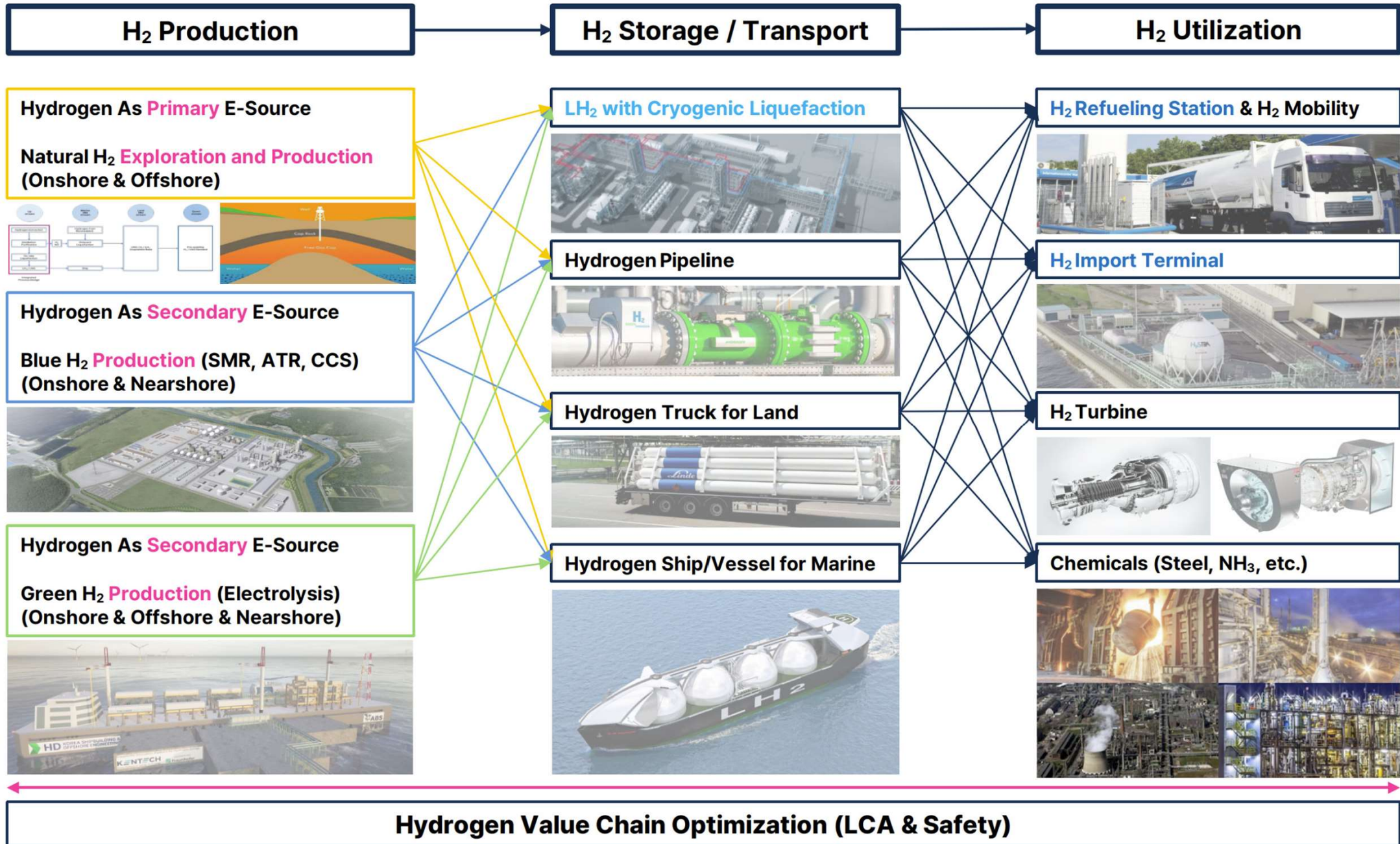


# 수소에너지 VC 소개 (수소 에너지 밸류체인 개발 프로젝트)

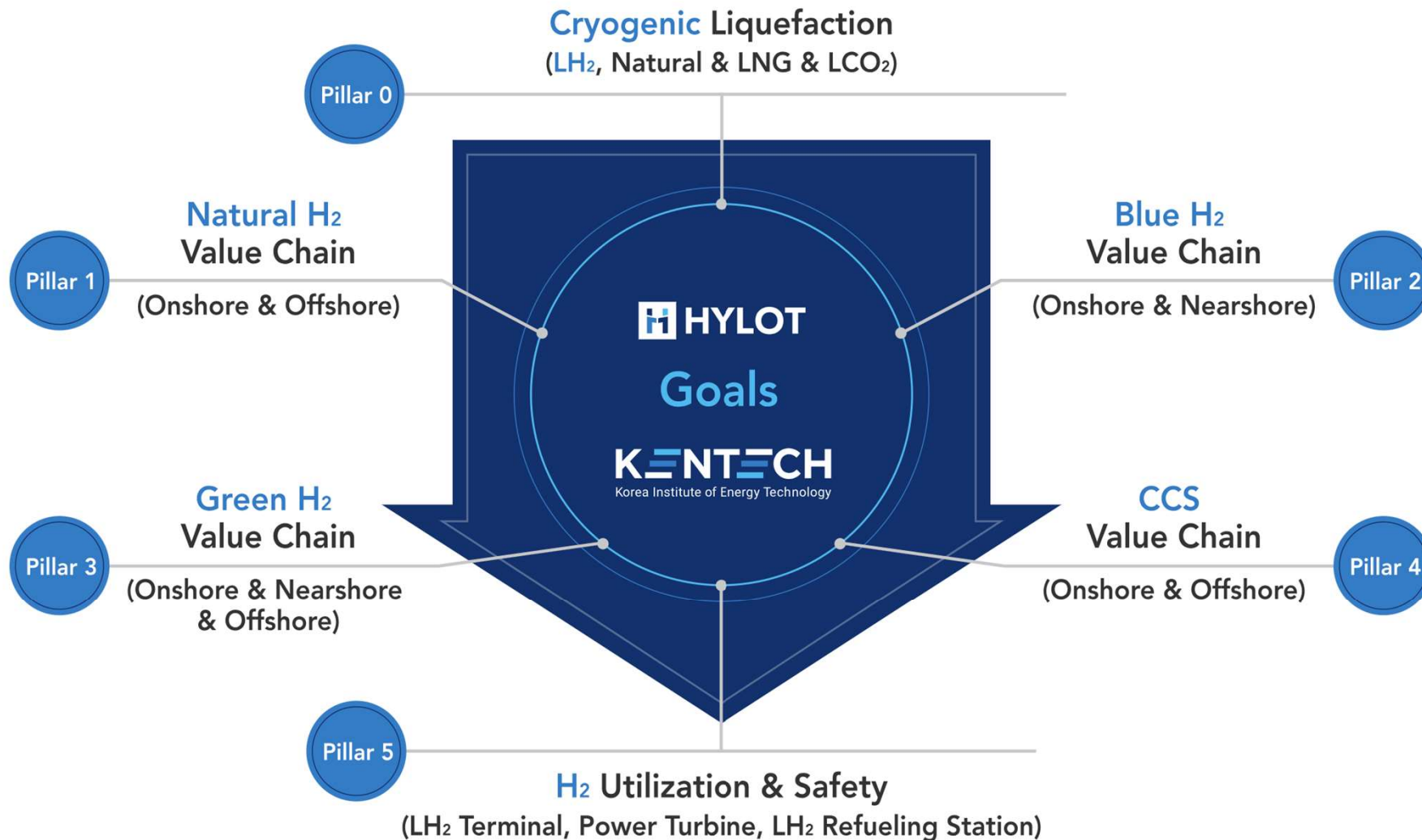
2024년 2월 22일 (목)

황지현 교수

# Hydrogen Energy Value Chain Technology



## World Leading R&D Lab for HYdrogen LIquefaction & Value Chain OPTimization Technologies(HYLOT)



Leading  
Professor

# Hydrogen Energy VC – Hydrogen Syllabus

## 1. 수업 계획표(Weekly Plan) ←

: “Hydrogen Value Chain Development” ←

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
강의 1	현장	프로젝트 1 (Concept)				PT1	강의 2 / 프로젝트 2 & 3 (White&Green)			현장	PT2	강의 3 / 프로젝트 4 (Blue)		PT3	
담당교수: 황지현 ←															

