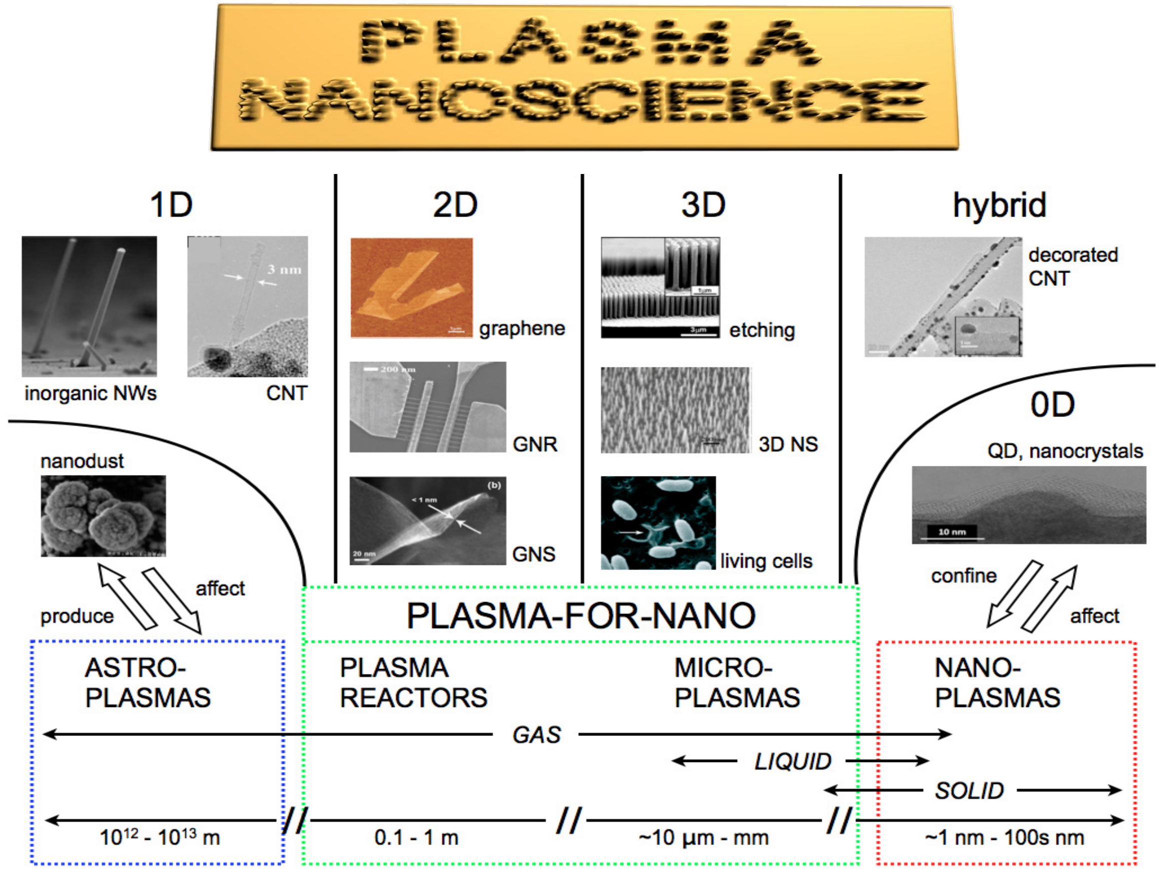
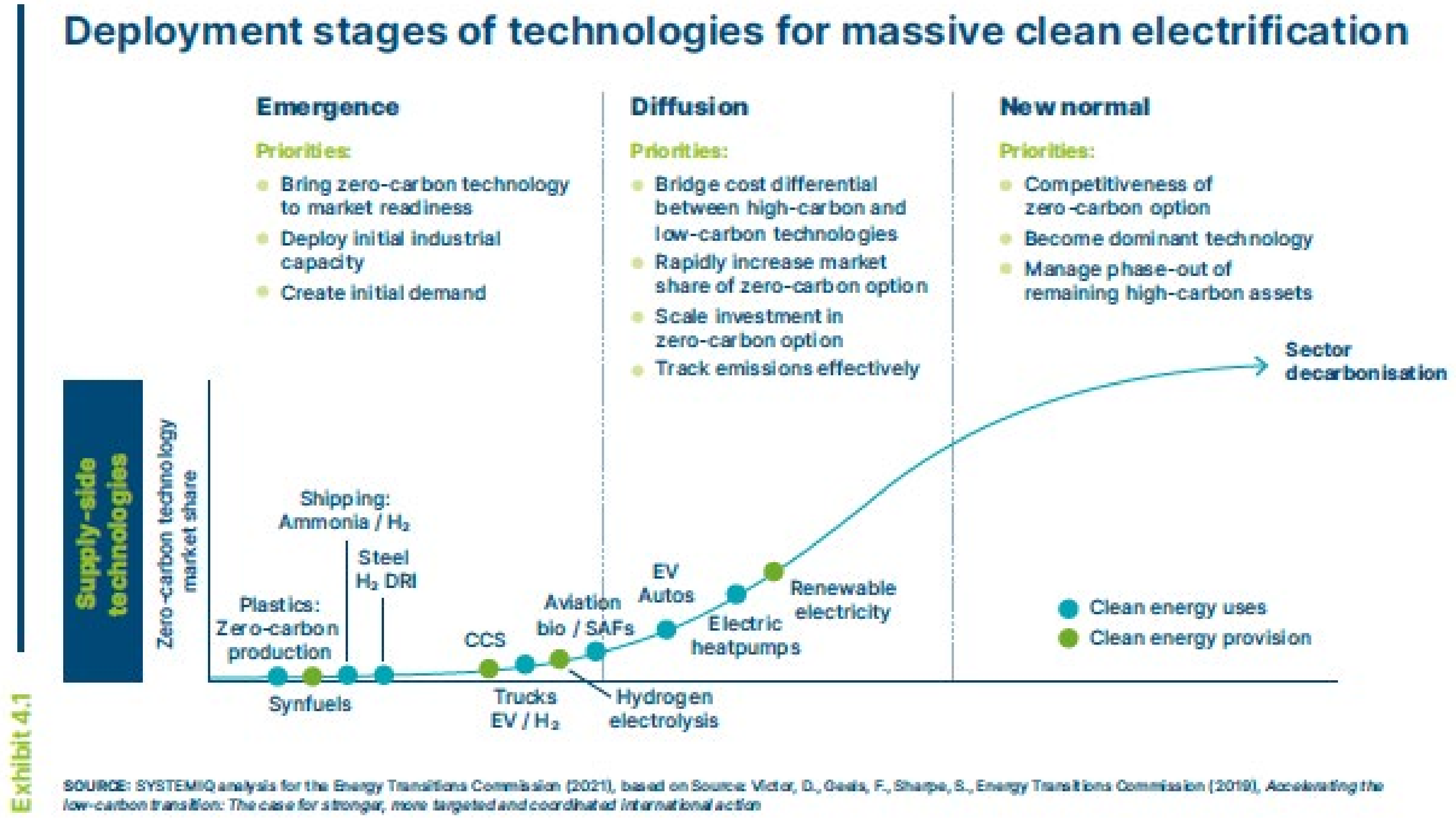


Plasma nanotechnology for clean energy, green chemistry, and zero-carbon future

Kostya (Ken) Ostrikov

Pathway to clean energy transition: de-carbonize power first

A net-zero greenhouse gas economy will be built on abundant, affordable zero-carbon electricity. Achieving massive electrification and early power decarbonisation – ahead of economy-wide decarbonisation - must be at the heart of all countries' paths to net zero. www.energy-transitions.org



Innovations to decarbonize materials industries

https://doi.org/10.1038/s41578-021-00376-y

November 2021

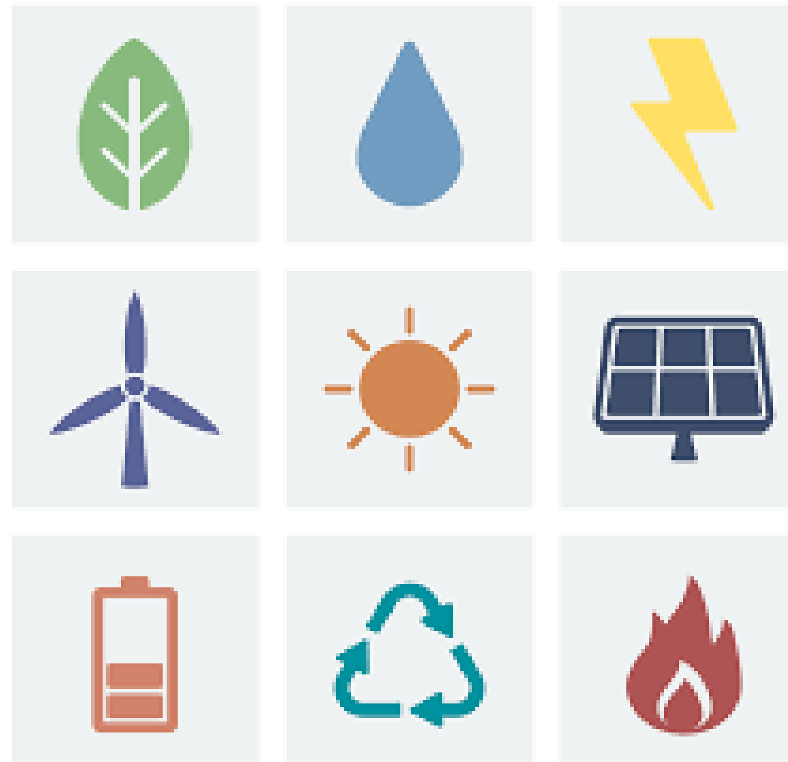
Katrin Daehn[1], *R. Basuhi*[1], *Jeremy Gregory*[2], *Maya Berlinger*[1], *Vrindaa Somjit*[1] *and Elsa A. Olivetti*[1] ✉

Table 1 | **Global CO_2 emissions associated with the production of different materials**

Material	Global CO_2 emissions associated with production in 2000 (Mt CO_2 per year)[210]	Global CO_2 emissions associated with production in 2017 (Mt CO_2 per year)	Current global average specific CO_2 intensity (kg CO_2 t^{-1} material)	Global production in 2017 (Mt per year)	Business-as-usual demand in 2050 (Mt per year)
Cement	1,588	2,200 (direct)[25]	860 (OPC with additional processing)[89]; 540 (direct)[25]	4,050 (REF.[211])	4,682 (REF.[25])
Steel and iron	1,319	3,700 (2,600 direct)[27]	2,000 (1,400 direct)[27]	1,736 (total crude steel)[212]	2,100 (final end-use); 2,535 (crude steel)[27]
Aluminium	324	1,000 (REF.[213])	14,400 (primary)[213]	64.3 (primary)[a]; 92 (plus secondary)[213]	110 (primary)[214]; 175 (plus secondary)[32]
Copper	47 (REF.[215])	70 (average CO_2 intensity multiplied by production in 2017)	3,500 (REF.[216])	20 (REF.[217])	50 (REF.[218])
Petrochemicals	2,013	1,500 (REF.[24])	1,700 (REF.[24])	960 (REF.[24])	1,500 (REF.[24])

Electrify to Decarbonize: Clean Electrification for Future Zero-Carbon Economy and Environment

