淨零大挑戰：在全球能源轉型浪潮中，臺灣如何轉危為機？

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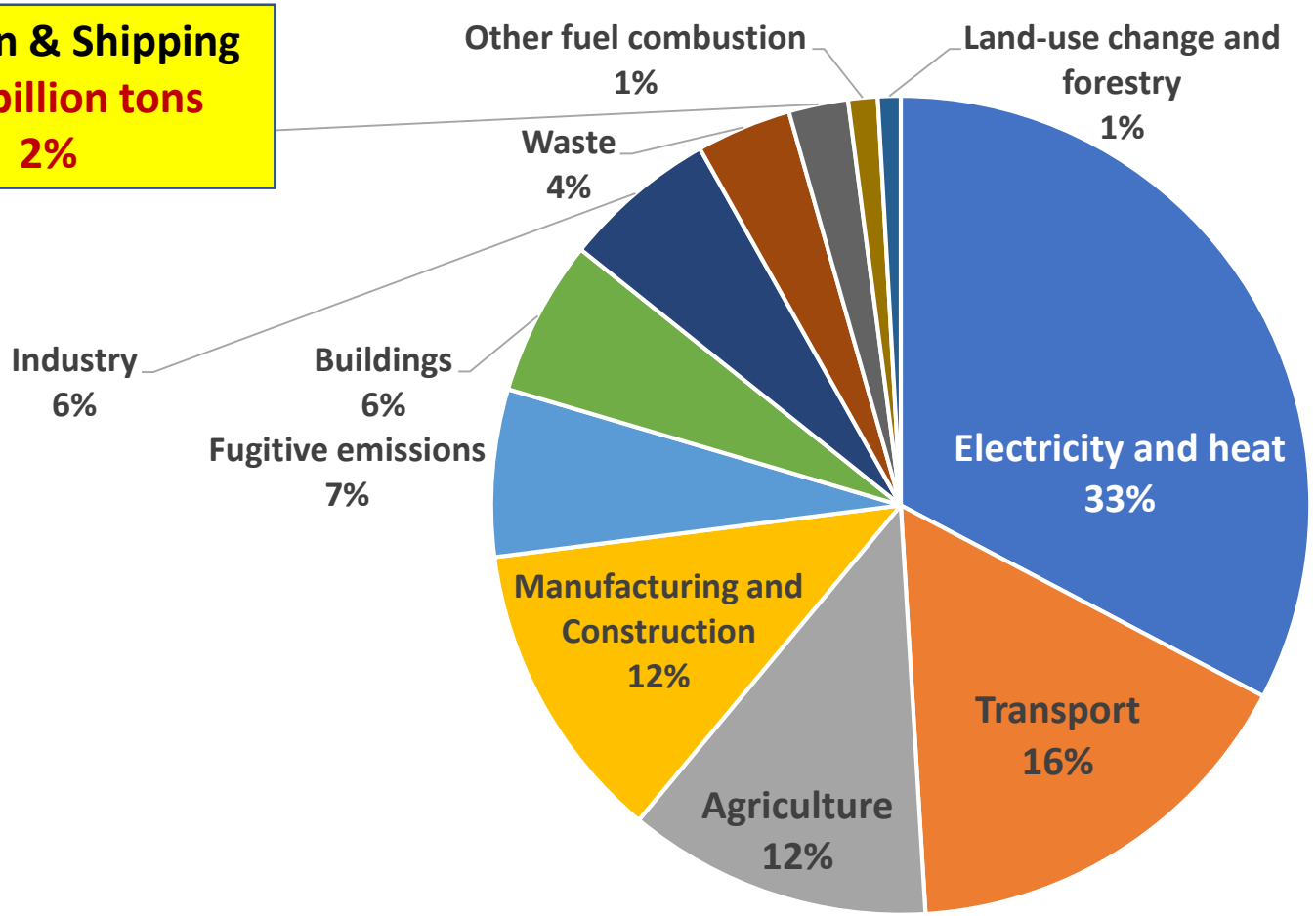
航空產業淨零碳排永續發展研討會

Global greenhouse gas emissions by sector, 2023

53.0 (57.1) billion tons

Aviation & Shipping
1.22 billion tons
2%



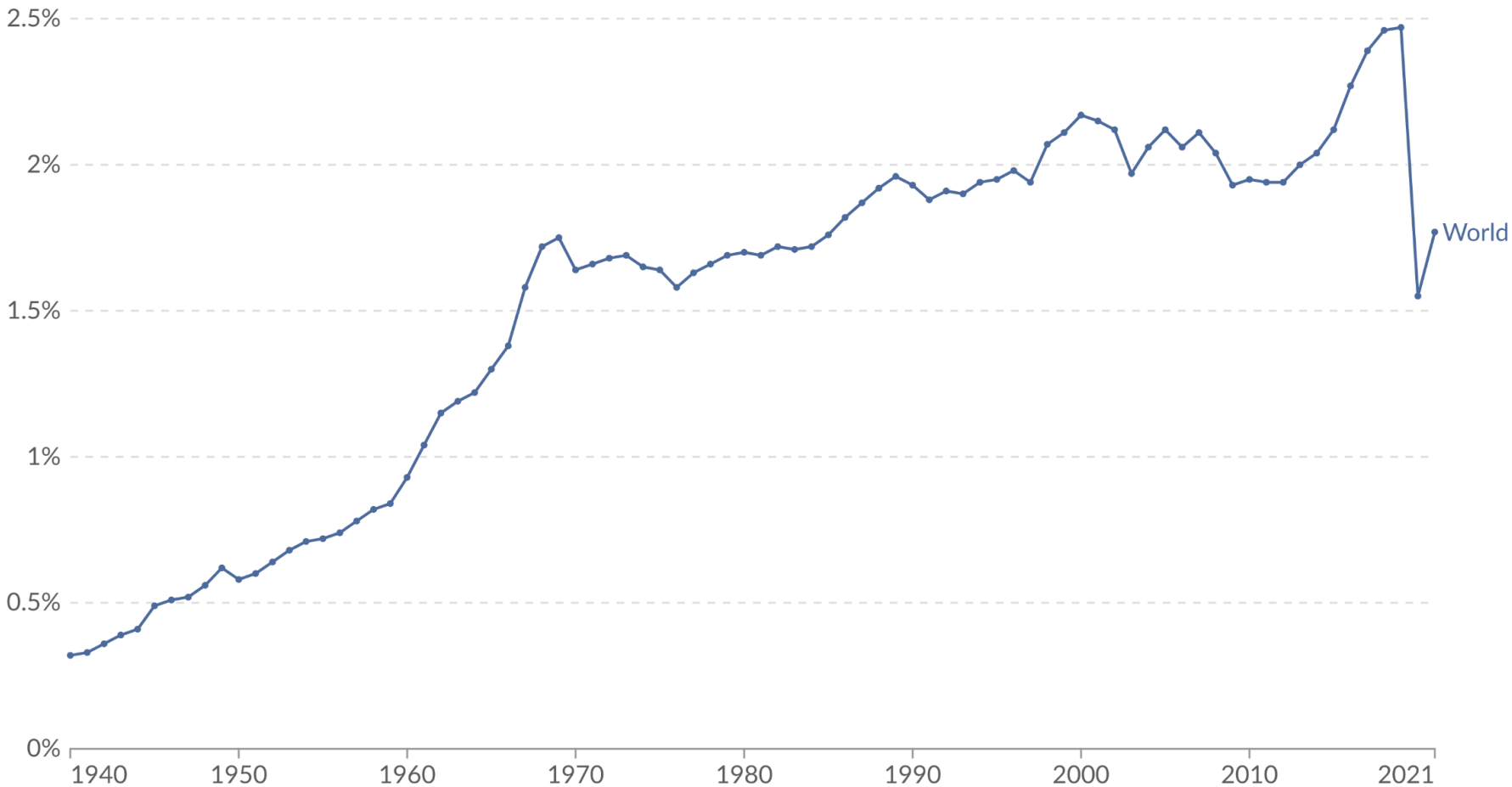
The energy sector is the largest contributor to global greenhouse gas emissions, responsible for approximately 73% to over 75% of total emissions.

Data source:
https://ourworldindata.org/grapher/ghg-emissions-by-sector
Climate Watch (2026) – Learn more about this data

Aviation's share of global CO_2 emissions, 1940 to 2021

Our World in Data

Given as a share of carbon dioxide emissions from fossil fuels[1] and land use change[2].

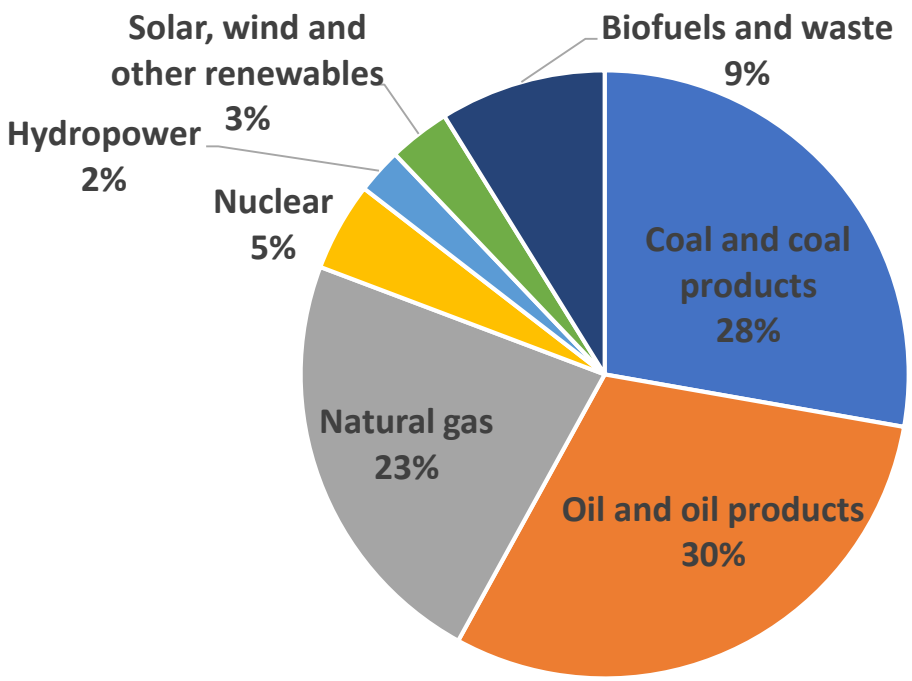


Data source: Calculated by Our World in Data based on Lee et al. (2020); Bergero et al. (2023); and the Global Carbon Project.