### 강의 1 – 수소 전주기 밸류 체인 기술 소개 (2주) ←

1주차-1	1주차-2	2주차-1	2주차-2
OT, 전주기 밸류체인	수소 생산 기술	수소 저장 & 운송 기술	수소 활용 기술

### 프로젝트 1 – 수소 밸류 체인 개념 개발 (4주) – 교수자 / 학생설계프로젝트 ←

생산: 천연수소, 그린 수소, 블루 수소, 청록 수소, 그레이 수소 => 비교 분석 후 팀별 선정 ←

공급(저장&운송): 수소 액화, 수소 합성, 고체화, 액상유기수소운반체 => 비교 분석 후 팀별 선정 ←

활용: 에너지 (연료전지, 수소터빈, 수소엔진 등), 석유화학, 제철 등 => 활용처 지정에 따른 선정 ←

최적조합: 수소 생산-공급-활용 전주기 밸류 체인 관점 기술 최적 조합 선정 (팀별 타당성 평가) ←

### 강의 2 – 천연 / 그린 수소 밸류 체인 프로젝트 소개 (2주) ←

1주차-1	1주차-2	2주차-1	2주차-2
OT, 천연 / 그린 수소 밸류체인	핵심 천연 / 그린 수소 기술 (I)	핵심 천연 / 그린 수소 기술 (II)	천연 / 그린 수소 밸류체인 프로젝트

### 프로젝트 2 & 3 – 천연/그린 수소 밸류 체인 프로젝트 개발 (3주) – 교수자 / 학생 설계프로젝트 ←

프로젝트 명: 세계 천연수소 개발 / 전남 신안 해상 풍력 연계 그린 수소 에너지 섬 개발 팀별 프로젝트 ←

### 강의 3 – 블루 수소 밸류 체인 프로젝트 소개 (2주) ←

1주차-1	1주차-2	2주차-1	2주차-2
OT, 블루 수소 밸류체인	핵심 블루 수소 기술 (I)	핵심 블루 수소 기술 (II)	블루 수소 밸류체인 프로젝트

### 프로젝트 4 – 블루 수소 밸류 체인 프로젝트 개발 (2주) – 교수자 / 학생 설계프로젝트 ←

프로젝트 명: 대한민국 블루 수소 인프라 개발 팀별 프로젝트 ←

## 2. 외부활동 계획표 ←

### 2-1. 외부강의 ←

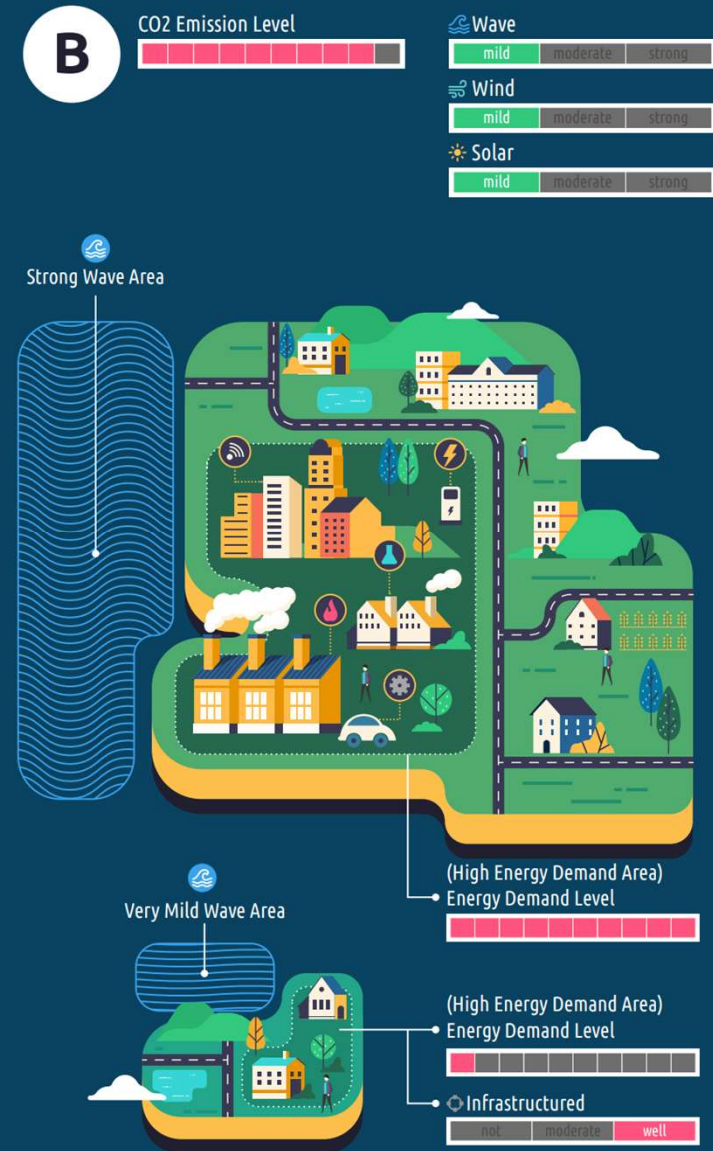
- 1) 독일 프라운호퍼 (Klemens 박사) – 수전해 기술 소개 (1시간, 영어) - 4주차 ←
- 2) 독일 Linde / 뮌헨공대 (Alexander 교수) – 수소액화 기술 소개 (1시간, 영어) - 5주차 ←
- 3) 독일 프라운호퍼 (Carsten 박사) – 수소연료전지 기술 소개 (1시간, 영어) - 6주차 ←
- 4) 독일 안할트 대학교 (Holz 교수) – 수소 밸류체인 소개 (1시간, 영어) - 7주차 ←
- 5) SK E&S (전경문 부사장) – 그린 / 블루 수소 및 액화수소 기술 소개 (1시간, 한글) - 4주차 ←
- 6) 두산 에너빌리티 (김재갑 상무) – 액화 수소 및 수소 터빈 기술 소개 (1시간, 한글) - 14주차 ←

### 2-2. 현장학습 ←

- 1) 두산 에너빌리티 – 창원 블루 수소 플랜트, 수소액화플랜트, 가스 터빈 생산 현장 견학 – 3주차 또는 4주차 ←
- 2) 한양 – (천연 수소 및 그린 수소 개발용) 광양 묘도 액화수소 도입터미널 현장 견학 – 12주차 ←

# Team Project 1 - Hydrogen Value Chain Concept Development

## KENTECH | HYDROGEN VALUE CHAIN



# Team Project 1 – Hydrogen Value Chain Concept Development (Production)

**1**

**PRODUCTION**

### Steam Methane Reforming (SMR)

Steam methane reforming (SMR) is the most commercially developed/universalized hydrogen production technology that reacts hydrocarbons (methane) with steam.

➤  $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$

**Features**

- High energy consumption (strong endothermic reaction)
- Energy efficiency can be improved through waste heat recovery facilities or the like.
- Hydrogen content in syngas (~ 70%)

KENTECH | VALUE CHAIN

**2**

**PRODUCTION**

### Partial Oxidation (POx)

Partial oxidation (POx) is mainly a method for producing hydrogen by partially oxidizing higher hydrocarbons.

➤  $\text{CH}_4 + \frac{1}{2} \text{O}_2 \rightarrow \text{CO} + 2\text{H}_2$

**Features**

- Low energy consumption (weak exothermic reaction)
- Difficult to control (fast reaction speed)
- Miniaturization, advancement
- Usually, no catalyst is needed.
- Hydrogen content in syngas (~ 60%)

KENTECH | VALUE CHAIN

**3**

**PRODUCTION**

### Autothermal Reforming (ATR)

Autothermal reforming (ATR) is a combination of SMR and POx.

➤  $\text{CH}_4 + \frac{1}{2} \text{H}_2\text{O} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO} + \frac{1}{2} \text{H}_2$

**Features**

- Easy to thermal management (balance of endothermic and exothermic)
- Limited commercial experience compared to other hydrogen production methods
- Hydrogen content in syngas (~ 65%)

KENTECH | VALUE CHAIN

**4**

**PRODUCTION**

### CO<sub>2</sub> Capture

CO<sub>2</sub> capture is a technology that uses absorbent, membrane gas separation or adsorption technology to separate CO<sub>2</sub> from sources such as steel and power plants using fossil fuels.

It is divided into post-combustion technology, pre-combustion technology, and oxy-fuel combustion technology.