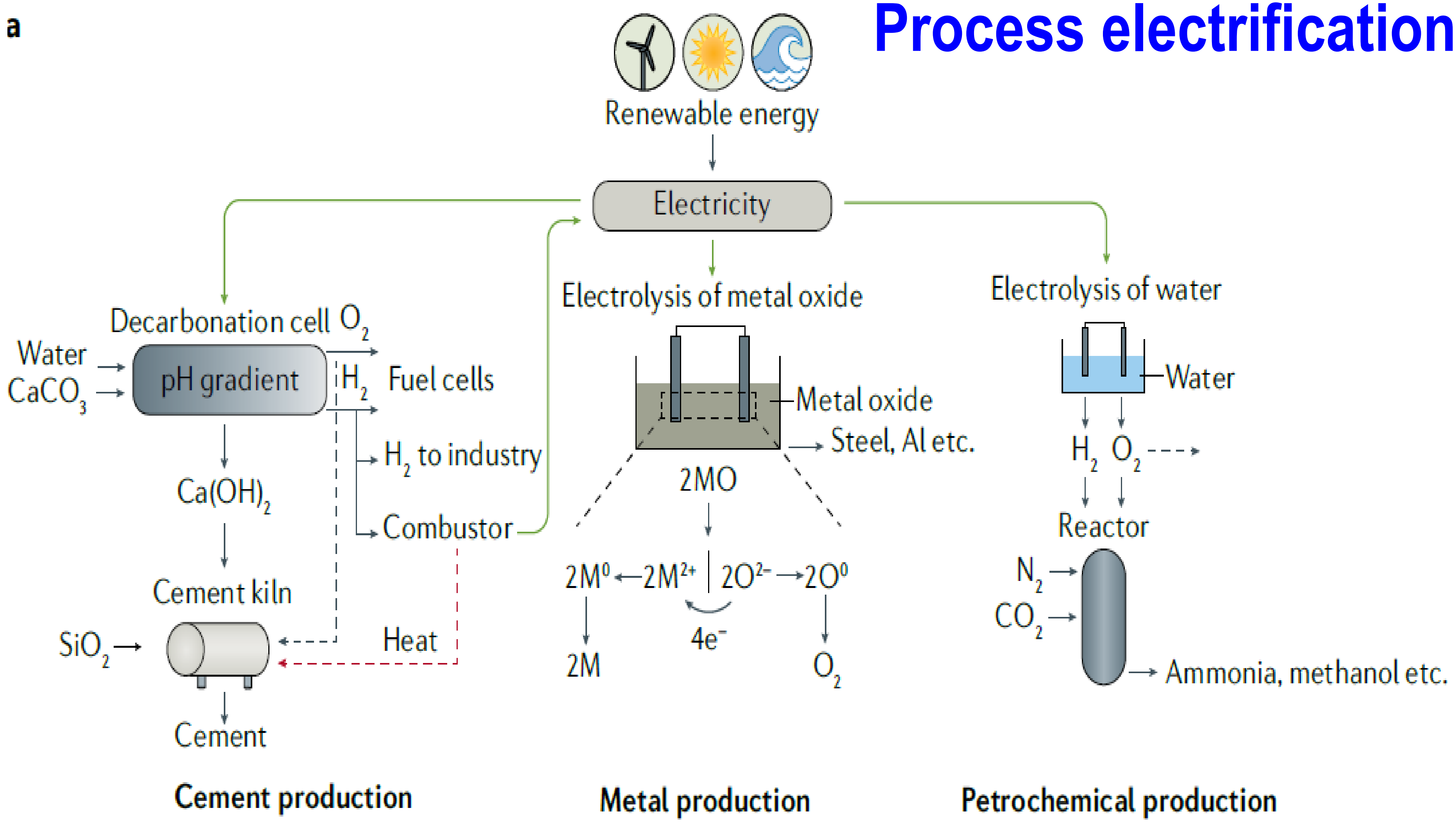
Electrifying industry and society by using renewable energy, innovating key carbon-emitting processes to achieve zero- (or even negative) carbon emissions without raising cost of products (otherwise inevitable to fund decarbonisation) by using renewable feedstocks (e.g., waste) and raising product values in targeted market segments



K. Ostrikov & A. O'Mullane (since ~2016): a vision for Australian Electro-Photo-Futures

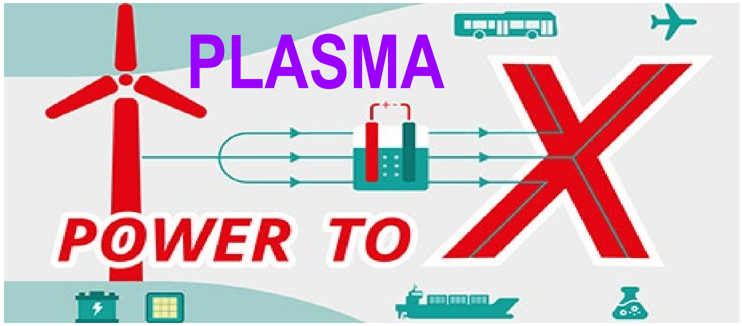
www.energy-transitions.org

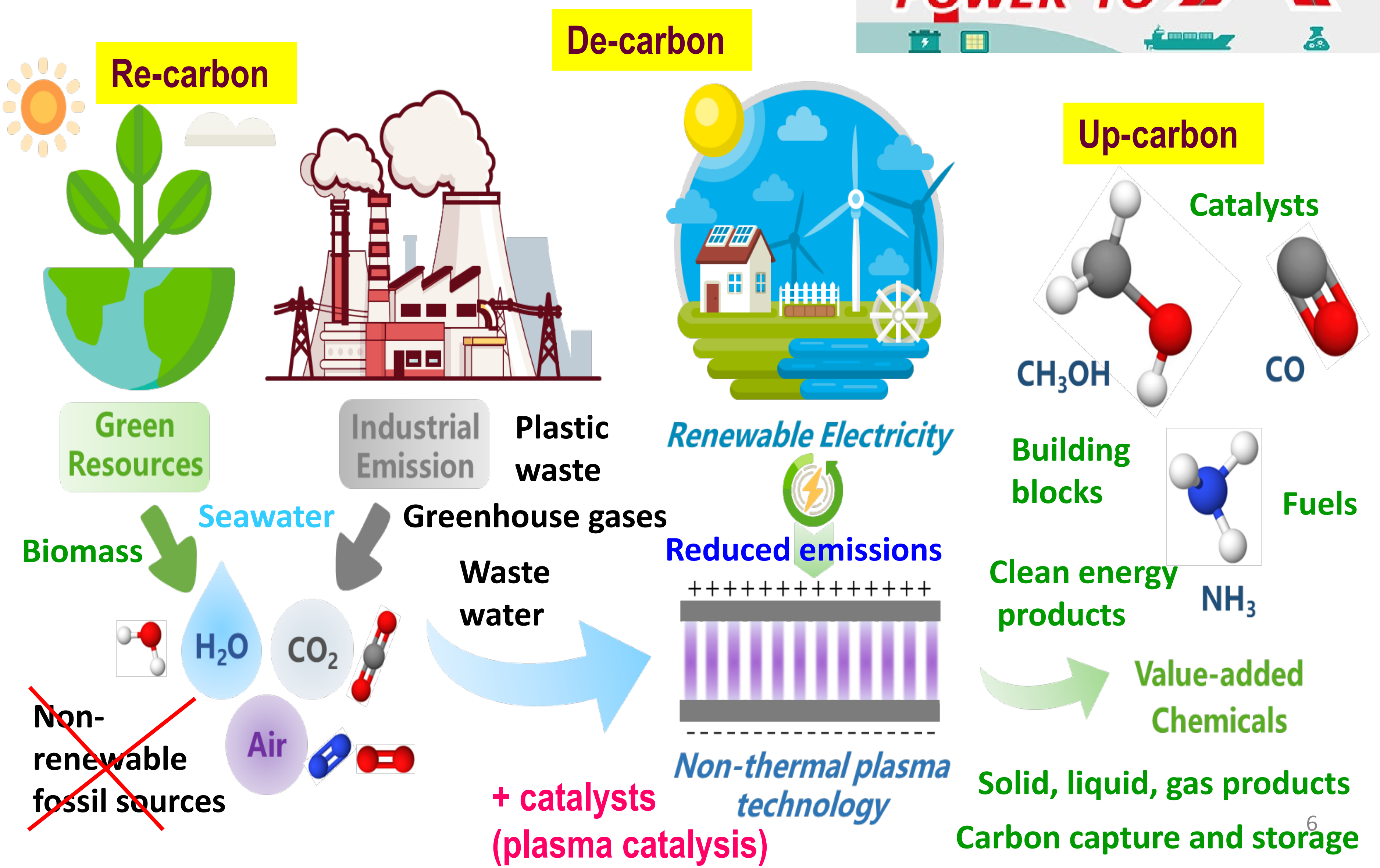
Process electrification



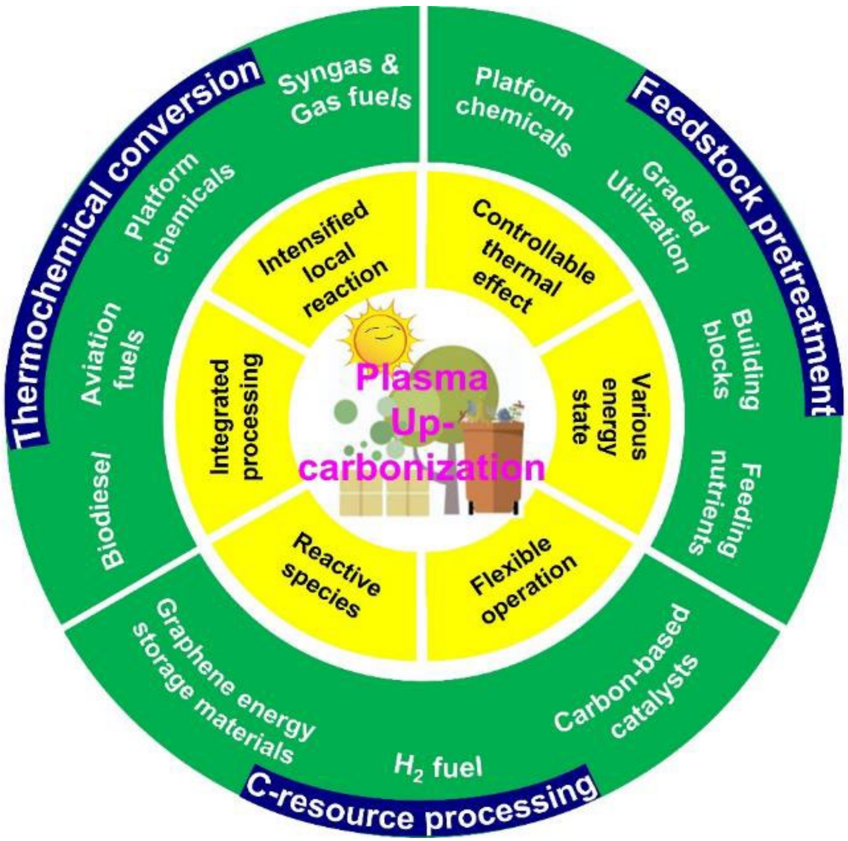
Paradigm shift: from traditional structure– property – performance to structure/composition – **e-processing** – property – performance

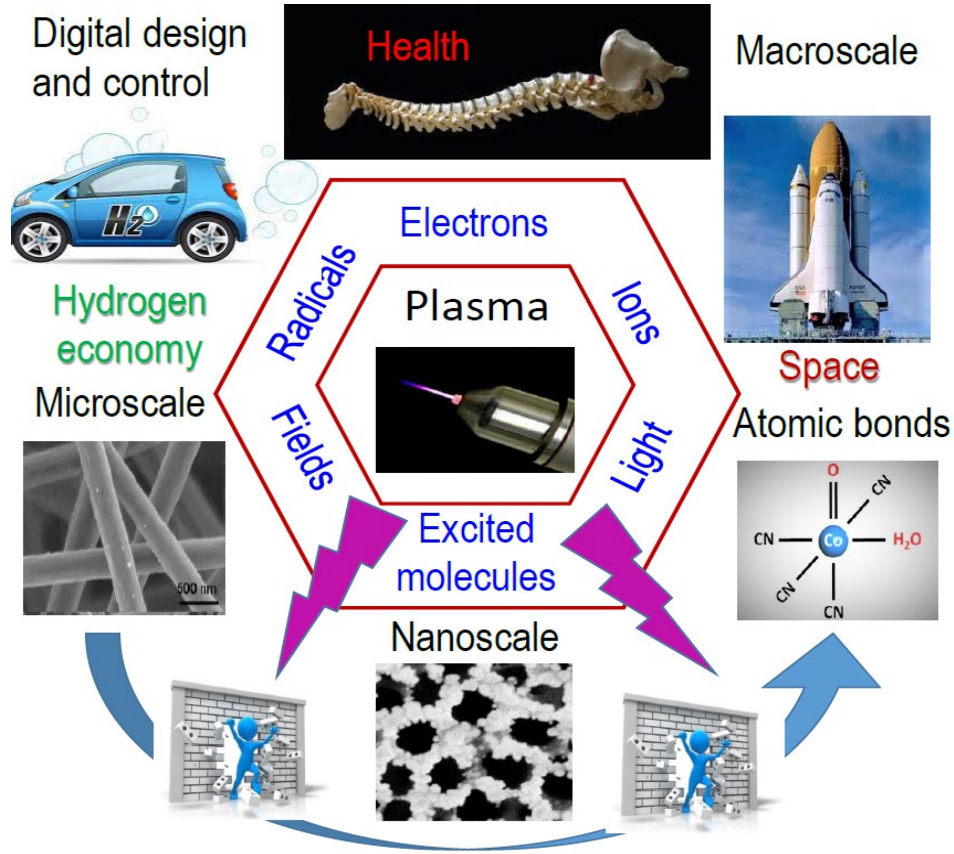
The PP2X Approach: Plasma e-Power to e-Products to de-Carbonize