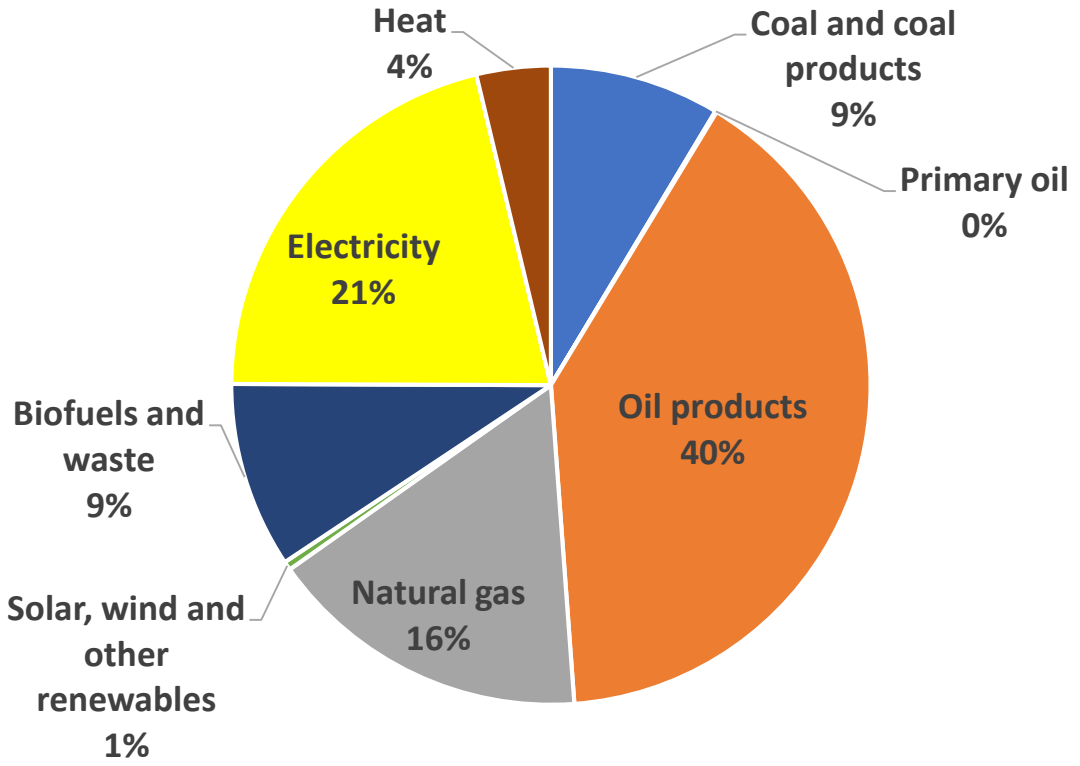
Note: Non-CO_2 forcings from aviation, and the increased warming impacts are altitude are not included.