KENTECH | VALUE CHAIN

**5**

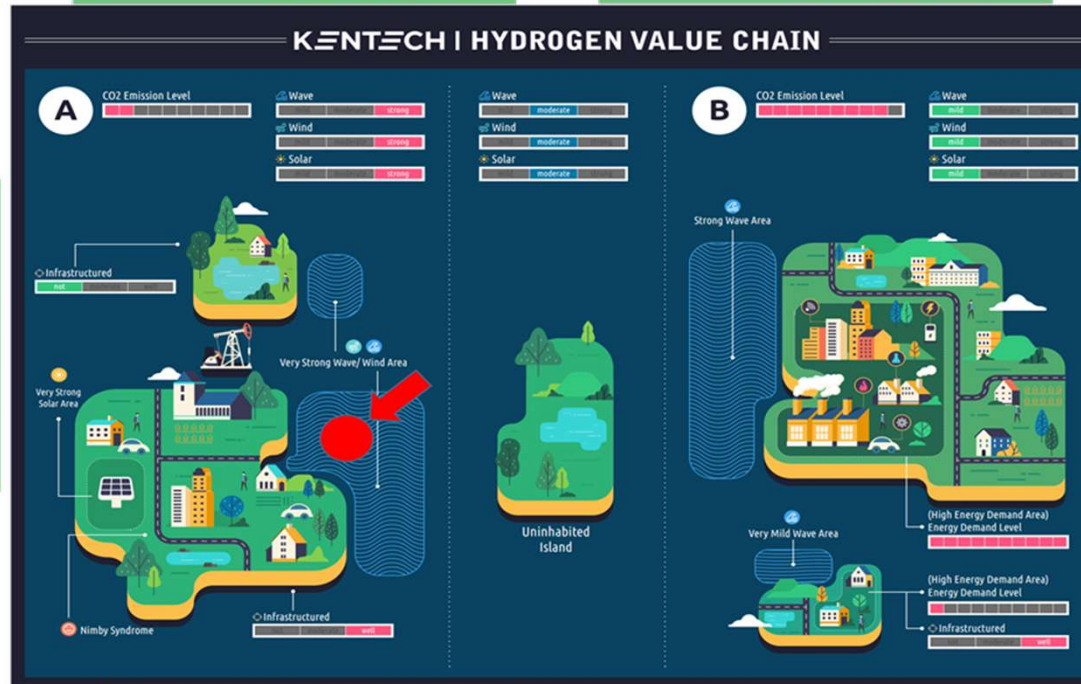
**PRODUCTION**

### CO<sub>2</sub> Transport

CO<sub>2</sub> transport is a technology for transporting CO<sub>2</sub> to place of demand or sequestration/storage using a ship/truck/pipeline.

Since most of these technologies are already widely used transportation methods, they are focused on demonstration rather than technology development. However, as the importance of CCUS increases, the development of LCO<sub>2</sub> carriers is also underway.

KENTECH | VALUE CHAIN



**6**

**PRODUCTION**

### CO<sub>2</sub> Utilization

CO<sub>2</sub> is widely used in manufacturing, welding, food, and beverages. The items are storage/conversion technologies using CO<sub>2</sub>:

- Enhanced coal bed methane recovery (ECBM)
- Mineral carbonation
- Biological algae cultivation
- Conversion into synthesized fuels
- Chemical feedstock and etc.

KENTECH | VALUE CHAIN

**7**

**PRODUCTION**

### Alkaline Electrolysis Cell (AEC)

The alkaline electrolysis cell (AEC) is a technology that uses an alkaline material as an electrolyte and produces hydrogen by transport anions (OH<sup>-</sup>) through a membrane.

➤ Anode:  $4\text{OH}^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^-$

➤ Cathode:  $4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{H}_2 + 4\text{OH}^-$

**Features**

- Operating temperatures (20 - 80 °C)
- Mature technology
- Low cost of facility investment
- Difficult to size down
- Difficult to absorbing fluctuations in renewable generation

KENTECH | VALUE CHAIN

**8**

**PRODUCTION**

### Proton Exchange Membrane Electrolysis Cell (PEMEC)

The proton exchange (or polymer electrolyte) membrane electrolysis cell (PEMEC) is a technology that produces hydrogen by transport cations (H<sup>+</sup>) through a membrane without an electrolyte.

➤ Anode:  $2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + \text{O}_2 + 4\text{e}^-$

➤ Cathode:  $4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2$

**Features**

- Operating temperatures (50 - 80 °C)
- High cost of facility investment (due catalyst as Pt)
- High productivity
- Easy to size down
- Easy to absorbing fluctuations in renewable generation

KENTECH | VALUE CHAIN

**9**

**PRODUCTION**

### Solid Oxide Electrolysis Cell (SOEC)

The solid oxide electrolysis cell (SOEC) is a technology that produces hydrogen by electrolyzing high-temperature steam using a non-corrosive solid oxide electrolyte.

➤ Anode:  $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$

➤ Cathode:  $2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 2\text{H}_2 + 2\text{O}^{2-}$

**Features**

- High operating temperature / pressure (600 - 900 °C)
- Efficiency can be maximized
- Low durability
- Slow start-up time
- Low technical maturity

KENTECH | VALUE CHAIN

**10**

**PRODUCTION**

### Anion Exchange Membrane Electrolysis Cell (AEMEC)

Like AEC, the anion exchange membrane electrolysis cell (AEMEC) is a technology that uses alkaline materials as electrolyte and transport anions (OH<sup>-</sup>) through a membrane.

➤ Anode:  $4\text{OH}^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^-$

➤ Cathode:  $4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{H}_2 + 4\text{OH}^-$

**Features**

- Operating temperatures (40 - 80 °C)
- Low cost of facility investment
- High productivity
- Easy to absorbing fluctuations in renewable generation
- Low technical maturity

KENTECH | VALUE CHAIN

White (Natural) Hydrogen Production ?

# Team Project 1 – Hydrogen Value Chain Concept

## Development (Storage & Transportation)

**11** TRANSPORT & STORAGE

### Hydrogen Liquefaction

Hydrogen can exist in liquid state in extremely low temperature of 20K(-253 °C). Liquid hydrogen is considered promising in terms of both gravimetric and volumetric hydrogen densities, high hydrogen purity. It requires cryogenic tanks to store. The storage tanks are reinforced and insulated in order to preserve temperature levels.

Refrigeration to low temperature is leading to high energy consumption.

Liquid hydrogen is not preferred for long term storage or long distance of transportation, because the energy input needed to keep the temperature very low is intensive.

KENTECH | VALUE CHAIN

**12** TRANSPORT & STORAGE

### Hydrogen Compression

Hydrogen can be compressed into high-pressure tanks in a gas form. Compression is the conventional and easiest way to store hydrogen.

The space occupied by the compressed gas is large.

To achieve a high pressure, advanced materials for vessels are required. Compression vessels should be regularly tested to ensure no leaks are taking place. Compressed hydrogen can directly contribute to the commercialization of hydrogen energy in the short term. But it has a relatively low storage capacity. Innovative technology development is required to be applied to large-capacity storage and transportation.

KENTECH | VALUE CHAIN

**13** TRANSPORT & STORAGE

### Materials-based Storage (Methanol)

Methanol has physical characteristics of being liquid at ambient temperature and pressure. It is easy to store and transport with existing infrastructure.

As methanol involves CO<sub>2</sub> in its synthesis, leading to environmental problems in the utilization site because of the release of CO<sub>2</sub> when methanol is directly utilized or decomposed.

Methanol reformulation also leaves the problem of the production of carbon monoxide (CO).

KENTECH | VALUE CHAIN

**14** TRANSPORT & STORAGE

### Materials-based Storage (Ammonia)

Ammonia can be directly utilized by extracting its stored hydrogen or directly utilized as fuel. It has high hydrogen density in gravimetric and volumetric, wide possibility for utilization, and good storability. The infrastructures of ammonia have been globally established.

For long-term, ammonia can fulfill the demand to store the energy in time and in space. Releasing the hydrogen from ammonia, a relatively huge amount of energy is consumed.

Ammonia has relatively higher apparent toxicity. It is potential to generate NO<sub>x</sub> during its combustion at high temperatures.

KENTECH | VALUE CHAIN

**15** TRANSPORT & STORAGE

### Hydrogen Hydride

Hydrides for hydrogen storage is a technology that stores hydrogen on the surface or inside of a material. They can reversibly adsorb and release hydrogen. At slightly higher pressure and ambient temperature, high hydrogen density can be achieved.

It is still low in terms of price and stability. Hydrides for hydrogen storage include metal, complex, chemical, and interstitial metal hydrides.

KENTECH | VALUE CHAIN

### KENTECH | HYDROGEN VALUE CHAIN

**18** TRANSPORT & STORAGE

### Rail

Suitable for mid to long distance transportation.

It is excellent in terms of stability and environment.

The loading weight is large.

Need of linked transportation due to lack of completeness (door to door).

It is not affected by the climate.

It runs at a fixed time, so it's very accurate.

KENTECH | VALUE CHAIN

**16** TRANSPORT & STORAGE

### Liquid Organic Hydrogen Carrier (LOHC)

LOHC is a liquid that store and release hydrogen reversibly through hydrogenation and dehydrogenation processes.

LOHCs are essentially liquid under ambient conditions with no high pressure or cryogenic temperature. Hydrogen density is high in gravimetric and volumetric.

Their handling, storage, and transportation are highly convenient. Using the existing infrastructure, a large amount of hydrogen can be economically stored and transported.

