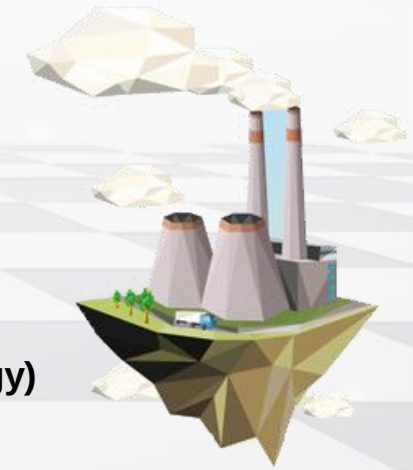
Speaker

South Korea CCUS Strategy: Carbon Mineralization Flagship Project-Green Cement with CFBC Coal Power Plant Byproducts

(4th Industrial Revolution-3D Printing Construction Technology for Sustainable Society)

ADB Head Quarters, Manila, Philippines

2018. 06. 7-8



Dr. Prof. Ji Whan Ahn

Head, Carbon Mineralization Center

KIGAM-CTCN Representative

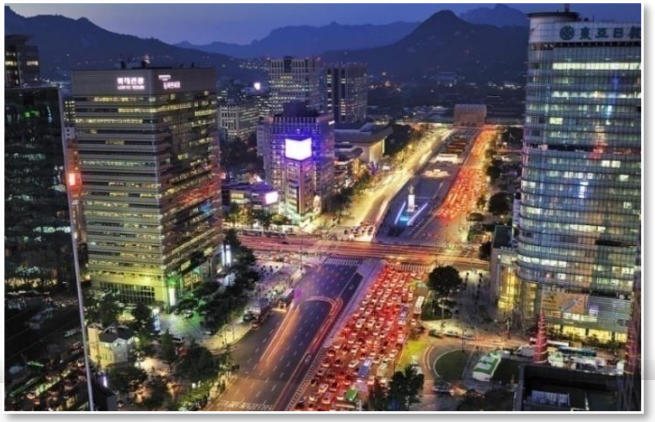
Professor, Resources and Recycling of UST (University of science and Technology)

Korea Institute of Geosciences and Mineral Resources(KIGAM), Korea

1 Carbon Capture Utilization Storage Technologies

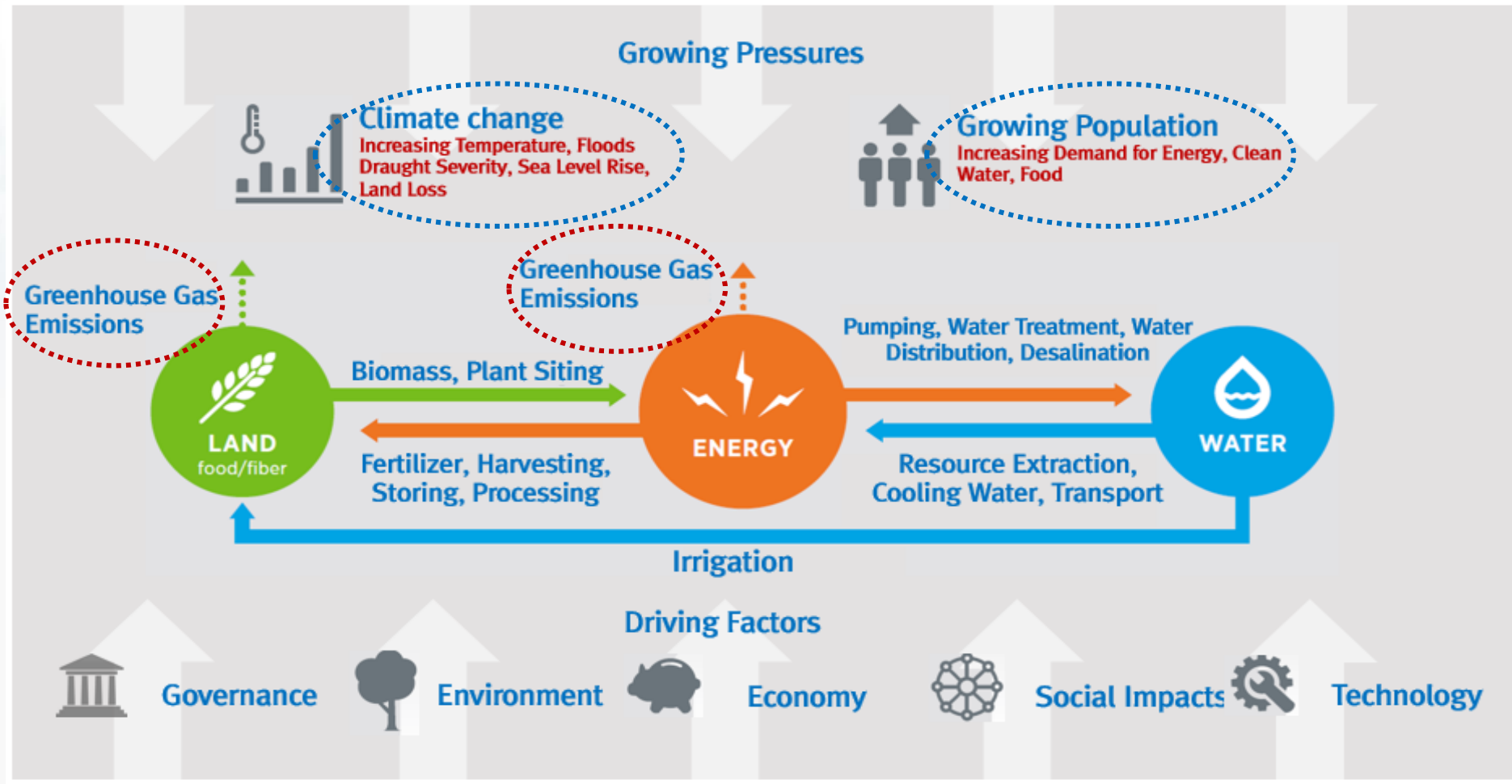
KIGAM's History

KIGAM was established as a Geological Survey of Korea in 1918 for geological mapping and mineral resources exploration.
And now, it has grown into a Comprehensive Geoscience Research Institute comprising diverse fields to meet the various social needs.



Why Today We Discussed About This?

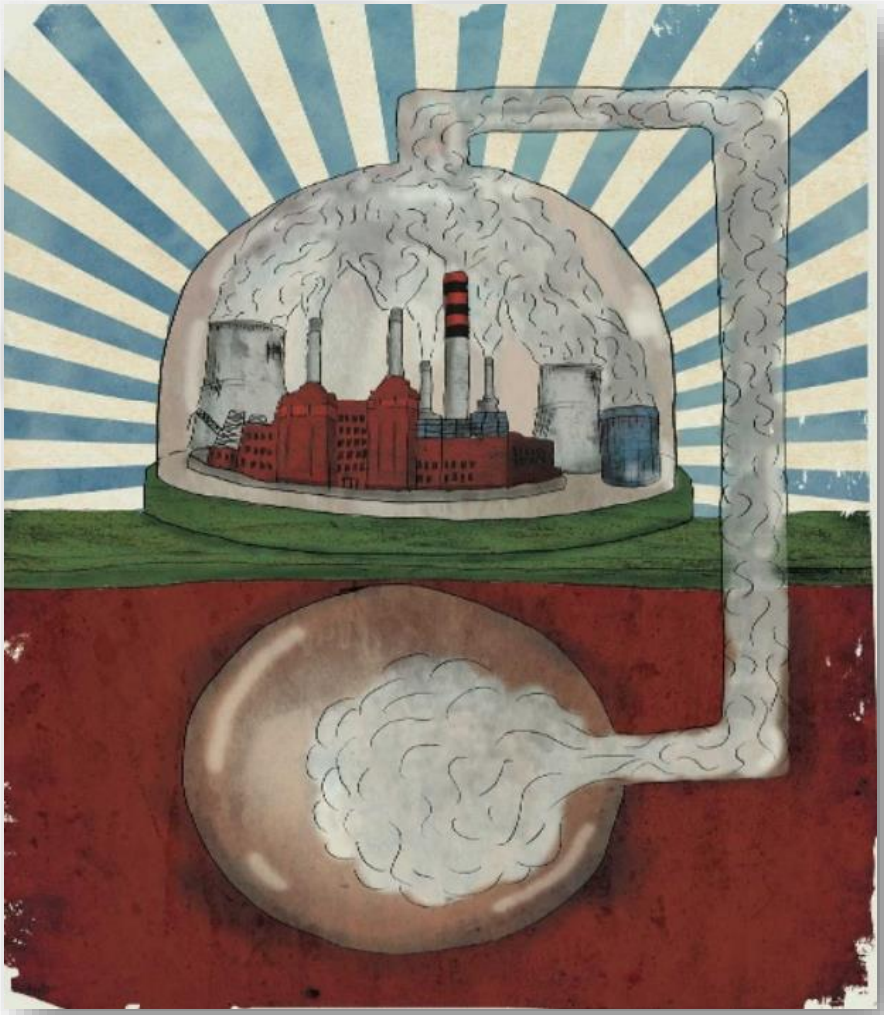
Growing Pressures and Challenges from Every Issue



Climate change is warning to humans for rethinking about energy options

Source: DOE, NERL, making sustainable energy choices insights on the energy/water/land nexus, 2014

Global Warming- What is the Solution?



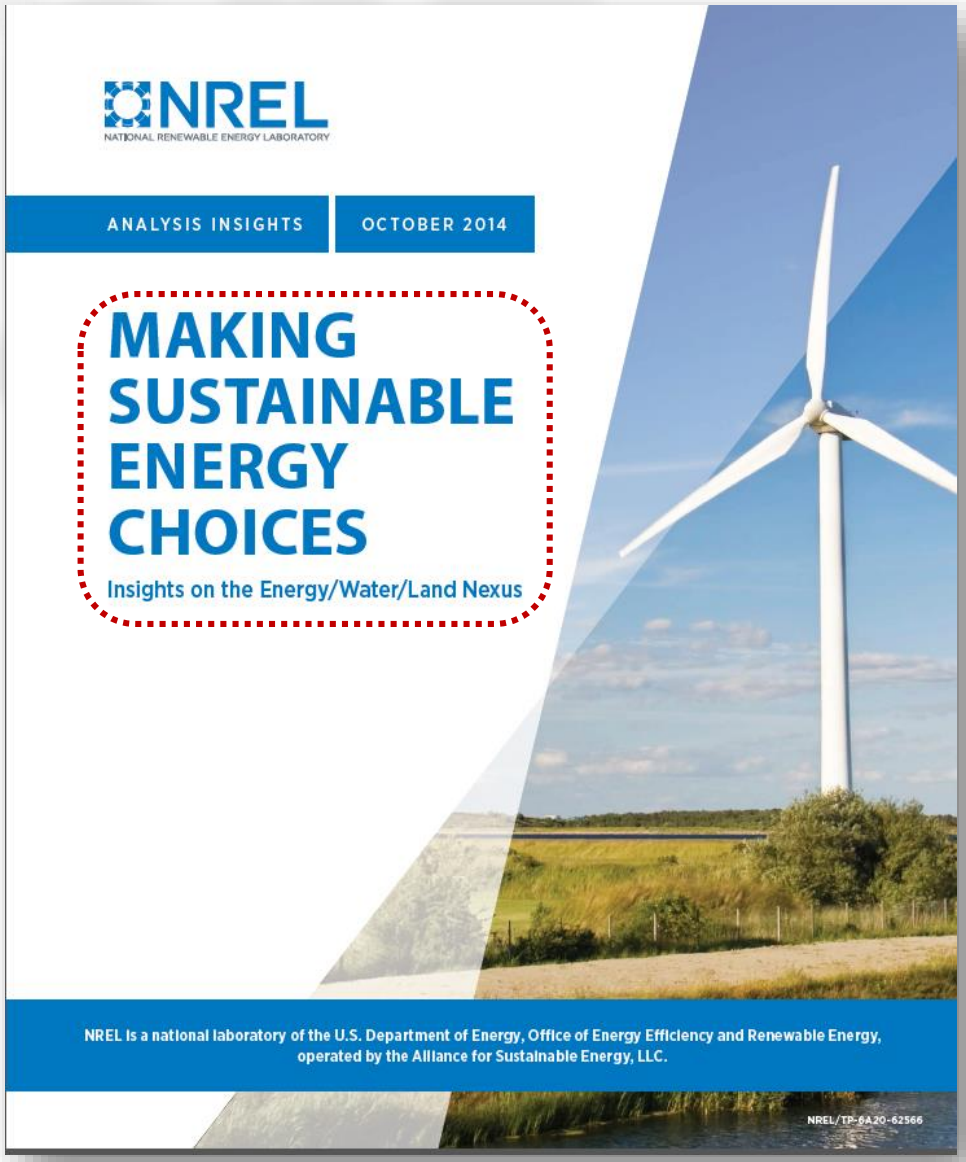
Carbon capture and Storage Illustration

ISSUES

- **Carbon capture is a global necessity**
- **CCUS will play a critical role in cutting emissions needed to limit global warming to 2°C** (Limiting warming to less than a 2°C may not be possible without CCUS)
- CCUS is demonstrated and possible today, with today's technologies.
- CCUS deployment will require a combination of policy support and technological innovation
- DOE analysis found that Federal Research Development Demonstration & Deployment (RDD&D) combined with tax credits could drive significant CCUS deployment

Source: Schiermeier et al., 2008,illustrator jay taylor, nature Journal
Dr.Darren Mollot, DOE, carbon capture utilization and storage:outlook &activities, 2016

Sustainable Energy Choices-DOE, USA

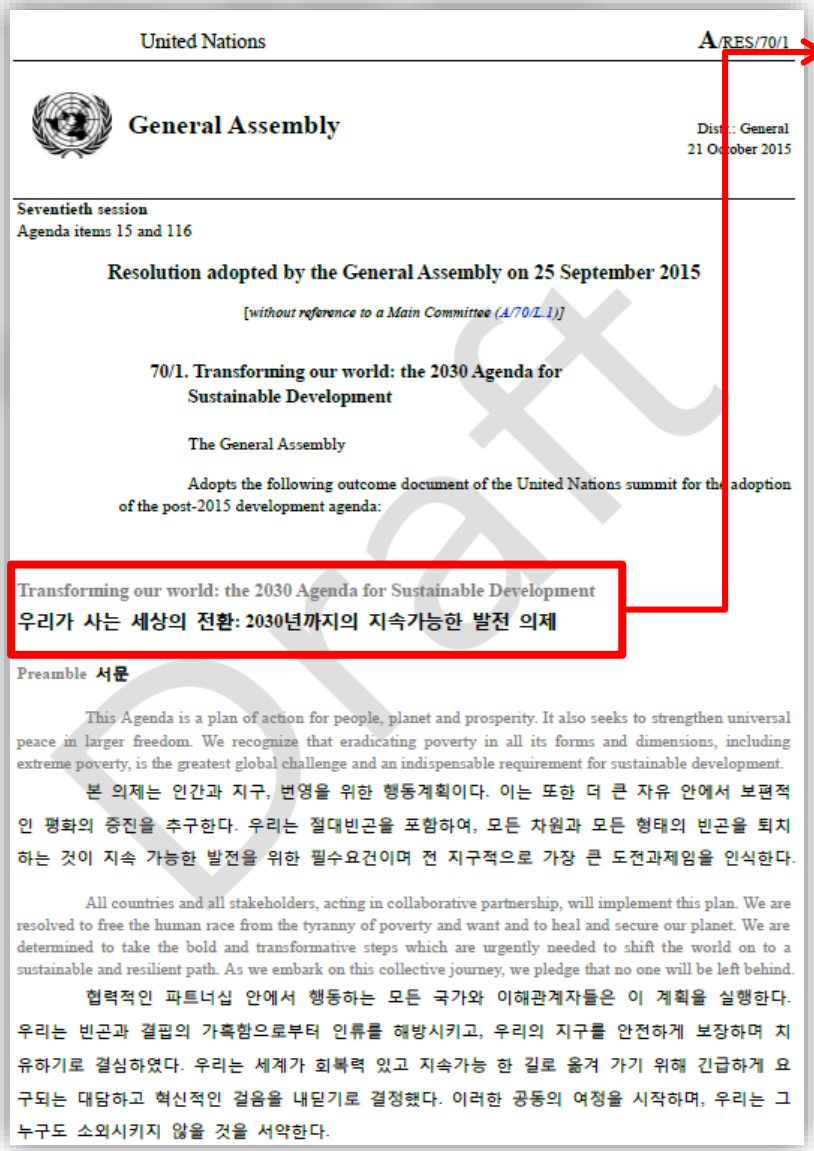


Energy choices can be framed within a 'nexus' of environmental, economic, and security priorities

The Department of Energy's National Renewable Energy Laboratory helps policymakers and investors understand and evaluate energy choices within this complex web of connections, or nexus, between energy, water, and land. Economics, energy markets and policies, system performance, environmental regulations, carbon emissions, and social impacts are all important components of this nexus.

