TOGETHER.
TOMORROW.
EWHA

Theme 1. Survey on Emerging CCS Technologies: Ocean Storage and Mineral Carbonization

권소현, 김정현, 안은지, 황수민, 신송아

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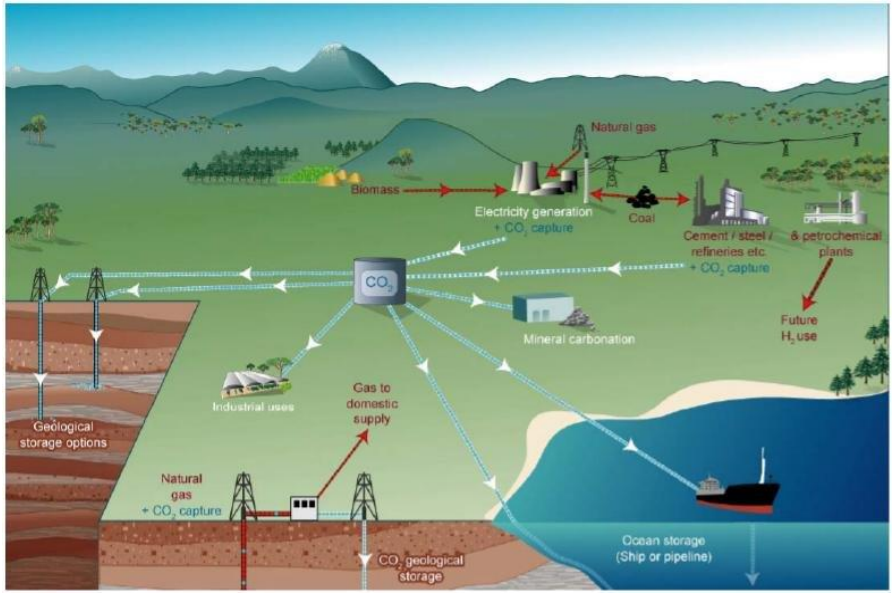
What is CCS?

- Carbon Dioxide Capture and Sequestration
- Process of Capturing Waste Carbon Dioxide



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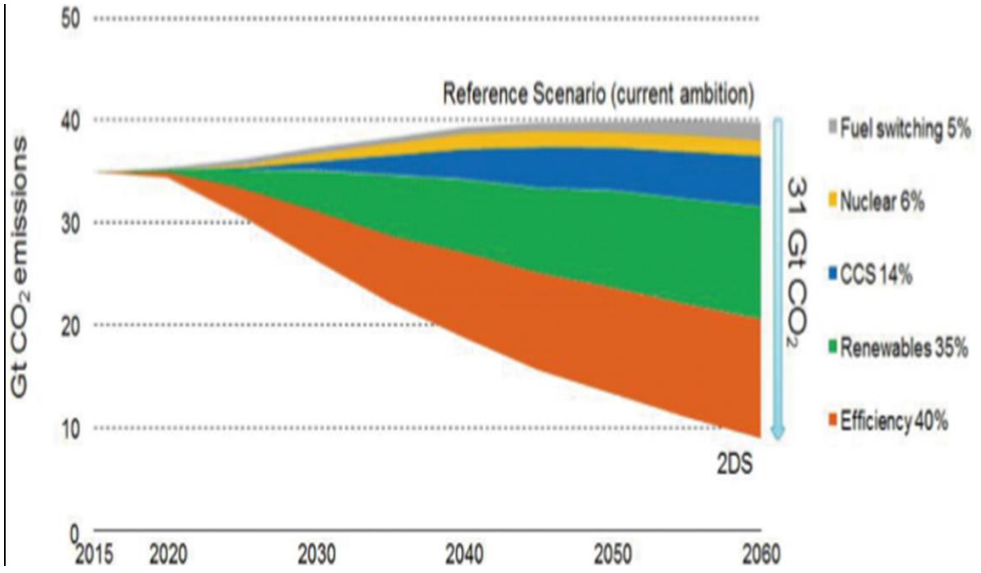
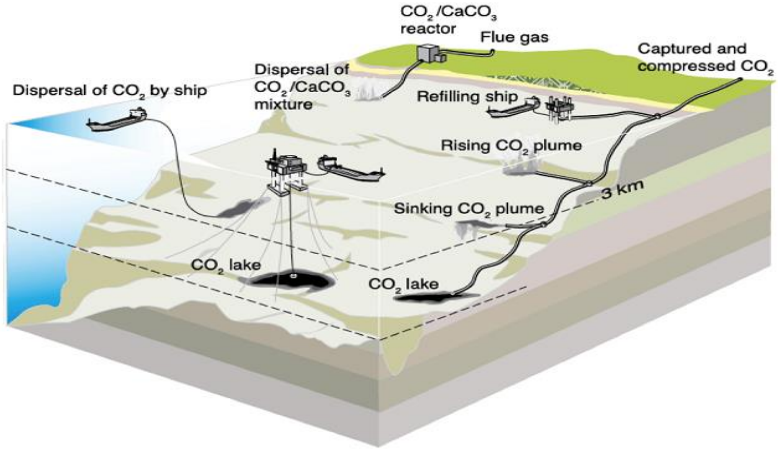


