

Welcome!

The program will begin soon.
You will not hear audio until we begin.

A cool way to store carbon dioxide via clathrate hydrates

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Professor

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About the Speaker

➤ Qualifications

- BTech (2000), University of Madras, India
- MTech (2002), IIT – Kharagpur, India
- PhD (2009), University of British Columbia (UBC), Canada
- PE (2018), PEB Singapore

➤ Research Interests

- Gas hydrates (fundamental and applied)
- Environmental Sustainability (CO₂ capture and storage, desalination)
- Clean energy (gas storage, energy recovery, data-center cooling)
- Contribute to SDG-6, SDG-7, SDG-13

➤ Research Impact

- Publications: 165⁺; H-index: 66; Citations: 16000⁺
- Co-founder of NewGen Gas Pte Ltd

➤ Professional Leadership

- Executive Editor, *Energy & Fuels* (ACS Publications)
- Editorial Advisory Board Member for *Applied Energy*, *Advances in Applied Energy*, *Current Opinion in Chemical Engineering*, and *Fluid Phase Equilibria*



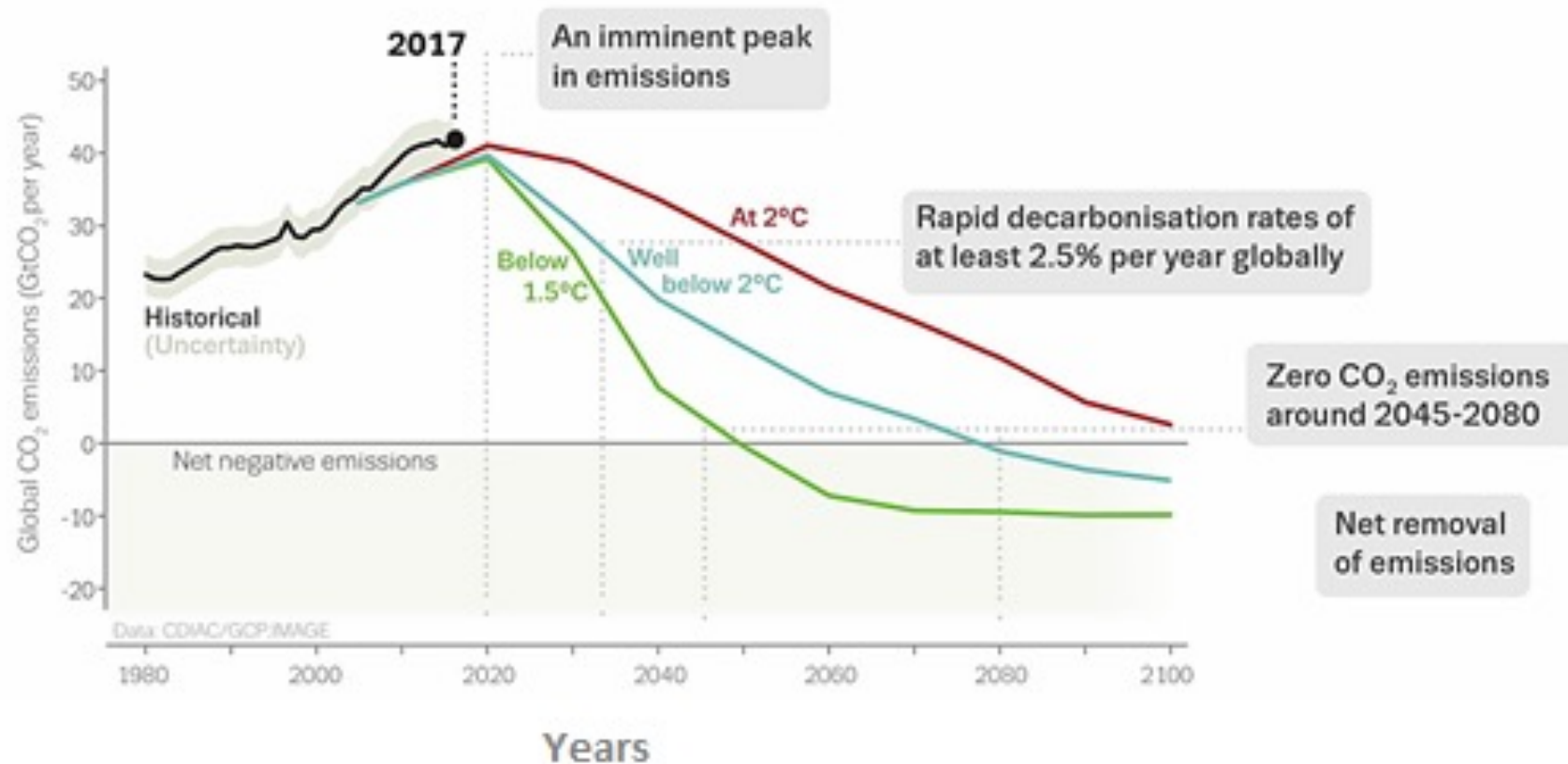
My academic tree



CO₂: The Major Contributor to Climate Change



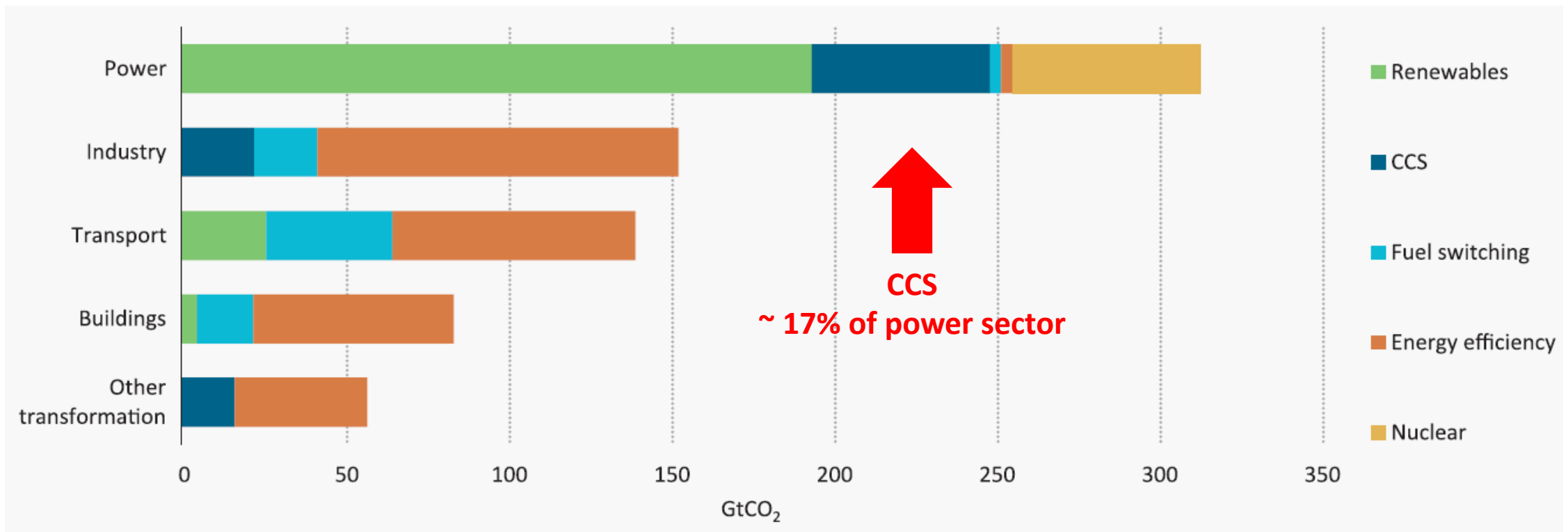
- CO₂ emission is the major contributor to climate change
- According to IEA (International Energy Agency), nearly 40 GtCO₂ was emitted annually
- The Paris Agreement aims to keep global temperature rise well below 2 °C above pre-industrial levels



