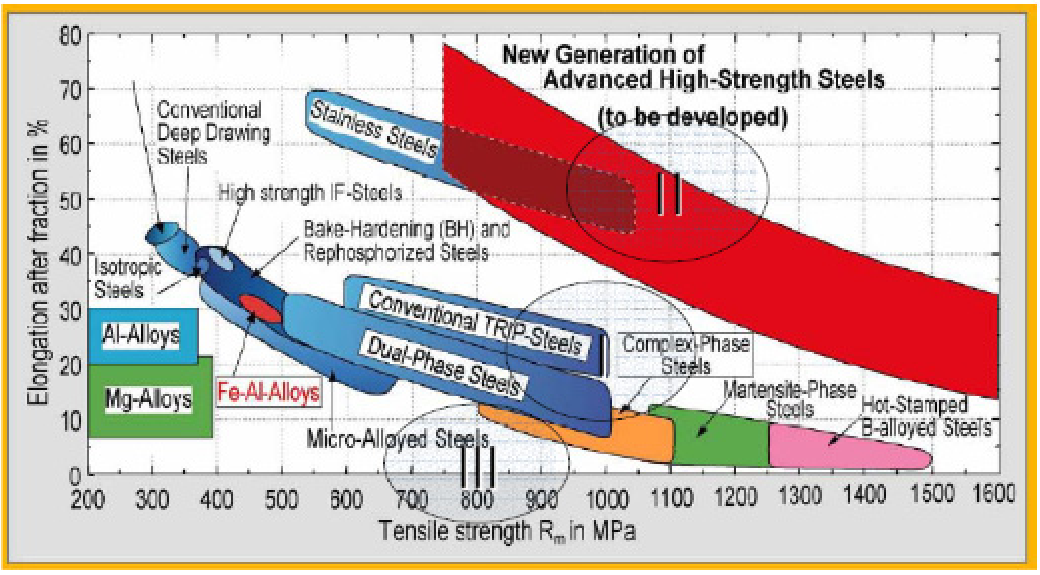
Automakers use more AHSS to reduce the weights of cars gradually. Light weight Fe-Al family high strength steel and highly flexible TWIP steel products are under development and various efforts in product diversification is being made.

Lighter cars are manufactured using tire cords with enhanced strength.

2.2.4.1.1.2. Future needs in 2030

2 million tons of high strength steel products can save 1.6 million tons of CO_2 from the auto industry alone.

<Figure 2.15> Trends of next-generation high strength steel product development



2.2.4.1.2. Ratio of coal use

2.2.4.1.2.1. Status

The current usage ratio of coal in the iron making process is 730kg per ton, and the ratio of the reducing agent is 500kg per ton. Long-term continuous reduction is required for energy savings and carbon reductions. Also developing injection technology of hydrocarbon family gas fuels into the entrance of air, improving PCI technology, and reducing the use of molten iron produced by converters with coal are also required. Cost savings and carbon reductions can be achieved through the technology to manufacture coke by partially replacing expensive high quality coking coal with low cost non-coking coal (PCI coal).

2.2.4.1.2.2. Future needs in 2030

The goal is to reduce the current coal ratio and reducing agent ratio by 8% at 2018 and by 15% until 2030.

2.2.4.1.3. Electric furnace technology

2.2.4.1.3.1. Status

Electric furnaces are used to manufacture pig iron by melting iron scrap using electricity and oxygen. Around 32% of the world's steel products are manufactured with the electric furnace process. The products contain more copper and aluminum than those produced by blast furnaces, and it is widely known to be difficult to manufacture high quality steel such as steel plates for cars. The trend in Europe is moving to electric furnace process for manufacturing steel products for the purpose of carbon emissions reduction. Technology to increase efficiency through the iron scrap pre-heating process is complete and commercialized.

2.2.4.1.3.2. Future needs in 2030

The value of pig iron produced by the electric furnace process must be increased through technology to separate copper and aluminum contained in pig iron. Strip casting technology to roll the iron produced directly from the continuous casting process of the stainless steel manufacturing process is commercialized, and is able to reduce energy consumption by 80%.

2.2.4.2. Assessment of the gap between the current status and future needs

[Table 2.10] Environmentally friendly steel products area's gaps between the current status and future needs

	Status overview	Future needs in 2030	Suitability for future needs	Reason for not suitable
Materials for cars	Increased use of AHSS materials	Better fuel efficiency and carbon reduction by reducing the weights of cars	Medium	The technology is under development and will be commercialized soon.
Coal ratio	Reduction of carbon required to manufacture steel products by reducing the use of coal	15% reduction of coal ratio	High	Research is being conducted with continuous interest.
Electric furnace process	Steel manufacturing process using iron scrap unlike the blast furnace process	Increased ratio of Electric furnace process	High	Research is being conducted with continuous interest.

Drawing & analyzing Alternative technologies for the future

2.2.4.2.1. Alternative technology by area

[Table 2.11] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative technologies to meet future needs	Reasons for suitability
Materials for cars	[4-A] Lightweight Fe-Al family high strength steel	Development of high strength Fe-Al family materials by developing phase transformation control technology.	Very High	Indirect carbon emissions reduction method or high value added steel products can be obtained.
	[4-B] Light high strength steel	Lighter and higher strength steel development compared to the current level	High	Indirect carbon emissions reduction method or high value added steel products can be obtained.
	[4-C] TWIP steel	TWIP steel	Medium	Under development
Coal ratio	[4-D] Enhanced oxygen enrichment	Reduction of hight-productivity and BFG by injecting oxygen to the hot air blowing into blast furnaces	Very High	The technology is already mature, and additional improvement depends on the availability of oxygen.
	[4-E] Use of non-coking coal	Reduction of the use of expensive coal by using low cost coal in manufacturing coke	Very High	The technology is already mature and more improvements are expected.
Electric furnace r	[4-F] Technology to improve the quality of cast iron	To improve the quality of pig iron by removing foreign substances in pig iron produced by the electric furnace process.	Very High	The role of the converter process becomes more important for carbon reduction, but the limitations of steel quality must be resolved.
Electric furnace	[4-G] Strip casting	To manufacture environmentally friendly products by saving energy	High	Energy saving performance is high.
Misc	[4-H] Lightweight structure materials	High corrosion resistant high tensile strength steel, including stainless steel	High	Increased long-term durability by improving the tensile strength and corrosion resistance of existing materials

2.2.4.2.2. Analysis on alternative technologies

2.2.4.2.2.1. Lightweight Fe-Ni family high strength steel

□ Overview and status

Fe-Ni family steel products are widely used as vehicle material, and the goal is to reduce the specific gravity and weight by improving strength. Phase transform control technology and surface quality improvement technology must be developed.

□ Maturity analysis

Lightweight Fe-Ni family high strength steel is at the experimental stage. Currently, the technology is under development.

□ Technological Barriers

Phase transformation control and surface quality control technology must be developed.

□ Expected technology realization period

Around 2020, many years will be required to stabilize the technology and mass production for commercializing.

2.2.4.2.2.2. Lightweight high strength steel

□ Overview and status

The concept is to improve the strength of lightweight materials by combining metal, ceramics, carbon fiber or polymer, and to improve the toughness of brittle materials, instead of simple enhancement of ductility.

As multi-layer material with ultra high strength martensite as one of the layers, high strength martensite with low ductility is used in the surface layer of composite layer materials to enhance the strength and to improve ductility by controlling the material quality, characteristics, and geometrical design of the multiple layer structure.

□ Maturity analysis

Currently, lightweight high strength steel is at the basic research stage. Mid-long term research is required.

□ Technological Barriers

Processing of material, easy to brittle by hydrogen characteristics, and welding must be secured.

□ Expected technology realization period

Around 2020, many years will be required for mass production and technology stabilization.

2.2.4.2.2.3. TWIP STEEL

□ Overview and status

TWIP steel products with high strength and high elongation rates are currently being manufactured in Korea, and the market needs to be expanded through new product development using new components (high contents of Mn and Al) and through product diversification.

□ Maturity analysis

TWIP STEEL is at the mass production and deployment stage. Development is complete and the market is being expanded.

□ Technological Barriers

New product development using new elements and product diversification is required.

□ Expected technology realization period

Around 2015, many years will be required for mass production and technology stabilization.

2.2.4.2.2.4. Oxygen enrichment improvement technology

□ Overview and status

Air blown into blast furnaces is pre-heated to temperature of around 1200ºC in the hot stove. Oxygen enriched air containing 5-15% oxygen has been used to improve the reaction inside the blast furnace since the 1990s.

Injected oxygen improves productivity, and produces less BFG waste gas and higher temperature inside the furnace.

□ Analysis on technological demand

The ratio of injected oxygen has been increased to higher level over time for improved productivity, but the facilities to produce oxygen should also be expanded accordingly.

□ Maturity analysis

Currently in the practical stage, this technology is already applied, and the effects of increased oxygen content must be analyzed.

□ Technological Barriers

Low cost oxygen production technology is essential for the commercialization of oxygen enriched air technology, but there are many technical challenges on application.

□ Expected technology realization period

Around 2015, the goal is to increase the content of oxygen in the air up to 40% by injecting oxygen to the level of 20% of air. Oxygen enrichment technology to inject oxygen during hot air production is already deployed, but continuous improvement is required for improved productivity and coal ratio reduction.

2.2.4.2.2.5. Non-coking coal

□ Overview and status

This is the technology designed to replace part of expensive high quality coking coal with low price non-coking coal (PCI coal) for coke production.

□ Analysis on technological demand

Manufacturing costs and coal ratios can be reduced using low cost non-coking coal.

□ Maturity analysis

Currently in the deployment stage, this technology is already deployed in advanced countries, and the replacement use of non-coking coal must be increased.

□ Technological Barriers

Technological assessment on the effects of increased non-coking coal on the quality of coke is needed.

□ Expected technology realization period

Around 2015, the goal is to increase the use of non-coking coal by up to 20%.

2.2.4.2.2.6. Technology to improve the quality of cast iron produced by electric furnace

□ Overview and status

The quality of pig iron produced through electric furnace by melting iron scrap is determined by the amount of foreign substances contained in the iron scrap.

In general, the quality of pig iron produced by electric furnace is known to be lower than that produced by blast furnaces because of the high content of foreign substances, such as copper or aluminum.

□ Analysis on technological demand

In the future, a move to less energy consuming electric furnace from blast furnaces in order to reduce carbon emissions will be required. Accordingly, technology to improve the quality of iron produced by electric furnace must be developed.

According to ULCOS, the level of pure iron can be increased to 97%, which is higher than blast furnace (93%) by using DRI (direct reduced iron) technology and improving the quality of iron scrap used in electric arc.

□ Maturity analysis

Currently in the experimental stage, DRI technology and iron scrap need to go through purification process to reach deployment stage, for which small-scale tests are being conducted.

□ Technological Barriers

Technology to selectively remove copper (Cu) from melted iron (Fe) is not established. DRI technology and iron scrap purification methods must be established and stabilized for deployment.

□ Expected technology realization period

After 2030, long-term research will be needed and new technology is required.

2.2.4.2.2.7. Strip casting technology

□ Overview and status

This is the technology designed to make thin sheet products directly from melted iron fresh out of furnaces. In the existing steel making process, hot coil (hot rolled steel sheet) is produced through the steel making process to produce steel by extracting carbon from melted iron. Continuous casting and the hot rolling process are used for making sheets from melted iron.

Strip casting technology is a new technology designed to skip the steel making, continuous casting, and hot rolling processes altogether, promising 200 billion won facility investment savings if applied to stainless steel production lines. Manufacturing costs will be lower than those of the existing steel technology by 30%.

This technology has been developed across the world in the 2000s.

□ Maturity analysis

Currently in the practical stage, this technology has been developed across the world in the 2000s.

□ Technological Barriers

Stabilization of the technology is required.

□ Expected technology realization period

Around 2015, this technology is expected to be commercialized soon.

2.2.4.2.2.8. Lightweight material for structures

□ Overview and status

Continuous research and development for commercialization are in progress in the areas of reducing the weight of materials used in bridges and buildings, and surface treatment technologies such as coating for improving corrosion resistance.

More nonferrous metals, such as aluminum and magnesium, are being introduced to reduce the weight of products.

□ Maturity analysis

Currently, as an experimental stage technology, the area is under development.

□ Technological Barriers

Surface treatment technology and material heat treatment technology are required.

□ Expected technology realization period

Around 2015, this technology will be commercialized soon.

2.3. Green Technological Needs in Cement Industry

Indicators have proved to help track progress against the cement roadmap. It is difficult to develop such indicators because technologies advance at different speeds and the implementation of CO_2 reduction options is unpredictable. Nevertheless, developing future science & technology and policy planning by stage are helpful in measuring the developing milestones of cement industry. The indicators became essential items to identify various items such as implementation of the best available technology, alternative fuel use, clinker substitution and CCS development, and demand by 2050. These indicators aim to illustrate what developments are needed in the cement industry to achieve the targets set out in the roadmap. They can be used as a general guideline for setting targets under an international collaborative framework. The figures for CCS display a doubt for unproven future technology and commercial viability in current status, and highlight the urgent need for detailed action in deployment phase.

[Table 2.12] Cement Roadmap Indicators

	2012	2015	2020	2025	2030	2050
Thermal energy consumption per tonne of clinker GJ/ tonne	3.9	3.8	3.5-3.7	3.4-3.6	3.3-3.4	3.2
Share of alternative fuel & biomass use (1)	5-10%	10-12%	12-15%	15-20%	23-24%	37%
Clinker to cement ratio	77%	76%	74%	73.5%	73%	71%
CCS						
No. of pilot plants	2	3				
No. of demo plants operating		2	6			
No. of commercial plants operating				10-15	50-70	200-400
Mt stored	0.1	0.4	5-10	20-35	100-160	490-920
Tonne CO_2 emissions per tonne cement (2)	0.75	0.66	0.62	0.59	0.56	0.42

Source: WBCSD-IEA (2009: 24)

2.3.1. Alternative Fuel and Source Material

2.3.1.1. Current Technologies and Issues

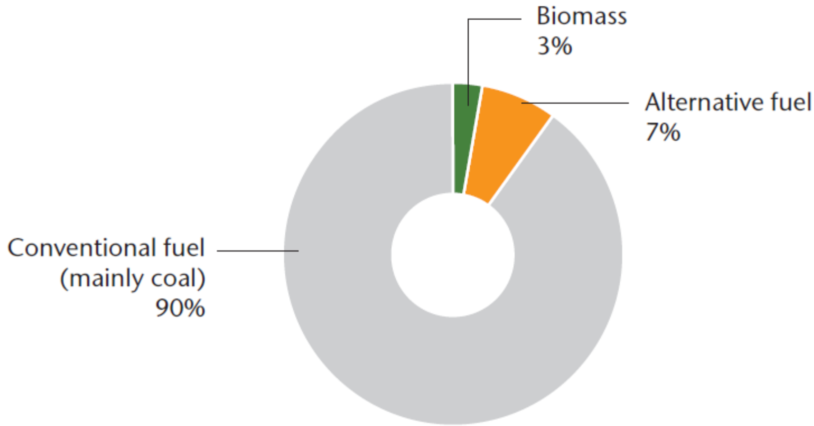
Scrap tires, scrap plastics and recycled oil that are used for alternative fuels for cement manufacturing can replace and reduce the consumption of coal. Other biomass sources can be recycled for saving and reusing energy. The cement industry is known to produce high levels of greenhouse gases during the clinker manufacturing process using limestone. Therefore, an alternative source material is being actively deployed to reduce the emission of greenhouse gases. The composition of alternative source materials to produce cement products are analyzed and go through the mixing and grinding processes in order to maintain quality homogeneity before use, to provide the elements required producing cement (CaO, SiO_2, Al_2O_3, Fe_2O_3).

2.3.1.1.1. Alternative fuels

2.3.1.1.1.1. Current status

85% of the fuel used in the cement industry is coal, and alternative fuels, including scrap tires, scrap plastics and recycled oil are also used for the rest. Other alternative fuels using biomass and other waste with high calorific values, such as waste sludge, are being planned for implementation. In order to use the various types of alternative fuels, both the infrastructure system such as waste handing regulations and corresponding technologies must be improved and developed.

<Figure 2.16> Percentage of total fuel consumption per fuel source (2006)



2.3.1.1.1.2. Future needs in 2030

Discovering various alternative fuels and application technologies are required to replace 23-24 % of coal with alternative fuels as a heat source. Cost-saving effects are anticipated through expanding technologies and facilities with which cement factories can treat the source materials directly or without pre-treatment, via improvements in the collection and treatment methods of alternative fuels. Plans for the distribution and securing of waste materials for extended application in the future should be considered, as well as the immediate needs of collection and application of alternative fuels.

2.3.1.1.2. Alternative source materials

2.3.1.1.2.1. Status

Various natural resources, such as limestone, clay, silica and iron ore are used to produce cement, and recycled materials, such as coal lime, molding sand, sludge and iron slag are also used.

The compositions of the alternative source materials are analyzed before their use to prevent any adverse impact on the quality and manufacturing processes. They are mixed and grinded with limestone, the main component of cement, and calcinated at over 1,450 ˚C in a kiln for a thermo-chemical reaction to produce cement minerals such as C3S, C2S, C3A, and C4AF.

2.3.1.1.2.2. Future needs in 2030

60% of CO_2 emission comes from decomposition of limestone in kilns during cement clinker production process. The development of CaO alternative material to replace limestone in the cement industry is required. Technologies to isolate Chlorine residue and to remove heavy metals should be developed in order to use waste material containing chloride and heavy metals such as incinerated lime from city waste. Technologies to convert hazardous waste, such as waste asbestos, into alternative source materials or alternative fuel could become very attractive.

2.3.1.2. Assessment of the gap between current status and future needs

[Table 2.13] Status of alternative fuel and source materials – Efforts to meet future needs

Area	Status summary	Future needs in 2030	Suitability to meet future needs	Reason for not suitable
Alternative fuel	Pre-treated industrial and city solid waste, scrap tires, waste oil, scrap plastic, and biomass are used.	Technology to convert waste with a high chloride content and hazardous flammable waste to fuel	Relatively Low	Manufacturing cost will increase
Alternative source material	Majorities of alternative source materials provides SiO_2, Al_2O_3, and Fe_2O_3 components but the alternative sources for CaO are insufficient. And use of alternative source materials containing high chloride is restricted	Alternative source materials containing CaO component and technologies to use waste with high chloride contents as alternative source materials are required	Relatively Low	Manufacturing cost will increase due to the transportation cost. Facilities to remove chloride is required

2.3.1.3. Drawing & analyzing Alternative Technologies in the Future

2.3.1.3.1. Alternative technology by area

[Table 2.14] Alternative technologies for fuels and source materials

Area	Alternative technologies	Concept (summary)	Suitability of alternative solutions to meet future needs	Reasons for suitability
Alternative fuel	[1-A] Technology to use ASR as a heat source	To use flammable waste with a high chloride content as a heat source	High	Converting hazardous waste to fuel and utilizing waste with high calorific values
Alternative source materials	[1-C] Technology to use iron slag as an alternative source material for limestone	Alternative source materials for CaO that can reduce CO_2 emissions from the demineralization process of limestone by 40%	High	Reduction of environment load by reducing CO_2 emissions and through waste treatment
	[1-D] Technology to use city waste incinerated lime as fuel	To use city incinerated lime as source materials for cement through chloride treatment	Relatively High	Longer lifetime of landfill sites and resource savings

※ [1-B] Biomass technologies are not listed here as they are covered in the steel industry section.

2.3.1.3.2. Analysis on alternative technology

2.3.1.3.2.1. Technology to use Automobile Shredder Residue (ASR) as a heat source

□ Overview and current status

The calorific value of ASR is 6,500 kcal/kg, which is relatively high. However, it is difficult to use as an alternative fuel source as the content of the chloride is over 15,000ppm. Multi stage separation processes are required as ASR contains various materials, including plastic, rubber, fiber, sponge and soil. There is also a high possibility of incomplete combustion, as it includes a large amount of flame retardant materials. There have been efforts in the research and development for the use of ASR to manufacture cement products by drying and gasification, but the problems of low production yield and heavy metal treatment still remain.