Global Energy Mix

Total energy supply in World, 2023
633,682,434TJ

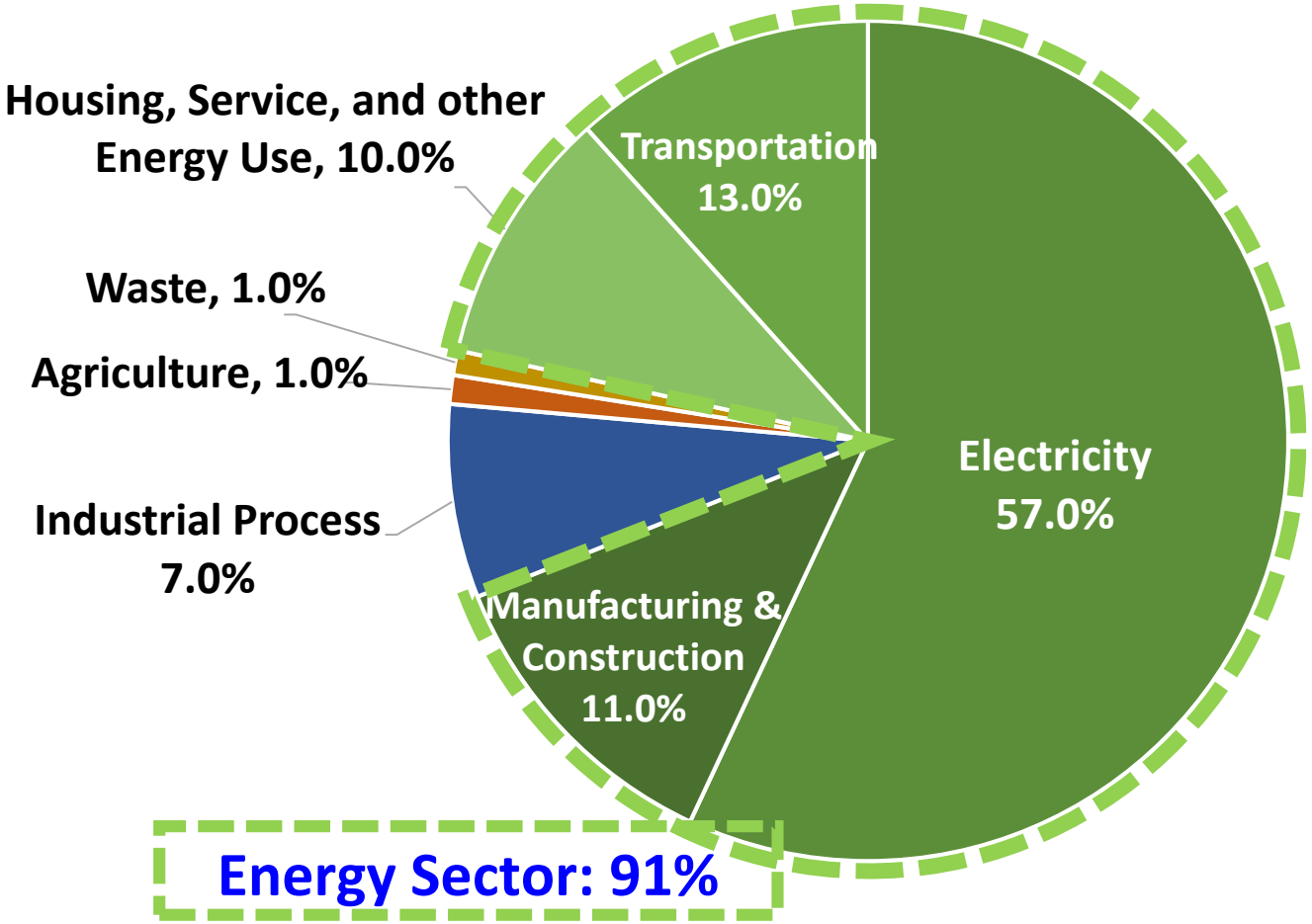


Total final consumption, World, 2023
429,107,543 TJ



https://www.iea.org/world/energy-mix

2023 Taiwan GHG Emissions: 279 Mt CO2 eq.



Population related

Transportation (electricity), 12.9%

Residential (electricity), 10.3%

Commercial (electricity), 9.8%

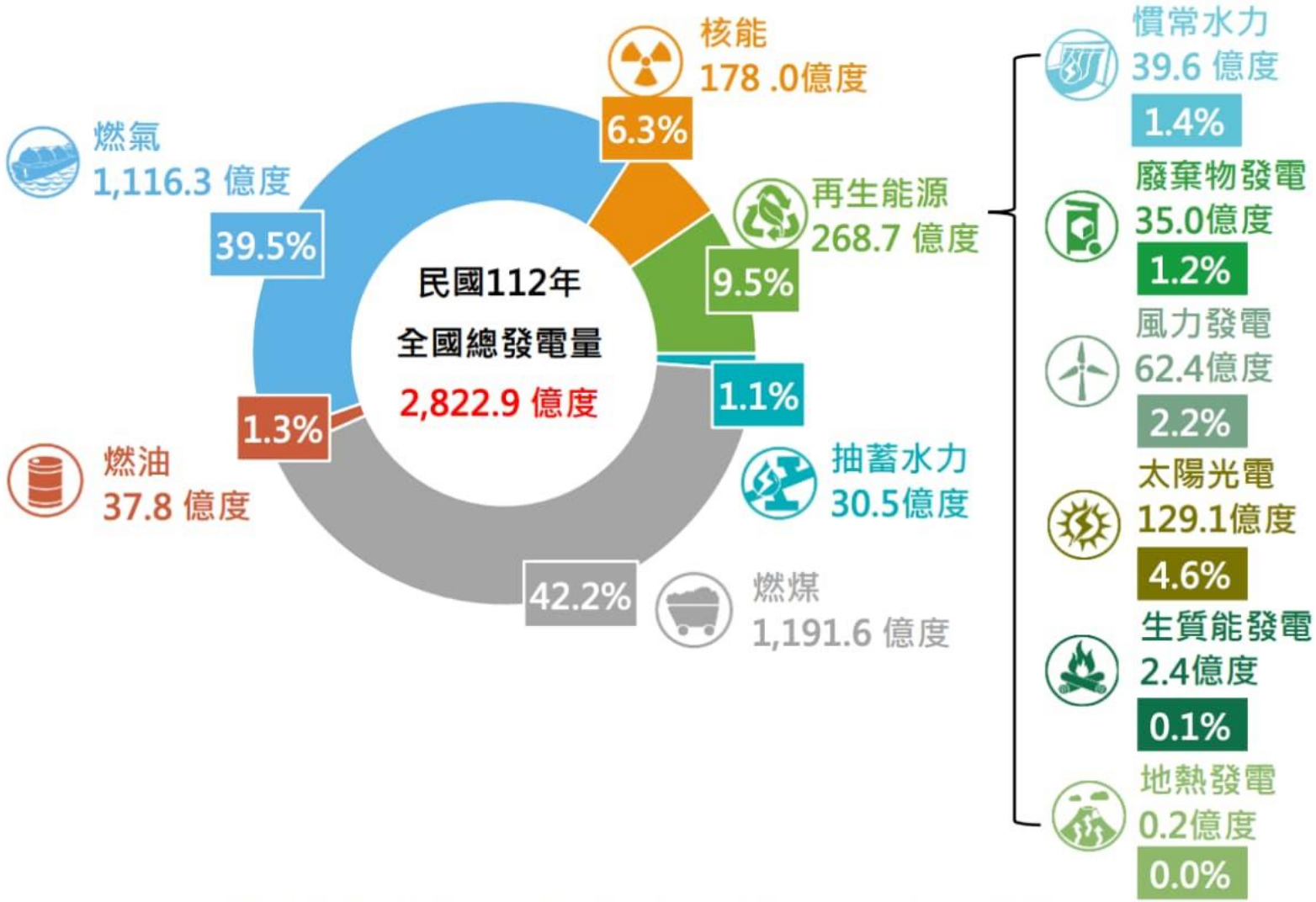
GDP dependent

Industry (electricity), 45.5%

Electrification toward 2050

Top Priority: Decarbonization in Electricity Generation

2023年台灣各種能源發電量及占比



註1：全國總發電量係為毛發電量，包括台電系統及自用發電設備的自用電量。
註2：百分比及發電量加總存在小數進位誤差。
資料來源：經濟部能源署，統計月報，民國113年7月版。

Solution: Low/No Carbon-emission Energy Sources

Renewable, Green, and other Energy Options

1. Solar
2. Wind
3. Geothermal
4. Marine Energy
5. Hydropower (NG)
6. Biomass (NG)
7. Hydrogen (grey, blue, green, turquoise, pink)
8. Nuclear (III, IV, fusion)

They are good and necessary, but ……

Roof-top space limited

Land area Limited (Agriculture competition)

Noise

Tough and higher investment

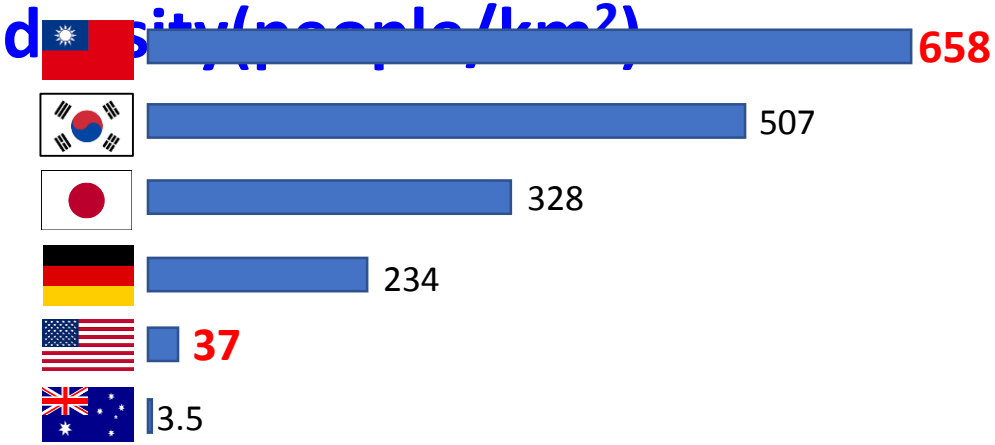
Beyond possible, how about higher conversion rate!

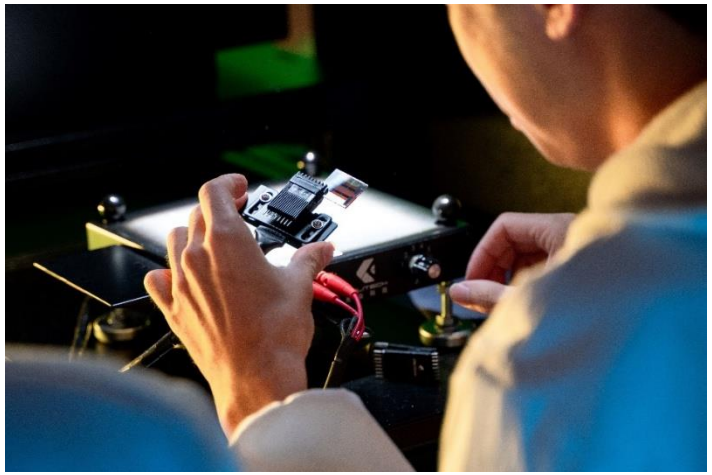
High-efficiency Solar Energy

Alleviate land demand

- The increase in power generation per unit area is very important for Taiwan, which lacks land for installation.
- By utilizing 40% of the available 43 thousand hectares, the installed capacity will be 28.41 GW, with a conversion rate of 22%.
- If the conversion rate is increased by 50%, the installed capacity could reach 42.62 GW using the same land area.

Population density(people/km²)

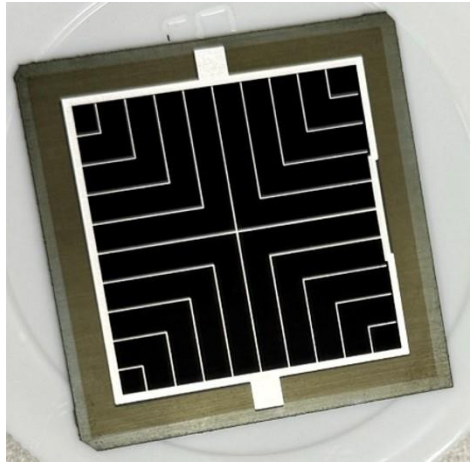




Tandem Perovskite-Silicon cells

Current Progress

- Installed a test production line for tandem perovskite/Si solar cells in the Southern Campus of Academia Sinica.
- Academia Sinica has developed next-generation solar cells with a light-to-electricity conversion efficiency exceeding 30% (3cmx3cm).



They are self-owned and needed, but ……

Base-loaded, Self-owned, ……
Need innovative exploration

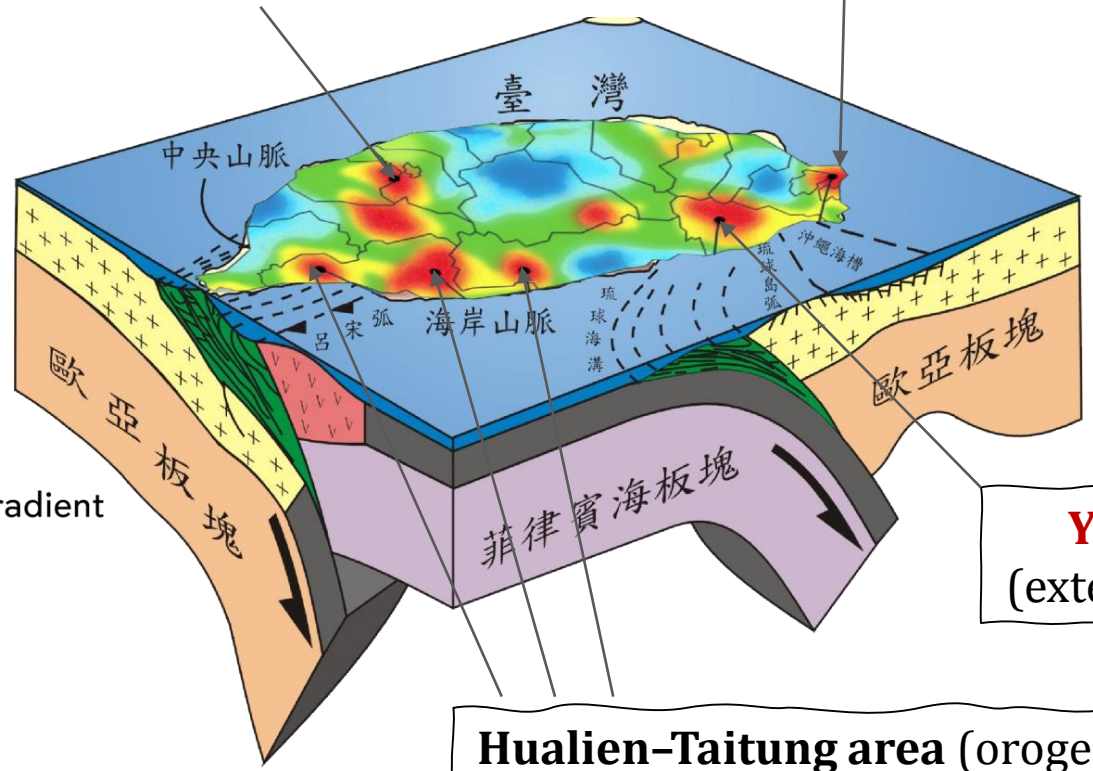
Some based-loaded, Self-produced, ….
Need novel exploration and technology

Explore and Deploy!