Role of CCS in Global Warming Mitigation

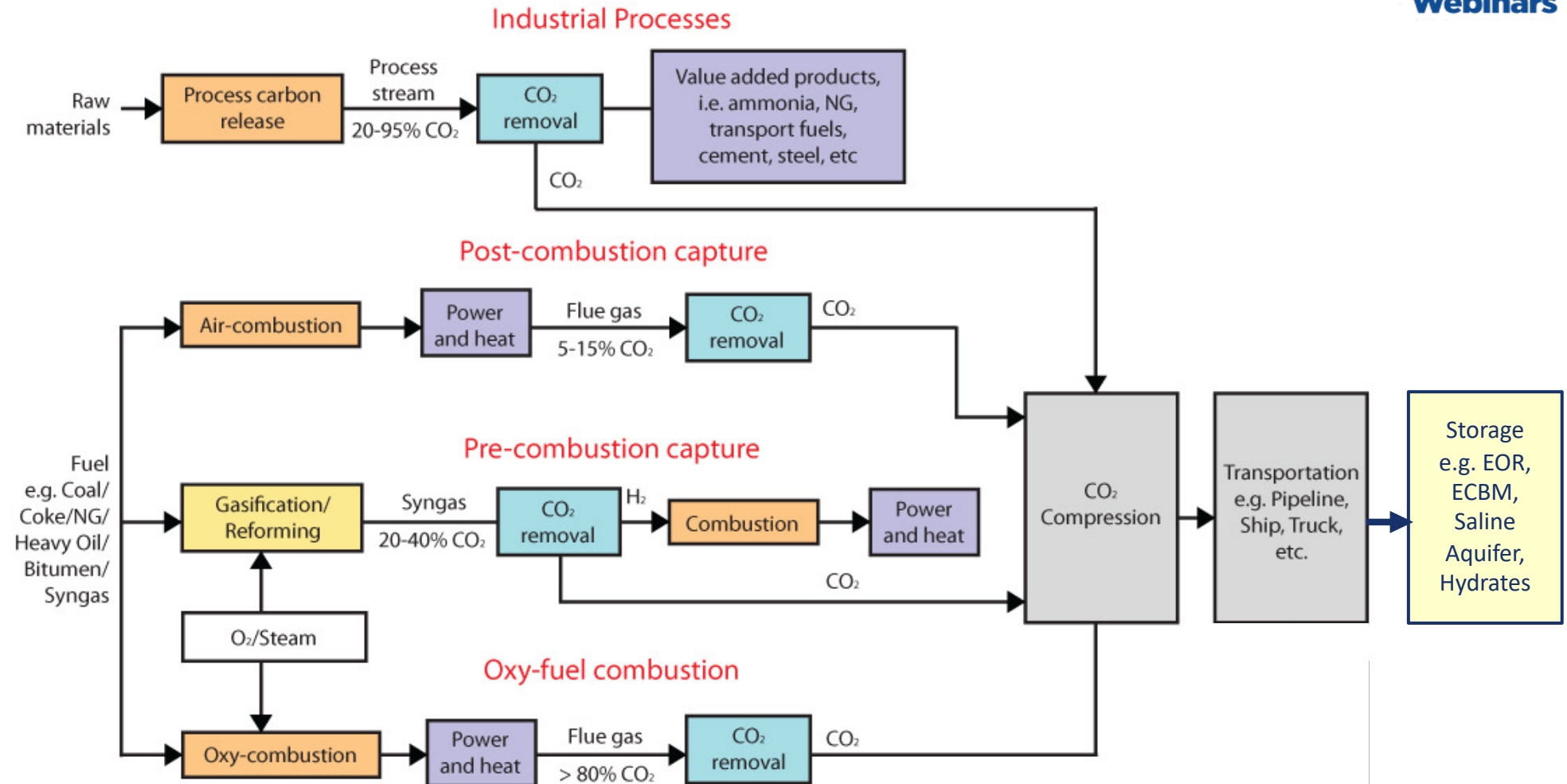


- IEA: more than 700 GtCO₂ to be reduced by 2050 to meet the 2°C Scenario
- **Carbon Capture and Sequestration (CCS)** is vital and becomes extremely important
- Power sector will be the major segment



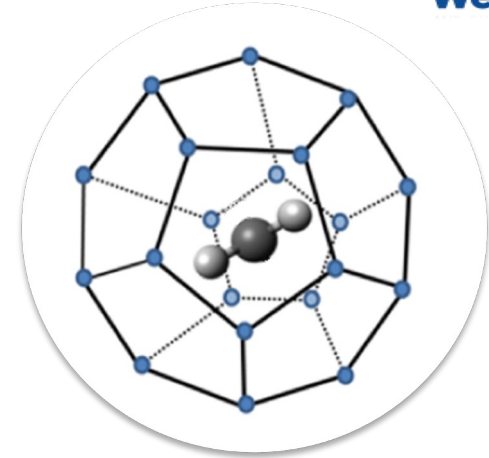
Cumulative CO₂ reductions in the 2°C Scenario by 2050

Various Pathways to Capture CO₂

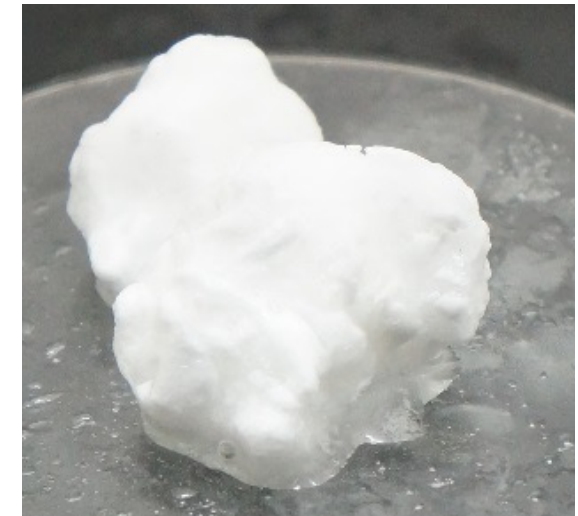


Introduction to Gas Hydrates

- Guest molecules surrounded by cages formed by water molecules
- Looks like ice, also known as combustible ice, flammable ice
- Requires relative high pressure and low temperature
- Different guest molecules (CO_2 , N_2 , H_2 , CH_4 ...) form gas hydrates at different pressure and temperature conditions