□ Technological demand

Total volume of waste from scrapped cars should be reduced to less than 5% by 2014 according to the Scrap Vehicle Treatment Regulations of the EU. Accordingly, there will be higher demand for utilization of ASR as a heat source. Using ASR as an alternative fuel is promising, as the technologies to remove the chloride inside kiln are now quite mature.

□ Maturity of the technology

Technology to use automobile shredder residue (ASR) as a heat source had undergone the experiment stage, and is at the prototyping stage for field trial stage.

□ Technological barriers

Chloride treatment technology is essential for using ASR as an alternative fuel source because the content of chloride is over 1,5000ppm. Multi stage separation processes are required, as ASR contains various materials. Pollution substances in the exhaust gas should also be considered, since there is a high possibility of incomplete combustion, as it includes a large amount of flame retardant materials.

□ Expected technology realization period

Around 2020, the concept of the technology has been established and environmentally friendly chloride treatment technology is under development.

2.3.1.3.2.2. Technology to use iron slag as an alternative material for limestone

□ Overview and current status

60% of CO_2 emissions come from the decomposition of limestone in the kiln during the cement clinker manufacturing process. The content of CaO in iron slag is about 40-46%, which is lower (approx.63%) than general Portland cement, but it can substitute for a large portion of limestone to reduce CO_2 emissions. But the early strength is lower and electric power demand in the grinding process is higher.

□ Maturity of the technology

Currently, this technology is not implemented because of economic feasibility but more research is required to evaluate its application.

□ Technological barriers

Transportation of the material from steel plants to the cement factory is the biggest cost increase factor.

□ Expected technology realization period

Around 2015, factories with cost effective processing facilities are anticipated.

2.3.1.3.2.3. Technology to use incinerated lime from city waste

□ Overview and current status

Utilizing general waste is very important from the viewpoint of environmental preservation, and one of the options is incinerated lime from city waste. Currently, all is buried. Key technologies to use city waste incinerated lime for producing cement are intended for the prevention of environmental pollution from heavy metals and dioxins contained in the incinerated lime, and the cost effective removal of chloride to be used in the cement manufacturing processes. The chloride bypass system, as a subsidiary facility designed to remove the chloride, is essential when seeking to use city waste incinerated lime for producing cement.

□ Maturity of the technology

Technology to use incinerated lime from city waste is at the prototyping stage. This technology is already being deployed in some cement factories.

□ Technological barriers

Cost effective chloride and heavy metal removal technologies are required to be developed.

□ Expected technology realization period

Around 2020, Cost effective chloride and heavy metal removal technologies are expected to be possible with increasing investments into this area.

2.3.1.3.2.4. Other clinker substitutes

Besides the abovementioned materials, fly ash, pozzolanas and limestone may be considered.

[Table 2.15] Clinker Substitutes

Clinker substitute	Source	Positive characteristics	Limiting characteristics	Estimated annual production level	Availability
Ground blast furnace slag	Iron or steel production	Higher long term strength and improved chemical resistance	Lower early strength and higher electric power demand for grinding	200 million tonnes(2006)	Future iron and steel production volumes are very difficult to predict
Fly ash	Fuel gases from coal-fired furnaces	Lower water demand, improved workability, higher long term strength, better durability (depending on application)	Lower early strength, availability may be reduced by change in fuel sources by the power sector	500 million tonnes(2006)	Future number and capacity of coal-fired power plants is very difficult to predict
Natural pozzolanas (e.g., volcanic ash), rice husk ash, silica fume	Volcanoes, some sedimentary rock, other industries	Contributes to strength development, can demonstrate better workability, higher long term strength and improved chemical resistance	Most natural pozzolanas lead to reduced early strength, cement properties may vary significantly	300 million tones available(2003) but only 50% used	Availability depends on local situation many regions do not provided use of pozzolana for cement
Artificial pozzolanas (e.g., calcined clay)	Specific manufacture	Similar to natural pozzolanas	Calcinations requires extra thermal energy and so reduces positive CO2 abatement effect	Unknown	Very limited availability due to economic constraints
Limestone	Quarries	Improved workability	Maintaining strength may require additional power for grinding clinker	Unknown	Readily available

Source: WBCSD-IEA (2009:12)

2.3.2. Energy Efficient Process

2.3.2.1. Status of current technologies and issues

The main processes for manufacturing cement are to mix and grind the limestone, the main component of cement, with other clay and mineral materials and calcinate the mixture at high temperature of 1,450 ˚C. The level of CO_2 emissions in this process is about 80% of the cement production volume. The total energy consumption required for the cement manufacturing process is about 780kcal/kg-cement, of which 690 kcal/kg-cement is supplied by the fuel and the remaining 90kcal/ kg-cement is supplied by electric power. Incremental improvements through the use of waste heat and through improving thermal exchange efficiency have reached their limitations and there is no more room left for improvements in energy savings. Existing ball-mills for the grinding process had been replaced by roller-mills, which have higher grinding efficiency and thus require less electric power, and also simplify the facilities, as they can perform grinding, feeding and drying at the same time. Additional energy saving plans include spare grinders and high efficiency feeders.

2.3.2.1.1. Kilns

2.3.2.1.1.1. Status

Since the early 1980s, in order to increase energy efficiency, the half-dry type Lepol process and the four stage SP (Suspension Preheater) process, which have low thermal efficiency, have been replaced by the NSP (New Suspension Preheater) process for cement calcination, a process that consumes over 70% of the energy in the cement industry, with a successful outcome.

A cyclone type pre-heater is installed at the front side of the rotary kiln in SP and NSP type kilns. 4-5 stages of cyclones are arranged and connected to the frame of the pre-heater at heights of 50-100 meters, and the source mixture power goes down through these cyclones sequentially, with the heat exchanged with the kiln exhaust gas coming from the opposite direction. It is pre-heated to a temperature of 850 ˚C before going into the kiln.

More stages of cyclone result in improved thermal efficiency. Therefore, converting the four stage cycle to five stages will improve productivity and energy efficiency.

2.3.2.1.1.2. Future needs in 2030

Environmentally friendly kilns with higher efficiency ratings and lower NOx, SOx and CO_2 emissions than existing rotary kilns need to be developed.

Also the kilns that can meet the needs of diversifying customer needs, as well as stable combustion technologies and kilns that can handle a wide range of coal types should be developed.

2.3.2.1.2. Combustion process

2.3.2.1.2.1. Status

The majority of the energy in cement manufacturing is consumed during the calcination process.

Since the main fuel used has been switched from heavy oil to coal, the majority of burners can work with both coal and heavy oil.

Recently, there have been many research projects undertaken on the optimization of the combustion of burners by utilizing the hydrokinetics simulation technologies.

Burners that can handle alternative fuels are supplied to follow the trend of moving from coal to alternative fuels.

2.3.2.1.2.2. Future needs in 2030

Technologies designed to handle various calcining states of clinker and to optimize burners are required to manufacture high quality clinker, stabilize the calcining process and save energy.

Oxyfuel combustion technology produces 90% of CO_2 and H2O in its exhaust. CO_2 can be captured through a simple condensing process. Oxyfuel technology is considered as one of the CO_2 capture technologies.

2.3.2.1.3. Cooling process

2.3.2.1.3.1. Status

Clinker produced through the calcination process is emitted at the temperature of about 1200-1300 ˚C. The cooler is a facility used to cool it down to below 100 ˚C in a short period of time.

Coolers are configured in multiple stages and clinker moves from the entrance (high temperature) to exit (low temperature) through a hydraulically driven linear motion of fixed and sliding gate plates.

Various types of horizontal rotating cylinder coolers and air rapid cooling systems are used for rapid cooling of clinker and pre-heating of combustion air simultaneously.

The majority of the existing systems are grate coolers (simple grate coolers in older systems and IKN or CIS type grate coolers in newer systems).

2.3.2.1.3.2. Future needs in 2030

The requirements for the future are higher energy efficiency than existing grate coolers, higher temperature 2nd and 3rd gas, reduced electric energy consumption, longer cooler lifetime, the prevention of clinker falls into the lower part of the cooler and ease of operation.

2.3.2.1.4. Heat recovery

2.3.2.1.4.1. Status

Hot air produced from clinker cooling process in coolers is reused for combustion air in pre-heater and kiln. The remaining air is cooled and emitted to a chimney through the exit of the cooler or filtered dust collector.

2.3.2.1.4.2. Future needs in 2030

It is essential to utilize the waste heat produced in the clinker cooling process to generate electricity or for other purposes due the characteristics of the cement industry, in which it consumes high levels of energy and produces high levels of CO_2.

2.3.2.2. Assessment of the gap between current status and future needs

[Table 2.16] Gap between current status and future needs in energy efficiency area

Area	Status summary	Future needs in 2030	Suitability to meet future needs	Remarks
Kiln	Low energy efficient rotary kilns are used.	High energy efficient kilns are required.	Relatively low	Mass production technology and Technology with economic efficiency is required.
Combustion process	Air is used to burn the fuel with a burner in the rotary type kiln.	Oxygen fuel technology is required to obtain high purity CO_2 from the cement manufacturing process.	Relatively high	Technology to deploy on a large scale with economic efficiency should be developed.
Cooling process	Mainly grate coolers are used. Higher efficiency coolers are required.	Higher efficiency and longer lifetime coolers are required for reducing energy consumption and CO_2 emissions.	Relatively low	Economic efficiency of facilities
Heat recovery	Some of the heat produced by the clinker cooler is exhausted.	Energy saving using waste heat is required.	Relatively high	Economic efficiency of facilities

2.3.2.3. Drawing & Analyzing Alternative Technology in the Future

2.3.2.3.1. Alternative technology by area

[Table 2.17] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative solutions to meet future needs	Remarks
Combustion process	[2-A] Oxyfuel technology	Obtaining relatively pure CO_2 by combustion using oxygen instead of air	Relatively High	Suitable for carbon capture
Cooling process	[2-B] High efficiency coolers	Optimization of conveying system and air distribution system	High	High energy efficiency and reduced energy consumption
Heat recovery	[2-C] Waste heat generation technology	Electricity generation with high temperature air generated from the cooler	High	Reduced electric energy consumption and reduced energy consumption

2.3.2.3.2. Alternative technology analysis

2.3.2.3.2.1. Oxyfuel technology

□ Overview and current status

Oxygen is used as the oxidizing agent instead of air. The concentration of CO_2 in the exhaust gas increases due to the reduced composition of nitrogen contained in air.

Issues with Oxyfuel technology are increased NOx emissions due to the higher temperature flames and the costs of producing oxygen.

□ Technological demand analysis

Because over 90% of the exhaust gas is CO_2 with a small amount of nitrogen and oxygen, by using Oxyfuel technology, CO_2 can be captured with relatively minor pressure. Therefore, Oxyfuel technology is considered to be one of the CO_2 capturing technologies.

Since Oxyfuel technology enables the combustion of materials with low calorific values, technological development for the burners should follow for wider application.

□ Maturity of the technology

The basic concept of Oxyfuel technology in connection with CO_2 capture technology is established. Currently, the technology is at the experimental stage, with small-scale prototypes having been developed.

□ Technological barriers

Oxyfuel technology as a CO_2 capture and storage technology should be developed in parallel with the design and operation technologies, and technologies for large-scale deployment should be developed as well.

The technology to produce low cost oxygen is essential in order to commercialize the Oxyfuel process, but there remain many difficulties.

□ Expected technology realization period

Around 2025, technologies for a cost effective method of capturing CO_2 contained in the exhaust gas that contains high concentration CO_2, and the technologies for Oxyfuel system operation control should be developed. More research will be required for the large-scale deployment and field trials.

2.3.2.3.2.2. High efficiency coolers

□ Overview and current status

Cross bar cooler is a type of high efficiency cooler with an optimized conveying system and air distribution system, unlike existing conventional coolers. It provides high energy efficiency and high temperature 2nd and 3rd air.

It is known to be more energy efficient than IKNS and CIS type grate coolers by saving 20-30kcal/kg-clinker.

□ Technological demand analysis

The effects of the technology have been proven, and it is highly probable that this technology will be commercialized in the cement industry, despite the additional costs, due to the benefits of energy savings and reduced carbon emissions.

□ Maturity of the technology

High efficiency coolers are at the commercialization stage. This technology is quite mature and it is already applied in some cement factories.

□ Technological barriers

The positive effects are being proven using the new facilities, but increased costs from additional facilities are problematic.

□ Expected technology realization period

Around 2015, improved cooler technology for better thermal efficiency is expected to reach the mass production stage by 2105.

2.3.2.3.2.3. Waste heat power generation

□ Overview and current status

Hot air (370 ˚C) coming from the ceiling of clinker coolers in the cement manufacturing process is sent to the waste heat boiler through dust collector. It heats the water and generates electricity by rotating turbine with steam. CO_2 emissions are reduced as a result.

The waste heat generation system is configured mainly as a boiler, turbine, generator and water treatment facilities.

□ Technological demand analysis

The effects of the technology are already proven, and the technology is promising for the cement industry, which consumes large amounts of energy and generates high levels of CO_2.

□ Maturity of the technology

Waste heat electricity generation is at the commercialization stage. This technology is mature to a certain level, and it has already been applied in some cement factories.

□ Technological barriers

The positive effects from the currently deployed facilities have already been proved, but cost increases due to the installing facilities might an issue.

□ Expected technology realization period

Around 2015, the same technology has already been applied to other industries, and has been put to use in the cement industry only recently. Mass production is expected in five years from now.

2.3.3. Backend Process including Recycling

2.3.3.1. Status of current technologies and issues

The alternative fuel replacement ratio is expected to reach 12-15% by 2020 and 23-24% by 2030, according to the Cement Roadmap Indicators (in case of the Blue scenario) of IEA. Some of the waste materials used as alternative source materials and fuels contain volatile substances, such as chloride. They are condensed inside the kiln and pre-heater, and form chemical compounds with low melting points and coating materials in kilns and pre-heaters. The coating materials formed in this way degrades the stability of the calcination process. The use of chloride substance is restricted in some countries because the irons inside the concrete are corroded by the presence of chloride substance in cement.

2.3.3.1.1. Environmentally friendly treatment of dust

2.3.3.1.1.1. Status

Some factories have alkali bypass systems or chloride bypass systems for the purpose of desalinization. Those systems isolate dust containing alkalis and chlorides from the kiln and pre-heater processes.

The isolated dust is usually used in the clinker grinding process.

2.3.3.1.1.2. Future needs in 2030

It is very important to develop the technology to treat dust from the chloride bypass system without causing adverse effects for the environment in order to expand the use of alternative source materials and to utilize city waste incinerated lime.

Dust coming from the chloride bypass system contains a large amount of useful materials, such as potassium chloride. Therefore, the technologies required to recover these materials need to be developed.

2.3.3.2. Assessment of the gap between current status and future needs

[Table 2.18] Environmentally friendly backend process, including recycling

Area	Status summary	Future needs in 2030	Suitability to meet future needs	Remarks
Environmentally friendly treatment of dust	There is a limitation in the use of alternative source materials and fuels due to the increased chloride substances in the kilns and pre-heaters, as more alternative source materials and fuels are used.	The system to remove chloride from kilns and pre-heaters effectively and the technology to isolate the dust from the system without having adverse effects for the environment need to be developed.	Medium	Loss in thermal efficiency and facility installation costs

2.3.3.3. Drawing and Analyzing Alternative Technology in the Future

2.3.3.3.1. Alternative technology by area

[Table 2.19] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative solutions to meet future needs	Reasons of suitability
Environment friendly treatment of dust	[3-A] Chloride by-pass system	Technology to isolate the dust that contains large amounts of chloride compound by bypassing some of the flue gas from the back side of the kiln during the calcination process	High	Use of alternative source materials and fuels can be increased.
	[3-B] Dust detoxification technology	Technology to remove the heavy metals and recover the useful substances such as potassium chloride from the dust exhausted from the chloride bypass system	Relatively High	Technology to recover the useful substances containing chloride from the dust and recycle the remaining materials

2.3.3.3.2. Alternative technology analysis

2.3.3.3.2.1. Chloride by-pass system

□ Overview and current status

This system uses the same principle of operation as the existing alkali bypass system. It isolates chloride selectively from kilns and pre-heater systems very effectively.

The major components of the chloride bypass system are probe, coarse particle separate cyclone, cooler, bag filter and etc.

The probe is a piece of equipment that takes part of the gas around the inlet of the kiln and cools it down below the solidification point of the chloride compound at the same time. The coarse particle separate cyclone filters the coarse particles with low chloride content and sends them back to kiln. The bag filter is a piece of equipment used to capture micro powder with a high content of chloride.

□ Technological demand analysis

This technology becomes essential as the use of alternative fuels increases. The demand for this technology is only likely to increase.

□ Maturity

The chloride by-pass system is at the mass production and commercialization stages. This technology is used for cement kilns using alternative source materials and fuels with a high content of chloride.

□ Technological barriers

The problem of reduced thermal efficiency is happening from bypassing flue gas inside the kiln.

The larger bypass volume makes less trouble by volatile substances inside the kiln but increases the amount of dust exhausted. Therefore, the technology to treat the dust effectively is required.

□ Expected technology realization period

Chloride bypass system is currently at commercialization stage. It is an applied technology of an existing technology, alkali bypass system, and is currently used by some cement factories. This equipment is expected to be used more widely by 2015, when the use of alternative fuels will be over 10%.

2.3.3.3.2.2. Dust detoxification technology

□ Overview and current status

Micro powders with high chlorine content are recovered as dust by the bag filter in the chloride bypass system. This micro powder dust is fed into the clinker grind mill to be added to the cement.

Technology to treat chloride and heavy metals should be developed, since the content of chloride and heavy metals in micro power dust increases, as more waste materials with high chloride content are being used.

Dust detoxification facilities are configured as a washing process that removes chloride and heavy metals, a waste water treatment process that removes heavy metals, and a crystallization process that recovers KCI.

□ Technological demand

This technology is becoming more essential as more alternative fuels are used, and the demand for this technology is only likely to increase.

□ Maturity of the technology

Dust detoxification technology is expected to be realized around 2015. Currently, development for large-scale deployment in connection with bypass dust systems is mature.

□ Technological barriers

Increased facility investment costs

□ Expected technology realization period

Around 2020, this is the same technology already used in other fields, such as washing systems, waste water treatment processes and crystallization processes. This system is expected to be deployed widely by 2020, when the chloride bypass system becomes popular and more alternative source materials and fuels with high chloride content are in use.

2.3.4. Environment-friendly Cement Products

2.3.4.1. Status of current technologies and issues

Nowadays, recycled materials are utilized not only for material sources and fuels for cement, but also for lowering clinker calcination reaction temperature range and reducing CO_2 emissions. Therefore, various types of environmentally friendly low temperature calcinations cements are reviewed. As the cement industry is actively exploring the feasibility of utilizing waste materials such as blast furnace slag and coal lime, other by-product or scrap materials are being more widely explored. Among them, technologies to manufacture cement products using city waste are at the deployment stage. Currently, incinerated lime is the main source of environmentally friendly cement in Japan, along with waste materials such as sewer sludge when required. Environmentally friendly cement has more limitations in application than general Portland cement due to the high content of Al2O3 and Cl. In the future, the technology to manufacture environmentally friendly cement using city waste or household waste as a main source while having similar characteristics with general Portland cement will be required, as the cost of treating waste material will increase due to the shortage of final landfill sites.

2.3.4.2. Assessment of the gap between current status and future needs

[Table 2.20] Gap between current status and future needs for environmentally friendly cement

Area	Status summary	Future needs in 2030	Suitability to meet future needs	Reason for not suitable
Environmentally friendly cement	Technology to manufacture cement products using city waste is at the deployment stage.	Technology to manufacture cement product using waste materials as the main source, with similar characteristics to Portland cement	Medium	Increased content of salt and heavy metals in cement

2.3.4.3. Drawing and Analyzing Alternative Technology in the Future

2.3.4.3.1. Alternative technology by area

[Table 2.21] Alternative technology by area for environmentally friendly cement

Area	Alternative technology	Concept (Overview)	Suitability of alternative solutions to meet future needs	Reasons for suitability
Environmentally friendly cement	[4-A] Eco-cement	Technology to manufacture cement product using waste materials, including city waste, as the main source, with similar characteristics to Portland cement	Relatively High	Reduced environment load by treating waste materials

2.3.4.3.2. Alternative technology analysis

2.3.4.3.2.1. Eco-cement

□ Overview and current status

Eco-cement products manufactured mainly with city waste incinerated lime along with other waste materials (including sewer sludge), depending on the need, as the source of clinker materials, are currently on the market in Japan. One issue with eco-cement is its degraded physical properties, as it contains more Al2O3 and Cl than general Portland cement.

