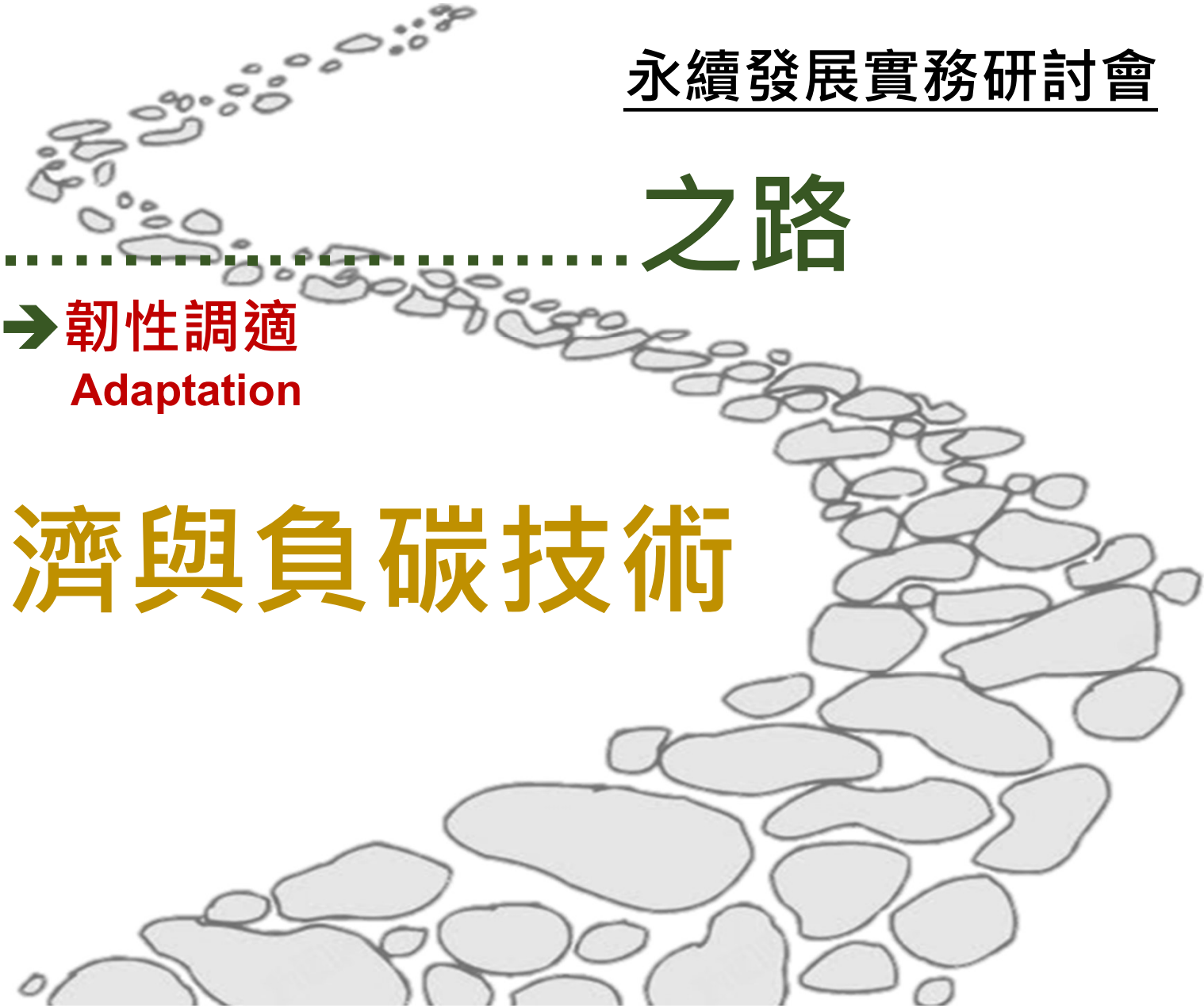
永續發展實務研討會

淨零碳排.....之路

節能減碳➔淨零碳排➔韌性調適

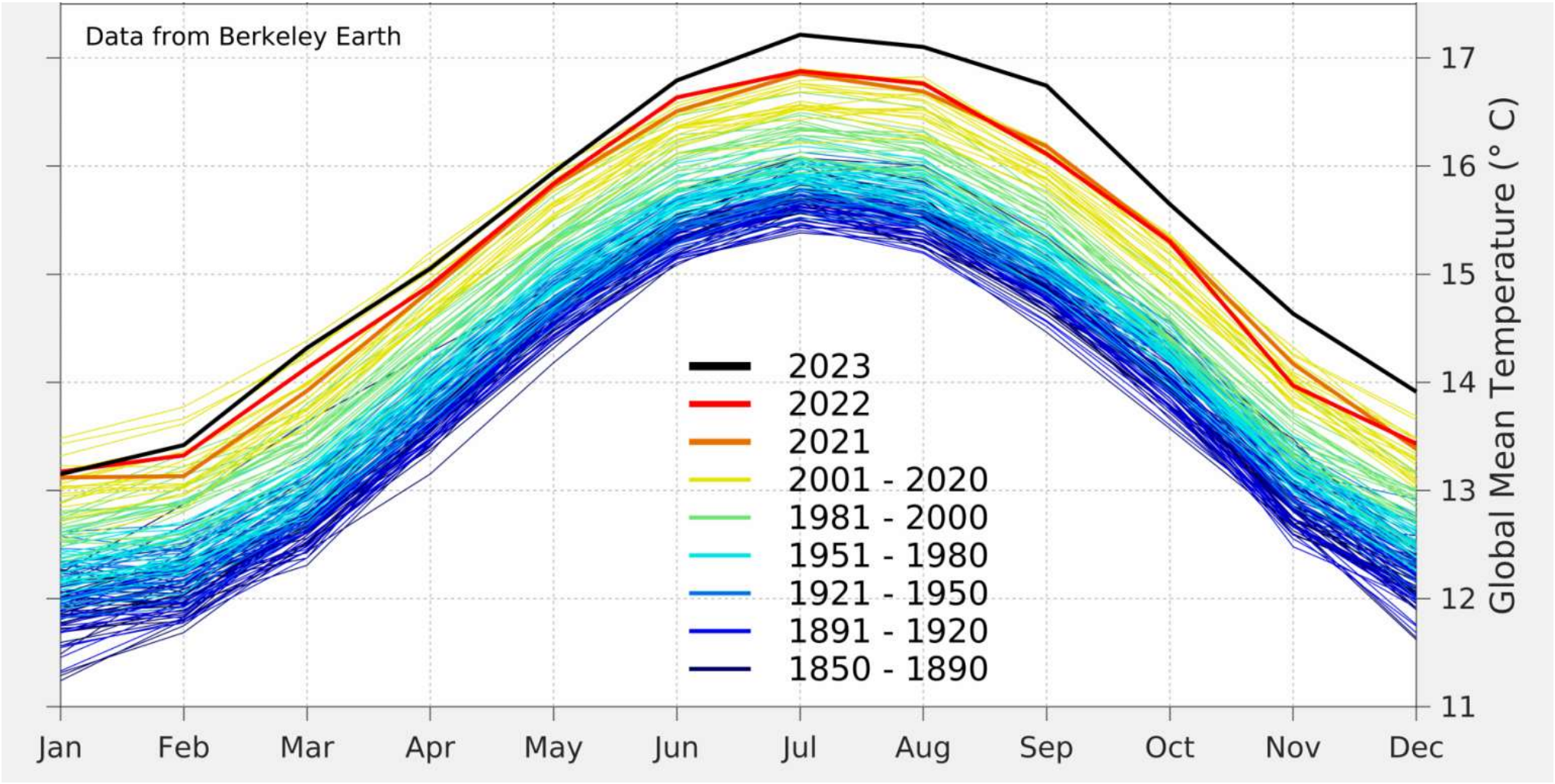
Mitigation Adaptation

碳循環經濟與負碳技術



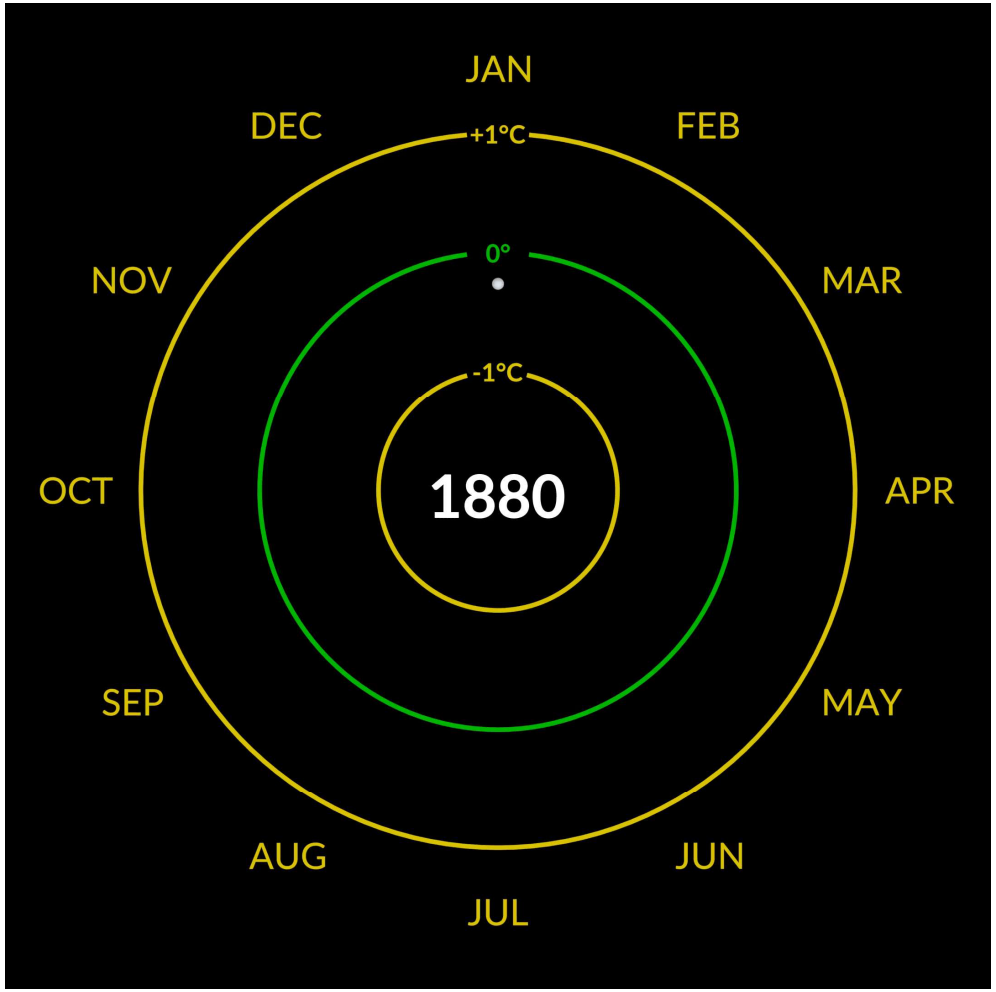
林大惠
工學院機械工程學系
能源科技與策略研究中心
國立成功大學

地表平均溫度變化趨勢(1/2)



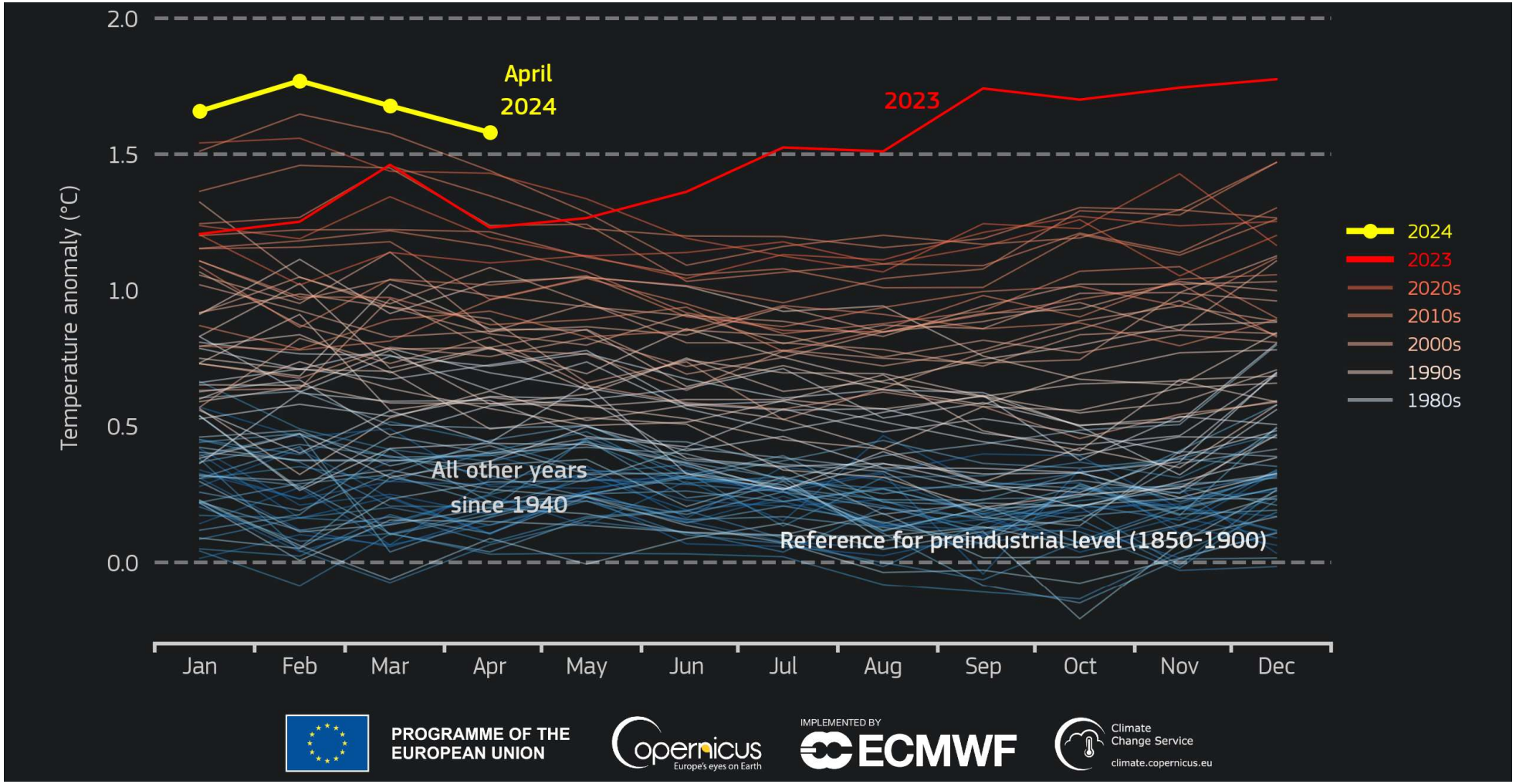
https://berkeleyearth.org/global-temperature-report-for-2023/