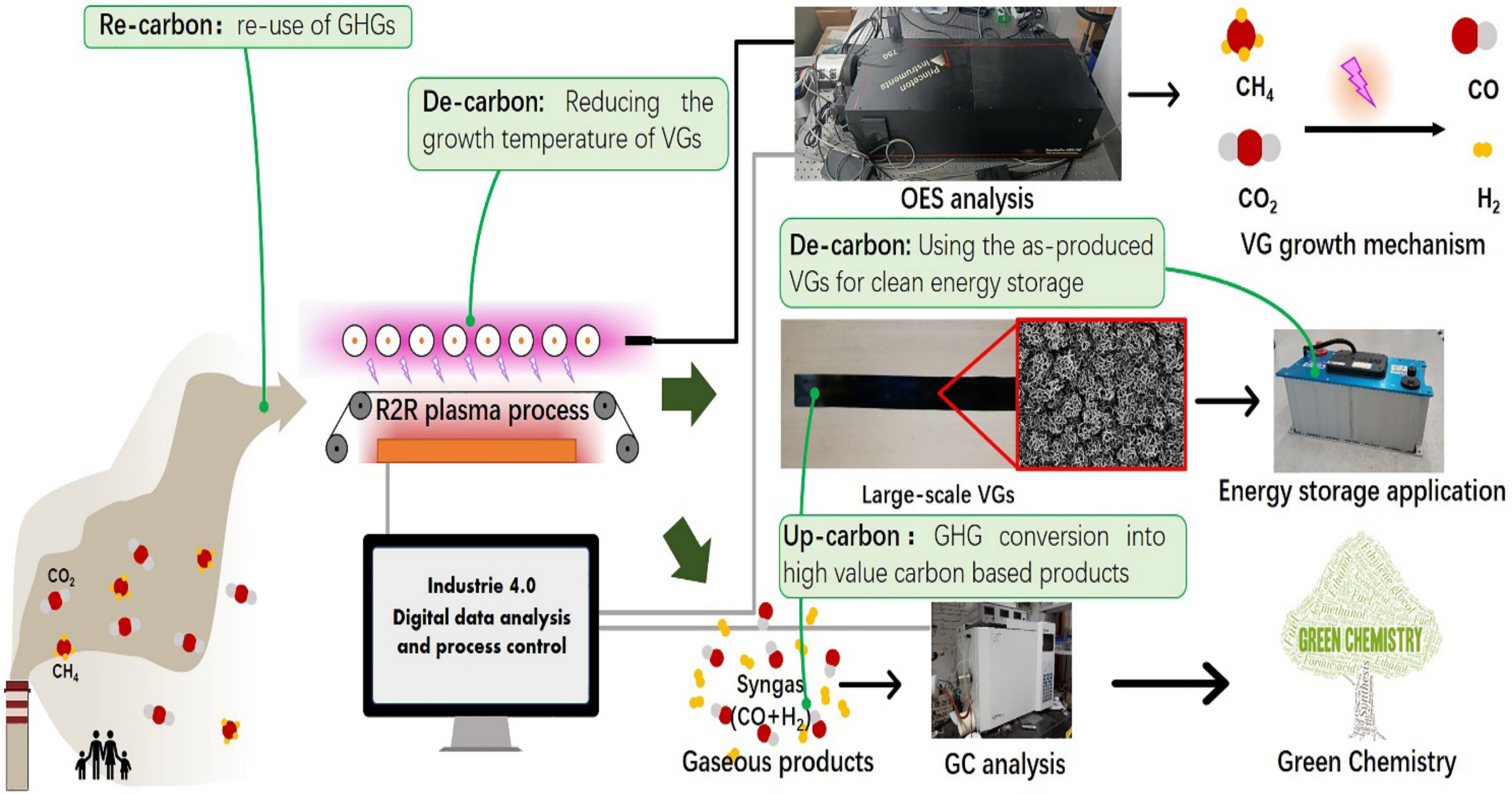
Up-carbonization: From Atomic- to Macro- via Nano-scales





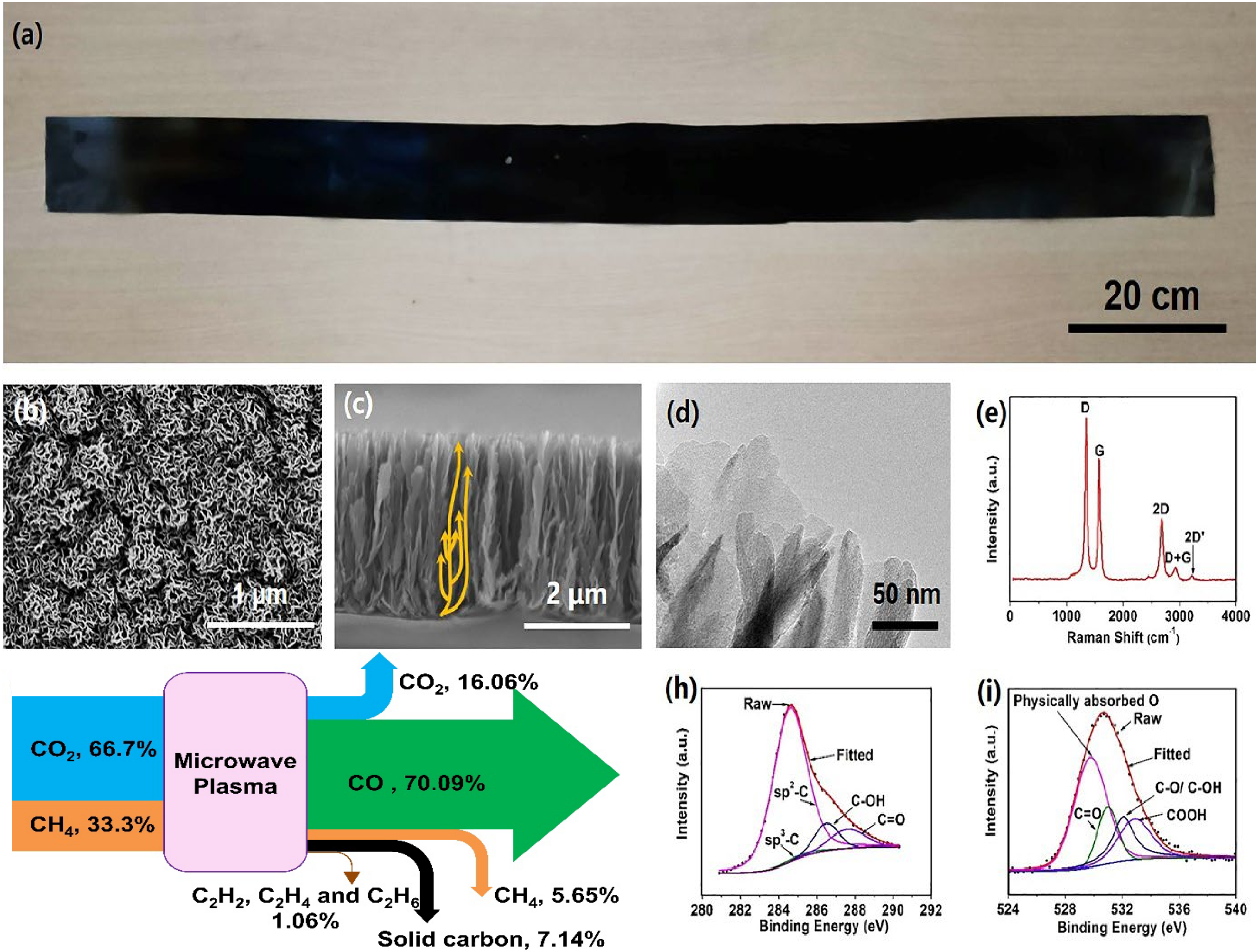
Plasma-electrified up-carbonization for low-carbon clean energy. Carbon Energy 5, e260 (2023). DOI: 10.1002/cey2.260 Plasmas, with the unique electricity-enabled physiochemical properities, electrify the conversion and up-carbonization of carbon-rich feedtsock into the higher-energy state and further create value-added products, such as clean energy, high-performance advanced carbon-based energy materials, high-value platform chemicals, customized manufactured products, etc.

Re-carbon, up-carbon, de-carbon: plasma-electrified roll-to-roll cleaner production of vertical graphenes and syngas from greenhouse gases

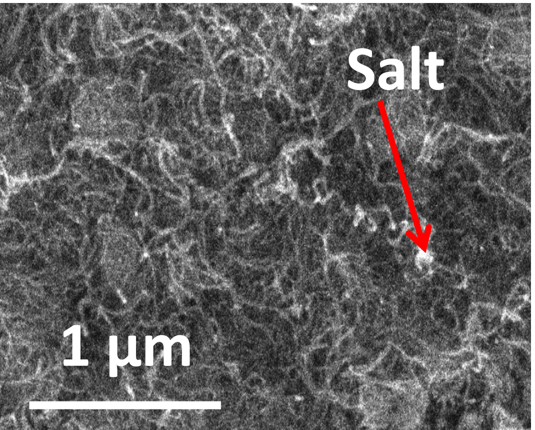


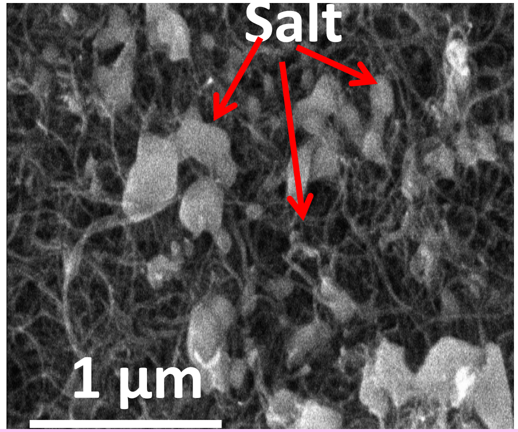
Intergrated *de-carbon*, *re-carbon* and *up-carbon* approach for conversion of GHGs into high-value functional nanocarbon materials, fuels and chemicals, while reducing the assocaited carbon emissions.

