Decarbonization
in Process Industry

Carbon reduction can be employed throughout the whole process industry

Feedstocks and Resources → Process → Products and Wastes

FROM CARBON-HEAVY TO SUSTAINABLE, CARBON-FREE FUTURE IN PROCESS INDUSTRY

Assoc. Prof. Dr. Uthaiporn Suriyapraphadilok

Petroleum and Petrochemical College,
Chulalongkorn University

Chulalongkorn University จุฬาลงกรณ์มหาวิทยาลัย

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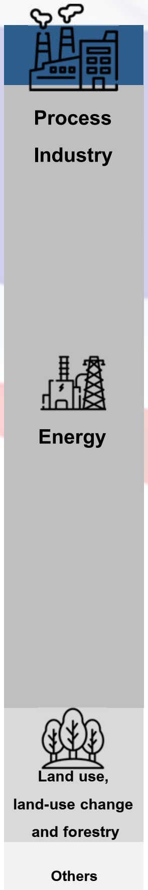
Thailand's Process Industry



2019 Thailand's Green House Gas Emission
(Thailand's 4th Biennial Updated Report, BUR4)

- Petroleum Refinery
- Chemical Industry
- Manufacturing Industry
- Fuel and Energy

2019 Thailand's Green House Gas Emission

Approx. **329,891,410** ton CO_2-eq (From Thailand's BUR4 Report)

Derived from the "Process Industry" Sector approximately **22,705,030** ton CO_2 eq

or **7%** of all total greenhouse gas emissions in Thailand

Thailand's Goals toward Carbon Neutrality and Net Zero

2025	2030	2050	2065
388 $MtCO_2eq$	Unconditional NDC Target 30% GHG Reduction; Conditional NDC Target 40% GHG Reduction	Carbon Neutrality: 61 $MtCO_2eq$	Net Zero Emissions: 0 $MtCO_2eq$

Nationally Determined Contribution (**NDC**)

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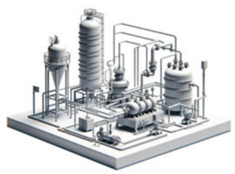
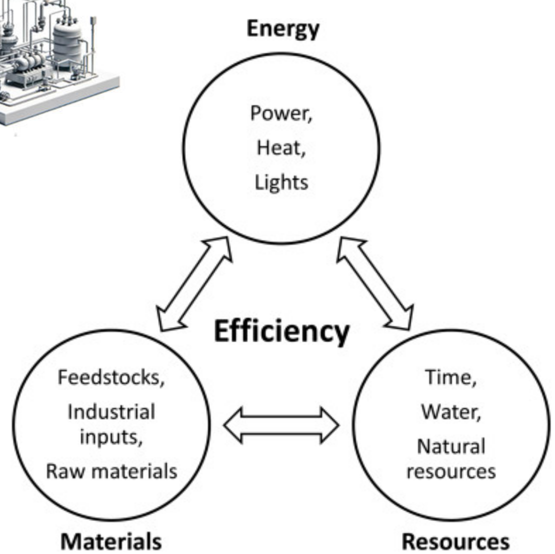
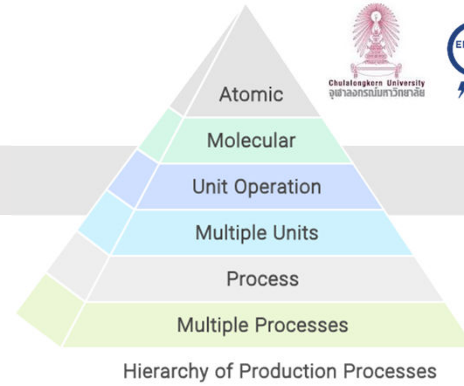
Feedstocks and Resources	Process	Products and Wastes
Biomass	Process Improvement	Carbon Capture, Utilization and Storage
Electrification		Circular Economy
Hydrogen		

A. Sustainable Process Optimization (Physical Transformation)

A1. Process Integration



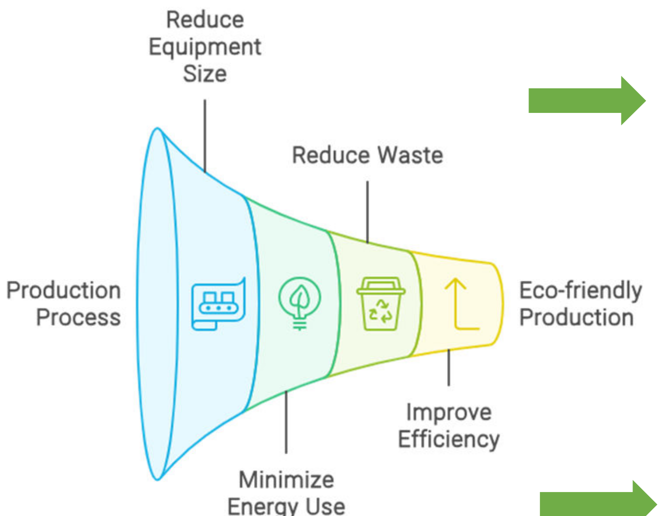




Methods	Scale	Outcome
Stoichiometric targeting (Less raw materials and waste reduction)	• **Molecular**	• **Minimum raw material usage** • **Minimum waste** • **Maximum yields**
Reaction pathways synthesis (New reaction pathways for higher production efficiency)	• **Molecular**	• **Alternative reaction routes**
Distillation network targeting (Optimal range and high efficiency for product separation)	• **Process** • **Unit** • **Molecular**	• **Optimum separation boundaries** • **Optimum product distribution**
Heat integration (Efficient use of thermal energy)	• **Process**	• **Minimum utilities usage**
Process simplification (Minimization of processing steps)	• **Process**	• **Minimum process steps**
Industrial symbiosis (Resources sharing to maximize utilization rate)	• **Process** • **Multiple processes** • **Unit**	• **Maximum resources utilization** • **Minimum waste discharge** • **Minimum raw material usage** • **Minimum processing steps**

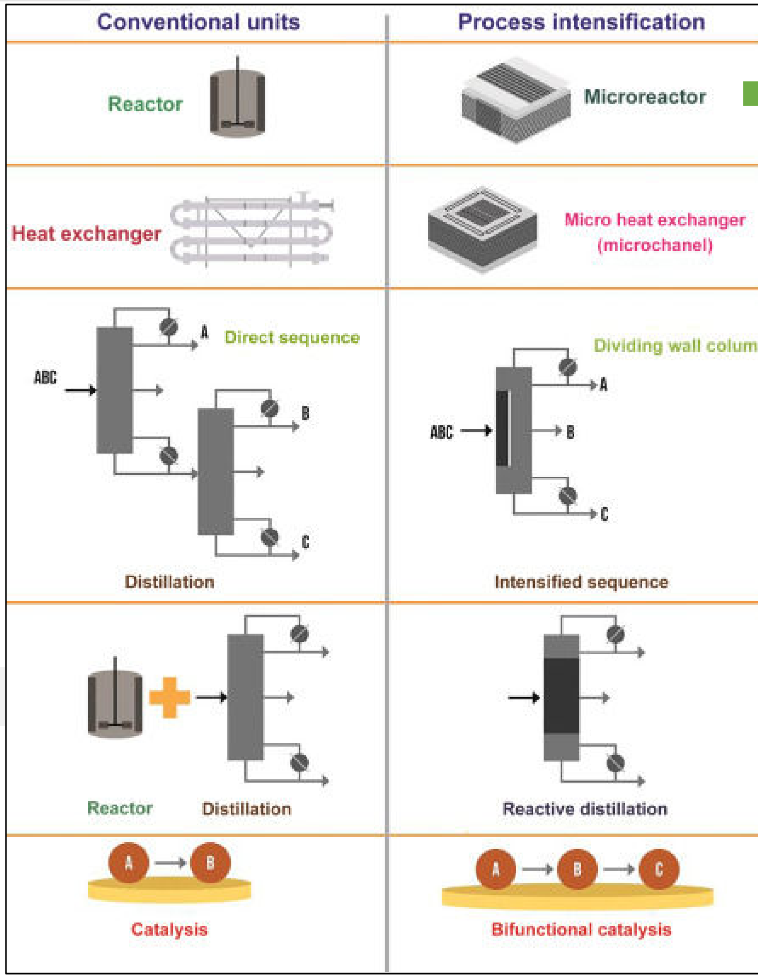
Sources:
1. El-Halwagi M.M., in Methods in Chemical Process Safety, 2023
2. Kim J., et al., Energy, material, and resource efficiency for industrial decarbonization: A systematic review of sociotechnical systems, technological innovations, and policy options. 2024
3. Decardi-Nelson B., et al. Generative AI and Process Systems Engineering: the next frontier., 2024

A2. Process Intensification



Commercialization of "Process Intensification" Technology

Leading global companies such as Shell, Sasol, Linde, UOP Honeywell and others have continuously invested and commercialized "Process Intensification" to improve process efficiency in all aspects

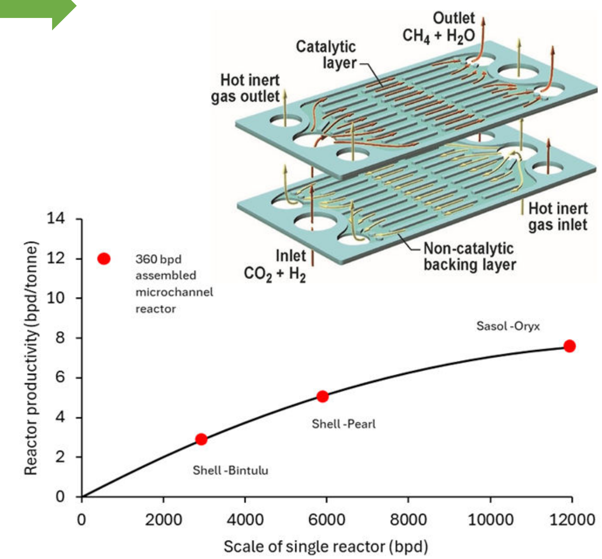


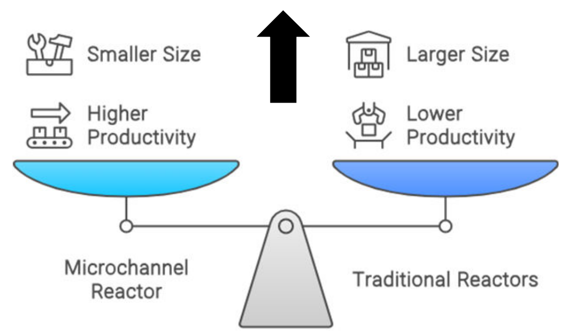
Sources:

1. Gutiérrez-Antonio C., et al. , Process intensification and integration in the production of biojet fuel, 2021
2. Sullivan N. et al., Development of a novel ceramic microchannel reactor for methane steam reforming, 2021
3. Lerou J., Microchannel reactor architecture enables greener processes, 2010

Examples

Microchannel reactor



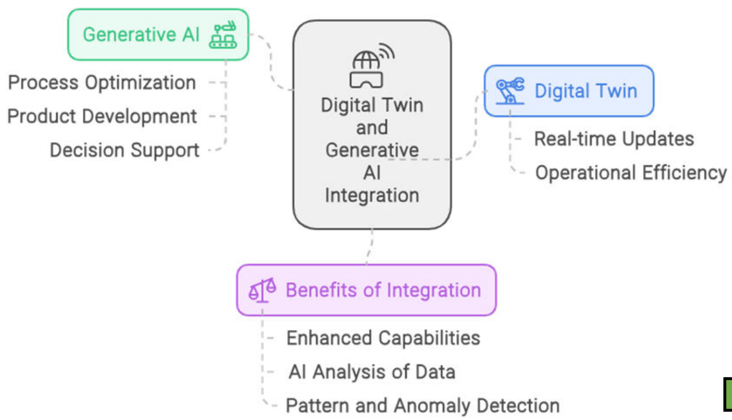


Microchannel reactors offer higher efficiency in Fischer-Tropsch synthesis.

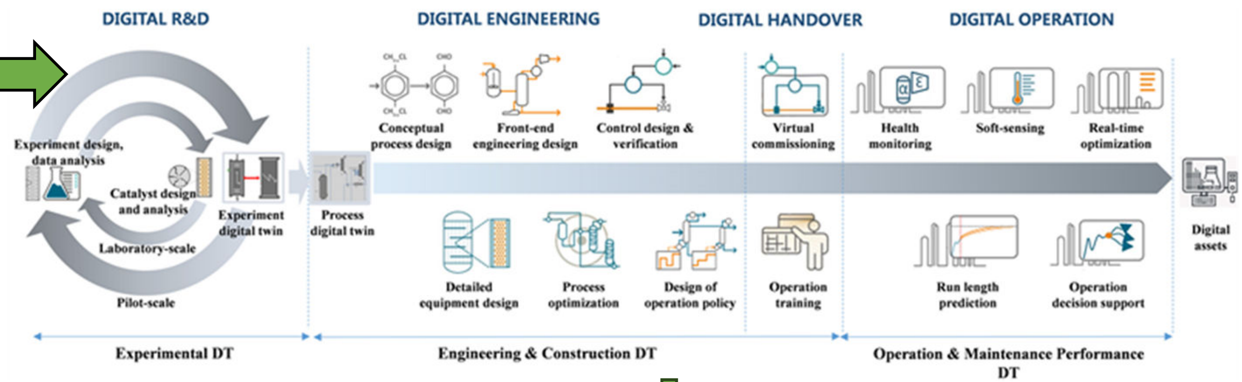
B. Sustainable Industry 4.0 (Digital Transformation)

B1. Digital Twin Technology + *Smart IoT & Automation*

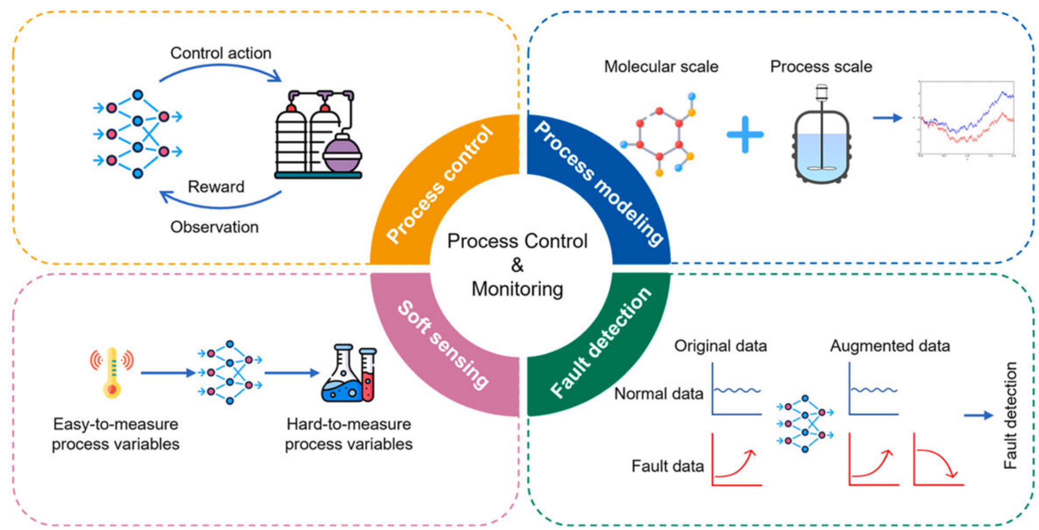
B2. Generative AI



B1



B2



Leaders in the field:

aspentech SIEMENS Ansys

- Several digital twin platforms and Generative AI are available from leading companies, e.g. AspenTech, Ansys, Siemens, etc.
- Cyber-security needs to be enhanced to a level where companies feel safe. Then widespread adoption of Digital Twin technology will become significantly more feasible.

Sources:

1. Perno M., et al. Implementation of Digital Twins in Process Industry, 2022
2. Libing G., et al. Process digital twins and its application in petrochemical industry, 2022
3. Decardi-Nelson B., et al. Generative AI and Process Systems Engineering: the next frontier., 2024

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- Electrification
- Hydrogen

Process

- Process Improvement

Products and Wastes

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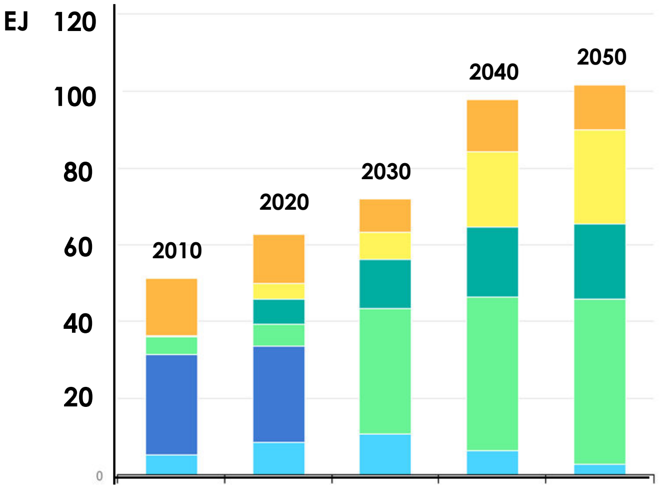
Biomass

Global Bioenergy Supply in the Net Zero Scenario



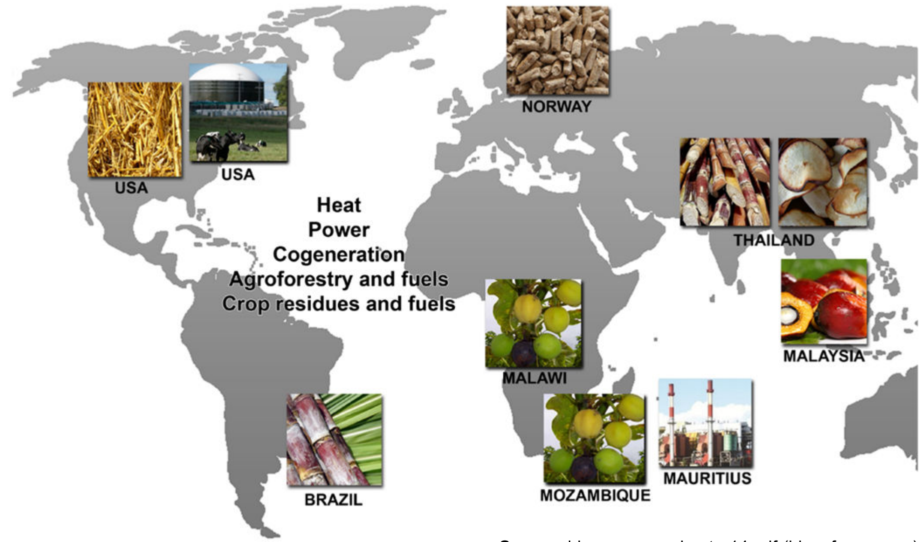
- Conventional bioenergy crops
- Traditional use of biomass
- Organic waste streams
- Forest and wood residues
- Short-rotation woody crops
- Forestry plantings

Bioenergy supply is expected to **increase** until 2050

The traditional use of biomass & bioenergy slightly **decrease** within 2050

In 2050, **over 60%** comes from **sustainable waste streams**

Global Potential of Bioenergy Feedstocks

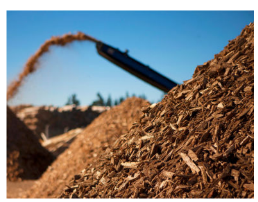


Source: bioen-scope_chapter14.pdf (bioenfapesp.org)