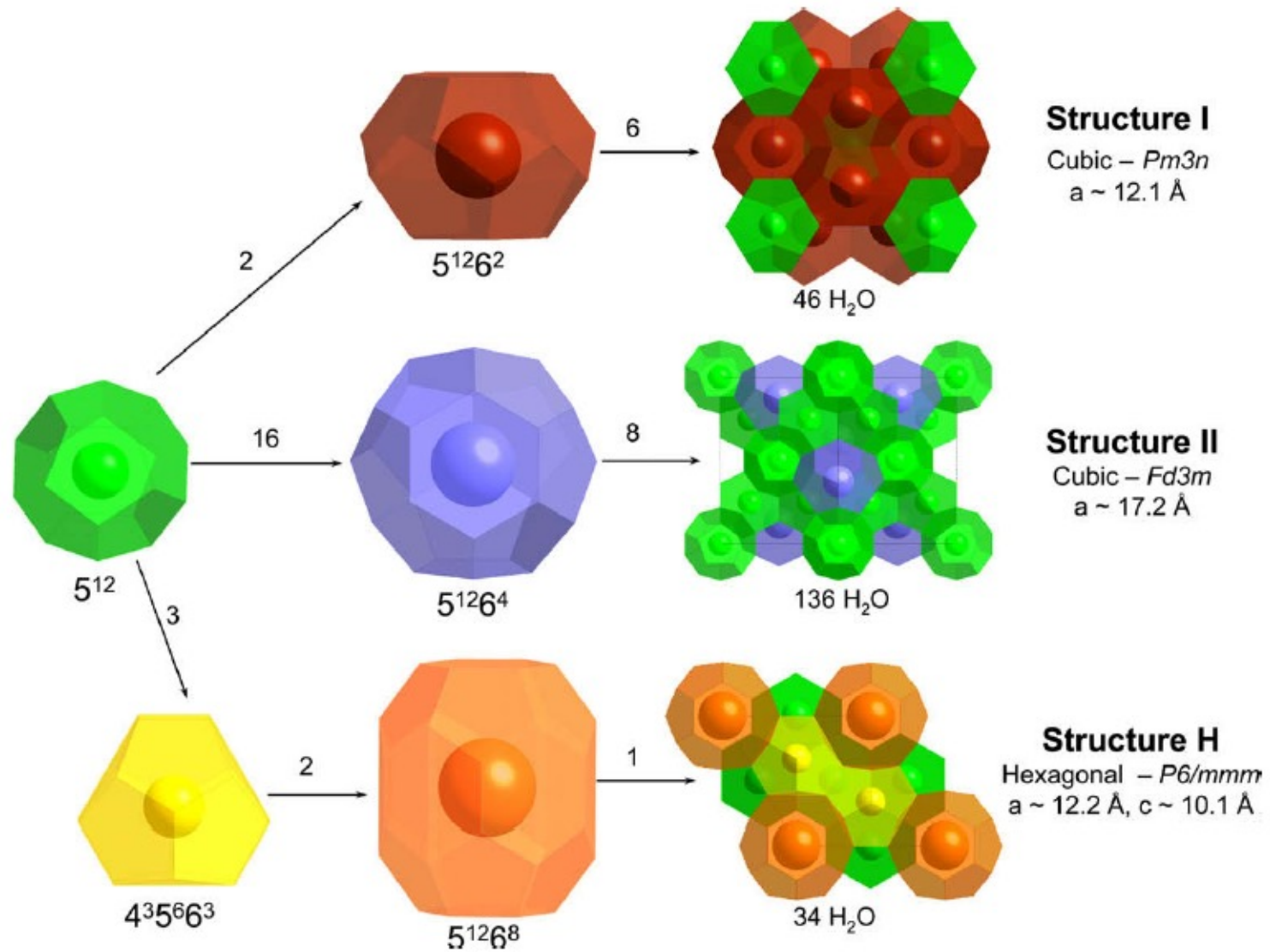


Molecular view

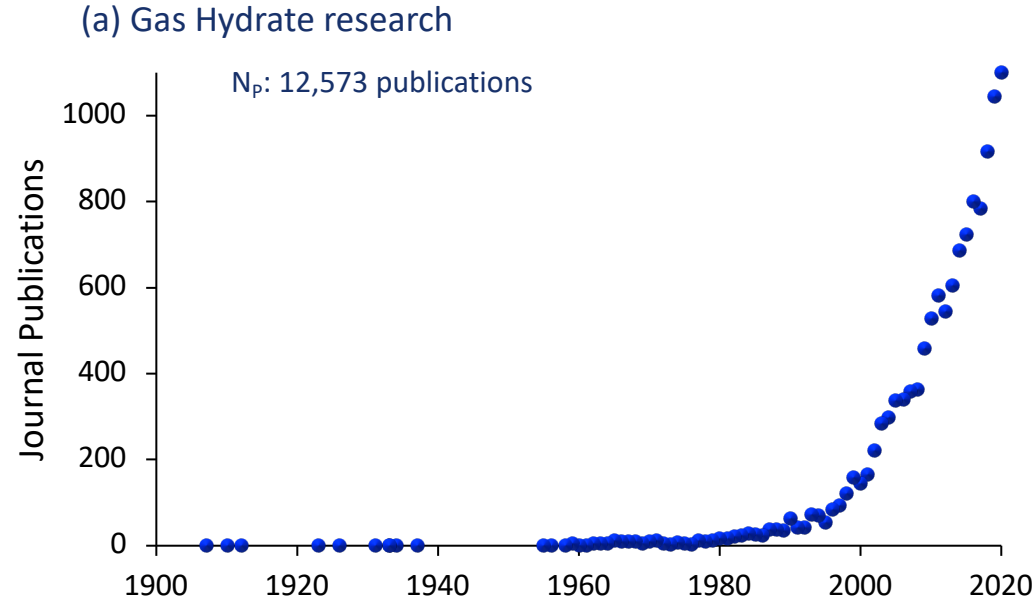


Naked eye view

Gas hydrates crystallize as three structures



About gas hydrate research

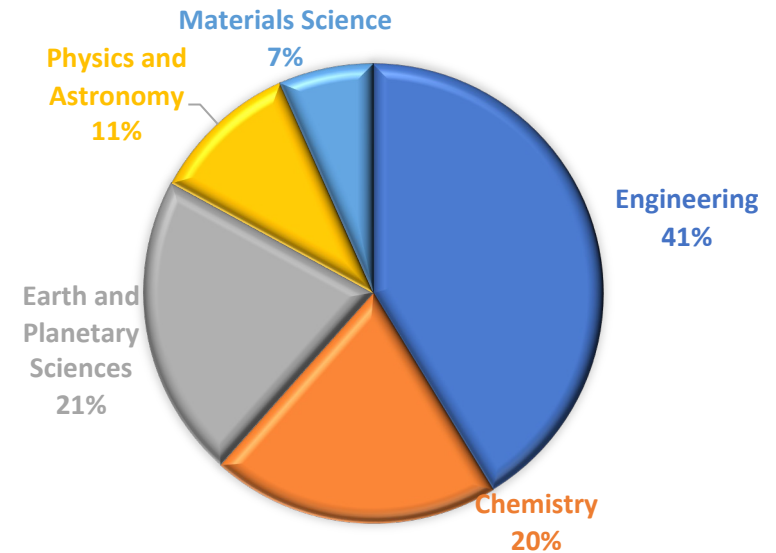


- First discovered in 1810
- Exponential growth in the past 25 years
- Multidisciplinary research field



Sir Humphry Davy (1778-1829, Source: Wiki)

(b) Field Classifications (historical data)



Significance of gas hydrate research

Flow assurance

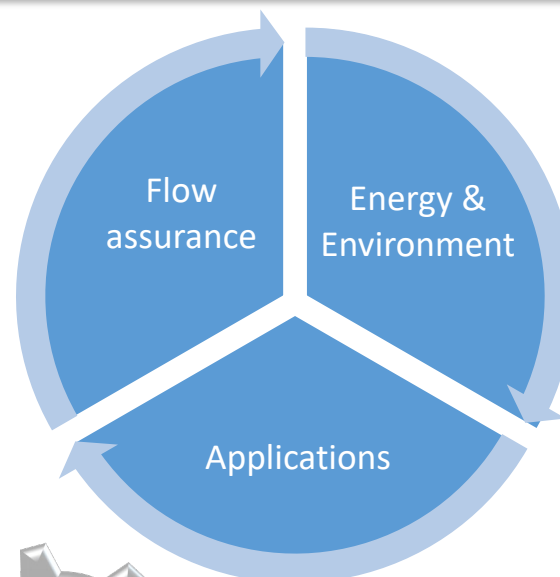


Apprehension

Hydrate Inhibition

Risk Management

Key Research Drivers

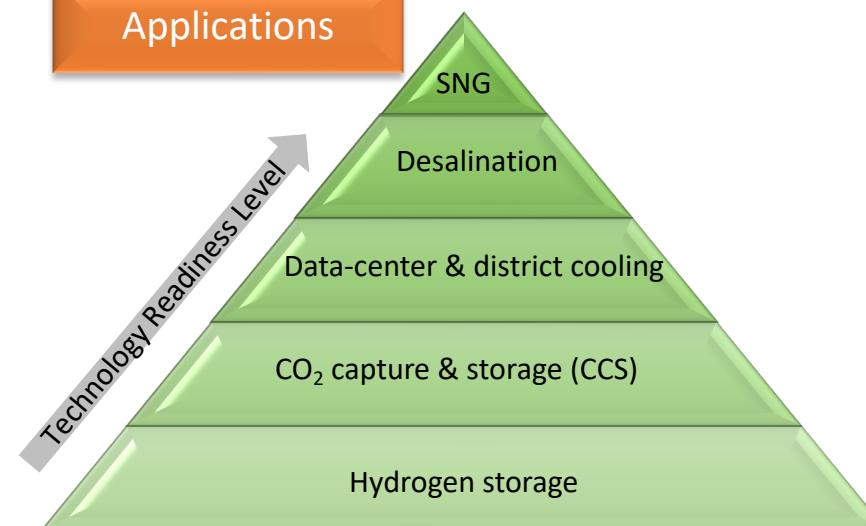


Energy & Environment

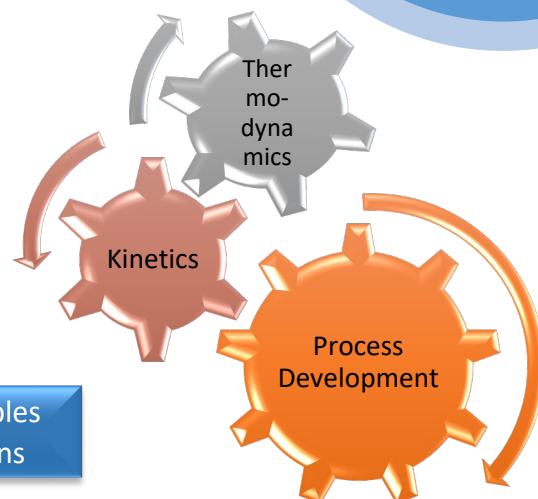
- 1-2 orders higher
- 1000+ years supply
- Evenly distributed
- Geo-hazard