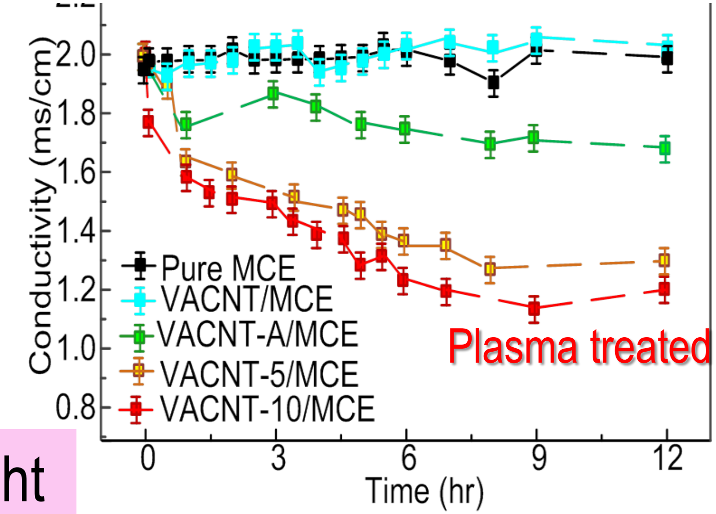
CARBON 197, 301 (2022); DOI: 10.1016/j.carbon.2022.06.024


(a)
20 cm
(b)
1 μm
(c)
2 μm
(d)
50 nm
(e)
D
G
2D
2D'
D+G
Intensity (a.u.)
Raman Shift (cm^{-1})
0
1000
2000
3000
4000
CO_2, 66.7%
CH_4, 33.3%
Microwave Plasma
CO_2, 16.06%
CO , 70.09%
C_2H_2, C_2H_4 and C_2H_6 1.06%
CH_4, 5.65%
Solid carbon, 7.14%
(h)
Raw
Fitted
sp^2-C
C-OH
C=O
sp^3-C
Intensity (a.u.)
Binding Energy (eV)
280
282
284
286
288
290
292
(i)
Physically absorbed O
Raw
Fitted
C-O/ C-OH
C=O
COOH
Intensity (a.u.)
Binding Energy (eV)
524
528
532
536
540

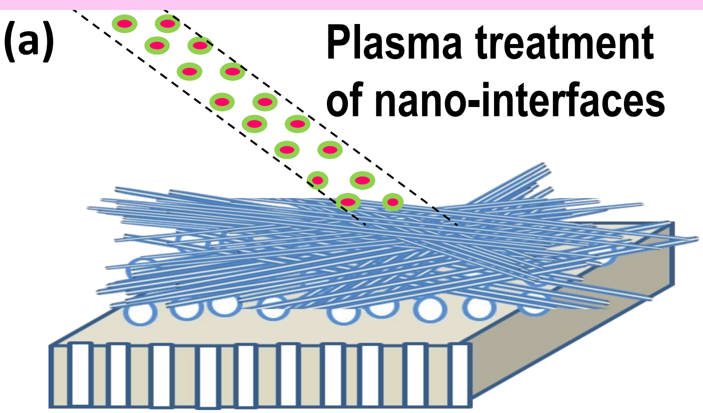
WATER DESALINATION & PURIFICATION [Nature Comm. 4, 2220 (2013)]

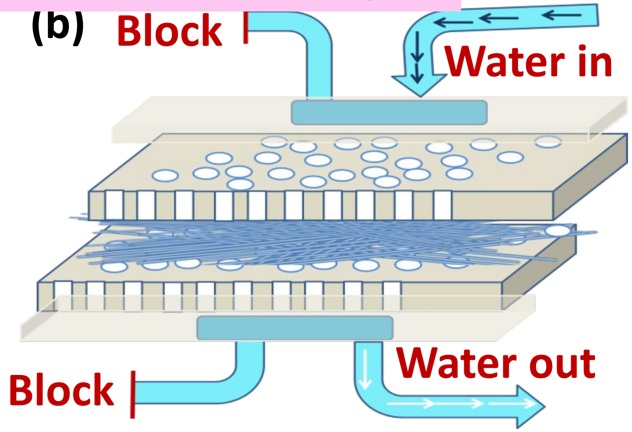


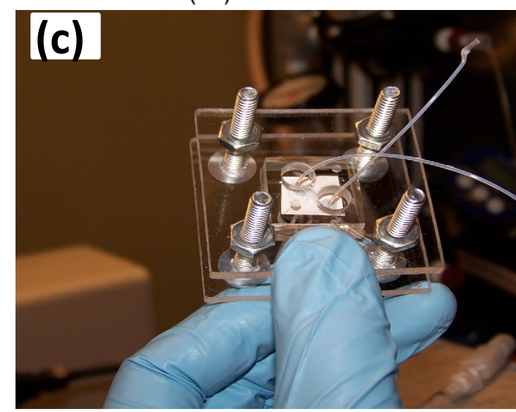


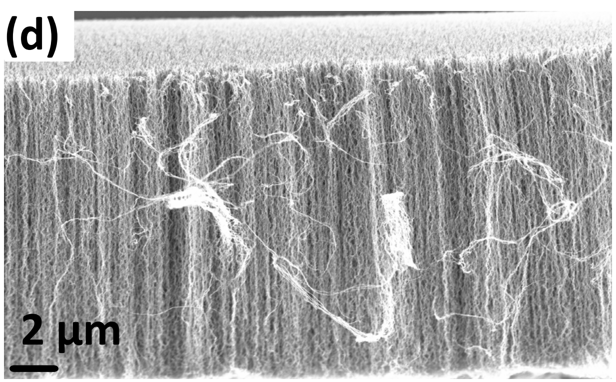


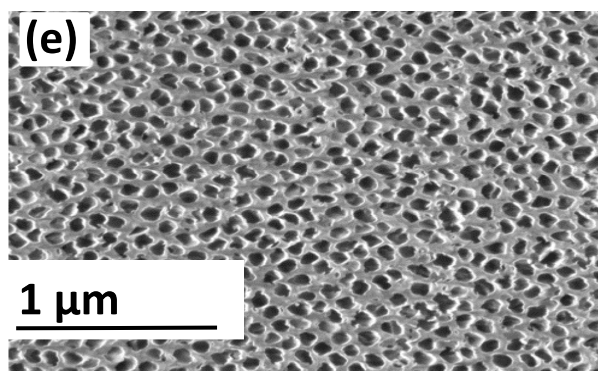
Plasma treated CNTs absorb salt 4x their weight

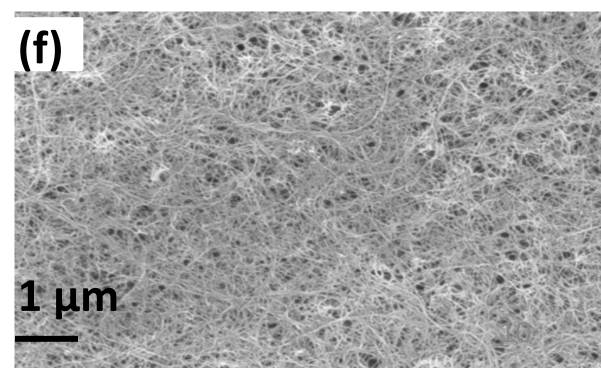






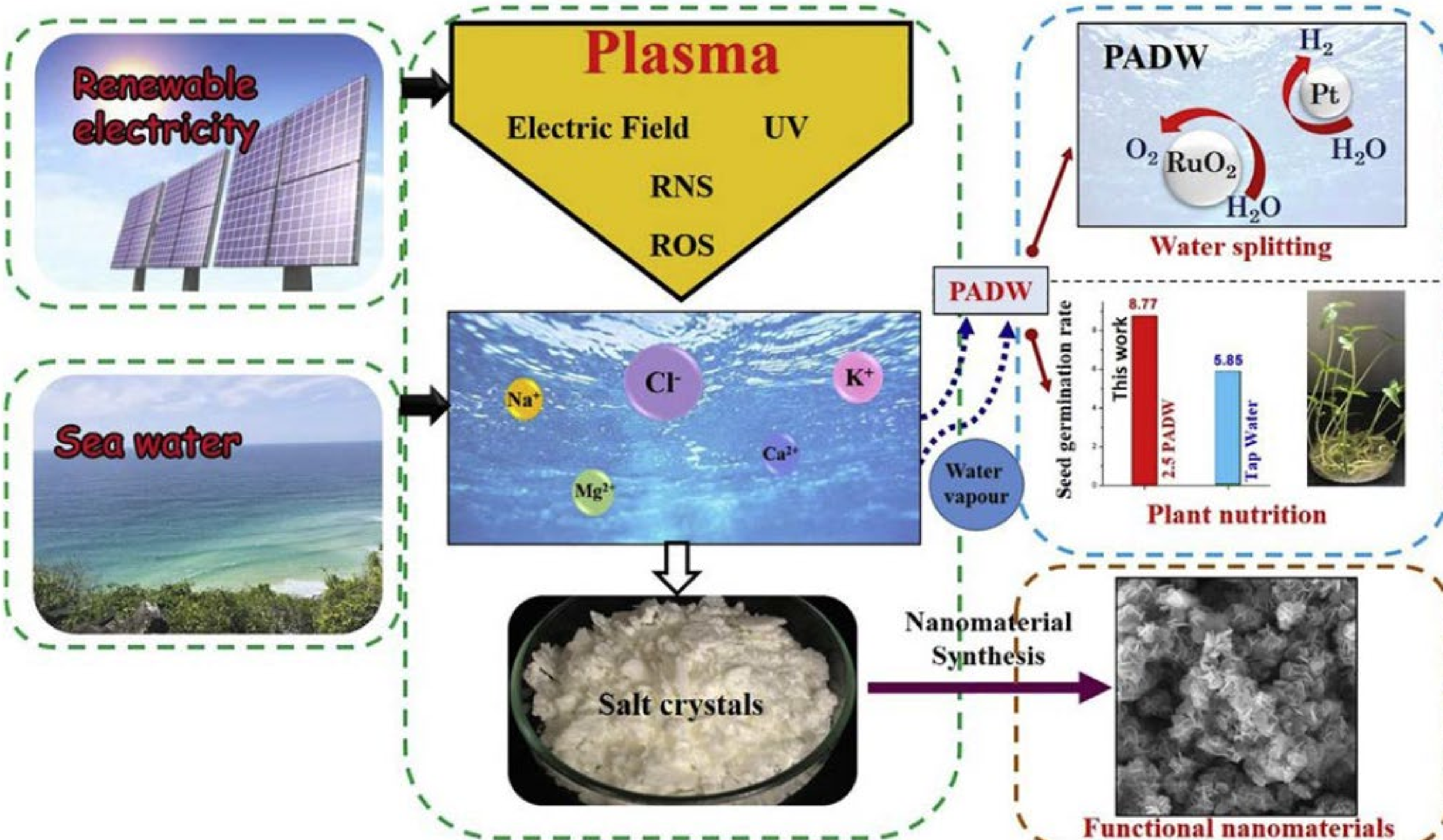




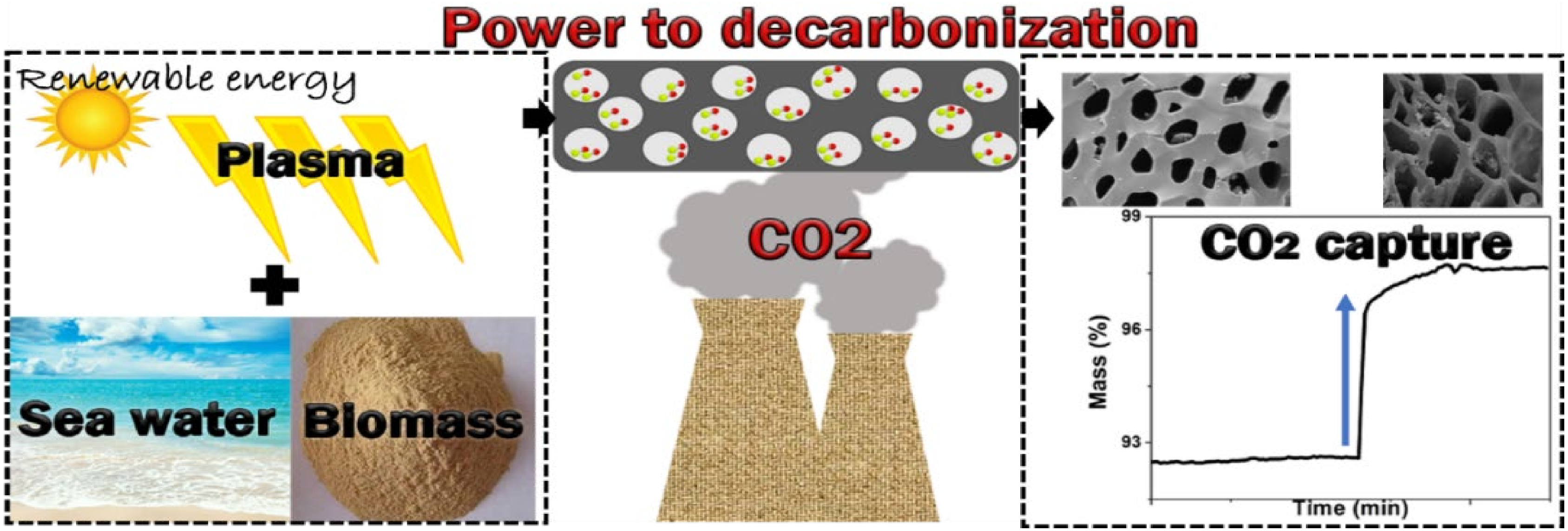


Atmospheric-pressure plasma seawater desalination: Clean energy, agriculture, and resource recovery nexus for a blue planet