Source: NREL report, Making Sustainable energy choices , **NREL/TP-6A20-62566** *, 2014*

UN, Post - 2030 Agenda (2015)



United Nations A/RES/70/1

General Assembly

Distr.: General
21 October 2015

Seventieth session
Agenda items 15 and 116

Resolution adopted by the General Assembly on 25 September 2015

[without reference to a Main Committee (A/70/L.1)]

70/1. Transforming our world: the 2030 Agenda for Sustainable Development

The General Assembly

Adopts the following outcome document of the United Nations summit for the adoption of the post-2015 development agenda:

Transforming our world: the 2030 Agenda for Sustainable Development
우리가 사는 세상의 전환: 2030년까지의 지속가능한 발전 의제

Preamble 서문

This Agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom. We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development.

본 의제는 인간과 지구, 번영을 위한 행동계획이다. 이는 또한 더 큰 자유 안에서 보편적인 평화의 증진을 추구한다. 우리는 절대빈곤을 포함하여, 모든 차원과 모든 형태의 빈곤을 퇴치하는 것이 지속 가능한 발전을 위한 필수요건이며 전 지구적으로 가장 큰 도전과제임을 인식한다.

All countries and all stakeholders, acting in collaborative partnership, will implement this plan. We are resolved to free the human race from the tyranny of poverty and want and to heal and secure our planet. We are determined to take the bold and transformative steps which are urgently needed to shift the world on to a sustainable and resilient path. As we embark on this collective journey, we pledge that no one will be left behind.

협력적인 파트너십 안에서 행동하는 모든 국가와 이해관계자들은 이 계획을 실행한다. 우리는 빈곤과 결핍의 가혹함으로부터 인류를 해방시키고, 우리의 지구를 안전하게 보장하며 치유하기로 결심하였다. 우리는 세계가 회복력 있고 지속가능 한 길로 옮겨 가기 위해 긴급하게 요구되는 대담하고 혁신적인 걸음을 내딛기로 결정했다. 이러한 공동의 여정을 시작하며, 우리는 그 누구도 소외시키지 않을 것을 서약한다.

The 2030 Agenda for Sustainable Development

▪ Preamble, Planet

We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.

▪ Sustainable Development Goals

Goal 13. Take urgent action to combat climate change and its impacts
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

New development paradigm: Sustainable Development

Conserve and sustainably use resources

Need for Diversity of Technology for Developing Countries

Paris Agreement (Technology Mechanism)

UN-Sustainable Development Goals-17

SDGs
17
Objectives

- The United Nations Development Programme (UNDP) has been one of the leading organizations working to achieve the MDGs.

- The 2030 Agenda with a set of 17 integrated and indivisible Sustainable Development Goals and targets to Sustainable Society.

- Major environmental threats I. Poverty, II. Climate Change, III. Ocean Acidity, and IV. Water Stress

Sustainability for Climate Change

Sustainability

Meeting the needs of society in ways that can continue indefinitely into the future without damaging or depleting natural resources.

"Cradle to Cradle" Design

Ending the "cradle to grave" cycle of manufactured products, by creating products that can be fully reclaimed or re-used.

Source Reduction

Reducing waste and pollution by changing patterns of production and consumption.

Innovation

Developing alternatives to technologies - whether fossil fuel or chemical intensive agriculture - that have been demonstrated to damage health and the environment.

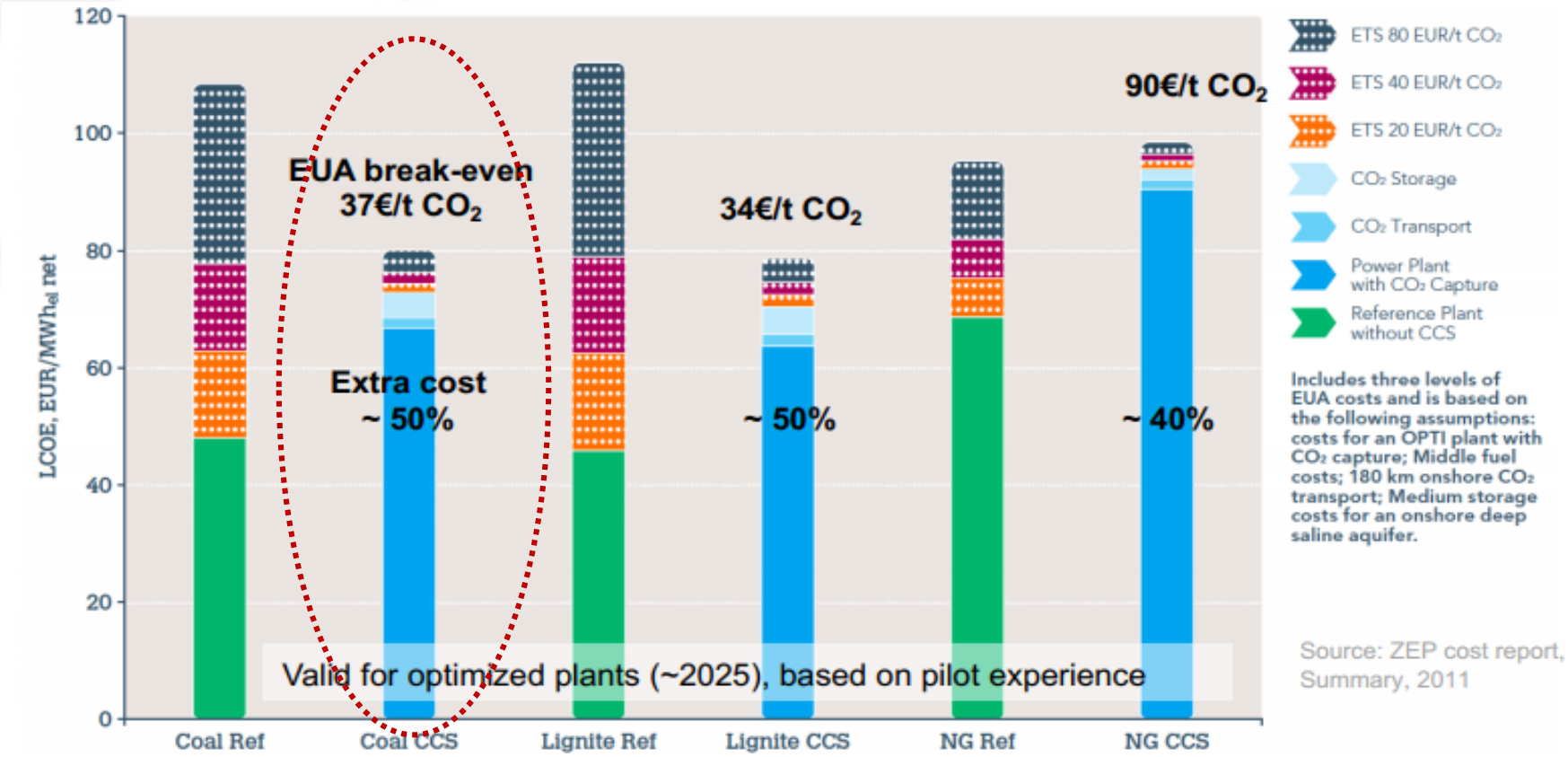
Viability

Creating a center of economic activity around technologies and products that benefit the environment.

Sustainability = "Recycling"

CCS Barriers

Technical , Political and Socio Economic Challenges

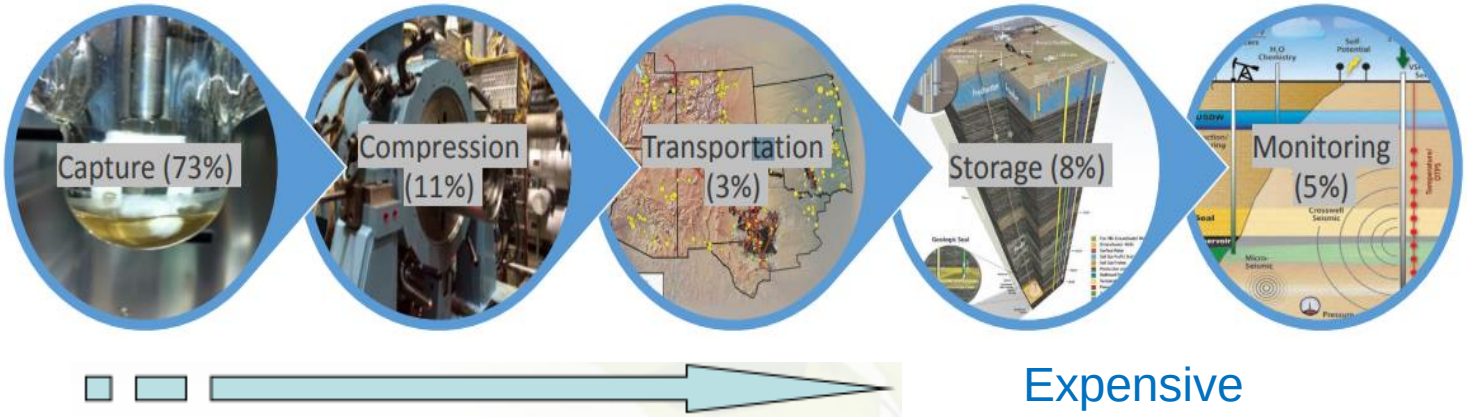


- Financial: High investment-cost & -risk, CCS ≠ business case
- Political/legal: Carbon price fluctuations
- Economy: Cost penalty passed onto consumer
- Social Acceptance: Public support needs for carbon capture and storage

Source: CCS and the Industry of Carbon-Based Resources – FS2016 – mischa.repmann@firstclimate.com 18.04.2016

CCS Limitations-2017

CCS Value Chain



Issues

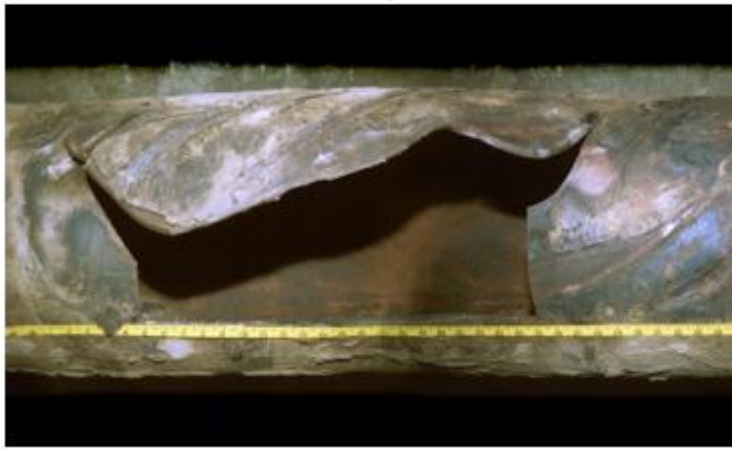
- Policy and regulatory frameworks are critical to CCS deployment.
- Technology limitations.
- Economically prohibitive.
- CO_2 capture and Transportation hazards.
- **Leakage problems**

Source: NETL, Cost and Performance Baseline for Fossil Energy Plants, Revision 3, July 2015

CO_2 Transport Hazards

A running fracture-result of a test

Fractured line undetected damage



Results of metal embrittlement

15 Jan 2009 Vancouver-line rupture

Low temperature releases, High pressures, Corrosion, High vapor density, Detection issues

Source: Neil Wildgust, ccs : risks and impacts, 2010

CCS Leakage Problems

EMISSIONS

19/26 DECEMBER 2013 | VOL 504 | NATURE | 339

Seabed scars raise questions over carbon-storage plan

Unexpected fractures above the world's biggest storage site could provide path for leaks.

BY RICHARD MONASTERSKY

Like a porpoise on the prowl, the sleek submersible HUGIN tracks its prey with sonar chirps. But the hunter set loose in the waters of the North Sea is not pursuing fish — the robot is trawling for geological clues that could help to determine whether billions of tonnes of carbon dioxide can be stored below the sea floor for centuries, keeping it from warming the planet.

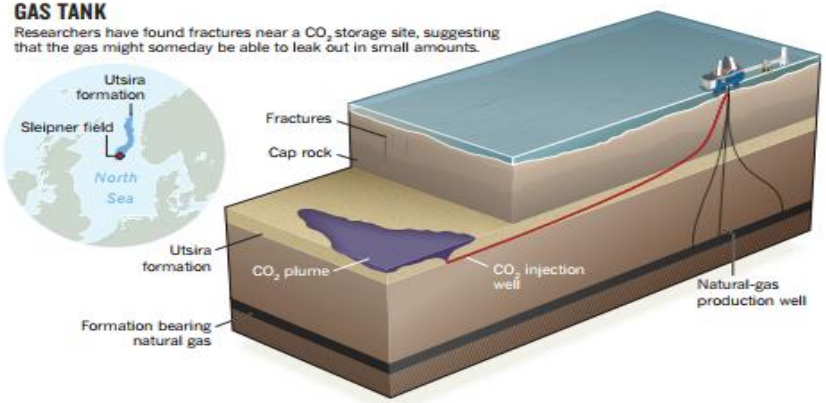
Now, the latest data from the autonomous underwater vehicle and other tools deployed by the European Commission's €10-million (US$13.8-million) ECO$_2$ research project suggest that the plan might not be so simple. The seabed is fractured and scarred more than researchers had appreciated — providing potential routes for CO_2 to leak from subseabed reservoirs where it is currently being stored. "We are saying it is very likely something will come out in the end," says Klaus Wallmann, ECO$_2$ coordinator and a marine geochemist at the GEOMAR Helmholtz Centre for Ocean Research in Kiel, Germany.

Such a conclusion could raise problems for the field of carbon capture and storage, especially in Europe, where any suggestion of leakage could reduce public support for the strategy. But ECO$_2$ researchers say that evidence from oil-industry carbon-storage efforts already under way in the North Sea and Barents Sea suggests no hint of leakage, and that there would be little cause for concern even if there were. "We are very confident that if it were to occur, the rates would be low and the impact would

NEWS IN FOCUS

GAS TANK

Researchers have found fractures near a CO_2 storage site, suggesting that the gas might someday be able to leak out in small amounts.