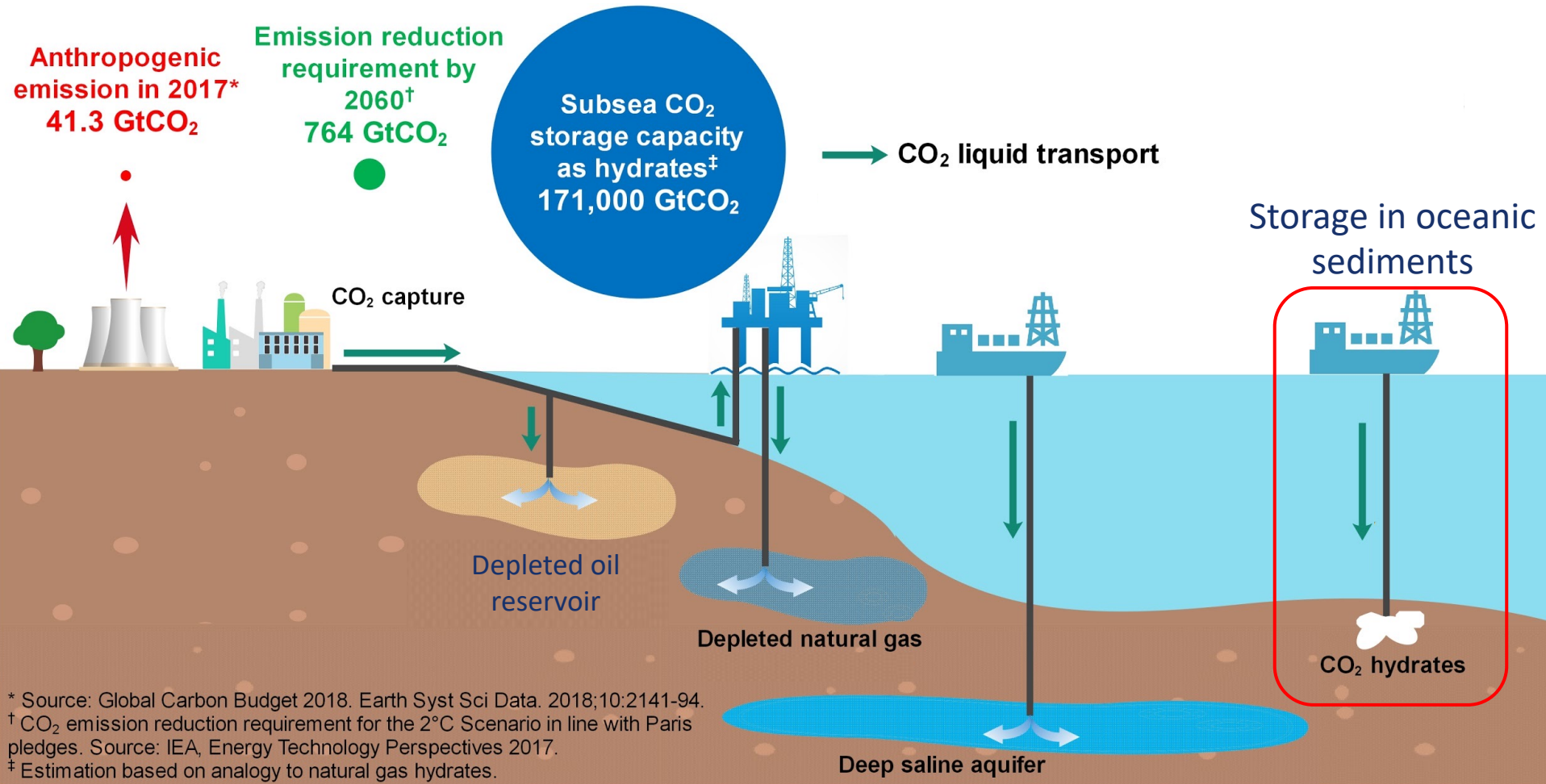
Applications



SNG: Solidified Natural Gas



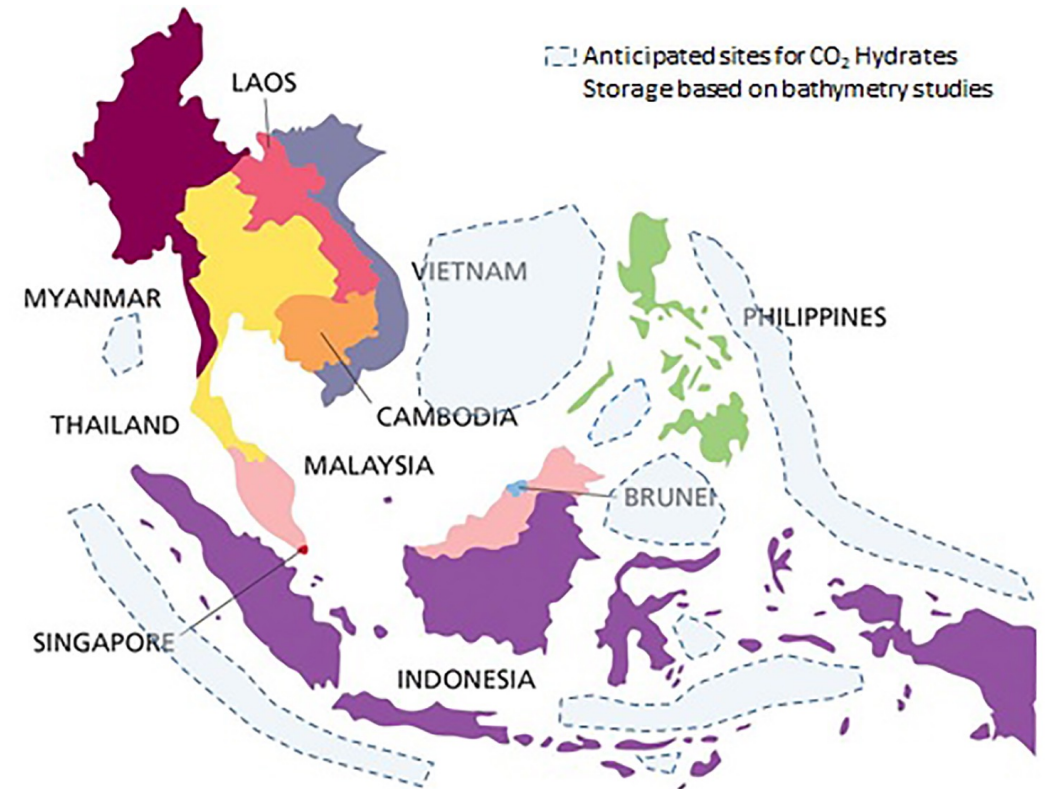
CO₂ Sequestration as Hydrates



Significance to Singapore and ASEAN region



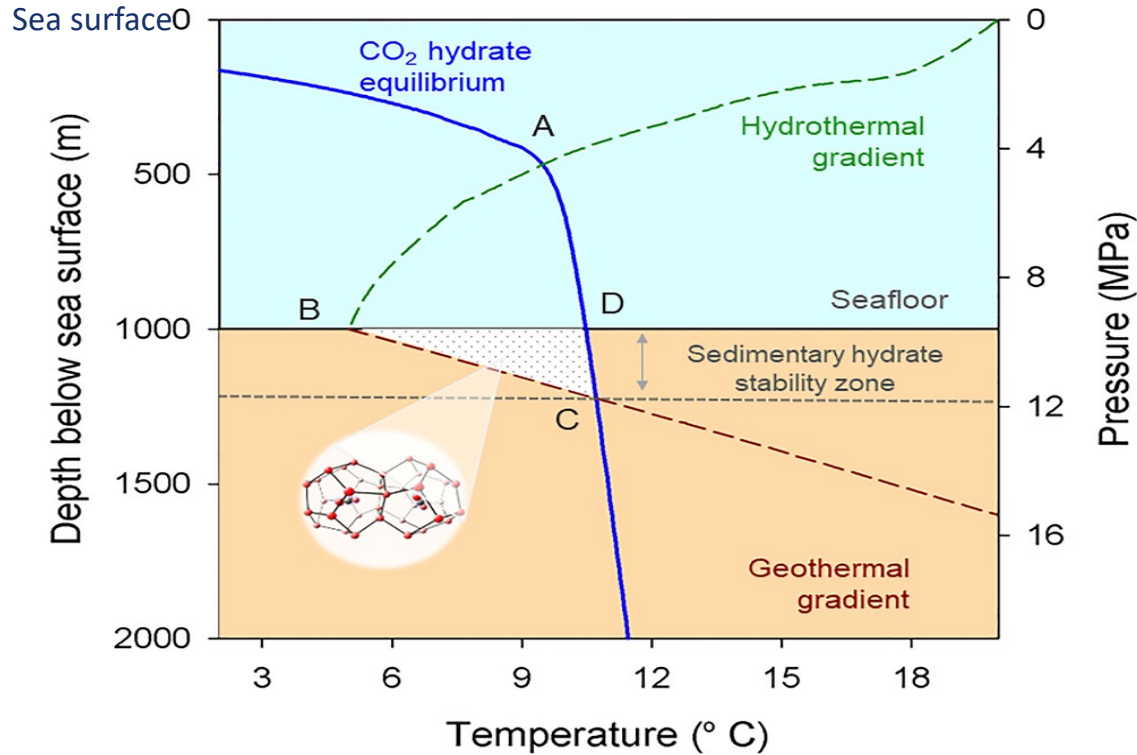
- Developing technologies for CCS in Singapore can have broader regional (ASEAN) and global impact
- Singapore's target is to reduce a total CO₂ emissions of **14 million tons** by the year 2030
- CO₂ hydrate storage potential in ASEAN, **>6000 GtCO₂**
- CO₂ sequestration as hydrates in oceanic sediments presents an opportunity to develop “CO₂ grid” or “Carbon grid” in ASEAN



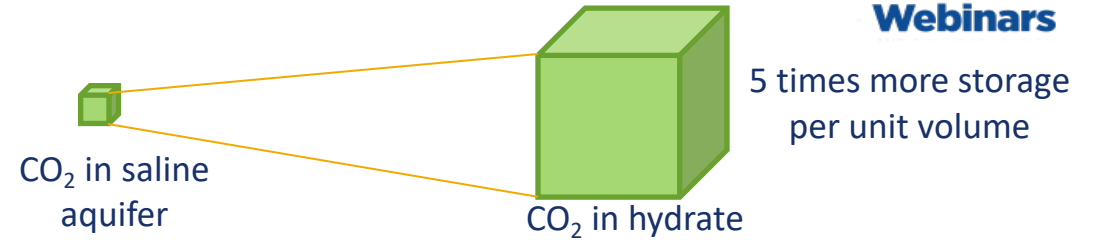
CO₂ sequestration as hydrates in deep sea sediments

Large volumes of CO₂ can be stored in hydrates.

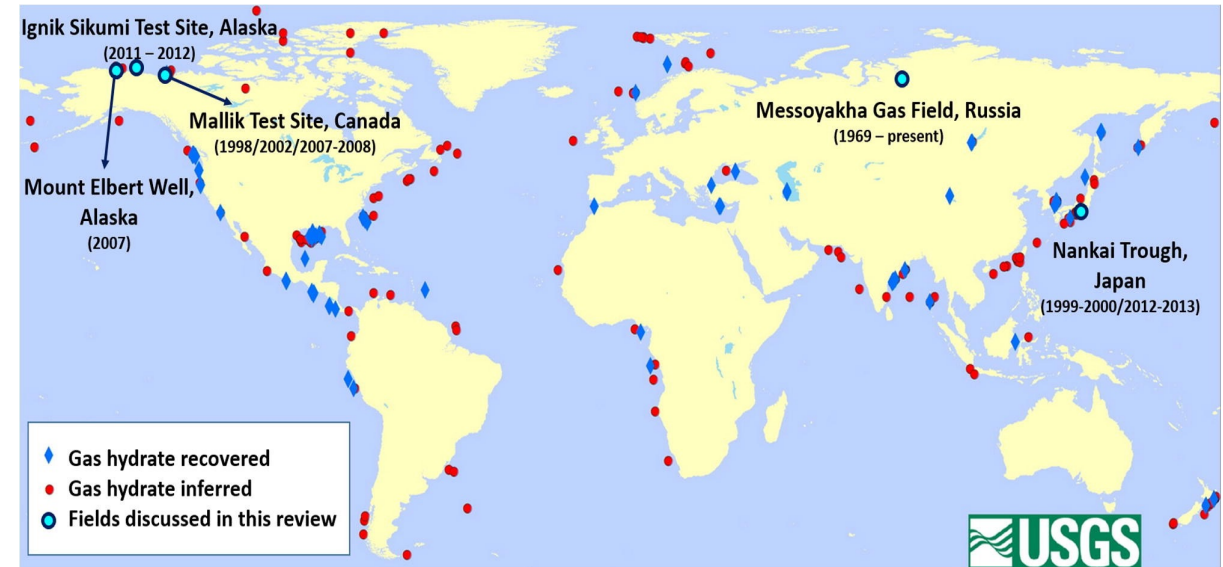
✓ 1 m³ of hydrate can store 183 m³ of CO₂



Where can we form CO₂ hydrates in nature?



Will CO₂ hydrates formed inside oceanic sediments remain stable for long term storage?