Geothermal Potential in Taiwan

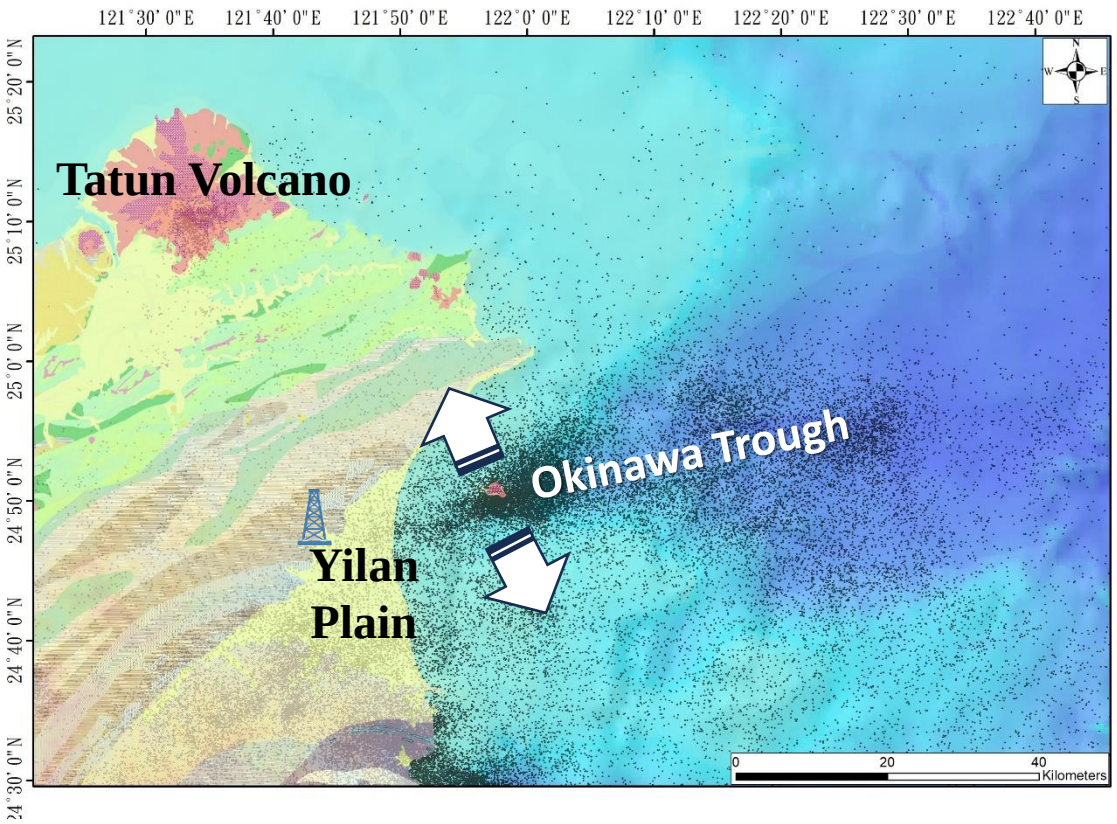
Tatun Volcano
(volcanic type)

Southwestern foothills
(geopressured geothermal system)



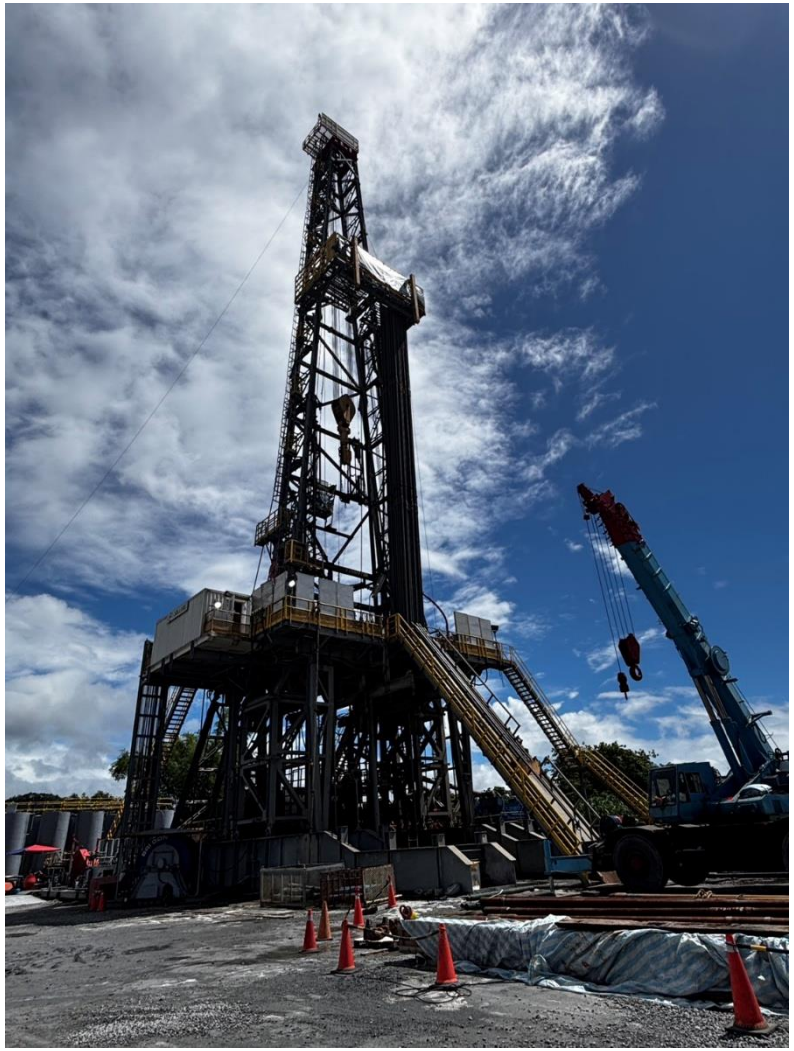
Temp.Gradient
(°C/km)

40
35
30
25
20

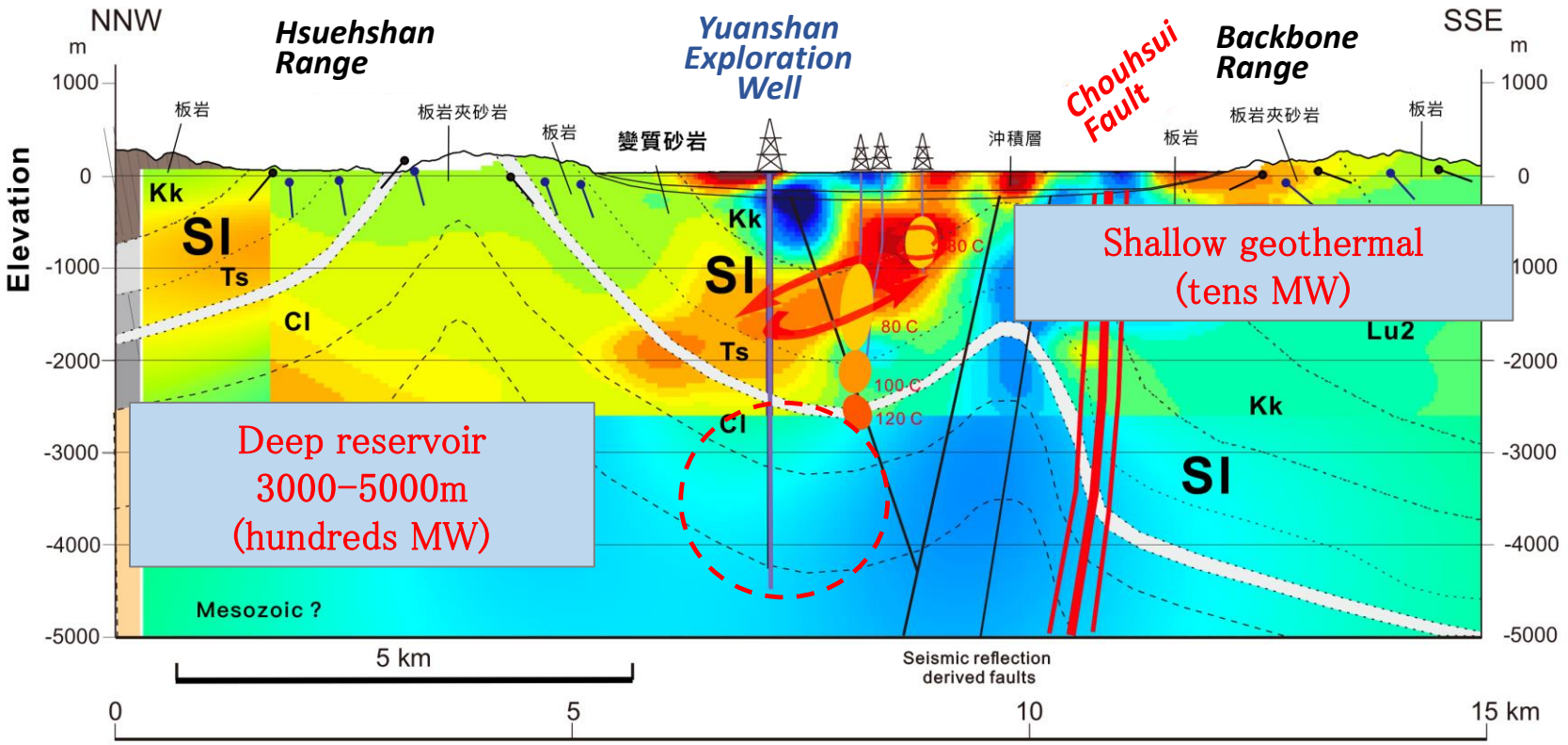


Yilan Plain
(extensional type)