Generation of Biomass

1st Generation: Eatable


2nd Generation: Non-Eatable



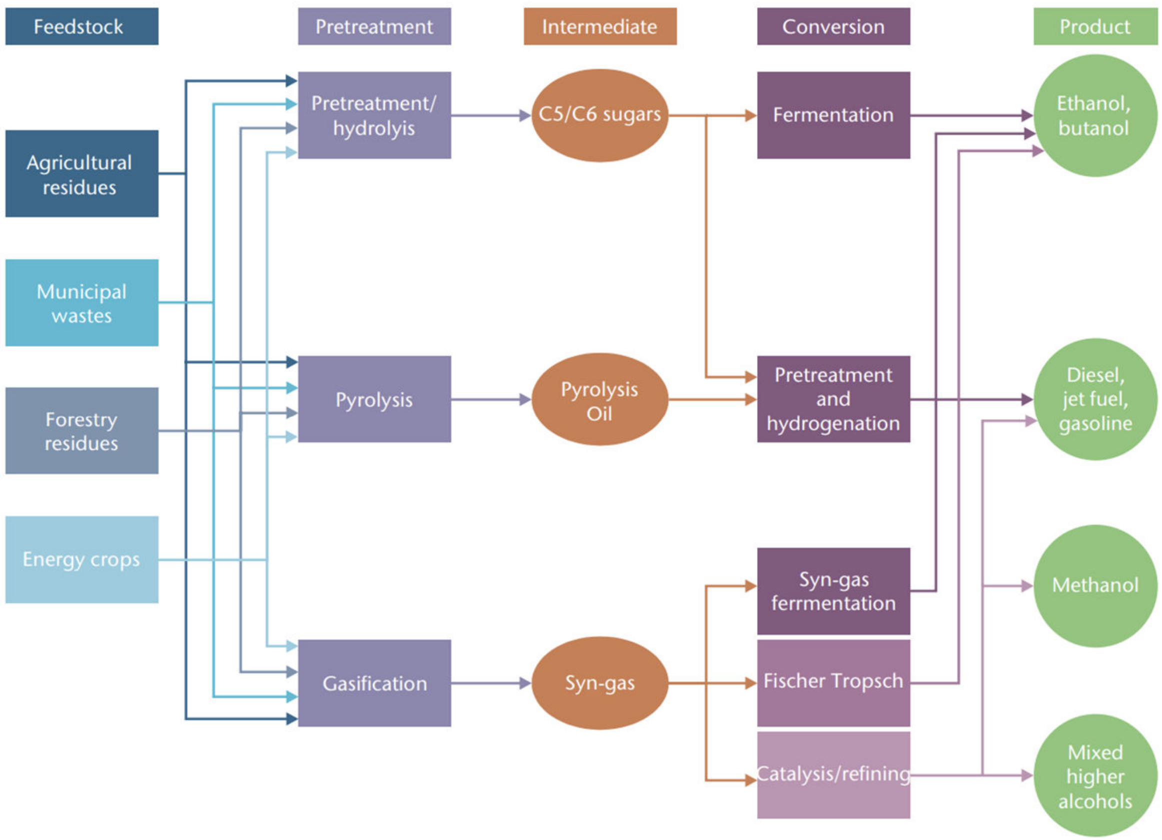

3rd Generation: Algae

4th Generation:

Source: Ministry of Energy (ADEP2015), Gérardy et al., 2020, Zhang et al., 2023 (Review article)

Innovative of Biofuels Routes

A range of next generation biofuels are under development using thermal or biological routes as summarized in the Figure.



The six next-generation liquid biofuels presented are:

1. Advanced Bioethanol
2. Biomethanol
3. Advanced Biodiesel
4. Hydrothermal Upgrading (HTU) Biodiesel
5. Hydrotreated Vegetable oil (HVO) Biodiesel
6. Algal Biofuels

Note: These liquid biofuels are based on processes still undergoing research and development or at a pilot stage.

Source: Next generation biofuels derived from thermal and chemical conversion of the Greek transport sector - ScienceDirect

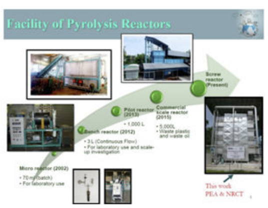
Biomass

Global Leader of Biomass Company

Renewable Energy Group, drax, cosan, POET, Verbio Biofuel and Technology, cropenergies, enviva, EnviTec Biogas, Green Plains, Enerkem

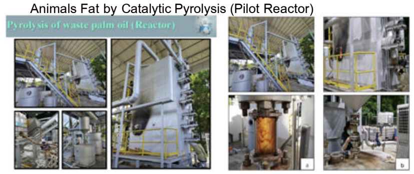
Thailand's Biomass Company

Center of Fuels and Energy from Biomass, Chulalongkorn University, Saraburi Province



Production of Diesel, form Waste Plastic Reactor 2000L/d Supported by PEA

Liquid Fuels for Electricity Generation from Palm Oil and Animals Fat by Catalytic Pyrolysis (Pilot Reactor)



BBGI

Production of biofuels, particularly bioethanol and biodiesel. Additionally, there are plans to expand into high-quality products such as Sustainable Aviation Fuel (SAF) and biosynthetic products.

PPP GREEN COMPLEX

PPPGC

Production of palm oil, refined palm oil, and biodiesel. It also utilizes by-products to generate biomass energy and biogas through advanced technology.

Purac (Thailand)

A global leader in lactic acid, food preservation, biochemicals, and polymers made from lactic acid, with a production capacity of 125,000 tons of lactic acid per year.

Value-added product

Cost of raw materials and selling prices for products ($/t)

Raw Material	Cost	Product	Selling Price
Corn grain	210	Corn grain	260
Wheat	260	Wheat	290
Corn stover	60	Ethanol	667
Wheat straw	60	Green gasoline	1063
Miscanthus	56	Biodiesel	841
Forest residue	47	Hydrogen	1580
Algal oil	131	DDGS	170
Waste cooking oil	200	Glycerol	600

*Based on European Union prices

Challenge and Future Opportunity

1. Technology and Cost of pruduction
2. Government policy
3. Sustainable supply chain management

Biomass Collection → Pre-Treatment → Storage of Biomass → Final Conversion and Energy Production

- Biomass Collection → Reduced biomass collection cost
  - Diverse source of biomass
  - Efficient collection system
  - Use of low-cost feedstock
- Pre-Treatment → Increased pre-treatment efficiency
  - Innovative pre-treatment
  - Improved pre-treatment
  - Increased energy density
- Storage of Biomass → Increased storage efficiency
  - Reduced storage loss
  - Optimized inventory management

Source: Net Zero by 2050 (IEA), Umakanth et al., (2022), Zhang et al., 2023 (Review article), https://www.bangkokbiznews.com/environment/1132416, https://www.mdpi.com/2227-9717/8/12/1588

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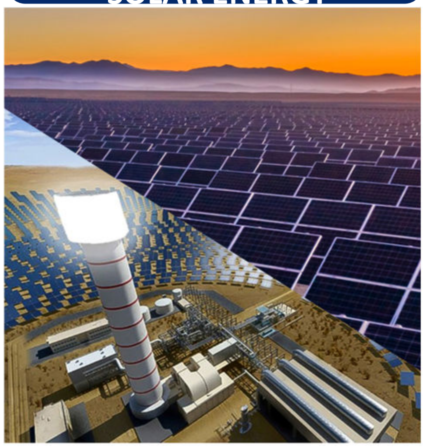
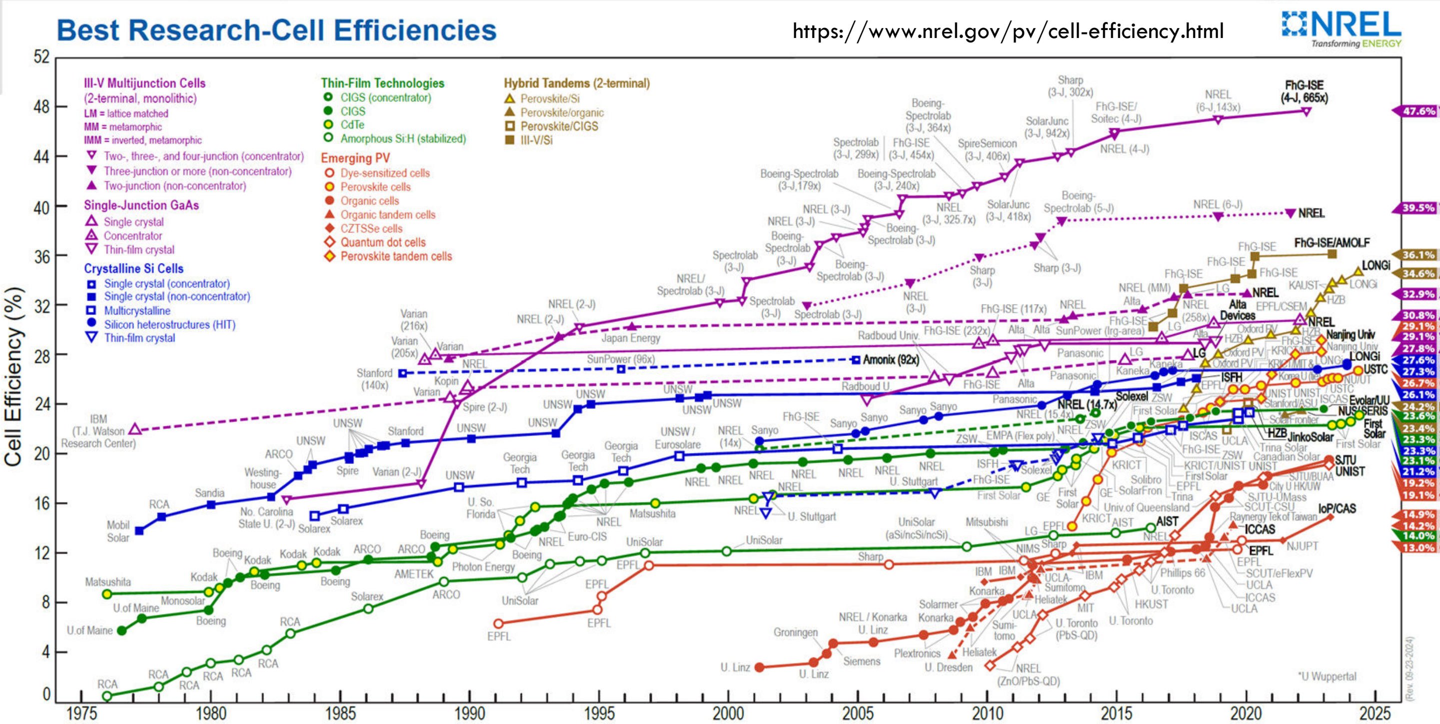
Electrification

