Supporting Information for

Sustainable Conversion of Harmful Algae Biomass into a CO_2 Reduction Electrocatalyst for Two-Fold Carbon Utilization

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Summary of the contents: 36 pages, 4 texts, 12 references, 13 tables, and 15 figures

Text S1. Synthesis of the nitrogen doped carbon materials from the algae biomass

The collected algae biomass was washed with deionized water and HCl solution (1.0 mol/L) in a row with solid to liquid ratio of 1: 100 to remove the inorganic impurities. Then, the clean biomass was filtrated and freeze-dried. For the *Enteromopha* biomass, 3.0 g of dried biomass was mixed with 25 mL of deionized water in a 50-mL autoclave, which was then sealed and heated at 180 ^{o}C for 12 h. After cooling down, the produced solid hydrochar was separated via filtration, and the filtrate was collected for further separation of value-added chemicals. The obtained hydrochar was then washed with deionized water several times and freeze-dried 48 hours to obtain carbon aerogel. The dried carbon aerogel was then annealed under a 10% NH_3 (90% argon) flow at 400 ℃ in the initial 2 h and then heated up to 700-1100 ℃ for further 2 h in a heating rate of 2.5 ℃ min^{-1}. After cooling down, the N-doped porous carbon material was finally obtained and denoted as E-NC. For the *Microcystis aeruginosa* biomass, 1.0 g of dried biomass was mixed with 1.5 g of NaCl via grinding, then annealed with NH_3 in the way similar to that of *Enteromopha* biomass, and finally obtained the N-doped carbon material, which was denoted as MA-NC.

Text S2. Characterizations of materials

The morphology and microstructure of the samples were characterized by SEM and TEM. The SEM images and elemental mapping of the samples were obtained using an X-650 scanning electron micro analyzer and JSM-6700F field emission SEM (JEOL Co., Japan). The TEM images (H-7650, Hitachi Co., Japan) of the samples were

recorded at an electron kinetic energy of 100 kV. The surface chemical composition and the valence states of the constituent elements were analyzed by XPS (ESCALAB250, Thermo Fisher Inc., USA). Nitrogen sorption isotherms were measured with a Tristar 3020 analyzer (Micromeritics Inc., USA) at -196 °C. The specific surface areas were calculated using the adsorption isotherms with the Brunauer-Emmett-Teller (BET) method. Pore distribution was calculated from the desorption branch of the isotherm using the Barrent, Joyner, and Halenda (BJH) method. Raman spectra were collected using a Horiba HR Evolution spectrometer (HR800UV LabRAMHR, HOBIN Co., France) with a 532 nm laser excitation. The samples for FTIR analysis were prepared by mixing the carbon materials with spectroscopy-grade KBr at a ratio of 1:100 and compressing into films. The films were analyzed using a FTIR spectrometer (EQUIVOX55, Bruker Co., Germany) with a detector at 2 cm^{-1} resolution from 4000 to 800 cm^{-1} and 16 scans per sample.

Text S3. Work electrode preparation

A total of 5.0 mg of carbon material (E-NC or MA-NC materials prepared under different temperatures) was dispersed into anhydrous ethanol (420 μL) and deionized H_2O (30 μL), with the addition of Nafion solution (50 μL), followed by mixing with the assistance of ultrasonication for at least 60 min to achieve a homogeneous ink. Then, 60 μL of the catalyst ink was pipetted onto a carbon paper electrode (1 cm^2) to form a work electrode.

Text S4. Details of the LCA analysis

The following two objectives should be achieved in this work with LCA: (1) assess the total environmental profiles of the N-doped porous carbon materials produced from algae biomass throughout its life cycle with the thermochemical conversion approach and (2) compare the environmental profiles of thermochemical conversion with the conventional landfilling approach for algae biomass treatment. The scope of the LCA and the defined system boundary are presented in Table S6 and Figure 4, respectively.

The procedures of inventory data collection depend on the unit processes, and thorough knowledge is required to avoid gaps or double counting. In addition to the public data, expert judgments and questionnaires on the HAB presented in Figure S1, computer models and laboratory experimental data were also applied to develop the LCA inventories in this work. The methods for collecting inventory data can be found in Table S7, and the main inventory data are provided in Table S8.