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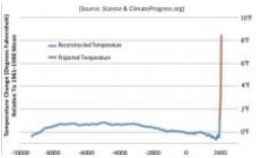
TRENDING: Climate Change | Climate Change Deniers | Media | Keystone XL | Coal

99 One-Liners Rebutting Climate Science Denier Talking Points

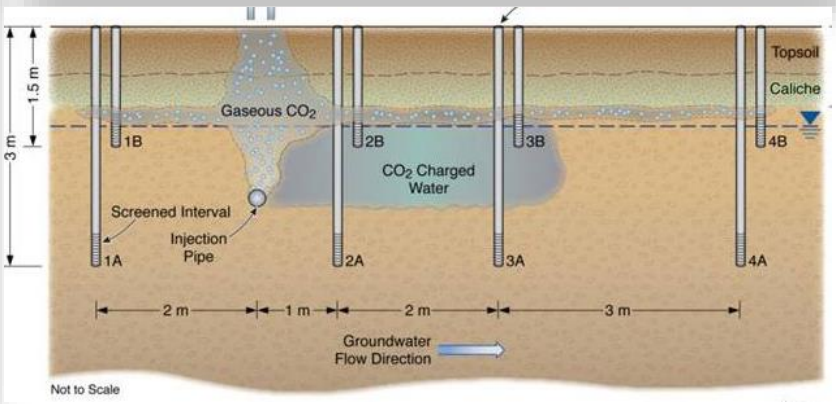
Tornadoes, Extreme Weather And Climate Change



Into The Valley Of 400 PPM Rode The 7 Billion

Weekend News Update: Underground storage of carbon dioxide may trigger earthquakes, limiting sequestration's large scale use

By **Joe Romm** on Dec 18, 2010 at 8:43 am



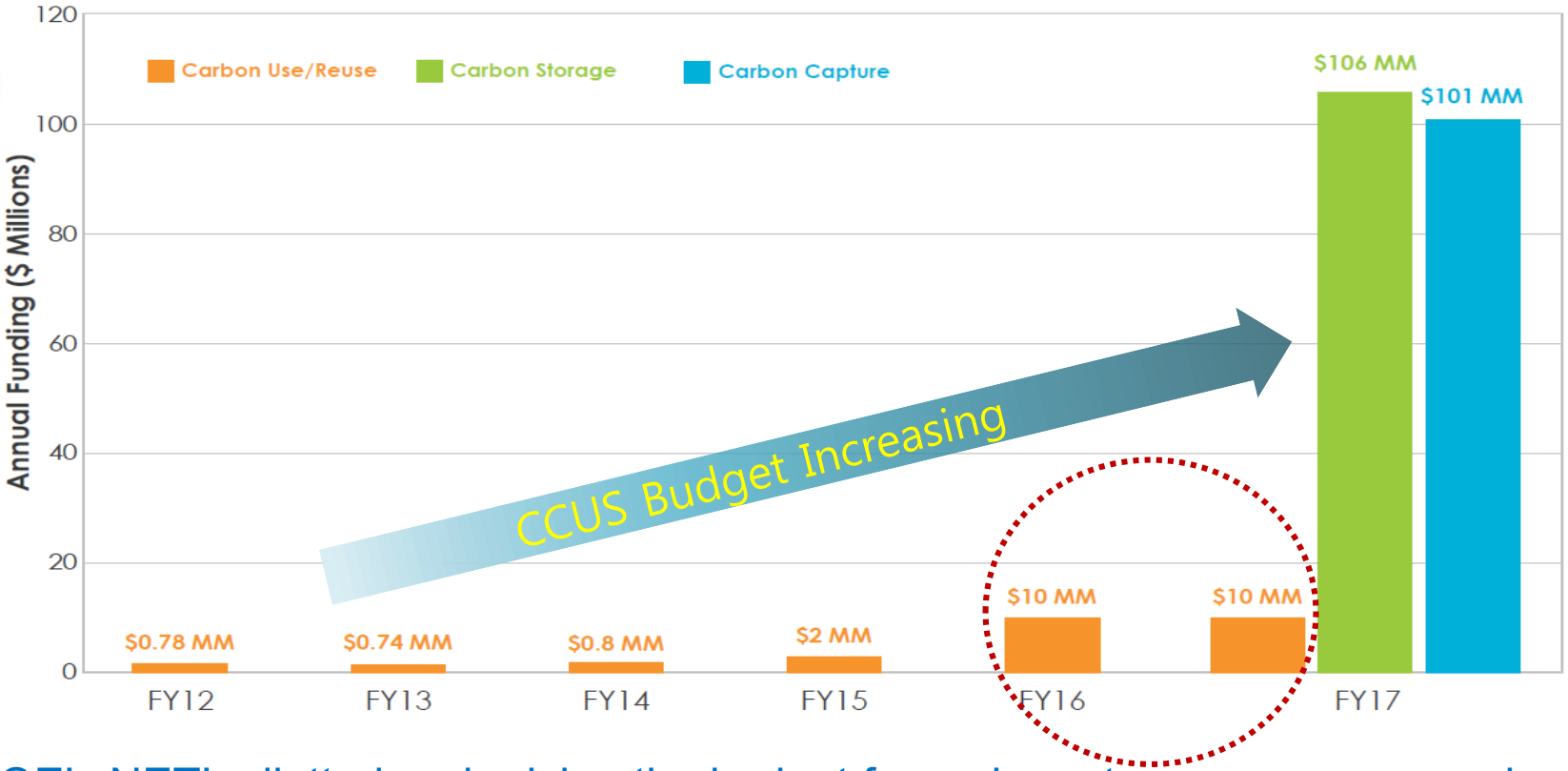
Leaks from CO_2 stored deep underground could contaminate drinking water and, earthquakes

Source: Joe Ramm, weekend news update, climate progress, 2010

DOE Funding for CCUS- 2017

Donald Trump takes major step to wiping out Obama's climate-change record

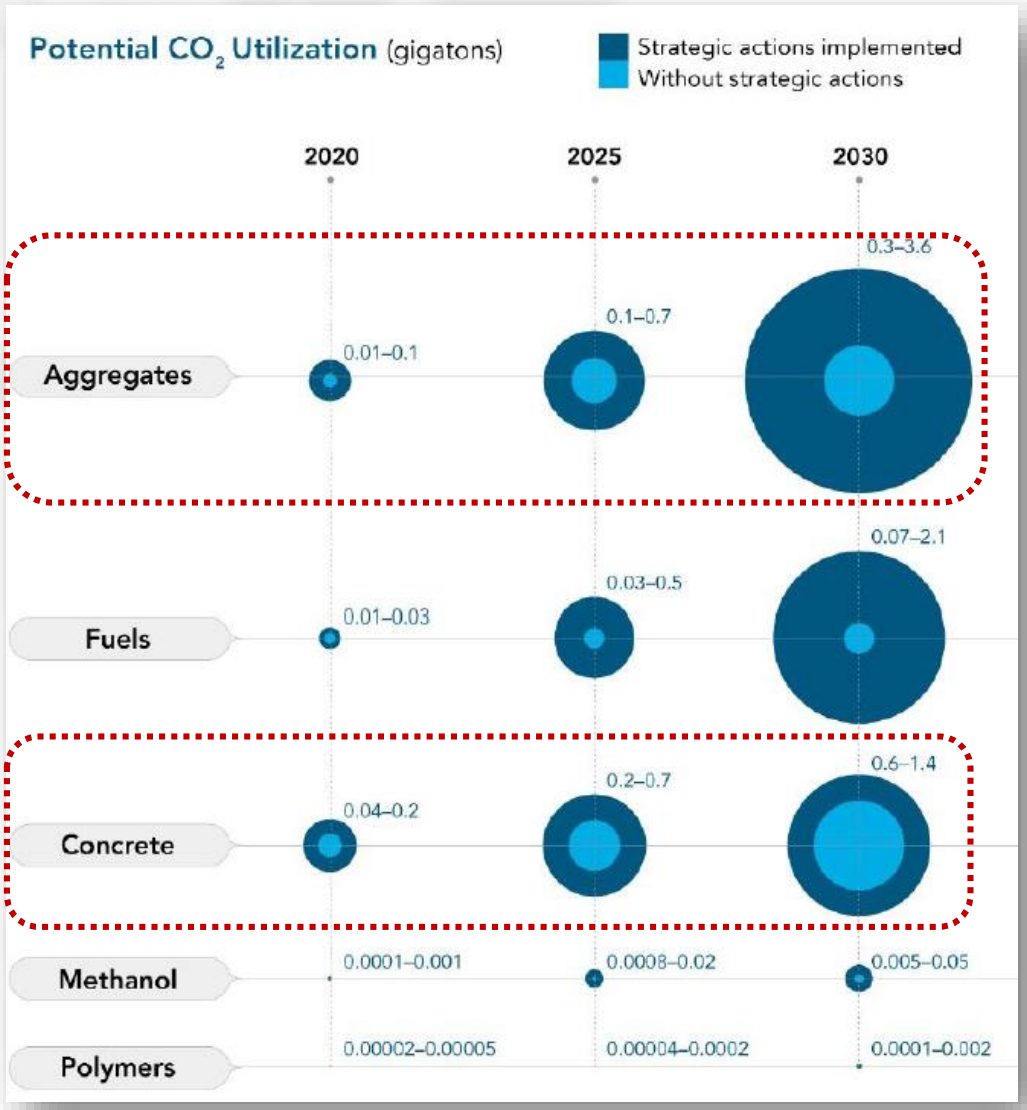
President Trump's executive order will tell the EPA to begin rewriting the 2015 regulation that limits greenhouse-gas emissions from existing power plants



DOE's NETL allotted and raising the budget for carbon storage program, carbon Use and Reuse(CCUS) from 2016 -2017 and in the future it may expanded

Source: Lynn Brickett, carbon use and reuse program overview briefing , 2017

Global CO_2 Utilization Initiatives



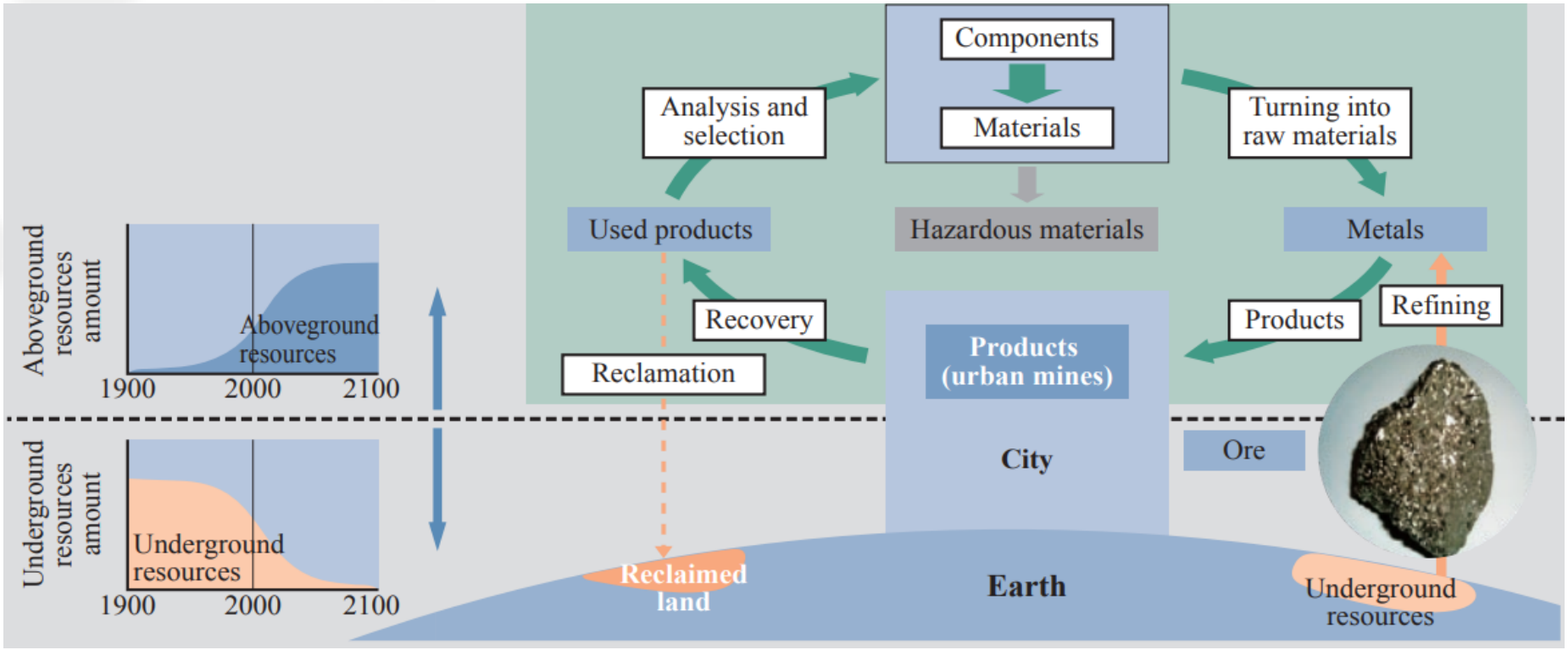
Perspective

- **"CO_2 has the potential to utilize 7 billion metric tons of CO_2 per year by 2030"**
- **Revenue potential estimated at >$800 billion by 2030**
- **"This is an upper bound estimate, assuming zero carbon energy is used in all production processes"**
- **"To the extent that climate benefits are a goal of those promoting CO_2 Utilization products, life cycle analysis (LCA) is essential."**
- **"Considerable work is needed to standardize life cycle analysis methodologies for CO_2 utilization**

Source: Dr.Daniel matsuszak, CO2 utilization beyond EOR , 2017

Carbon Resources Recycling Technologies for Sustainable Society

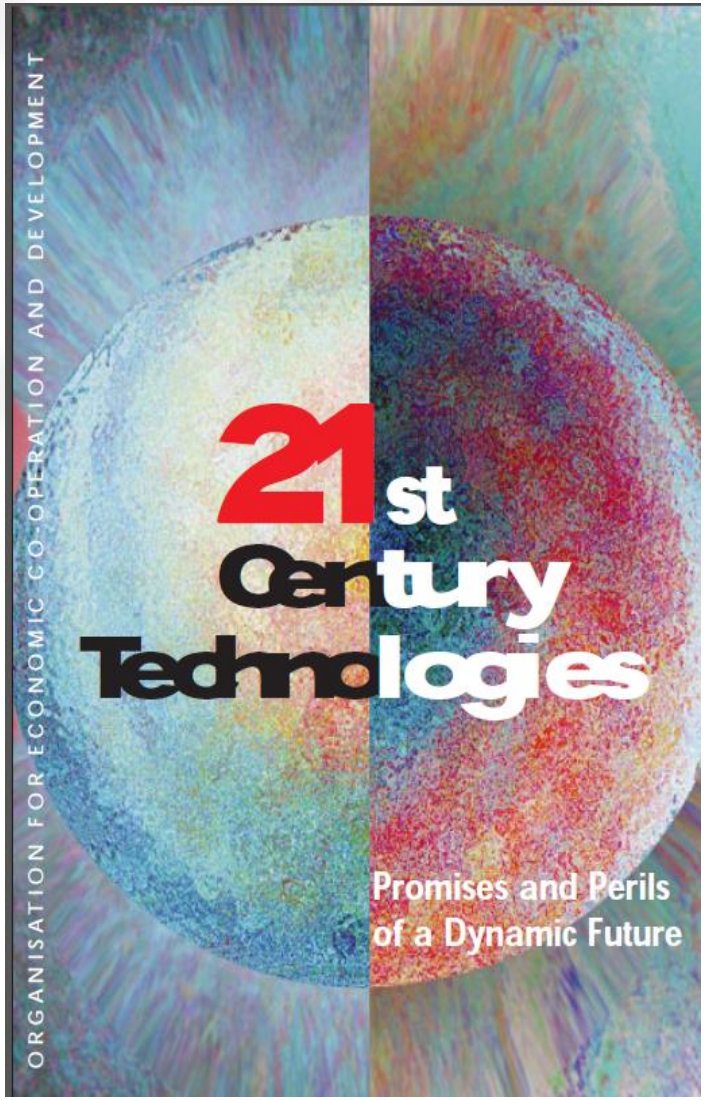
Recycling Resources



- To establish a society that cannot sustain with limited resources, so recycling of resources is essential.
- Slowly the underground sources are disappearing (because of mining), for this reason the alternative way is, to reduce the underground mining and increasing the recycling activities.
- By applying this cycling process, we are helping to build a sustainable society.