Sustainable Materials and Technologies 25 (2020) e00181

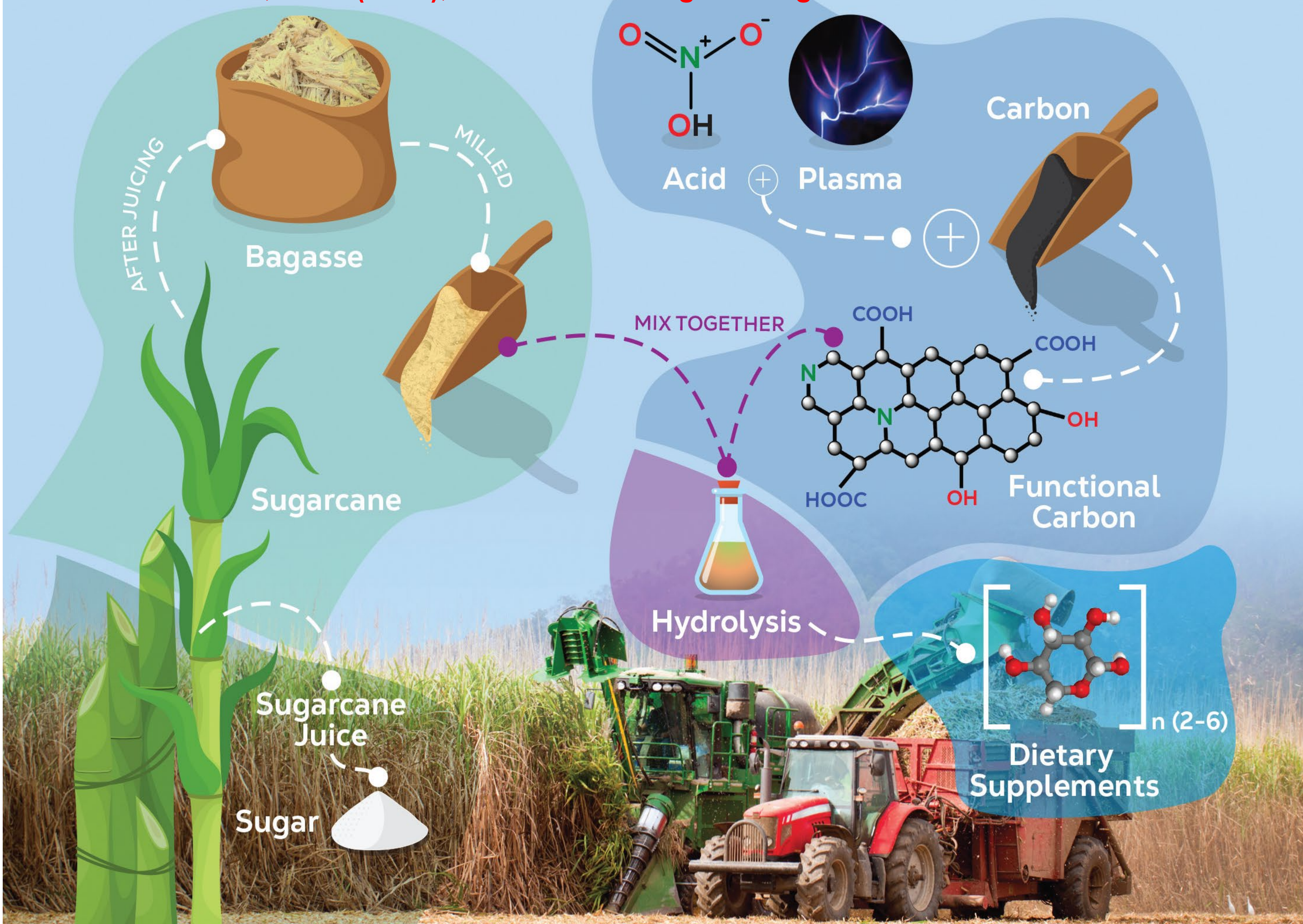


Power-to-decarbonization: mesoporous carbon-MgO nanohybrid derived from plasma-activated seawater salt-loaded biomass for efficient CO_2 capture [Journal of CO_2 Utilization 53, 101711 (2021)]

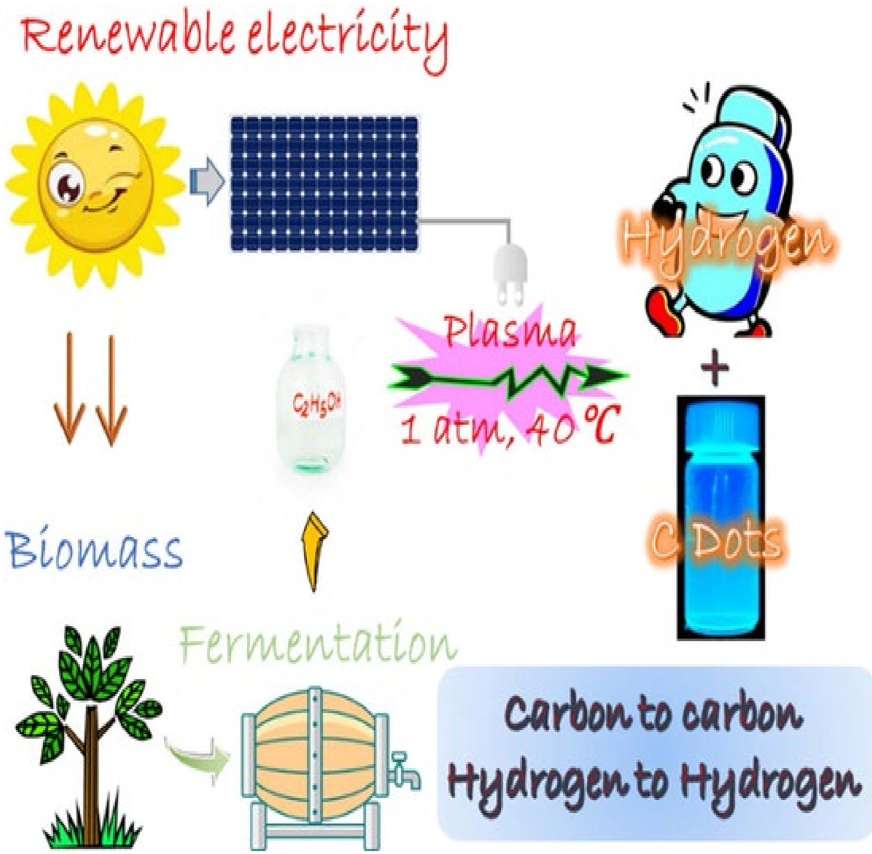


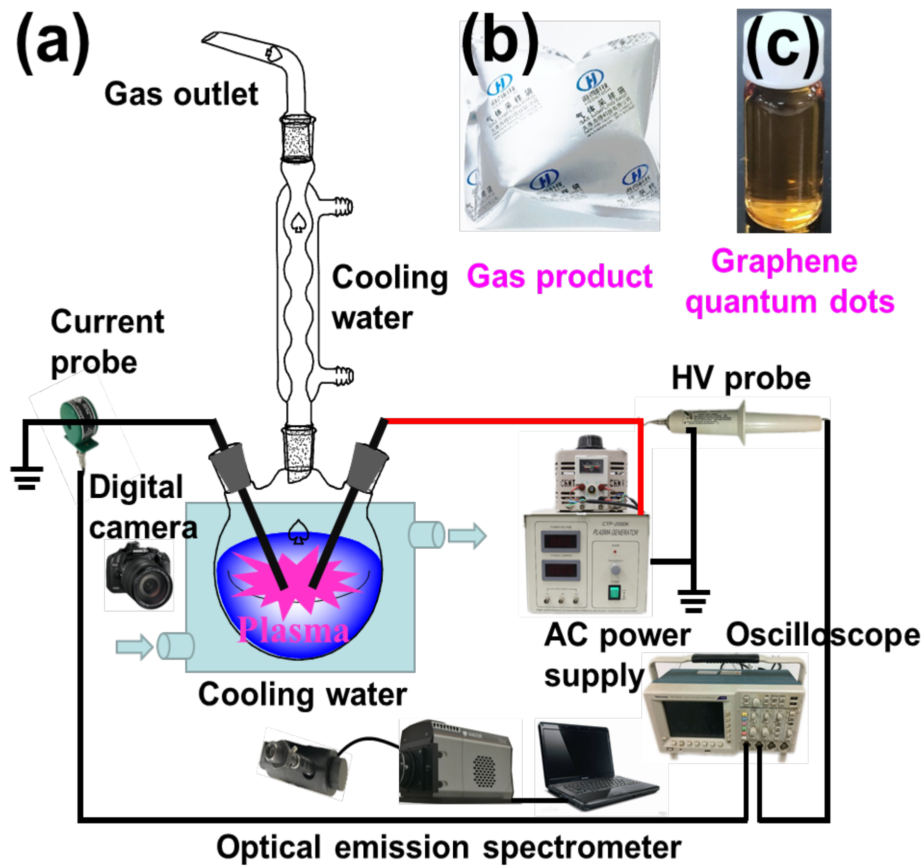
- Novel sustainable CO_2 capture through material recovery from sea water and biomass
- Highly reactive species from plasma enhances the surface area of obtained materials.
- N-containing species on the carbon-MgO nanohybrid enhances the CO_2 capture.
- Dispersion and surface crystallization of MgO are important for CO_2 adsorption.

Green Chem. 24, 7410 (2022), DOI: 10.1039/d2gc01303g



Plasma production of carbon dots and hydrogen (Chem. Eng. J. 2019, DOI: 10.1016/j.cej.2019.122745)