地表平均溫度變化趨勢(2/2)



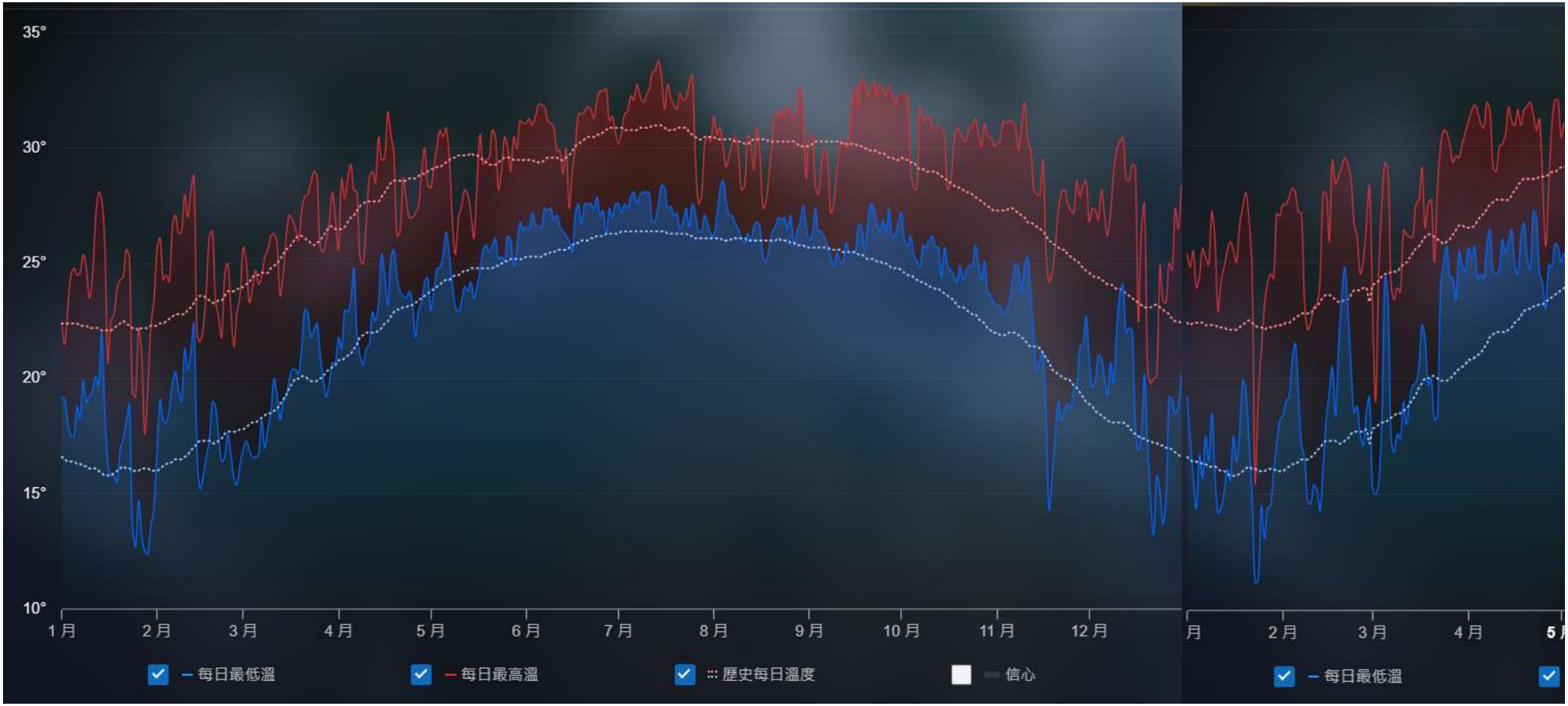
https://svs.gsfc.nasa.gov/vis/a000000/a005100/a005190/GISTEMP_Spiral_English_degC_2160p60.mp4

地表平均溫度變化趨勢(2024/1-2024/4)

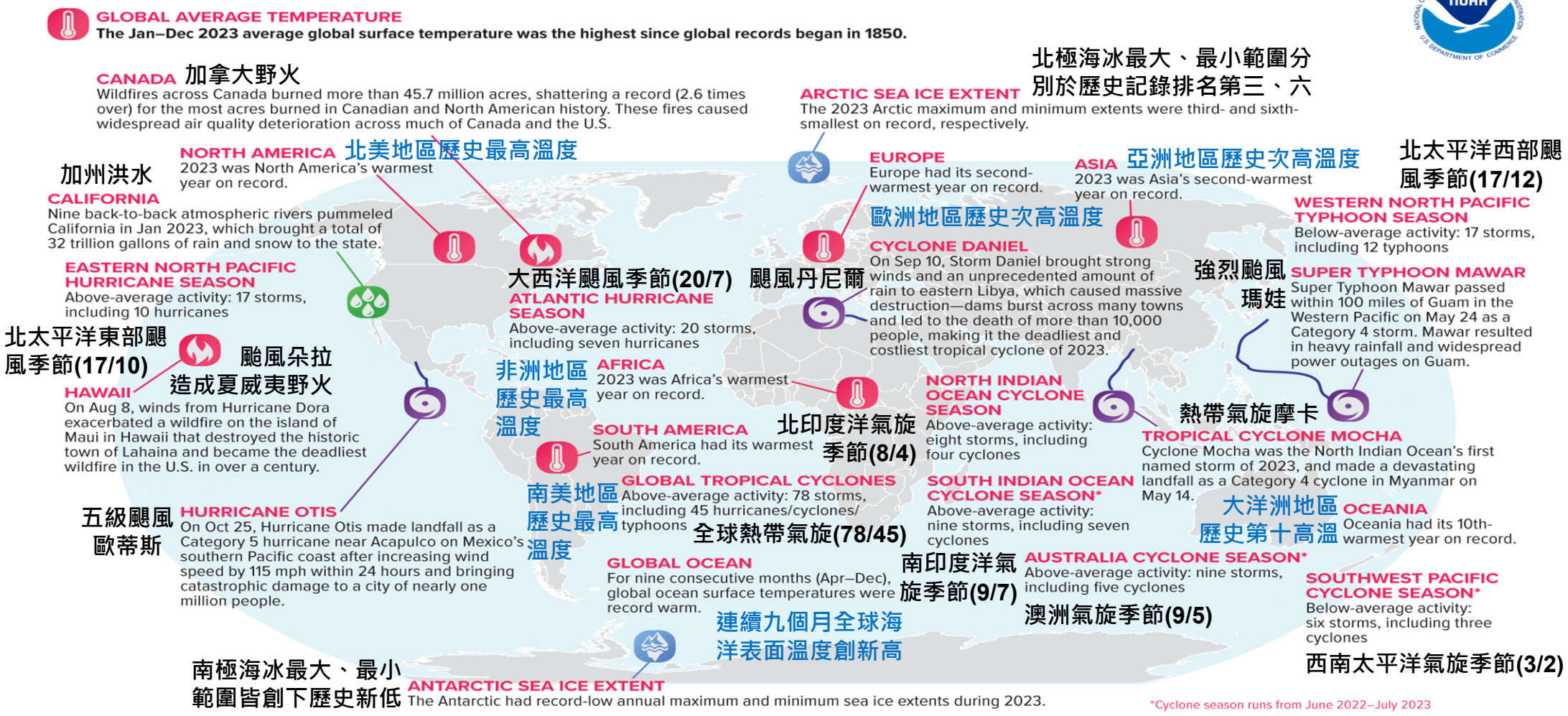


https://climate.copernicus.eu/copernicus-global-temperature-record-streak-continues-april-2024-was-hottest-record

高雄平均溫度變化趨勢(2023/1-2024/4)



全球氣候異常與災害事件(2023)

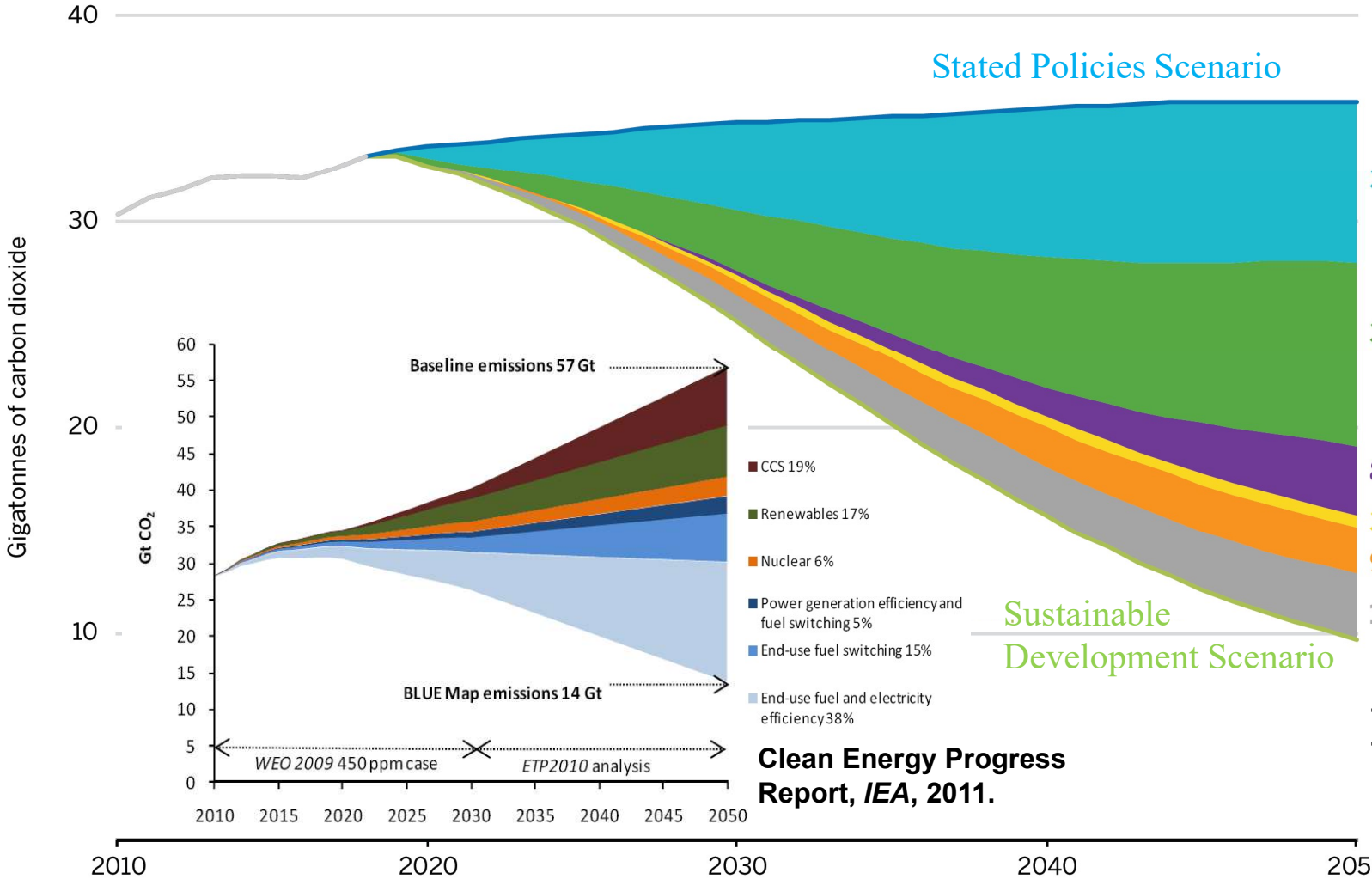


https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202313

青蛙與螞蟻

Minx, J.C., et Al., Negative Emissions-Part 1: Research Landscape and Synthesis, *Environ. Res. Lett.*, Vol.13, 063001, 2018.