2018 Technical Report from Korean Agency for Technology and Standards(KATS)

Types of CCS

CCS Component	CCS Technology
Geological Storage	Enhanced Oil Recovery(EOR)
	Gas or Oil Fields
	Saline Formations
	Enhanced Coal Bed Methane
	Enhanced Coal Bed Methane Recovery(ECBM)
Ocean Storage	Direct Injection(Dissolution Type)
	Indirect Injection(Marine Fertilization)
Mineral Carbonization	Natural Silicate Minerals
	Waste Materials

Ocean Storage



ft.com/content/
theliquidgrid.com/category/environmental/climate-change/

- Ocean Capacity

  (Amount of Carbon Stored in Ocean)

  = (Amount of Carbon Stored in Atmosphere) * 50

- Eighty percent of the carbon stored in the ocean is stored permanently, and 20 percent of the carbon leaks differently depending on the topography and depth of the water.

Ocean Storage

1. Theoretical Background

2. Types of Ocean Storage Technologies

    2.1. Direct Injection

        2.1.1. Gas Phase CO_2

        2.1.2. Liquid Phase CO_2

        2.1.3. Solid Phase CO_2

        2.1.4. Direct Injection of CO_2 Hydrate and Sea Water Mixture

        2.1.5. Direct Injection of Diluted or Neutralized CO_2 and Sea Water Mixture

    2.2. Indirect Injection

        - Marine Fertilization

3. Legal Implication of CO2 Ocean Storage

4. Ocean Storage- Cost, Consideration

1. Theoretical Background

- Since the industrial revolution, the ocean absorbs about 1/3 of the carbon dioxide emitted by mankind every year, and 85-90 percent of all CO_2 to be released in the future is also expected to ultimately be stored in the ocean.
- Carbon dioxide storage is a natural phenomenon that accelerates as the concentration of atmospheric carbon dioxide increases.
- The biggest difficulty is that the reaction rate of carbon dioxide absorption in the ocean is too slow compared to the rate of increase in carbon dioxide in the atmosphere.
- Based on these phenomena and predictions, some scientists have presented various scenarios that could accelerate the carbon dioxide melting reaction and are conducting rudimentary studies on long-term processing efficiency or potential side effects to the environment and the marine ecosystem.

2. Types of Ocean Storage Technologies

2.1. Direct Injection Method

A method of storing CO_2 collected from the ground in the sea and on the seabed with various forms.

2.1.1. Direct Injection of Gas type CO_2

- Injecting CO_2 into the shallow sea level below the mixed layer to dissolve it into the sea water.
  - Possible to isolate CO_2 for a short period of time.
- The Injector: Designed to a size, small enough to dissolve all within 100 m of the injection depth.
  - Reducing the possibility of discharging it back into the atmosphere.

Ocean Storage: Direct Injection

2.1.2. Direct Injection of Solid CO_2

- Subsiding CO_2 on the seabed using ship
  - Dry ice's density >> sea water
- Risk of CO_2 release into the air
  - Direct injection from sea to sea surface layer

    ▶SOLUTION 1) Reducing cross section area of dry ice
    2) Increasing descendent velocity
    3) Surface coating
- High cost of producing and transporting CO_2
  - 2 times more than liquid CO_2