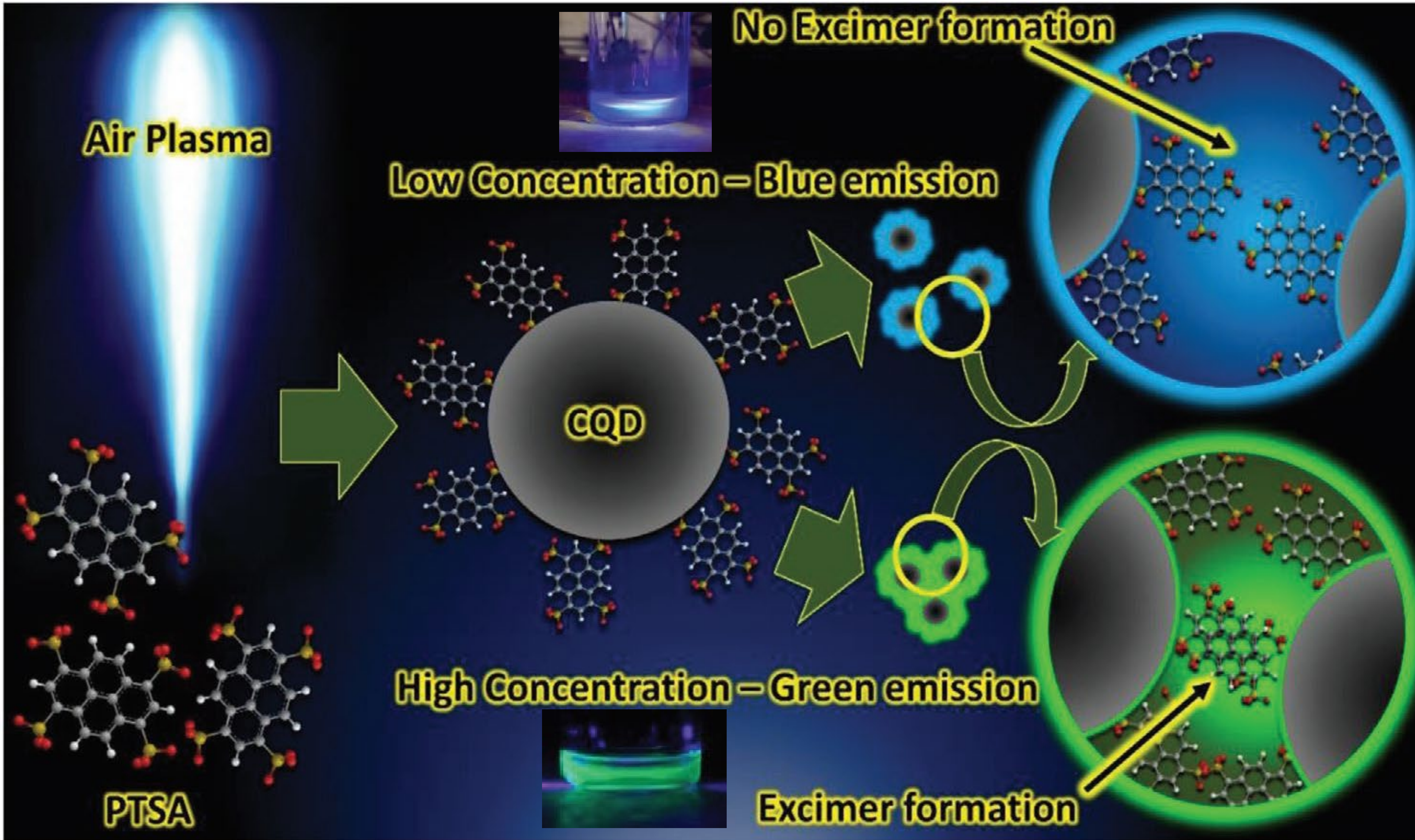


A favourable combination of low temperature (< 40 °C), attractive conversion rate (gas flow rate of ~120 mL/min), high hydrogen yield (H_2 content > 90%), low energy consumption (~0.96 kWh/m^3 H_2) and the effective generation of photo-luminescent GQDs in the MSM indicate that the proposed strategy may offer a new carbon-negative avenue for mitigating the energy and environmental issues.

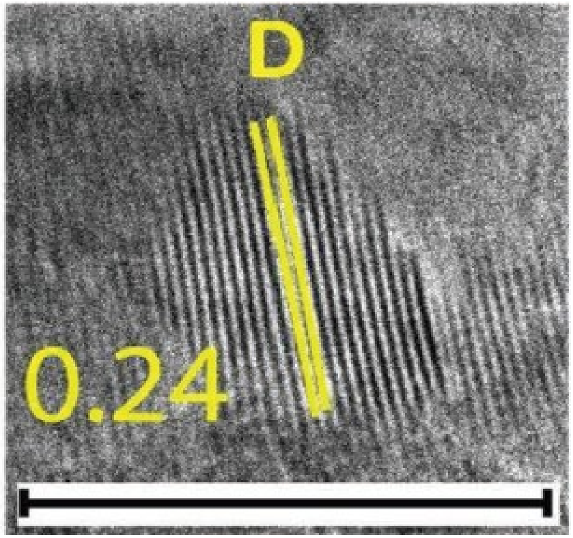
Monochromatic Blue and Switchable Blue-Green Carbon Quantum Dots by Room-Temperature Air Plasma Processing

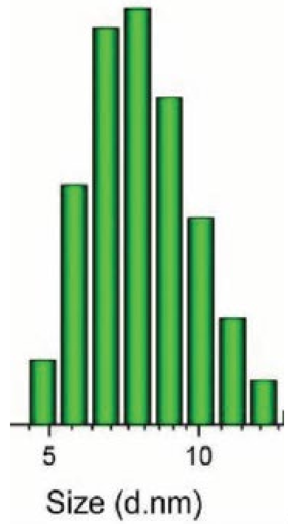
ADVANCED MATERIALS TECHNOLOGIES
DOI: 10.1002/admt.202100586
Adv. Mater. Technol. **2021**, 2100586

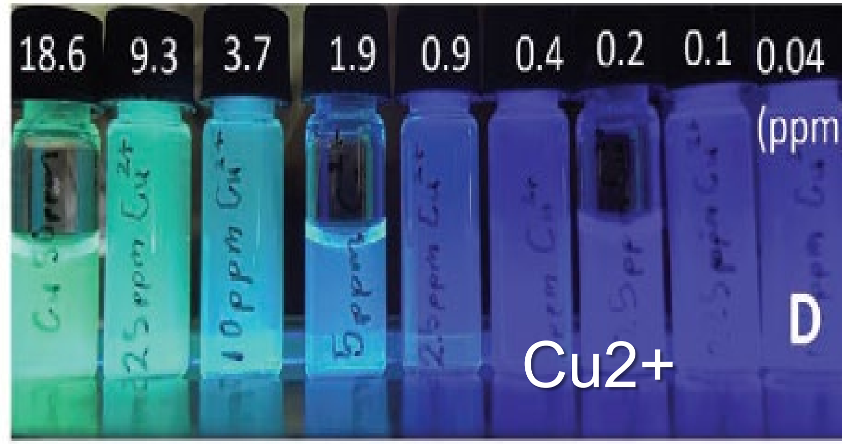
Collaboration with Griffith Uni (Prof. Q. Li)

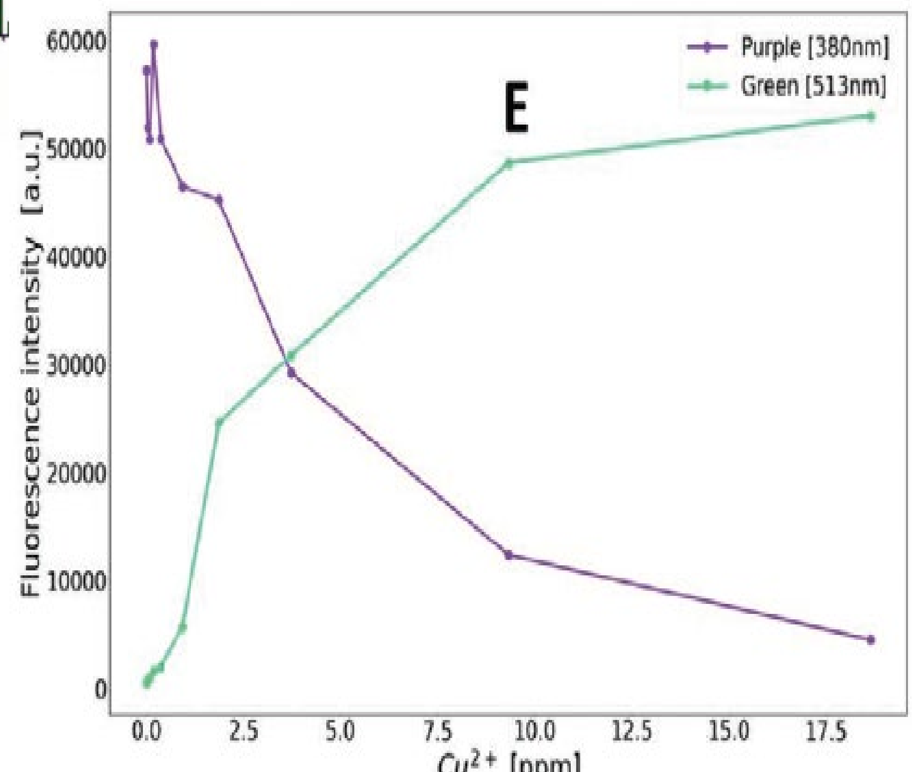


Ion sensing for environmental applications



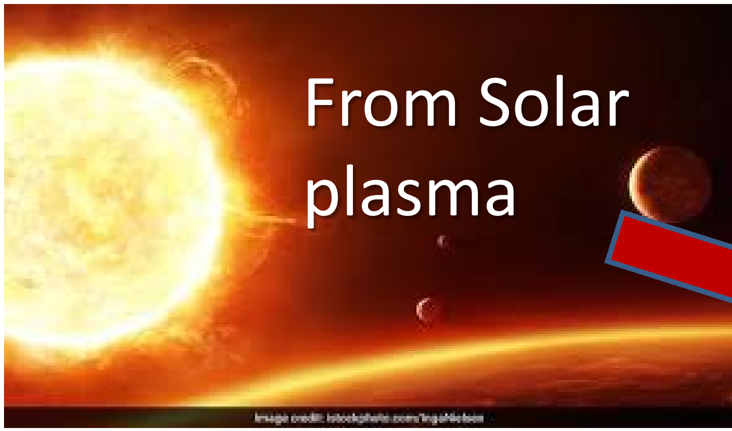






A fast, effective, and single-step method is developed for the bulk synthesis of monochromatic blue and switchable blue-green carbon quantum dots (CQDs) by room-temperature air plasma processing, and the emission mechanisms are revealed. A proof-of-principle demonstration of fluorescence sensing of Cu^{2+} ions opens new opportunities for CQDs applications in environmental and biomedical sensing.

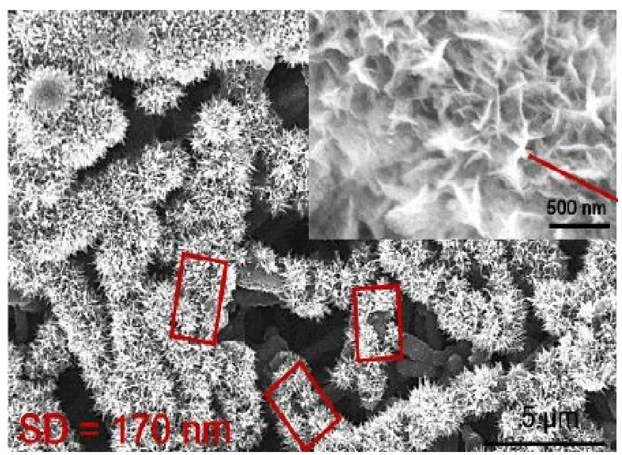
From solar photons to chemical bonds: activating liquids, reforming biomass (renewable energy + modular PP2X reactors)