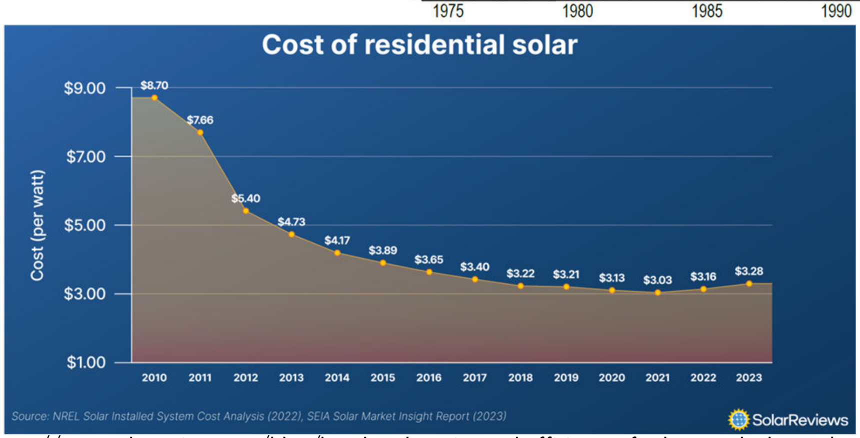
SOLAR ENERGY



CONCENTRATED SOLAR

Source: Siemens Accelerating the electrification of everything





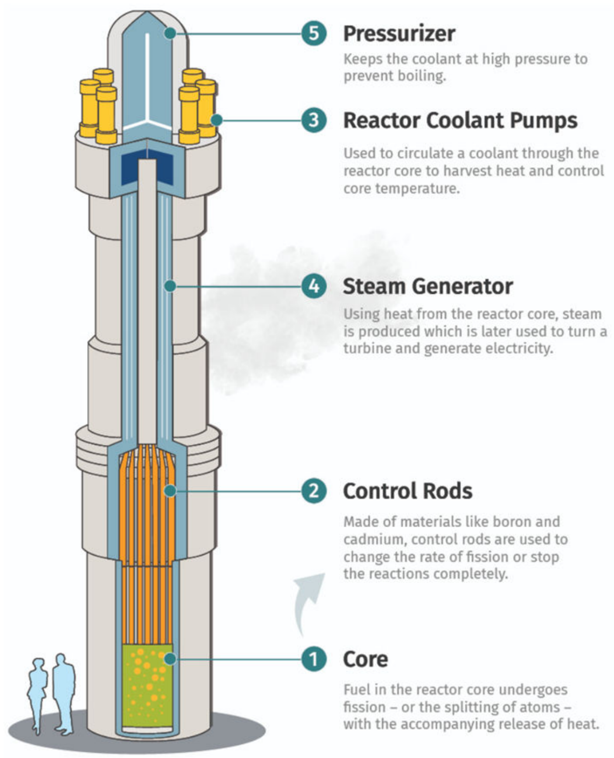
Source: https://www.solarreviews.com/blog/how-has-the-price-and-efficiency-of-solar-panels-changed-over-time

Levelized Cost of Energy

Technology	LCOE*($/MWh)
Solar PV - Utility	29-92
Concentrated Solar Power	118
Gas Combined Cycle	45-108
Coal	69-168

Source: Lazard (2024), IRENA

SMALL MODULAR REACTORS (SMR)

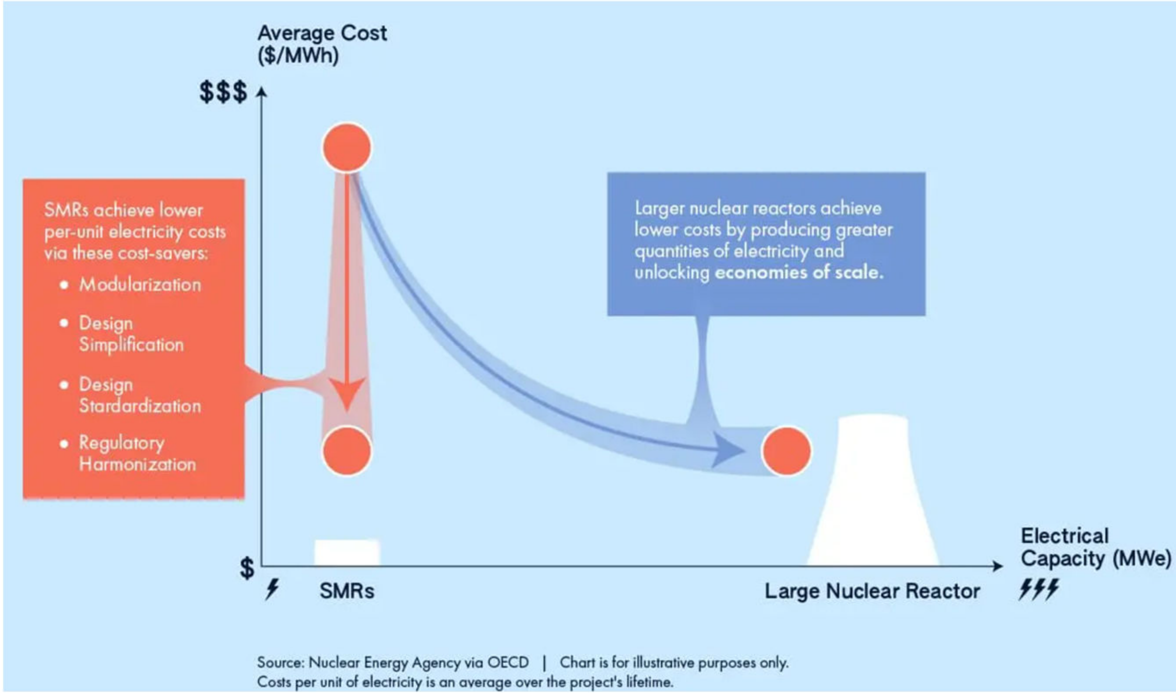


https://thoughtleadership.rbc.com/think-small-how-canada-can-make-small-modular-nuclear-reactors-a-priority/

Small – physically a fraction of the size of a conventional nuclear power reactor. (1 to 300 MW Small modular reactor , 1-10 MW Microreactor)

Modular – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation.

Reactors – harnessing nuclear fission to generate heat to produce energy.

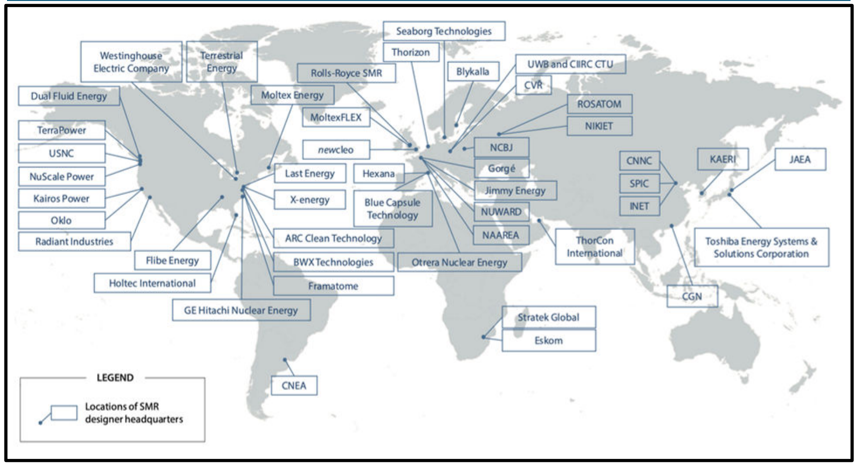


https://www.motive-power.com/visualized-the-four-benefits-of-small-modular-reactors/

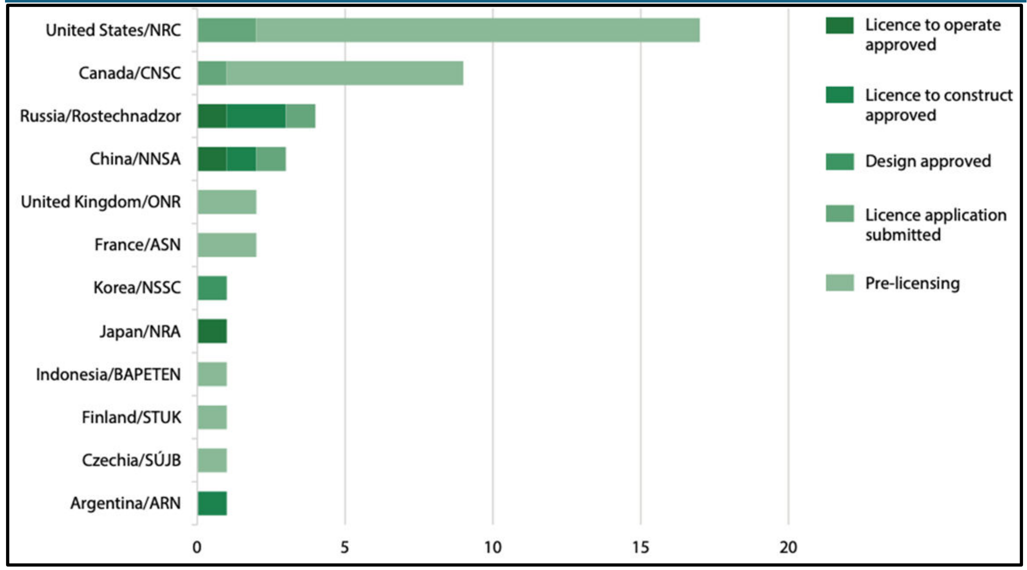
Electrification

Case study of SMRs

Global map of SMR designer



Count of SMRs in pre-licensing or licensing activities With nuclear safety regulators, by country