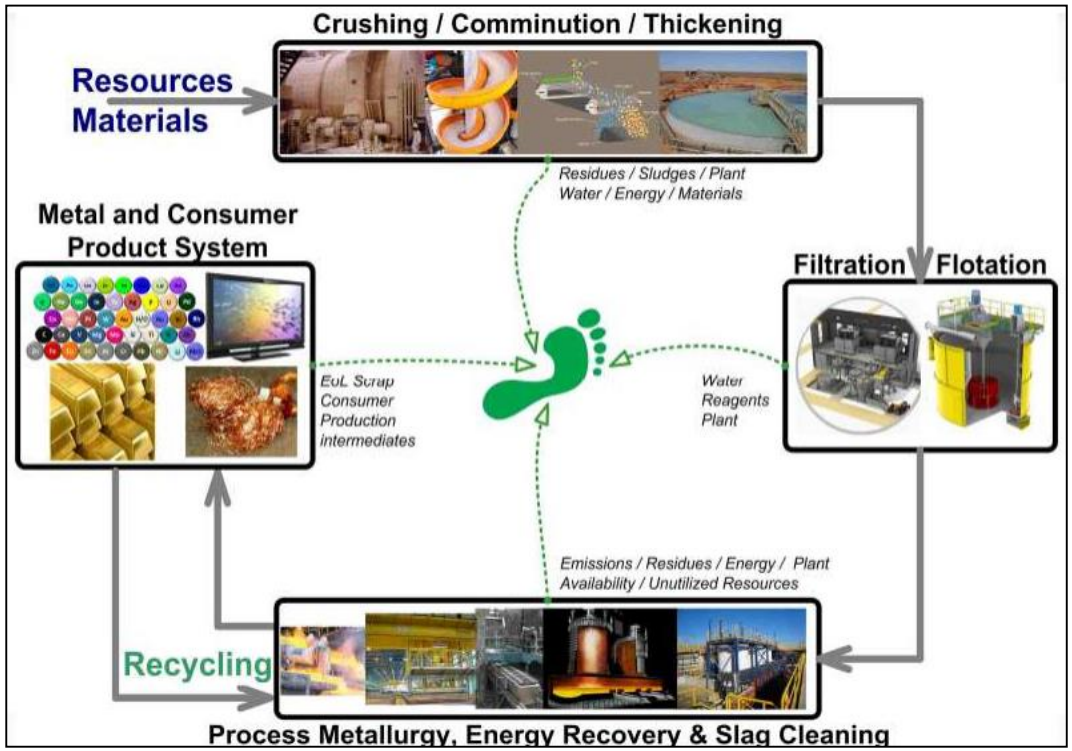
Source: Takeshi Nemoto et al., Recycling technologies for both carbon dioxide reduction and resource saving, 57(5), 2008, 214-219

21st Century Mineral Processing Technologies (Emerging Technology)



Without minerals there are no products

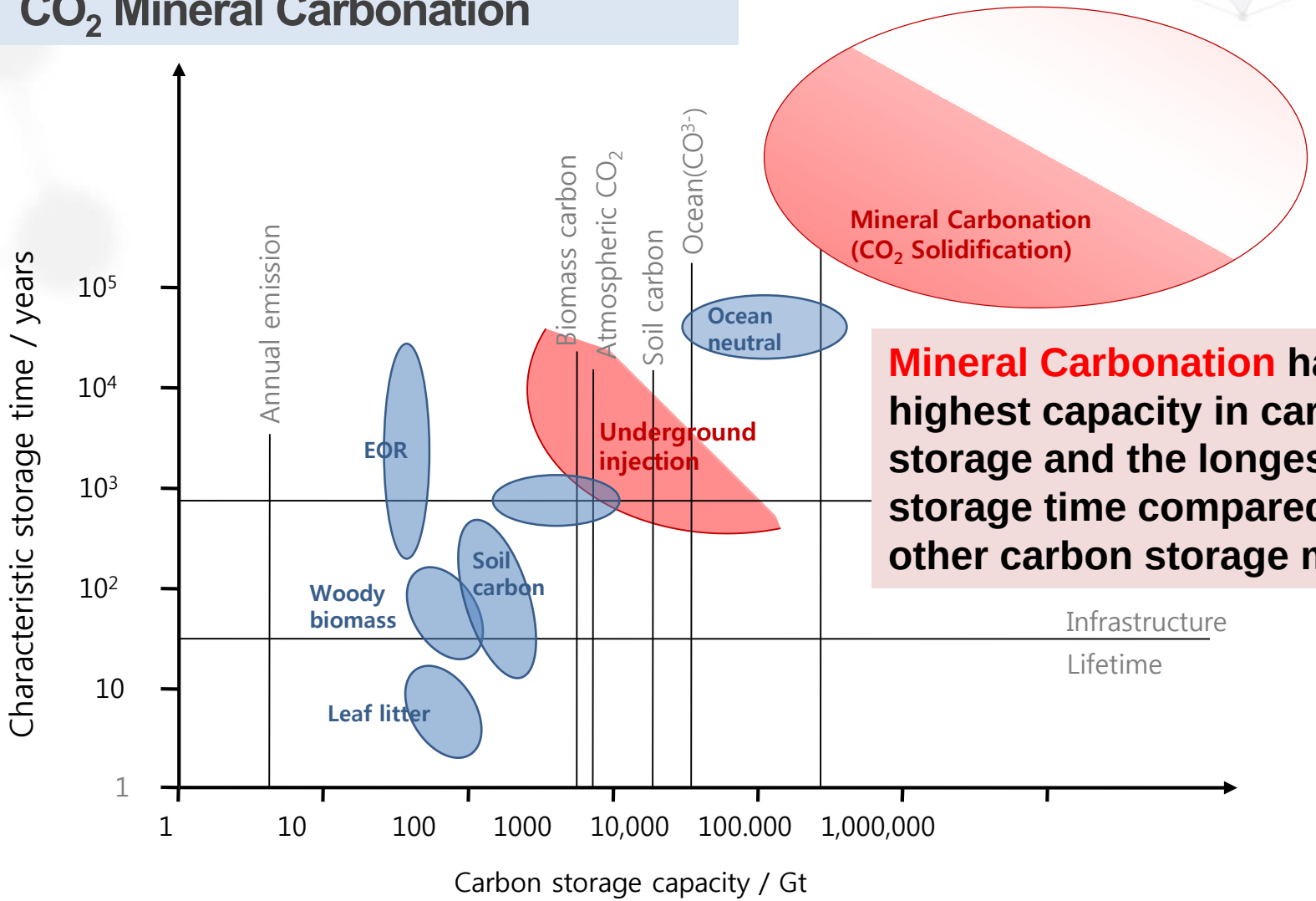
Imagining possible applications of technology two or three decades from now calls for a better understanding of the ways in which performance trends interact with societies' readiness to embrace economic, social and technical change.



Source : 21st CENTURY TECHNOLOGIES PROMISES AND PERILS OF A DYNAMIC FUTURE (OECD)

Mineral Carbonation

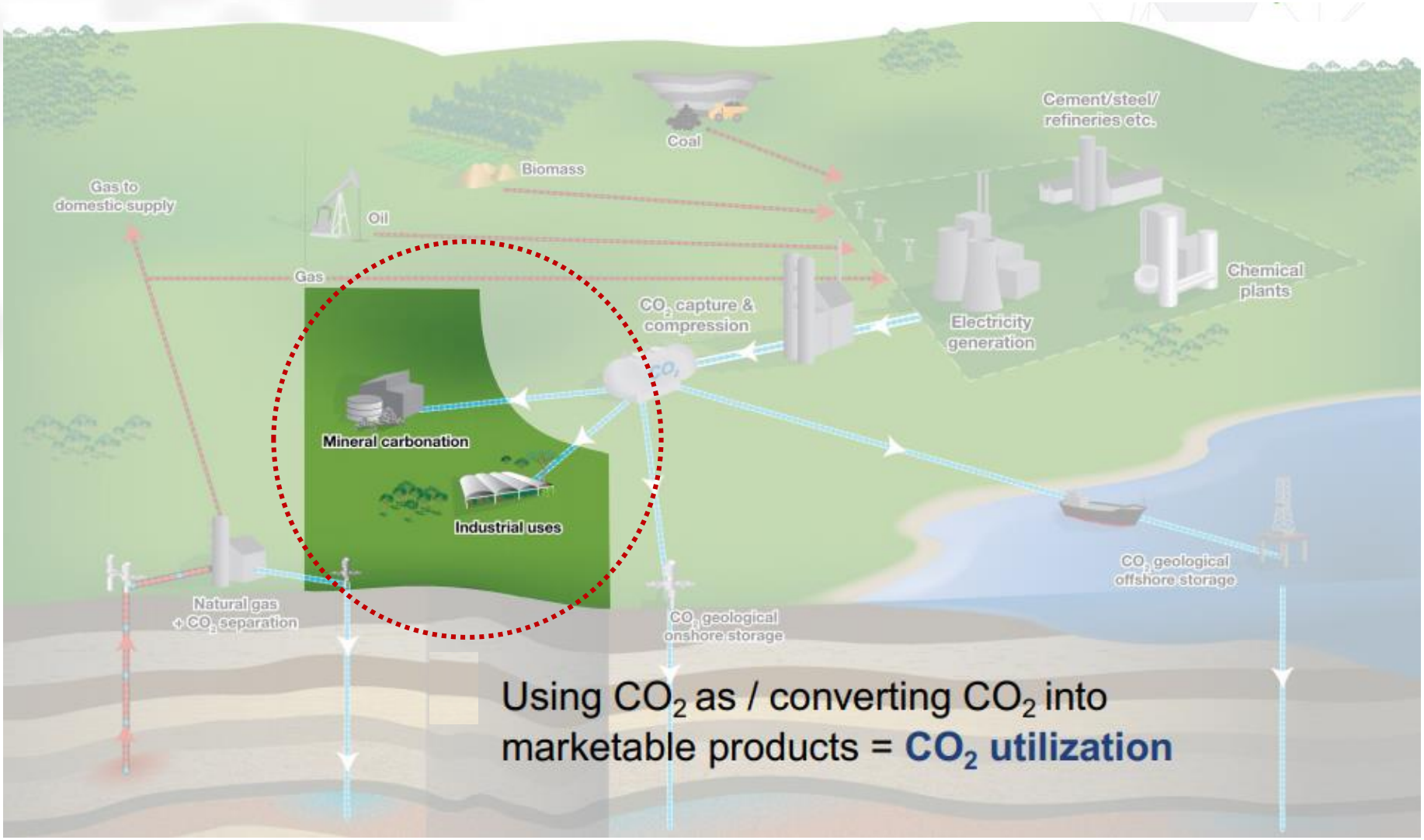
CO_2 Mineral Carbonation



Mineral Carbonation has the highest capacity in carbon storage and the longest storage time compared to other carbon storage methods.

Ref: ***K.S. Lackner, Science. 2003***

Mineral Carbonation



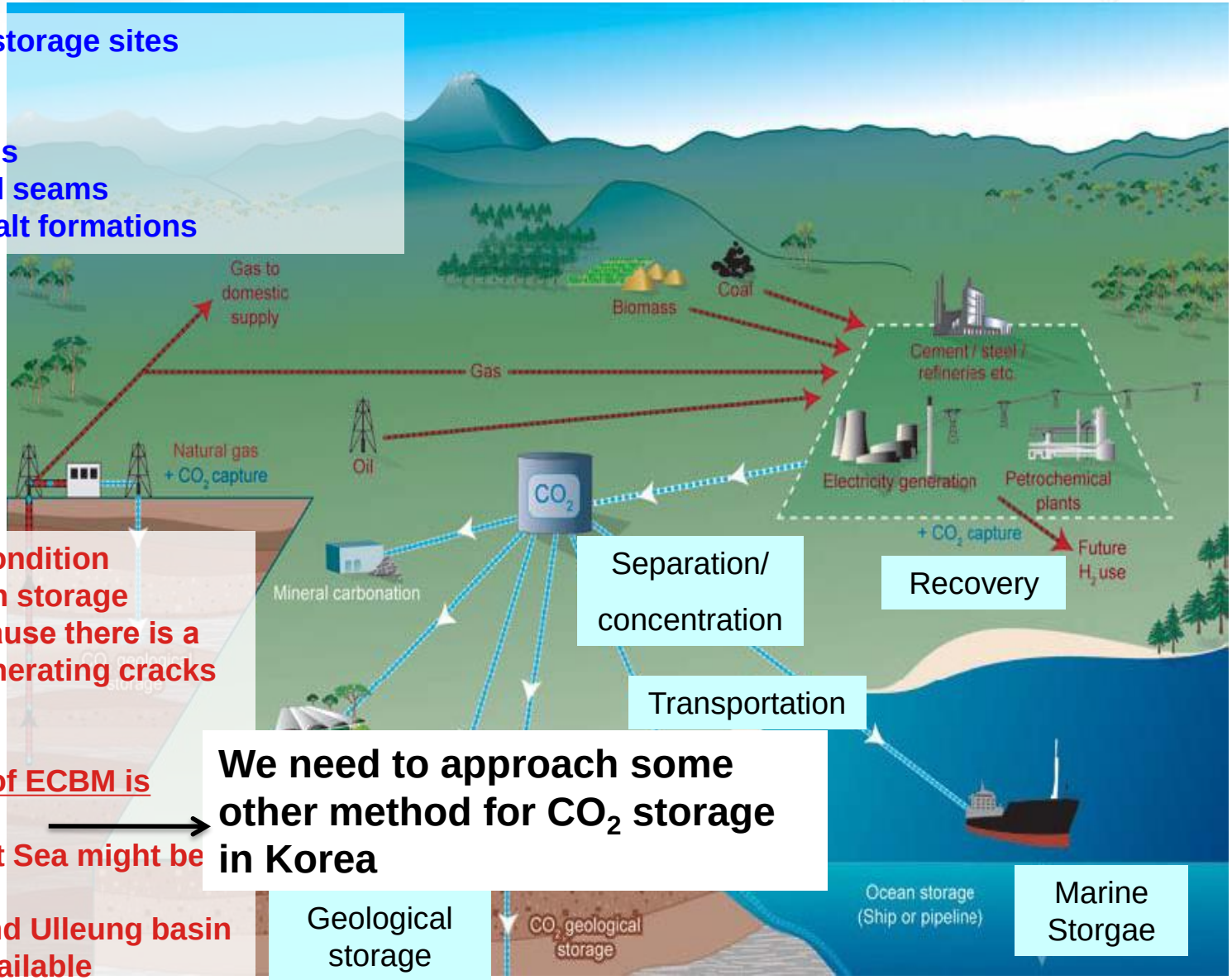
Mineral Carbonation is one of the best example of CCUS where CO_2 is stored in the form of inert carbonate rock