LOHCs require the large amount of energy during dehydrogenation.

KENTECH | VALUE CHAIN

**19** TRANSPORT & STORAGE

### Truck

Suitable for short to medium distance transportation.

It is highly affected by environmental pollution due to high emissions.

Compared to other transportation, the loading weight is relatively small.

Door to door transportation is possible.

It is flexible because it operates when necessary.

Cargo safety is not high due to factor such as traffic accident.

KENTECH | VALUE CHAIN

**17** TRANSPORT & STORAGE

### Ship

Suitable for long-distance transportation of bulk cargo.

Exhaust emissions are low compared to the volume of transportation. But, the resulting environmental pollution is high.

There is almost no limit on the volume and weight of the cargo.

It needs to be linked to land transportation. The accuracy is not high because the operation is affected by the sea.

KENTECH | VALUE CHAIN

**20** TRANSPORT & STORAGE

### Pipeline

Suitable for long distance transportation.

It is an eco-friendly means of transportation.

(Continuous mass transportation is possible).

The products used are limited (mainly used for energy resources).

Limited to a specific location.

Initial facility costs a lot.

KENTECH | VALUE CHAIN

**29** ESS

### Compressed Air Energy Storage (CAES)

The CAES is the energy storage system (ESS) that can store the excess electricity in the compressed air. It is consisted of 3 steps.

- 1 The compressor that increases pressure of ambient air
- 2 The storage that keeps the compressed air at constant pressure, and stores heat for operating the steam turbine later.
- 3 The gas turbine generates electricity by expanding compressed air.

Features

- ▶ Able to save surplus energy by the variable power generation of renewable energy
- ▶ Zero emission of CO<sub>2</sub>
- ▶ Suitable with region that geological salt structures

KENTECH | ENERGYVERSE

**30** ESS

### Liquid Air Energy Storage (LAES)

The LAES is ESS where electricity is stored in the form of liquid air at cryogenic temperatures.

- 1 Charging: Ambient air is first purified, compressed using excess electricity and finally cooled down to liquid phase. Liquid air is stored in near-atmospheric pressure vessels.
- 2 Storage:
- 3 Discharging: Electricity is retrieved by pumping, evaporation and expansion of the liquid air through turbines.

Features

- ▶ High energy density and ease of deployment
- ▶ Locatable anywhere and provide large-scale
- ▶ Vacuum or perlite insulation is effective in limiting boiloff.

KENTECH | VALUE CHAIN

# Team Project 1 – Hydrogen Value Chain Concept Development (Utilization)

**21**

**UTILIZATION**

### Proton Exchange Membrane Fuel Cell (PEMFC)

The proton exchange (or polymer electrolyte) fuel cell (PEMFC) produces the power by the acidic electrochemical reaction. It is built out of membrane electrode assemblies (MEA) which include the electrodes, electrolyte, catalyst, and gas diffusion layers.

▶ Anode:  $H_2 \rightarrow 2H^+ + 2e^-$   
▶ Cathode:  $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

**Features**

- ▶ Low operating temperature/ pressure (50-100°C)
- ▶ Easy to size down
- ▶ Use catalyst as Pt
- ▶ Max. qualified power : 500 kW

KENTECH | VALUE CHAIN

**22**

**UTILIZATION**

### Alkaline Fuel Cell (AFC)

The alkaline fuel cell (AFC) produces the power by the alkaline electrochemical reaction. The two electrodes are separated by a porous matrix saturated with an aqueous alkaline solution, such as potassium hydroxide (KOH).

▶ Anode:  $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$   
▶ Cathode:  $\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^-$

**Features**

- ▶ Operating temperatures (25 - 50°C)
- ▶ Use catalyst as silver/iron phthalocyanines
- ▶ Poison effect by CO (It need pure H<sub>2</sub> & O<sub>2</sub>)
- ▶ Need pure oxygen

KENTECH | VALUE CHAIN

**23**

**UTILIZATION**

### Solid Oxide Fuel Cell (SOFC)

The solid oxide fuel cell (SOFC) produces the power by directly oxidizing a fuel. Solid oxide fuel cells are a class of fuel cells characterized by the use of a solid oxide material as the electrolyte.

▶ Anode:  $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$   
▶ Cathode:  $O_2 + 4e^- \rightarrow 2O^{2-}$

**Features**

- ▶ High operating temperature / pressure (500 - 1000°C)
- ▶ Use catalyst as ceramic material
- ▶ Max. qualified power : 100 MW
- ▶ Slow start-up time

KENTECH | VALUE CHAIN

**24**

**UTILIZATION**

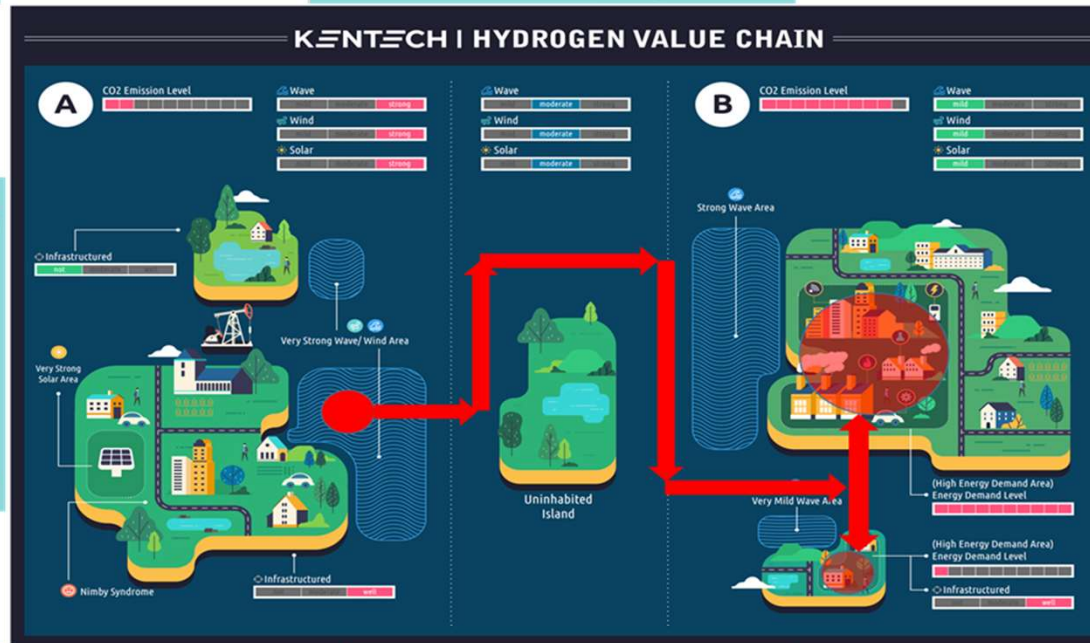
### Hydrogen Gas Turbine

The hydrogen gas turbine generates the power by the combustion of hydrogen gas. The system does not emit CO<sub>2</sub> if the feed is the pure O<sub>2</sub>. By the reaction with H<sub>2</sub> & O<sub>2</sub>, the H<sub>2</sub>O are formed then existing in steam. And it would be the power source of the turbine to move.

**Features**

- ▶ Probability of flashback
- ▶ For stable combustion, it need efficient mixing of hydrogen and air.
- ▶ NOx emission increase because of the higher flame temperature of hydrogen combustion.

KENTECH | VALUE CHAIN



**25**

**UTILIZATION**

### Hydrogen & LNG Mixed Fuel Turbine

The mixed hydrogen & LNG turbine generates the power by the combustion of mixed hydrogen & LNG gas. The system emits CO<sub>2</sub> by the mix ratio. By the reaction with H<sub>2</sub> & O<sub>2</sub>, the H<sub>2</sub>O are formed then existing in steam. And it would be the power source of the turbine to move.

**Features**

- ▶ Low CO<sub>2</sub> emission than conventional LNG turbine
- ▶ It can not achieve zero emission of CO<sub>2</sub>.

KENTECH | VALUE CHAIN

**26**

**UTILIZATION**

### Hydrogen Engine

The hydrogen internal combustion engine (H2ICE) is the engine that use hydrogen fuel instead of gasoline/diesel. It works the exact the same way as a petrol based ICE.

**Features**

- ▶ It can achieve zero emission of CO<sub>2</sub>.
- ▶ Hydrogen fuel does not need to be as pure as a fuel cell.
- ▶ NOx emission exists.
- ▶ Low volumetric energy density than the petrol.

KENTECH | VALUE CHAIN

**27**

**UTILIZATION**

### Chemical Fuel

Hydrogen used as chemical reactant. By the catalyst, the covalent bond can be broken. Then, each hydrogen atom can react with various compound to make commercial chemicals.