2050減碳情境預測比較



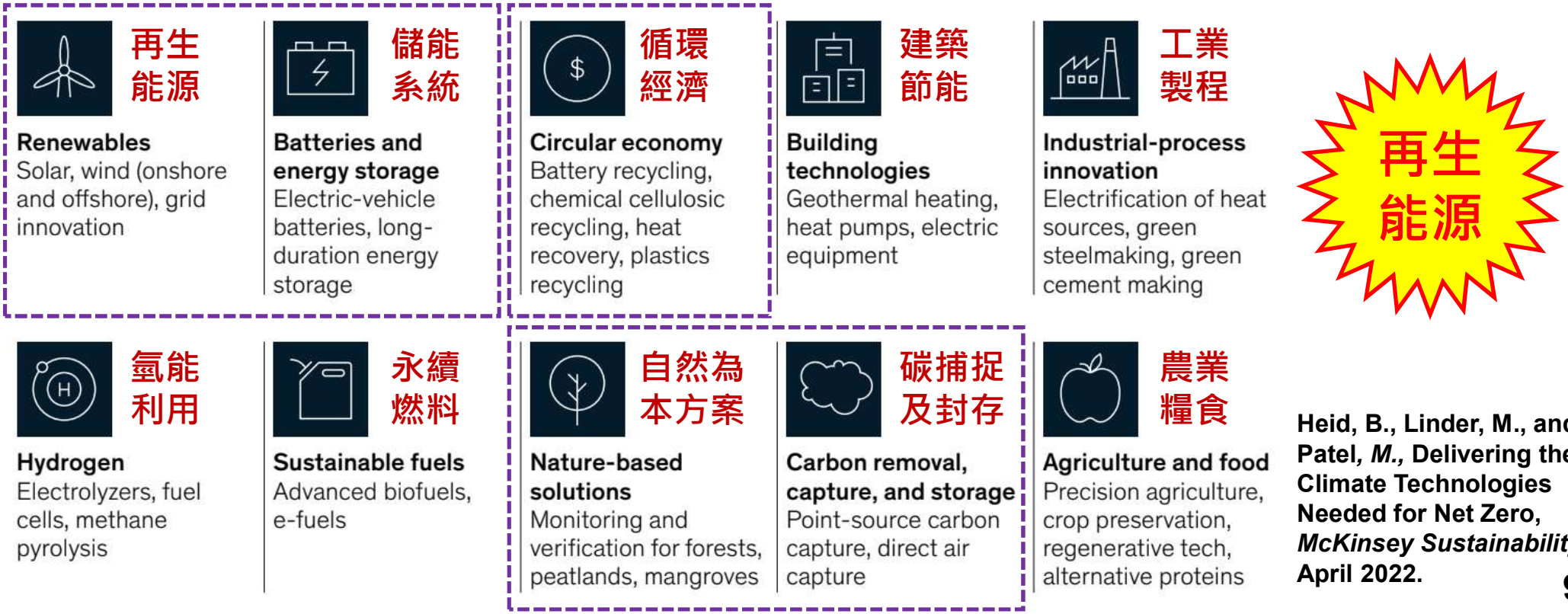
2011	2020
43%	↓ 37%
17%	↑ 32%
15%	↓ 8%
6%	↓ 3%
19%	↓ 9%

Clean Energy Progress Report, *IEA*, 2011.

Tracking SDG7, The Energy Progress Report 2020, *IEA*.

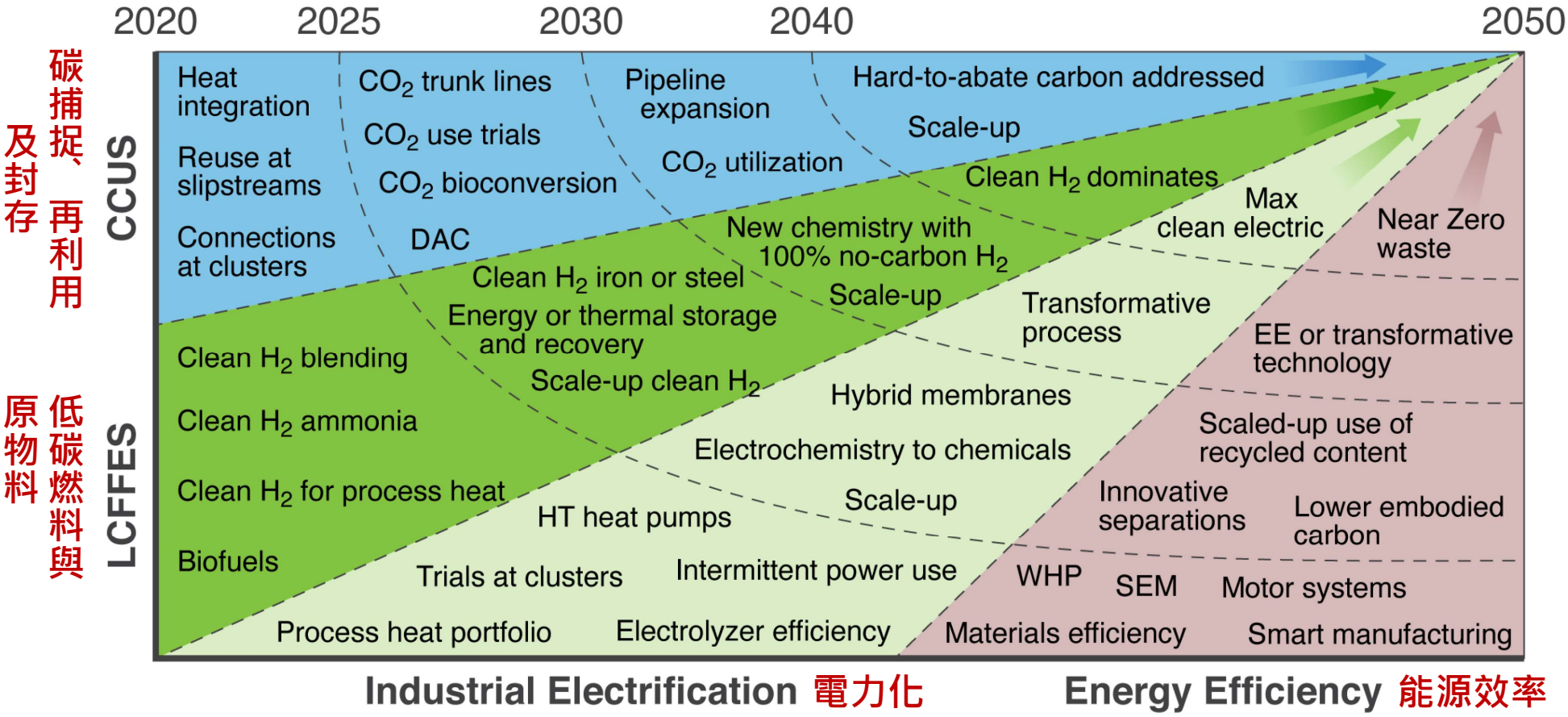
淨零碳排關鍵條件

- A critical prerequisite for the success of many climate technologies - including green methanol and green hydrogen, other synthetic fuels, green steel, and carbon capture - is the buildout of capacity to generate and store renewable electricity.
- Ten families of climate technologies can play important parts in mitigating carbon emissions.



Heid, B., Linder, M., and Patel, *M.,* Delivering the Climate Technologies Needed for Net Zero, *McKinsey Sustainability*, April 2022.

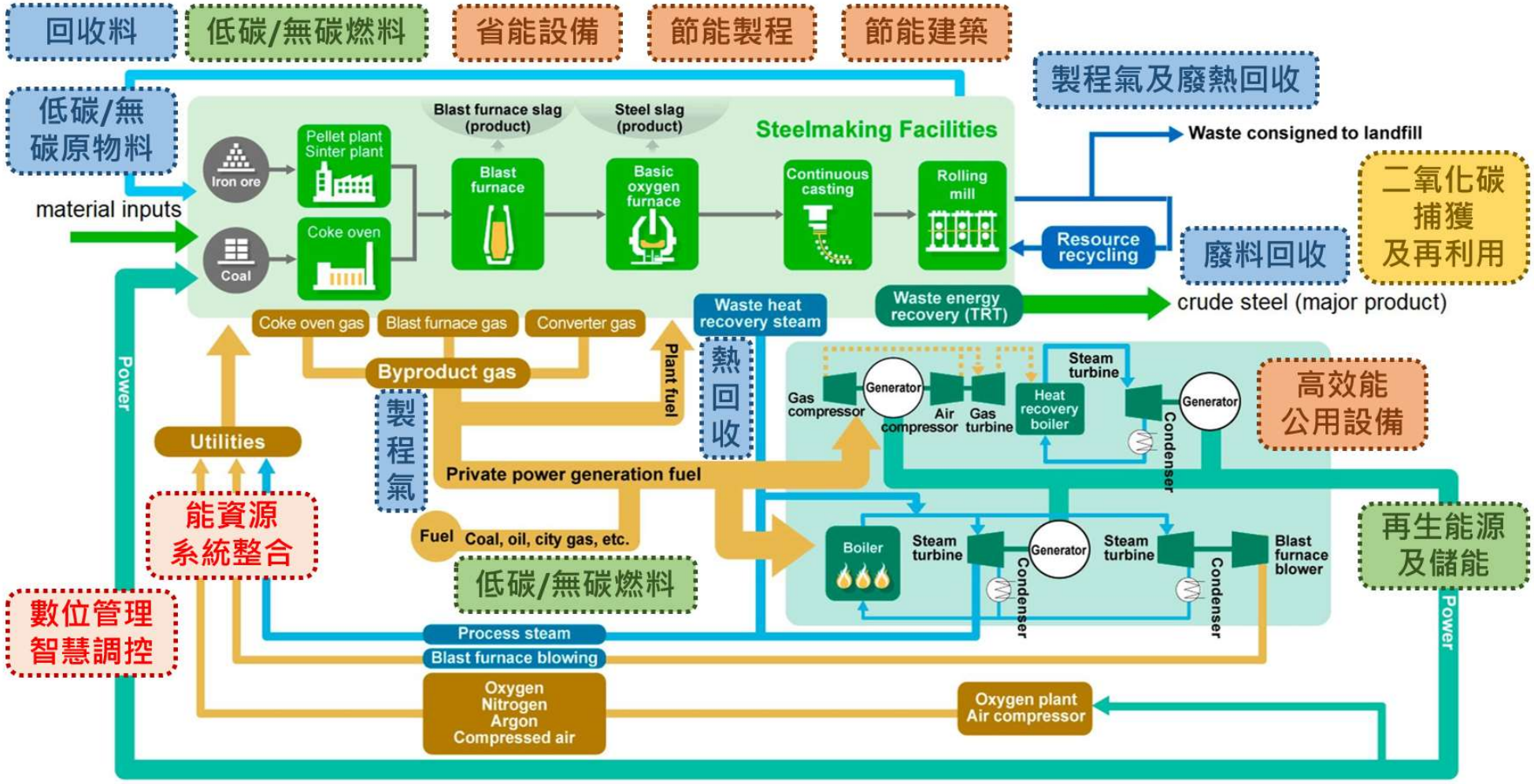
邁向2050製造業脫碳技術發展



Landscape of Major RD&D Investment Opportunities for Industrial Decarbonization Across All Subsectors by Decade and Decarbonization Pillar

Industrial Decarbonization Roadmap, *U.S. Department of Energy*, Sept. 2022.

鋼鐵製程相關減碳技術



Sun, W. et al., Material and Energy Flows of the Iron and Steel Industry: Status Quo, Challenges and Perspectives, *Applied Energy*, 268, 15, 114946, 2020.

低碳煉鐵技術

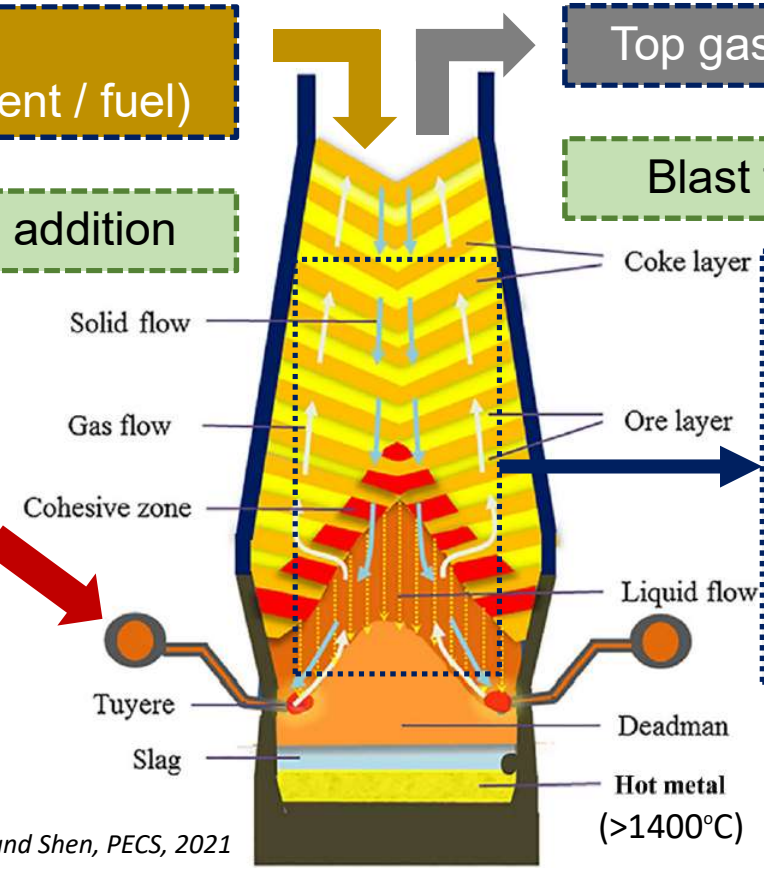
Targets: Develop low-carbon blast furnace ironmaking technology by replacing carbon with hydrogen to reduce CO_2 emission in the ironmaking process.