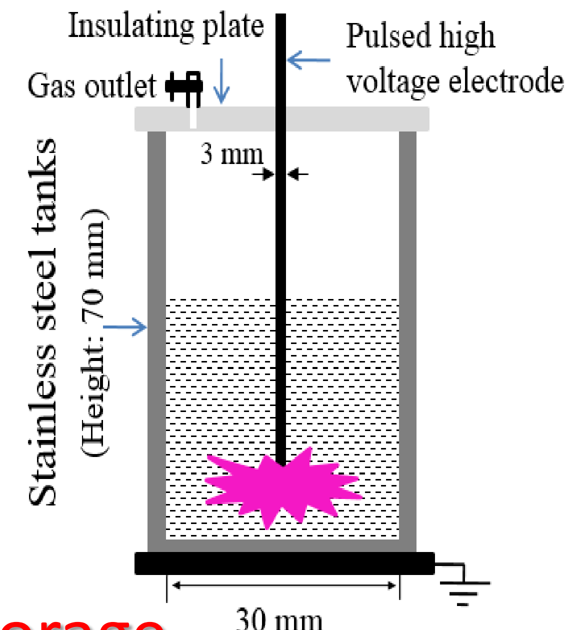


Supercapacitor

Big thanks to Renwu Zhou, Rusen Zhou, and Zhi Fang

Meso/nano pores

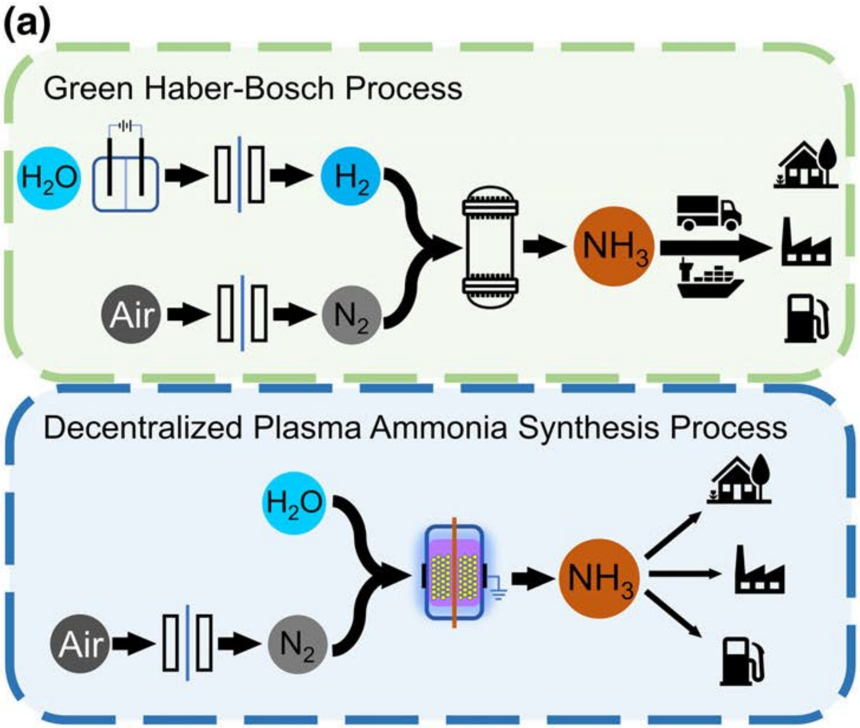


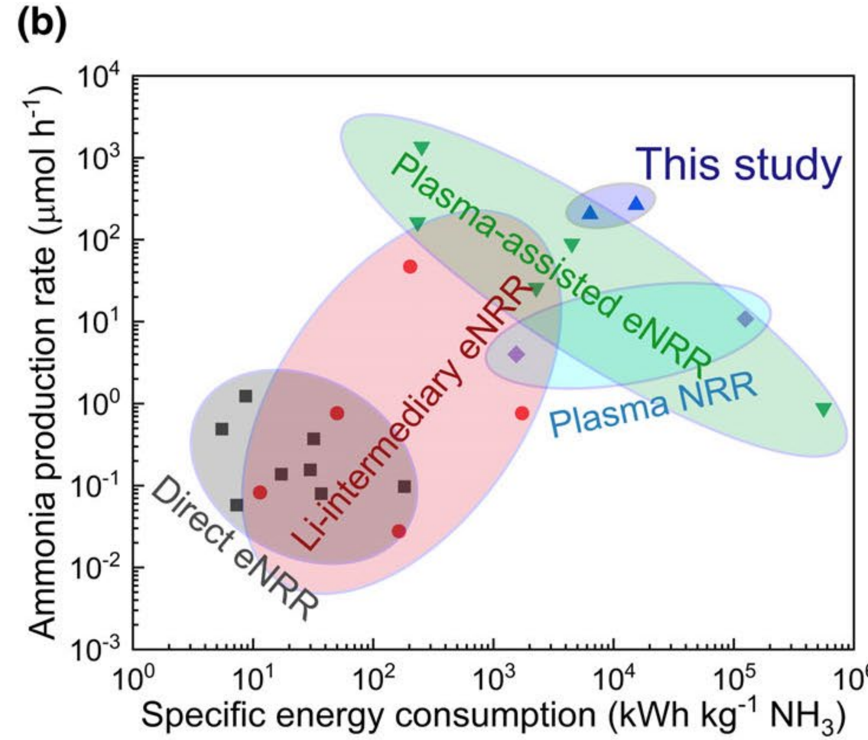


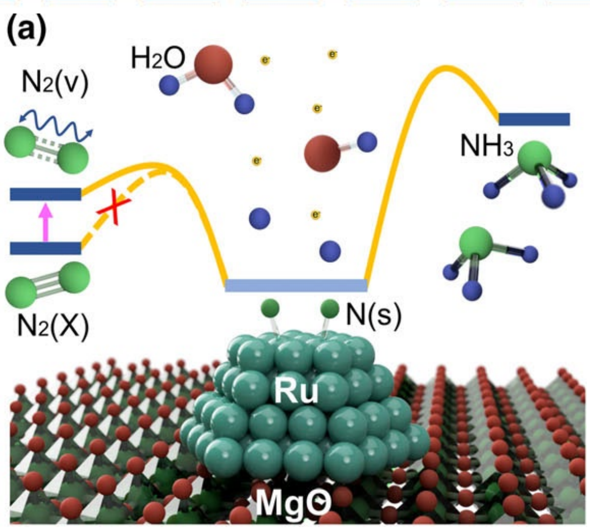
For (e-,p-,bio-)fuels and energy storage

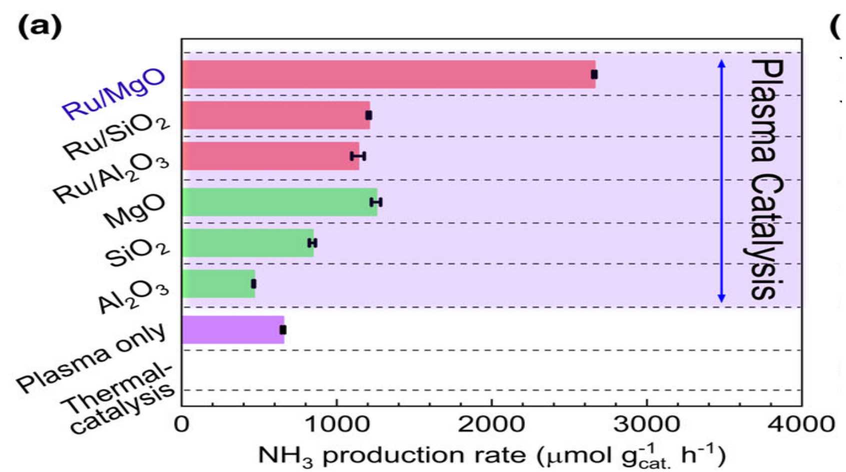
Sustainable Ammonia Synthesis from Nitrogen and Water by One-Step Plasma Catalysis,

Energy Environmental Mater. 6, e12344 (2023), DOI: 10.1002/eem2.12344



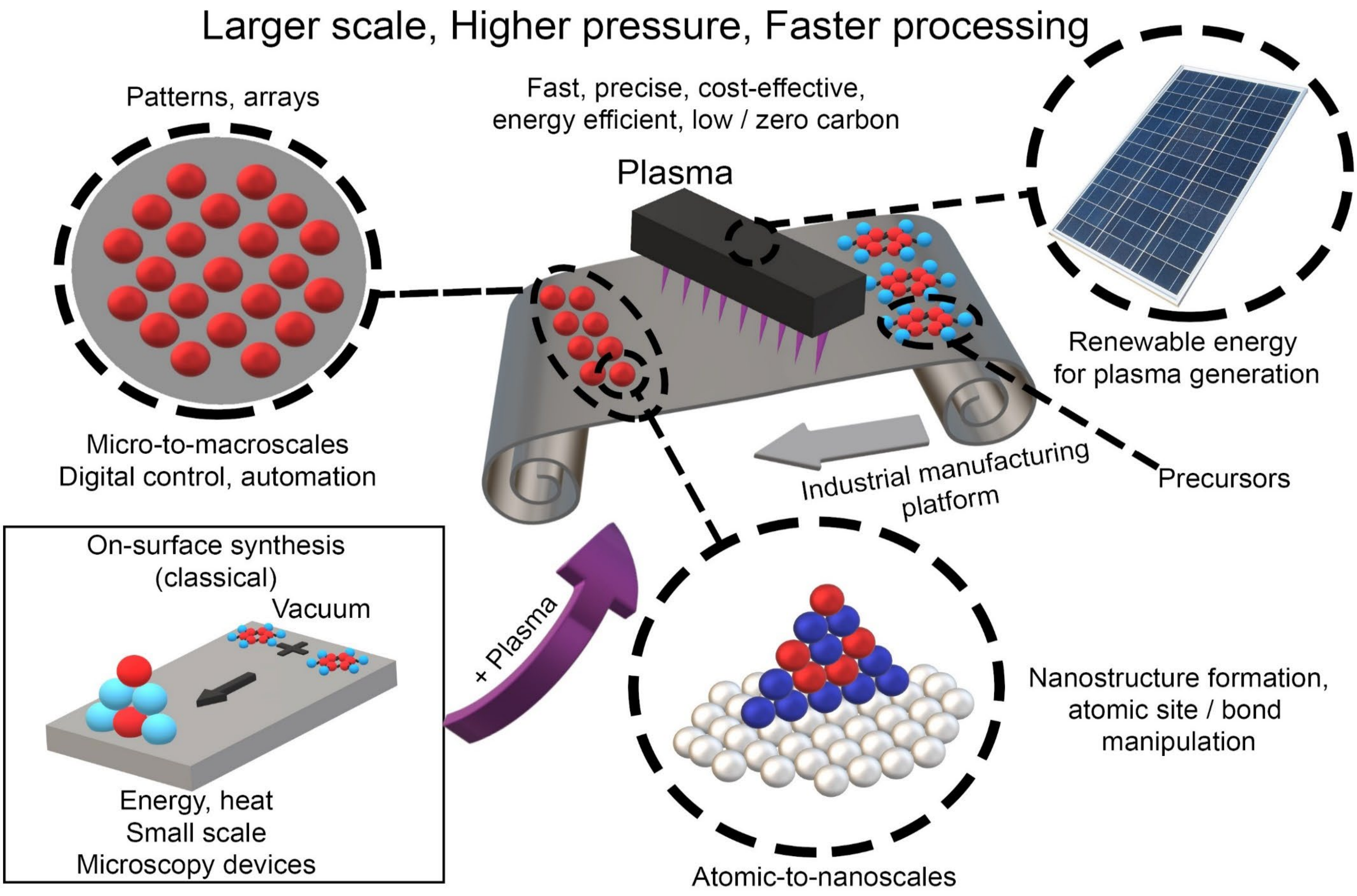






Scaling up: Multiscale Plasma-Catalytic On-Surface Assembly

[Small (2020), DOI: 10.1002/smll.201903184]