**Features**

- ▶ React with organic/inorganic material
- ▶ Used to synthesize various functional group

KENTECH | VALUE CHAIN

**28**

**UTILIZATION**

### Hydrogen Ironmaking

Hydrogen is used for ironmaking. It is endothermic reaction that requires heat for the reduction of iron. The process is separated by the reduction reaction and melting.

**Features**

- ▶ It can achieve zero emission of CO<sub>2</sub>.
- ▶ A lot of heat is needed for the reaction relative to conventional furnace.

KENTECH | VALUE CHAIN



# Team Project 1 – VC Promotion Video on Youtube & Feedbacks



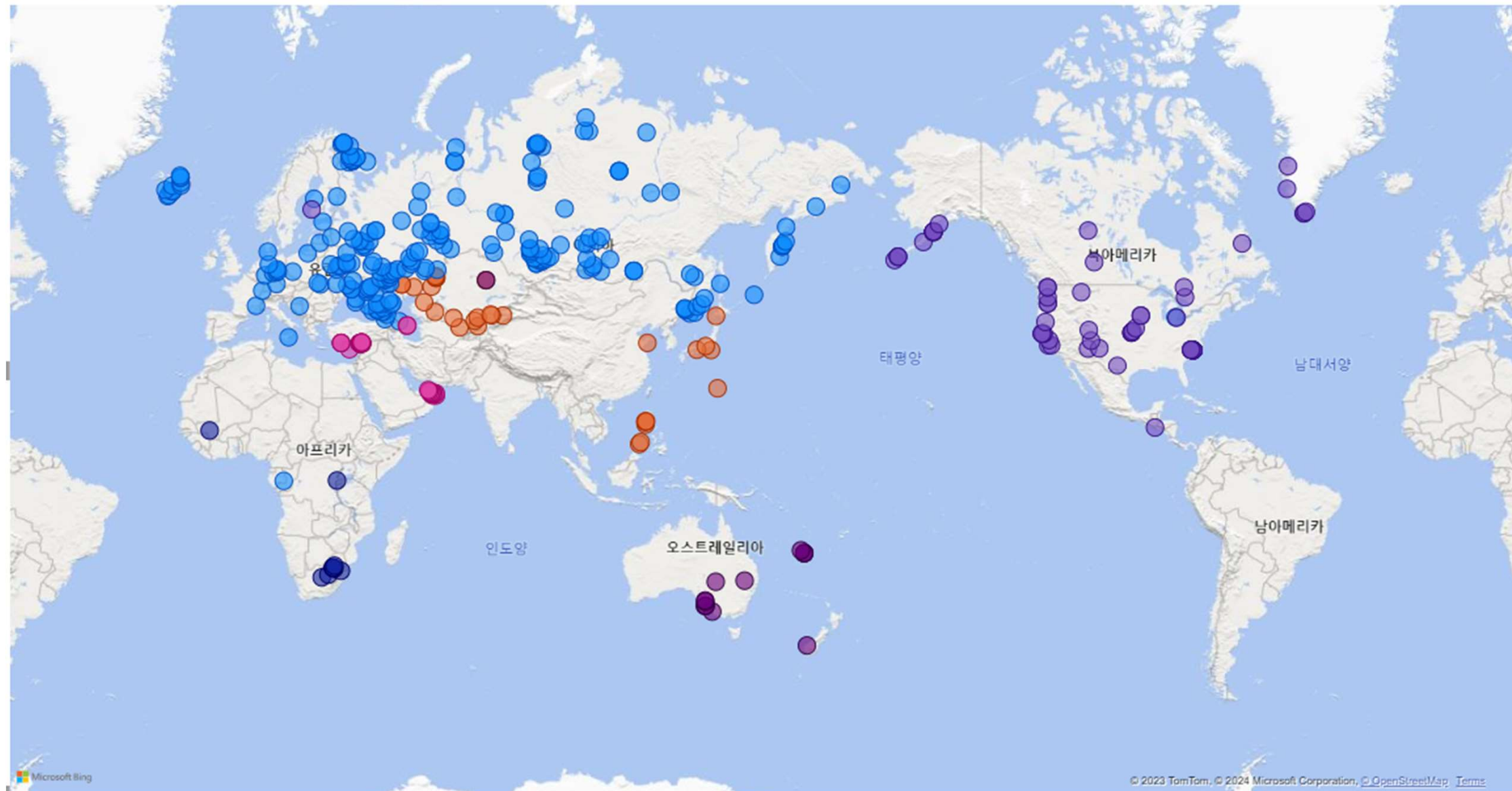
KENTECH Visionary Course (Hydrogen Energy)



# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)

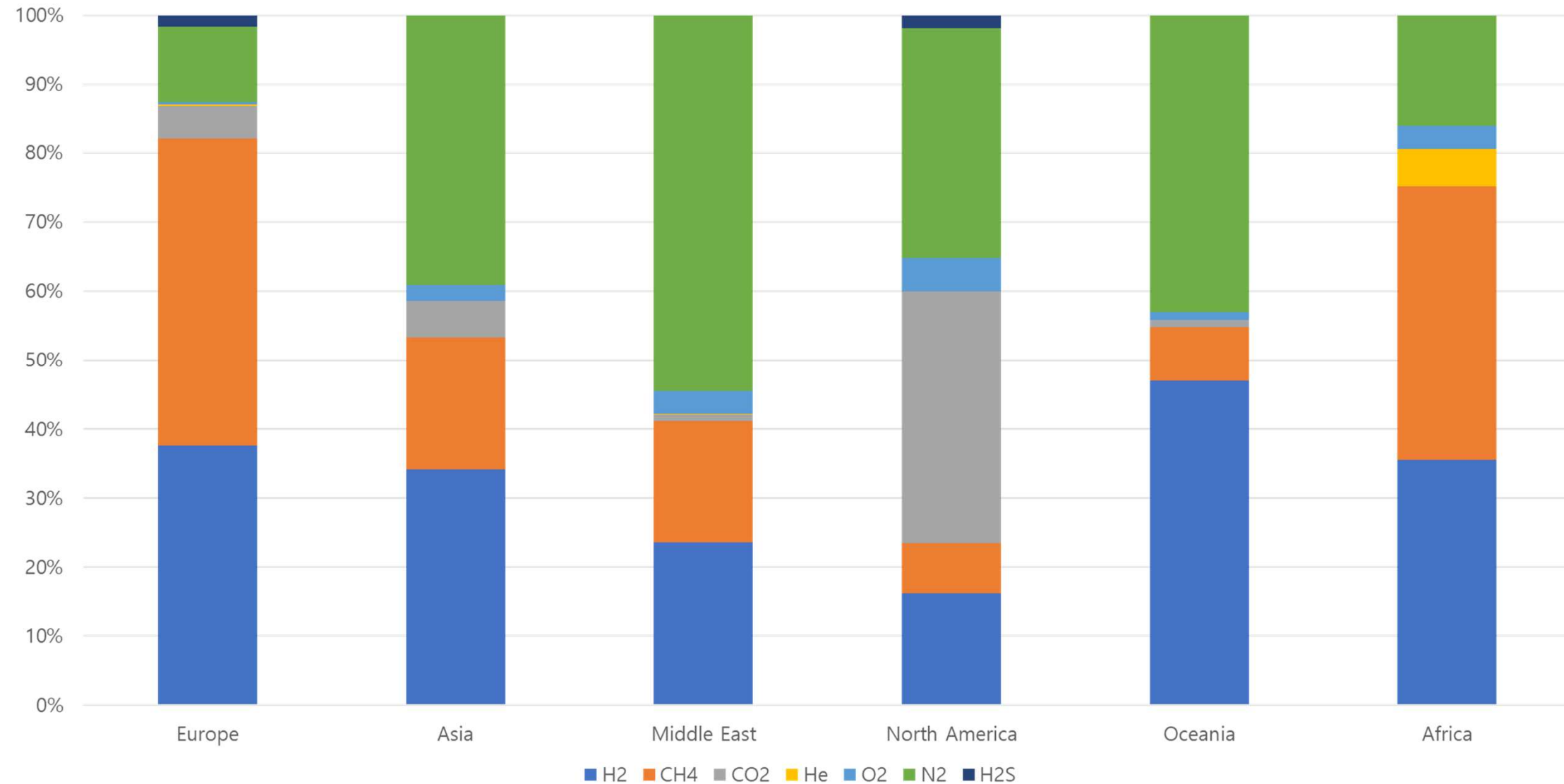
Region, Lat(위도) 및 Long(경도)