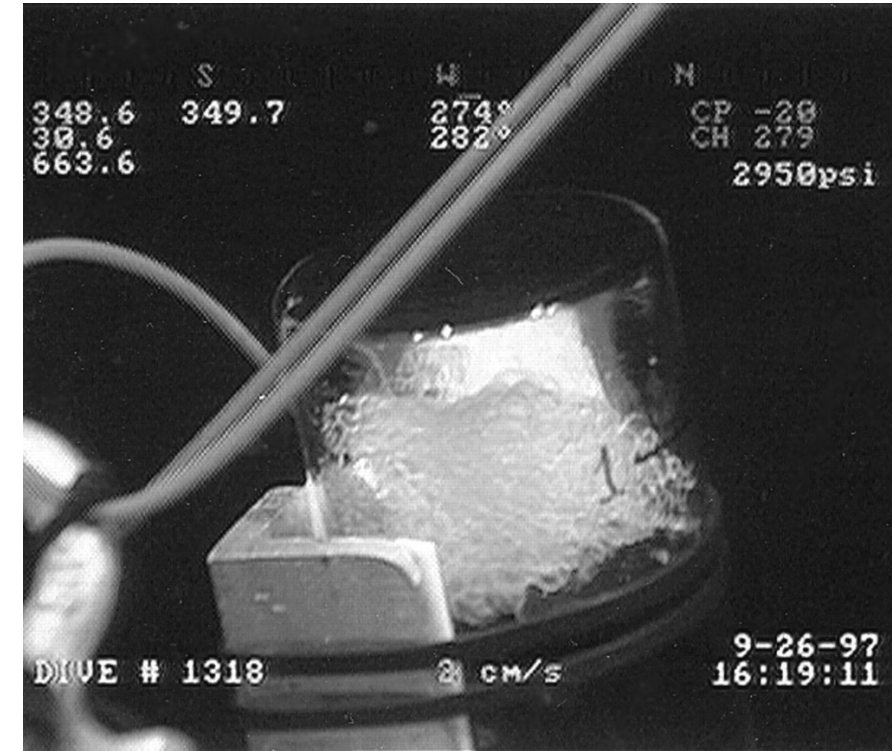


Nature has been storing methane as hydrates and they are stable in similar locations for millions of years

CO₂ Hydrates in Deep Ocean Water



- ✓ Huge CO₂ storage capacity due to great abundance of ocean volume
- ✓ Easy delivery of CO₂ hydrates to seafloor by negative buoyancy effect
- × Instability under the disturbance of ocean current
- × Potential adverse impacts on marine environment and ecosystem



CO₂ hydrates formed at 349 m below sea level, T = 8 °C



CO₂ Hydrates in Deep Oceanic Sediments

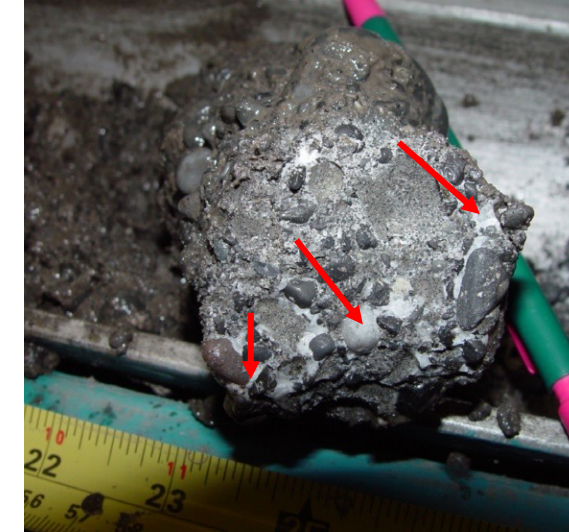


Under seafloor sediments:

- ✓ No disturbance from ocean current
- ✓ Aided by hydrate formation, gravitational trapping

Permafrost region:

- ✓ More accessible than marine locations
- × Sensitive to global warming



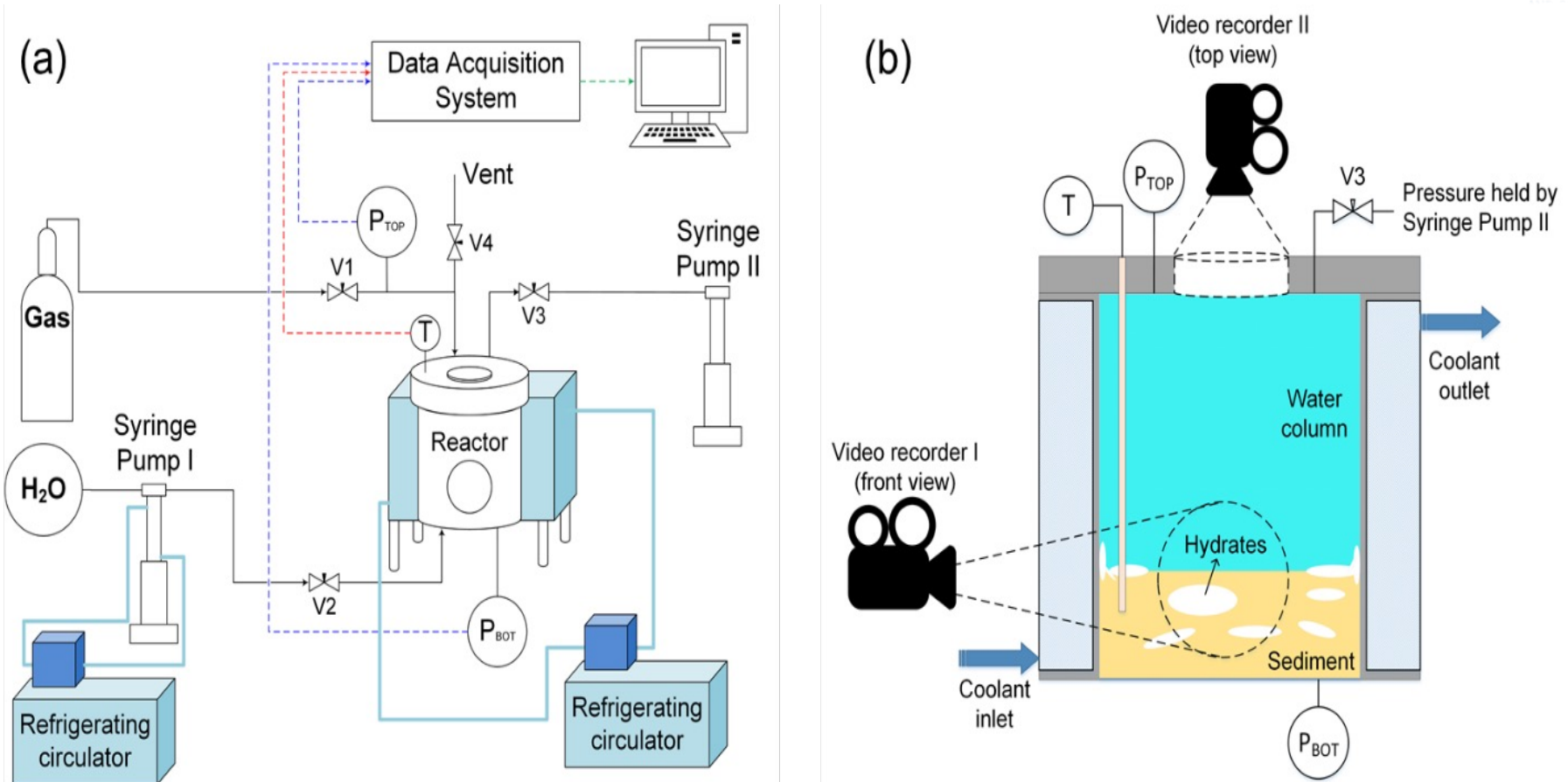
Gas hydrates in coarse sands extracted from permafrost region in Mallik Site, Canada



Fracture-filled gas hydrate veins in clay sediment extracted from eastern Qiongdongnan Basin, China