Hualien–Taitung area (orogenic belt type)



Geothermal Potential in Yilan



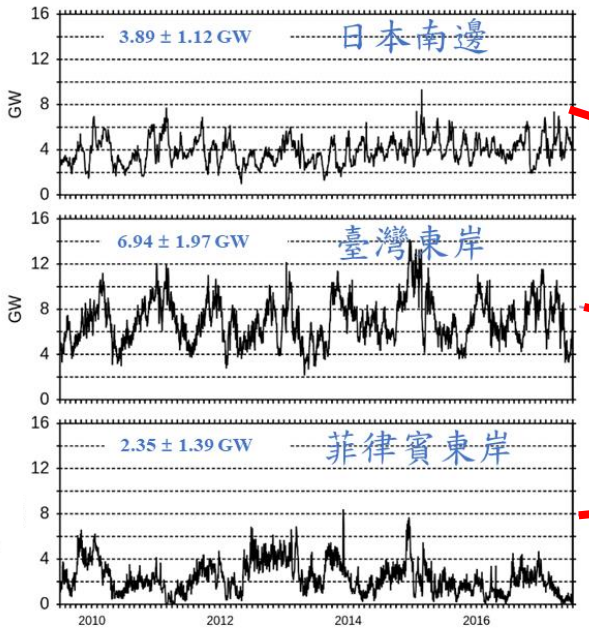
Marine (Kuroshio Current) Energy

Southern Japan

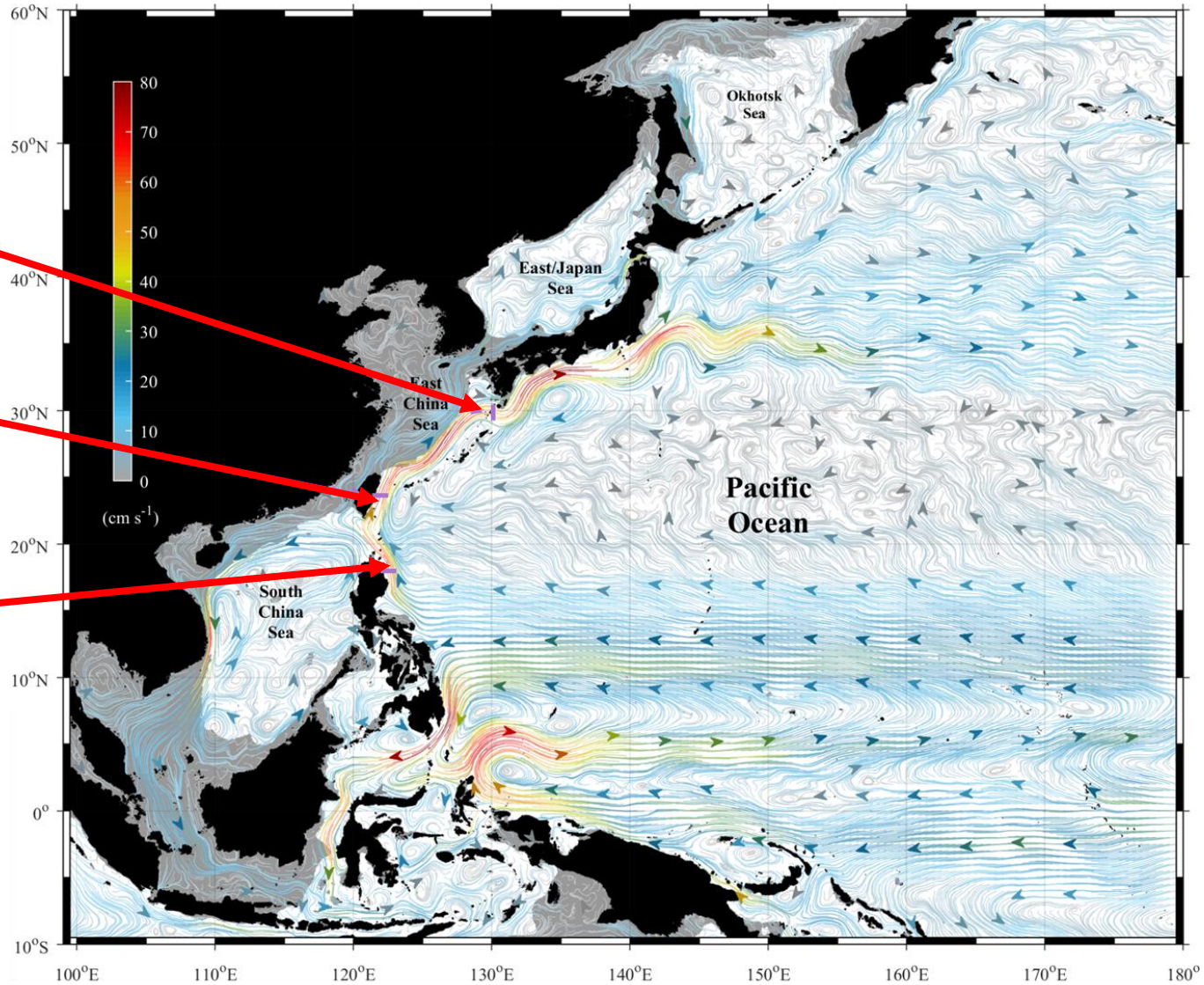
Eastern Taiwan

Philippines

Capacity Observation



資料來源：環變中心海洋數值模式



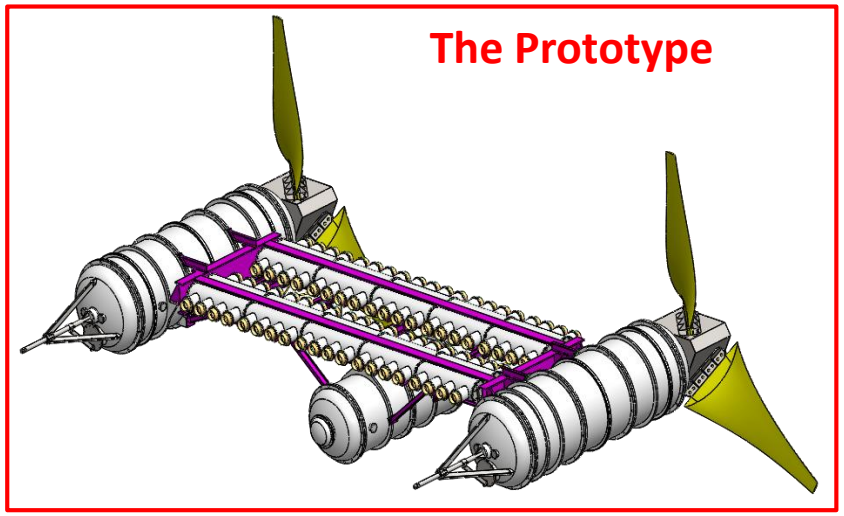
資料來源：ARGO drifter trajectories (全球浮標觀測資料)

- Taiwan's east coast is **1.5-2.5** times stronger.

Marine (Kuroshio Current) Energy (It takes longer time!)

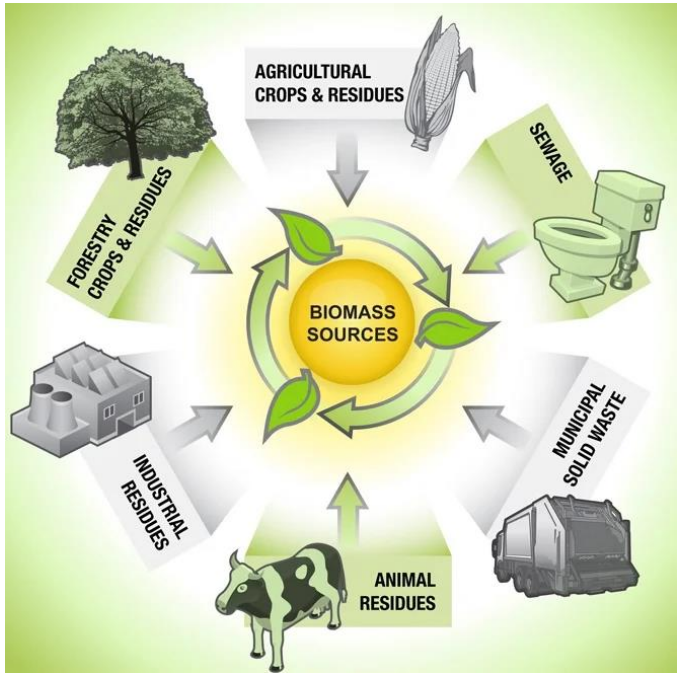
Key Technologies:

- Generator (50kWx2)
- Shell (working pressure 100m)
- Blades and bearings
- Anchor system



They are possible contributors, but ……

Not enough quantity



https://lotusarise.com/biomass-energy-upsc/

Challenging due to the environmental concern and global climate change

https://www.tetratech.com/en/markets/energy/solutions/hydropower

If there is still no solution for the waste….., we probably have to wait for fusion…..