Solid charge:
Iron ore, coke (reducing agent / fuel)

Low carbon (LC) material addition

Pulverized coal injection

Hydrogen-rich (HR)
gas injection



Liu and Shen, PECS, 2021

Top gas emissions: H_2, CO, CO_2, etc.

Blast furnace **gas recycling (GR)**

Traditionally, the use of CO as reducing agent for ironmaking causes high CO_2 emission.

- ✓ $2C + O_2 = 2CO$
- ✓ $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$
- ✓ $Fe_3O_4 + CO = 3FeO + CO_2$
- ✓ $FeO + CO = Fe + CO_2$

The strategy of replacing carbon with hydrogen is essential.

High temperature and high pressure with multi-phase reaction in blast furnace

邁向零碳製造的基本做法

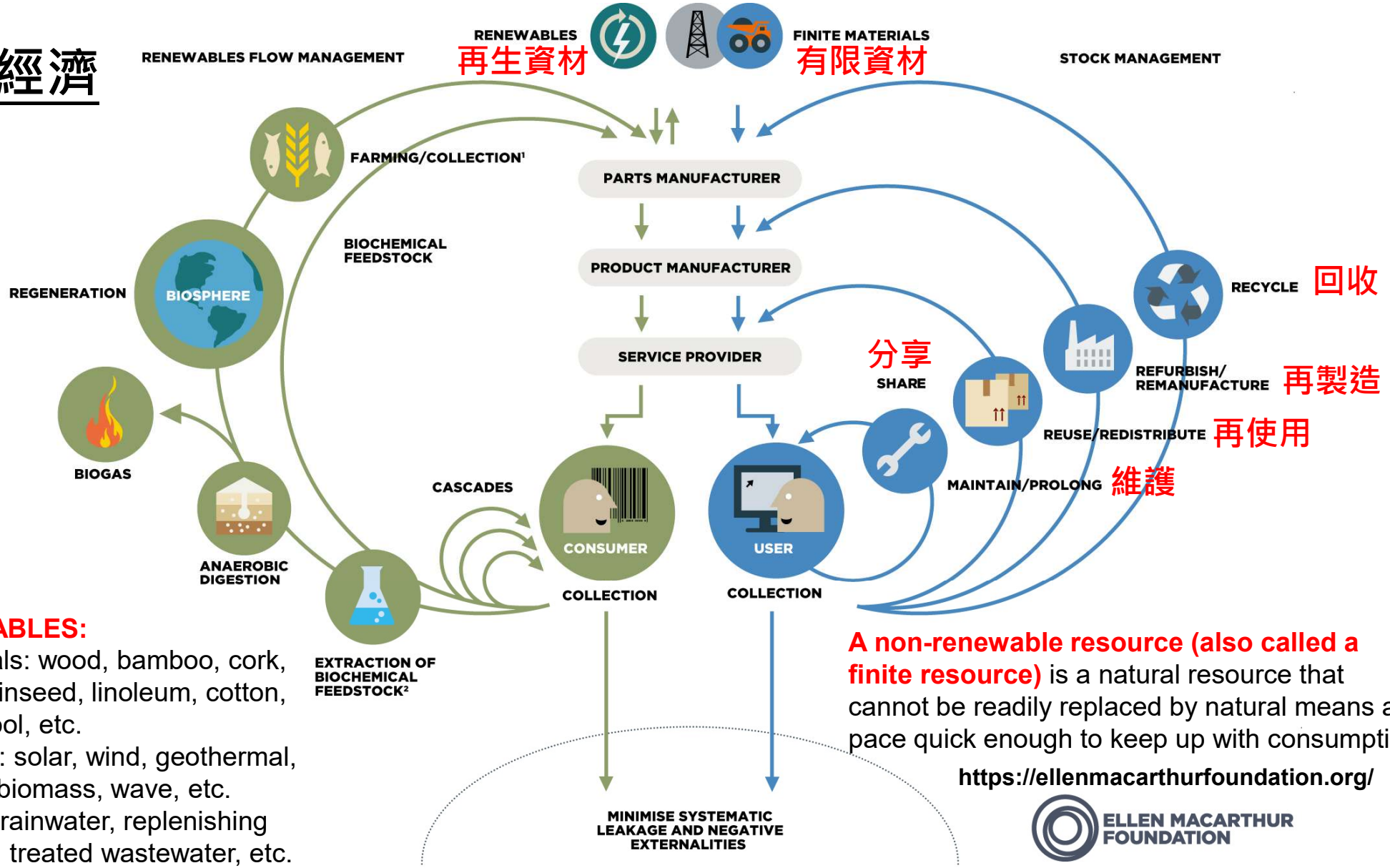
- Renewable energy sourcing（取得再生能源）
  Companies can transition to renewable energy sources such as wind, solar, and hydropower to power their factories and production processes.
- Energy-efficient practices（能效設備、生產製程、製造工序及生產排程）
  Companies can implement energy-efficient practices such as the use of LED lighting, efficient heating and cooling systems, and optimizing their production processes to reduce energy consumption.
- Carbon capture technologies（碳捕捉、再利用及封存）
  Carbon capture, utilization, and storage (CCUS) technologies can be used to capture carbon emissions from the production processes and store them underground.
- Sustainable material sourcing（低碳或無碳資材、及其循環利用）
  Companies can adopt sustainable sourcing practices to reduce the carbon footprint of their products. This can be achieved by sourcing materials from sustainable sources, recycling waste materials, and reducing waste generation.
- Green logistics（綠色通路）
  Companies can reduce the carbon footprint of their logistics by optimizing transportation routes, using electric vehicles, and reducing packaging waste.

https://chat.openai.com/chat

碳循環經濟

- The Carbon Circular Economy (CCE) is a concept and framework aimed at reducing carbon emissions and mitigating climate change while promoting sustainable economic growth and resource efficiency. It combines principles of the circular economy with a specific focus on carbon, which refers to carbon dioxide and other greenhouse gases that contribute to global warming.
- It is a closed-loop system involving 4Rs: reduce, reuse, recycle, and remove.
- Key components and strategies of the Carbon Circular Economy include:
  - Reducing Emissions（減少碳排）: transitioning from fossil fuels to renewable energy source and improving energy efficiency.
  - Resource Efficiency（資源效率）: maximizing the use of resources and minimizing waste in various industries.
  - Carbon Capture, Use and Storage (CCUS)（碳捕捉、再利用及封存）.
  - Carbon Offsetting (Carbon Removal, Carbon Sink)（碳抵換）.
  - Sustainable Agriculture（永續農業）: no-till farming, cover cropping, and agroforestry.
  - Sustainable Transportation（永續運輸）: electric vehicles, public transportation, and alternative fuels.
  - Sustainable Consumption（永續消費）.

循環經濟



RENEWABLES:

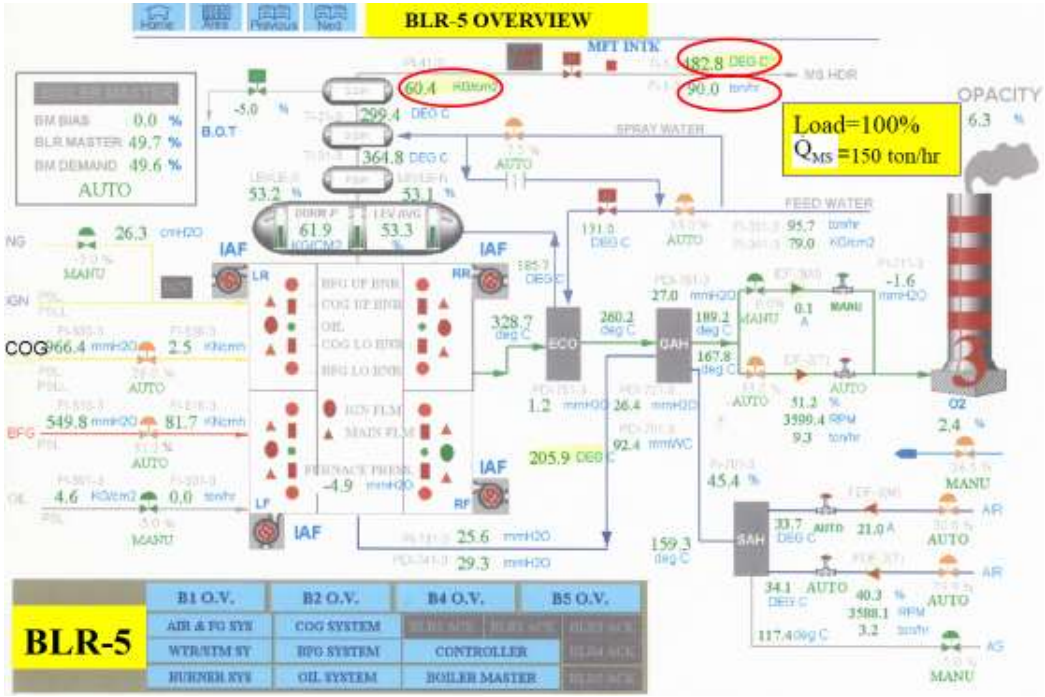
- Materials: wood, bamboo, cork, straw, linseed, linoleum, cotton, soy, wool, etc.
- Energy: solar, wind, geothermal, hydro, biomass, wave, etc.
- Water: rainwater, replenishing aquifer, treated wastewater, etc.

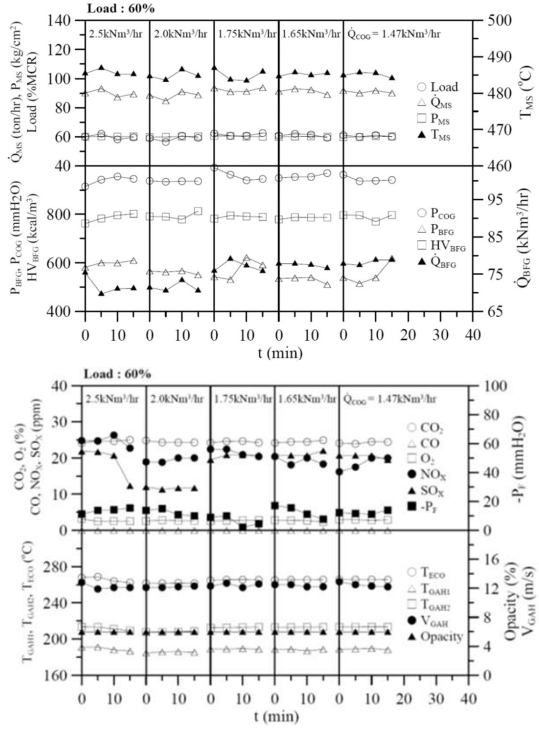
A non-renewable resource (also called a finite resource) is a natural resource that cannot be readily replaced by natural means at a pace quick enough to keep up with consumption.