nature climate change

ARTICLES

https://doi.org/10.1038/s41558-021-01089-4

Dream Big: Electrify the Ocean

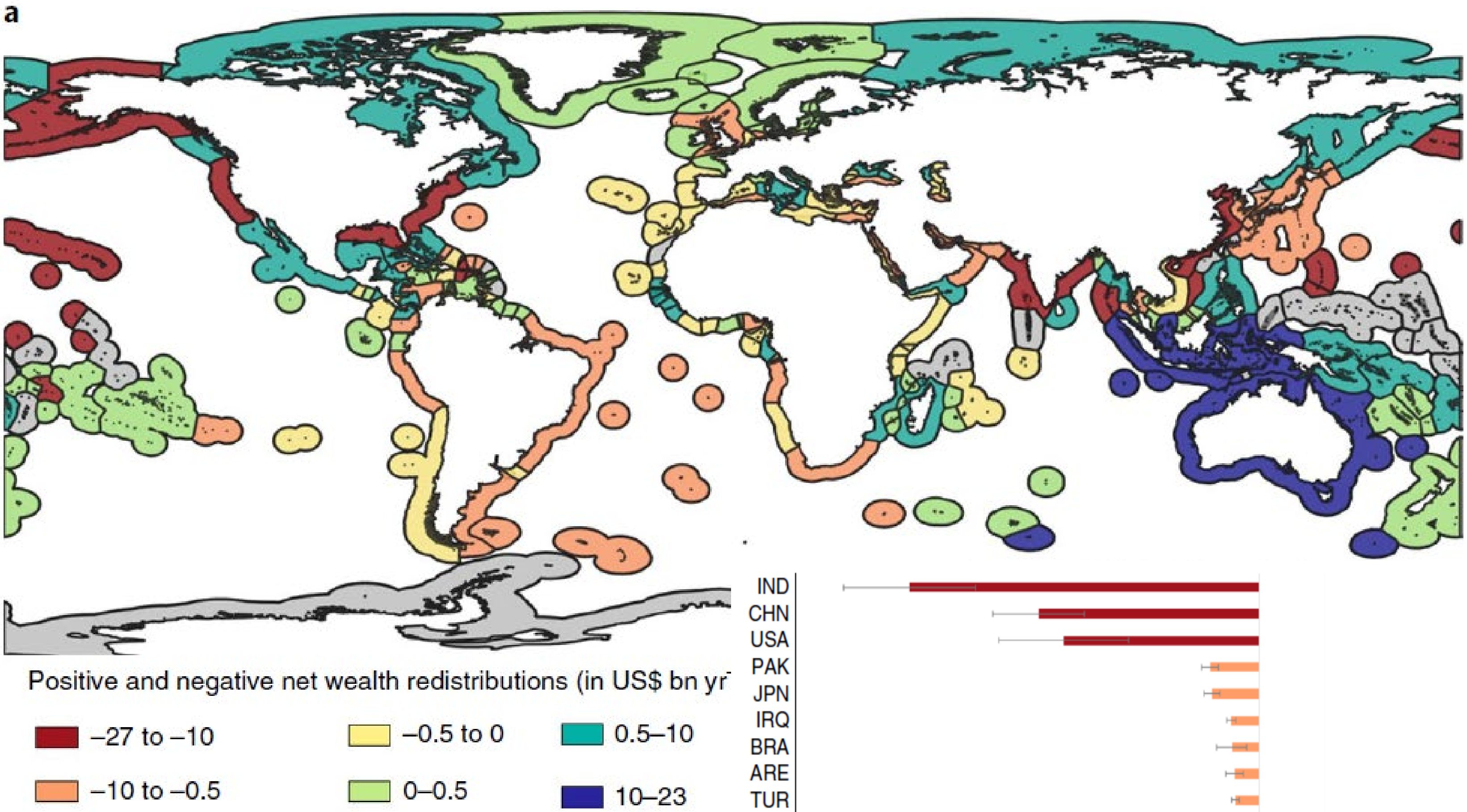
OPEN

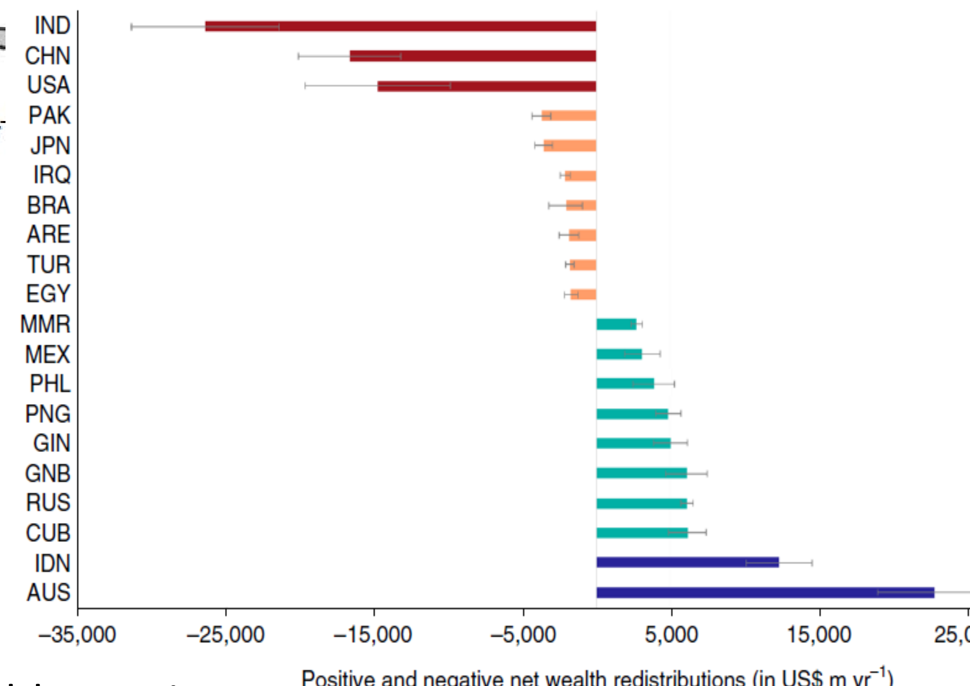
The blue carbon wealth of nations

Christine Bertram[1], Martin Quaas[2], Thorsten B. H. Reusch[3], Athanasios T. Vafeidis[4], Claudia Wolff[4] and Wilfried Rickels[1]✉

Carbon sequestration and storage in mangroves, salt marshes and seagrass meadows is an essential coastal 'blue carbon' ecosystem service for climate change mitigation. Here we offer a comprehensive, global and spatially explicit economic assessment of carbon sequestration and storage in three coastal ecosystem types at the global and national levels. We propose a new approach based on the country-specific social cost of carbon that allows us to calculate each country's contribution to, and redistribution of, global blue carbon wealth. Globally, coastal ecosystems contribute a mean ± s.e.m. of US$190.67 ± 30 bn yr^{-1} to blue carbon wealth. The three countries generating the largest positive net blue wealth contribution for other countries are Australia, Indonesia and Cuba, with Australia alone generating a positive net benefit of US$22.8 ± 3.8 bn yr^{-1} for the rest of the world through coastal ecosystem carbon sequestration and storage in its territory.

Kiel Institute for the World Economy, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel University, Germany

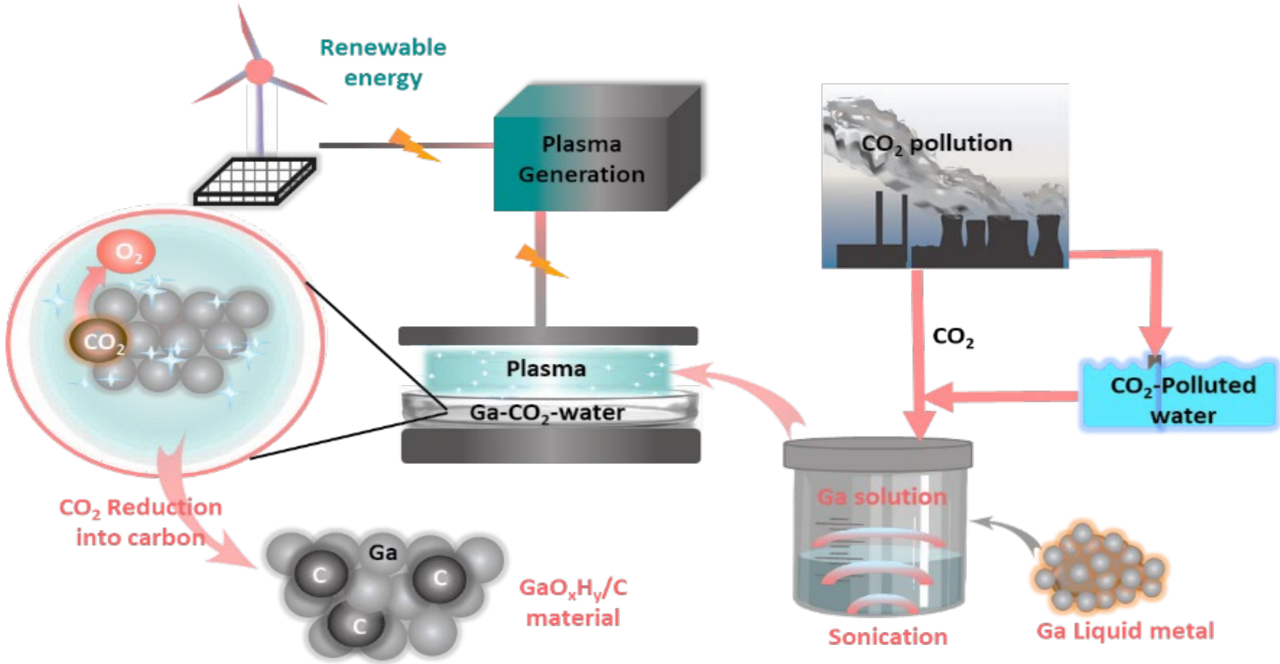




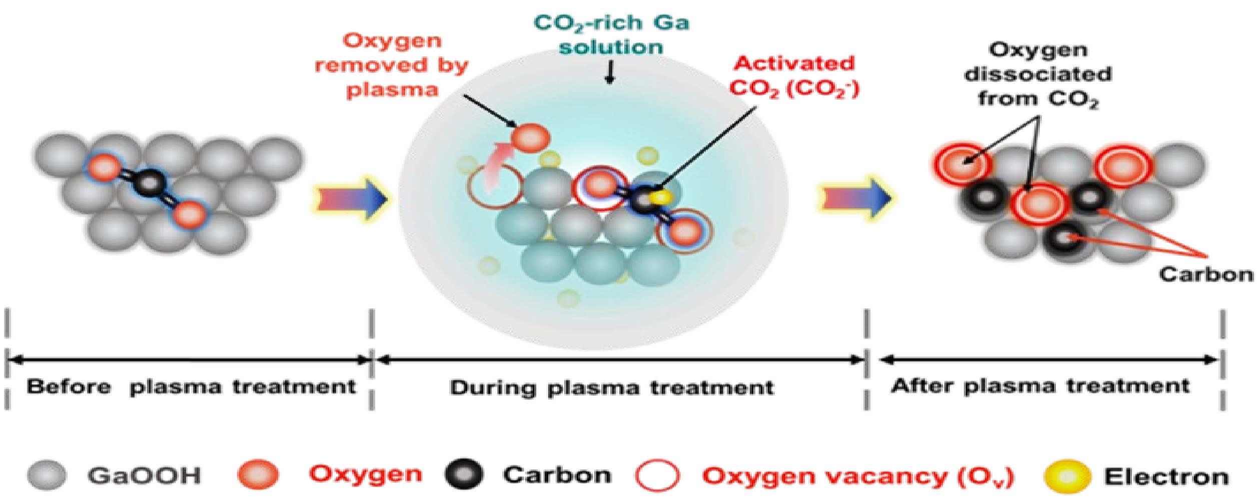
Brown: produce and "waste" carbon "wealth"

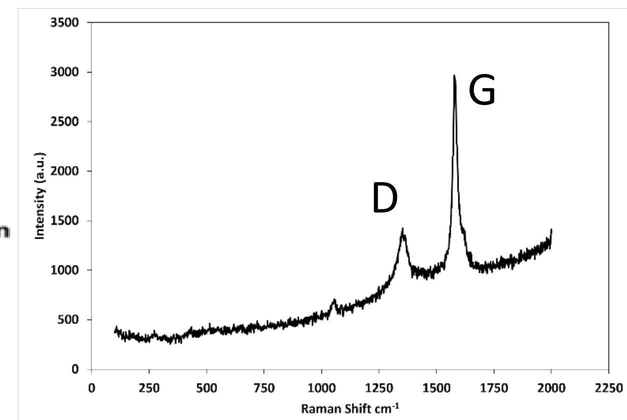
Dark blue: capture these carbon emissions and "wealth"

What to do with it? Huge potential for wealth creation



CO2 capture and up-carbonization in water: plasma and liquid metal catalyst convert CO2 to solid carbon, for later use as clean energy catalyst [Adv. Funct. Mater. 2024, accepted]





Schematic outlining the mechanism for CO_2 conversion into solid carbon starting with CO_2 introduction to the Ga solution (left side) followed by O_v creation and CO_2 activation by plasma together which is followed by adsorption on the catalyst surface where oxygen dissociation from CO_2 takes place (middle), and finally depiction of the carbon-rich catalyst surface after plasma treatment (right side). Collab. with A. O'Mullane and team.

Plasma nano-decarbonase: summary

- Cross-disciplinary research area
- Fundamental plasma-specific processes
- Plasma interactions with other states of matter
- Many unique functional nanomaterials are enabled
- Conditions where other methods often fail
- Diverse applications (energy, water, environment, health, etc.)
- Electrify to decarbonize for zero-carbon-emissions world

[Plasma] Power-to-[WW-whatever works] to de-carbonize: the Plasma2WW dream – p-fuels etc.