□ Technological demand

The demand for this technology is expected to grow in the future as a means of reducing environment load from city waste and other general living waste.

□ Maturity

This technology is at the mass production and commercialization stage, and the technology that improves the quality to the level of general Portland cement is required.

□ Technological barriers

While incinerated lime contains substances required for manufacturing cement, it also contains other undesirable elements, such as Cl. The technology to overcome this deficiency and to improve the quality to the level of general Portland cement is required.

□ Expected technology realization period

Around 2020, unlike the existing cement manufacturing technology recycling waste materials, this technology is expected to be realized when the social needs of technology for manufactured cement from waste material as main source and treatment of city waste increase rapidly.

2.3.4.3.2.2. Other potential low-carbon cement (Quoted from IEA data)

A number of low-carbon or carbon-negative cement options are currently under development through start-up companies expecting to build pilot plants in 2010/11. The mechanical properties of these cement products appear to be similar to those of Portland cement. However, these new processes are still at the development stage. And the developed cements are currently neither proven to be economically viable nor tested at scale for their long-term suitability.

In the long term, they may offer opportunities to reduce the CO_2 intensity of cement production, and their processes should be followed carefully and potentially supported by governments and industry.

Novacem is based on magnesium silicates (MgO) rather than limestone (calcium carbonate), as is used in Ordinary Portland Cement. Global reserves of magnesium silicates are estimated to be quite large, but they are not uniformly distributed and processing would be required before use. The company's technology converts magnesium silicates into magnesium oxide using a low-carbon, low temperature process, then adding mineral additives that accelerate strength development and CO_2 absorption. This offers the prospect of carbon-negative cement.

Calera is a mixture of calcium and magnesium carbonates, and calcium and magnesium hydroxides. Its production process involves bringing sea-water, brackish water, or brine into contact with the waste heat in power station flue gas, which had absorbed CO_2, precipitating the carbonate minerals.

Calix cement is produced in a reactor through the rapid calcination of dolomitic rock in superheated steam. The CO_2 emissions can be captured using a separate CO_2 scrubbing system.

Geopolymer cement utilizes waste materials from the power industry (fly ash, bottom ash), the steel industry (slag), and from concrete waste, to make alkali-activated cement. The performance of such a system is dependent on the chemical composition of the source materials, the concentration of sodium hydroxide (NaOH) and potassium hydroxide (KOH) chemical activators, and the concentration of soluble silicates. Geopolymer cement has been commercialized at small-scale facilities, but remains yet to be used in large-scale applications where strength is critical. This process was developed in the 1950s.

2.4. Carbon Capture and Storage and CO_2 monitoring

2.4.1. Carbon Capture and Storage[15]

2.4.1.1. Status of current technologies and issues

CCS technology will play the largest role in carbon reductions for all industries that produce high amounts of CO_2 (Refer to <Table 2.22>, [Figure 2.17]). Large-scale CO_2 capturing technologies can be largely divided into pre-combustion CO_2 capture, post-combustion CO_2 capture and Oxyfuel combustion technology. Storage technologies for the captured CO_2 are classified as underground storage, ocean storage, industrial use and mineral carbonation.

[Table 2.22] CCS technological demand from energy intensive industries

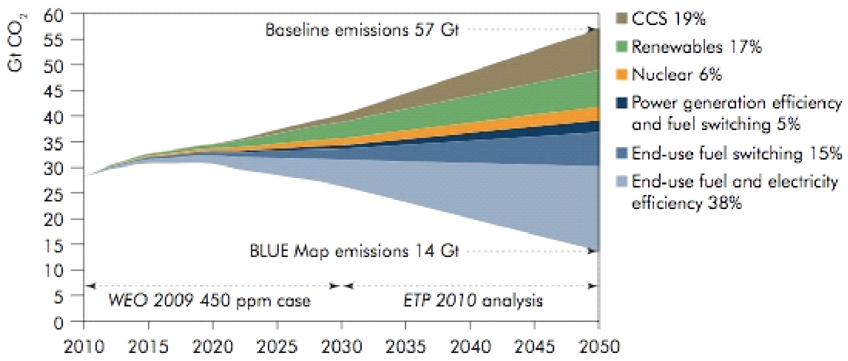
Iron and steel	Cement	Chemicals	Pulp and paper	Aluminum
Application of current best available technologies Including CHP, efficient motor and steam systems, waste heat recovery and recycling				
Fuel and feedstock switching				
DRI, charcoal and waste plastics injection	Alternative fuels, clinker substitutes	Biomass feedstocks	Increased biomass	
New technologies				
Smelt reduction		Membranes	Lignin removal	Wetted drained cathodes
Electrification (MOE)		New olefin processes	Black liquor gasification	Inert anodes
Hydrogen		Process intensification	Biomass gasification	Carbothermic reduction
CCS for blast furnaces	CCS post-combustion	CCS for ammonia	CCS for black liquor gasification	
CCCS for DRI	CCS oxyfuel	CCS for large scale CHP		
CCS for smelt reduction	CCS pre-combustion	CCS for ethylene		

Source: IEA (2009:45)

72% of greenhouse gas emission is CO_2. The CO_2 emission from massive emission facilities assumes about 58.5% of total CO_2 emissions. The scale of emission by massive emission facilities is about 13,468MCO_2 ton/yr, and the contribution by the cement industry is 932MCO_2ton/yr, roughly 7% of the total. The efforts to reduce carbon emission are extended to all industries that produce large amounts of CO_2, as well as the cement industry. (Refer to Figure 2.17) Energy saving technologies are taking the biggest portion among the applied technologies, but the application of CSS technologies that can reduce CO_2 emissions with large amount will be essential in consideration of the limitations of the energy saving technologies.

15 As mentioned before, there are many issues with CCS. There is a stance that carbon storage is not acceptable because of geographical reason beside of technological reason. In this case, carbon capturing is also not applicable. The descriptions in this study is based on IEA technology outlook scenarios, which differs from each country.

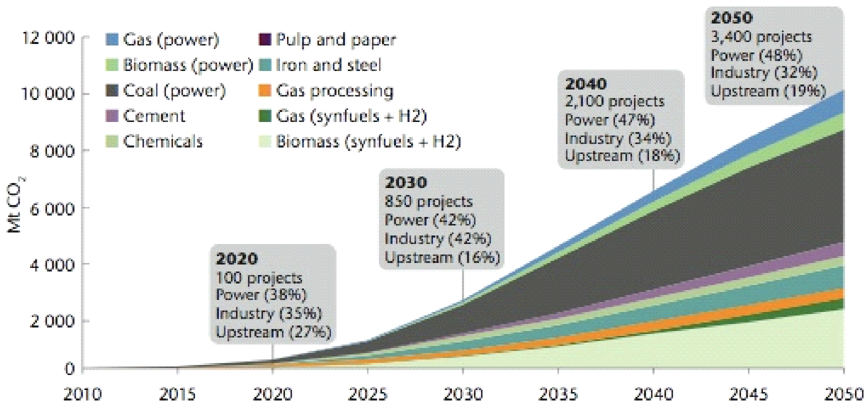
<Figure 2.17> Major technologies for reducing carbon emissions under the Blue map scenario



Source: IEA 2010, Energy Technology Perspectives 2010

IEA presented a long term development model up until 2050 for CCS technologies which is expected to take a critical part in reducing carbon emissions. (Refer to Figure 2.18)

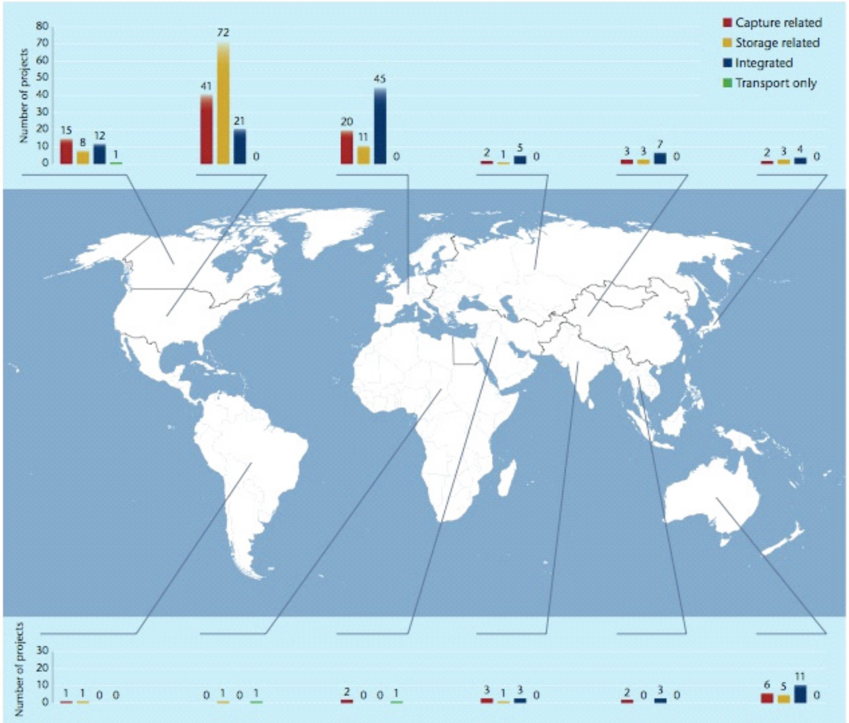
<Figure 2.18> CCS technology development projects and expected CO_2 reductions by industry area



Source: IEA, Technology Roadmap - Carbon Capture and Storage, 2009

The introduction of CCS technologies is actively being discussed across the world, and many projects for developing CCS technologies are being driven by the developed countries. (Figure 2.19)

<Figure 2.19> Worldwide CCS projects status



Source: IEA, Technology Roadmap - Carbon Capture and Storage 2009

CCS technologies are divided into the three major areas of CO_2 capture, CO_2 transportation and storage, and CO_2 application technology.

2.4.1.1.1. CO_2 capturing

2.4.1.1.1.1. Status

Currently, applicable CO_2 capturing technologies are the absorption method, absorption and adhesion method, and membrane separation method. Yet a successful commercialization case of CO_2 capturing technology has been reported. But in power plant and steel industries, pilot plants that utilizing CO_2 capturing had been deployed. The capturing technology closest to commercialization throughout all industries is the chemical absorption method using amine based absorbent; KS-1 of MHI (Mitsubishi Heavy Industry).

World Steel Association (ex International Iron and Steel Institute, name changed to World Steel Association in Oct. 2008) introduced the ‘CO_2 Breakthrough Programme’ in the 2000s, and steel manufacturers across various countries participated at meetings every year to share their efforts in CO_2 reduction, and to establish a plan to reduce carbon emissions appropriate for the steel manufacturing industry. The USA (AISI), Japan, Europe and other countries are trying to develop the technology to reduce carbon emissions suitable for the environment of each country, and the status of technology development are shared at annual meetings.

CO_2 capturing in the steel industry is mostly concentrated on the iron making process. Research on CO_2 emissions reduction and capturing technology is being conducted for blast furnaces in Japan (COURSE50 Project), with the typical example being the CO_2 capturing process (30 ton/day) to capture CO_2 contained in BFG (blast furnace gas) using amine based absorbent, recently completed by New Nippon Steel (NSC-Kimitsu Works) in March 2010. Furthermore, steel companies in Japan are executing comprehensive technology development strategies considering the storage as well as capturing processes through collaboration with research institutes and companies, including RITE and Japan CSS. European countries are developing blast furnace top gas recycling (BF-TGR) technology as a sub level project of the ULCOS (Ultra-Low CO_2 Steelmaking) project. Research on lab scale CO_2 capturing technology using adhesion agent (PSA absorbent replacement) is also being conducted.

2.4.1.1.1.2. Future needs in 2030

Aggressive deployment of CCS technology along with energy efficiency improvements is important in achieving the goal of CO_2 emissions reductions. In the aspect of CO_2 emission restriction, introducing and applying CO_2 capturing technology is not feasible in short-term period, but it is expected to be emerged in long-term perspective as an important technology for CO_2 reduction. The quota of the industries, including the steel and cement industries, in carbon reduction will be significant.

2.4.1.1.2. CO_2 transportation and storage

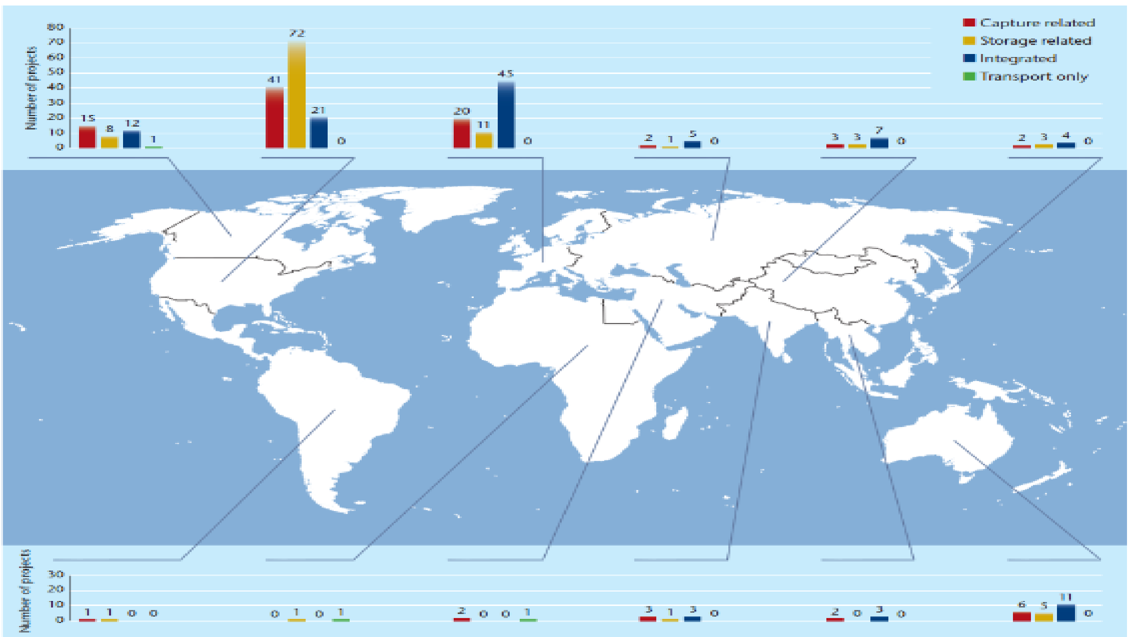
2.4.1.1.2.1. Status

CO_2 transportation and storage across all industries

With current technologies, captured CO_2 will be moved through pipelines in land and by ships in ocean to the storage. Transportation technologies may not face technical difficulties in commercialization considering that liquefied natural gas, liquid oxygen, liquid nitrogen and liquid carbon dioxide are distributed across domestic and international markets. However, underground storage and ocean storage methods have advantages and disadvantages which should be resolved in the future.

The Sleipner Project of Norway, beginning in 1996, can be considered as the first large-scale underground storage of CO_2 (one million tons of CO_2 storage per year). A number of CCS projects are being executed or planned across the world. (Refer to [Fig 4]). For Saline reservoir, EOR (Enhanced Oil Recovery), and abandoned gas and oil field storage, Oil companies in the USA constructed a few thousands kilometer pipelines for transporting CO_2 for EOR (Enhanced Oil Recovery) a few decades ago, and CO_2 transportation is not expected to cause serious technological problems.

<Figure 2.20> Planned and operational large-scale (>1 $MtCO_2$/year) CCS projects>

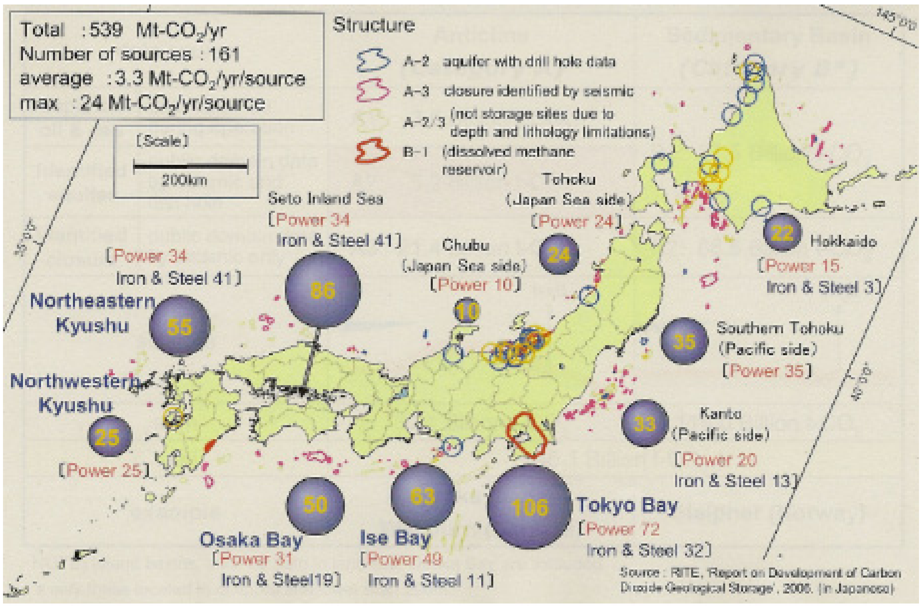


Source: Strategic Analysis of the Global Status of Carbon Capture and Storage: Report 1 Project Status (forthcoming), prepared for the Global CCS Institute by WorleyParsons Services Pty Ltd. (2009).

□ CO_2 transportation and storage in the steel industry

No successful case of underground storage of CO_2 captured from the steel manufacturing process has been reported. The 'Top-Gas Recycling Blast Furnace Pilot and Demonstrator Program', one of the projects of ULCOS II (2010-2015), is supported by the TGR-BF consortium and storage consortium, and the plan is to use the Lorraine area in France as a underground storage site (Birat, 2009). After the successful execution of the project of underground storage of CO_2 in the Nagaoka Project in Japan, the next stage of research is progressing. Japan is currently conducting surveys on CO_2 emissions locations and sites for saline reservoir storage (Refer to [Figure 2.21], RITE, 2008).

<Figure 2.21> Large CO_2 emissions locations and saline reservoir storage sites



Source: RITE, 2008

2.4.1.1.2.2. Future needs in 2030

Underground storage of CO_2 is the most realistic and permanent method of CO_2 storage at the largest scale, and many CCS projects are being executed across the world. Among various underground storage technologies, there are EOR technology, which was designed to inject carbon dioxide into the active oilfield to increase oil production and the technology to store carbon dioxide by substituting the methane combined with coal by injecting carbon dioxide into the underground coal layer. Ocean storage technology is prohibited internationally due to concerns for the ocean eco-system, and additional verification will be required for underground storage on stability from large-scale storage, due to a lack of long-term storage experience. The demand for large-scale CO2 storage will increase when the reliability and stability of the underground storage CCS projects are proven. The cost of CO_2 storage is expected to be much lower than the current level, which is around \$20/CO_2 ton (estimated). The demand for underground CO_2 storage is expected to grow gradually as the cost of CO_2 storage declines. CCS is expected to be commercialized after 2020.

2.4.1.1.3. CO_2 Recycling

2.4.1.1.3.1. Status in steel industry

□ Reuse in the process

The best way to reuse CO_2 back in the steel manufacturing process would be to convert CO_2 to CO and use it as a reducing agent for the steel making process. However, it seems to have almost no value at the moment without the availability of the low cost energy source that is required to convert to CO, due to the thermodynamic stability of CO_2 and additional energy consumption.

□ Industrial use of CO_2

Technology to produce chemical products such as methanol using CO_2 is still at the lab research stage, and the issue with this technology is that of 'low cost hydrogen production'.