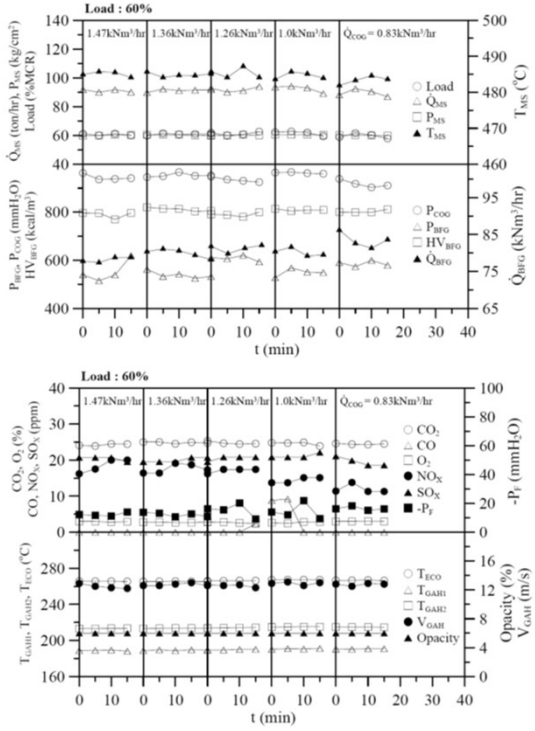
https://ellenmacarthurfoundation.org/

ELLEN MACARTHUR FOUNDATION

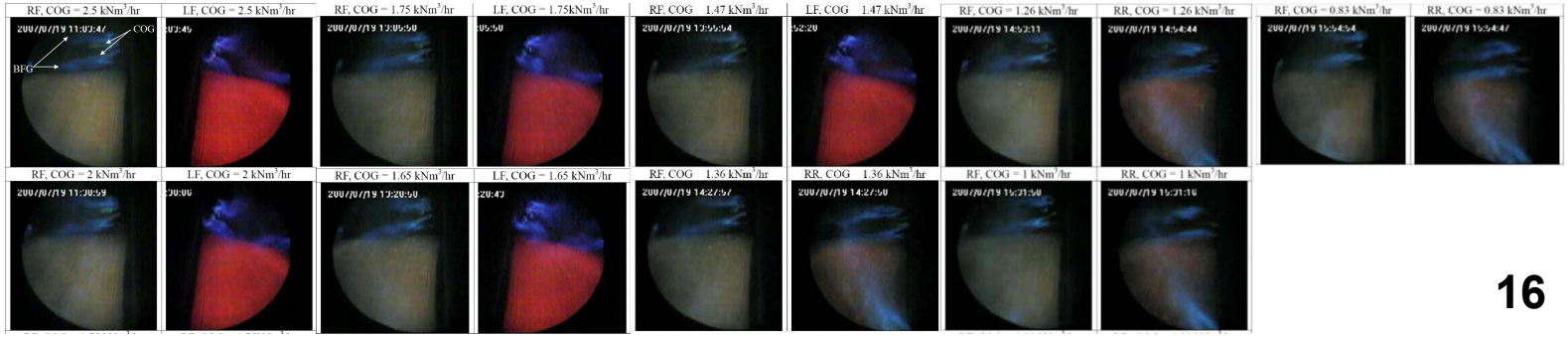
製程氣回收再利用-單燒高爐氣之燃燒技術建立與應用(2006)





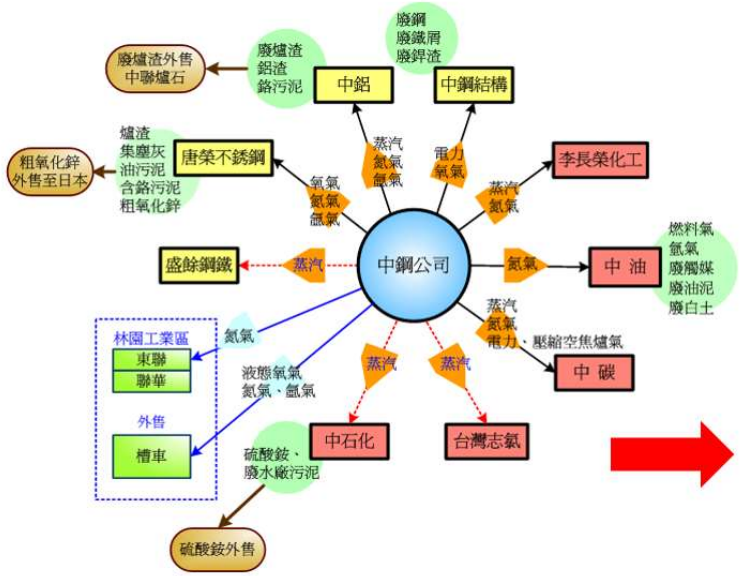


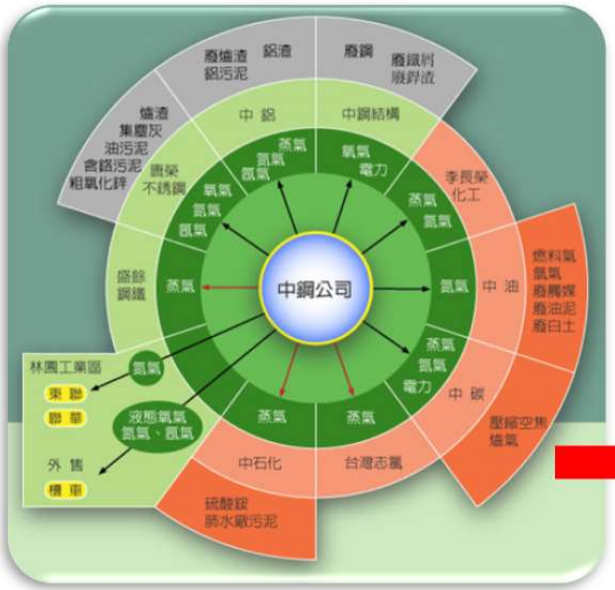
在60%及70%的鍋爐負載下，調降煉焦爐氣流率最低可至1~0.83 kNm^3/hr，增加高爐氣流率最高可至約100 kNm^3/hr，鍋爐皆可穩定運轉，無火焰不穩定或熄火問題，CO排放濃度幾乎皆為0。



產業共生(Industrial Symbioses)

臨海工業區之區域性能源資源整合規劃(2004-2006)





產業生態學(Industrial Ecosystem, IE)

- 尋求物質與能源循環使用的最大效益。
- 建立產業的物質流循環。

生態工業園區(Eco-Industrial Park, EIP)

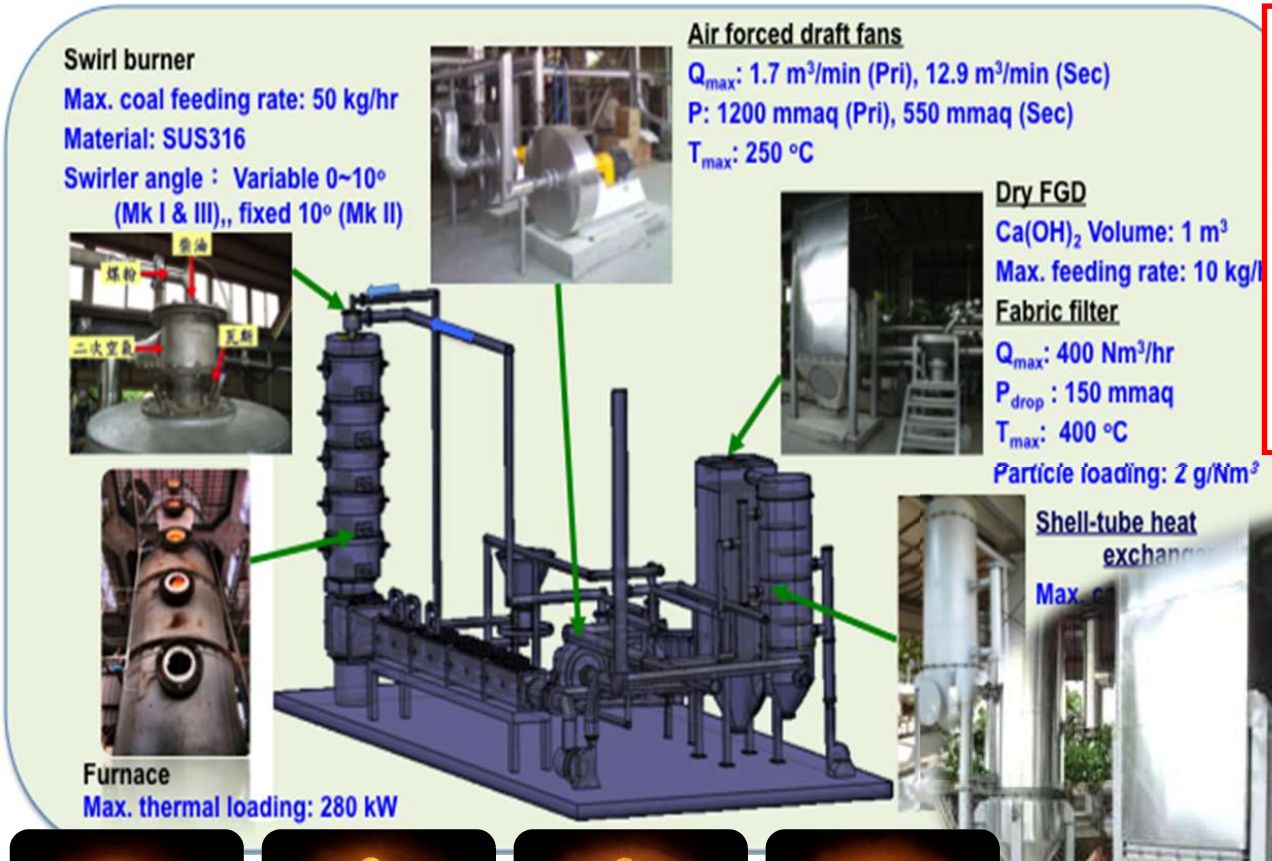
- 建立不同工業間物質與能量的再循環及再利用。
- 某一生產者的廢棄物可當作另一生產者的資源，並作有效率的分享。
- 規劃物質及能源交換的產業系統。

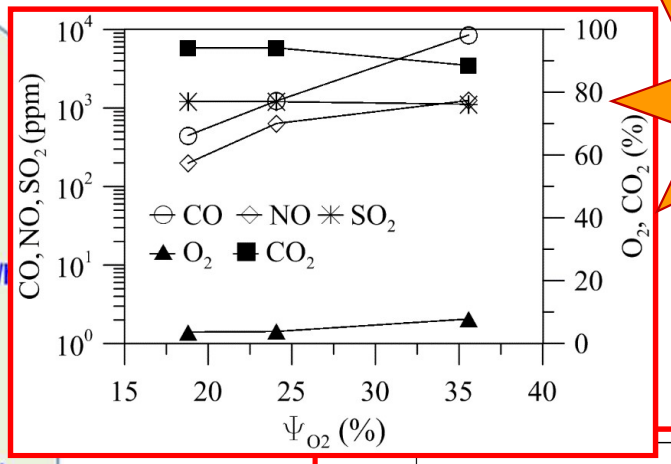
建構區域能資源整合系統

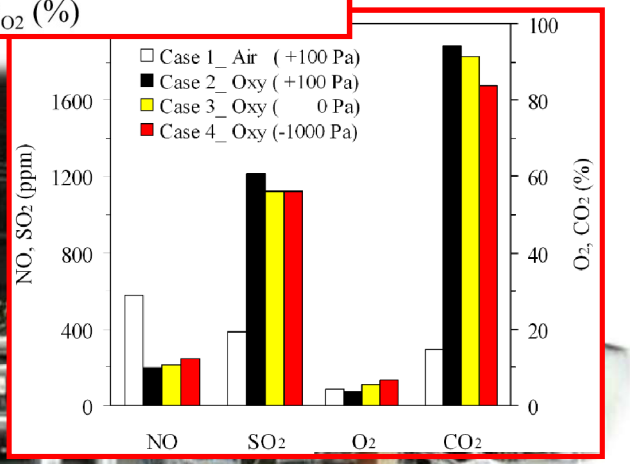
將過剩蒸汽、工業氣體供應給鄰近13家工廠。透過資源共享、互通有無的機制，達到節能減排的效益。2021年銷售蒸汽158萬噸，節能減排效益：

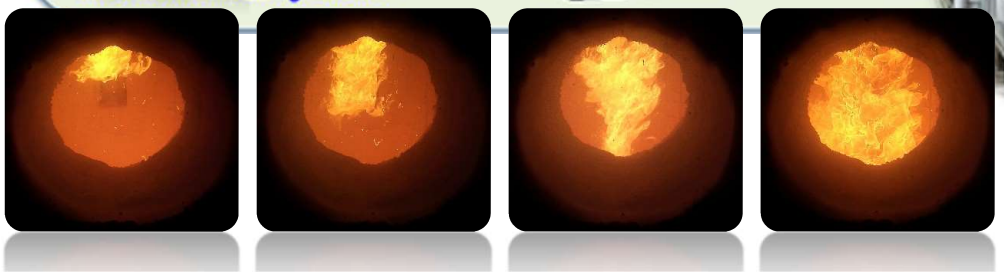
項 目	數 量
硫氧化物	1,161公噸
氮氧化物	805公噸
粒狀物	114公噸
二氧化碳	38萬公噸

二氧化碳捕捉-純氧燃燒結合煙道氣迴流技術(2008-2010)