2. Types of Ocean Storage Technologies

2.1.3. Direct Injection of liquid CO_2

Maintaining liquid until CO2 dissolves in seawater at a depth of 500m or more

1) Injection through pipeline from land

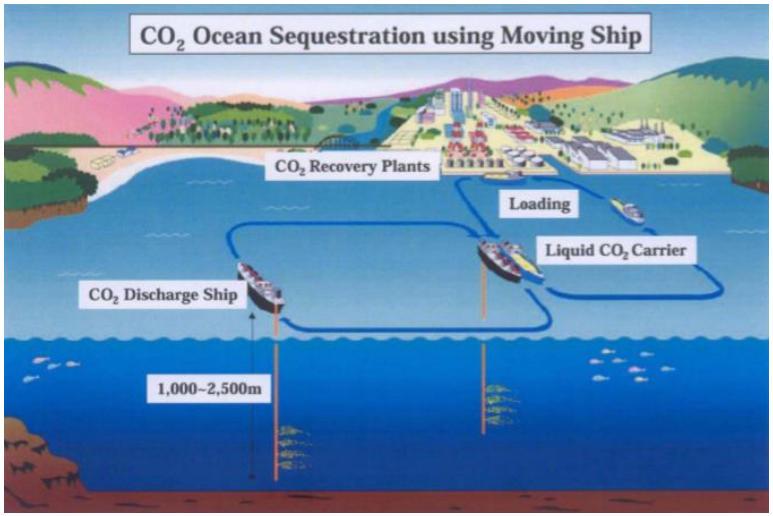
- Using large CO_2 generating or storage facilities
- No difficulties in technology
  - Gas or Oil development companies' experience

Ocean Storage: Direct Injection

2.1.3. Direct Injection of Liquid CO_2

2) Injection through ship or fixed platform

- CO_2 separated or stored near the coast
  - Transferred back to ship and injected below water
- Application of LPG transport technology
- Pressure over 6bar, Temperature under -55 ℃



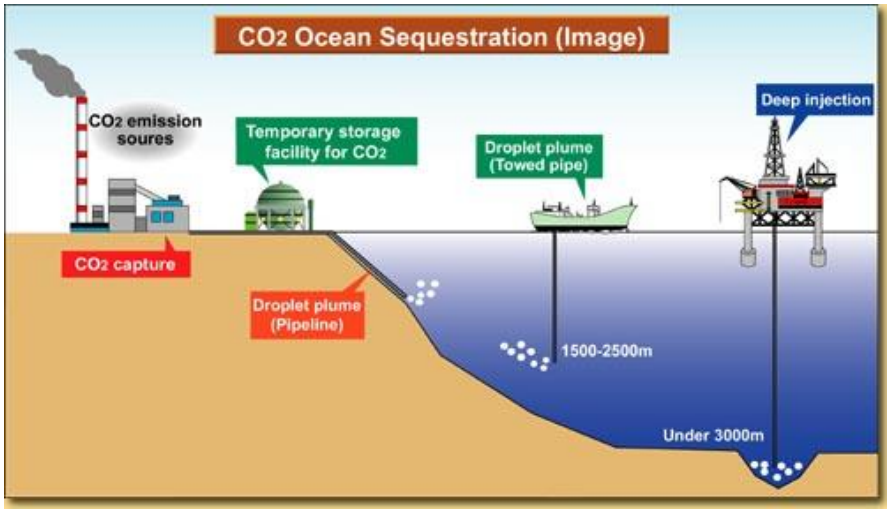
The Korean Association of Ocean Science and Technology Societies(KAOSTS)

Ocean Storage: Direct Injection

2.1.3. Direct Injection of liquid CO_2

3) Injection to trenches on seabed

- Using pipeline, ship, or fixed platforms connected to shore
  - Store under water at a depth of more than 3000m
- Formation of CO_2 lake in submerged area of ocean floor
  - Injected CO2's large density



rite.or.jp

Environmental Problem

https://imgur.com/gallery/65Gogeb

Types of Ocean Storage_Direct

2.1.4. Direct injection of carbon dioxide hydrate and sea water mixture

Inject the mixture of sea water and carbon dioxide hydrate into sea water.

→ The density of this mixture is higher than that of the sea, so it subsides to the bottom.

2.1.5. Direct injection of diluted or neutralized carbon dioxide and sea water mixture

- Combine carbon dioxide and sea water and inject them into the bottom of the thermocline layer.
  - → The density of the mixture is higher than that of the sea water so it move into the deep sea.
  - → As the mixture moves into the deep sea, the density difference disappears and carbon dioxide is injected along the underwater canyon
- Dissolve limestone or carbonate minerals together to neutralize acidity caused by carbon dioxide melting.