The CO_2 requirement for feedstock is trivial compared to total CO_2 emissions: for example, the estimated amount of CO_2 required to produce urea fertilizer is around 70 million tons per year. The sum of worldwide demand for CO_2 required to produce other chemical compounds does not exceed 50 million tons per year (IPCC, 2005).

The estimated consumption of CO_2 for industrial applications (welding, fire extinguishers, and dry ice) and food (carbonated drinks), where CO_2 is used directly, is around 20 million tons per year (IPCC, 2005).

□ Carbonate production using CO_2

The concept of 'CO_2 mineral carbonation' technology, which fixes CO_2 as a carbonate, was proposed in the 1990s, and the major research efforts in the early stages were on the carbonation process for silicate family rocks (serpentine rock, olivine and wollastonite). Research on carbonation technology using industrial by-products has been conducted in Europe and Japan since the 2000s. Mineral carbonation technology is still at the research phase and small-scale lab research is being conducted. Research in the carbonation process using slag from the steel making process is also being attempted by research groups such as TKK (Helsinki University of Technology) and ECN (the Energy Research Center of the Netherlands).

2.4.1.1.3.2. Status in cement industry

The current status of CO_2 application technology in the cement industry is at the lab research stage. Calera Corp. in the US succeeded in manufacturing concrete with carbonate by-products obtained by injecting carbon dioxide in sea water. Carbonate manufacturing technology using captured CO_2 as a means of obtaining new source materials for the cement industry is likely to be highlighted in the future. There is also a high possibility of the industrial utilization of captured CO_2. Technologies to use captured CO_2 for chemical product manufacturing, industrial welding, fire extinguishers, dry ice and carbonated drinks are under development.

2.4.1.1.3.3. Future needs in 2030 in steel industry

□ Reuse in the steel manufacturing process

Technology to reduce the use of coal and coke by recycling CO_2 as a reducing agent for steel manufacturing process through the development of technology to convert CO_2 to CO, is required.

□ Industrial application of CO_2

The demand for converting CO_2 to other chemical substances such as urea fertilizer, methanol, or DME that can be produced at large quantities is expected to grow in the future.

New industrial areas that recycle CO_2 to new resources are expected to appear.

□ Carbonate production using CO_2

The size of the high purity powder carbonate calcium market continues to grow as technologies and industries are developed. The development of new industries to produce high value added carbonates (carbonate calcium) and CO_2 fixing through mineral carbonation using CO_2 and industrial by-products (or waste materials) is anticipated.

2.4.1.1.3.4. Future needs in 2030 in cement industry

The size of the high purity power carbonate calcium market is increasing continuously, along with the development of the technology and industry. Technologies to manufacture carbonate using CO_2 are expected to be developed to meet this demand.

Exploring various technologies and industry areas that directly and indirectly use captured CO_2 for industrial purposes is required.

2.4.1.2. Assessment of the gap between the current status and future needs

2.4.1.2.1. CO_2 capturing

Currently there is no commercialized CO_2 capturing process that has been applied to process, but technological verification on a prototype (demo) scale capturing technology with the capacity of tens of tons of CO_2 per day is expected in less than five years.

The full-scale commercialization of CCS technology will be realized after 2020, and CO_2 emitted from the steel manufacturing process will also be captured.

2.4.1.2.2. CO_2 transportation and storage

To date, there have been no reported projects/facilities that execute capturing, transporting and underground storing of CO_2 emitted from the steel manufacturing process.

CSS technology coupled with capturing technology will be commercialized in full-scale after 2020.

2.4.1.2.3. CO_2 Recycling

There have been no reported cases of capturing and directly reusing CO_2 emitted from the steel manufacturing process, converting to CO for reuse in the steel manufacturing process, or producing other chemical compound materials such as urea fertilizers.

Since steel making factories have the highest level of CO_2 emissions per unit business premise, technologies to utilize (reuse or covert) captured CO_2 must be developed to reduce CO_2 emissions.

[Table 2.22] Gap between the current status and future needs in the CCS area

	Status overview	Future needs in 2030	Suitability for future needs	Reason for not suitable
CO2 capturing	- There is no commercialized CO2 capturing process.	- CO2 capturing technology for storage and utilization is required.	Medium	No technology that can be applied in the short term Issues of the energy efficiency of applicable technologies
CO2 transportation and storage	- No case of storage of CO2 captured from the steel making process has been reported.	- CO2 transportation and storage technology is required to deploy CCS technology.	Medium	Social issue of storage technology
CO2 Utilization	- Lack of technology to convert to CO and reuse in the process - Almost no industrial use	- To convert CO2 to CO and reuse it as a reducing agent in the process - New method of CO2 fixing and new carbonate calcium production	Medium	Insufficient technology development for the industrial use of captured CO2
General	- Lack of large-scale CSS projects for CO2 reduction in the steel making process	- Large-scale CO2 storage is essential.	Medium	

2.4.1.3. Drawing and analyzing Alternative technologies for the future

2.4.1.3.1. Alternative technology by area

2.4.1.3.1.1. CO_2 capturing

For CO_2 capturing, there are CO_2 capturing technology using absorbent and CO_2 capturing technology using adhesion are currently exist. Meanwhile, CO_2 refining is the technology to remove impurities from captured CO_2 and maintain an appropriate thermodynamic state for ease of transportation and storage of CO_2. The methods may vary depending on the conditions, methods and travel distance of CO_2 transportation but the concept is to maintain a thermodynamic state of CO_2 suitable for transportation and storage, such as supercritical CO_2 or liquid.

2.4.1.3.1.2. CO_2 transportation technology

This is an area coupled with temporary storage and transportation of CO2. Thermodynamics research related with CO2 is required for CO2 transportation and injection technology development. On the other hand, Pipe plugging could occur frequently due to the formation of CO_2 hydrate by moisture during the CO_2 transportation and injection processes. A CO_2 hydrate inhibitor must be developed to prevent this. This technology can be considered as different area and also as an area of CO_2 transportation and storage technologies for analysis.

2.4.1.3.1.3. CO_2 storage technology

This is comprehensive large-scale technology including the detailed core areas of storage layers, capacity and geographical distribution, injection technology and operation, storage mechanisms and stability, monitoring and verification, risk management, and assessment and improvement. Other legal/political issues and public perception issues are also considered to be important to address.

[Table 2.23] CCS-Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative technologies to meet future needs	Reasons for suitability
CO_2 capturing	[5-A] CO_2 capturing technology using absorbent	Technology to capture CO_2 selectively from BFG using chemical absorbent (ammonia, amine, etc.)	Very High	Not used in the steel making process Mid-low temperature waste heat can be used as regenerated energy.
	[5-B] CO_2 capturing technology using adhesion	Capturing CO_2 produced from the steel making process using an adhesion agent based on oxidized metal (where high concentration CO_2 over 30% is generated)	High	The PSA method may have benefits over the absorption method in the case of high concentration CO2 capture.
	[5-C] CO_2 refining technology	Technology to refine/condition the captured CO_2	Very High	Needs depend on the requirements of lower level CO2 treatment technology, and it is generally required.
CO_2 transportation and storage	[5-D] CO_2 hydrate technology	Technology to prevent the formation of hydrate during transportation (inhibitor development, etc.)	High	Generation of hydrate needs to be suppressed for CO2 transportation and underground storage (plugging of transportation pipes and pressure losses will occur otherwise).
	[5-E] CO_2 transportation technology	Technology to transport CO_2 in a supercritical fluid state	Very High	A deep understanding of thermodynamics and hydromechanics (including impurity) of CO2 is required.

	[5-F] CO_2 underground storage technology	Technology to inject and store CO_2 into a saline formation later and abandoned oil and gas fields stably	Very High	Overall information about monitoring before and after CO_2 injection and environmental effects
CO_2 utilization	[5-G] CO_2 conversion technology	To convert CO_2 to CO and use it as a reducing agent in the steel making process	Very High	Reduced use of coal by converting to CO using unused waste heat in the steel making process (melted slag sensible heat, sintered iron sensible heat, coke furnace sensible heat, etc.) (CO_2 emissions reduction) appears possible.
	[5-H] CO_2 mineral carbonation technology	Generation of carbonate using the carbonation reaction between CO_2 and minerals (natural minerals and industrial by-products)	Very High	CO_2 fixing and environmentally friendly processing of industrial by-products (slag from the steel making process) are achieved at the same time.

2.4.1.3.2. Analysis on alternative technologies

2.4.1.3.2.1. CO_2 capture

□ Overview and status

No successful research and commercialization of CO_2 capturing technology has been reported.

□ Analysis of technological demand

In Steel industry, around 90% of total CO_2 emission is from blast furnaces in general steel manufacturing processes. CO_2 reduction efforts in the steel manufacturing process should be focused on this process. Capturing CO_2 contained in BFG, the highest volume byproduct gas produced during the steel manufacturing process, is essential for the efficient utilization of BFG for backend processes (combustion, etc). CO_2 capturing technology based on the absorbent method must be developed to achieve the mid-long term CO_2 emissions goals (30% reduction from 2005).

Similarly in cement industry, CO_2 generation will be suppressed to the level of 5-10MCO_2 ton/yr by 2020 and 100-160MCO_2 ton/yr by 2030. (Refer to IEA, Cement Roadmap 2009)

□ Maturity

The current status of CO_2 capturing technology can be defined as at the experiment stage.

Amine-based absorption technology has enormous potential for short-term application, but the disadvantage is the high cost of installation and operation.

Organic solvent absorption and membrane separation methods are entering the experiment stage.

□ Technological barriers

CO_2 capturing technology using absorbent is not very difficult, but the development of absorbents, process optimization and waste heat recycling technology should be developed for improved efficiency of processes and increased economic value.

□ Expected technology realization period

At best, this technology is expected to reach the deployment or mass production stage by 2020. In the case of steel industry, the development of a new absorbent material that consumes less recycled energy is being accelerated, and process energy can be reduced if the waste heat generated from the steel manufacturing process is fully recovered. And that would be similarly developed in cement industry.

2.4.1.3.2.2. CO_2 transportation and storage

□ Overview and current status

CO_2 transportation technology has already been secured by oil companies for the application of EOR, and the CO_2 gas refining technology required for CO_2 transportation should accompany these developments. CO_2 storage in the saline formation layer has been conducted by Sleipner in Norway for around ten years, and long-term research is required for the technologies related to monitoring and leak prevention. There are many social and technical obstacles to resolve for underground storage and ocean storage.

□ Technological demand analysis (demand forecast as at 2020)

CO_2 transportation using pipelines will become a significant environmental industry around 2020, when the CO_2 markets take off.

□ Maturity

CO_2 transportation technology can be defined as at the deployment stage, considering the status of CO_2 transportation facility built by oil companies. CO_2 storage technology also appears to be at the deployment stage, considering the examples in some developed countries.

□ Technological barriers

In the case of CO_2 transportation technology, CO_2 gas refining technology should be developed for liquefaction. In the case of CO_2 storage technology, research on securing stability through long-term monitoring, indentifying the possibility of CO_2 storage through geological surveying, and CO_2 leakage problems associated with long-term storage should be conducted in advance.

□ Expected technology realization period

Technology verification may be completed by around 2015, and commercialization will take off around 2020.

2.4.1.3.2.3. CO_2 utilization

□ Overview and status

No case of capturing CO_2 and reusing in the process has been reported to date. No case of direct or indirect industrial recycling of CO_2 has been reported.

□ Technological demand analysis (demand forecast as at 2030)

While CO_2 reduction in the cement industry is expected to become mandatory in the future, the need for alternatives to CO_2 fixing will be highlighted. Demand for CO_2 recycling technology as one of the alternatives will grow accordingly.

□ Maturity of the technology

Technologies to manufacture chemical compounds by using CO_2 as a source material may generate various products, but remain at the lab experiment stage.

The technologies to utilize CO_2 directly in industrial substances and food through the CO_2 refining can be applied immediately.

□ Technological barriers

Economic efficiency in converting to other substances and using them in chemical compound production will be the biggest issue.

□ Expected technology realization period

The time for securing economic efficiency of the process depends on the time when the waste heat recovery technology in the manufacturing process and low cost CO_2-free hydrogen manufacturing technologies become more mature. Small-scale deployment is expected after 2020.

2.4.2. CO_2 Monitoring

Source materials, including waste, are grinded and mixed and fed to rotary kilns through a pre-heater or calciner to produce clinker. Various components contained in the source materials are evaporated and emitted to the air as a pollution source in this process. These pollutant materials can be emitted due into air to the incomplete combustion of fuels and alternative fuel components used in the various stages of calcination facilities. Pollutants in the exhaust gas emitted from the cement calcination facilities are monitored continuously with a TMS (telemetry system) in chimneys using a CMS (continuous monitoring system). EU has appointed dust, NOx, CO and the highest possible concentrations of SO2 as the applied items of CMS along with continuous monitoring on pressure, temperature and O_2 concentrations. Metals and their compounds, TOC, HCl, HF, NH3 and PCCD/F are also need to be monitored periodically and regularly. CO_2 emission can be calculated by either direct method or indirect method. The direct method is directly calculating concentration and flow rate by using a measurement device at the exhaust of the pollution source. The indirect method calculates CO_2 emission volume theoretically by considering the type and quantity of the burning fuel, combustion efficiency and the emission coefficient. The direct method has the advantage of providing accurate information on the final emission volume by reflecting the final combustion process of the fuel. However, the disadvantages are the time and cost for installation and operation of the equipment, and limitations of the measurements. And there is an issue on the accuracy. The indirect method has the advantage of ease of calculation, but the disadvantages are reduced accuracy and unreliability of data. Currently, the indirect method is primarily used.

2.4.2.1. Future needs in 2030

A direct method that reflects the combustion process and measures accurate final emission volume of fuel is expected to become widely used in the future. CO_2 emissions will be measured and monitored continuously with TMS (telemetry system) installed at chimneys for exhaust gas measurement using a CMS (continuous monitoring system). But this kind of measurement method should guarantee the accuracy through calculation method.

2.4.2.2. Assessment of the gap between current status and future needs

[Table 2.24] Gap between current status and future needs in environmental monitoring

	Status summary	Future needs in 2030	Suitability to meet future needs	Reason for not suitable
Carbon dioxide	Estimation of CO_2 emissions by the indirect method using an emission coefficient	Measurement of CO_2 emissions using TMS installed at chimneys	Medium	Time consuming for installation and operation of equipment, and limitations in measurements

2.4.2.3. Drawing and Analyzing Alternative Technology in the Future

2.4.2.3.1. Alternative technology by area

[Table 2.25] Alternative technology by area

Area	Alternative technology	Concept (Overview)	Suitability of alternative solutions to meet future needs	Reasons for suitability
CO_2 monitoring	[6-A] Direct CO_2 emission monitoring	Direct estimation of CO_2 emissions by monitoring with TMS installed at chimneys	High	The fuel combustion process is reflected and accurate final emission information can be obtained.

2.4.2.3.2. Alternative technology analysis

2.4.2.3.2.1. CO_2 Monitoring

□ Overview and current status

The direct CO_2 monitoring technology directly calculates CO_2 emissions by measuring CO_2 emissions through TMS installed at chimneys.

The system is configured with measurement equipment and data transmission equipment. The measurement equipment consists of chimney continuous measurement device and systems. The data transmission equipment consists of a data collector, intermediate data collector and the network.

□ Technological demand analysis

The demand for the technology for accurate calculation of CO_2 emissions will grow in the future.

□ Maturity

Direct CO_2 monitoring technology is at the deployment stage. The concept has been established, and it is already applied in other industries.

□ Technological barriers

The much time and cost for installation and operation of measurement equipment and data transmission equipment, and limitations in accurate CO_2 measurement

□ Expected technology realization period

Around 2015, the demand for the accurate estimation of greenhouse gas emissions is expected to grow by 2015.

2.5. Technology Road Map

The realization periods of detailed technologies including green technology, CO_2 capturing & storage, and carbon monitoring in steel and cement industries are presented comprehensively in the following. The presented year in this technology roadmap is that point in time when the technology development is completed to the level of commercialization.

2.5.1. Steel Industry TRM

The estimated period of process improvement and commercialization of eco-friendly products is around 2015. Commercialization of major eco-friendly and energy saving processes, such as energy efficiency/back end processes, will be realized during this period. Also in the product area, high function and eco-friendly products that are currently being promoted might be launched to the market during this period. Technology to utilize waste resources will be implemented during this period in the alternative fuel area.

The estimated period of commercialization of CCS technologies and high-tech eco-friendly process technologies is around 2020. Major CCS technologies will be commercialized during this period. The ratio of commercialization will continue to rise after the commencement of commercialization. This period is defined as the period of 'large-scale plants commercially available for new buildings and retrofit applications' according to the IEA (2009). Some of the process technologies that are currently facing challenging problems, such as Oxyfuel technology and high function slag treatment processes from byproduct gas, will be commercialized during this period. The technology developments for hydrogen fuel will be completed as an alternative fuel source, and it will become applicable to industrial purposes.

The estimated period of commercialization of technically challenging process technologies is around 2025. Top gas recycling technology, which requires long periods of research for evaluating large-scale deployment and technical safety, and coal chemistry application technologies that require many years to secure economic efficiency, and production technologies that might be commercialized during this period are included here.

[Table 2.26] Roadmap for green technology realization in the steel industry

Process	Area	2015	2020	2025
Alternative fuel	Alternative fuel		[1-A] Hydrogen fuel (hydrogen production)	
		[1-B] Waste resources, including scrap plastics		
				[1-C] Biomass
High energy efficiency process	Blast furnace			[2-A] Blast furnace top gas recycling
	High temperature heat recovery	[2-B] Melted slag sensible heat recovery technology		
	Mid-low temperature heat recovery	[2-C] Electricity generation with waste heat		
	Combustion		[2-D] Oxyfuel technology	
		[2-E] Combustion control technology		
Recycling and eco-friendly back end processes	Process to add value to waste gas			[3-A] Coal chemistry
	Slag utilization technology		[3-B] High function slag treatment technology	
		[3-C] Technology to recover non-ferrous metals from the by-products of steel making processes		
	Collection technology	[3-D] High temperature dry collection technology		
Eco-friendly steel products	Steel for cars		[4-A] Light Fe-Al high-strength steel	
			[4-B] Light high strength steel	
		[4-C] TWIP steel		
	Coal ratio	[4-D] Oxygen enriched combustion		
		[4-E] Use of non-coking coal		
	Electric furnace		[4-F] Technology to improve the quality of cast iron	
		[4-G] Strip casting		
	Misc.	[4-H] Light steel for structures		

2.5.2. Cement Industry TRM

Green technology development in the cement industry has a similar path to green technology in the iron and steel industry. It is estimated that the period of commercialization of major process improvement technologies and recycled raw materials will be around 2015 just as in steel industry. Commercialization of major eco-friendly and energy saving processes, such as energy efficiency/back end processes, will be realized during this period. Recycled source materials from steel slag, city waste and incineration lime will be commercialized, too.

The estimated period of commercialization of CCS technologies and various eco-friendly cement products is around 2020.

Some of the process technologies that are currently facing challenging problems, such as Oxyfuel technology and dust detoxifying technology will be commercialized during this period. Alternative fuel using ASR heat sources will be realized during this period.

Around 2025 will be a period with accelerated technological innovations in which commercialization rate of every area will rise and high-tech processes will be developed.

[Table 2.27] Roadmap for green technology realization in the cement industry

Process	Area	2015	2020	2025
Alternative fuel/source material	Alternative fuel		[1-A] Technology to utilize ASR heat sources	[1-B] Biomass
	Alternative source material	[1-C] Technology to use steel slag as an alternative source material for lime stones		
		[1-D] Technology to use city waste incineration lime as a source material		
High energy efficient process	Combustion			[2-A] Oxyfuel technology
	Heat recovery	[2-B] Electricity generation with waste heat		
Recycling and eco-friendly back-end processes	Eco-friendly dust treatment	[3-A] Chloride by-pass system		
			[3-B] Dust detoxification technology	
Eco-friendly cement products	Eco-friendly cement		[4-A] Eco-cements	

2.5.3. Carbon Capture and Storage and CO_2 Monitoring TRM

The estimated period of commercialization of CO_2 monitoring technology is around 2015. During this period, large scale power plants and related factories will introduce the monitoring technology. For its introduction process, the process design will be required to optimize the use of the heat source and electricity in steel or cement related furnaces. CCS technology is developed with fuel conversion facilities of centralized heat and power systems. Appropriate recognition and use of bio-fuel, including biomass, is one of the factors for the development of CCS technology.