SMR Projects

(Source: IAEA Advanced Reactors Information System (ARIS) 2022)

Design	Oputput MW(e)	Technology Type	Designer	Country	Status
CAREM	30	PWR	CNEA	Argentina	Under Construction
ACP100	125	PWR	CNNC/NPIC	China	Under Construction
BREST-OD-300	300	LMFR	NIKIET	Russian	Under Construction
KLT-40S	70	PWR	JSC Afrikantov OKBM	Russian	In operation
HTR-PM	210	HTGR	INET, Tsinghua University	China	In operation
HTTR	30	HTGR	JAEA	Japan	In operation

PWR: Water-cooled small modular reactors

HTGR: High - temperature gas cooled small modular reactors

LMFR: Liquid metal cooled fast neutron spectrum small modular reactors

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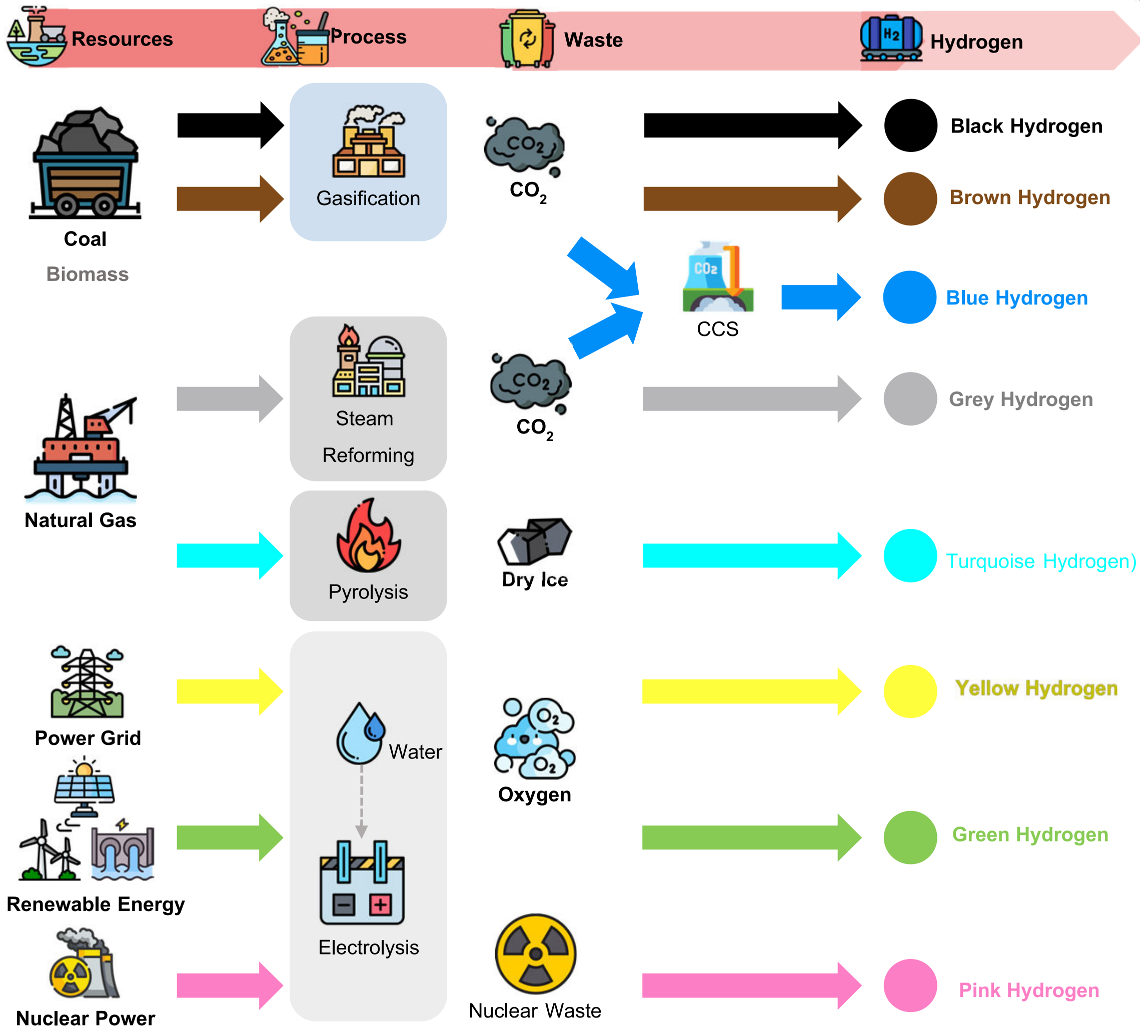
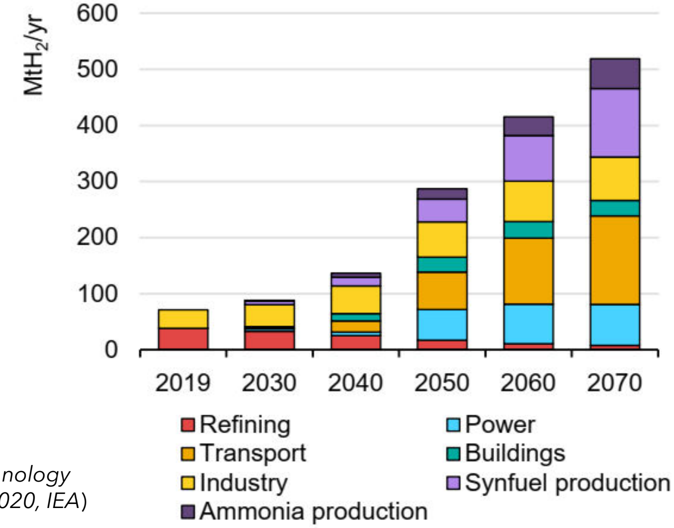
Hydrogen

Types of Hydrogen



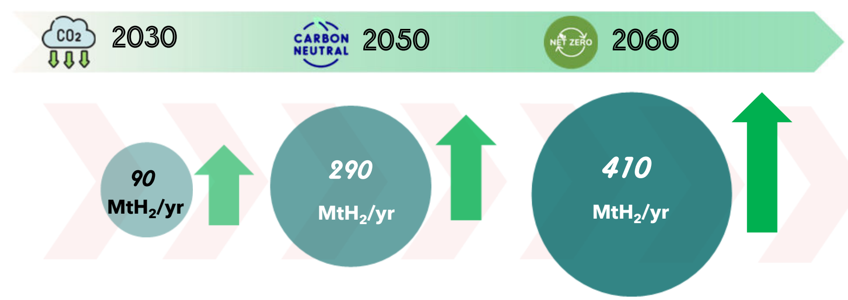
Why hydrogen is important?

Hydrogen demand by sector in the sustainable development



(Energy Technology Perspectives 2020, IEA)

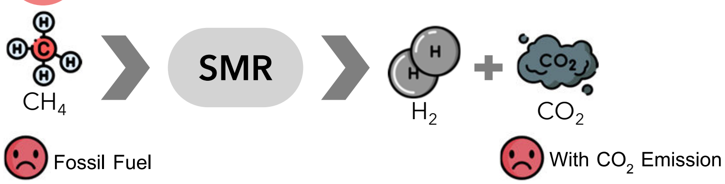
❑ Increasing demand for hydrogen as a transition toward net zero goal