Region ● (공백) ● Africa ● Asia ● Europe ● Middle East ● North America ● Oceania



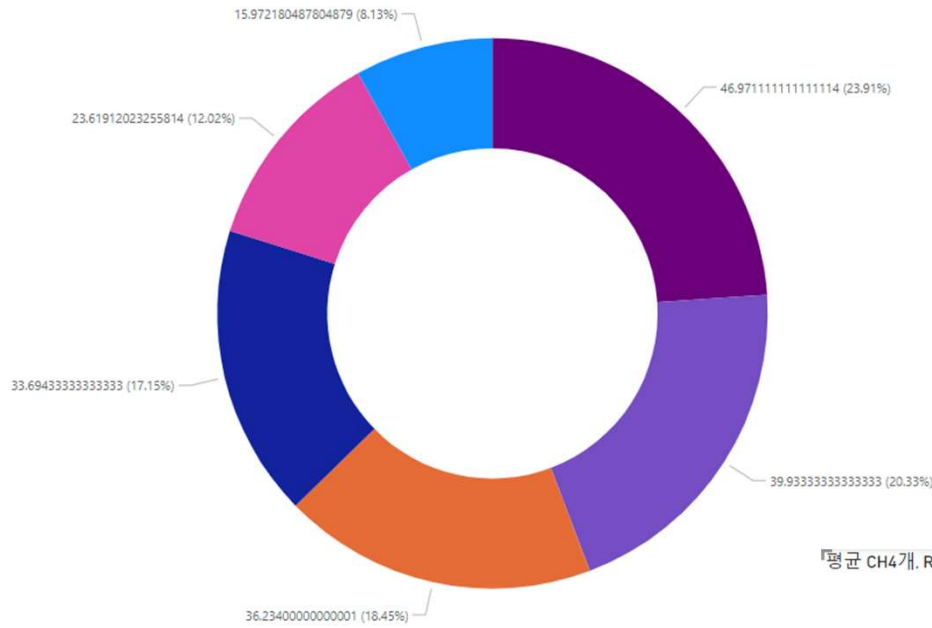
# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)

World Natural Hydrogen Well

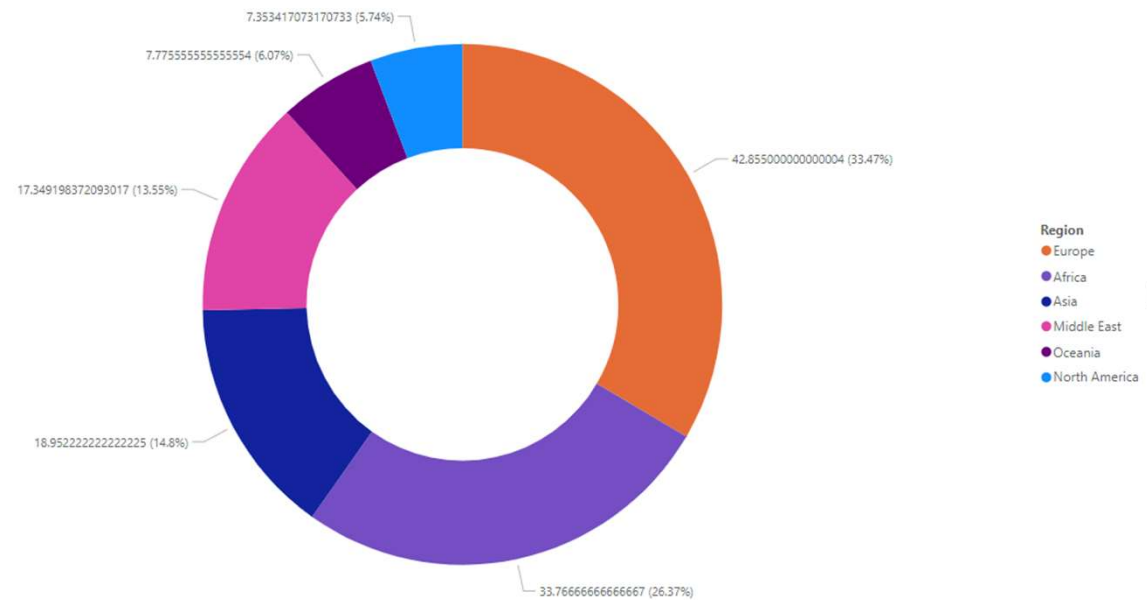


# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)

평균 H2개. Region

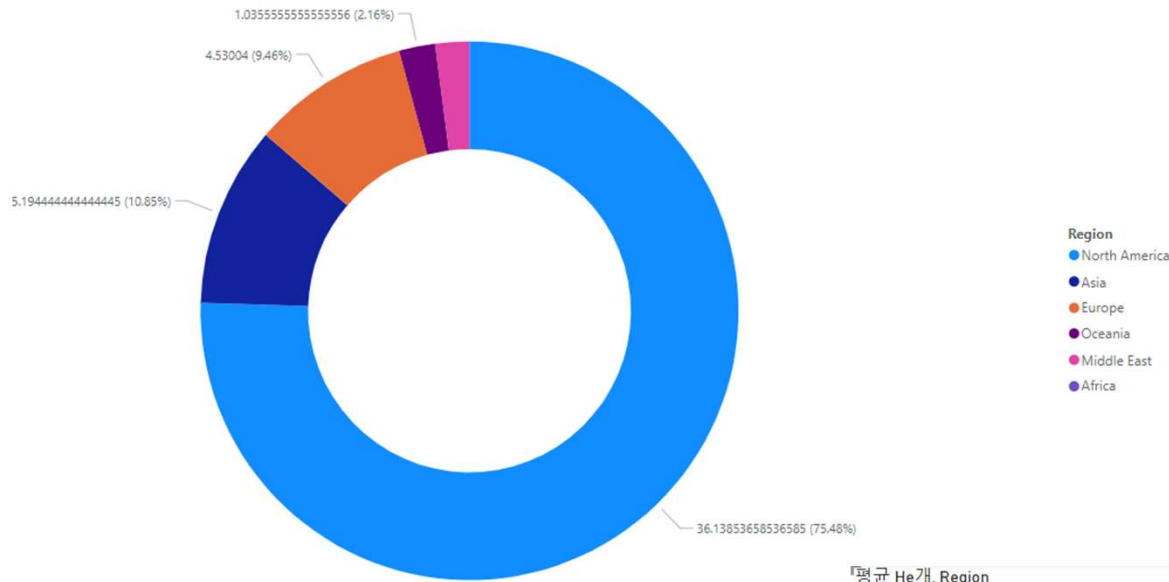


평균 CH4개. Region

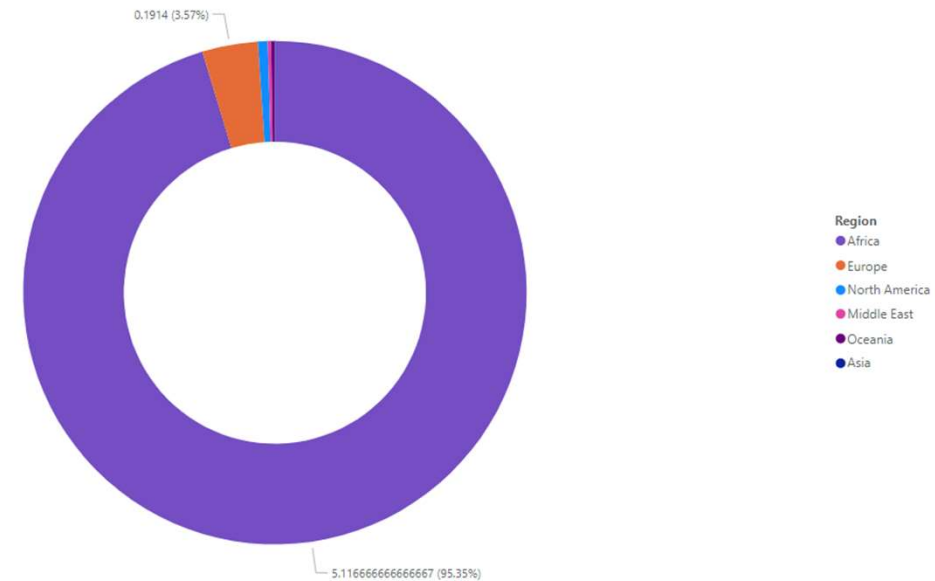


# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)