Source: CCS and the Industry of Carbon-Based Resources – FS2016 – mischa.repmann@firstclimate.com 18.04.2016

Carbon Capture & Storage (CCS) Technology

General Geological storage sites

1. **Gas field**
2. **Oil field**
3. **Saline formations**
4. **Unmineable coal seams**
5. **Saline-filled basalt formations**



Korean geological condition for geological carbon storage
→ Not available because there is a possibility of generating cracks on aquifers

- **Only some part of ECBM is available**
- **Gas field on East Sea might be available**
- **Gunsan basin and Ulleung basin also might be available**

We need to approach some other method for CO_2 storage in Korea

Mineral Carbonation(Process Step of CO_2 Solidification)

- Power Plant
- Steel Making Industry
- Cement Industry
- Chemical Fiber Industry

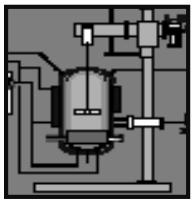
- Industry Solid Wastes
  - Coal Fly Ash
  - Steel Making Slag
  - Waste Cement
  - MSWI Ash

발전소
(CO_2 회수)

철강산업
(CO_2 회수)

시멘트산업
(CO_2 회수)

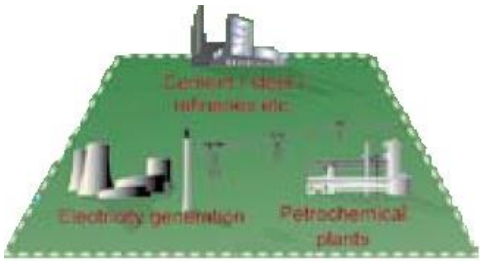
석유화학산업
(CO_2 회수 및 응용)



- CO_2 Solidification
[Carbonation Process]

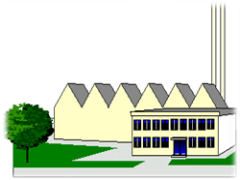
- **Alternative Construction Materials**

- Society



- **CO_2 Capture**

- **PCC Products**



- **Paper Industry**
- **Plastic Industry**
- **Pant Industry**

Korean Type On-Site CO_2 Solidification Process

Korean Type-CO_2 Solidification)

대통령인수위원회
에너지 · 기후변화 대응 T/F팀

Commercialization plan of CO_2 Solidification Technology

CO_2 고형화(Solidification)
처리 기술 실용화 사업

기획보고서

한국지질자원연구원

제 출 문

기후변화 협약 대통령인수위원회 귀하

이 보고서를 "CO_2 고형화(Solidification) 처리 기술 실용화 사업"과제의 기획보고서로 제출합니다.

2008. 01. 31

주관기관명 : 한국지질자원연구원

기획책임자 : 안 지 환

KIGAM
Jiwhan Ahn

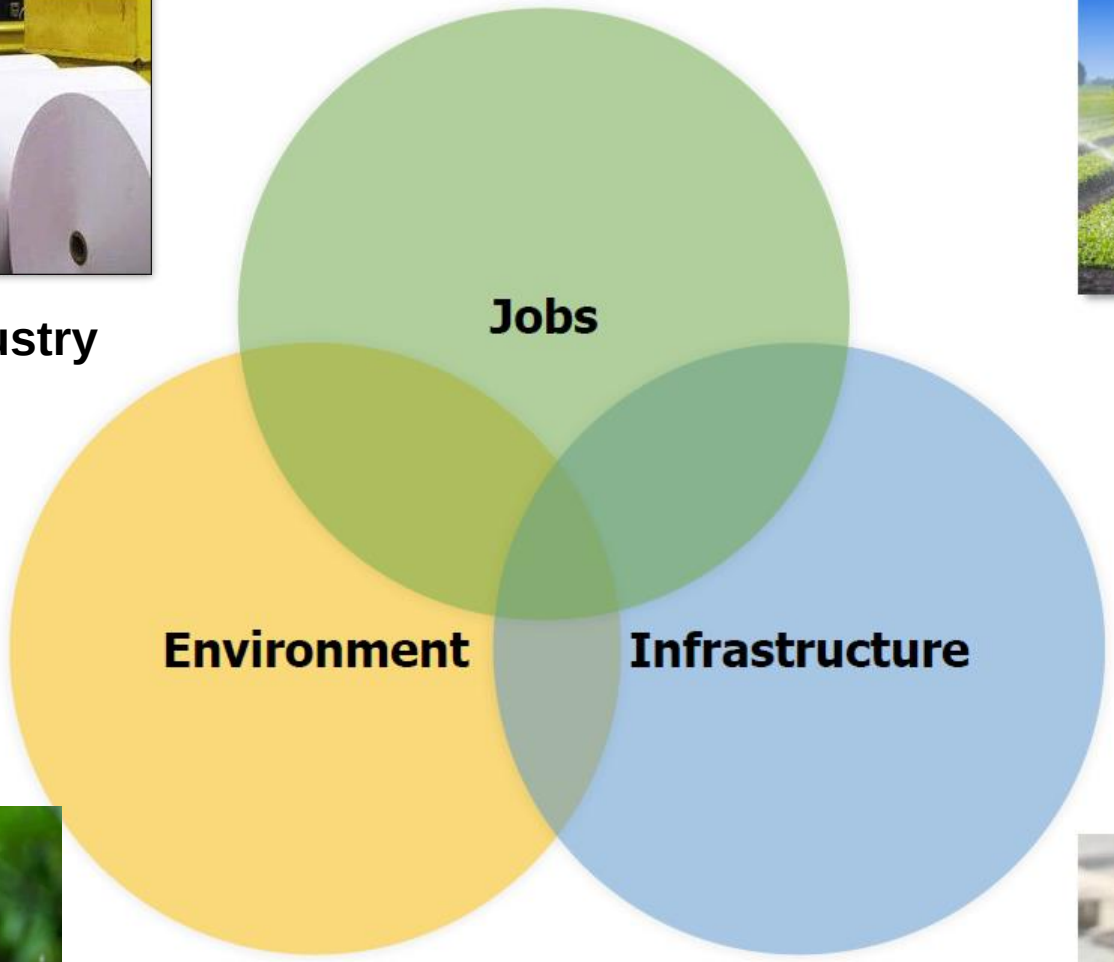
KIGAM suggested a plan on Korean Type-CO_2 Solidification to the present Korean government (The presidential transition committee).

2 South Korea CCUS Strategy

Many Reasons to Advance CO_2 Utilization Technologies

Paper Industry

Agriculture



Environment

Green cement

Source: Dr.Daniel matsuszak, CO2 utilization beyond EOR , 2017

Building Materials for Eco-Friendly Low Carbon City

Aggregates and their qualities are essential to well functioning and durable concrete structures. They can be made by mineralizing CO_2

IMAGES: Portland Cement Association

Key trend: Urbanization

Key Challenges*. Forming stable mineral carbonates is

- highly process-dependent and thus has the potential to emit more CO_2 than is sequestered
- may be constrained to a limited scale due to the supply of make up materials

By 2030, 60% of the population will live in an urban world. Less developed regions will add more than 1 billion people to urban centers.

DATA: UN DESA

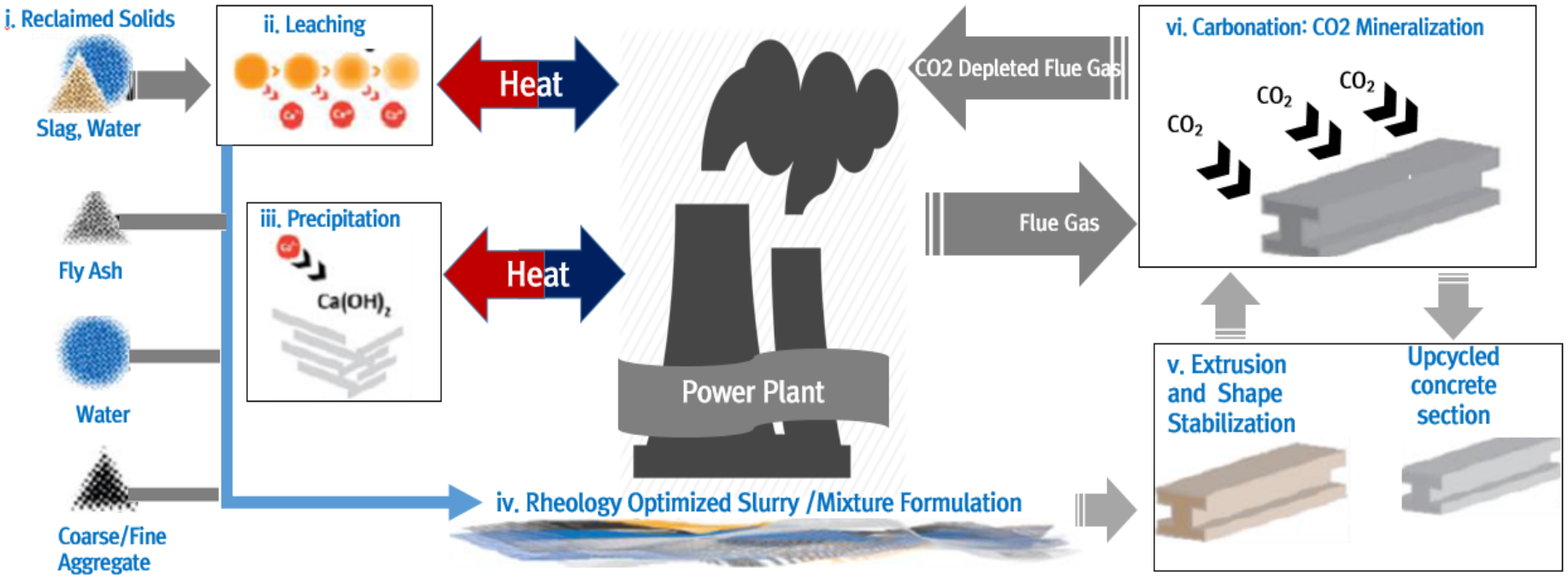
IMAGE: ErlaZwingle(National Geographic)

*** Newall, P. S., Clarke, S.J., Haywood, H.M., Scholes, H., Clarke, N.R ., King, P.A., Barley, R.W., 2000: CO2 storage as carbonate minerals, report PH3/17 for IEA Greenhouse Gas R&D Programme, CSMA Consultants Ltd, Cornwall, UK**

Source: Dr.Daniel matsuszak, CO2 utilization beyond EOR , 2017

CCUS Utilization Possibilities in Coal Power Plants

Novel CO_2 utilization strategies



The develop technologies that utilize CO_2 from coal-fired power plants as a reactant to produce useful products without generating additional CO_2 or greenhouse gas emissions validated via a product Life Cycle Analysis.

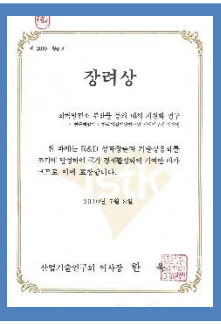
Source: *Daniel Matuszak, DOE, CO2 utilization beyond EOR, 2017*

KIGAM CCUS Technology History for Energy Technology Innovation

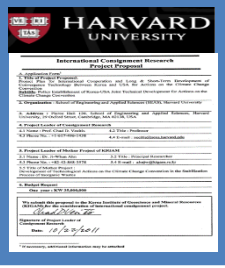
2009. **"The Excellent Researcher"** from the Korea Research Council for Industrial Science and Technology, Ministry of Knowledge Economy, Korea
→ **Green Cement from coal ash**


ISTK
CHAIRMAN
AWARD
이사장상
안 지 환

2010. **"The Excellent Research Award 2010"** from the Korea Research Council for Industrial Science and Technology, Ministry of Knowledge Economy, Korea
→ **Green Cement from coal ash**


장려상

2011.
2012.
"Follow-up of the Excellent Research Award 2010"
Harvard University School of Engineering and Applied Sciences (SEAS), Department of Environmental Science & Engineering


HARVARD
UNIVERSITY
International Consignment Research Project Proposal

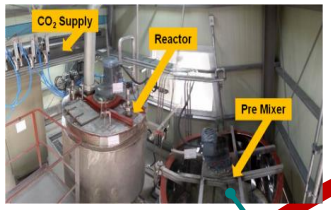
Mineral Carbonation/ Sustainability for Climate Change / CO_2 Utilization

KIGAM CCUS Technology

* Carbon Capture, Utilization and Storage

Low Carbon Green Cement

In-situ PCC Waste Paper Recycling Technology



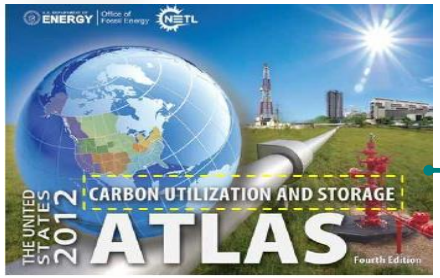
KIGAM Lead-up Technology

- Carbon Mineralization Technology: COE
- Establishment of new CDM and carbon credits
- Recycling of waste resources for resource security strategy

- CTCN-KIGAM : COG
- Carbon Resource Recycling Appropriate Technology standardization [ISO TC 82, 27]
- Global Organization Agencies Cooperation (UNEP, UNIDO, UNESCO, APEC etc.)