Hydrogen

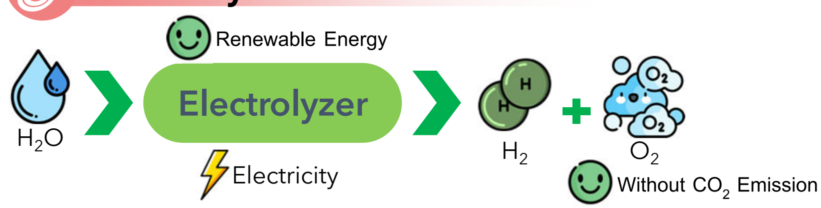
Hydrogen Production Technology

1 Steam Methane Reforming (SMR)

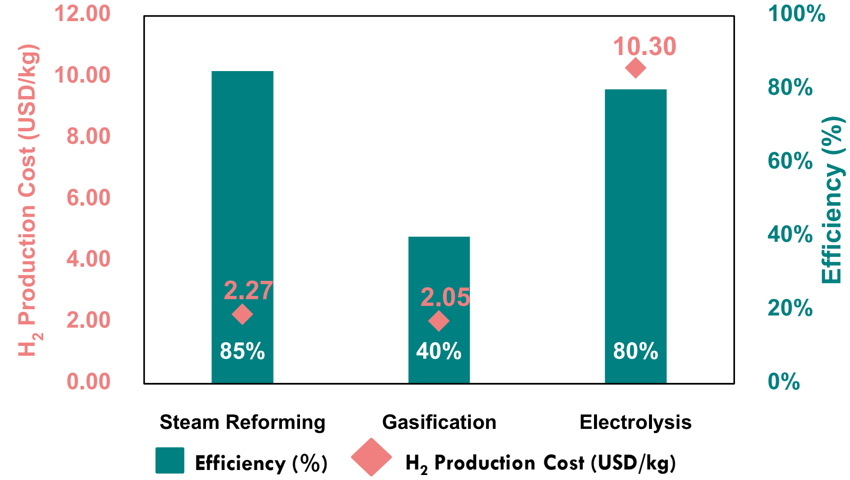


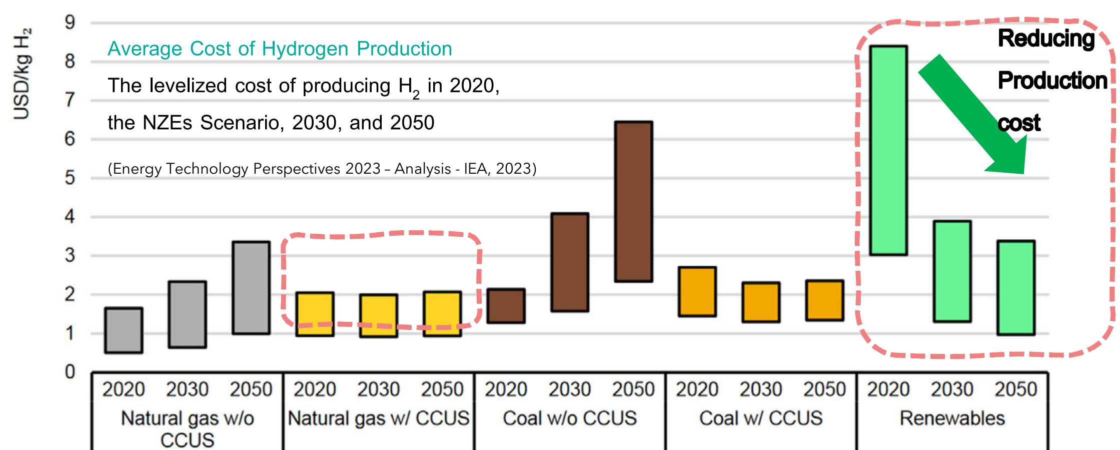
2 Gasification

3 Electrolysis



H_2 Production Cost (USD/kg)





PTTEP

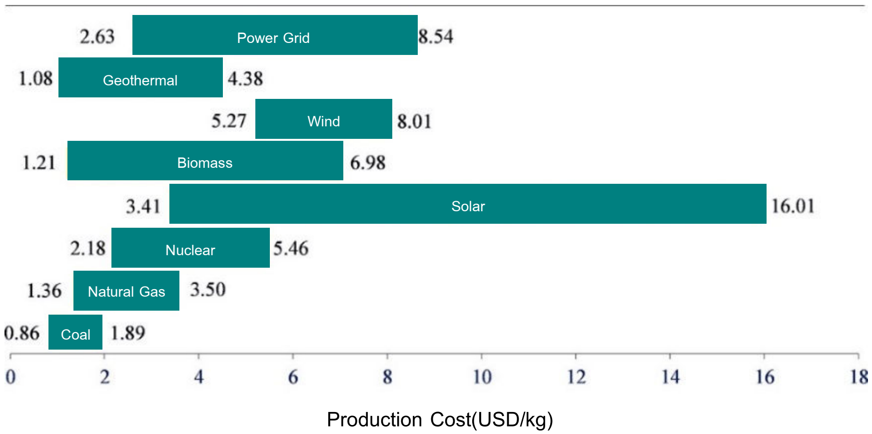
CCS Project at Arthit Gas Field

Hydrogen

Challenges in Thailand

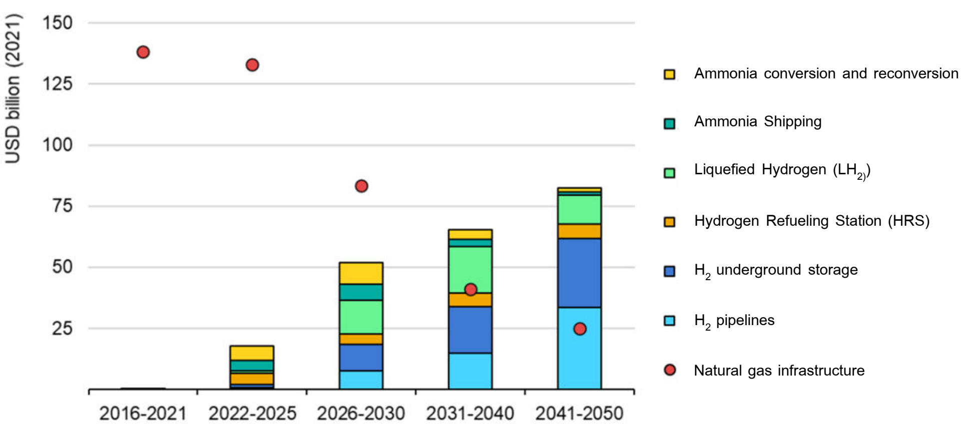
Hydrogen production cost (refered to raw material and energy

(El-Emam & Özcan, 2019)



Average investment per year in infrastructure for hydrogen and natural gas

(Energy Technology Perspectives 2023 - Analysis - IEA, 2023)



Technology Readiness

(Energy Technology Perspectives 2020, IEA)

Low-carbon hydrogen production

- Electrolysis
- Natural gas reforming with CCUS
- Coal gasification with CCUS
- Methane splitting

Hydrogen use in industry

- Fossil-based ammonia with carbon capture
- Fossil-based methanol with carbon capture
- Electrolysis for methanol and ammonia
- Blending into commercial iron processes
- Full hydrogen direct reduced iron

Hydrogen use in power generation

- High-temperature fuel cells
- Hydrogen-fired gas turbines
- Co-firing ammonia in coal power plants

Mature | Early adoption | Demonstration | Large prototype

Challenges

- Infrastructure
- Ammonia

Blue Hydrogen

- CCS in the gulf of Thailand

Green Hydrogen

- Cost of Electrolyser
- Renewable Energ)

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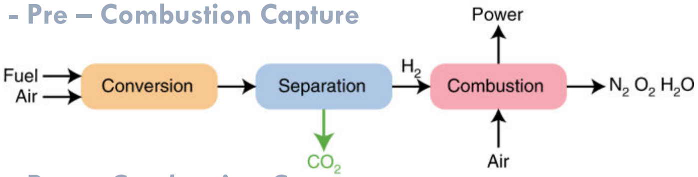
Carbon Capture, Utilization, and Storage (CCUS)

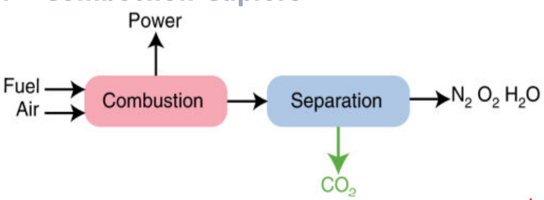
Capture

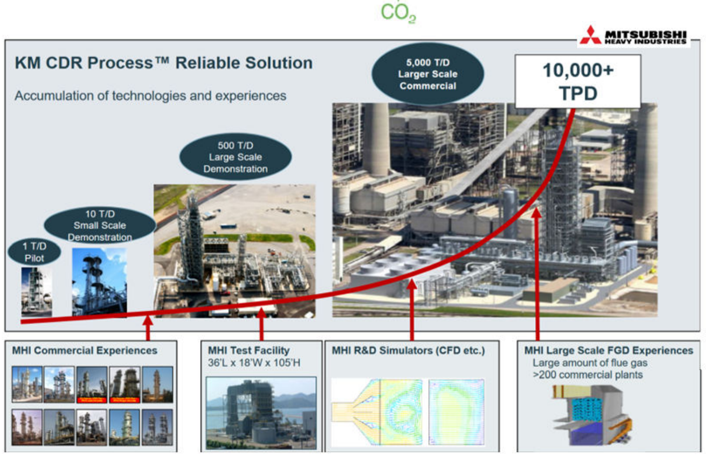
1. Pre- and Post- combustion

- Pre – Combustion Capture



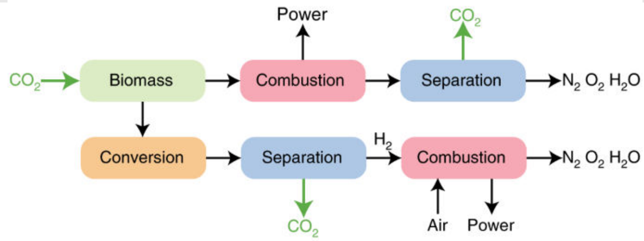
- Post – Combustion Capture





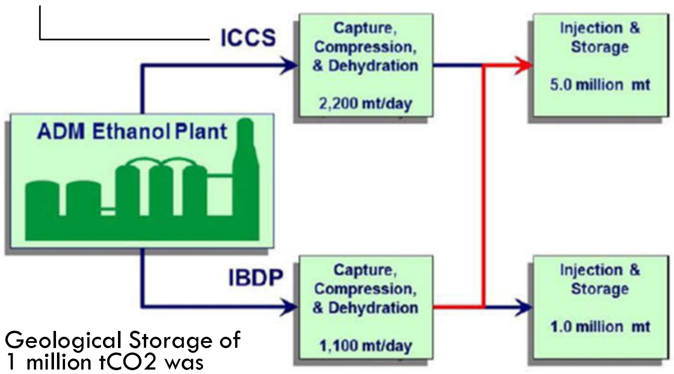
https://www.globalccsinstitute.com/wp-content/uploads/2021/10/1-6_P1_S6_MHIE_Takashi-Kamijo.pdf

2. Bioenergy with Carbon Capture and Storage (BECCS)



Project cost: $207 million (of which 68% from federal funding

Total capital and operational cost of the project: $28.35/tCO2

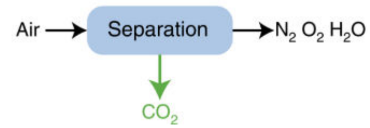


Geological Storage of 1 million tCO2 was achieved in November 2014

https://www.ieabioenergy.com/wp-content/uploads/2023/03/BECCUS-1.0_US-Case-Study_final_update.pdf

Source: https://www.linkedin.com/pulse/cement-concrete-carbon-capture-paving-way-greener-xz4qc/