The estimated period of commencing major CCS technology commercialization is after 2020. Commercialization of major CCS technologies (CO_2 capture, refining, hydrate, transportation, storage, mineral carbonation technology, etc.) is directly related with strengthening carbon emissions regulations, and the commercialization rate will continue to rise after commercialization has started around 2020. According to the IEA (2009), it is expected that every factory will introduce the CO2 capture system that can captured up to 85% of emitted carbon for the all fuel types by 2025.

[Table 2.28] Roadmap for green technology realization in CCS and Carbon monitoring

Process	Area	2015	2020	2025
CO_2 Capture and Storage (CCS)	CO2 Capture		[5-A] CO_2 Capture Technology using absorbing agent	
			[5-B] CO_2 Capture Technology using Absorbent	
			[5-C] CO_2 Refining Technology	
	CO_2 Transportation and Storage		[5-D] CO_2 Hydrating Technology	
			[5-E] CO_2 Transportation Technology	
			[5-F] CO_2 Underground Storage Technology	
	CO_2 Use		[5-G] CO_2 Conversion Technology	
			[5-H] CO_2 Mineral Carbonation Technology	
CO_2 Monitoring	CO_2 Monitoring	[6-A] CO_2 Direct Monitoring		

Chapter 3. Reviews on Skills Requirement

3.1. Changes on Responding Skills & Workforce Demand by Technology

This section is based on the green technology outlook of steel industry, which was carried-out by this study, according to IEA's global level steel industry greening scenario, and will present the skills demand change and related workforce demand in response to detailed technologies and carbon capturing & storage technologies.

3.1.1. Steel Industry

[1] Alternative fuel

[1-A] Alternative fuel: Hydrogen fuel

The technology to produce hydrogen from COG(coke oven gas) is already established. What is necessary is to develop the technology and process that uses hydrogen as a reducing agent for steel making in blast furnace, as well as R&D workforce for that. Because the reducing process that uses hydrogen has different chemical reaction in blast furnace from present CO gas reducing process, new expert workforce with the backgrounds in metal, material and chemical engineering, who understand the process and can control it, will be demanded. The operation workforce, who can operate equipment/facility that produces hydrogen from COG, can be replaced by reeducation of present blast furnace operation workforce. Also with the focus on hydrogen production and related compressed, liquefied and solidified gas operation and management, the demand for production/transportation/storage equipments is expected.

[1-B] Alternative fuel: Waste resource like waste plastic

On the basis of the understanding for coking process of existing coal, acquiring the control technologies for coke strength change, produced calorie per weight unit, producing emission gas and producing amount per iron production unit when using organic matters like waste plastic as an auxiliary fuel, is required. R&D workforce that develop the process that uses waste organic materials like waste plastic to be combined with coke for source material of steel making, is also required. Related departments are metal engineering and chemical engineering.

The engineers and technicians needed in the pre-treatment process of waste plastic to be used as a source material in steel making, can be possible with reeducation of existing workforce. The research for recycling slag that is being produced when waste plastic is used for coke mixing source material can create the demand for R&D workforce. The knowledge that can analyze the effect of waste plastic when it is used as a steel making material in the retreatment of using existing slag as concrete mixture, and present an optimal recycling is necessary. Related departments are ceramic engineering, material engineering and chemical engineering.

Meanwhile, utilizing waste resources can be deployed in a diverse way and currently a part of it is already deployed. While new demand for undergraduate level technology workforce in relation with utilizing waste materials is expected, re-education/training of existing related technician workforce will be important.

[1-C] Alternative fuel: Biomass

Developing detailed technologies and process for using biomass like lumber as a source material of coke is required. R&D for utilizing scrub wood that has low economic value as lumber, and biomass that is being produced during agricultural production process, is necessary. New demand for R&D and engineer workforce from forestry, biology, metal engineering and chemical engineering is expected partially. Engineers and technicians workforce who manage pre-treatment process that enables biomass to be used as a source material of coke can be supplied by reeducation of existing workforce.

[2] Energy efficiency

[2-A] Energy efficiency: Blast furnace - Top Gas Recycling

R&D workforce who can develop the technology and process that can separate and capture CO2 from byproduct gas in blast furnace is necessary. Along with the self research and study of researchers from existing blast furnace managing steel makers, new doctoral class expert workforce, who professionally researched movement in mixed gas, is required. Also because this technology is closely related to 'Oxyfuel technology' a demand for research workforce who can connect these two fields is expected, as well as self-research and study of existing researchers. The doctoral class researcher, who can develop the technology and process for recycling CO2 captured from blast furnace byproduct gas into iron ore reducing, can be supplied by self research and study of existing researchers. The workforce demand on related equipment operation for blast furnace byproduct gas separation, capturing and recycling can be provided from reeducation of existing related workforce. New master/doctoral class workforce for professional research on CO2 recycling is also necessary. Master and above level high class workforce from chemical engineering, reaction engineering and material engineering would play key roles.

Reeducation and training of equipment/facility operation workforce who separate, capture and recycle CO2 from blast furnace byproduct gas is also necessary. Equipment/facility operation will require new undergraduate level engineer supplement along with reeducation/training of existing engineers and technicians.

[2-B] Energy efficiency: High temperature heat recovery - Melted slag heat recovery

R&D workforce, who can professionally research to develop the technology and process, and slag property for using the sensible heat of melted slag that has over 1500℃ temperature, is necessary. Supplementing R&D workforce from metal engineering, material engineering, chemical engineering and reaction engineering would be critical. The operation workforce for melted slag heat recovery related equipment/facility can be provided by reeducation of existing related workforce. The related departments are ceramic engineering, metal engineering and civil engineering.

[2-C] Energy efficiency: Mid-to-low heat recovery - Electricity generation technology

R&D workforce, who can develop the technology and process that utilizes mid-to-low waste heat recovery of below 300℃ temperature, is required that can be provided from existing R&D workforce in high temperature heat recovery field with chemical engineering, mechanical engineering and facility engineering majors. For designing heat exchanger and producing technology for utilizing below 300℃ temperature mid-to-low waste heat recovery, utilizing existing university graduate level expert workforce is possible, and the related departments are mechanical engineering, chemical engineering and facility engineering. Operating electricity generation equipment from waste heat can be possible by reeducating existing related workforce.

[2-D] Energy efficiency: Oxyfuel technology

New R&D workforce demand for the technologies and processes in reducing iron ore by using oxygen or gas with high oxygen rate as an oxidizing agent instead of present heat wind from heated air, in mass producing oxygen in more economic way, and separating and capturing CO2 from Oxyfuel gas is expected. Reeducation of R&D workforce in existing related area is also important, and the related departments are metal engineering and chemical engineering. Equipment/facility operating workforce for oxygen mass production and using it as blast furnace oxidizing agent can be provided by reeducation of existing workforce.

[2-E] Energy efficiency: Combustion area - Combustion control technology

R&D staff, who can develop control logic technology and process according to combustion condition such as the type and form of combustion energy, is expected to be supplemented somewhat from self-research of existing workforce. The demand for new R&D workforce will be on the convergence technology expert workforce, who came from inter-curricular researches in combustion engineering and control engineering on the basis of chemical engineering, control engineering and mechanical engineering. Facility/equipment operation workforce can be provided from reeducation of existing workforce.

[3] Eco-friendly post-treatment including Recycling

[3-A] Eco-friendly post-treatment including Recycling: High value adding on byproduct gas - Coal chemistry

R&D workforce, who can develop the technologies and process for manufacturing half-chemical products such as methanol, ammonia, sulfuric acid, diesel oil and tar from byproduct gas in steel making process instead of using that as simple heat source, is necessary. And its operation can create new demand for various expert workforces. Diverse expert workforce demand in inter-curricular education based R&D workforce from chemical engineering, material engineering and reaction engineering, is expected. Because new workforce demand is closely related with oil price increase, it should be implemented as mid/long term project by considering oil price trend.

Also the technology and process development that utilizes byproduct gas with high CO content such as COG(coke oven gas) and LDG(linze donawitz gas) will create R&D workforce demand. Meanwhile, the operating byproduct gas utilization process itself is possible by education/training of existing engineers and technicians.

[3-B] Eco-friendly post-treatment including Recycling: Slag using technology - High function slag treatment technology

R&D workforce for presenting optimal recycling area according to the type and treating method of slag is required. It is possible to supplement from existing related area workforce but new workforce supply is necessary because of additional workforce demand. Operating the process itself is possible with education/training of existing technician workforce but new demand for engineer and technician workforce in slag utilization is expected. Related departments are ceramic engineering, material engineering and civil engineering.

[3-C] Eco-friendly post-treatment including Recycling: Slag using technology - Technology to recover nonferrous metals from the by-products of the steel making process

Strengthening R&D workforce for developing technology and process in recovering nonferrous metals such as Si, Ca, Al, Mg, Ni and Zn from steel and iron slag, is necessary. Related departments are metal engineering and material engineering. Equipment/facility operation for the technology can be supplemented from reeducation of existing workforce but in case of additional demand by settling as a major industry area, supplying expert workforce with differentiated university education is necessary. Related departments are metal engineering and material engineering, and strengthening chemical metallurgy subjects, which had been weakened in undergraduate curriculum due to rapid decrease in demand, is required. Also reeducation/training on existing engineer and technician workforce is necessary.

[3-D] Eco-friendly post-treatment including Recycling: Dust collecting technology - Dry collection technology

R&D workforce for developing capturing & removing technology of particle material such as dust in blast furnace emission gas in a way other than water sprinkling method along with developing material for filter that captures blast furnace emission gas is necessary. Related departments are mechanical engineering, environmental engineering and material engineering. Equipment/facility operation itself is expected to be supplemented from reeducation/training of existing bachelor class engineer and technician workforce.

[4] Eco-friendly steel product

[4-A] Eco-friendly steel product: Automobile material – Lightweight Fe-Al family high strength steel

While utilizing existing workforce, who has experience in alloy steel development, is partially possible, new supplement of convergence technology expert workforce based on metal engineering, material engineering, and mechanical engineering is expected. For production, engineer workforce with university degree, who can process calcinations according to already developed Fe-Al family high-strength steel press method, is required, which can be supplemented from reeducation of existing material related engineers (metal engineering, material engineering, mechanical engineering).

[4-B] Eco-friendly steel product: Automobile material - Light high strength steel

Developing the technology to produce carbon fiber and high-strength polymer fiber (Aramid fiber) at low-price, along with developing composite material manufacturing and related process by using carbon fiber and high-strength polymer fiber for automobile, are necessary. Convergence technology expert workforce, who can connect material engineering and chemical engineering, is required. Even with the partial supplement from existing related expert workforce through self-R&D, new supplement of convergence technology expert workforce came from inter-curricular research is necessary. For production, reeducation of existing material related engineers (metal engineering, material engineering, mechanical engineering) can supply the needs.

[4-C] Eco-friendly steel product: Automobile material - TWIP steel

R&D developing workforce from metal engineering, material engineering and mechanical engineering is necessary to carry out manufacturing TWIP steel, developing related process and mass production facility. Facility operation can be possible with reeducation of existing related engineer and technician workforce.

[4-D] Eco-friendly steel product: Coal ratio - Enhanced oxygen enrichment

R&D workforce for developing manufacturing process of low-price oxygen production is required. New workforce demand for oxygen production related research is expected with a focus on chemical engineering. Engineer and technician workforce for facility operation can be supplemented from reeducation of related workforce.

[4-E] Eco-friendly steel product: Coal ratio - Use of non-coking coal

It is a technology that is already commercialized and the related technologies are already developed. This is an area in which applying already commercialized technology is required rather than developing technology. Related engineers and technicians in existing steel manufacturing can supplement the needs.

[4-F] Eco-friendly steel product: Electric furnace - Technology to improve the quality of cast iron

R&D developing workforce for the technology that efficiently removes impurities such as Cu and Al, especially Cu, from melted Fe, and scrap metal cleaning technology that removes harmful foreign materials from scrap metal is required. The importance of R&D workforce is high because impurity removing technology for scrap metal is continuously required. Metal casting related R&D experience can be applied. Utilizing existing related research workforce is possible and the related departments are metal engineering, material engineering, mechanical engineering and chemical engineering. For facility operation, existing related engineers and technicians can be supplemented.

[4-G] Eco-friendly steel product: Electric furnace - strip casting

Developing the technology that stabilizes Strip casting process is necessary. Utilizing R&D workforce with experiences in metal casting and rolling is possible. Related departments are metal engineering, material engineering, control engineering and mechanical engineering. Operation for renovated equipment/facility can be supplemented from existing related engineers and technicians.

[4-H] Eco-friendly steel product: Other - Lightweight structure materials

While R&D workforce for developing new surface treatment technology that aims adding corrosion resistance is necessary, utilizing existing R&D workforce will be possible. Related departments are metal engineering, material engineering and chemical engineering. Process operation for new surface treatment technology can be supplemented from reeducation of existing engineers and technicians.

3.1.2. Cement Industry

[1] Alternative fuel /Source material area

[1-A] Alternative fuel /Source material area: Alternative fuel - Technology to use ASR as a heat source

University graduate level engineer workforce is required for chlorine removing technology for safe use of waste that contains large volume chlorine, burning technology and environmental effect evaluation technology. Reeducating existing chemical engineering and material engineering departments is possible but newly establishing a convergence major that includes energy and environment is advisable. The related department is energy environment engineering. Operation and maintenance workforce for kiln, burner and pre-treatment facility is necessary, which can be supplied from high school or college graduate level technicians.

For energy recycling, comprehensive understanding on cement manufacturing process and energy is required. New demand for university graduate level engineers with convergence knowledge on energy engineering, chemical engineering, material engineering and environmental engineering is expected. Technician workforce for operating related equipment/facility needs a partial supplement of new technician workforce, while reeducation/training of existing technician workforce is required.

[1-B] Alternative fuel /Source material area: Alternative fuel - biomass

Developing detailed technologies and process for using biomass like lumber as a source material of coke is required. Establishing technology that utilizes scrub wood that has low economic value as lumber, and biomass that is being produced during agricultural production process, is necessary. Related departments are forestry, biology, metal engineering and chemical engineering. New workforce supplement centering on bachelor class engineers for converting and using biomass like lumber and agricultural product as source material, along with additional education/training of existing engineer & technician workforces is critical.

[1-C] Alternative fuel /Source material area: Alternative source material - Technology to use iron slag as an alternative source material for limestone

Workforce for cement product design and engineer workforce at university graduate level for evaluating CO2 in cement manufacturing are required which is possible with reeducation of existing workforce.

Improving cement manufacturing process for utilizing iron slag is necessary. While new R&D workforce from material engineering and chemical engineering majors is expected, the most of the workforce demand related to process improvement can be supplied through reeducation/training of engineer level workforce with material engineering and chemical engineering background. Equipment/facility operation can be possible with reeducation/training of existing technician workforce.

[1-D] Alternative fuel /Source material area: Alternative source material - Technology to use city waste incinerated lime as fuel

University level engineer is necessary for a source material technology which efficiently removes chlorine and heavy metals from hard to throwaway waste that contains high volume chlorine and heavy metals for making safe product. Related departments are chemical engineering, material engineering and mechanical engineering.

For workforce demand, new R&D workforce from material engineering and chemical engineering major for source materializing by removing chlorine and heavy metals, and operation and maintenance workforce are expected. This can be supplemented from reeducation/training of existing related workforce.

[2] Energy efficiency process

[2-A] Energy efficiency process: Combustion process - Oxyfuel technology

University graduate level high class new workforce demand is created for Oxyfuel technology and burner design that can be applied to cement industry. Realted departments are mechanical engineering and chemical engineering. There is a demand for kiln & burner operation, and maintenance related workforce (college level). Related departments are chemical engineering, mechanical engineering and material engineering.

For workforce demand, new demand for R&D workforce and university level engineer is expected for developing combustion technology, and new technology development and application to process. Also operation for introduced equipment needs not only education/training of existing technician workforce but also a new workforce demand for technician.

[2-B] Energy efficiency process: Cooling process - High energy efficient cooler manufacturing technology

It is possible with reeducation of related workforce to existing coolers, and the related departments are chemical engineering and material engineering. There are not many patents related to high efficiency cooler, and the current situation is to improve existing cooler maker. In the future, it can be responded with reeducation/training of existing engineer and technician workforce.

[2-C] Energy efficiency process: Heat recovery - Waste heat generation technology

In cement industry, new workforce demand for university level engineer and college level technician is to be created for operation and management of waste heat generation facility.

For workforce demand, the understanding on energy recycling and electricity generation is required. While it has a nature of utilizing technology rather than developing new technology, new demand for university level engineer with convergence knowledge on electric engineering and mechanical engineering is expected. For technician workforce in operation of related equipment/facility, reeducation/training of existing workforce can respond.

[3] Post-treatment process including Recycling

[3-A] Post-treatment process including Recycling: Eco-friendly treatment of Dust - Chloride by-pass system

Knowledge and dexterity on fluid and energy is critical, and the technician workforce for equipment operation (high school or college level) can be supplied from reeducation of existing related workforce.

For workforce demand, as an improvement for process management related to liquid and energy, it is more likely to utilize technology rather than developing new technology. For process management, partial supplement of new engineer from chemical engineering and material engineering major, and reeducation/training of existing engineer can respond. Meanwhile, equipment operation itself for process can be supplemented from education/training of existing technician workforce.

[3-B] Post-treatment process including Recycling: Eco-friendly cement - Dust detoxification technology

Workforce for designing detoxification facility for chlorine and heavy metal containing dust, and constructing plant is necessary. For facility building and plant construction based on new technology, new workforce demand for R&D and university level engineer from material engineering, mechanical engineering and chemical engineering majors is created. Equipment operation technician workforce (high school or college graduate) from chemical engineering and material engineering department can be supplied through reeducation/training of existing related workforce.

[4] Eco-friendly cement product

[4-A] Eco-friendly cement product: Eco-friendly cement - Eco-cement

Workforce for designing eco-cement production technology by using city-originated general waste and constructing plant is necessary. University level engineer from mechanical engineering, chemical engineering, environmental engineering and material engineering major is required. New demand for new technology is created.

Engineer workforce for cement product quality management and environmental safety is required, which is mainly with university graduate level. Related departments are material engineering and environmental engineering. Equipment operation technician workforce (high school or college graduate) related to chemical engineering department can be responded with reeducation of existing related workforce. Production process change and plant construction according to new product development requires high level R&D ability and practical R&D experience. Convergence R&D with existing expert workforce is important.

3.1.3. Carbon Capture and Storage and CO_2 Monitoring

[5] Carbon capturing/storage

[5-A] CCS: CO2 capture - CO2 capturing technology using absorbent

It is newly issued technology area from carbon emission restriction which has demand for new expert workforce from chemical engineering, material engineering and environmental engineering backgrounds. R&D workforce is required for developing capturing technology and process that captures CO2 from blast furnace emission gas economically with absorbent. The key technology is to develop an absorbent appropriate for economic mass capturing beside of already developed amine or ammonia absorbents. By acquiring expert workforce with master degree or over in related major, R&D must be carried on continuously.

While new engineer workforce demand is expected in the operation of CO2 capturing facility, relocation of existing engineer & technician workforce through reeducation/training is necessary. It is necessary to open CO2 capturing and storage related subjects in chemical engineering, material engineering and environmental engineering departments.

[5-B] CCS: CO2 capture - CO2 capturing technology using adsorbent

R&D workforce is required for developing the technology and process that economically capture CO2 from blast furnace emission gas with an oxidized metal base absorbent. It is a newly issued technology area from carbon emission restriction which has new workforce demand from chemical engineering, material engineering and environmental engineering backgrounds.

Also, the operation of CO2 capturing facility will create new workforce demand along with relocation of existing engineer & technician workforce through reeducation/training. It is necessary to open CO2 capturing and storage related subjects in chemical engineering, material engineering and environmental engineering departments.