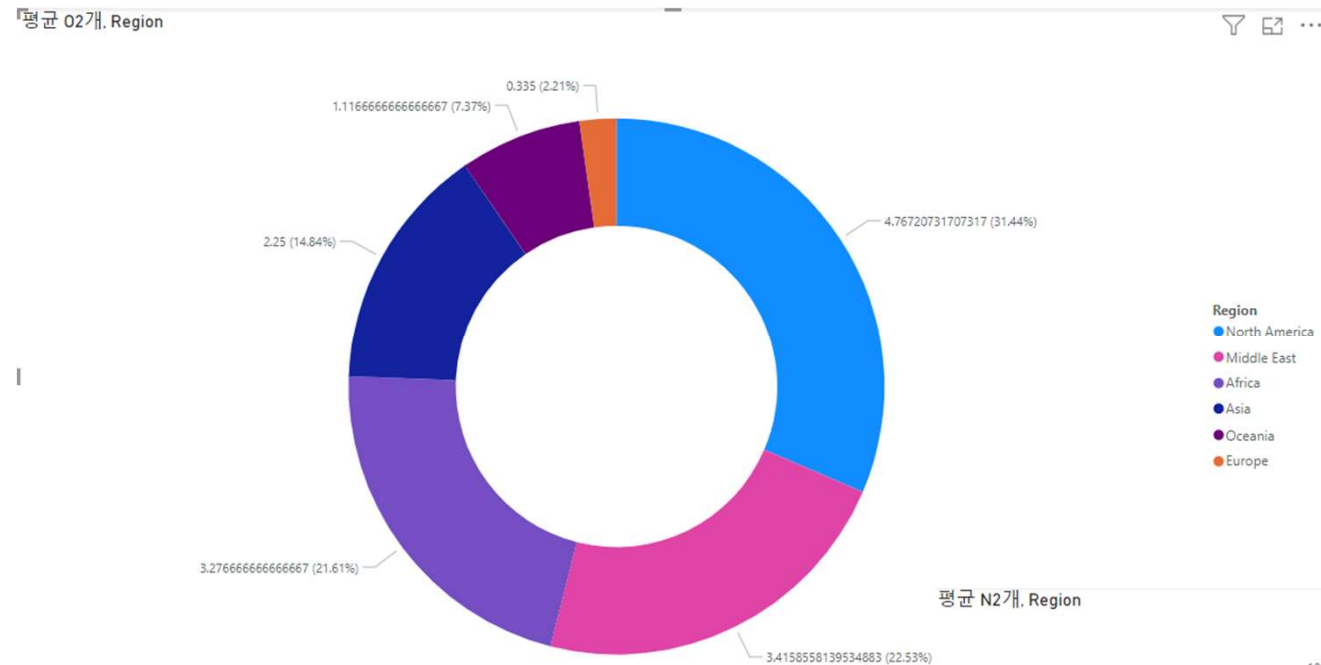
평균 CO2개, Region



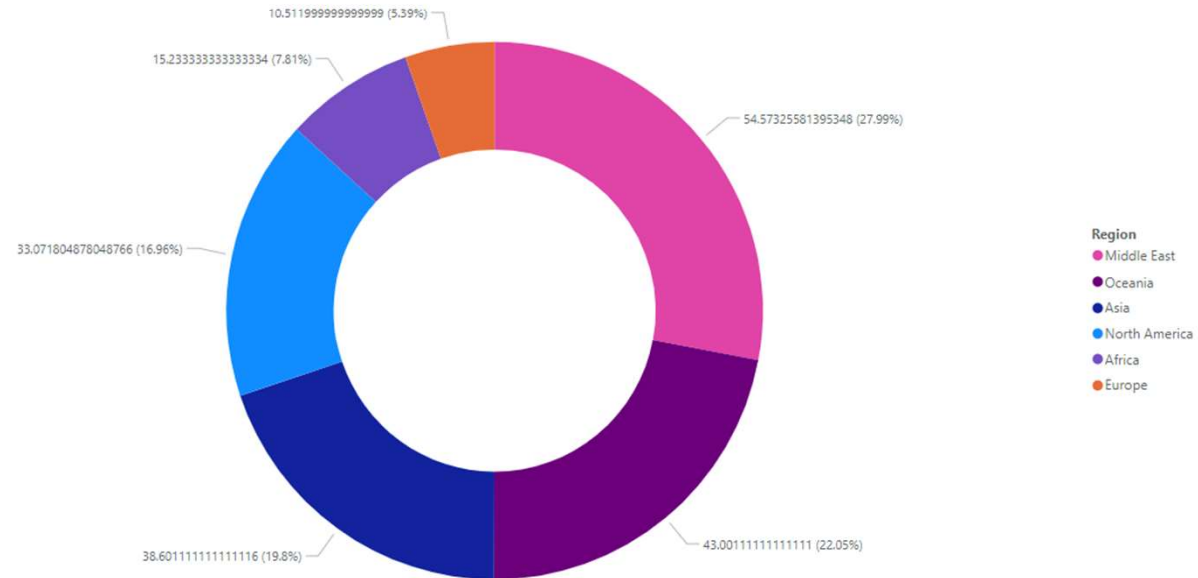
평균 He개, Region



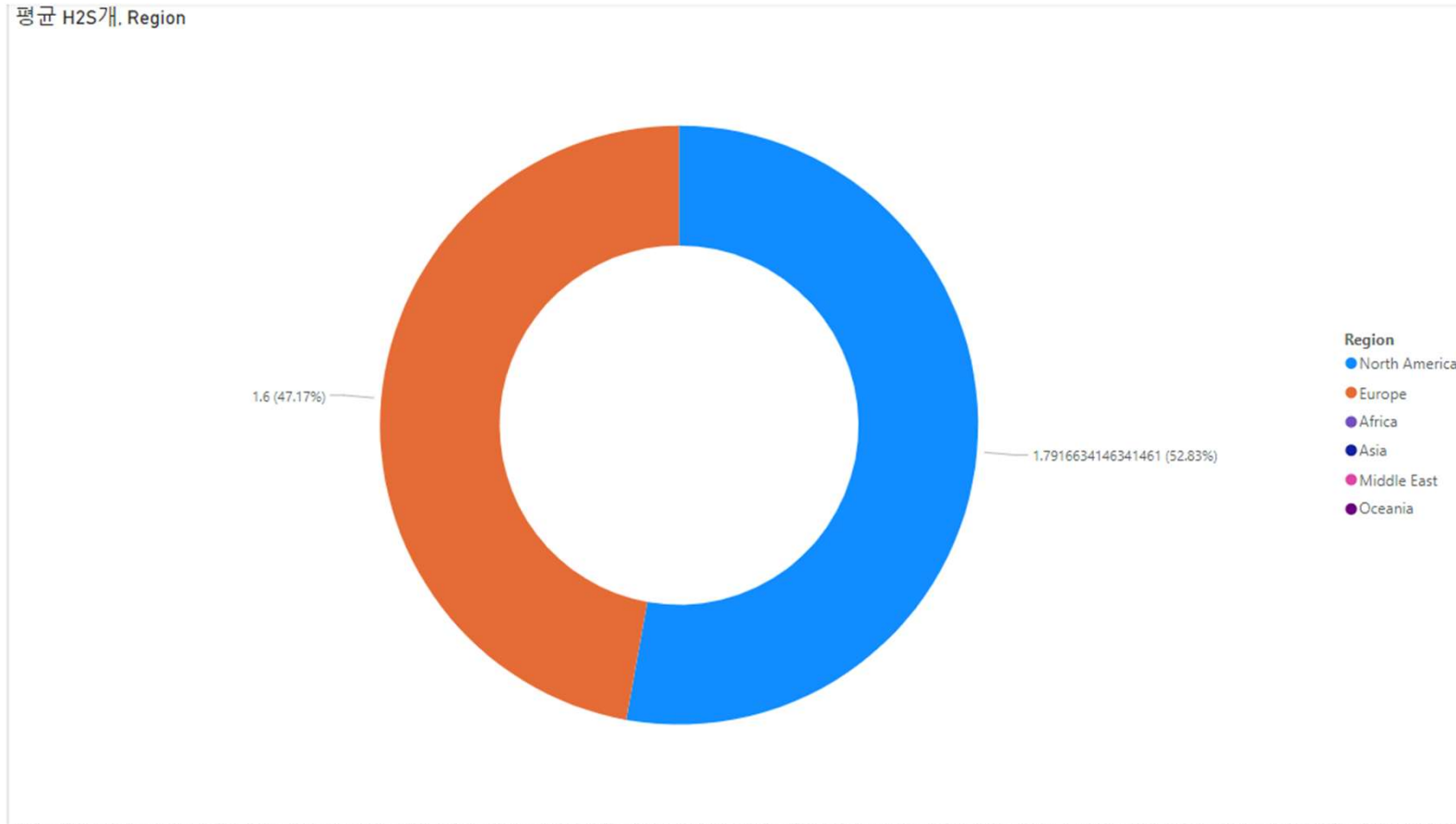
# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)