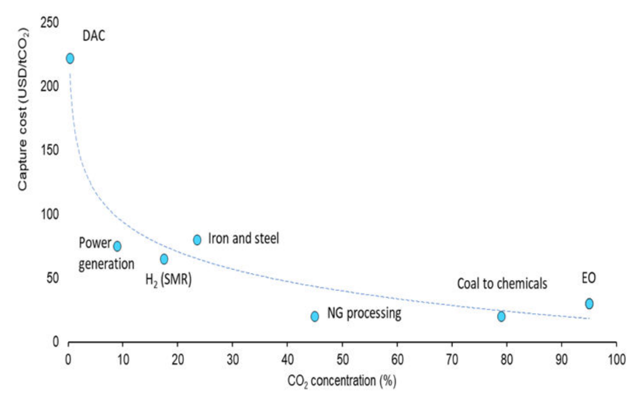
3. Direct Air Capture



	DAC
Capture capacity (MtC/year)	0.5 – 1
Levelised cost of capture (USD/tC)	Up to 340

Source: https://carboncredits.com/how-direct-air-capture-works-and-4-important-things-about-it/

CO_2 capture cost at varying CO_2 concentrations, 2020



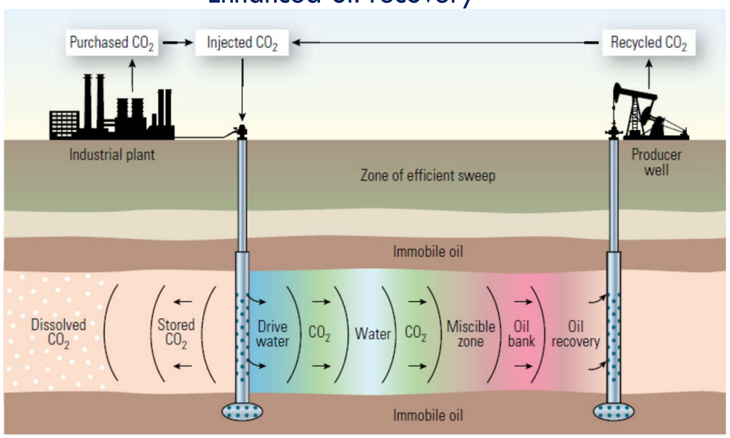
https://iea.blob.core.windows.net/assets/9766b4da-a5e3-4d76-874d-ea286e333956/DirectAirCapture_Akeytechnologyfornetzero.pdf

Carbon Capture, Utilization, and Storage (CCUS)

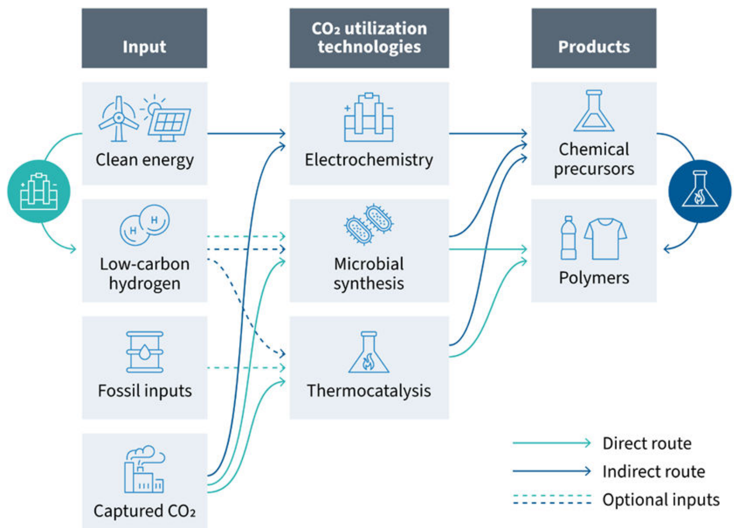
Utilization

1. Direct utilization

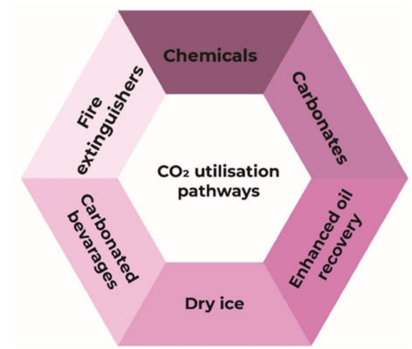
Enhanced oil recovery



2. Conversion of CO2 to useful chemicals/materials



Source: IDTechEx Research, 2022



Challenges of CO2 conversion to useful chemicals

- Technology Readiness: TRL 4-7
- Improving process efficiency and energy efficiency
- Hydrogen and Energy Input
- Catalyst Development
- Purity of CO2 feed

Abdullah, N., Hasan, N. Effects of miscible CO_2 injection on production recovery. *J Petrol Explor Prod Technol* **11**, 3543–3557 (2021).

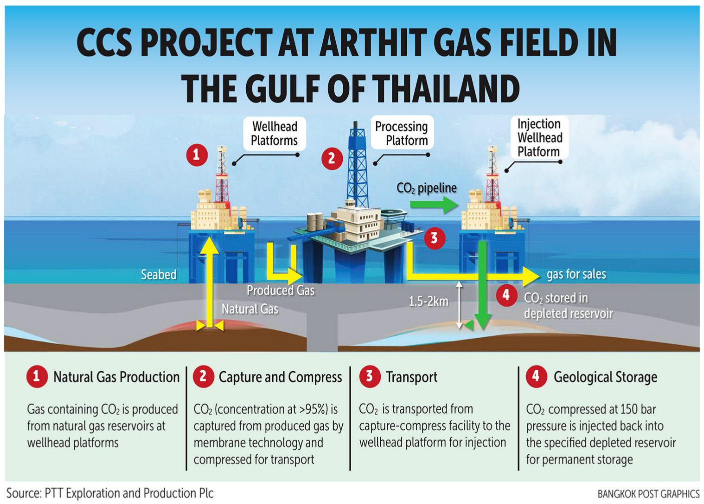
https://rmi.org/from-waste-to-value-how-carbon-dioxide-can-be-transformed-into-modern-lifes-essential-products/

https://cstep.in/drupal/sites/default/files/2024-11/Carbon-to-chemicals_A%20techno-commercial%20assessment.pdf

Carbon Storage

CCS Projects in Thailand

1. Arthit upstream CCS Project



- First national CCS pilot project--Aiming to commence operation in 2027 at Arthit concession area.
- Utilize the existing E&P infrastructure to capture CO_2 from E&P activities, then reinject into the subsurface.
- Aim to reduce up to 1,000,000 tonnes of CO_2 per year.

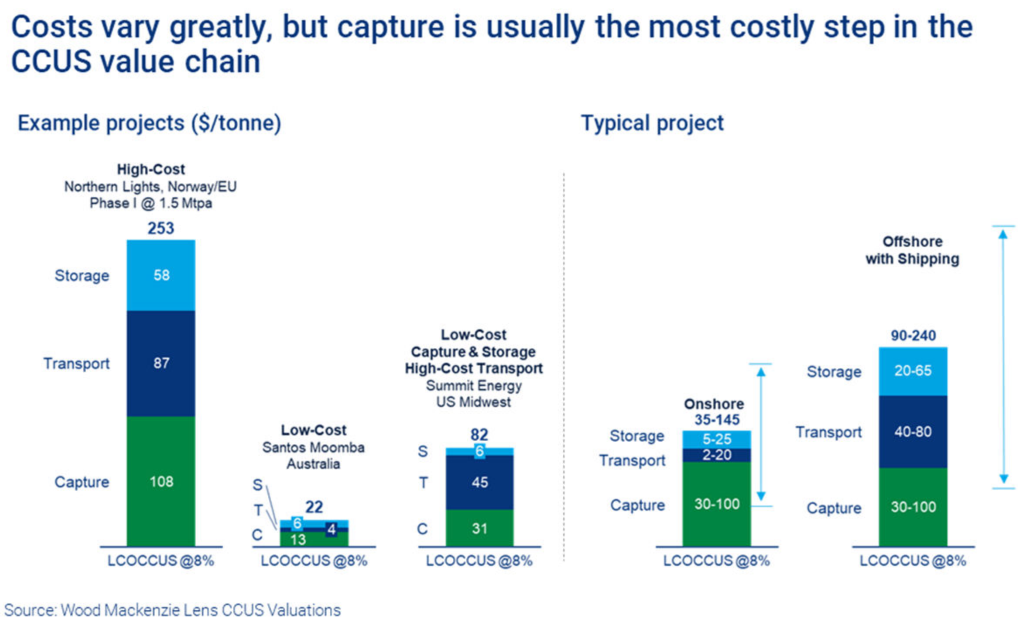
2. Eastern Thailand CCS Hub Project

- Large-scale CCS implementation to support long-term decarbonization of domestic industrial clusters along the East coast.
- Collect CO_2 emissions from industrial sources in the east coast, then transport to offshore for storage in the Gulf of Thailand., where multiple emitters can take advantage of a single Transportation & Storage (T&S) facThis model represents the so-called CCS.
- Expect to be operational by 2033 and will have a CO_2 storage capacity of approximately 6 Mtpa.

Source: PTT Exploration and Production Plc

Carbon Capture, Utilization, and Storage (CCUS)

Challenges and Future Prospects



Challenges

- **High costs** – The cost of carbon capture and the development of infrastructure for carbon transportation and storage still require massive investment.
- **Policy** – The lack of clear supportive policies from the government.
- **Collaboration** – Collaboration between the government, private sector, educational institutions, and the public.

Opportunities and Future Prospects

- **Decarbonizing Hard-to-Abate Sectors** – decarbonization of process emission from large sources, such as cement, refineries, and chemical industries.
- **Global Policy and Regulatory Support** – i.e. government policies, regulations, incentives (subsidies, tax credits, and funding for CCS infrastructure.
- **Utilization and Circular Economy** – conversion of captured CO_2 into valuable products, e.g. synthetic fuels, building materials, plastics and chemicals.