[5-C] CCS: CO2 capture - CO2 refining technology

Although it is a newly emerging area for carbon emission restriction, it can apply existing general gas refining technology significantly, and therefore, workforce demand for R&D expert won't that high. Rather supplementing new engineer & technician workforce related to facility operation and responding with reeducation/training of existing engineer & technician workforce is necessary.

[5-D] CCS: CO2 transport & storage - CO2 hydrate technology

It is a newly emerging area for carbon emission restriction in which the importance of expert workforce related to continuous R&D for improving efficiency of carbon storage and transport is raised. R&D workforce is necessary for developing the technology that restricts hydrate generation from moisture during CO2 transport. New expert workforce demand with master degree or over in chemical engineering and material engineering is required. New engineer & technician workforce for facility operation is partially necessary, while responding with reeducation/training on existing engineer & technician workforce is requested.

[5-E] CCS: CO2 transport & storage - CO2 transportation technology

Doctoral class research workforce is necessary for developing technology that transports CO2 in supercritical liquid status, carbon storage and improving transport efficiency. Related departments are chemical engineering and mechanical engineering. The technology that can operate CO2 transportation system is in the area of new workforce demand creation for which developing related education courses in chemical engineering and material engineering departments is necessary. For technician workforce related to facility operation, new workforce demand is expected, as well as reeducation of existing technician workforce.

[5-F] CCS: CO2 transport & storage - CO2 underground storage technology

It is a newly emerging area in relation with carbon emission restriction. In long-term perspective, carbon conversion is required rather than carbon storage but in current stage, carbon storage is predicted to be precedent in technology level and cost perspective. R&D workforce is necessary for developing the technology and process that stores CO2 in enhanced oil recovery or closed oil rig. New demand for expert workforce with master degree or over in chemical engineering, mechanical engineering, environmental engineering, civil engineering and geology is required. In related facility operation, new workforce demand is expected, and developing curriculum at college and university is advisable.

[5-G] CCS: CO2 utilization - CO2 conversion technology

R&D workforce is required for developing the technology that recycles CO2 by converting it to CO gas for using it as iron ore reducing agent for which utilization of existing research workforce is possible. It has a higher importance in the aspect of recycling emitted carbon than simple storage. Currently the center of R&D is by the experts with master degree or over in chemical engineering and material engineering. The workforce demand for engineer & technician in relation with the operation of related equipment/facility after commercialization will be in full-scale. It is necessary to arrange new workforce and existing workforce appropriately.

[5-H] CCS: CO2 utilization - CO2 mineral carbonation technology

CO2 conversion technology including carbonation is a very important technology in the aspect of ultimate resolution for emitted carbon, which must be commercialized with significant future workforce demand in relation with CO2 emission restriction. Expert workforce demand will be generated for who had been educated related content systematically, while the related departments are chemical engineering, material engineering and mechanical engineering. After commercialization point, reeducation/training of existing engineer & technician workforce should go in parallel with partial supplement of new engineer & technician workforce.

[6] Carbon monitoring

[6-A] Direct CO2 emission monitoring

Developing the technology and facility that measures emitted carbon accurately by being attached to exit of blast furnace gas in direct relation with carbon emission permit trade and carbon tax imposing is urgent. Along with new and existing master/doctoral class research workforce related to technology development, technician workforce who can operate CO2 measuring facility is requested, for which reeducation of existing workforce is suffice. Related departments are chemical engineering, mechanical engineering, control engineering and environmental engineering.

3.2. Job Changes

3.2.1. Analysis System

The consideration in this section is about workforce composition and workforce supplement by retailed technology. Workforce composition is according to graduate level which means relative composition among R&D workforce with master/doctoral degree, university graduate level engineer workforce, college and below graduate level technician workforce. This workforce composition is related with difficulty of technology as for higher the difficulty, higher the relative importance of R&D workforce and lower the importance of technician workforce.

[Table 3.1] Distribution of green technologies in steel industry depending on difficulty and uniqueness

Difficulty (R&D dependency) ↓ / Uniqueness from existing technologies →	← Low		High →
↑ High	[2-D] Oxyfuel technology [4-A] Light Fe-Al family high strength steel [4-B] Light high strength steel [4-C] TWIP steel [4-F] Cast iron quality improvement technology		[1-A] Hydrogen fuel (hydrogen production) [3-A] Coal chemistry
	[2-A] Top gas recycling [2-B] Melted slag heat recovery technology [2-C] Waste heat electricity generation technology [3-B] High function slag treatment technology [3-C] Technology to recover nonferrous metal from by-products of steel process [4-D] Enhanced oxygen enrichment [4-G] Strip casting	[4-H] Lightweight material for structures	
Low ↓	[2-E] Combustion control technology [4-E] Non-coking coal	[1-B] Waste resources, such as scrap plastics [1-C] Biomass [3-D] High temperature dry collection technology	

[Table 3.2] Distribution of green technologies in cement industry depending on difficulty and uniqueness

Difficulty (R&D dependency) \ Uniqueness from existing related technologies	← Low		High →
↑ High	[2-A] Oxyfuel technology [4-A] Eco-cement		
	[3-B] Dust detoxification technology	[1-A] Technology to use ASR as a heat source [1-D] Technology to use city waste incineration lime as source material	
Low ↓	[1-C] Technology to use steel slag as alterative source materials replacing lime stone [2-B] High efficiency cooler [2-C] Electricity generation with waste heat [3-A] Chloride by-pass system	[1-B] Biomass	

[Table 3.3] Distribution of CCS technologies depending on difficulty and uniqueness

Difficulty (R&D dependency) ↓ / Uniqueness from existing technologies →	← Low		High →
↑ High			[5-G] CO2 conversion technology [5-H] CO2 mineral carbonation technology
		[5-C] CO2 purification technology	[5-A] CO2 capture technology using absorbent [5-B] CO2 capture technology using adhesive absorbent [5-D] CO2 hydrate technology [5-E] CO2 transportation technology [5-F] CO2 geological storage technology
Low ↓		[6-A] Direct CO2 monitoring	

3.2.2. Steel Industry

3.2.2.1. Area with new job creation with focus on R&D workforce

New job creation with focus on R&D workforce is expected in hydrogen fuel and coal chemistry areas where with high R&D dependency and high differentiation from existing technology. Light weigh material for structure was classified as the same category because it has high importance in new R&D workforce even though it has considerably lower R&D dependency than these technologies.

[Table 3.4] Technology with high New R&D workforce demand

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low		High
High			[1-A] Hydrogen fuel (hydrogen production) [3-A] Coal chemistry
		[4-H] Light weight material for structure	
Low			

3.2.2.2. Area with new job creation with focus on engineer & technician workforce

New workforce demand for engineer and technician is expected in waste resources like waste plastic, Biomass and dust collecting technology where operating managing the process through new workforce is more important than R&D dependency.

[Table 3.5] Technology with high new engineer & technician workforce demand

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low		High
High			
Low		[1-B] Waste resource like waste plastic [1-C] biomass [3-D] High temperature dry dust collection technology	

3.2.2.3. Area with greening of existing jobs with focus on R&D workforce

For the technologies that has high R&D dependency but can satisfy the demand by reeducating existing workforce such as Oxyfuel technology, light weight Fe-Al family high strength steel, Light High Strength Steel, TWIP iron and molten iron quality improvement technology, the greening of existing R&D workforce is expected. Also the technologies that has relatively less R&D dependency but has high importance in the greening of existing R&D workforce such as Top Gas Recycling, molten slag waste heat recovery technology, waste heat generation technology, high function slag treatment technology, nonferrous metal recovery technology from steel making byproduct, oxygen enrichment and Strip Casting were included in this category.

[Table 3.6] Technology with greening of existing R&D workforce

	Low	Uniqueness from existing technologies	High
High	[2-D] Oxyfuel technology [4-A] Light weight Fe-Al family high strength steel [4-B]light high strength steel [4-C]TWIP Steel [4-F] Melted iron quality improving technology		
Difficulty (R&D dependency)	[2-A] top gas recycling [2-B] melted slag waste heat recovery technology [2-C] waste heat generation technology [3-B] High function salg treating technology [3-C] Nonferrous metal recovery from steel byproduct [4-D] oxygen enrichment [4-G]strip casting		
Low			

3.2.2.4. Area with greening of existing jobs with focus on engineer & technician workforce

For the technologies that have more importance in the operation and management of process through reeducation of existing workforce than R&D dependency such as combustion control technology and the technology that uses non-coking coal, the greening of existing engineer & technician workforce is expected.

[Table 3.7] Technology with greening of existing engineer & technician workforce

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low		High
High			
Low	[2-E] Combustion control technology [4-E] Non-coking coal use		

3.2.3. Cement Industry

3.2.3.1. Area with new job creation with focus on R&D workforce

In the areas of ASR heat source utilizing technology and city waste in which R&D dependency is high with high differentiation from existing technology, new job creation with focus on R&D workforce is expected.

[Table 3.8] Technology with New R&D workforce demand

	Low	Uniqueness from existing technologies	High
High			
Difficulty (R&D dependency)		[1-A] Heat source utilizing technology of ASR [1-D] City waste incinerated slime source materializing	
Low			

3.2.3.2. Area with new job creation with focus on engineer & technician workforce

For the technology that has more importance in the operation and management of process than R&D dependency such as Biomass, new workforce demand on engineer & technician is expected.

[Table 3.9] Technology with high new workforce demand on engineer & technician

	Low	Uniqueness from existing technologies	High
High			
Difficulty (R&D dependency)			
Low		[1-B] Biomass	

3.2.3.3. Area with greening of existing jobs with focus on R&D workforce

For the technologies that have high R&D dependency but can be satisfy the demand by reeducating existing workforce such as Oxyfuel technology and eco-cement, greening of existing R&D workforce is expected. Also the Dust detoxification technology which has relatively less R&D dependency but has high importance in the greening of existing R&D workforce is considered to be included in this category.

[Table 3.10] Technology with greening of existing R&D workforce

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low		High
High	[2-A] Oxyfuel technology [4-A] Eco-cement		
	[3-B] Dust detoxification technology		
Low			

3.2.3.4. Area with greening of existing jobs with focus on engineer & technician workforce

For the technologies that have more importance in the operation and management of process than R&D dependency such as steel slag utilizing technology as an alternative fuel of limestone, high efficiency cooler, waste heat generation and Chloride by-pass system, the greening of existing engineer & technician workforce is expected.

[Table 3.11] Technology with greening of existing engineer & technician workforce

Difficulty (R&D dependency) \ Uniqueness from existing technologies	Low		High
High			
Low	[1-C] Steel slag utilizing technology as an alternative fuel for limestone [2-B] High efficiency cooler [2-C] waste heat generation [3-A]Chloride by-pass system		

3.2.4. Carbon Capture and Storage and CO_2 Monitoring

3.2.4.1. Area with new job creation with focus on R&D workforce

In the areas of CO2 conversion technology and CO2 mineral carbonizing technology where R&D dependency is high with high differentiation from existing technology, new job creation with focus on R&D workforce is expected. CO2 refining technology that has lower R&D dependency than these technologies is classified in the same category because it has high importance on new R&D workforce.

[Table 3.12] Technology with high new R&D workforce demand

Difficulty (R&D dependency)	Low	Uniqueness from existing technologies	High
High			[5-G] CO2 conversion technology [5-H] CO2 mineral carbonizing technology
		[5-C] CO2 refining technology	[5-A] CO2 capturing technology with absorbent [5-B] CO2 capturing technology with absorbent [5-D] CO2 hydrate technology [5-E] CO2 transport technology [5-F] CO2 underground storage technology
Low			

3.2.4.2. Area with new job creation with focus on engineer & technician workforce

For the technology that has more importance in the operation and management of process than R&D dependency such as CO2 monitoring technology, new workforce demand on engineer & technician is expected. But the most of this new workforce demand for engineer & technician can be supplemented by conversion of existing related workforce.

[Table 3.13] Technology with high new workforce demand for engineer & technician

	Low	Uniqueness from existing technologies	High
High			
Difficulty (R&D dependency)			
Low		[6-A] CO2 direct monitoring	

3.2. Appendix 1. Creation of New Jobs

The outlook for new job creation is summarized for green technologies of the steel industry, green technologies of the cement industry, and CCS technologies, by combining the distribution of green technologies and changes of job demands arranged by difficulties by technology and uniqueness from existing technologies.

3.2. Appendix 1.1. Steel Industry

[1-A] Hydrogen fuel (hydrogen production)

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.

[2-D] Oxyfuel technology

- Partial new green jobs related to R&D work force are expected to be created.

[3-A] Coal chemistry

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.

[4-A] Lightweight Fe-Al family high strength steel

- Partial New green jobs related to R&D work force are expected to be created.

[4-B] Light High Strength Steel

- Partial New green jobs related to R&D work force are expected to be created.

[4-C] TWIP steel

- Partial New green jobs related to R&D work force are expected to be created.

[4-F] Iron quality improvement technology

- Partial New green jobs related to R&D work force are expected to be created.

[4-H] Light steel for structures

- Partial New green jobs related to R&D work force are expected to be created.

3.2. Appendix 1.2 Cement Industry

[1-A] Technology to utilize ASR as a heat source

- Partial New green jobs related to R&D work force are expected to be created.

[1-D] Technology to use city waste incineration lime as source material

- Partial New green jobs related to R&D work force are expected to be created.

[2-A] Oxyfuel technology

- Partial New green jobs related to R&D work force are expected to be created.

[4-A] Eco-cement

- Partial New green jobs related to R&D work force are expected to be created.

3.2. Appendix 1.3 Carbon Capture and Storage and CO_2 Monitoring

[5-A] Technology to capture CO_2 using absorbent

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.
- Partial New green jobs related to technician work force are expected to be created.

[5-B] Technology to capture CO_2 using adhesive absorbent

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.
- Partial New green jobs related to technician work force are expected to be created.

[5-C] CO_2 purification technology

- Partial New green jobs related to R&D work force are expected to be created.

[5-D] CO_2 hydrate technology

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.
- Partial New green jobs related to technician work force are expected to be created.

[5-E] CO_2 transportation technology

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.
- Partial New green jobs related to technician work force are expected to be created.

[5-F] CO_2 underground storage technology

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.
- Partial New green jobs related to technician work force are expected to be created.

[5-G] CO_2 conversion technology

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.

[5-H] CO_2 mineral carbonation technology

- Various new green jobs related to R&D work force are expected to be created.
- Partial new green jobs related to engineer work force are expected to be created.

3.2 Appendix 2. Greening Existing Jobs

The outlook for greening existing jobs is summarized for green technologies of the steel industry, green technologies of the cement industry, and CCS technologies, by combining the distribution of green technologies and changes of job demands arranged by difficulties by technology and uniqueness from existing technologies.

3.2. Appendix 2.1. Steel Industry

[1-B] Waste resources such as scrap plastic

- A significant portion of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[1-C] Biomass

- A significant portion of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.

[2-A] Top gas recycling

- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[2-B] Technology to recover heat from melted slag

- Most R&D work force related jobs will be converted to green jobs.
- Most of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[2-C] Waste heat electricity generation technology

- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[2-D] Oxyfuel technology

- A significant portion of R&D work force related jobs will be converted to green jobs.

[2-E] Combustion control technology

- Most R&D work force related jobs will be converted to green jobs.
- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[3-A] High function slag treatment technology

- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[3-C] Technology to recover nonferrous metal from by-products of the steel making process

- Most of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[3-D] High temperature dry collection technology

- A significant portion of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.

[4-A] Lightweight Fe-Al family high strength steel

- A significant portion of R&D work force related jobs will be converted to green jobs.

[4-B] Light high strength steel

- A significant portion of R&D work force related jobs will be converted to green jobs.

[4-C] TWIP steel

- A significant portion of R&D work force related jobs will be converted to green jobs.

[4-D] Enhanced oxygen enrichment

- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[4-E] Use of non-coking coal

- Most R&D work force related jobs will be converted to green jobs.
- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[4-F] Iron quality improvement technology

- A significant portion of R&D work force related jobs will be converted to green jobs.

[4-G] Strip casting

- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[4-H] Lightweight material for structures

- A significant portion of R&D work force related jobs will be converted to green jobs.

3.2. Appendix 2.2. Cement Industry

[1-A] Technology to use ASR as a heat source

- A significant portion of R&D work force related jobs will be converted to green jobs.

[1-B] Biomass

- A significant portion of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.

[1-C] Technology to use steel slag as a source material to replace lime stone

- Most R&D work force related jobs will be converted to green jobs.
- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[1-D] Technology to use city waste incineration lime as a source material

- A significant portion of R&D work force related jobs will be converted to green jobs.

[2-A] Oxyfuel technology

- A significant portion of R&D work force related jobs will be converted to green jobs.

[2-B] High efficiency cooler

- Most R&D work force related jobs will be converted to green jobs.

- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[2-C] Waste heat electricity generation
- Most R&D work force related jobs will be converted to green jobs.
- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[3-A] Chloride by-pass system
- Most R&D work force related jobs will be converted to green jobs.
- Most engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[3-B] Dust detoxification technology
- Most R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.
- A significant portion of technician work force related jobs will be converted to green jobs.

[4-A] Eco-cement
- A significant portion of R&D work force related jobs will be converted to green jobs.

3.2. Appendix 2.3. Carbon Capture and Storage and CO_2 monitoring

[5-C] CO_2 purification technology
- A significant portion of R&D work force related jobs will be converted to green jobs.

[6-A] Direction CO_2 monitoring
- A significant portion of R&D work force related jobs will be converted to green jobs.
- A significant portion of engineer work force related jobs will be converted to green jobs.

3.3. Direction for Developing Education/Training Courses in response to Green Technology

This section provides the information for education/training development by comprehending overall patent analysis, skills change and job change analysis results. In earlier part of detailed technology analysis, 4 different types were presented at the standard of new workforce cultivation, existing workforce reeducation and the level of necessary workforce.

- Technology area with high new R&D workforce demand: area with more focus on R&D rather than commercialization at current level such as CCS related technology

- Technologies with high demand for new engineer & technician workforce: alternative fuel, eco-friendly post-treatment, carbon monitoring, etc.

- Technologies with expected greening of existing R&D workforce: Area with greening deployment by developing current technology level such as energy efficiency, eco-friendly post-treatment and eco-friendly product

- . Technologies with greening of existing engineer & technician workforce: area with greening deployment through applying technology on existing process such as energy efficiency and eco-friendly product.

3.3.1. Steel Industry

3.3.1.1. Technology area with high new R&D workforce demand

It is the area with focus on R&D at current level rather than commercialization including hydrogen fuel(hydrogen production), coal chemistry and light weigh t material for structure, which has nature of eco-friendly original-base technology. This area requires comprehensive consideration such as international carbon emission regulation and economic situation until reaching realization and commercialization. R&D workforce for related technologies should be cultivated through related research projects in university. Not only the engineering departments including material, metal, chemical and mechanical engineering, which are directly related to steel industry, but also the fundamental science departments including physics, chemistry and biology should plan cultivating elite workforce along with long-term research development plan.

3.3.1.2. Technologies with high demand for new engineer & technician workforce

This area attracts the most attention in relation with greening of steel industry including waste resource utilization like waste plastic, biomass and high temperature dust collection. This technology area contains currently emerging or being realized technologies such as alternative fuel and eco-friendly post-processing, for which active workforce cultivation is required. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally highly related with steel industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening steel subject in related departments and to promote improving curriculum, while government level support is also necessary.

3.3.1.3. Technologies with expected greening of existing R&D workforce

This is the area in which greening is being contrived by improving current technology level including energy efficiency, eco-friendly post-processing and eco-friendly products. Rather than separate workforce cultivation plans, expanding research development opportunities, to which existing researchers can participate, is required. But government supervising on the researches that should be implemented on enterprise level, is not advisable, while entrepreneurs need to guide research developments into vitalization. For government, vitalizing on-offline forum that delivers related info of researchers in private companies systematically and promptly is expected.