LCA was performed with the methodologies available in GaBi (CML2016), and an explanation of how the LCAs were conducted is provided in Table S6. The environmental impact categories considered in the present analysis were (1) agricultural land occupation (m^2a); (2) GHG emissions (kg CO_2-eq); (3) fossil depletion (kg oil-eq); (4) freshwater ecotoxicity (kg 1,4-DCB-eq); (5) freshwater eutrophication (kg P-eq); (6) human toxicity (kg 1,4-DCB-eq); (7) ionizing radiation (kg U235-eq); (8) metal depletion (kg Fe-eq); (9) ozone depletion (kg CFC-11-eq); (10) particulate matter formation (kg PM10-eq); (11) photochemical oxidant formation (kg NMVOC); (12) terrestrial acidification (kg SO_2-eq); (13) terrestrial ecotoxicity (kg 1,4-DCB-eq); (14)

urban land occupation (m^2a); and (15) water depletion (m^3). The various categories (1)-(15) were weighted based on the data collected in Tables S7 and S8 in Aspen Plus, relevant GaBi Professional and Ecoinvent Datasets (if available) and the literature. The distribution and use of the biofuels and chemicals produced from algae and the GHG emissions in the functionalization of the biochar materials were excluded from the impact categories.

Table S1. Important terms from the field of LCA.

LCA items	Definitions
Life cycle assessment (LCA)	An ISO-standardized method to quantify environmental impacts from inputs (resources used) and outputs (chemical emissions) along the life cycle of one or more defined product or service systems on a common functional basis. LCA consists of four iterative methodological phases, namely goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation.
Life cycle stages	The stages of product or service life cycles, which mainly include raw materials extraction, manufacturing, use, and end-of-life.
Life cycle inventory analysis	The phase of LCA quantifying life cycle inputs and outputs for product or service systems as flows from or toward the natural environment.
Life cycle impact assessment	The phase of LCA characterizing life cycle inputs and outputs of product or service systems in terms of the magnitude and significance of their potential impacts on human health, ecosystem quality and natural resources.
Impact category	The class of impacts that represent an environmental issue of concern. Examples of impact categories are global warming, ozone depletion, human toxicity, ecotoxicity, land use, water use, and resources use, to which product system life cycle inputs and outputs may be assigned.
Cradle-to-gate	LCA where the product system is defined from raw materials extraction (‘cradle’) to factory gate, that is, not all life cycle stages are covered.
Cradle-to-grave	LCA where the product system is defined from raw materials extraction (‘cradle’) to end-of-life (‘grave’), that is, all life cycle stages are covered.
End-of-life	The life cycle stage representing the end of the product’s use. It may include processes like reuse, recycling, chemical and energy recovery, incineration, landfilling, wastewater treatment, and release of bio-based products in nature.

Table S2. The elemental composition of the algae biomass.

Elemental composition	*Enteromopha*	*Microcystis aeruginosa*
C (wt.%)	46.3	49.2
H (wt.%)	5.9	6.2
N (wt.%)	3.2	3.4
O (wt.%)	41.2	36.5

Table S3. Compounds and their contents in the biodiesel obtained from the algae biomass

C14:0 ($C_{14}H_{29}COOH$)	1.19±0.001
C16:0 ($C_{16}H_{33}COOH$)	20.98±0.149
C16:1 ($C_{16}H_{33}COOCH_3$)	9.57±0.265
C17:0 ($C_{17}H_{35}COOH$)	2.14±0.032
C18:0 ($C_{18}H_{37}COOH$)	0.63±0.006
C18:1 ($C_{18}H_{37}COOCH_3$)	39.27±0.584
C18:2 ($C_{18}H_{36}(COOCH_3)_2$)	22.90±0.383
C18:3 ($C_{18}H_{35}(COOCH_3)_3$)	3.31±0.045
SFAME[a] (%)	25
UFAME[b](%)	75

a: Saturated fatty acid methyl esters/total fatty acid methyl esters.

b: Unsaturated fatty acid methyl esters/total fatty acid methyl esters.

Table S4. The elemental composition of the algae biomass.

Yields	*Enteromopha*	*Microcystis aeruginosa*
Liquid-oil (wt.%)	47.2	52.3
Hydrochar (wt.%)	48.6	47.3

Table S5. The comparison of biomass derived carbon materials with other reported carbon materials for the catalytic activity of CO_2 electrochemical reduction.