In case, we may still need their contribution!

Hydrogen is a rising and necessary energy source, but ……

Color	GREY HYDROGEN	BLUE HYDROGEN	TURQUOISE HYDROGEN*	GREEN HYDROGEN
Process	SMR or gasification	SMR or gasification with carbon capture (85-95%)	Pyrolysis	Electrolysis
Source	Methane or coal	Methane or coal	Methane	Renewable electricity

+PINK

Note: SMR = steam methane reforming.

https://www.weforum.org/agenda/2021/07/clean-energy-green-hydrogen/

	Electrolysis	Pyrolysis	SMR
Source material	H_2O	CH_4	CH_4, H_2O
Energy Input	$2H_2O \rightarrow O_2 + 2\mathbf{H_2}$	$CH_4 \rightarrow C_{(S)} + 2\mathbf{H_2}$	$CH_4 + 2H_2O \rightarrow \mathbf{CO_2} + 4\mathbf{H_2}$
	572 kJ	76 kJ	126 kJ (per 2 mole H_2)
Energy Output	$2H_2 + O_2 \rightarrow 2H_2O$	$2H_2 + O_2 \rightarrow 2H_2O$	$2H_2 + O_2 \rightarrow 2H_2O$
	572 kJ	572 kJ	572 kJ
Energy Net	572-572= **0** kJ	572-76= **496** kJ	572-126= **446** kJ
By Product	–	Solid carbon	CO_2
Pros	Long-term energy storage	Base-loaded zero-carbon electricity	Already commercialized
Cons	No energy gain	Nature gas import	Nature gas import
	Hydrogen storage	Not yet commercialized	Need carbon capture

Methane Pyrolysis to Clean Power

$CH_4 \xrightarrow{\text{pyrolysis}} H_2 + C\,(s)$

Materials with C

Collaborated with *TAIPOWER* in MPCP + Micro-gas turbine

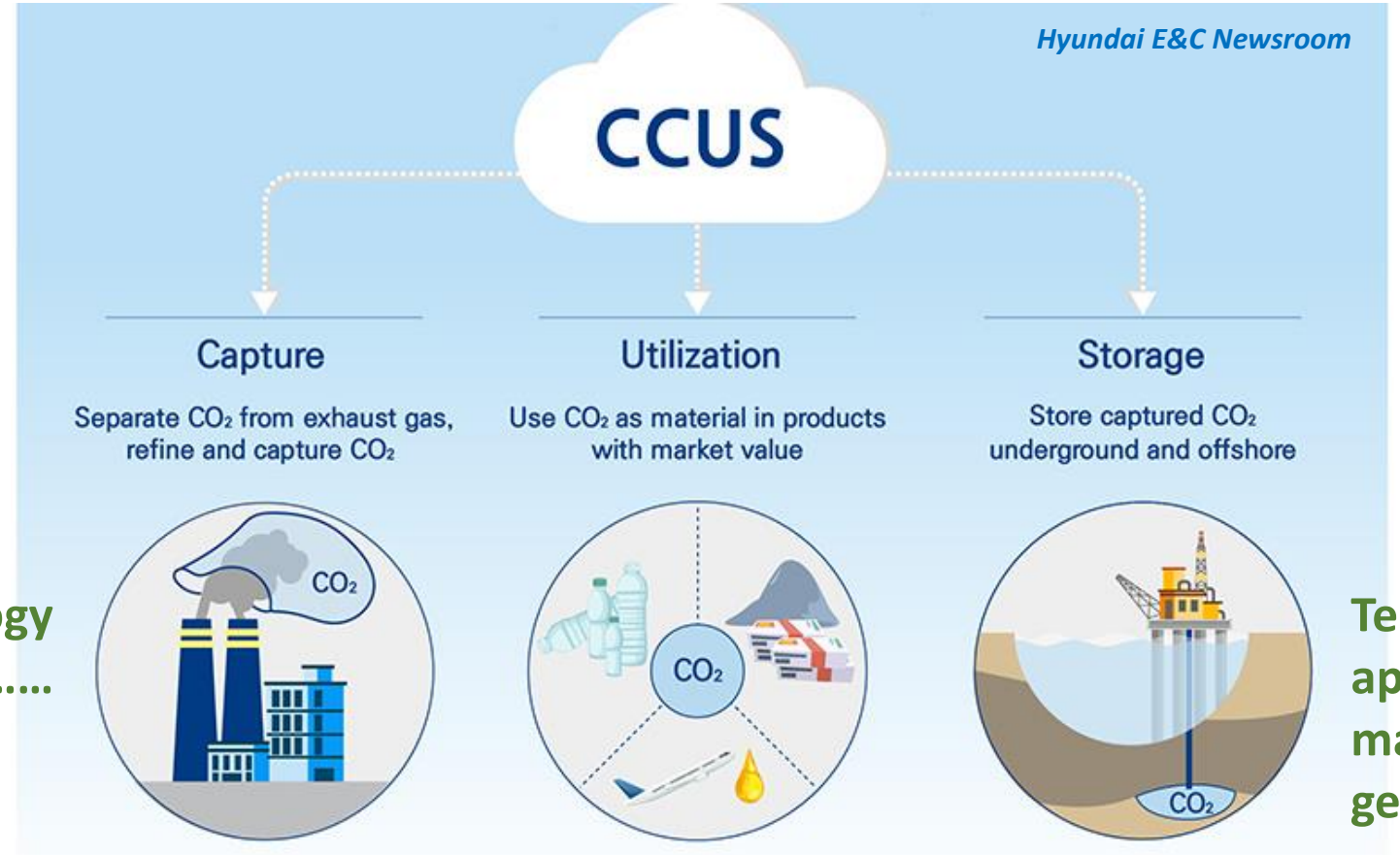
***TAIPOWER* is Taiwan's largest electric company (>85%) and the only power grid operator.**

Solutions for the rest of emissions

Decarbonization Options

1. Electrification and New fuel (replace fossil fuel combustion)
2. Lower Industrial Emissions of other GHG
3. Energy Efficiency (save electricity and recycle the heat)
4. CCS and CCU
5. Nature Carbon Sinks (Forest, Soil, Marsh, Marine phytoplankton, Marine deposit)
6. Other Carbon Capture Technology (i.e., DAC, Biomass)

It is useful technology, but ……



Existing technology and developing ……

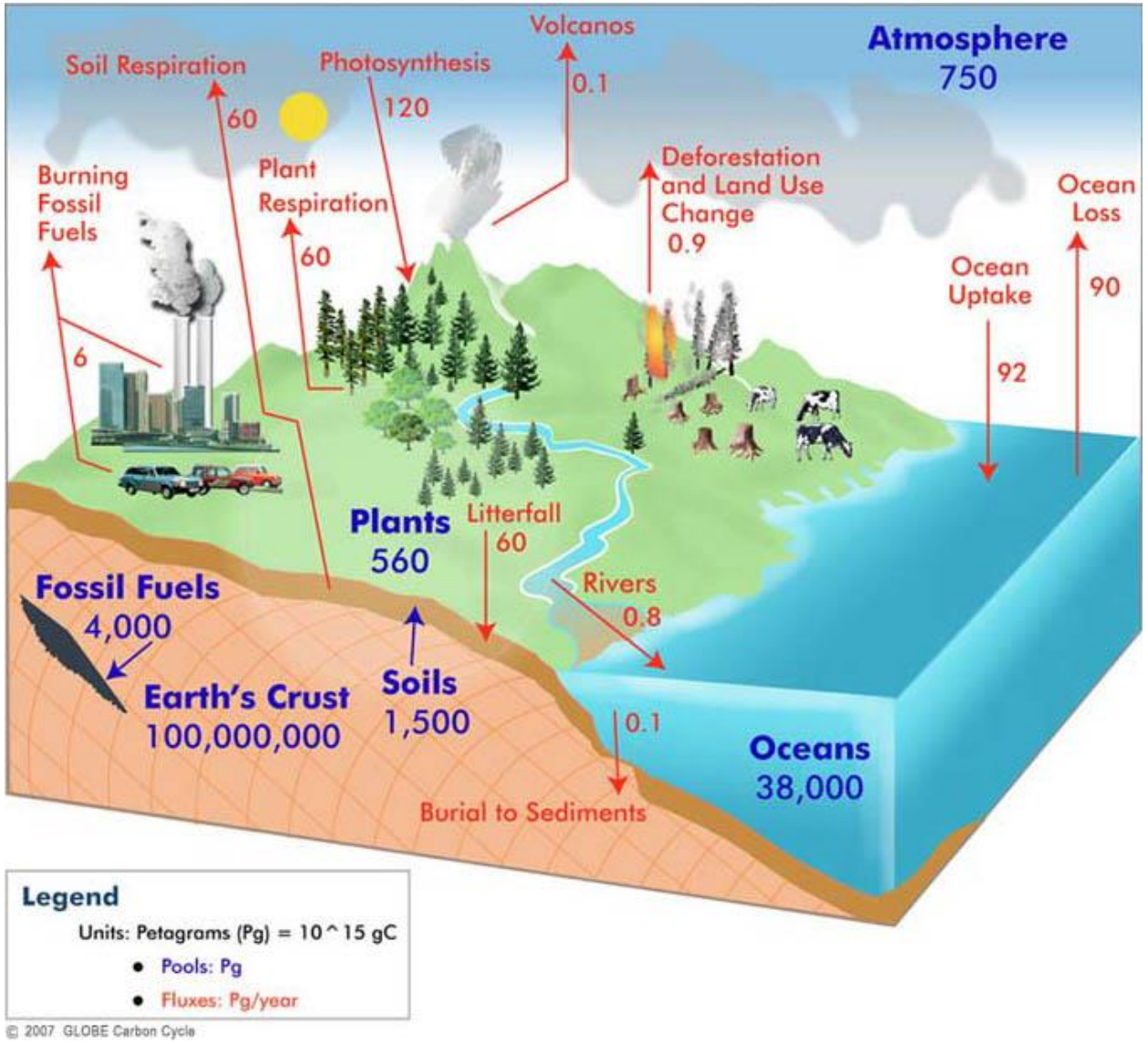
Technology has been approved, but needs mapping subsurface geology ……

Key is no extra CO_2 emission. Even though, the amount is still limited.