3.3.1.4. Technologies with greening of existing engineer & technician workforce

In relation with the greening of steel industry, this area is the most focused area along with the technology area for high demand on new engineer & technician workforce. The technologies in this area try greening through applying technology from energy efficiency and eco-friendly products on existing process, for which retaining of present workforce is important. To induce flexible response to fast technological development, not only training & education but also rearranging related certificates is required. For fruitful outcome of training and education, analysing job changes according to the proceeding of greening, and systematizing of education & training are also necessary. By combining green technology distribution chart, which was arranged by difficulty of technology and differentiation from existing technology, and outlook on job demand change, the outlook on new job creation and greening of existing jobs is presented along with the direction for education & training.

3.3.2. Cement Industry

3.3.2.1. Technology area with high new R&D workforce demand

It is the area with focus on R&D at current level rather than commercialization including heat resource utilizing technology of ASR and city waste source materializing by burning technology, which has nature of eco-friendly original-base technology. To reach realization and commercialization, comprehensive consideration on international carbon emission regulation and economic situation is required as well as significant amount of time and investment. R&D workforce for the technology should be cultivated from related research projects of university. Not only the engineering departments including material, chemical and mechanical engineering, which are directly related to cement industry, but also the fundamental science departments including physics, chemistry and biology as well as environmental engineering should be the target of cultivating elite workforce along with long-term research development plan.

3.3.2.2. Technologies with high demand for new engineer & technician workforce

This area attracts the most attention in relation with greening of cement industry including biomass. This technology area contains currently emerging or being realized technologies such as alternative fuel and eco-friendly post-processing, for which active workforce cultivation is required. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally highly related with cement industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening cement subjects in related departments and to promote improving curriculum, while government level support is also necessary.

3.3.2.3. Technologies with expected greening of existing R&D workforce

This is the area in which greening is being contrived by improving current technology level including energy efficiency, eco-friendly post-processing and eco-friendly products. Oxyfuel technology, eco-cement and dust detoxification technology are included. Rather than separate workforce cultivation plans, expanding research development opportunities, to which existing researchers can participate, is required. But government supervising on the researches that should be implemented on enterprise level, is not advisable, while entrepreneurs need to guide research developments into vitalization. For government, vitalizing on-offline forum that delivers related info of researchers in private companies systematically and promptly is expected.

3.3.2.4. Technologies with greening of existing engineer & technician workforce:

In relation with the greening of cement industry, this area is the most focused area as the technology area for high demand on new engineer & technician workforce along with re-education/training of existing workforce. The technologies in this area try greening through applying technology from energy efficiency and eco-friendly products on existing process, in which steel slag utilization technology as an alternative fuel of limestone, high efficiency cooler, waste heat generation and chloride by-pass system are included. To induce flexible response to fast technological development, not only training & education but also rearranging related certificates is required. For fruitful outcome of training and education, analysing job changes according to the proceeding of greening, and systematizing of education & training are also necessary.

3.3.3. Carbon Capture and Storage and CO_2 Monitoring

3.3.3.1. Technology area with high new R&D workforce demand

CCS related technologies, belong to here of which have focus on R&D instead of commercialization on current technology level. While CCS related technologies have high difficulty on current technology level, geographic situation in storage aspect after capturing carbon became a very big limitation. This area requires comprehensive consideration such as international carbon emission regulation and economic situation until reaching realization and commercialization. R&D workforce for related technologies should be cultivated through related research projects in university. It is not limited to steel and cement industries, and a long-term research development plan on the fundamental science areas such as physics, chemistry and biology rather than traditional material, metal, chemical and mechanical engineering, is considered to be more important.

3.3.3.2. Technologies with high demand for new engineer & technician workforce

Carbon monitoring belongs to here, which should get attention first than CCS. While it's importance has already recognized, active workforce cultivation should be implemented for the area during realization. It is not limited to steel and cement industries, and a long-term research development plan on the fundamental science areas such as physics, chemistry and biology rather than traditional material, metal, chemical and mechanical engineering, is considered to be more important. Comprehensive connection not only with material engineering, metal engineering, chemical engineering and mechanical engineering, which are traditionally not limited with steel industry, but also with environmental engineering became very important, which requires converged education on undergraduate level. It is necessary to urge opening convergence subjects in related departments and to promote improving curriculum, while government level support is also necessary.

3.3. Appendix 1. Steel Industry

3.3. Appendix 1.1. Alternative fuel

Technology field	[1-A] Hydrogen fuel (hydrogen production)		
Definition	Use of hydrogen as a reduction agent for blast furnace steel making (requires confirmation)		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
		Required knowledge and dexterity	Knowledge of hydrogen use technology and process, understanding and control technologies for the changes of the reduction process by replacing CO gas with hydrogen
		Related department and major	Metal Engineering, Material Engineering, Chemical Engineering, or Mechanical Engineering
	Engineer	Demand	New resource supplementation is important.
		Required knowledge and dexterity	Retraining for the operation of equipment and facilities to produce hydrogen from COG (coke oven gas)
		Related department and major	Metal Engineering, Material Engineering, Chemical Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Operation and management of compression, liquefaction, and solidified gas, understanding of equipment related to transportation and storage
		Related department and major	Chemical Engineering, Material Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is limited.
		Required knowledge and dexterity	Knowledge of technologies and processes to use hydrogen
		Related work	Metal Engineering, Material Engineering, Chemical Engineering, or Mechanical Engineering
	Engineer	Demand	Utilization of existing work force is limited.
		Required knowledge and dexterity	Retraining for the operation of equipment and facilities to produce hydrogen from COG (COKE OVEN GAS)
		Related work	Existing blast furnace operation works
	Technician	Demand	Utilization of existing work force is limited.
		Required knowledge and dexterity	Retraining for blast furnace operation using hydrogen
		Related work	Existing blast furnace operation works

Technology fields	[1-B] Waste resources, such as scrap plastics		
Definition	Mix the waste resource with coke and use as source materials for making steel products.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Knowledge required to develop the processes using waste resources, method of recycling slags generated when waste resources are used for mixing with coke
		Related department and major	Metal Engineering, Chemical Engineering, Ceramic Engineering, or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Technologies to measure and control all changes occurring when waste resources are used an auxiliary fuel
		Related department and major	Metal Engineering or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Pre-treatment process operation technologies for using waste resources as source materials for the steel making process
		Related department and major	Metal Engineering or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
		Required knowledge and dexterity	Knowledge in research on the differences between existing slag re-treatment method
		Related work	Existing research related to slag treatment
	Engineer	Demand	Full utilization of existing work force through retraining
		Required knowledge and dexterity	Functions to utilize waste resources, including waste organic materials
		Related work	Existing works related to the recycling of waste resources
	Technician	Demand	Utilization of existing work force is important.
		Required knowledge and dexterity	Pre-treatment process operation technologies for using waste resources as source materials for the steel making process
		Related work	Existing process operation work

Technology fields	[1-C] Biomass		
Definition	Use biomass, including wood, as a source material for coke		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Knowledge about the use of biomass with less economic value as wood for making coke
		Related department and major	Forestry Engineering, Biology, Metal Engineering, Chemical Engineering, or Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Technologies on biomass pre-treatment process
		Related department and major	Forestry Engineering, Biology, Metal Engineering, Chemical Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
		Required knowledge and dexterity	Biomass pre-treatment technology
		Related department and major	Forestry Engineering, Biology, Metal Engineering, Chemical Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
		Required knowledge and dexterity	Knowledge about the use of biomass with less economic value as wood for making coke
		Related work	Forestry Engineering, Biology, Metal Engineering, or Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
		Required knowledge and dexterity	Biomass pre-treatment technology
		Related work	Existing works related to coke source material
	Technician	Demand	Utilization of existing work force is important.
		Required knowledge and dexterity	Biomass pre-treatment technology
		Related work	Existing works related to coke source material

3.3. Appendix 1.2. Energy Efficiency Improvement

Technology fields	[2-A] Top gas recycling		
Definition	Separate and capture CO_2 from blast furnace gas, and reuse it for the reduction of iron ore.		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Research on technologies to separate and capture CO_2 from blast furnace gas, knowledge in connection with Oxyfuel technology, and knowledge related to the research on CO_2 recycling
	R&D	Related department and major	Chemical Engineering, Reaction, Metal Engineering, Mechanical Engineering, Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate the equipment related to separation, capturing and use of CO_2 from blast furnace gas
	Engineer	Related department and major	Chemical Engineering, Reaction, Metal Engineering, Mechanical Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Production functions and processes related to separation, capturing and use of blast furnace gas
	Technician	Related department and major	Chemical Engineering, Reaction, Metal Engineering, Mechanical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to the cycling of captured CO_2
	R&D	Related work	Research on blast furnace gas
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate the equipment related to separation, capturing and use of CO_2 from blast furnace gas
	Engineer	Related work	Existing works related to equipment operation
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate the equipment related to separation, capturing and use of CO_2 from blast furnace gas
	Technician	Related work	Production work inside existing blast furnace gas treatment process

Technology fields	[2-B] Technology to recover heat from melted slag		
Definition	Use sensible heat with temperatures over 1500℃ of the melted slag.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge to conduct professional research on the physical properties of slag
	R&D	Related department and major	Metal Engineering, Material Engineering, Chemical Engineering, Reaction Engineering, Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technologies to operate the equipment and facilities related to the heat recovery from melted slag
	Engineer	Related department and major	Metal Engineering, Material Engineering, Chemical Engineering, Reaction Engineering, Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technologies to operate the equipment and facilities related to the heat recovery from melted slag
	Technician	Related department and major	Metal Engineering, Material Engineering, Chemical Engineering, Reaction Engineering, Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge of the development of technologies and processes to recover heat from melted slag, research on recycling technology
	R&D	Related work	People who majored Ceramic Engineering, Metal Engineering, or Civil Engineering, or researchers in the field of high temperature heat recovery
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Technologies to operate the equipment and facilities related to the heat recovery from melted slag
	Engineer	Related work	Existing related works
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Technologies to operate the equipment and facilities related to the heat recovery from melted slag
	Technician	Related work	Existing related works

Technology fields	[2-C] Technology to generate electricity with waste heat		
Definition	Utilize the waste heat of mid/low temperatures below 300℃.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Development of technologies and processes to use mid/low temperature waste heat
	R&D	Related department and major	Chemical Engineering, Mechanical Engineering, or Facility Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology to design and manufacture heat exchangers suitable for the utilization of mid/low temperature waste heat
	Engineer	Related department and major	Chemical Engineering, Mechanical Engineering, or Facility Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technology to operate equipment related to waste heat electricity generation
	Technician	Related department and major	Chemical Engineering, Mechanical Engineering, or Facility Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Professional research in the field of existing high temperature heat recovery
	R&D	Related work	Research related to high temperature heat recovery
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Technology to design and manufacture heat exchangers suitable for the utilization of mid/low temperature waste heat
	Engineer	Related work	Works related to facility manufacturing
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Technology to operate equipment related to waste heat electricity generation
	Technician	Related work	Existing related works

Technology fields	[2-D] Oxyfuel technology		
Definition	Reduce iron ore using oxygen or oxygen enriched gas as oxidizing agents instead of heated air.		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Development and technologies and processes to reduce iron ore using oxygen as the oxidizing agent
	R&D	Related department and major	Metal Engineering, Chemical Engineering, or Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Mass production of oxygen, technologies to operate facilities and equipment using blast furnace oxidizing agents
	Engineer	Related department and major	Metal Engineering, Chemical Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Mass production of oxygen, technologies to operate facilities and equipment using blast furnace oxidizing agents
	Technician	Related department and major	Metal Engineering, Chemical Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Development of technologies to produce oxygen in large quantities in more economically efficient ways, and development technologies and processes to separate and capture CO_2 from Oxyfuel combustion gas
	R&D	Related work	Chemical Engineering or Metal Engineering related research
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Mass production of oxygen, technologies to operate facilities and equipment using blast furnace oxidizing agents
	Engineer	Related work	Combustion related works
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Mass production of oxygen, technologies to operate facilities and equipment using blast furnace oxidizing agents
	Technician	Related work	Combustion related works

Technology fields	[2-E] Combustion control technology		
Definition	Development of control logic depending on the combustion conditions, such as type and shape of combustion energy		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge gained through inter-department research including Combustion Engineering or Control Engineering
	R&D	Related department and major	Chemical Engineering, Control Engineering, Mechanical Engineering, or Combustion Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology to operate flexible processes based on combustion conditions and environments
	Engineer	Related department and major	Chemical Engineering, Control Engineering, Mechanical Engineering, or Combustion Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technology to operate flexible processes based on combustion conditions and environments
	Technician	Related department and major	Chemical Engineering, Control Engineering, Mechanical Engineering, or Combustion Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Development of combustion control logic and process
	R&D	Related work	Existing combustion related research
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Technology to operate flexible processes based on combustion conditions and environments
	Engineer	Related work	Existing combustion related research
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Technology to operate flexible processes based on combustion conditions and environments
	Technician	Related work	Existing combustion related research

3.3. Appendix 1.3. Environmentally friendly backend processing including recycling

Technology fields	[3-A] Coal chemistry		
Definition	Manufacture various interim chemical products such as methanol, ammonia, sulfuric acid, diesel oil, and TAR from waste gases from steel manufacturing processes instead of using it as a simple heat source.		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Development of related technologies and processes and knowledge that can be obtained from inter-department research
	R&D	Related department and major	Chemical Engineering, Material Engineering, Reaction, Mechanical Engineering, or Control Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Operation of related technologies and processes
	Engineer	Related department and major	Chemical Engineering, Material Engineering, Reaction, Mechanical Engineering, or Control Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Operation of related technologies and processes
	Technician	Related department and major	Chemical Engineering, Material Engineering, Reaction, Mechanical Engineering, or Control Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is limited.
	R&D	Required knowledge and dexterity	Development of technologies and processes to inject the waste gas containing high contents of COG (COKE OVEN GAS) and LDG (LINZE DONAWITZ GAS) to blast furnaces and use it as the reduction gas for the steel manufacturing process
	R&D	Related work	Existing CO_2 related research
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Operation of related technologies and processes
	Engineer	Related work	Existing works related to waste gas
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Operation of related technologies and processes
	Technician	Related work	Existing works related to waste gas

Technology fields	[3-B] High function slag treatment technology		
Definition	Research of optimum recycling fields depending on the type of slag and treatment method		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies
	R&D	Related department and major	Ceramic Engineering, Material Engineering, Chemical Engineering, or Civil Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology and function required to use slag
	Engineer	Related department and major	Ceramic Engineering, Material Engineering, or Civil Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technology and function required to use slag
	Technician	Related department and major	Ceramic Engineering, Material Engineering, or Civil Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies
	R&D	Related work	Existing research related to slag treatment
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Technology and function required to use slag
	Engineer	Related work	Existing works related to slag treatment
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Technology and function required to use slag
	Technician	Related work	Existing works related to slag treatment

Technology fields	[3-C] Technology to recover nonferrous metal for by-products of steel making process		
Definition	Recover nonferrous metal such as Si, Ca, Al, Mg, Ni, and Zn from steel or iron slag.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies and processes
	R&D	Related department and major	Metal Engineering, Material Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate equipment and facilities to recover nonferrous metal
	Engineer	Related department and major	Metal Engineering or Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate equipment and facilities to recover nonferrous metal
	Technician	Related department and major	Metal Engineering or Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies and processes
	R&D	Related work	Metal Engineering, Material Engineering or Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate equipment and facilities to recover nonferrous metal
	Engineer	Related work	People who completed Chemical Metallurgy courses
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate equipment and facilities to recover nonferrous metal
	Technician	Related work	People who completed Chemical Metallurgy courses

Technology fields	[3-D] High temperature dry collection technology		
Definition	Capture and remove particles such as dust included in the blast furnace exhaust gas without using the water spray method.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies and knowledge to develop filter materials to capture blast furnace waste gas
	R&D	Related department and major	Mechanical Engineering, Environment Engineering, Material Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate the system related to blast furnace waste gas filtering
	Engineer	Related department and major	Mechanical Engineering, Environment Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate the system related to blast furnace waste gas filtering
	Technician	Related department and major	Mechanical Engineering, Environment Engineering, or Material Engineering, or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge to develop related technologies and knowledge to develop filter materials to capture blast furnace waste gas
	R&D	Related work	Mechanical Engineering, Environment Engineering, Material Engineering, or Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate the system related to blast furnace waste gas filtering
	Engineer	Related work	Existing works related to blast furnace waste gas treatment
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Functions to operate the system related to blast furnace waste gas filtering
	Technician	Related work	Existing works related to blast furnace waste gas treatment

3.3. Appendix 1.4. Eco-friendly steel products

Technology fields	[4-A] Lightweight Fe-Al family high strength steel		
Definition	Develop Fe-Al family high strength steel for automobiles.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge related to the development of high strength steel and professional knowledge about alloy technology
	R&D	Related department and major	Metal Engineering or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Metal forming suitable for the forming method of developed Fe-Al family high strength steel
	Engineer	Related department and major	Metal Engineering, Material Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Metal forming suitable for the forming method of developed Fe-Al family high strength steel
	Technician	Related department and major	Metal Engineering, Material Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to the development of high strength steel
	R&D	Related work	Knowledge related to the research of high strength steel
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Metal forming suitable for the forming method of developed Fe-Al family high strength steel
	Engineer	Related work	Existing works related to material engineering (Metal Engineering, Material Engineering, or Mechanical Engineering)
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Metal forming suitable for the forming method of developed Fe-Al family high strength steel
	Technician	Related work	Existing works related to material engineering (Metal Engineering, Material Engineering, or Mechanical Engineering)

Technology fields	[4-B] Light high strength steel		
Definition	Production of carbon fiber and high strength polymer fiber (aramid fiber, etc) at lower costs and manufacturing composite material using them.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge about composite material manufacturing using carbon fiber and high strength polymer fiber
	R&D	Related department and major	Material Engineering, Chemical Engineering, or Aerospace Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology to operate production equipment
	Engineer	Related department and major	Works related to material and mass production, Metal Engineering, Material Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technology to operate production equipment
	Technician	Related department and major	Works related to material and mass production, Metal Engineering, Material Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge about the technologies to reduce the manufacturing cost of carbon fiber and high strength polymer finer
	R&D	Related work	Existing research knowledge in the related fields, Material Engineering, Chemical Engineering, or Aerospace Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Technology to operate production equipment
	Engineer	Related work	Works related to material and mass production, Metal Engineering, Material Engineering, or Mechanical Engineering
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Technology to operate production equipment
	Technician	Related work	Works related to material and mass production, Metal Engineering, Material Engineering, or Mechanical

Technology fields	[4-C] TWIP steel		
Definition	Develop TWP steel (ultra strength steel) mass production facilities.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge related to the development of facilities
	R&D	Related department and major	Metal Engineering, Material Engineering, or Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Knowledge related to the operation of facilities
	Engineer	Related department and major	Metal Engineering, Material Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Knowledge related to the operation of facilities
	Technician	Related department and major	Metal Engineering, Material Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to the development of facilities
	R&D	Related work	Existing TWIP steel research
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Knowledge related to the operation of facilities
	Engineer	Related work	Operation works of existing production facilities
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Knowledge related to the operation of facilities
	Technician	Related work	Operation works of existing production facilities

Technology fields	[4-D] Enhanced oxygen enrichment		
Definition	Develop the production process to produce oxygen at low cost to inject oxygen into the air for reducing high-productivity and BFG values while producing heated air blowing to blast furnaces.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Research knowledge related to oxygen production cost reduction
	R&D	Related department and major	Chemical Engineering, Material Engineering, or Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate oxygen production facilities
	Engineer	Related department and major	Chemical Engineering , Material Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate oxygen production facilities
	Technician	Related department and major	Chemical Engineering, Material Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Research knowledge related to oxygen production cost reduction
	R&D	Related work	Existing oxygen production related research
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate oxygen production facilities
	Engineer	Related work	Operation of oxygen production facilities
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate oxygen production facilities
	Technician	Related work	Operation of oxygen production facilities

Technology fields	[4-E] Use of non-coke coal		
Definition	Reduce the use of expensive coal by using low cost coal for producing coke.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Application of commercialized technology
	R&D	Related department and major	Chemical Engineering or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate production facilities using fossil fuel
	Engineer	Related department and major	Chemical Engineering or Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate production facilities using fossil fuel
	Technician	Related department and major	Chemical Engineering or Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Application of commercialized technology
	R&D	Related work	Research related to Chemical Engineering or Material Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate production facilities using fossil fuel
	Engineer	Related work	Existing engineers in the related fields
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate production facilities using fossil fuel
	Technician	Related work	Existing works in the related fields