2.2. Marine Fertilization

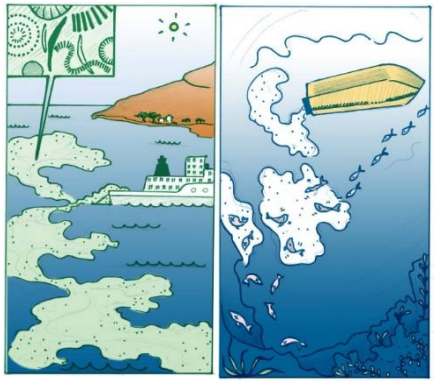
1) Definition

Injection of nutrients to the surface seawater that can accelerate photosynthesis of plant plankton

2) Process

Photosynthesis acceleration → Carbon concentration reduction in surface water → Carbon dioxide absorption from atmosphere increases → Restores fish population → Fishery production increases

ex) Iron fertilizations



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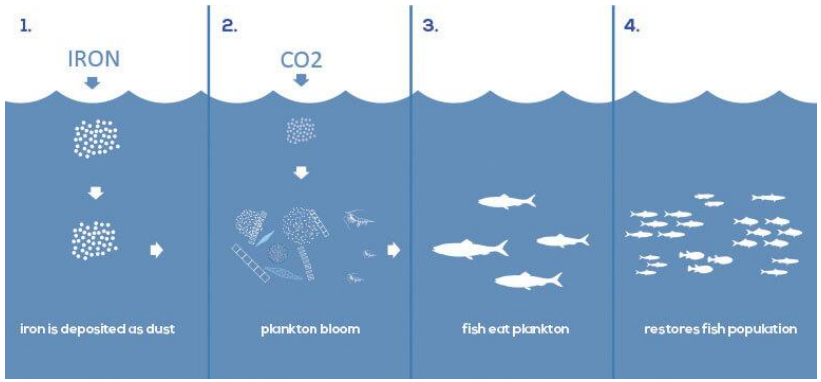
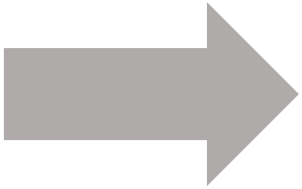


nextbigfuture.com

Ocean Storage

Direct CO_2 Injection	Advantage	Disadvantage
Gas	Isolate CO_2 from the atmosphere in a short period of time	High possibility of releasing back into the atmosphere
Liquid	Injection through a pipeline will be useful to receive and store CO_2 directly from the plant	Makes CO_2 lake
Solid	High cost of manufacturing and transporting CO_2	Certain amount of CO_2 released into the atmosphere while it's sinking



Direct CO_2 Injection of liquid CO_2 is most probable

3. Legal Implication of CO_2 Ocean Storage

- Existing legal framework relevant to ocean storage of CO_2 both encourage and prohibit the development of this new technology.

The Framework Convention on Climate Change

Supports the study and future use of the oceans as a partner in reducing the level of anthropogenic greenhouse gas emissions, unless not affecting the marine ecosystem. But not strongly recommend.

London Convention, the Clean Water Act and the Ocean Dumping Act

Prohibit most uses of the ocean, because of linkages between atmospheric carbon dioxide and climate change

Framework Convention on Climate Change, 1992

The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.

-Principle 3 of the Convention

4. Ocean Storage- Cost, Consideration

- Cost (cf. Mineral Carbonization 50~100 USD/tCO2)

USD/tCO_2	Platform		Shipping	
Injection Depth	3,000m		2,000~2,500m	
Transportation distance by shipping	100km	500km	100km	500km
Ocean Storage Cost	11.9	13.2	14.2	15.7

- Consideration

It affects short-term effects such as increased mortality of marine life and changes in marine ecosystems. However, it is difficult to find a clear relationship because of a lack of scientific evidence and limitations of information.