평균 N2개, Region



# Team Project 2 – White (Natural) Hydrogen Value Chain Development (World Natural Hydrogen Project Development)



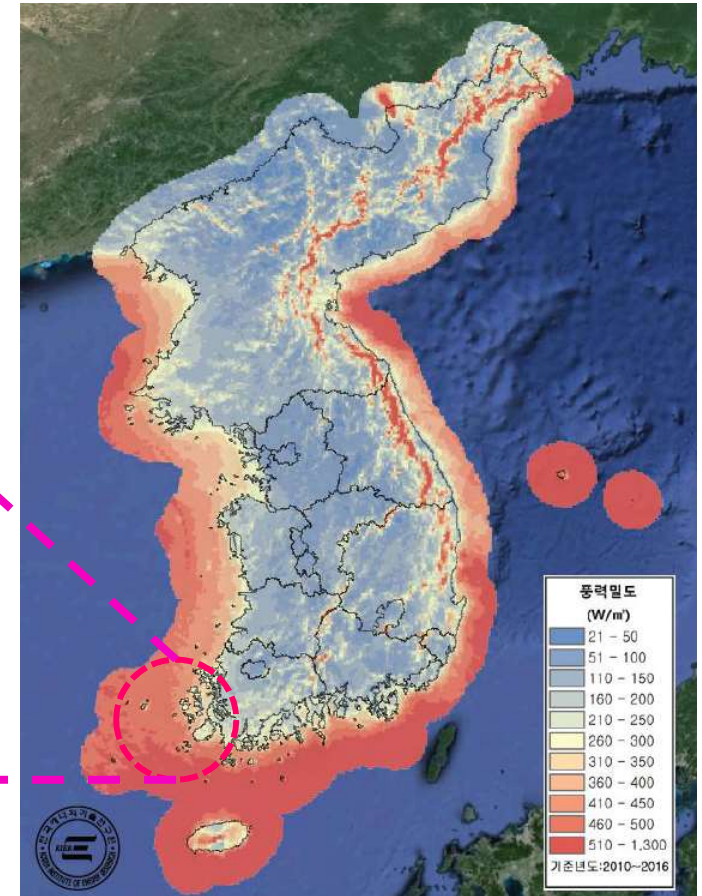
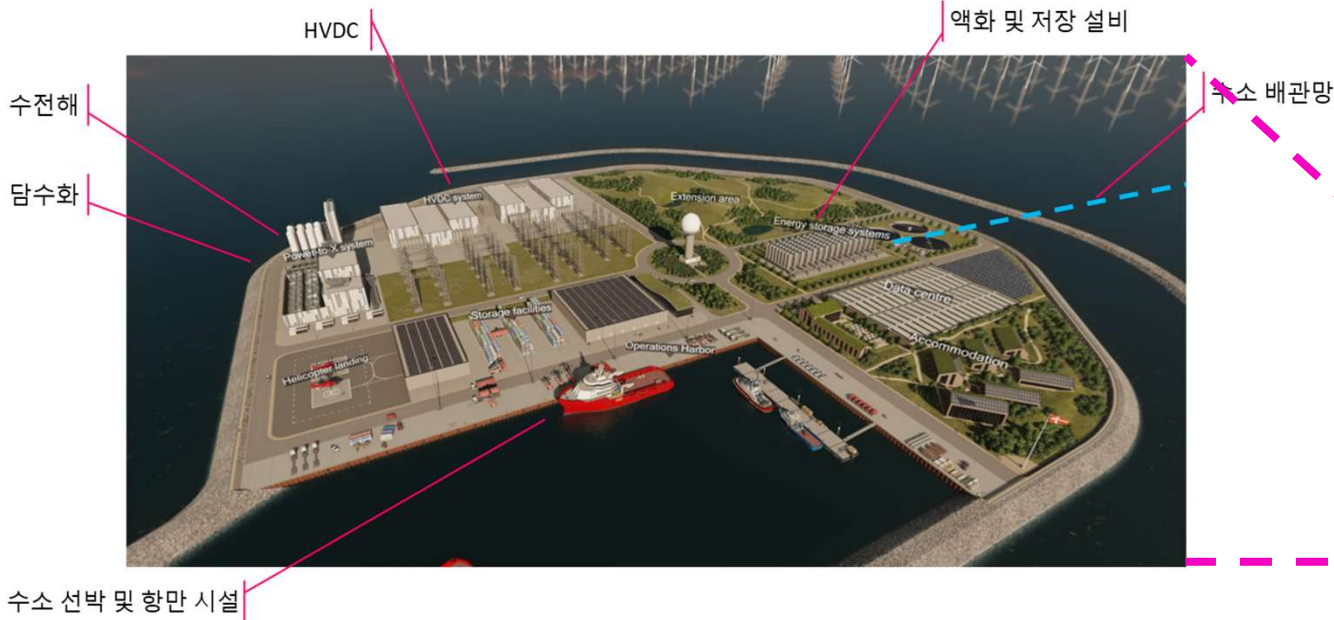
# Team Project 3 – Green Hydrogen Value Chain Development (Green Hydrogen Energy Island Development)





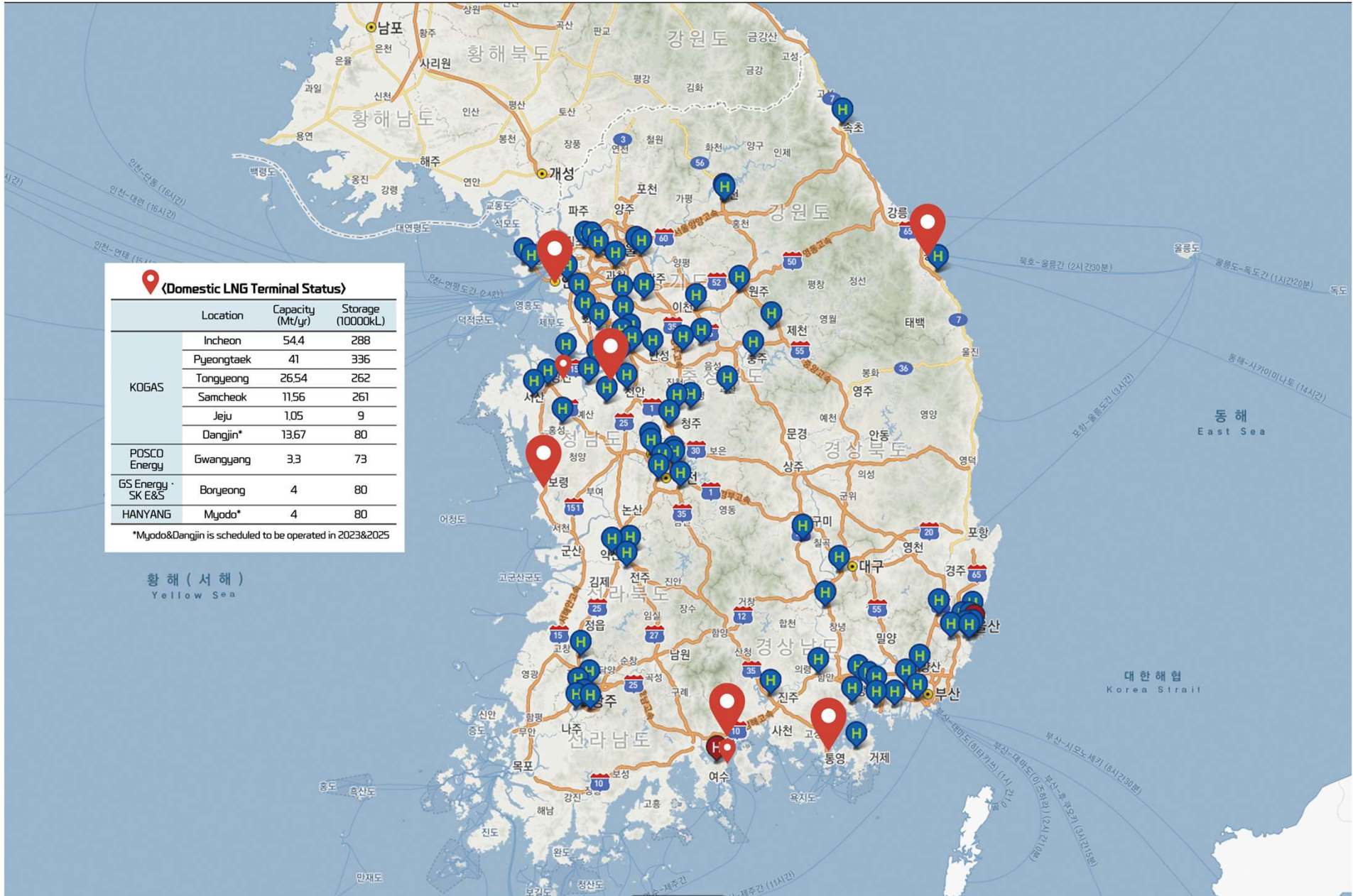
# Team Project 3 – Green Hydrogen Value Chain

## Development (Green Hydrogen Energy Island Development)



# Team Project 4 – Blue Hydrogen Value Chain

## Development (Blue Hydrogen Development in South Korea)



# Team Project 4 – Blue Hydrogen Value Chain

## Development (Blue Hydrogen Development in South Korea)