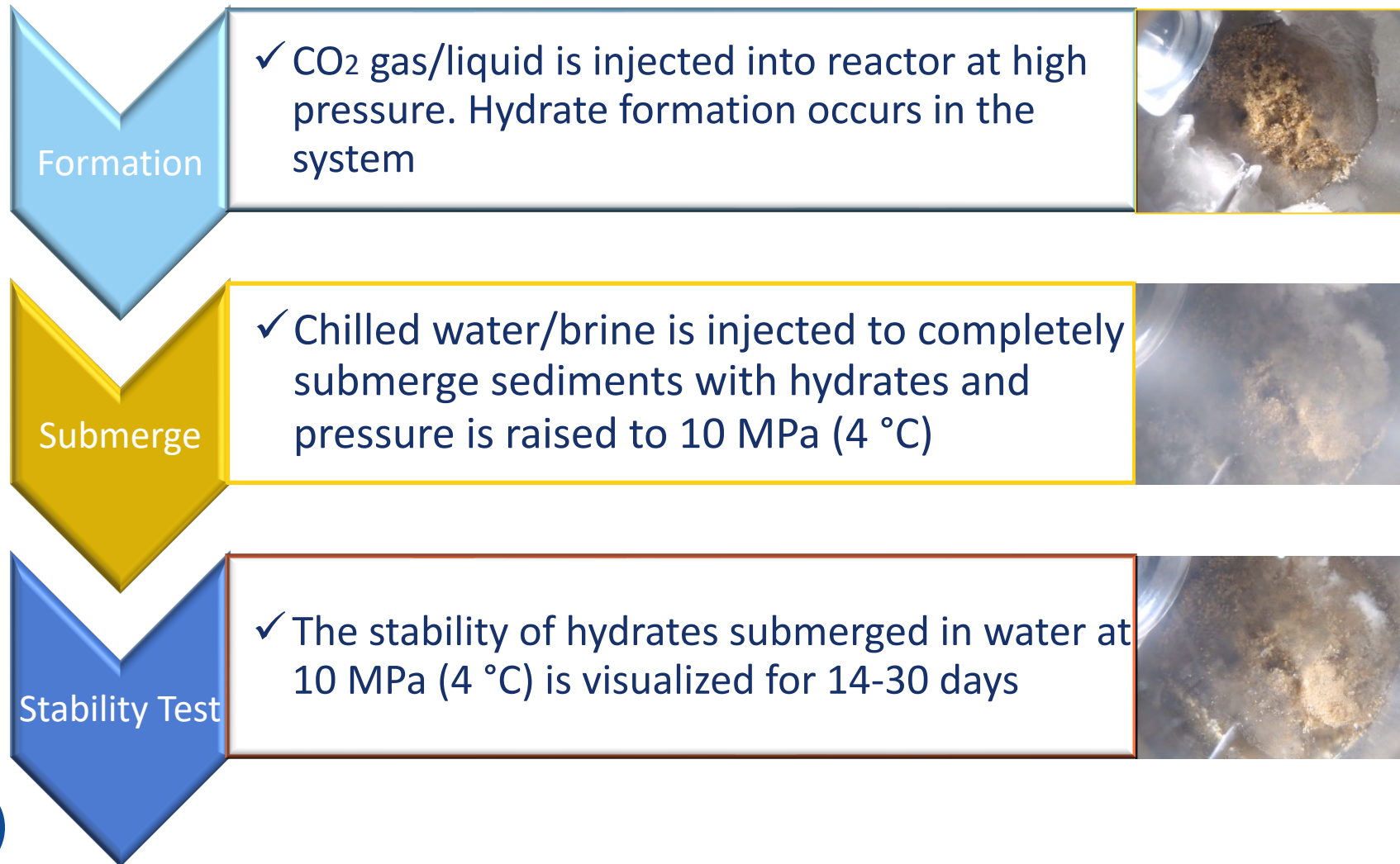


Experimental Apparatus

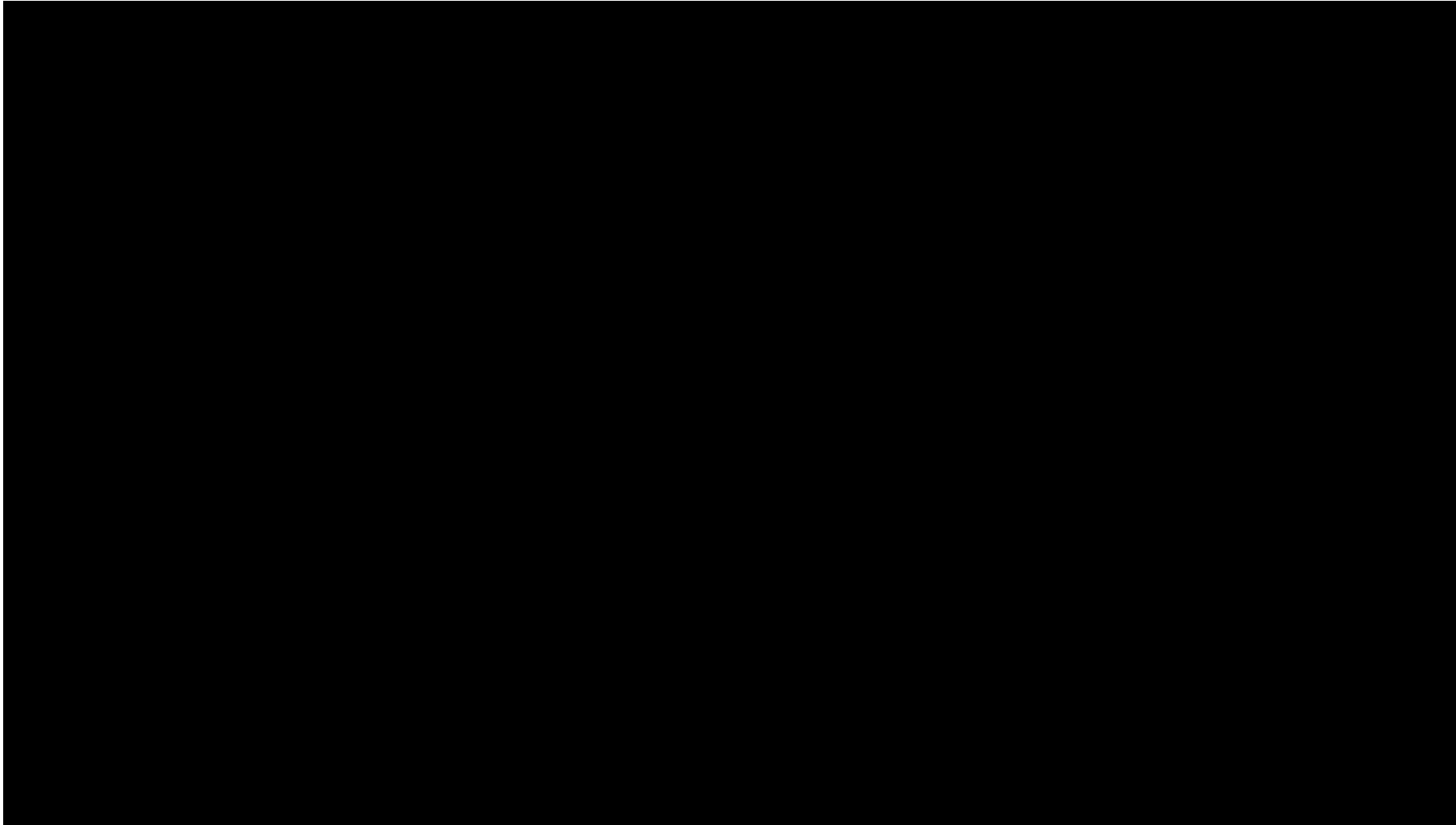


(a) Experimental set-up schematic for CO₂ sequestration project, (b) Schematic of the high-pressure reactor with top and front view cameras

How to form hydrates and simulate oceanic conditions?