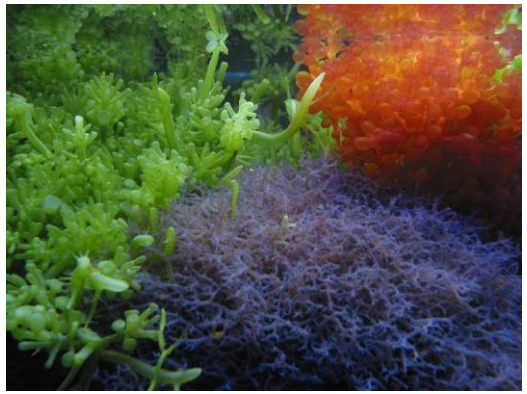
Major carbon sinks:

1. Plants (Trees, Forest, and Grass)
2. Soils and Sediments (Organics and Carbonates)
3. Oceans (Marine phytoplankton and DIC/DOC)

Increase the capacity!



Biomass Carbon Sink



Hydrolysis-Fermentation

Anaerobic Digestion

Pyrolysis

Bio-Energy

Biofuel

Bio-methane

H_2

Bio-hydrogen

Utilization

FLY NET ZERO

SAF

Storage

Bio-carbon

Bio-chemicals

Biomass Carbon Sink

Pennisetum purpureum

- **Widely distributed in tropical and subtropical regions around the world.**

Plant Species	CO^2 fixation power (t/ha/yr)	Max CO^2 fixation (Mt/yr)	Account for TW's CO_2 Emissions (%)	note
Bamboo	150.0	15.75	5.73%	Moso bamboo
Pennisetum	**100.0**	**10.5**	**3.82%**	**3 harvests/yr**
Corn	50.0	5.25	1.91%	2 harvests/yr

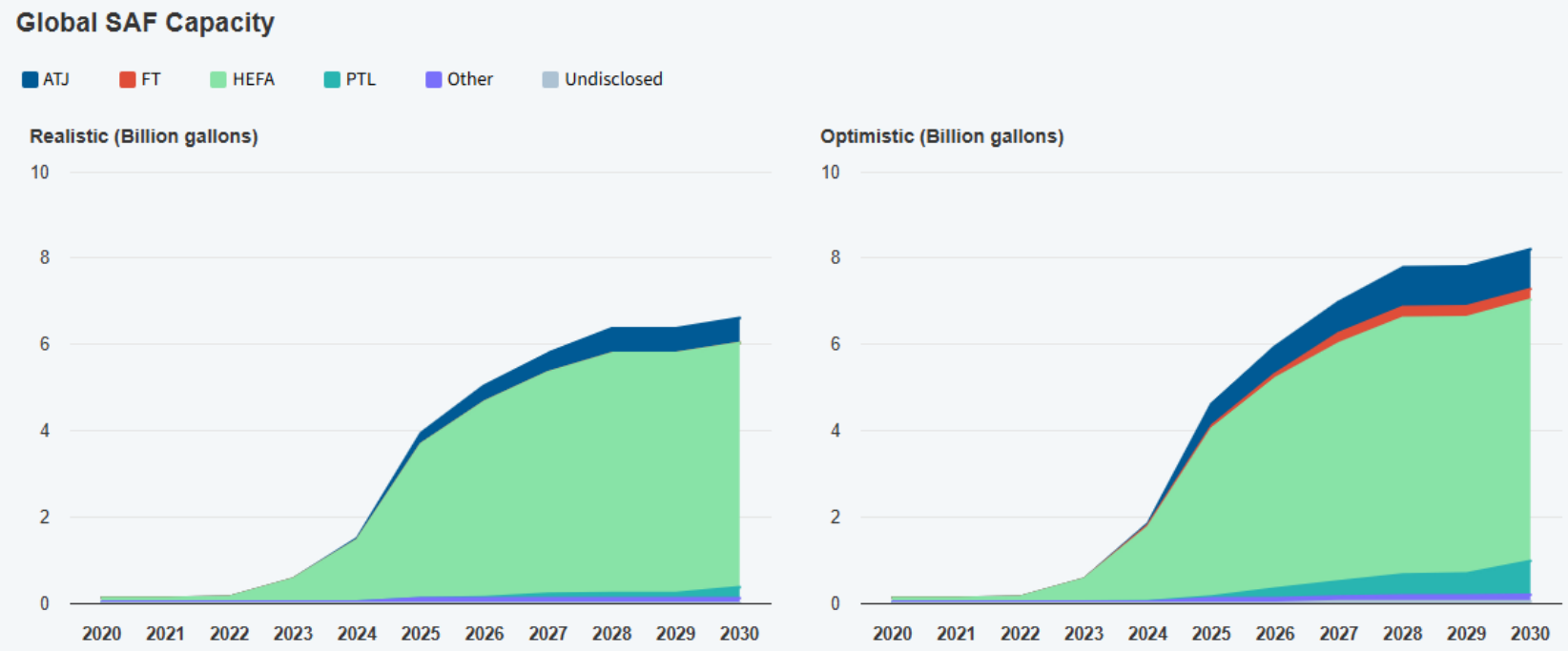
Crushed *Pennisetum* to be burned into biochar.

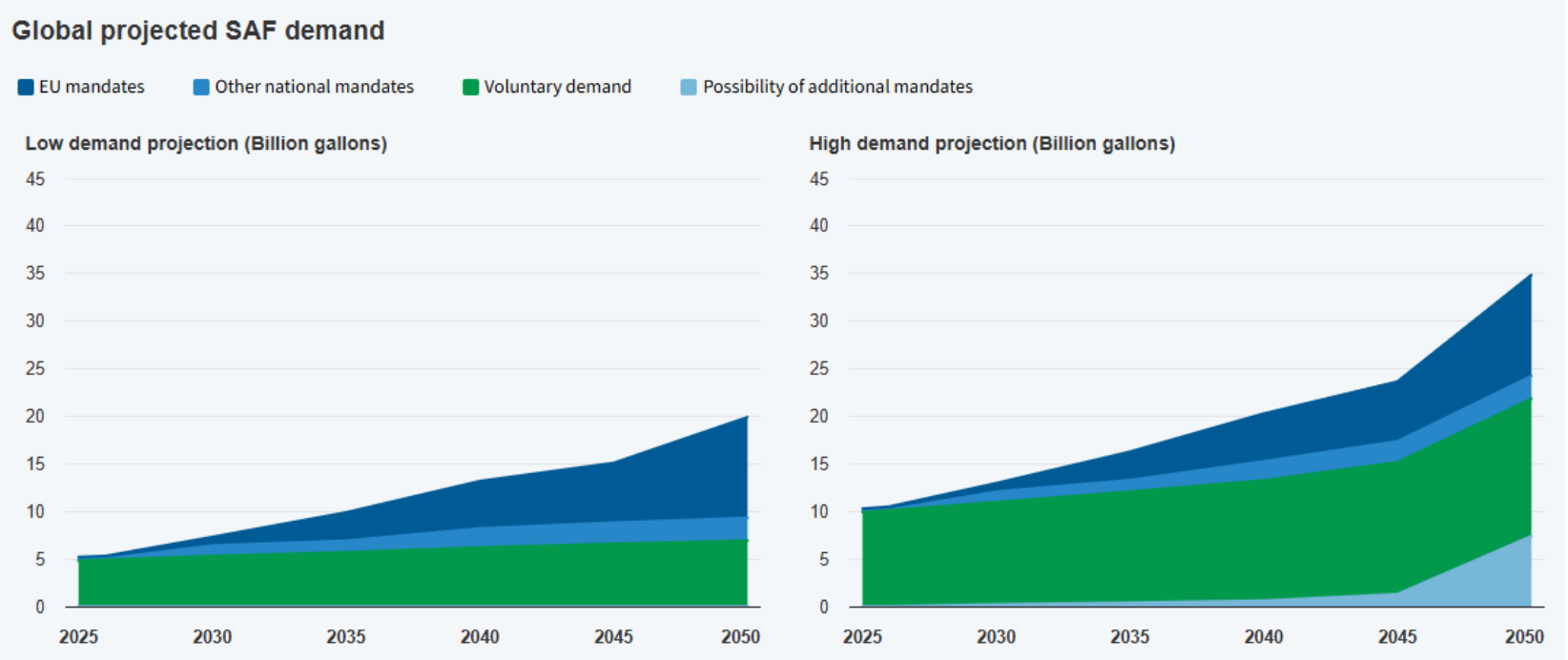
Pyrolysis

The final biochar from *Pennisetum*

#4 *Pennisetum* is able to grow up to 3m.