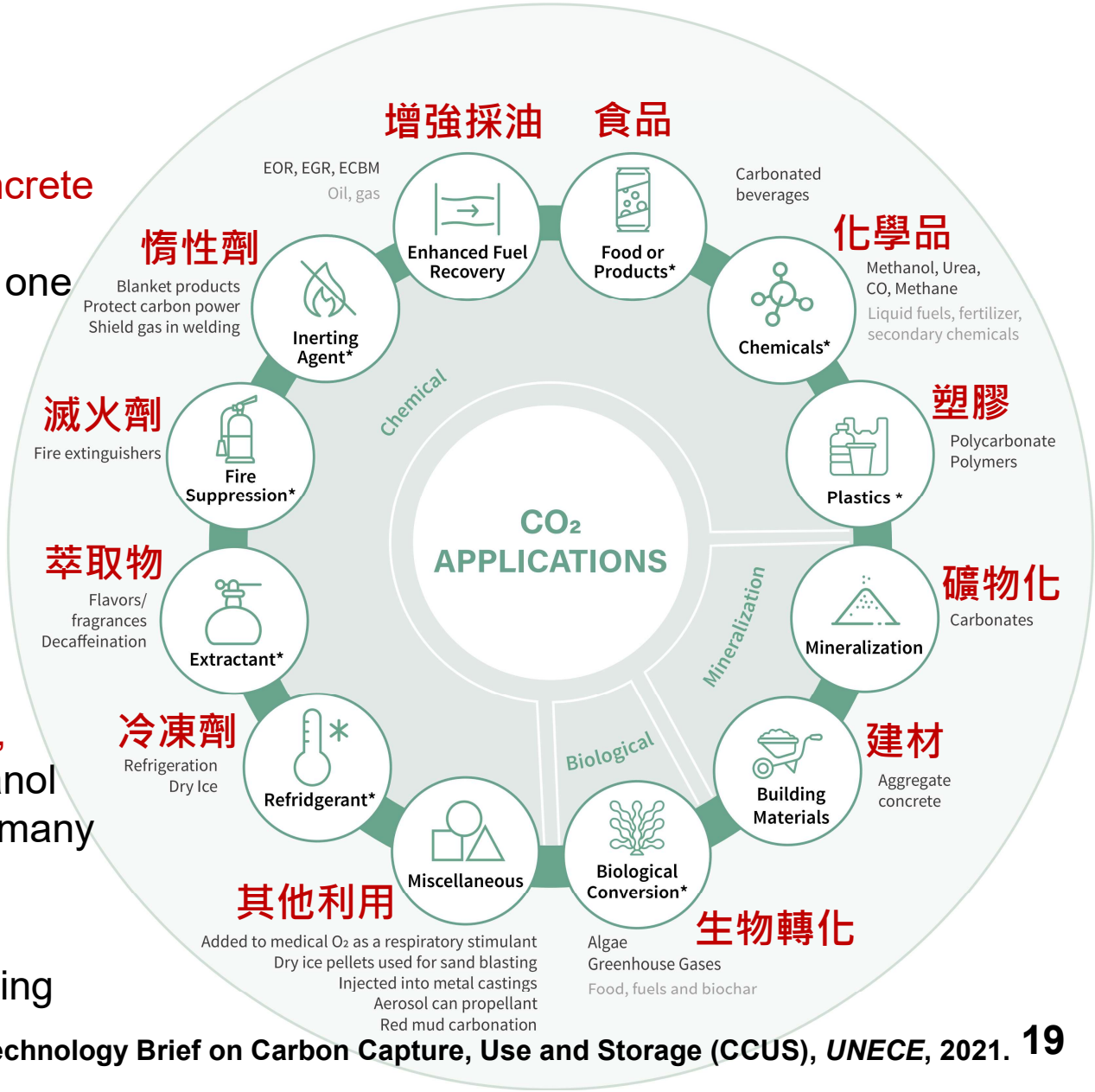




工業爐窗氧燃燒及廢氣再循環技術建立

碳利用(Carbon Utilization)

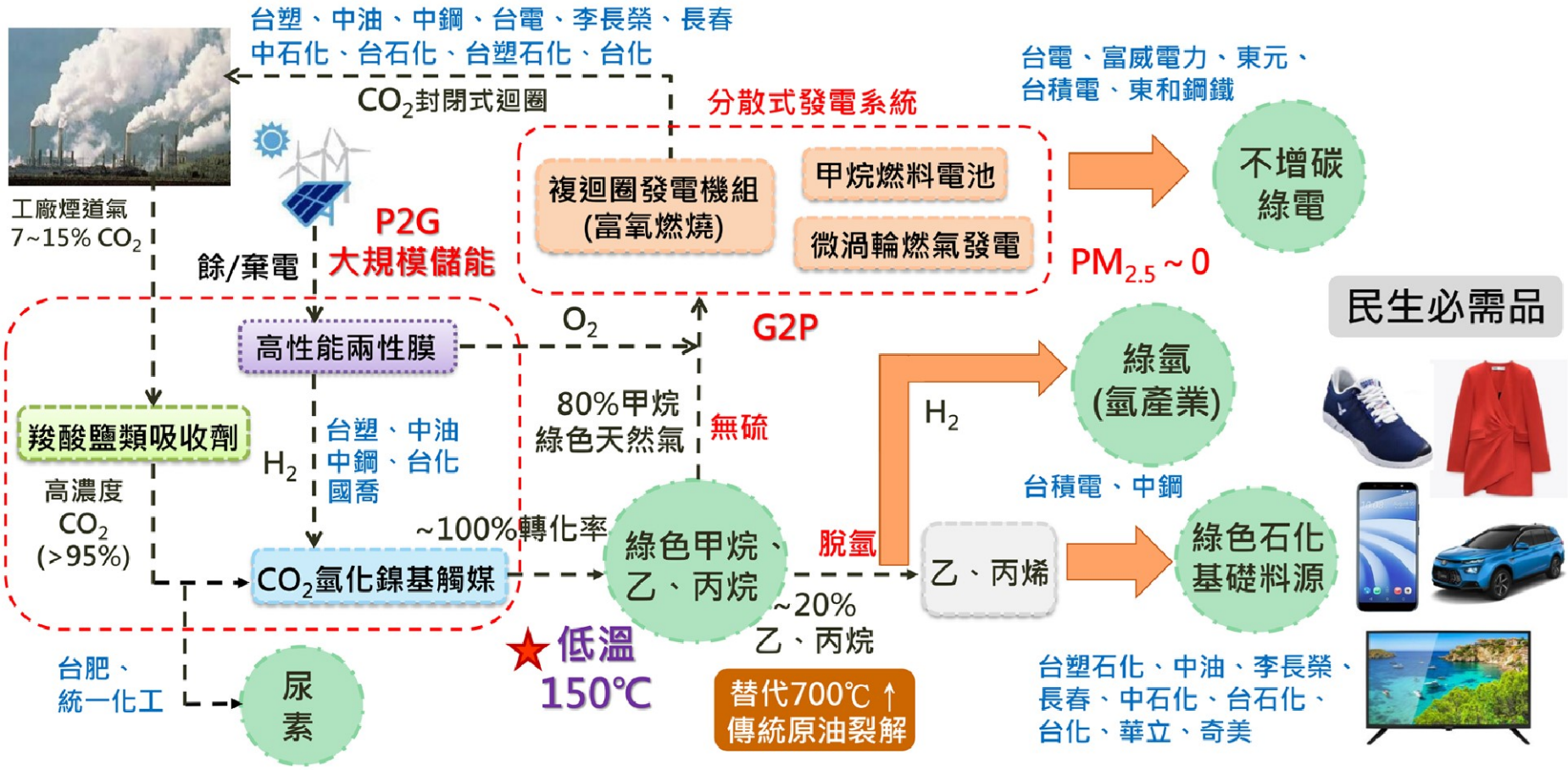
- Mineralization: Incorporating CO_2 into concrete has the most potential to become a large market for CO_2 in the near term. Cement, one of the components of concrete, is responsible for 8% of the total GHG. This process is energy efficient using minimal external energy.
- Chemicals: CO_2 is currently used in small quantities to make urea fertilizer and some special polymers. In a future hydrogen economy, CO_2 could be combined with H_2 to make synthetic fuels, syngas and methanol. Syngas and methanol are basic chemical feedstock from which many chemicals and polymers can be made.
- Biological: CO_2 is used to promote plant growth and can be captured in soils by using biochar to increase soil quality.



Technology Brief on Carbon Capture, Use and Storage (CCUS), *UNECE*, 2021.

碳循環再造(Carbon Upcycling)

碳中和產業鏈：以CO_2產製綠電、綠氫、綠色石化基礎料源



陳志勇，邁向碳中和-產業綠色、低碳技術與人才培育及應用計畫簡報，2022年。

廢棄物料資源化-電弧爐爐碴應用於高質化板材

循環資材再利用經驗

10年以上

- 將矽基改質技術導入耐燃摻劑應用、無機原料熱改質。
- 利用燃燒技術提升循環資材所需成份的純度、化合作用的穩定度。
- 不銹鋼爐碴矽酸鈣板於2021年取得GREENGUARD的黃金級認證。

Date Issued: January 20, 2021
Product ID#: 10010184O3-3249347
Test Report #: 10010184O3-3249347
©2021 UL
BCM2

GREENGUARD CERTIFICATION TEST REPORT

Customer Information	WALTUO GREEN RESOURCE CORP CHUAN WEN CHOU 47 BADE RD, YANSHUI DISTRICT TAINAN 73742, TAIWAN				
Product Description	CNS 13777 Fiber Reinforced Cement Board Sample, 9mm Thickness				
Test Group	Surfacing Materials - 01				
Category	Building Products				
Test Type	Initial				
Test Method	UL 2821 "GREENGUARD Certification Program Method for Measuring and Evaluating Chemical Emissions From Building Materials, Finishes and Furnishings Using Dynamic Environmental Chambers"				
	Environment	TVOC	Formaldehyde	Total Aldehydes	CREL/TLV
GREENGUARD	Office	✓	✓	✓	✓
GREENGUARD Gold	Office	✓	✓	✓	✓
	Classroom	✓	✓	✓	✓
✓ - meets criteria; X - over criteria					
Authorized by	Ring Zhong Laboratory Testing Supervisor				

氧化碴水泥板

提升2倍強度 提升2倍隔熱

- 107年所開發的板材產品。
- 通過耐燃一級試驗。
- 符合毒性特性溶出程序(TCLP)再利用標準。
- 正與製品廠接洽小型試量產。

氧化銹皮水泥板

提升2倍隔熱

- 107年所開發的板材產品。
- 通過耐燃一級試驗。
- 符合毒性特性溶出程序(TCLP)再利用標準。
- 正與製品廠接洽小型試量產。

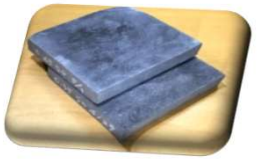
電弧爐爐碴應用於高質化板材流程規劃

還原碴水泥澆灌板

提升1.5倍強度 提升2成隔熱

- 108年所開發的板材產品。
- 通過耐燃一級試驗。
- 符合毒性特性溶出程序(TCLP)再利用標準。
- 已進行小型試量產並用於業者廠內辦公室，於今年度完成進行空間場域示範。


氧化碴水泥板


鐵粉水泥板

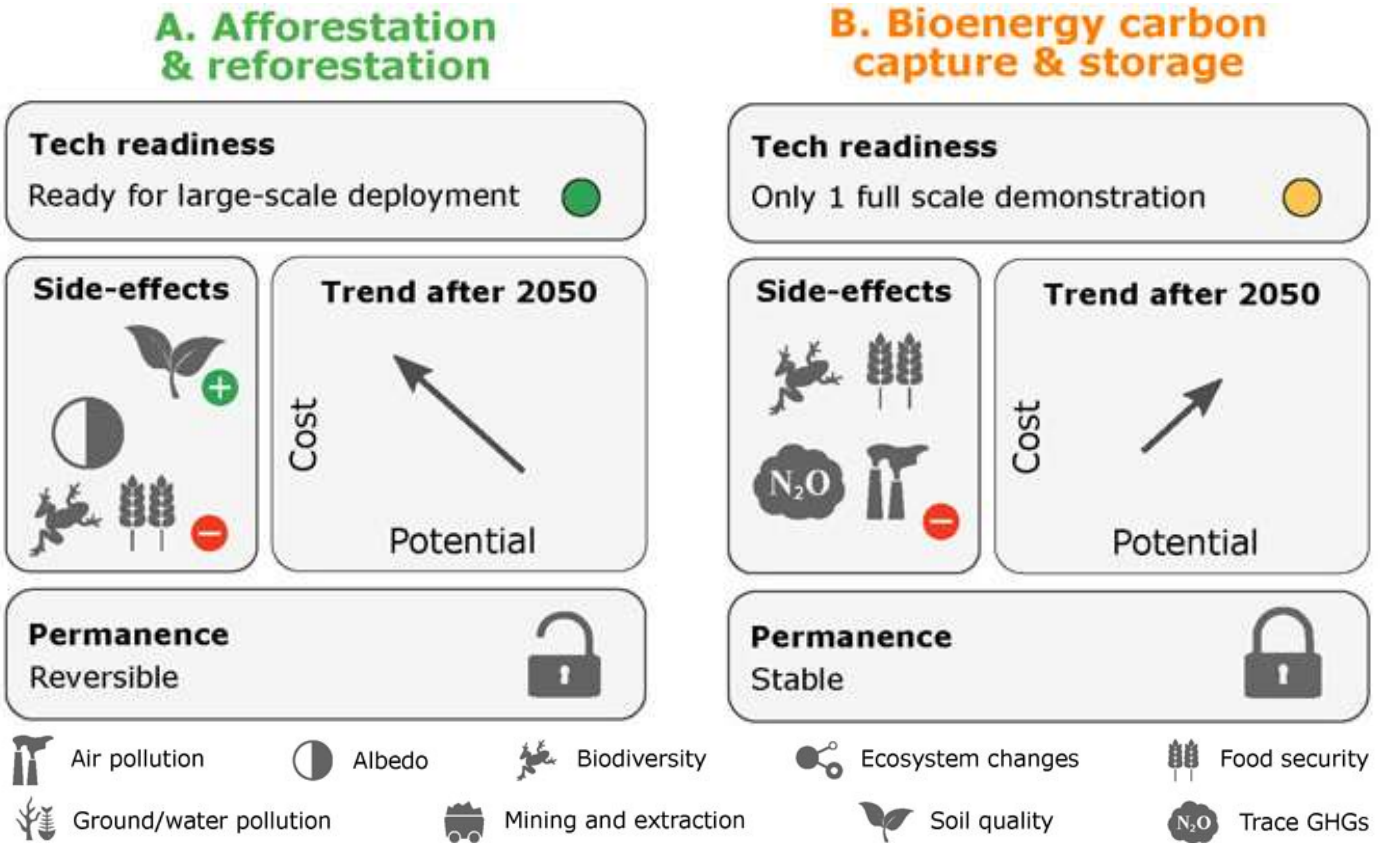

還原碴水泥板


還原碴纖維水泥板

負碳技術(1/3)