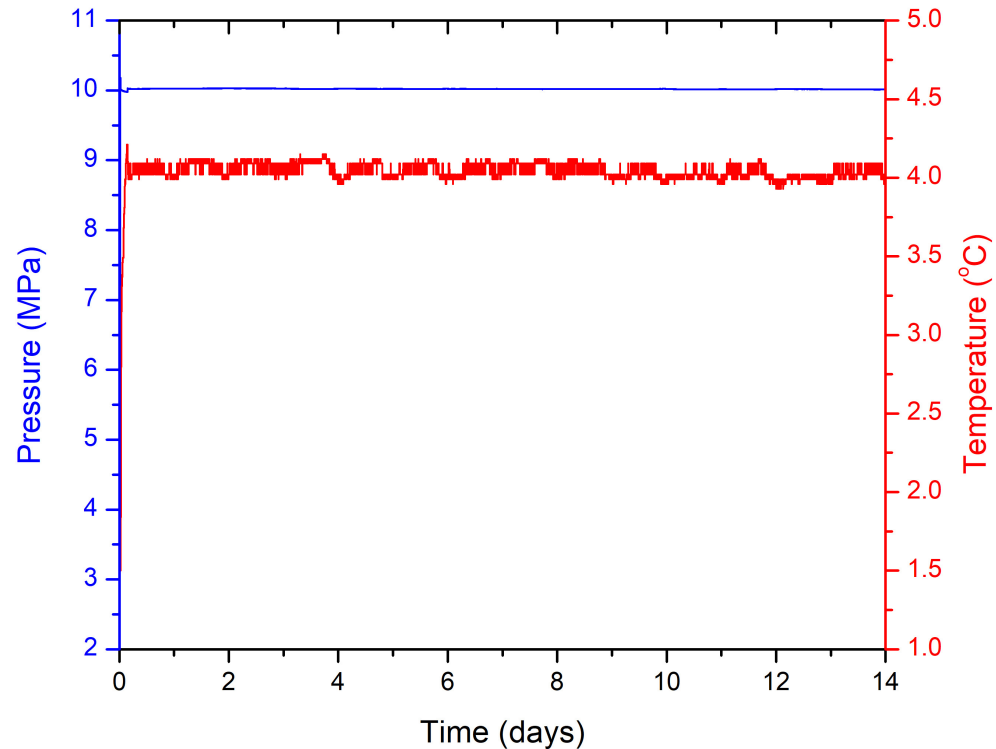


Liquid CO₂ hydrate formation is very fast



*Unpublished data

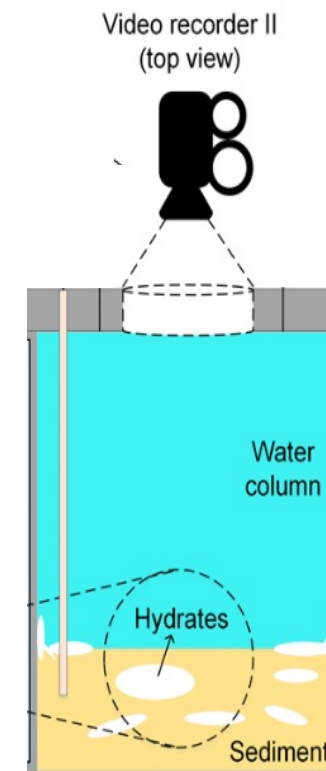
Laboratory Demonstration of Stability



Stability Video-6000X



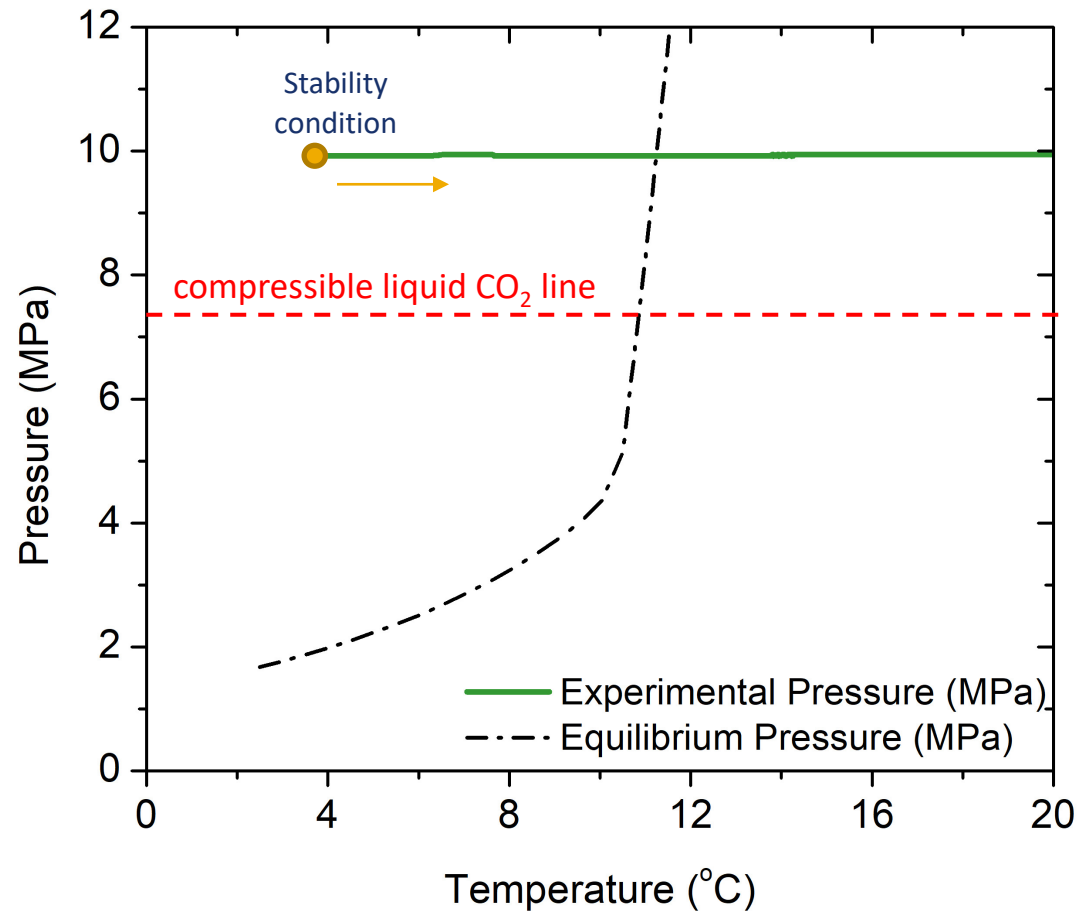
Laboratory Demonstration of Stability



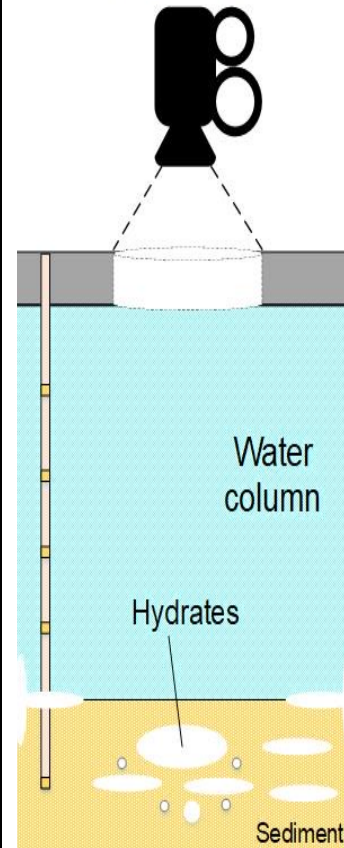
Stability Video-6000X

Linga Lab: Qureshi et al. *Chemical Engineering Journal*
(2022), 432, 134290

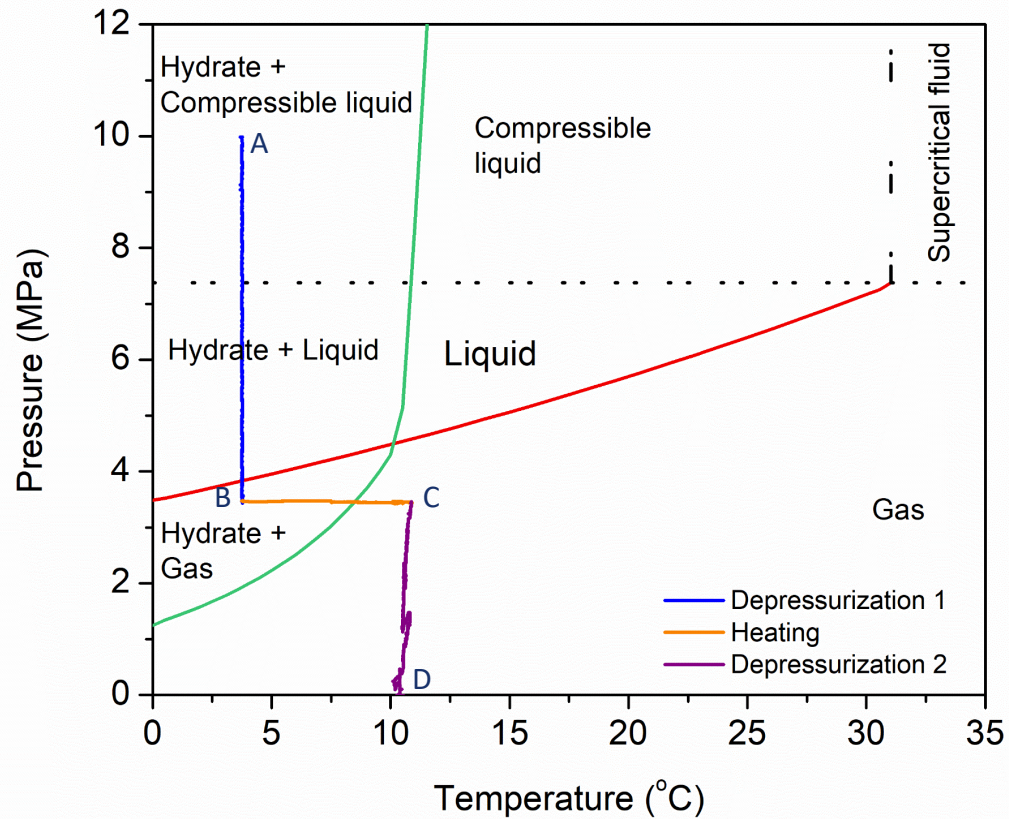
Are hydrates stable inside the sediments?



Top View Heating Video – 33X

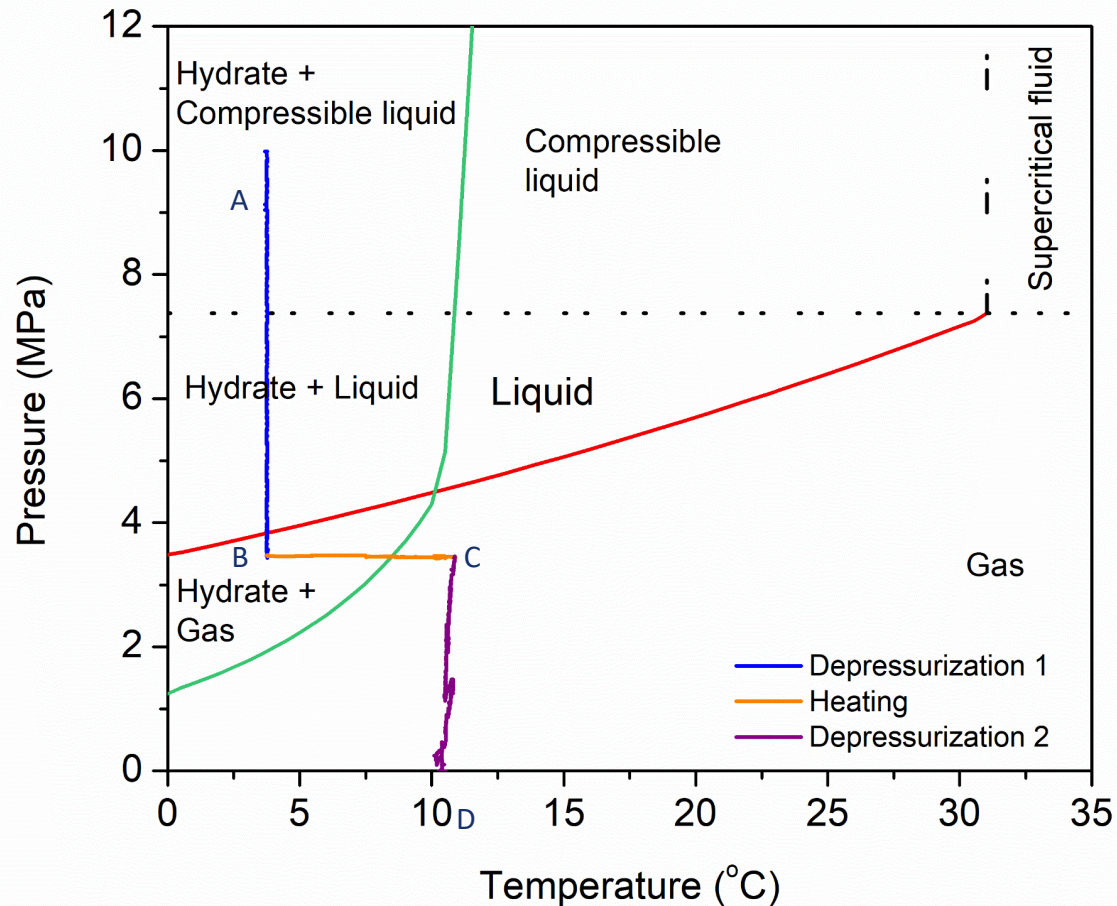


Depressurization [10 - 3.5 MPa]