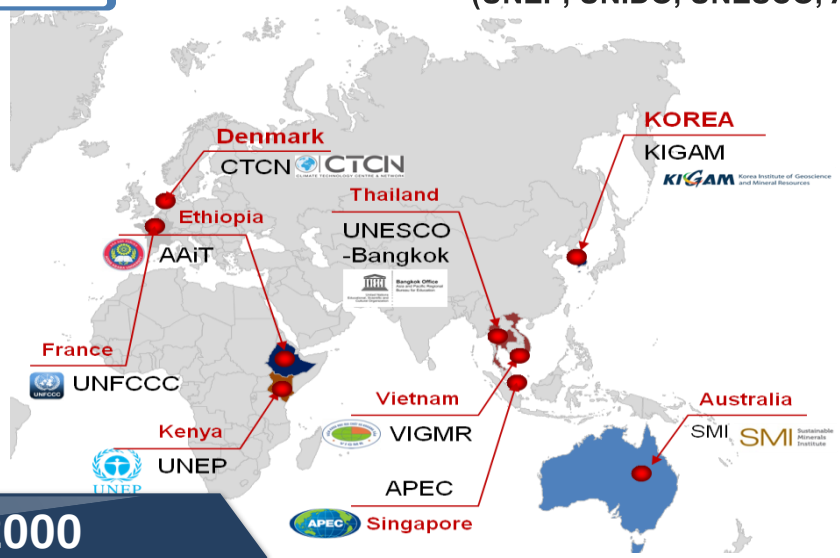
KIGAM Semi Pilot Plant
2014 Finish

USA, DOE
2012 Start



MIT 10 Emerging Technologies 2010

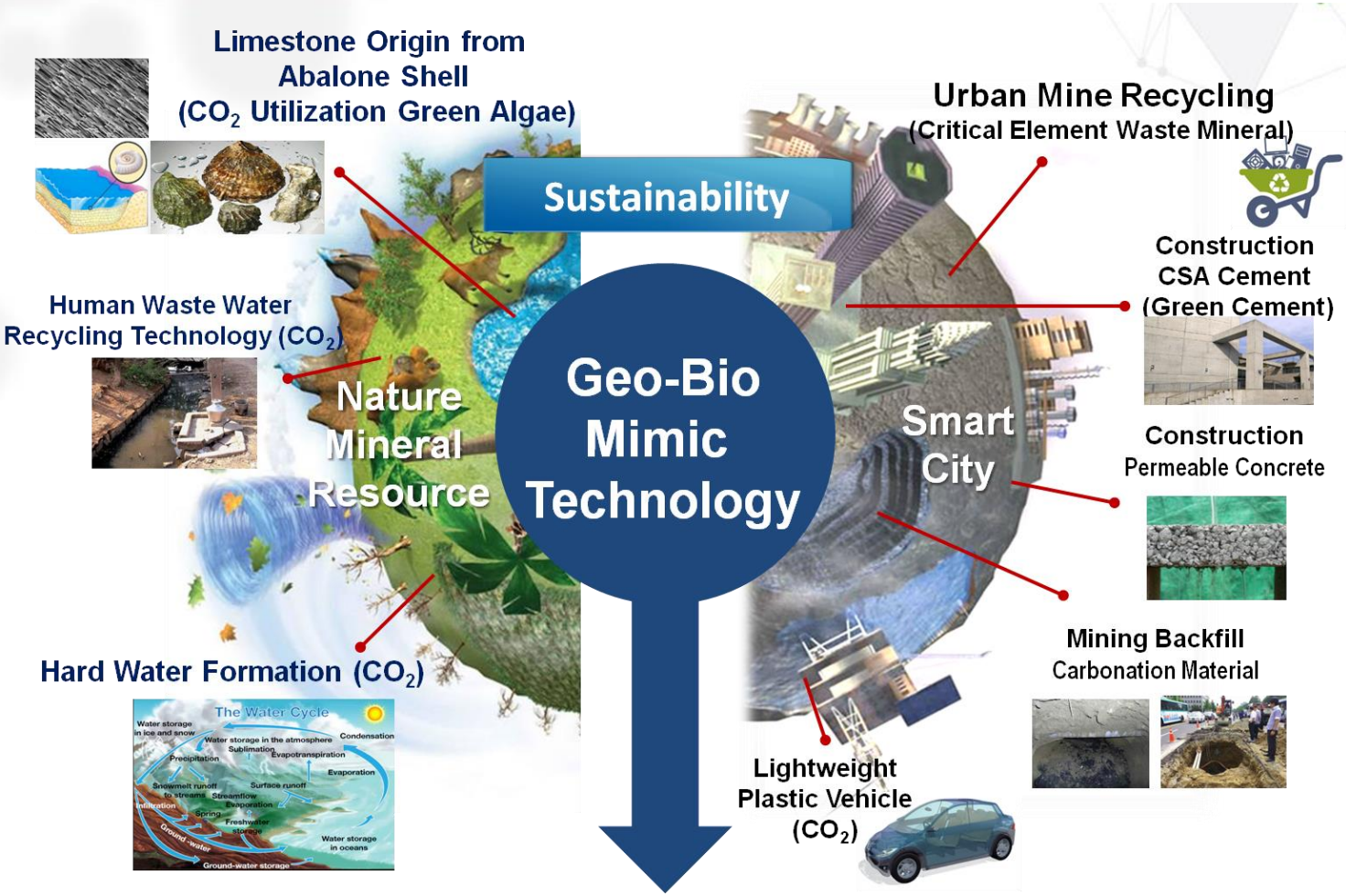
KOREA, KIGAM
2000 Start



KIGAM 21C Frontier Since 2000
(Center for Resource Recycling)

* CTCN: Climate Technology Centre & Network
* COG: Center of Globalization, COE: Center of Excellent

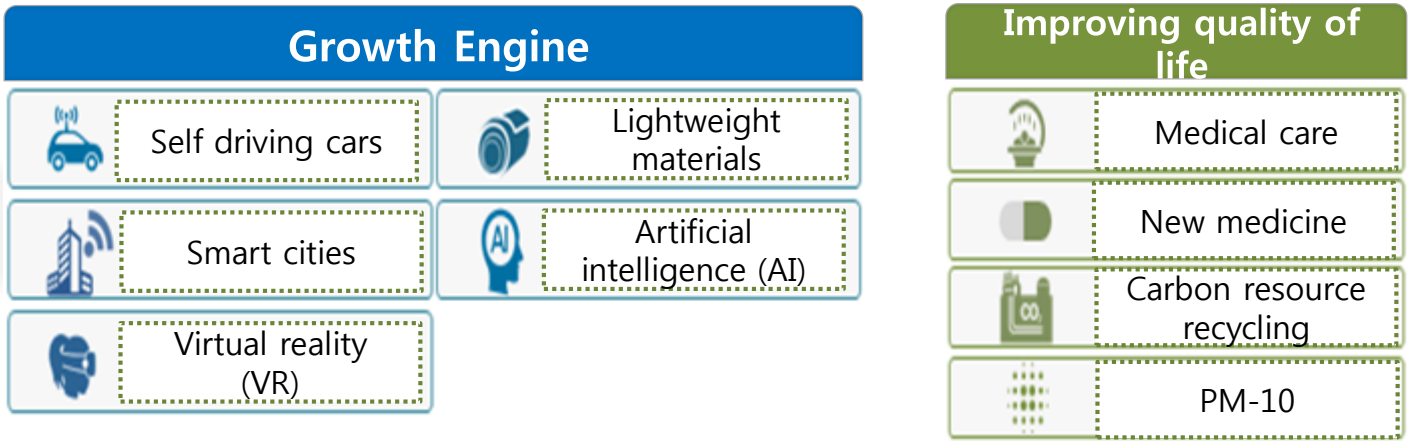
KIGAM Carbon Resource Recycling Appropriate Technology



- **Transfer the Carbon Resource Recycling Appropriate Technology Overseas**
  - ✓ KIGAMs Carbon Resource Recycling Appropriate Technology with the collaboration of Asian and African countries
  - ✓ Carbon Resource Recycling Appropriate Technology Standardization
  - ✓ Climate Change (human waste/Water contamination treatment technology **(UNEP, UNIDO, UNESCO, APEC etc.)**
  - ✓ Climate Change Eco museum/Climate change education for **'Better Life for All'**

“ National Strategic Project”-Korea

Government national strategic projects (2016.08.10)



"Science and technology will help find solutions to overcome this crisis, and also build momentum for the economy to give itself a boost," said president of Republic of Korea during the second presidential panel on science and technology at Blue House in Korea.
During the meeting, the government national projects in nine different industries toward which it would direct funding.

Artificial intelligence (AI); virtual reality (VR) and augmented reality (AR); self-driving cars; lightweight materials; smart cities; precision medicine; carbon resource recycling; particulate matter management and related pollution issues; and, finally, biomedicine and biopharmaceuticals.

The government named those industries as having potential breakthroughs that could help break the current era of low growth, and which could lead to the fourth industrial revolution. The government promised KRW 1.6 trillion of financial support for those industries over the next decade.

Development of CO_2 Mineralization for Commercialization

Report of the 33rd National Science and Technology Advisory Council for Carbon Resources Strategic Establishment('16.4)

Contents

CO_2 resource

Power

Cement

CO_2 resource recycling

CO_2 + By products, waste, et al

Products

- Green cement, Concrete, Porous block
- Backfilling materials for abandoned mine
- Eco-friendly paper
- Nano composite materials for light weigh vehicle

* Backfilling materials: Reduce of CO_2 -> Benefit (2,000$/1t)

Technological level

- **Technological level**

	Basic → Commercialization
International	Japan, Finland, et al
Domestic	Best in the world

- **National R&D Investment :** Approx. 10 M$/year (2015)

Strategy of demonstration & commercialization

Commercialization of No.1 Proven technology

~2020

- Demonstration of Green cement, Backfilling materials (Gang-won, Chung-cheong pilot area)
- Demonstration of Eco-friendly paper
- Technical transfer to other countries
- Development of new technology

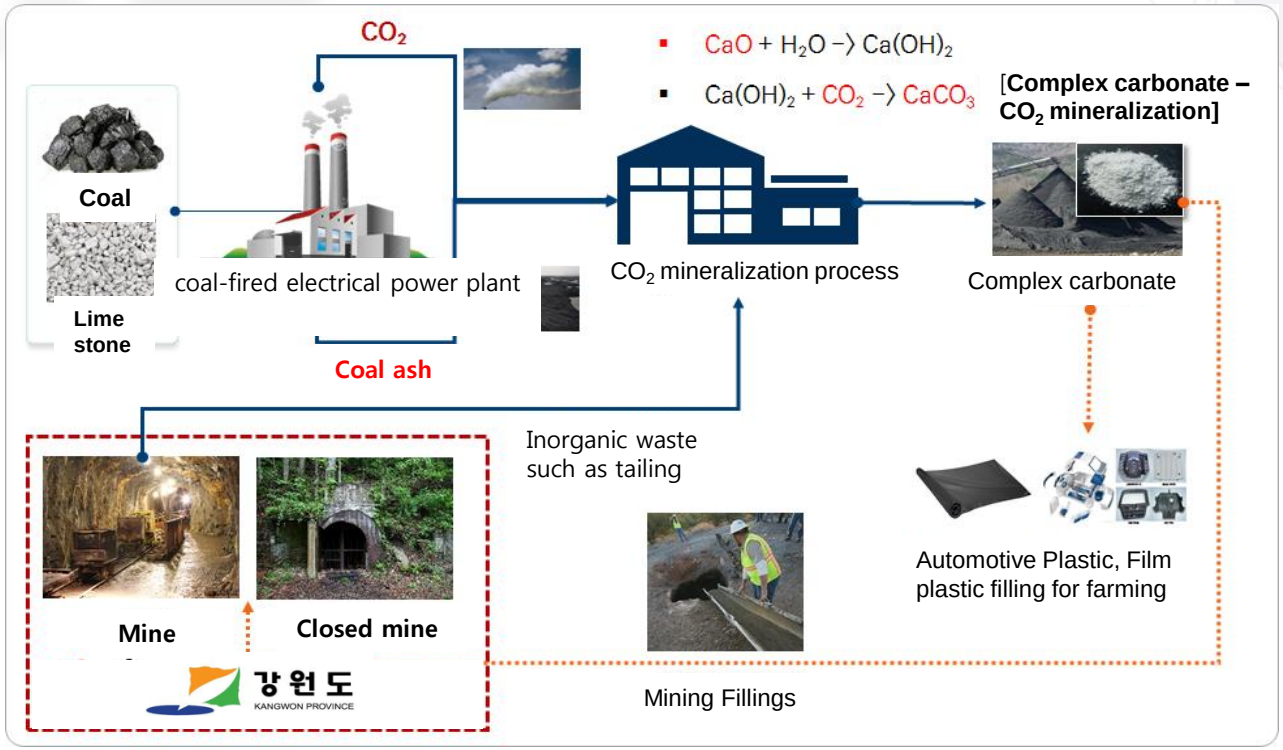
~2025

- Engineering and optimization of production process
- Improve production efficiency and standardization
- New technology demonstration

~2030

- Technology diffusion and commercialization of the world market
- Expansion of technology transfer
- Achievement of the international reduction goal
- Commercialization of technology

Current state of CCUS Technology Projects - MSIT



KIGAM's Progress of R&D related to Mineral Carbonation

- 2000~2010 : 21C Frontier business "Development of Direct accelerated carbonation source technology" Establishment of Direct carbonation technology utilizing 13% CO_2 concentration, Semi-pilot (200kg/h) Construction
- 2008~2012 : Government-sponsored business "Development of low-carbon green cement source technology utilizing industrial by-products such as thermal power plant byproducts"
- 2011~2013 : Demonstration business "World's first success in making 50,000 ton of inorganic waste per year recyclable and 3,000 ton of CO_2 Storage demonstration"
- 2013~up to date : "Low-carbon green cement source technology" Completion of demonstration and commercialization (Representative technology of Korean Green Cement COP 21 Waste Sector)

3 Green Cement with CFBC Coal Power Plants Byproducts

KIGAM Green cement Technology - Calcium SulfoAluminate (CSA)

Background

- The high functional cements has been focused on, with increase on the need for multistoried building, complex constructions and so on.
- The calcium sulfoaluminate is a representative cement with high functions.
- The aluminate resource, such like bauxite, is used as main raw material to manufacture calcium sulfoaluminate.

Properties

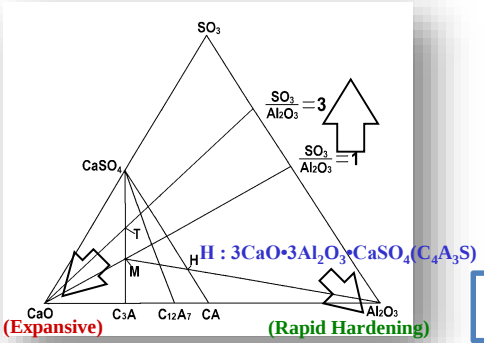
- Hydraulic reaction with water take place instantaneously
- Contribute expansion, high strength, and rapid hardening to material

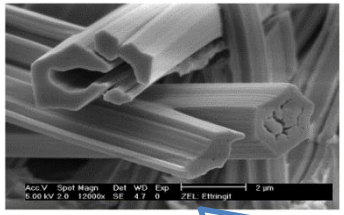
Application

- Expansion :
  - · Compensation for shrinkage
  - · Self-leveling
- Rapid hardening :
  - · Repair & Maintenance (ex. Tunnel)
  - · Waterproof
  - · Reclamation by solidification
- High strength :
  - · Bridge, High-rise building
  - · Marine structure

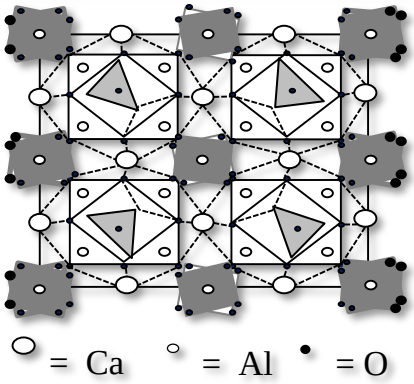
Calcium Sulfoaluminate(CSA) from Coal Ash & Bauxite residues

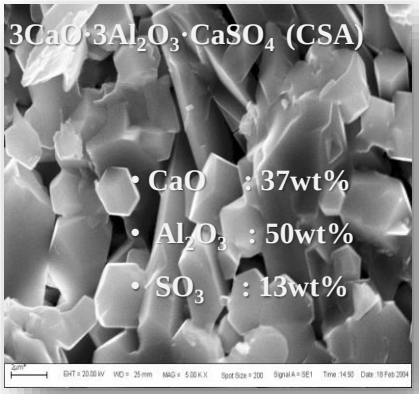
$4CaO \cdot 3Al_2O_3 \cdot SO_3$ (CSA)





$4CaO3Al_2O_3SO_4+8CaSO_4+6Ca(OH)_2+96H_2O \rightarrow 6CaO3Al_2(SO_4)_3 \cdot (OH)_{12} \cdot 26H_2O$





Crystal of CSA shows cubic shape composed with Al-O hexagonal group, form axial hole path, and a square column of Ca-O on the axis of unit cell

Calcium Sulfo Aluminate(CSA)

New Modified Calcium Modulus

· **Coefficient of correlation for SO_3**

The amount of CaO in gypsum = $0.0919 \times 4CaO \cdot 3Al_2O_3 \cdot SO_3$

$= 0.0919 \times 7.62 \times SO_3$

$= 0.7 \cdot SO_3$

· **Coefficient of correlation for Al_2O_3**

The amount of CaO in CSA = $0.0919 \times 4CaO \cdot 3Al_2O_3 \cdot SO_3$

$= 0.0919 \times (5.984 \cdot Al_2O_3 - 0.639 \cdot Fe_2O_3)$

$= 0.55Al_2O_3 - 0.059 \cdot Fe_2O_3$

· **Coefficient of correlation for SiO_2**

The amount of CaO in $C_2S = 0.326 \times 2CaO \cdot SiO_2$

$= 0.93 \cdot SiO_2$

· **Coefficient of correlation for Fe_2O_3**

The amount of CaO in $C_4AF = 1/4 \times 0.46 \times 4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