Decarbonization in Oil & Gas Industry

Decarbonization
in Process Industry

Carbon reduction can be employed throughout the whole process industry

Feedstocks and Resources	Process	Products and Wastes
Biomass	Process Improvement	Carbon Capture, Utilization and Storage
Electrification		Circular Economy
Hydrogen		

Circular Economy

Circular economy is the utilization of existing resources within a system to maximize benefits while minimizing resource consumption

Global Circular Economy

- Reduce pressure on natural resources and create sustainable job growth
- Achieve climate neutrality in 2050

Objectives

- Establish sustainable products as the standard in the European Union.
- Focus on resource-intensive sectors with high recycling potential, such as plastics, construction, textiles, and food.
- Reduce waste generation.
- Enable circularity for people, regions, and cities.
- Lead global efforts in advancing the circular economy.

Source: https://petromat.org/home/circular-economy-model/

Benefits

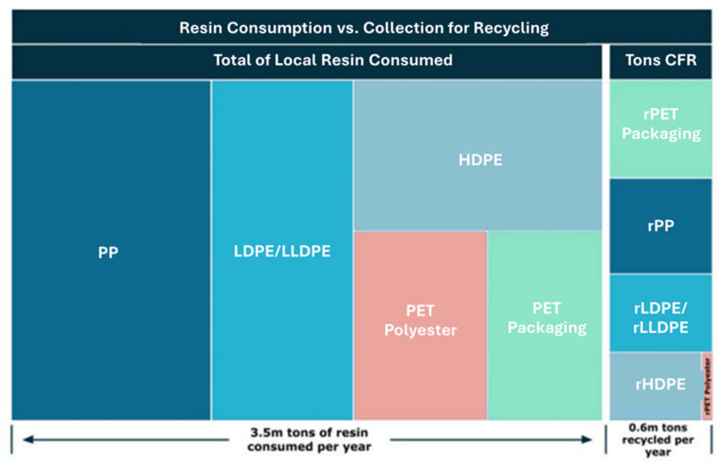
- Reduce waste, enhance value, and maximize the utility of used materials/waste.
- Sustainably recycle and reuse resources.
- Minimize landfill disposal and incineration, leading to reduced carbon dioxide emissions.

Technology readiness of plastic recycle

Recycling Technology	Mechanical Recycling	Depolymerizatio n	Pyrolysis
PET	4	3	2
PU	2	3	3
PA	1	3	3
PS	4	3	4
PE	4	1	4
PP	4	1	4

Potential level: 4 = High, 3 = Medium, 2 = Low, 1 = very Low

Highlight = Currently applied technologies. Source: Boston Consulting group



Source: Market Study for Thailand: Plastic Circularity Opportunities and Barriers

Reuse and Reduce

- The production of plastic pellets using SMX technology by SCG Chemicals Co., Ltd. (SCGC) enhances durability while using less material, maintaining the original product properties.

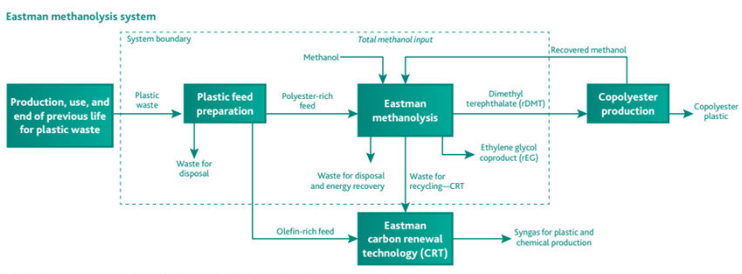
Mechanical Recycling

- Recycling without chemical alteration involves collecting and sorting materials before processing.
- Example: ENVICCO utilizes cutting-edge technology to enhance accuracy and efficiency in sorting, particularly for PCR PET and PCR HDPE.
- Collaboration: PPC and the ASEAN Vinyl Council are working together to establish a database for PVC recycling in Thailand.

Chemical Recycling

Depolymerization

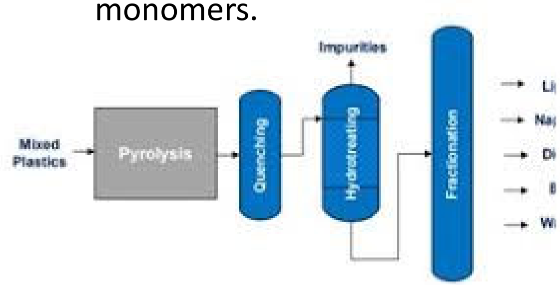
- The process involves breaking down polymer chains into monomers through chemical reactions.
- Example: Eastman utilizes Polyester Renewal Technology (PRT) and Carbon Renewal Technology (CRT) for polymer recycling.



Eastman Methanolysis System
Source: LCA summary report for Eastman methanolysis technology (North America)

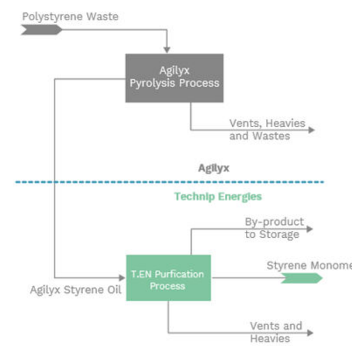
Pyrolysis

- This process involves high-temperature heating to break down complex structures into smaller molecules.
- The resulting products can be used to produce fuels or monomers.



Pyrolysis of Mixed plastic

Source: https://www.sulzer.com/en/shared/applications/mixed-plastics-pyrolysis



Production of styrene monomer from pyrolysis process
Source: https://www.ten.com/sites/energies/files/2023-05/Brochure_TruStyrenyx.pdf

Decarbonization Technology

Thailand's Goals toward Carbon Neutrality and Net Zero

2030 | 2050 | 2065

Unconditional NDC Target
30% GHG Reduction

Carbon Neutrality

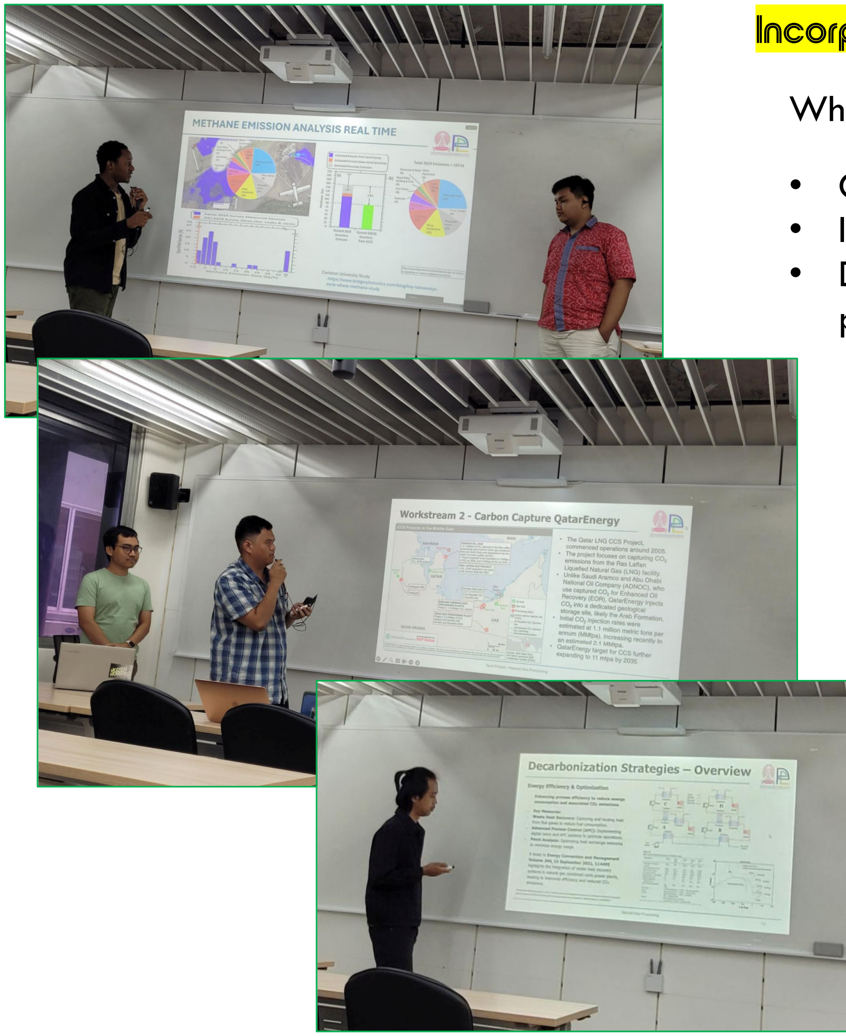
Net Zero Emissions

Conditional NDC Target
40% GHG Reduction

Carbon reduction can be employed throughout the whole process industry

- **Biomass**
- **Electrification**
- **Hydrogen**
- **Process Improvement**
- **Carbon Capture, Utilization and Storage (CCUS)**
- **Circular Economy**

Way Forward: Universities as Partners in Global Decarbonization



Incorporating Decarbonization / Digital Tools in Graduate Education

Why It Matters?

- Climate crisis demands urgent emissions reduction
- Industries face net-zero mandates and carbon pricing
- Decarbonization is reshaping job markets and research priorities

How to Integrate?

- Case studies on real-world decarbonization projects
- Group projects solving industrial challenges
- Guest lectures from sustainability professionals

Outcomes for Students

- Competency in low-carbon technologies & strategy
- Career readiness for future sustainability roles
- Systems-thinking skills for complex energy transitions

Empower the next generation to lead the net-zero transition.

Acknowledgement

The Thai Institute of Chemical Engineering and Applied Chemistry (TIChE)

White Paper on “Decarbonization for Sustainability in Thailand’s Process Industry”

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Petroleum and Energy Institute of Thailand (PEIT)

PEIT Climate Change Task Force

THANK YOU