Negative emissions technologies (NETs) refers to techniques designed to remove carbon dioxide (CO_2) and other greenhouse gases from the atmosphere. Some common NETs include:

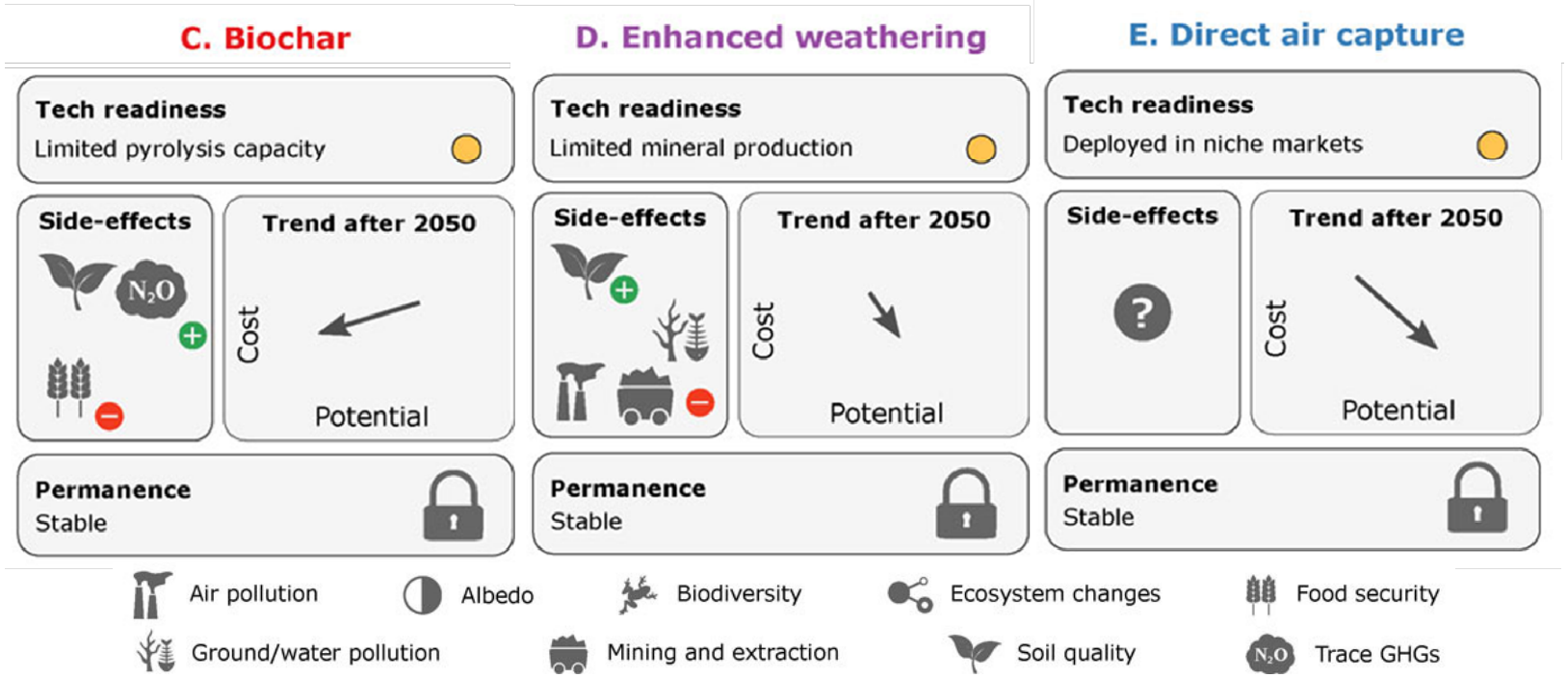
- Afforestation and Reforestation（造林與林地復育）: Planting trees (afforestation) or restoring and expanding existing forests (reforestation) can help capture and store carbon from the atmosphere.
- Bioenergy with Carbon Capture and Storage (BECCS)（生質能結合碳捕捉及封存）: This technology combines the use of biomass, such as crops or forestry residues, for energy production with CCS.



https://www.carbonbrief.org/guest-post-seven-key-things-to-know-about-negative-emissions/

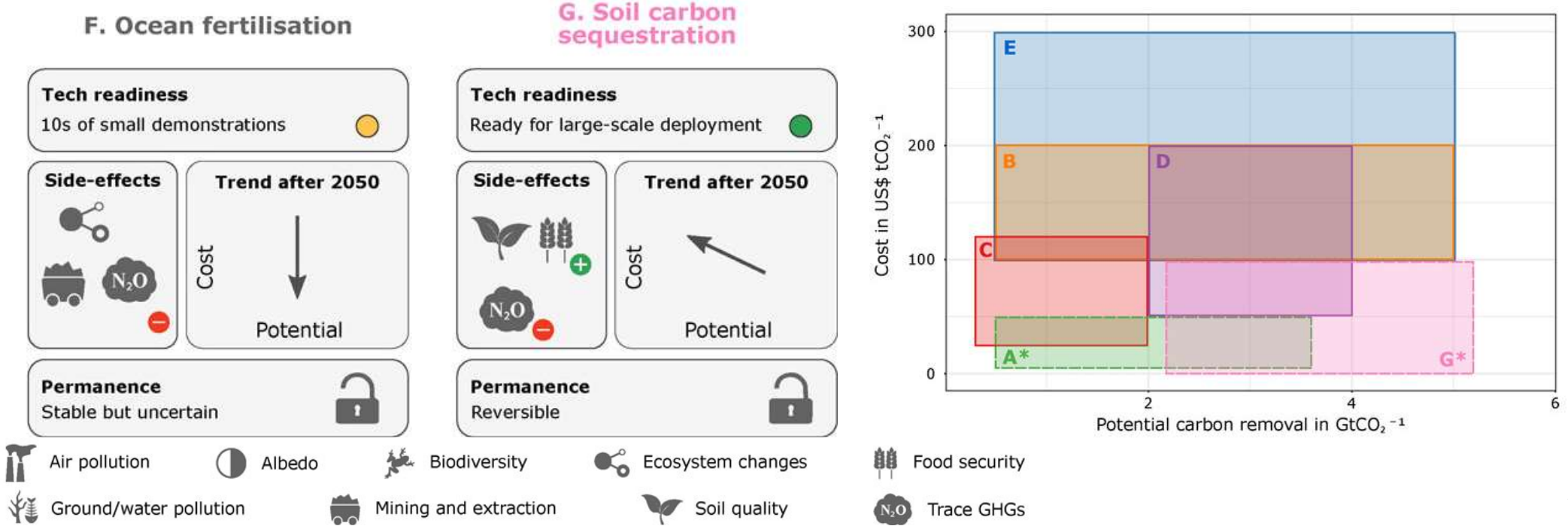
負碳技術(2/3)

- Biochar（生質碳）: Biochar is a type of charcoal produced from organic materials like agricultural waste or wood, which can be added to soils to enhance their carbon storage capacity.
- Enhanced Weathering（增強風化）: This involves spreading finely ground rock (basalt), on land or in oceans. Over time, this can react with CO_2 in the air, removing it from the atmosphere.
- Direct Air Capture (DAC)（直接空氣捕捉）: DAC systems use chemical processes to capture CO_2 directly from the air. Once captured, the CO_2 can be stored underground or used for various industrial purposes.



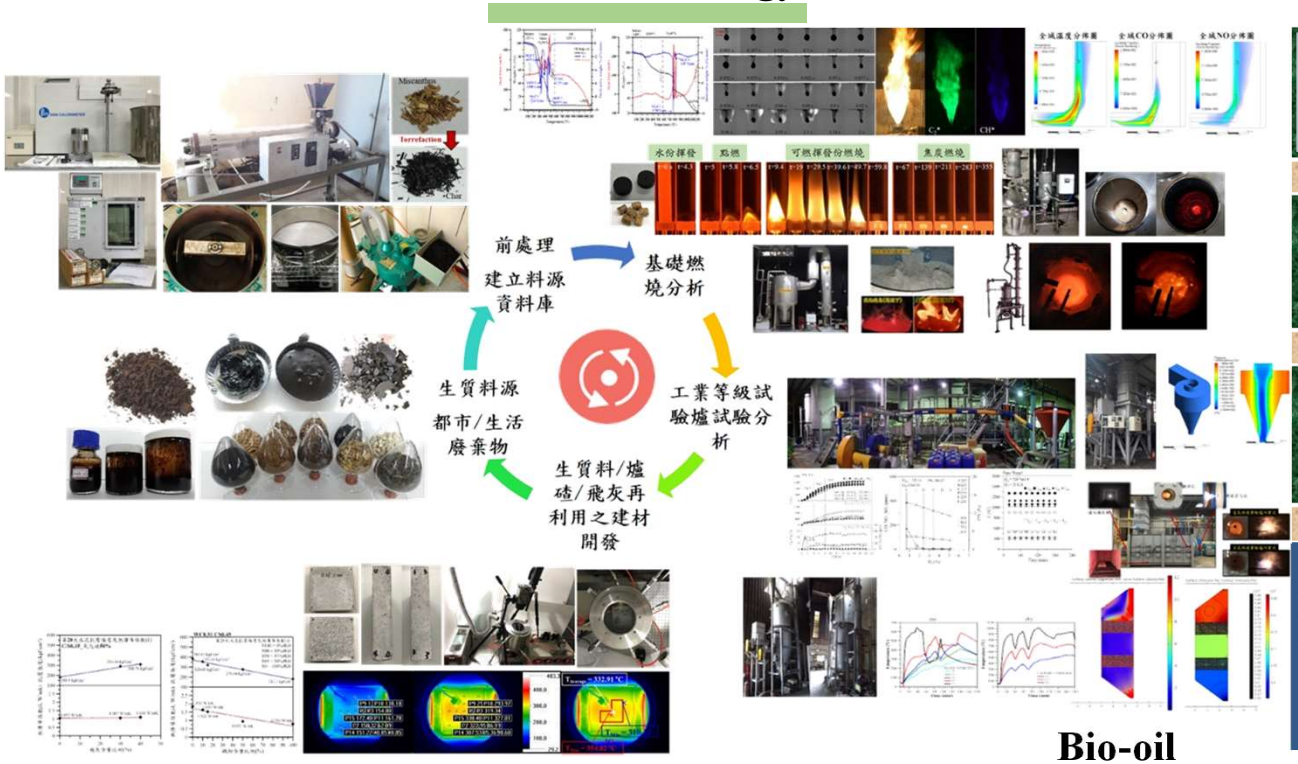
負碳技術(3/3)

- Ocean-based Solutions: These include techniques like ocean fertilization or ocean alkalinity enhancement, which aim to enhance the ocean's ability to absorb and store CO_2.
- Soil Carbon Sequestration: Practices that enhance the carbon content in soils, such as no-till agriculture, cover cropping, and agroforestry, can help store carbon in the ground.
- Carbon Mineralization: This technology involves turning CO_2 into stable minerals through chemical reactions, effectively locking it away from the atmosphere.