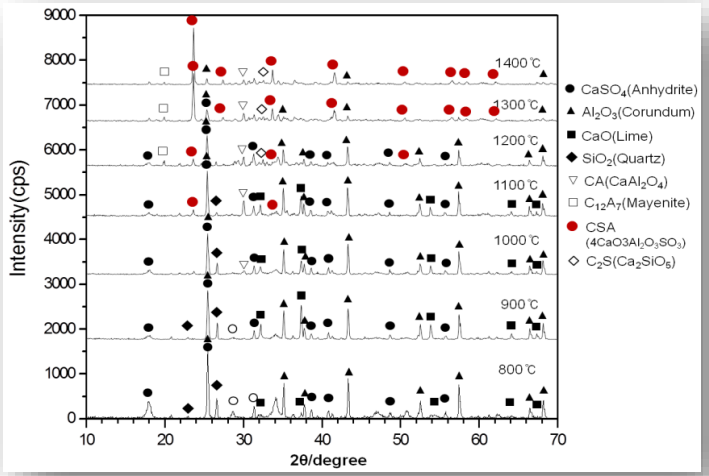
$= 0.351 \cdot Fe_2O_3$

New Modified Calcium Modulus

$$CM = 100 \left[\frac{CaO}{0.70\,SO_3 + 0.29\,Fe_2O_3 + 0.55\,Al_2O_3 + 0.93\,SiO_2} \right]$$

The Change of Sintered Products at CM = 100

<XRD>



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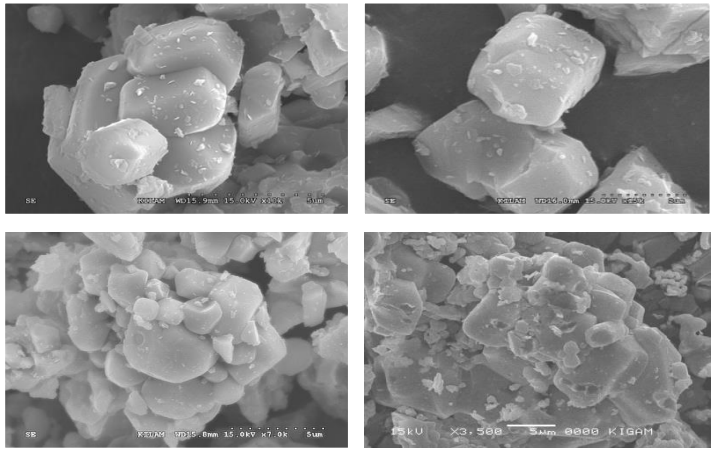
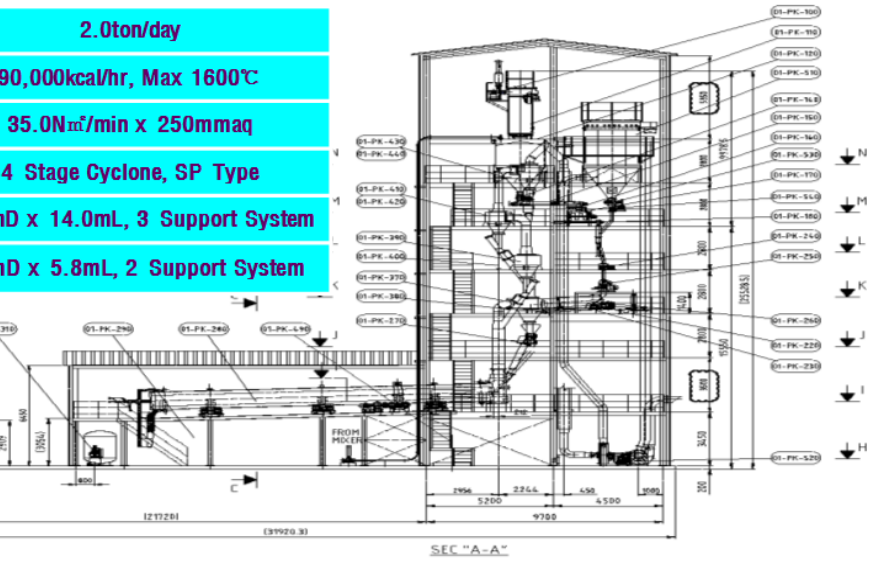


Application of Calcium SulfoAluminate(CSA)

CSA Pilot Kiln Spec.

Plant Capacity	2.0ton/day
Kiln Burner	90,000kcal/hr, Max 1600℃
Kiln I.D Fan	35.0N㎥/min x 250mmaq
Pre-Heater	4 Stage Cyclone, SP Type
Rotary Kiln	1.08mD x 14.0mL, 3 Support System
Rotary Cooler	0.9mD x 5.8mL, 2 Support System



Front View

Dry Oven

Kiln & Cooler

Cyclone

Cyclone

Cyclone Building

Actual Output of CSA

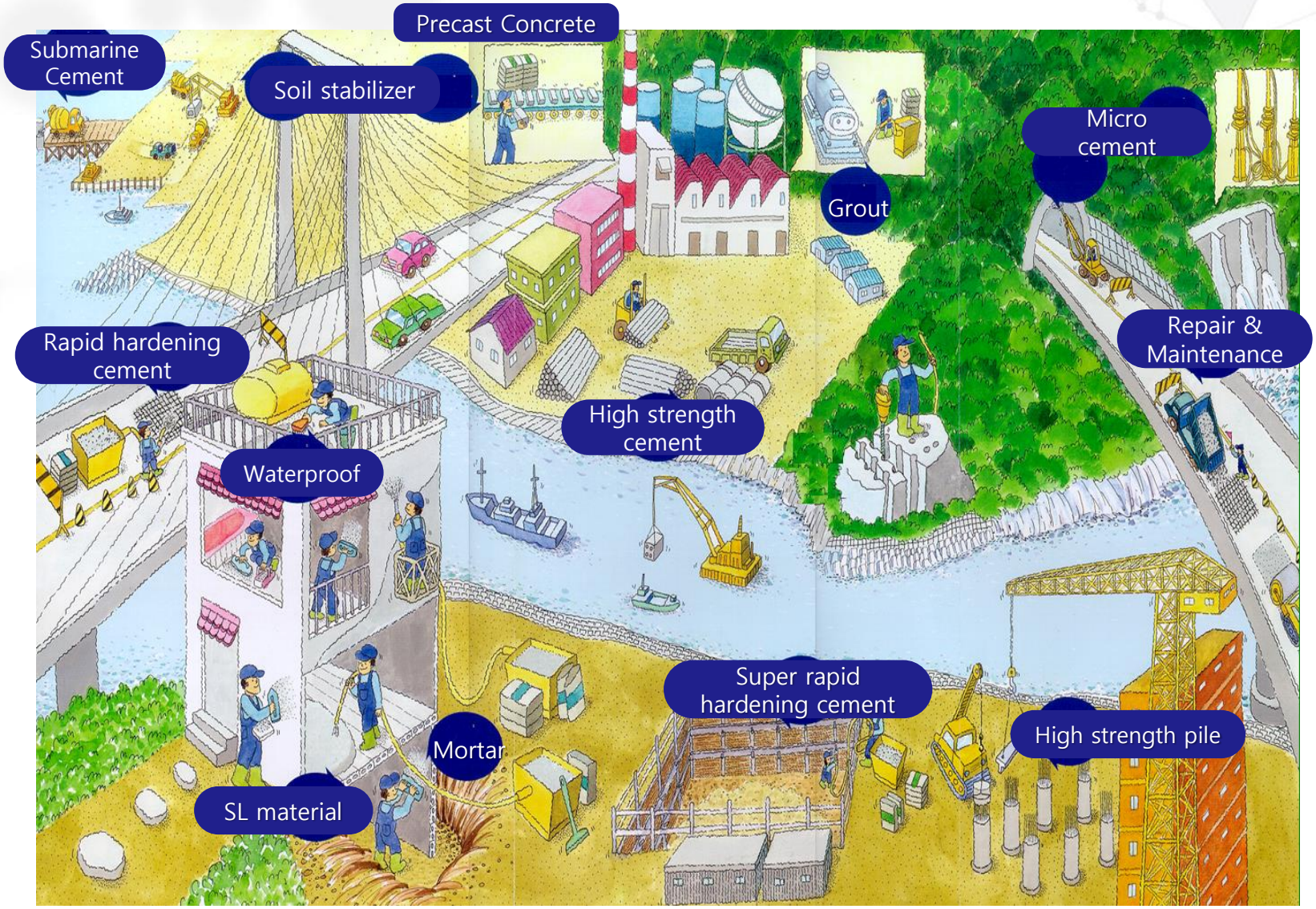
Lime-based High functional Expansive admixture

Product	Period	Plant	Output[ton]		Main Raw Material
			Mixed	Clinker	
Lime-based High functional Expansive admixture(CSA)	2013. 10. 1 ~ 9	Pilot Plant	10	7	Limestone, Coal ash, Phospho-Gypsum
	2014. 2. 3 ~ 5	#1R/M, #1K/L	3,100	2,000	Limestone, Coal Ash B/A, Chinese gypsum etc

Pilot Plant

#1Kiln Room Processing

Application of Calcium Sulfo Aluminate(CSA)



10 Emerging Technologies 2010 by MIT

10 Emerging Technologies 2010

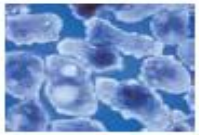
Each year, *Technology Review* selects what it believes are the 10 most important emerging techn
the editors' coverage of k
is the technology likely to
are on the largest scale po
cells, and green concrete
years ahead. Other chang
use technology: for exam
applications for cloud con
ways to implant medical
will affect us on the most
making our lives healthie

Real-Time Search
Social networking is changing the way we find information.

Social TV
Relying on relationships to rebuild TV audiences.

Mobile 3-D
Smart phones will take 3-D mainstream.

Green Concrete
Storing carbon dioxide in cement.



Engineered Stem Cells
Mimicking human disease in a dish.

Implantable Electronics
Dissolvable devices make better medical implants.

Solar Fuel
Designing the perfect renewable fuel.

Dual-Action Antibodies
Fighting cancer more efficiently.

Light-Trapping Photovoltaics
Nanoparticles boost solar power's prospects.

Cloud Programming
A new language will improve online applications.

CO_2 solidification into solid wastes (e.g. Green Concrete) is currently evaluated as a more innovative technology than Mobile 3-D in the world.

- **Green concrete (storing CO_2 in cement) was made by coal ash and bauxite as raw material in KIGAM and Hanil Cement**

The 4th Industrial Revolution Link Technology

The 4th Industrial Revolution Link Technology

The Fourth Industrial Revolution - The Impact of 3D Printing on Building Materials Technology

UC Berkeley unveils first-of-its-kind 3-D-printed cement structure

3D Printed Eiffel Tower (3d printing 3dprint ideas)

basketball court sticker placed around garbage cans to make throwing out litter a game

3D printing seems posed to become important in architecture, but it's early days yet. One potential step forward comes from a team of UC Berkeley researchers led by Associate Professor of Architec...

conceptMODEL : Photo

conceptmodel.tumblr.com에서

3D Castle Completed. It has been two years since I first began toying with the idea of a 3D printer that was capable of constructing homes. In my vision of using 3D printers as new technology, I wanted a light, portable, and stable machine. First, I built a small 3D printer that used plastic for its main material, and from that, I started experimenting on enlarging the printer and using variations of cement mixes. Layering cement was an extremely difficult task- it required extensive tuning...

The 3D-printed cool brick can hold water in its pores, like a sponge Design studio Emergingobjects has come up with a simple way to cool homes, build them with 3D-printed porous bricks called Cool Bricks which can be filled with water to bring down temperatures.

construção por impressora 3D

3D Duomo Milano, piuLAB, #3D #3Dprint #3Dprinting [more pics on Cults website]

Unfold.be's innovative porcelain 3D prints: "One nice benefit of designing in tool paths is the ability to draw a single line that intersects itself."

Skanska and Foster + Partners Collaborate on World's First 3D Concrete Printing Robot

Skanska+and+Foster+++Partners+Collaborate+on+World's+First+3D+Concrete+Printing+Robot

'The Age of the Fourth Industrial Revolution'- Changes in architectural paradigm using cement

- **3D printing of cement concrete turns into an era of short-term, low-cost construction of buildings**
- **Fast-curing, high-strength, eco-friendly properties of green cement (CSA) - unlimited potential for 3D printing architectural materials**

The 4th Industrial Revolution Link Technology

2050 Giant Construction Market Forecast

World population

6.9 Billion

7.7 Billion

9.2 Billion

2010

2020

2050

Urban construction population nation(%)

51.6%

56%

67.2%

Urban construction market scale($)

$ 7.5 Trillion

$ 12.7 Trillion

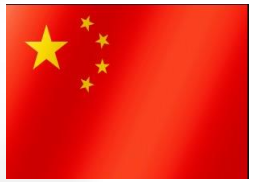
14,000 New Town Needs

$ 1,000 Trillion

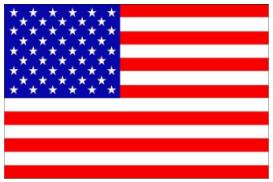
(UN 보고서, 2012)

The 4th Industrial Revolution Link Technology

3D printing material development example



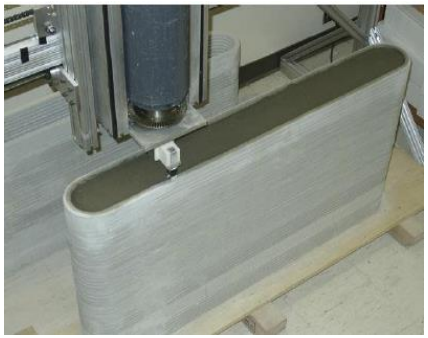
China

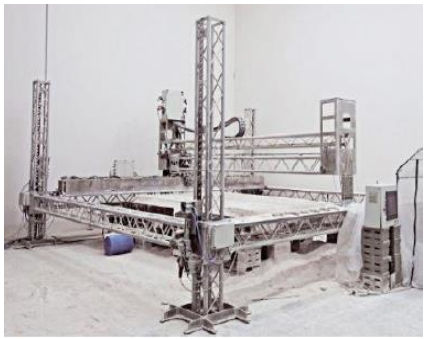


USA

Netherland

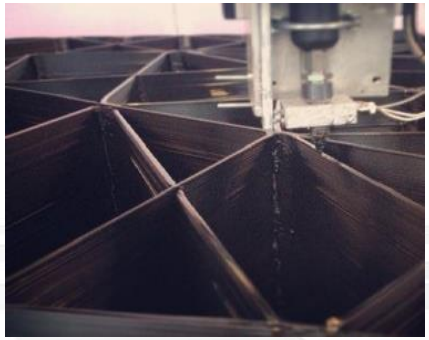
Italy





Winsun

Unvi. Of Southern California



DUS Architects

D-Shape

The 4th Industrial Revolution Link Technology

Russia 3D printer startup: Apis Cor.

3D printing houses

- Buildings built with existing 3D printers work in the field after 3D printing in other places, and can work on site with this 3D printer
- The cost of house building with a size of 38m2 including a kitchen and a bathroom is worth $ 10,000. The durability of a built house is 175 years.