Top View Depressurization 1 – 33X-(0-1 hr)

Intentional dissociation by heating



Top View Heating Video – 33X

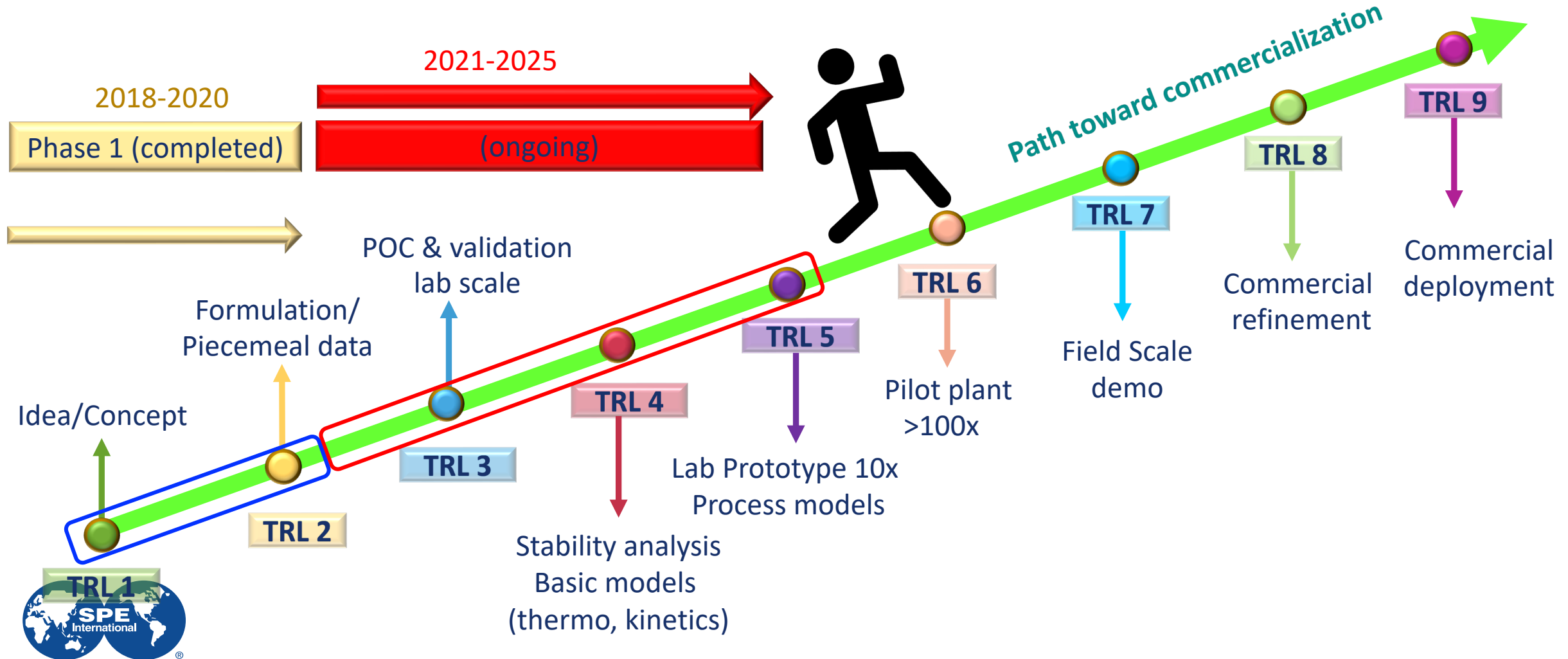
What are the next steps?



- Develop **methods/tools** to quantify the CO₂ amount in the stable hydrates and monitor CO₂ concentration in the water table.
- Identify and evaluate promoters to **enhance the kinetics** of CO₂ hydrate formation.
- Evaluate the **effect of salts** on the kinetics and stability of CO₂ hydrates – thermodynamic properties are known, kinetics unknown!
- Demonstrate **long term stability** (~6 months).
- Develop and validate models to predict the stability of CO₂ hydrates – **10s to 100s of years**.



Technology Road Map



Concluding Remarks



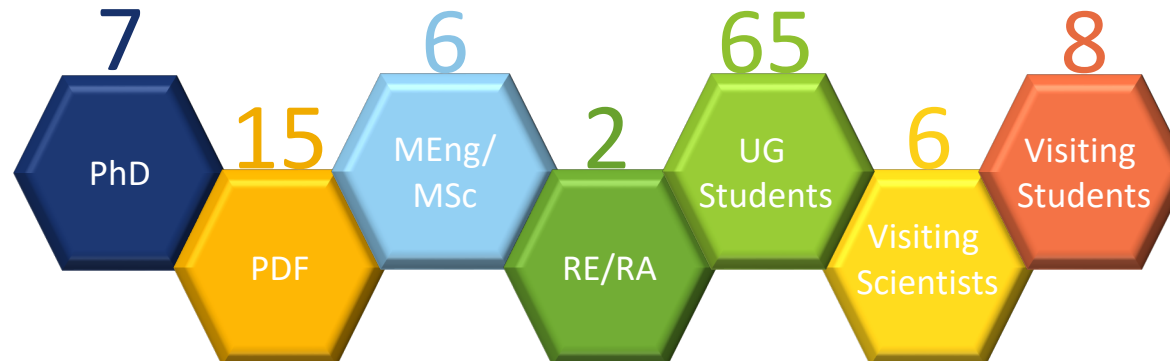
- Gas hydrates present a huge potential for long-term CO₂ sequestration, can lock large volumes of gas.
- Sequestration capacity as CO₂ hydrates under deep ocean seafloor is estimated to be >100,000's GtCO₂.
- We have made significant strides in evaluating the stability of CO₂ hydrates mimicking oceanic sediments.
- Our initial findings offer much promise to develop this approach.



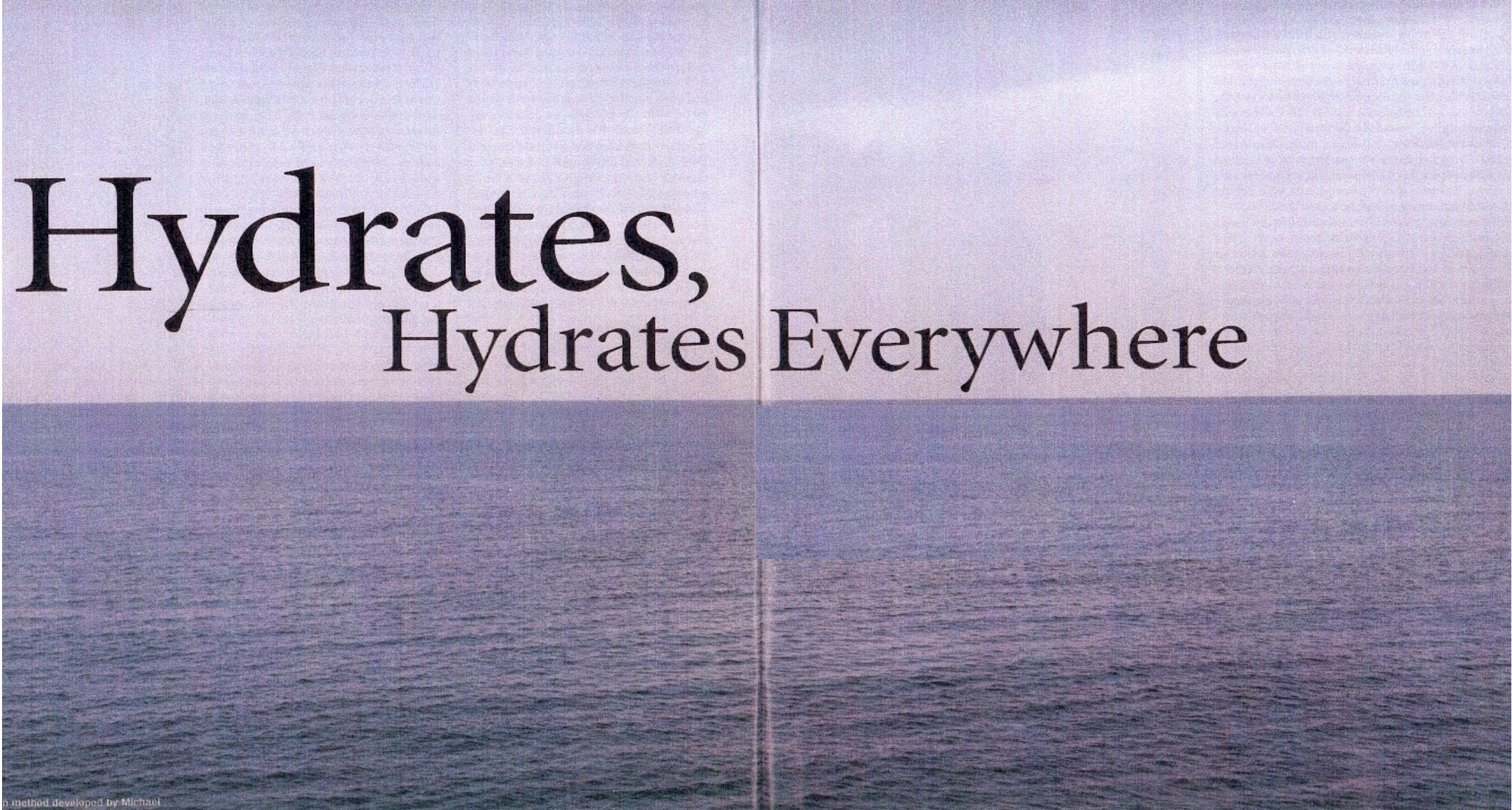
Acknowledgement



Linga Lab AlumNUS (>100)



Thank you!!!



Hydrates,
Hydrates Everywhere