Technology fields	[4-F] Iron quality improvement technology		
Definition	Remove foreign substances in the pig iron produced in electric furnaces to produce high quality pig iron.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge to develop iron scrap cleaning technology to remove hazardous impurities from iron scrap
	R&D	Related department and major	Metal Engineering, Material Engineering, Mechanical Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate facilities
	Engineer	Related department and major	Metal Engineering, Material Engineering, Mechanical Engineering, or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate facilities
	Technician	Related department and major	Metal Engineering, Material Engineering, Mechanical Engineering, or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge to develop technologies that can remove impurities including Cu and Al, especially Cu, effectively from melted Fe
	R&D	Related work	Research related to Metal Engineering or Material Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Functions to operate facilities
	Engineer	Related work	Existing engineers in the related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Functions to operate facilities
	Technician	Related work	Existing related works

Technology fields	[4-G] Strip casting		
Definition	Produce eco-friendly products by saving energy through process compression.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge of technology research to stabilize the strip casting process
	R&D	Related department and major	Metal Engineering, Material Engineering, Control Engineering, or Mechanical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate facilities and equipment
	Engineer	Related department and major	Metal Engineering, Material Engineering, Control Engineering, or Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate facilities and equipment
	Technician	Related department and major	Metal Engineering, Material Engineering, Control Engineering, or Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge of technology research to stabilize the strip casting process
	R&D	Related work	Researches related to Metal Engineering, Material Engineering, Control Engineering, or Mechanical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions to operate facilities and equipment
	Engineer	Related work	Existing engineers in the related fields
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate facilities and equipment
	Technician	Related work	Existing engineers in the related fields

Technology fields	[4-H] Lightweight materials for structures		
Definition	High corrosion proof and high tensile strength steel including stainless steel		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Research knowledge about new surface treatment technology to provide corrosion proof surfaces
	R&D	Related department and major	Research related to Metal Engineering, Material Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate processes based on new surface treatment technology
	Engineer	Related department and major	Research related to Metal Engineering, Material Engineering, or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate processes based on new surface treatment technology
	Technician	Related department and major	Research related to Metal Engineering, Material Engineering, or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Research knowledge about new surface treatment technology to provide corrosion proof surfaces
	R&D	Related work	Researches Metal Engineering, Material Engineering, or Chemical Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Functions to operate processes based on new surface treatment technology
	Engineer	Related work	Existing engineers in related the fields
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Functions to operate processes based on new surface treatment technology
	Technician	Related work	Existing related works

3.3. Appendix 2. Cement

3.3. Appendix 2.1. Alternative fuel / source material area

Technology fields	[1-A] Technology to use ASR as a heat source		
Definition	Use high chloride flammable waste as a heat source.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Overall understanding of the cement manufacturing process and understanding of energy are required.
	R&D	Related department and major	Energy Engineering, Chemical Engineering, Material Engineering, or Environment Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology to remove chloride from the waste containing large amounts of chloride for safe use, combustion technology, and environmental impact assessment technology
	Engineer	Related department and major	Chemical Engineering or Material Engineering (New departments combining related departments such as Energy and Environment Engineering are required.)
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Knowledge of operation, maintenance, and management of kilns, burners, and pre-treatment facilities
	Technician	Related department and major	Chemical Engineering or Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Overall understanding of the cement manufacturing process and understanding of energy are required.
	R&D	Related work	Energy Engineering, Chemical Engineering, Material Engineering, or Environment Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Technology to remove chloride from the waste containing large amounts of chloride for safe use, combustion technology, and environmental impact assessment technology
	Engineer	Related work	Existing engineers in related the fields
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Knowledge of operation, maintenance, and management of kilns, burners, and pre-treatment facilities
	Technician	Related work	Existing related works

Technology fields	[1-B] Biomass		
Definition	Use biomass such as wood to make coke.		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge of using biomass with less economic value than wood to make coke
	R&D	Related department and major	Forestry Engineering, Biology, Metal Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Technology for the biomass pre-treatment process
	Engineer	Related department and major	Forestry Engineering, Biology, Metal Engineering, or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Biomass pre-treatment technology
	Technician	Related department and major	Forestry Engineering, Biology, Metal Engineering, or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge of using biomass with less economic value than wood to make coke
	R&D	Related work	Forestry Engineering, Biology, Metal Engineering, or Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Technology for the biomass pre-treatment process
	Engineer	Related work	Existing works related to the source material to make coke
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Biomass pre-treatment technology
	Technician	Related work	Existing works related to the source material to make coke

Technology fields	[1-C] Technology to use steel slag as alternative source material for lime stone		
Definition	Alternative source material replacing the Ca source that reduces 40% of the CO_2 basic unit through the decarbonation of lime stone		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Assessment of CO_2 in the cement process and knowledge related to manufacturing process improvement
	R&D	Related department and major	Material Engineering or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Overall understanding of the cement manufacturing process
	Engineer	Related department and major	Material Engineering or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Overall understanding of the cement manufacturing process
	Technician	Related department and major	Material Engineering or Chemical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Assessment of CO_2 in the cement process and knowledge related to manufacturing process improvement
	R&D	Related work	Material Engineering or Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Understanding of the overall cement manufacturing process
	Engineer	Related work	Existing cement manufacturing processes
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Understanding of the cement manufacturing process
	Technician	Related work	Existing related works

Technology fields	[1-D] Technology to convert city waste incineration lime to source material		
Definition	Use city waste incineration lime to make cement through chloride treatment.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge of technology to convert hazardous waste that contain large amounts of chloride and heavy metals to safer source materials to make cement
	R&D	Related department and major	Chemical Engineering or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions to operate the facilities to remove chloride and heavy metals
	Engineer	Related department and major	Chemical Engineering or Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Functions to operate the facilities to remove chloride and heavy metals
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge of technology to convert hazardous waste that contain large amounts of chloride and heavy metals to safer source materials to make cement
	R&D	Related work	Chemical Engineering, Material Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Functions to operate the facilities to remove chloride and heavy metals
	Engineer	Related work	Existing by-products removal works
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Functions to operate the facilities to remove chloride and heavy metals
	Technician	Related work	Existing by-products removal works

3.3. Appendix 2.2. High energy efficient process

Technology fields	[2-A] Oxyfuel technology		
Definition	Reduce iron ore using oxygen or oxygen enriched gas as the oxidizing agent instead of heated air blowing into furnaces.		
Expected Realizable Year	2025		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Development of technologies and processes to reduce iron ore using oxygen as the oxidizing agent
	R&D	Related department and major	Metal Engineering, Mechanical Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Mass production of oxygen and technologies to operate equipment and facilities using oxygen as a blast furnace oxidizing agent
	Engineer	Related department and major	Metal Engineering, Mechanical Engineering, or Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Knowledge related to the operation and maintenance of kilns and burners
	Technician	Related department and major	Chemical Engineering, Mechanical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Development of technologies to produce large quantities of oxygen in cost effective ways and the development of technologies and processes to separate and capture CO_2 generated from Oxyfuel combustion gas
	R&D	Related work	Research related to Chemical Engineering, Mechanical Engineering, or Metal Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Mass production of oxygen and technologies to use equipment and facilities using oxygen as a blast furnace oxidizing agent
	Engineer	Related work	Combustion related works
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Mass production of oxygen and technologies to use equipment and facilities using oxygen as a blast furnace oxidizing agent
	Technician	Related work	Combustion related works

Technology fields	[2-B] High efficient cooler		
Definition	Improve energy efficiency by optimizing the conveying system and air distribution system.		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	R&D	Related department and major	Chemical Engineering, Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	Engineer	Related department and major	Chemical Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	R&D	Related work	Overall knowledge and research on coolers
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	Engineer	Related work	Existing cooler related works
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Improvement of existing cooler manufacturing technologies
	Technician	Related work	Existing cooler related works

Technology fields	[2-C] Electricity generation with waste heat		
Definition	Electricity generation using waste heat of high temperature gas from the cooler		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge on electricity generation with waste heat
	R&D	Related department and major	Electric Engineering, Mechanical Engineering, or Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Knowledge of management of waste heat electricity generation facilities
	Engineer	Related department and major	Electric Engineering, Mechanical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Knowledge of management of waste heat electricity generation facilities
	Technician	Related department and major	Electric Engineering, Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Research on existing waste heat electricity generation
	R&D	Related work	Existing related works
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Knowledge of management of waste heat electricity generation facilities
	Engineer	Related work	Existing related works
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Functions to operate waste heat generation facilities
	Technician	Related work	Existing related works

3.3. Appendix 2.3. Eco-friendly back-end process, including recycling

Technology fields	[3-A] Chloride bypass system		
Definition	Technology to extract the dust containing large amounts of chloride compound by bypassing part of the flue gas from the rear end of the kiln during the calcination process		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge of the path of dust, research on the emitted volume of gas, etc.
	R&D	Related department and major	Chemical Engineering or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Knowledge and functions related to fluid and energy
	Engineer	Related department and major	Chemical Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Basic equipment operation function
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to fluid and energy
	R&D	Related work	Existing related research
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Knowledge and functions related to fluid and energy
	Engineer	Related work	Existing related works
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Basic equipment operation function
	Technician	Related work	Existing related works

Technology fields	[3-B] Dust detoxification technology		
Definition	Technology to remove heavy metals from the dust extracted from the chloride bypass system and to recover valuable potassium chloride.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge related to designing dust detoxification facilities containing chloride and heavy metals and plant construction
	R&D	Related department and major	Material Engineering, Mechanical Engineering, Chemical Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Functions related to designing dust detoxification facilities containing chloride and heavy metals and plant construction
	Engineer	Related department and major	Material Engineering, Mechanical Engineering, Chemical Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Basic equipment operation functions
	Technician	Related department and major	Existing related works
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to designing dust detoxification facilities containing chloride and heavy metals and plant construction
	R&D	Related work	Material Engineering, Mechanical Engineering, Chemical Engineering
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Functions related to designing dust detoxification facilities containing chloride and heavy metals and plant construction
	Engineer	Related work	Existing related works
	Technician	Demand	Full utilization of existing work force through retraining
	Technician	Required knowledge and dexterity	Basic equipment operation functions
	Technician	Related work	Existing related works

3.3. Appendix 2.4. Eco-friendly cement product

Technology fields	[4-A] Eco-cement		
Definition	Technology to manufacture eco-cements with characteristics similar to general Portland cement using waste resources such as city waste as the main source materials		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Knowledge related to designing eco-cement production technologies and plant construction planning
	R&D	Related department and major	Mechanical Engineering, Chemical Engineering, Environment Engineering, or Material Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Cement product quality management and verification of the environmental safety of products
	Engineer	Related department and major	Chemical Engineering, Environment Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Basic equipment operation function
	Technician	Related department and major	Existing related works
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge related to actual verification for the changes of production processes caused by new product development
	R&D	Related work	Research related to existing processes
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Cement product quality management and verification of the environmental safety of products
	Engineer	Related work	Existing related works
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Basic equipment operation function
	Technician	Related work	Existing related works

3.3. Appendix 3. Carbon Capture and Storage and CO_2 Monitoring

3.3. Appendix 3.1. CO_2 Capture

Technology fields	[5-A]CO_2 capture technology using absorbent		
Definition	Technology to capture CO_2 selectively from BFG using chemical absorbent (ammonia, amine, etc.)		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Knowledge to develop absorbents suitable for capturing CO_2 in large volumes more economically efficiently than existing developed amine-based or ammonia water absorbents
	R&D	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Engineer	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
	Technician	Demand	New resource supplementation is important.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Technician	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is important.
	R&D	Required knowledge and dexterity	Knowledge related to the development of technologies and processes to capture CO_2 in economically efficient ways using CO_2 absorbents
	R&D	Related work	Existing research related to CO_2 absorption
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Engineer	Related work	Existing CO_2 absorption related process operation
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Technician	Related work	Existing CO_2 absorption related process operation

Technology fields	[5-B] CO_2 capture technology using adhesive absorbent		
Definition	Capture CO_2 generated from steel manufacturing processes using oxidizing metal based absorbents.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Use of oxidizing metal based absorbents to capture CO_2 from blast furnace exhaust gas and knowledge related to the development of economic capture technologies and processes
	R&D	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Engineer	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
	Technician	Demand	New resource supplementation is important.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Technician	Related department and major	Chemical Engineering, Material Engineering, Environment Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is important.
	R&D	Required knowledge and dexterity	Knowledge related to the development of technologies and processes to capture CO_2 in economically efficient ways using CO_2 absorbents
	R&D	Related work	Existing research related to CO_2 adhesive absorption
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Engineer	Related work	Existing CO_2 absorption related process operation
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 capture facilities
	Technician	Related work	Existing CO_2 absorption related process operation

Technology fields	[5-C] CO_2 purification technology		
Definition	Technology to purify and condition captured CO_2		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	New resource supplementation is important.
	R&D	Required knowledge and dexterity	Capability to apply existing gas purification technologies
	R&D	Related department and major	Chemical Engineering, Environment Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Existing gas purification technology and process management functions
	Engineer	Related department and major	Chemical Engineering or Environment Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Existing gas purification technology and process management functions
	Technician	Related department and major	Chemical Engineering, Environment Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Capability to apply existing gas purification technologies
	R&D	Related work	Chemical Engineering, Environment Engineering
	Engineer	Demand	Utilization of existing work force is important.
	Engineer	Required knowledge and dexterity	Existing gas purification technology and process management functions
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Existing gas purification technology and process management functions
	Technician	Related work	Existing related works

3.3. Appendix 3.2. CO_2 transportation and storage

Technology fields	[5-D] CO_2 hyderate technology		
Definition	Technology to prevent the formation of hydrate during transportation		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Basic knowledge to suppress carbon emission
	R&D	Related department and major	Chemical Engineering, Material Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Knowledge to operate related facilities
	Engineer	Related department and major	Chemical Engineering, Material Engineering
	Technician	Demand	New resource supplementation is important.
	Technician	Required knowledge and dexterity	Knowledge to operate related facilities
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is important.
	R&D	Required knowledge and dexterity	Basic knowledge to suppress carbon emission
	R&D	Related work	Chemical Engineering, Material Engineering
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Knowledge to operate related facilities
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Knowledge to operate related facilities
	Technician	Related work	Existing related works

Technology fields	[5-E] CO_2 transportation technology		
Definition	Technology to transport CO_2 in the supercritical fluid state		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Knowledge of related technology development (understanding of thermodynamics and hydromechanics)
	R&D	Related department and major	Chemical Engineering, Material Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Knowledge to operate related facilities
	Engineer	Related department and major	Chemical Engineering, Material Engineering
	Technician	Demand	New resource supplementation is important.
	Technician	Required knowledge and dexterity	Knowledge to operate related facilities
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is important.
	R&D	Required knowledge and dexterity	Knowledge of related technology development (understanding of thermodynamics and hydromechanics)
	R&D	Related work	Chemical Engineering, Material Engineering
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Knowledge to operate related facilities
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Knowledge to operate related facilities
	Technician	Related work	Existing related works

Technology fields	[5-F] CO_2 geological storage technology		
Definition	Technology to inject or store CO_2 in a saline formation layer or abandoned oilfields or gas fields stably.		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Knowledge related to the development of technologies and processes for CO_2 geological storage
	R&D	Related department and major	Chemical Engineering, Civil Engineering, Mechanical Engineering, or Geology
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 geological storage facilities
	Engineer	Related department and major	Chemical Engineering, Environment Engineering, Mechanical Engineering, Civil Engineering, Geology
	Technician	Demand	New resource supplementation is important.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 geological storage facilities
	Technician	Related department and major	Chemical Engineering, Environment Engineering, Mechanical Engineering, Civil Engineering, Geology
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is important.
	R&D	Required knowledge and dexterity	Knowledge related to the development of technologies and processes for CO_2 geological storage
	R&D	Related work	Chemical Engineering, Civil Engineering, Mechanical Engineering, Geology
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Functions to operate CO_2 geological storage facilities
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Functions to operate CO_2 geological storage facilities
	Technician	Related work	Existing related works

Technology fields	[5-G] CO_2 conversion technology		
Definition	Technology to convert CO_2 to CO gas and use it as a reduction agent for iron ore		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Systematic knowledge of related contents
	R&D	Related department and major	Chemical Engineering, Material Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Technologies to operate related processes
	Engineer	Related department and major	Chemical Engineering, Material Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technologies to operate related processes
	Technician	Related department and major	Chemical Engineering, Material Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is limited.
	R&D	Required knowledge and dexterity	Systematic knowledge of related contents
	R&D	Related work	Chemical Engineering, Material Engineering
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Technologies to operate related processes
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Technologies to operate related processes
	Technician	Related work	Existing related works

Technology fields	[5-H] CO_2 mineral carbonation technology		
Definition	Produce carbonates through the carbonation reaction between CO_2 and minerals (natural minerals and industrial by-products).		
Expected Realizable Year	2020		
New work force (training)	R&D	Demand	The scale of new resource supplementation is large.
	R&D	Required knowledge and dexterity	Systematic knowledge of related contents
	R&D	Related department and major	Chemical Engineering, Material Engineering, Mechanical Engineering
	Engineer	Demand	New resource supplementation is important.
	Engineer	Required knowledge and dexterity	Technologies to operate related processes
	Engineer	Related department and major	Chemical Engineering, Material Engineering, Mechanical Work force
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Technologies to operate related processes
	Technician	Related department and major	Chemical Engineering, Material Engineering, Mechanical Engineering
Existing work force (retraining)	R&D	Demand	Utilization of existing work force is limited.
	R&D	Required knowledge and dexterity	Systematic knowledge of related contents
	R&D	Related work	Chemical Engineering, Material Engineering, Mechanical Engineering
	Engineer	Demand	Utilization of existing work force is limited.
	Engineer	Required knowledge and dexterity	Technologies to operate related processes
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is limited.
	Technician	Required knowledge and dexterity	Technologies to operate related processes
	Technician	Related work	Existing related works

3.3. Appendix 3.3. CO_2 monitoring

Technology fields	[6-A] Direct CO_2 monitoring		
Definition	Accurate measurement of the volume of CO_2 with the measurement units attached to the exhaust of blast furnaces		
Expected Realizable Year	2015		
New work force (training)	R&D	Demand	Scale of new resource supplementation is small.
	R&D	Required knowledge and dexterity	Knowledge required to develop related technologies and facilities
	R&D	Related department and major	Chemical Engineering, Mechanical Engineering, Control Engineering, or Environment Engineering
	Engineer	Demand	Scale of new resource supplementation is small.
	Engineer	Required knowledge and dexterity	Working knowledge of related processes
	Engineer	Related department and major	Chemical Engineering, Mechanical Engineering, Control Engineering, or Environment Engineering
	Technician	Demand	Scale of new resource supplementation is small.
	Technician	Required knowledge and dexterity	Working knowledge of related processes
	Technician	Related department and major	Chemical Engineering, Mechanical Engineering, Control Engineering, or Environment Engineering
Existing work force (retraining)	R&D	Demand	Full utilization of existing work force through retraining
	R&D	Required knowledge and dexterity	Knowledge required to develop related technologies and facilities
	R&D	Related work	Existing research related to CO_2 measurement
	Engineer	Demand	Full utilization of existing work force through retraining
	Engineer	Required knowledge and dexterity	Working knowledge of related processes
	Engineer	Related work	Existing engineers in related fields
	Technician	Demand	Utilization of existing work force is important.
	Technician	Required knowledge and dexterity	Working knowledge of related processes
	Technician	Related work	Existing related works

References

IEA(2007). Tracking Industrial Energy Efficiency and CO2 Emissions.

IEA(2009). Energy Technology Transitions for Industry.

ILO(2009). International Institute for Labour Studies: World of Work Report 2009- The Global Jobs Crisis and Beyond.

OECD(2010). Interim Report of the Green Growth Strategy : Implementing Our Commitment for a Sustainable Future.

UNEP(2008). Green Jobs: Towards decent work in a sustainable, low-carbon world.

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