The 4th Industrial Revolution Link Technology

3D printing material development example

March 21, 2017 *Updated: March 21, 2017 08:45 PM*

Related

Inflation heats up in building sector as energy prices rise

3D printing breakthrough in the Middle East – video

Dubai company ready to 3D print your house,

A start-up enrolled in Dubai's Future Accelerators programme has created a "green" cement compound from industrial waste geared for use in 3D printing.

Renca, a joint venture between Russian businessman Andrey Dudnikov, 33, and Alex Reggiani, 40, an Italian, has created a geopolymer cement from industrial by-products that uses only a 10th of the energy compared with traditional Portland cement.

The company is working with Dubai Municipality to develop its material for use in 3D printing projects in Dubai. Mr Dudnikov said that it is also looking to set up a plant for its product in the city.

Mr Dudnikov set up Renca with Mr Reggiani, a geologist and mineralogist, in January last year after meeting at a Geopolymer Institute conference in France.

as knowledge of the concrete industry as well as a
, said the pair have since collaborated with companies in
re such as Russian firm Apis Cor (which recently built a
nd the Singapore Centre for 3D Printing at Nanyang
rsity.

nent and concrete produced from industrial waste such
and ground granulated blast slag has greater thermal
than regular concrete, so is better in hot climates at

A startup registered with Dubai's Future Accelerators program has created a "green" cement compound that can be used for 3D printing from industrial waste.

Geopolymer cements and concrete produced from industrial wastes such as fly ash and blast furnace slag have greater thermal insulation properties than ordinary concrete and are therefore better in hot temperature to resist heat.

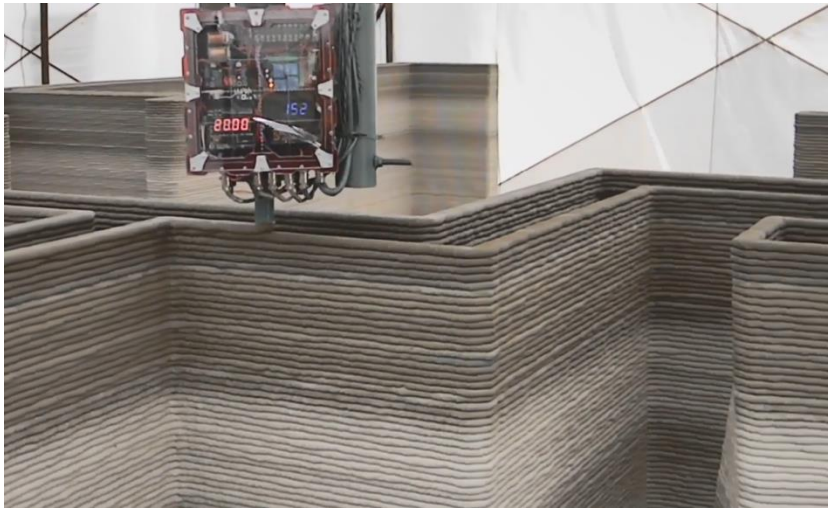
However, the main advantage of 3D printing with geopolymer cement is that it is cheaper to use than Portland cement

New Dubai company creates 'green' cement for 3D printing

- Developed 3D printing technology using geopolymer cement (fly ash and slag mixture) in cooperation with Renca - Nanyang Technological University
- Green cement material that improves fluidity and has excellent thermal insulation properties

The 4th Industrial Revolution Link Technology

The Importance of Developing 3D Printing Materials (MIT, USA)



Currently, 3D printing architecture is a method of laminating cementitious materials and printing structures
- Fast curing of materials, prevention of sagging, mechanical strength, flow, etc. -

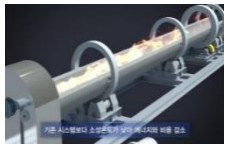
Capable of utilizing excellent engineering performance of KIGAM carbon mineralization (CSA green cement)

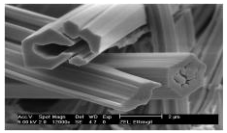
The 4th Industrial Revolution Link Technology(KIGAM)

Green cement development and overseas commercialization strategy

Green cement manufacturing technology

- Development of original technology for manufacturing high performance expandable CSA cement using CFBC ash
- Development of low-cost CSA cement manufacturing technology utilizing by-products such as Bauxite Residue and CFBC power generation abundant in developing countries such as Vietnam





International standardization

- Guidelines for the effective utilization of coal ash
  - Guideline development and standardization of coal ash cement raw material
- Cement manufacturing standard
  - Standardization of portland cement manufacturing considering CO_2 footprint reduction

Green cement and abandoned mine filler material technology CCUS demonstration and overseas commercialization

Demonstration of abandoned mines using green cement

Utilizing high-performance fast-curing cement material for 3D printing construction

Environmentally friendly functional permeable concrete

4th Industrial Revolution-related 3D printing business field expansion

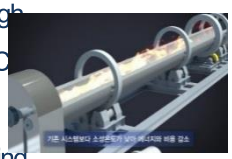
3D Printing Construction Technology by Green Cement

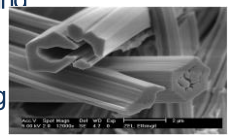
Eco-friendly green cement production using coal ash and 4th industrial revolution - Convergence 3D printing construction

Coal Power Plant

Coal Ash

- Developed original technology for manufacturing high performance expandable CSA cement using CFBC ash single substance
- Development of low-cost CSA cement manufacturing technology using by-products such as Bauxite Residue and CFBC coal as abundant in developing countries such as Vietnam

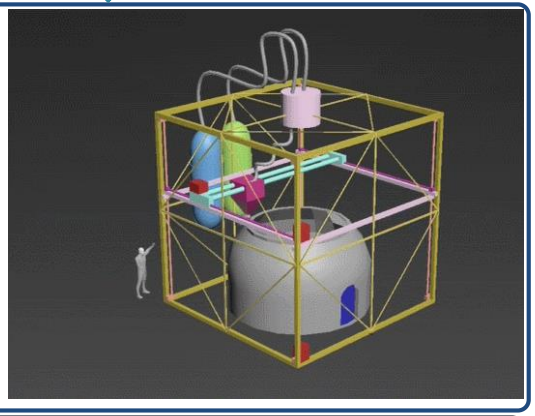




Utilization & production of eco-friendly green cement raw materials

강원도 KANGWON PROVINCE

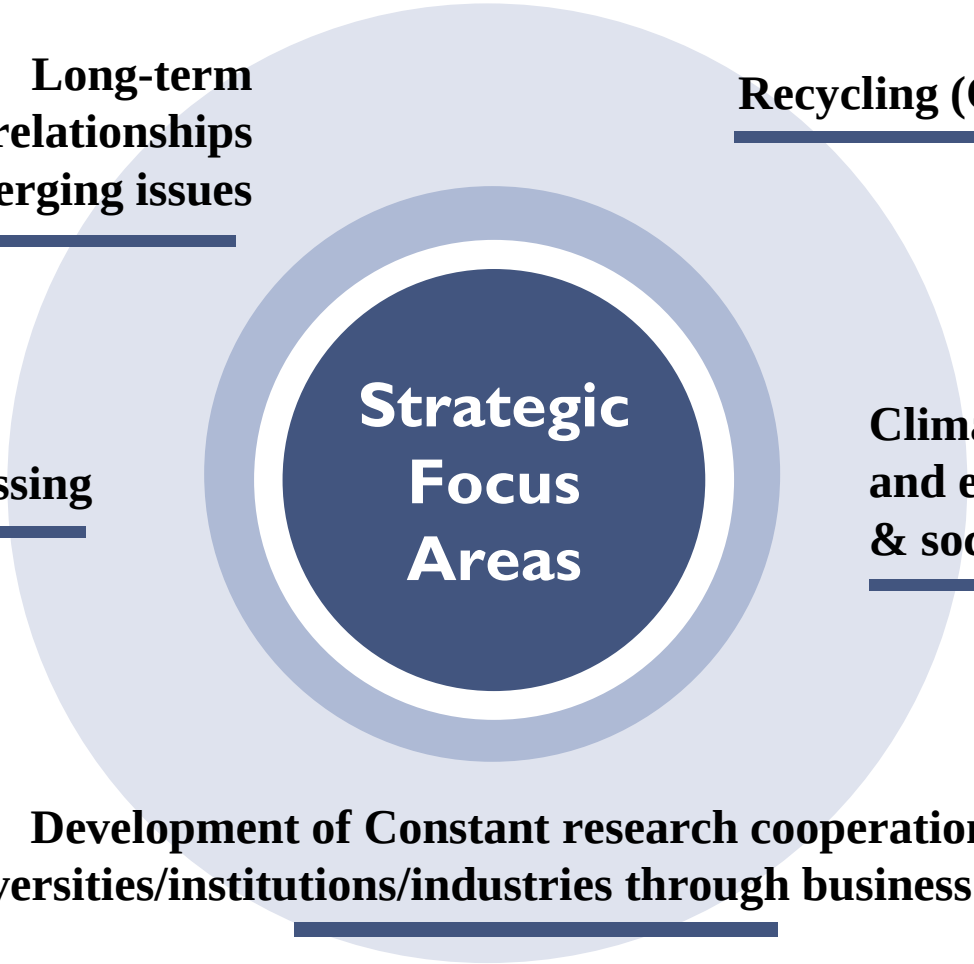
- Cement 3D printing makes it possible to build buildings in a short period of time and at low cost
- Contributing to the construction of eco-friendly, low-carbon self-reliance by utilizing the rapid hardness, high strength, and eco-friendliness of Green Cement (CSA)



Utilize 3D printing architectural material

4 Conclusions

ACTBN's Action Plan ,Strategy and Priorities



Long-term Business network relationships in Asian emerging issues

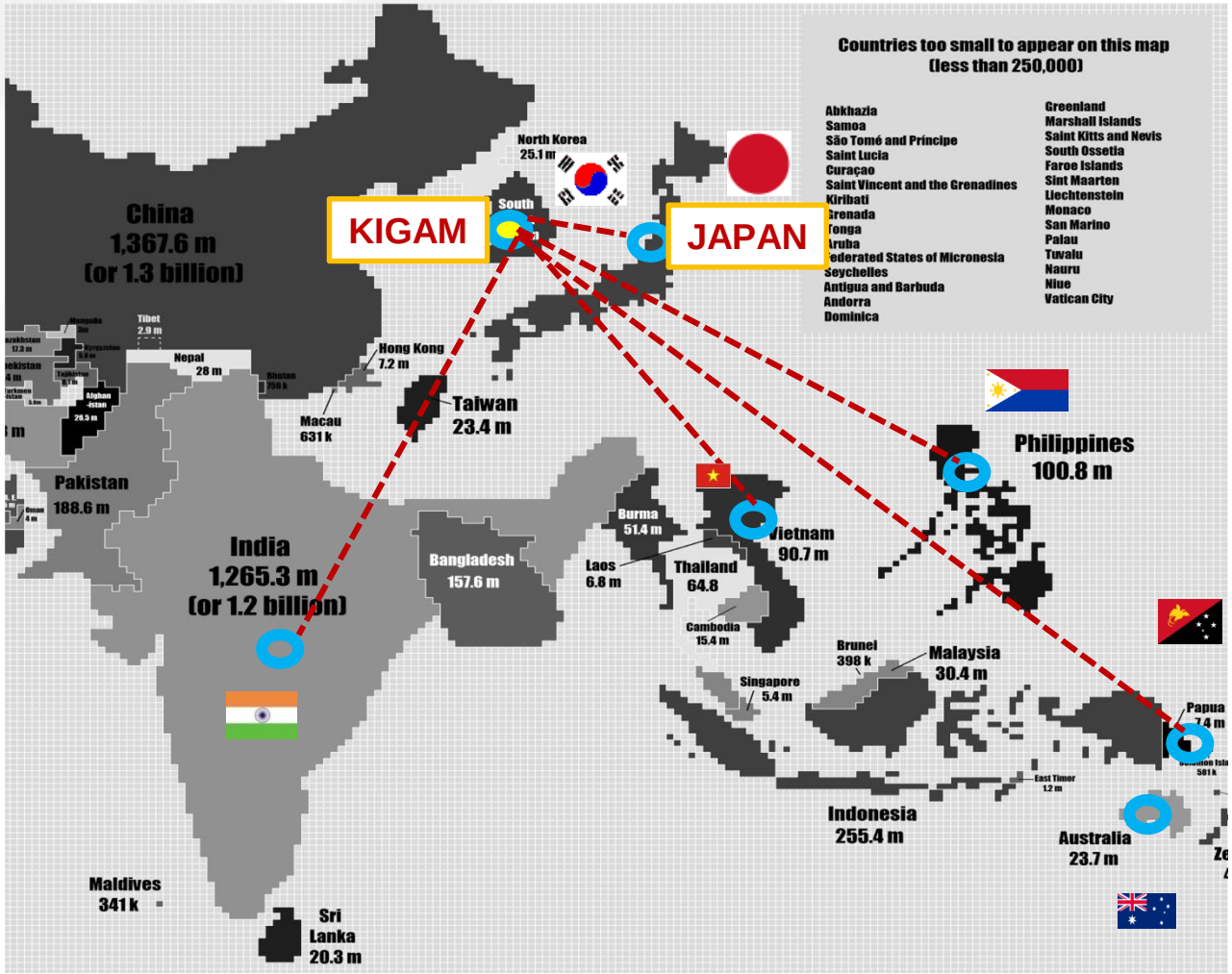
Recycling (CCUS)

Mineral Processing

Climate change and environmental & social sustainability

Development of Constant research cooperation to universities/institutions/industries through business network

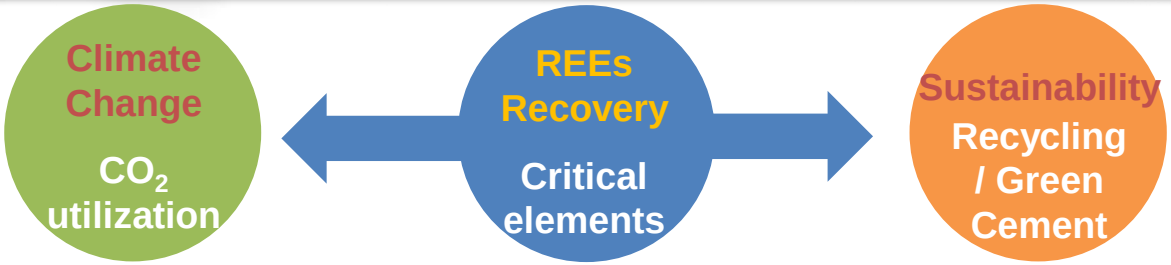
KIGAM International Collaborators



1. Korea
2. Japan
3. Australia
4. India
5. Philippines
6. Vietnam
7. Papua New Guinea

Conclusions

Sustainability for Climate Change – Converging Technology –



- The United States is pursuing various government projects such as DOD and DOE to strategically explore and research the rare earth metals recovery, which are closely related to the defense industry.
- Coal, which is a fuel for coal-fired power plants, contains some amount of rare earth metals, and rare earth metals are still contained in the coal power plant ash after combustion.
- In the United States, various projects are being carried out to recycle rare earth metals. Commercialization researches related to the reduction of CO_2 in response to climate change and the recovery of rare earths, which the Neumann system is promoting, are being promoted.
- Therefore, in Korea, where rare earth metals are lacking, various researches are being conducted in order to extract rare earth metals from coal ash after combustion of coal. This is a very important study to secure Clean Development Mechanism (CDM) which is utilizing CO_2 generated from industries through technology transfer in developing countries.
- **KIGAM has already conducted research on Green cement technology utilizing coal ash generated from coal power plants, and is conducting research on the recovery of rare earth metals from coal ash. This is a technology that can realize a sustainable society that solves the problems of climate change and the depletion of natural resources.**

Thank you