生質物料能源化

Core Technology



Biomass

Bio-oil


蓖麻裂解油

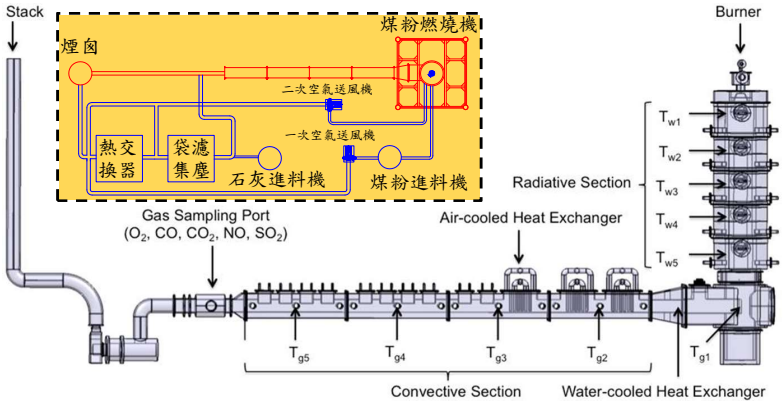
蓖麻冷壓油

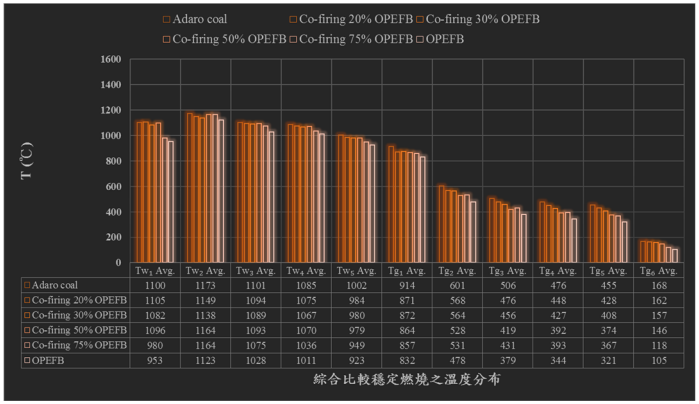

下水汙泥裂解油


中油塔底油


潤滑油再製油

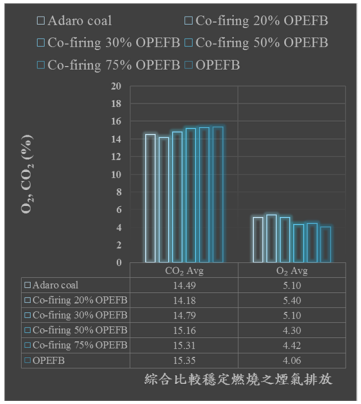
生質物料能源化-棕櫚空果串與印尼煤於300 kW燃燒爐混燒研究(2015-2016)





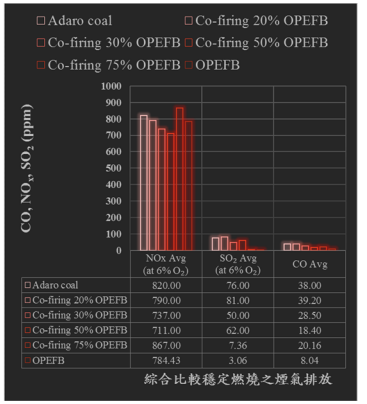
	Tw1 Avg.	Tw2 Avg.	Tw3 Avg.	Tw4 Avg.	Tw5 Avg.	Tg1 Avg.	Tg2 Avg.	Tg3 Avg.	Tg4 Avg.	Tg5 Avg.	Tg6 Avg.
Adaro coal	1100	1173	1101	1085	1002	914	601	506	476	455	168
Co-firing 20% OPEFB	1105	1149	1094	1075	984	871	568	476	448	428	162
Co-firing 30% OPEFB	1082	1138	1089	1067	980	872	564	456	427	408	157
Co-firing 50% OPEFB	1096	1164	1093	1070	979	864	528	419	392	374	146
Co-firing 75% OPEFB	980	1164	1075	1036	949	857	531	431	393	367	118
OPEFB	953	1123	1028	1011	923	832	478	379	344	321	105

綜合比較穩定燃燒之溫度分布



	CO2 Avg	O2 Avg
Adaro coal	14.49	5.10
Co-firing 20% OPEFB	14.18	5.40
Co-firing 30% OPEFB	14.79	5.10
Co-firing 50% OPEFB	15.16	4.30
Co-firing 75% OPEFB	15.31	4.42
OPEFB	15.35	4.06

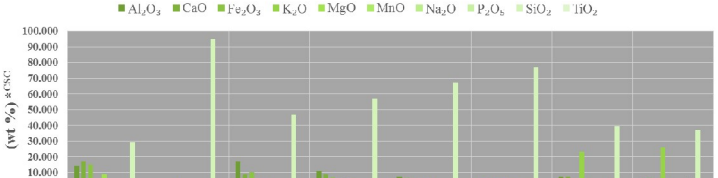
綜合比較穩定燃燒之煙氣排放



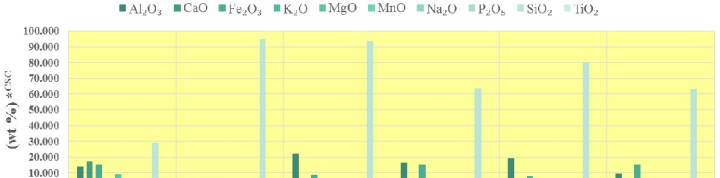
	NOx Avg (at 6% O2)	SO2 Avg (at 6% O2)	CO Avg
Adaro coal	820.00	76.00	38.00
Co-firing 20% OPEFB	790.00	81.00	39.20
Co-firing 30% OPEFB	737.00	50.00	28.50
Co-firing 50% OPEFB	711.00	62.00	18.40
Co-firing 75% OPEFB	867.00	7.36	20.16
OPEFB	784.43	3.06	8.04

綜合比較穩定燃燒之煙氣排放

	Adaro coal	OPEFB	ATcoal 100 (AP)	ATEFB 20 (AP)	ATEFB 30 (AP)	ATEFB 50 (AP)	ATEFB 75 (AP)	ATEFB 100 (AP)
Al_2O_3	14.088	0.744	9.037	16.110	9.511	5.982	6.453	6.497
CaO	16.966	1.422	2.826	1.871	2.676	2.291	3.421	3.627
Fe_2O_3	14.906	0.482	5.295	8.398	5.516	5.658	3.988	4.298
K_2O	1.058	3.829	2.102	1.007	2.162	2.443	10.146	8.237
MgO	9.192	0.928	1.685	0.849	1.528	1.382	1.701	2.044
MnO	0.163	0.121	0.151	0.222	0.152	0.148	0.094	0.115
Na_2O	0.964	0.300	0.428	0.431	0.284	0.224	0.894	0.827
P_2O_5	0.108	1.528	0.389	0.204	0.422	0.537	1.520	2.109
SiO_2	29.020	94.960	95.930	61.100	86.100	88.670	70.250	73.550
TiO_2	0.711	0.055	0.340	0.728	0.350	0.210	0.264	0.201

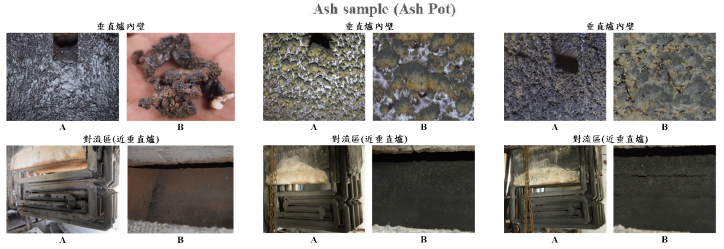


	ADARO coal	OPEFB	ATcoal 100 (BH)	ATEFB 20 (BH)	ATEFB 30 (BH)	ATEFB 50 (BH)	ATEFB 75 (BH)	ATEFB 100 (BH)
Al_2O_3	14.088	0.744	17.351	10.796	7.421	4.010	6.938	5.568
CaO	16.966	1.422	9.249	8.991	6.559	4.327	7.310	6.510
Fe_2O_3	14.906	0.482	10.068	6.888	4.686	2.732	4.760	4.091
K_2O	1.058	3.829	1.228	3.051	3.732	4.394	22.973	25.907
MgO	9.192	0.928	4.830	4.939	3.650	2.485	4.014	3.463
MnO	0.163	0.121	0.156	0.154	0.144	0.141	0.133	0.125
Na_2O	0.964	0.300	0.691	0.612	0.471	0.309	1.141	1.146
P_2O_5	0.108	1.528	0.180	1.049	1.498	1.935	5.506	5.358
SiO_2	29.020	94.960	46.840	57.330	66.890	76.740	39.500	36.970
TiO_2	0.711	0.055	0.741	0.449	0.315	0.175	0.308	0.253

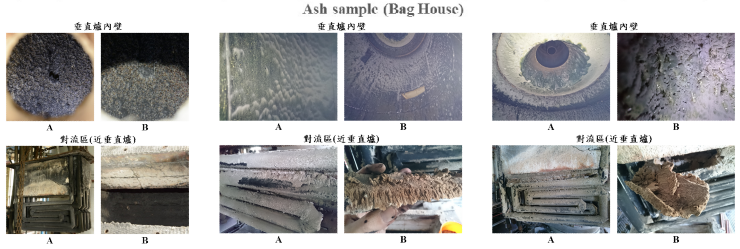


	ADARO coal	OPEFB	ATcoal 100 (Slag)	ATEFB 20 (Slag)	ATEFB 30 (Slag)	ATEFB 50 (Slag)
Al_2O_3	14.088	0.744	22.232	16.242	19.110	9.671
CaO	16.966	1.422	3.187	2.872	1.001	2.020
Fe_2O_3	14.906	0.482	8.713	15.058	7.885	11.889
K_2O	1.058	3.829	1.784	1.820	0.962	2.374
MgO	9.192	0.928	1.849	1.198	0.680	1.086
MnO	0.163	0.121	0.218	0.221	0.253	0.204
Na_2O	0.961	0.300	0.611	0.394	0.389	0.913
P_2O_5	0.108	1.528	0.375	0.421	0.179	0.439
SiO_2	29.020	94.960	93.630	63.540	80.230	63.230
TiO_2	0.711	0.055	0.562	0.657	0.695	0.457

Ash sample (Ash Pot)



Ash sample (Bag House)



Ash sample (Slag)

工業與元素分析結果*1st CSC

工業分析		Adaro coal	OPEFB	元素分析		Adaro coal	OPEFB
內含水分*AD	(wt%)	21.35	3.35	碳*AD	(wt%)	73.57	61.50
揮發份*D	(wt%)	46.72	44.16	氫*AD	(wt%)	2.76	4.43
固定碳*D	(wt%)	49.66	41.16	氧*AD	(wt%)	19.45	18.25
灰分*D	(wt%)	3.62	14.69	氮*AD	(wt%)	0.52	1.10
				硫*AD	(wt%)	0.08	0.04

Adaro coal*1st 總熱值*D (kcal/kg) [MJ/kg]
4,989 [20.89]
OPEFB*1st 總熱值*D (kcal/kg) [MJ/kg]
4,762 [19.94]

永續發展實務研討會

淨零碳排.....之路

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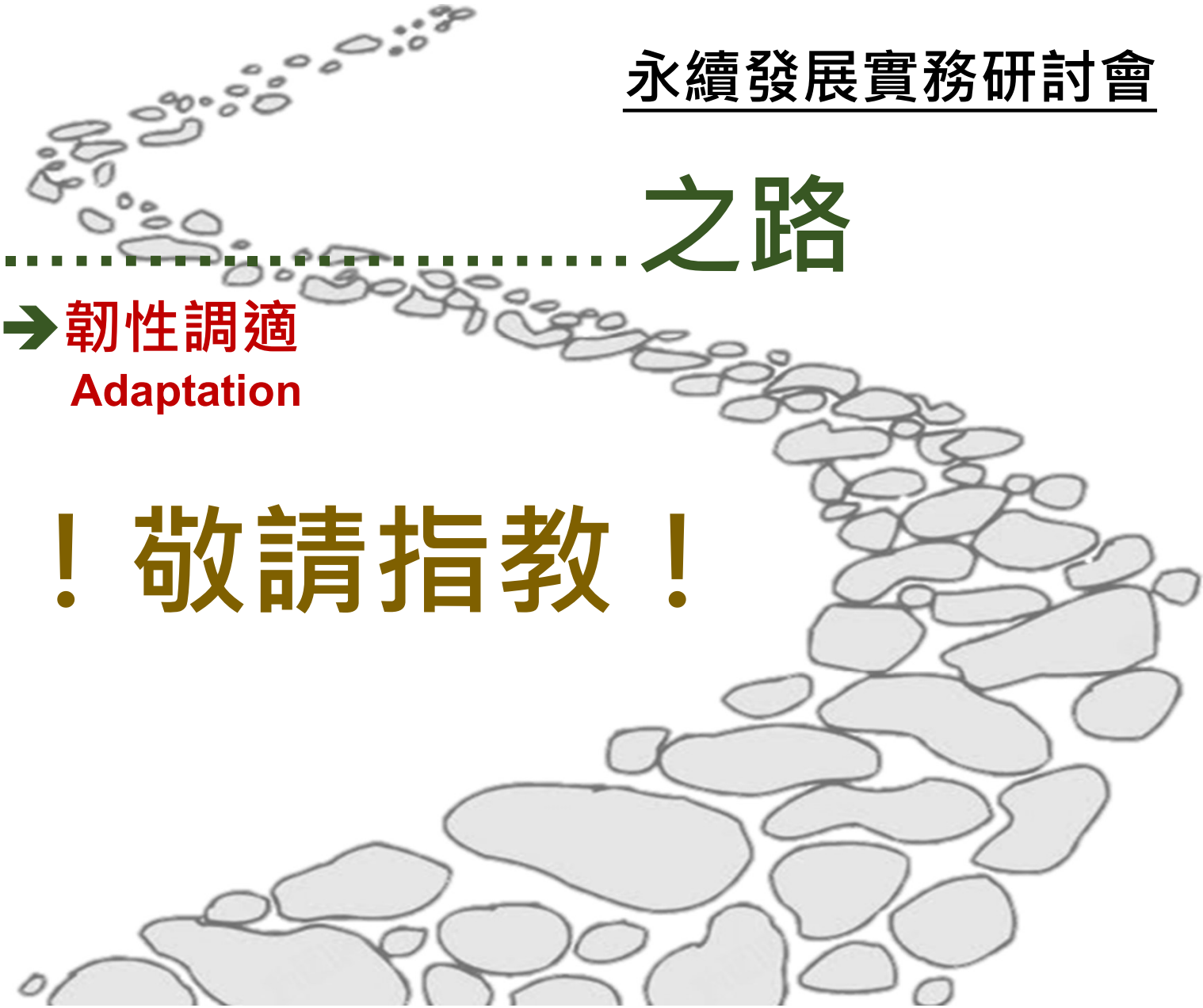
Mitigation Adaptation



謝謝聆聽！敬請指教！

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