Global SAF Market





https://saf.rmi.org/

Economic Boosters

- green financial action (tax), carbon price, carbon trade, circular economics, environmental friendly investment

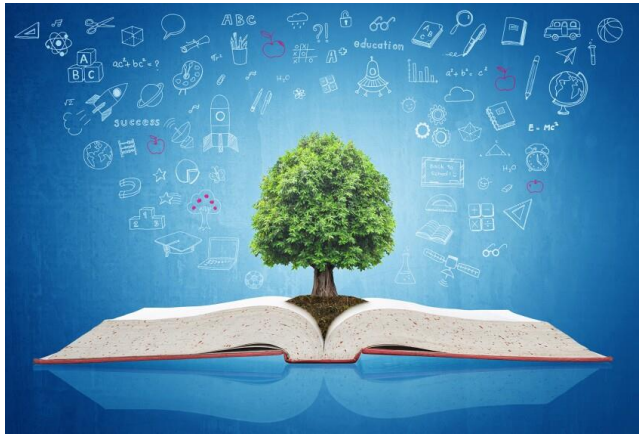
New Currency =  + 

New Recycle =  + 

Social Boosters

- just transition, citizen participation, education

Leave no one behind



Terminal success needs well-educated mindset.

Opinions are all welcomed

Opportunities

1. Multiple novel technologies are definitely needed. New market and supply chain are reforming.
2. Self-owned energy sources are anticipated to be larger contributors.
3. Prioritization has to be correctly made, but time is ticking.

Thank you very much for listening.

中央研究院 永續科學中心
Center for Sustainability Science

多少能源用在發電？ 45%

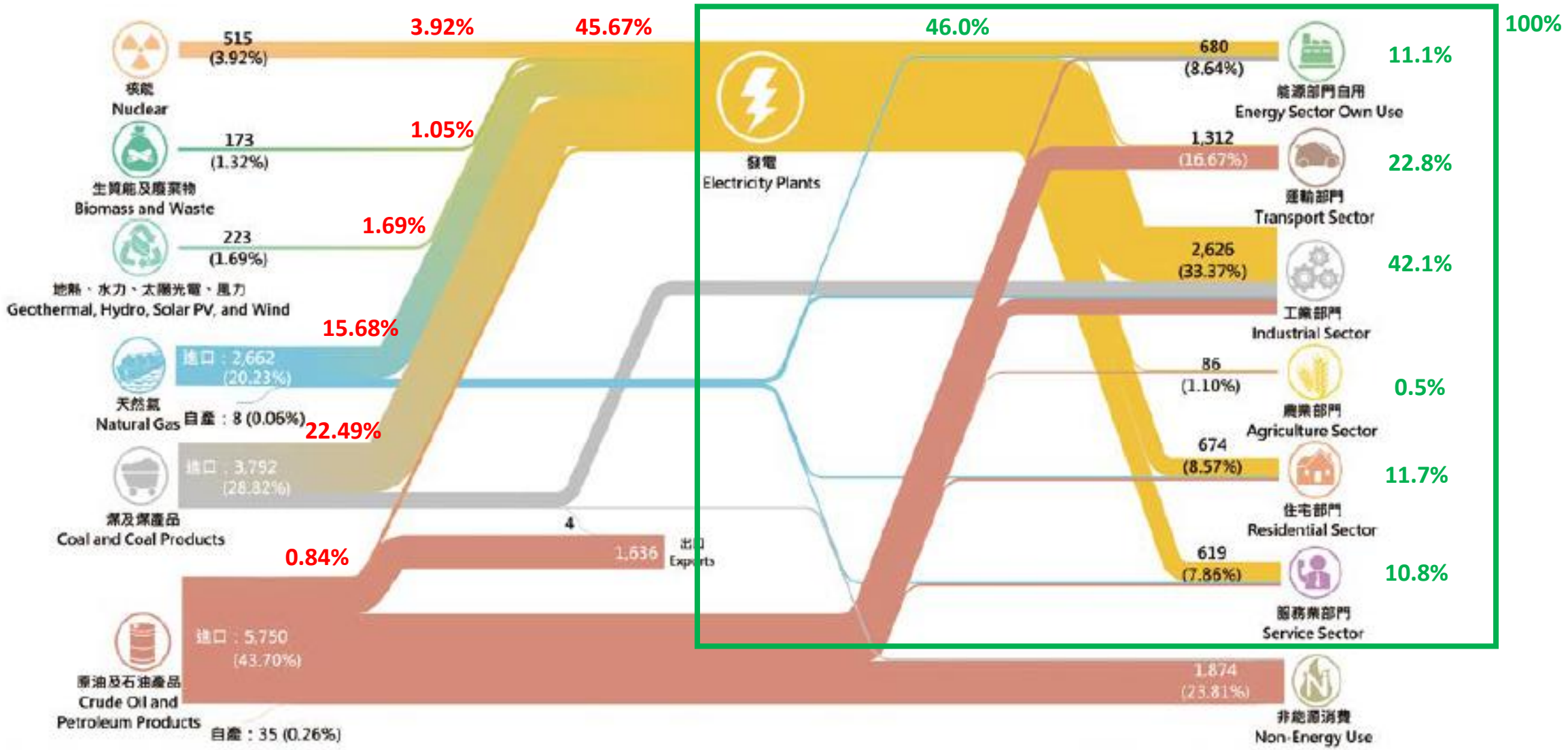
各能源用於發電佔能源總供給

能源供給與消費流程圖（112年）
Energy Supply and Consumption Flowchart (2023)

排除非能源消費　電力佔 46%

各部門佔能源總消費

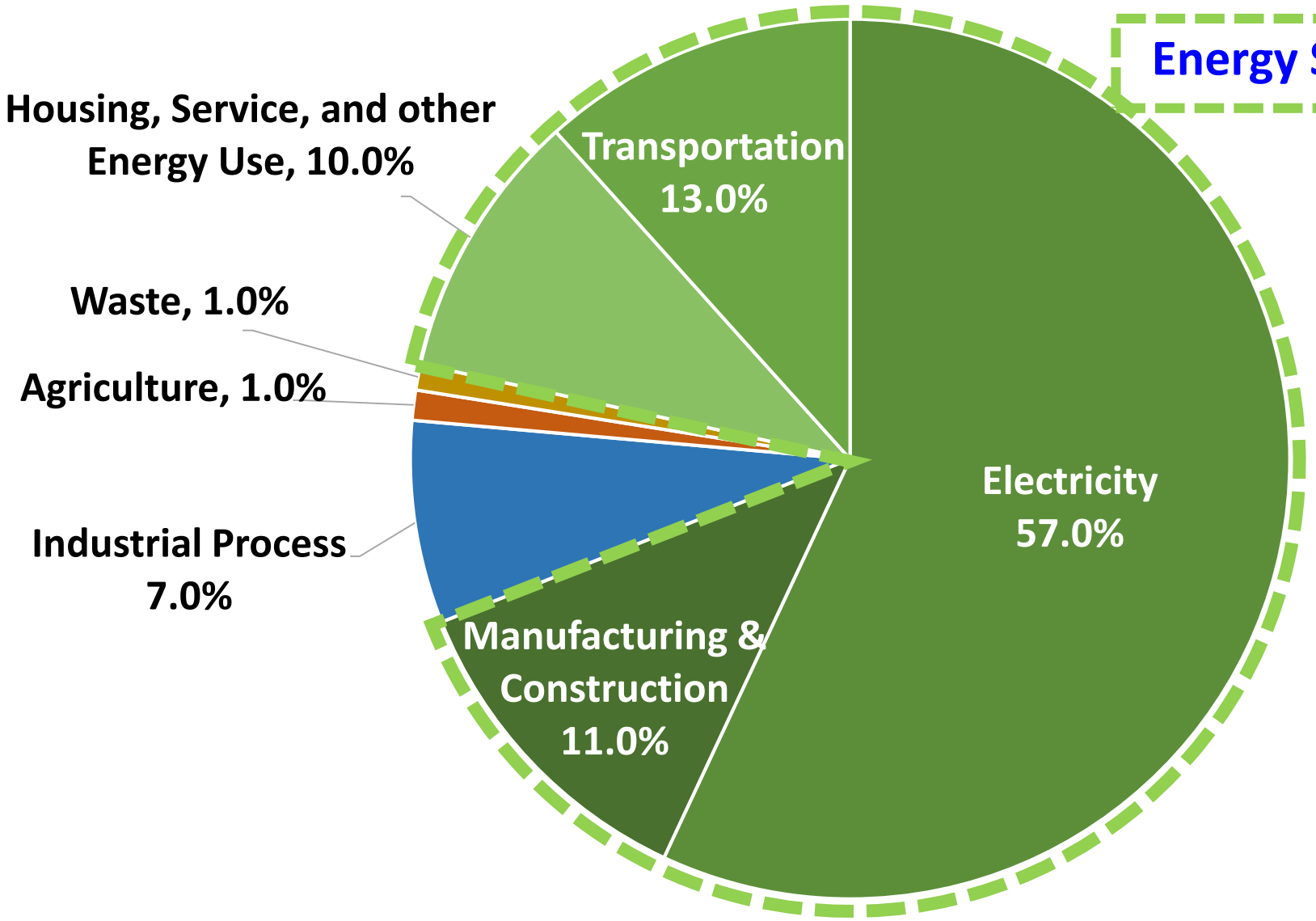
單位: 萬公秉油當量
Unit: 10⁴KLOE



能源總供給：1億3,159萬公秉油當量
Energy Supply: 131.59 Million KLOE

能源總消費：7,871萬公秉油當量
Energy Consumption:78.71Million KLOE

2023 Taiwan GHG Emissions: 279 Mt CO2 eq.



Energy Sector: 91%

57% in 91%, but Electrification toward 2050

Top Priority:
Decarbonization in Electricity Generation