Mineral Carbonization

1. Definition of Mineral Carbonization
2. Origin of Metal Oxide
3. Process of Carbonate Mineralization
4. Treatment of Byproducts
5. Overall Process and Cost Assessment
6. Environmental Impact of Carbonate Mineralization

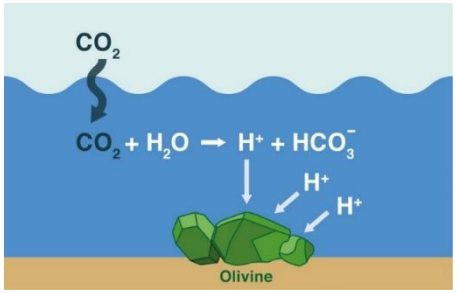
Overview of Mineral Carbonization

- Process of Carbonate Mineralization

  (Gas Phase CO_2) + (Minerals Containing Metallic Oxide)

  → (Solid-Phase Carbonate or Silicate minerals)

- Most representative carbonate mineralization reaction: Carbonate mineralization reaction of Olivine(감람석), a natural silicate mineral



climitigation.org

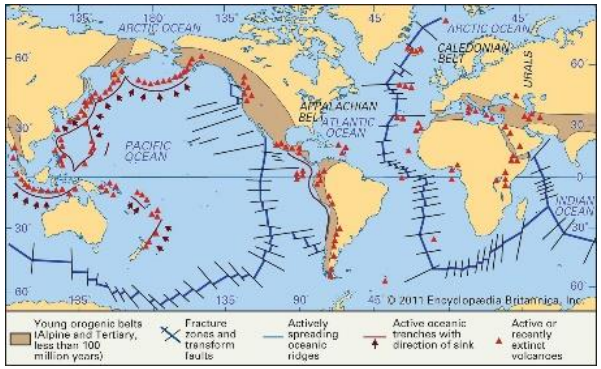
- The speed of natural inorganic carbonation reaction is very slow. In order to induce mineralization reactions with appropriate reaction speeds, energy or catalysts should be added to the reactants.

1. Definition of Mineral Carbonization

- Definition: A method of reacting carbon dioxide with metal oxides under conditions of much higher carbon dioxide concentration than natural processes to hold carbon dioxide with solid phase carbonate in a short period of time.
- Advantage: Effective way to store CO_2
  1. Amount of reactant used in Mineral Carbonization is abundant
  2. Carbon dioxide is permanently stored in a **stable** solid phase.
- Goal
  1. Minimizing energy addition and catalyst addition
  2. Eco-friendly recycling of heat generated during mineralization.
- Chemical formula: $MO + CO_2 \rightarrow MCO_3 + Heat$

2. Origin of Metal Oxide

britannica.com, norcalcompactors.net



Substances that can be applied to mineral carbonization

:Silicate Rock, Alkaline industrial waste

1) Silicate Rock: Ex-situ method, In-situ method

- Serpentine rock and Olivine are usually found in metamorphic rocks on plate boundaries.
- (The amount of Magnesium required to mineral carbonization of CO_2 released from coal resources) < (The amount of magnesium that exists on the Earth)

2) Industrial waste

Mineral carbonization process can be carried out at the plant where the industrial waste is produced. Industrial waste and mining tailing(광미, 광산찌꺼기) provide alkaline earth metal which can used to mineral carbonization reactant

2. Origin of Metal Oxide

1) Silicate Rock: Research stage

2) Industrial Waste: Commercialization stage

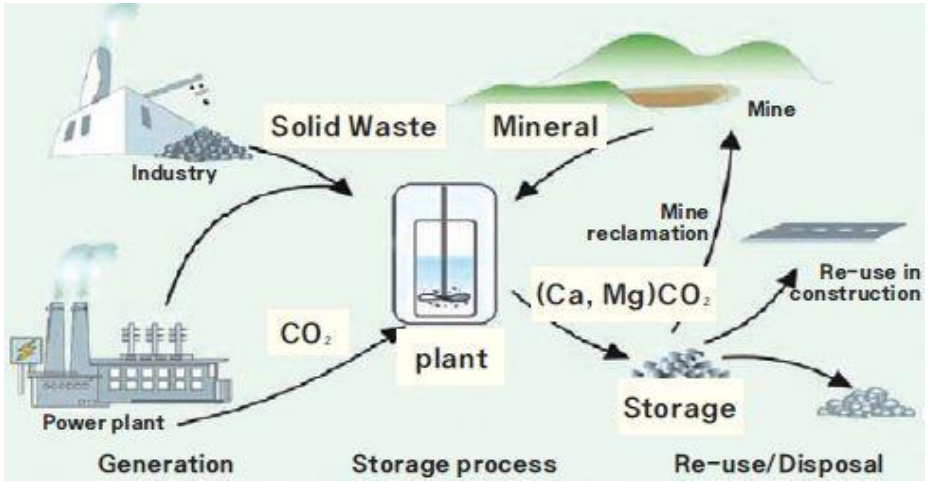
Ex) Skyonic

- Skyonic has carried out the Skymine project since 2010 with the support of the U.S. Department of Energy.
- Skyonic utilize the technique that after producing caustic soda, hydrogen and chlorine through electrolysis of saline water, the caustic soda produces sodium bicarbonate in response to CO_2 emitted from cement factories, and use hydrogen and chlorine to manufacture hydrochloric acid.
- Skyonic Corporation which developed SkyMine & Technology, a process for transforming CO_2, acid gases and other heavy metals and pollutants into marketable products, such as sodium bicarbonate, hydrochloric acid, and bleach. The first SkyMine plant has operated since October 2014 in San Antonio, Texas near the Capitol Aggregates cement plant. The plant will reduce carbon dioxide emissions by 15 percent - 83,000 tons of CO_2 per year.

3. Process of Carbonate Mineralization

- Three main part of Carbonate Mineralization: Generation, Storage process, Re-use Treatment
- Process of Carbonate Mineralization

  Mineral mining → Mineral pretreatment → Carbon dioxide preprocessing → Carbonization reaction



Global CCS Institute

3. Process of Carbonate Mineralization

Mineral mining → Mineral pretreatment → Carbon dioxide preprocessing → Carbonization reaction

- Mineral Mining - Factories conducting carbonate mineralization should be installed near the location of the metal oxide supply (ex. Near mines or factories)
- Mineral Pretreatment - Crushing, grinding, rolling and mechanical separation process
- Carbon Dioxide preprocessing - The pressure in the carbonate mineralization process and in the carbon dioxide transport process should be kept similar for preventing bulk strain.
- Carbonation reaction - on next page

3. Process of Carbonate Mineralization

Carbonation reaction

- Variables : temperature, concentration of additives, pressure of CO_2
- Impossible with unrefined minerals

  → solution: extract minerals that can react well with CO_2
- How to accelerate response velocity?
  - Increasing the temperature
  - Making the reaction of minerals higher
  - Adding the additives and increase extraction

    (examples of additives : a strong acid, a weak acid and a alkalinity solution)

4. Treatment of Byproducts

- Carbonate mineralization should be proceeded with the establishment of a plan to treat produce or by-product reliably.
- The processing method differs based on the size of the material produced, and the most suitable place to handle the product is the area around the mine where the reactant was mined.
- Other useful minerals can be extracted when ore is turned into particulate powder for carbonate mineralization.

5. Overall Process and Cost Assessment

- Additional energy & CO_2 emissions are inevitable
- Cost of Additional Energy Consumption

  vs. Positive Effects of Mineralization

  (Additional energy consumption processes: mining, pre-op processing of ore, treatment of products, restoration of mines, etc.)

- The positive effects of mineralization:

  1. No risk of re-discharge from leakage!
  2. Very few additional facilities are required to monitor carbon dioxide leaks around

→Overall process cost prediction

: To hold one ton of carbon dioxide, about 100 USD!

6. Environmental Impact of Carbonate Mineralization

- Direct impact: Site development, contamination of soil, water and air in the area around the mine

- Indirectly: Destruction of ecosystem habitats

1. Development of a Mine Site

   Development of a site in a large area to store and move mined ore is required

2. Atmospheric Environment

   Impairment of vision and breathing, contamination of surrounding streams and forests -> sol: monitoring the quality of atmos. frequently & prevention of particle external diffusion by solidification method

3. Treatment of Mining Tailing (광미, 광산찌꺼기)

   Most of them will be applied to artificially constructed ponds around the mine and treated later.

4. Leachate(침출수) Control Solution: In the case of landfill, a reaction wall(반응벽) can be installed near the landfill to prevent the release of heavy metals. → Prevent the spread of soil pollution

5. Pollution restoration Solution: Restoration programs (Eco systemic recovery, natural environment restoration) should be designed in conjunction with mine development plans.

→ Reduction of treatment costs and reduction of pollution problems

Overview

	Advantage	Disadvantage
Mineral Carbonization	-Enough minerals to use -Low possibility of leakage	- Not available everywhere - High cost required
Ocean Storage	-A good chance of storage compared to the atmosphere	-High risk of leakage -Environmental pollution problem