Electrocatalysts	Electrolyte	Potential (V vs. SHE)	Main products	Faradaic efficiency	Ref.
Nitrogen-doped nanocarbons	0.5 M $NaHCO_3$	-0.90	CO	90%	S1
Nitrogen-doped carbon nanofibers	EMIM-BF_4 ionic liquid	-0.573	CO	98%	S2
Nitrogen-doped carbon nanotube Arrays	0.1 M $KHCO_3$	-1.05	CO	80%	S3
N and S Co-doping porous carbon nanotubes	0.1 M $KHCO_3$	-0.7	CO	94%	S4
Nitrogen-doped carbon nanotubes	0.1 M $KHCO_3$	-0.78	CO	80%	S5
Nitrogen-doped 3D graphene foam	0.1 M $KHCO_3$	-0.90	CO	85%	S6
MOF-derived nitrogen-doped carbon	0.1 M $KHCO_3$	-0.93	CO	78%	S7
Nitrogen-doped nano-porous carbon	0.1 M $KHCO_3$	-0.99	CO	11.3%	S8
C_3N_4-multiwalled carbon nanotubes	1 M KCl	-1.46	CO	98%	S9
3D N-doped graphene nanoribbon network	0.5 M $KHCO_3$	-0.49	CO	87.6%	S10
Holey carbon layers with F engineering	0.1 M $KHCO_3$	-0.6	CO	90%	S11
2D carbon nanosheets	0.5 M $KHCO_3$	-0.36	CO	92%	S12
Microcystis aeruginosa biomass derived Nitrogen-doped nano-porous carbon	0.5 M $KHCO_3$	-0.55	CO	96.9%	This work
Enteromopha biomass derived Nitrogen-doped nano-porous carbon	0.5 M $KHCO_3$	-0.60	CO	82.1%	This work

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Table S6. Goal and scope definition for the LCA model

Goals and scope	Definitions
Reason for conducting the LCA	To assess the sustainability and environmental impacts of harmful algae blooms and inform the research community about the state-of-the-art research outcome
Audiences	Environmental researchers, chemical engineering researchers, policy makers, industrial stakeholders, research and public community, sustainability evaluation researchers
Applications	To support interdisciplinary research development on sustainable treatments and resource recovery of the harmful algae blooms
Scopes	
Product system	Bio-fuels and chemicals, functional biochar materials
Function	Harmful algae blooms without treatments or treated by landfill
Functional unit	1 ton of algae biomass (dried weight)
System boundary	See Figure 5
Allocation	In the LCA, 100% of the algae will decay if it does not be treated, in which 20% of its carbon will convert into CH_4, and 80% will convert into CO_2, all the nutrition elements will return to the waterbody or release to the environment. 80% of the algae will decay if it be treated by landfill, in which 60% of its carbon will convert into CO_2, and 40% will convert into CH_4. In principle, allocation should be avoided via system expansion and subdivision, which is not possible in this study due to resources constraints. As such, a simplified LCA model is developed where input and output data are allocated based on exergy analysis performed using Aspen Plus
Assumptions	(I) The life span of the product system is 20 years; (II) The product system is primarily made of steel, which is 100% recycled at the end of life; (III) The carbon in the bio-fuels or chemicals finally converts into CO_2 and releases to the environment (IV) The product system is based in China
Requirements on data and quality	Output data acquired from the process model simulated in Aspen Plus, relevant GaBi Professional and Ecoinvent Datasets (if available) and literature.
Impact categories assessed in the LCA	(1) Agricultural land occupation (m^2a) (2) GHG emissions (kg CO_2-eq) (3) Fossil depletion (kg oil-eq) (4) Eutrophication Potential (kg P-eq);

	(5) Freshwater ecotoxicity (kg 1,4-dichlorobenzene (DCB)-eq); (6) Ionizing radiation (kg U235-eq); (7) Human Toxicity Potential (kg DCB-eq); (8) Photochemical Ozone Creation Potential (kg ethane-eq); (9) Terrestric Ecotoxicity Potential, (kg DCB-eq); (10) Odour Potential (kg H_2S-eq); (11) Metal depletion (kg Fe-eq); (12) Ozone depletion (kg CFC-11-eq) (13) Water depletion (ton) (14) Natural land transformation (m^2) (15) Particulate matter formation (kg PM10-eq) (16) Urban land occupation (m^2)
Limitations	The following aspects are not assessed in this study (I) Distribution and use of the bio-fuel and chemical produced from algae (II) GHG emission during the functionalization of the biochar materials

Table S7. List of the parameters and assumptions for the algae treatment

Parameters	Optimistic	Most probable	Pessimistic	Units
Harmful algae blooms parameters				
Algae contents in the waterbody	1.0×10^8	6.0×10^7	3.0×10^7	Cells/L water
Algae lipid contents	45	35	25	%(dry weight)
Algae settling efficiency	0.99	0.95	0.90	-
Algae ash contents	4.0	7.0	10.0	%(dry weight)
P concentration in the waterbody	7.5	5.5	3.5	mg/L
N concentration in the waterbody	37.0	30.0	23.0	mg/L
Algae molar N:P composition	5.0	7.0	9.0	-
Biorefinery parameters and assumptions (Hydrothermal liquefaction (HTL) and carbonization)				
Distance to biorefinery place	25	50	100	km
Temperature for HTL reaction	250	300	350	^oC
Temperature for carbonization	1000	800	600	^oC
Solids content of dewatered algae	35	30	25	%
Moisture of dried algae	5	7	10	%
Liquid bio-oil yield	30	25	20	%
Solid biochar yield	45	40	30	%
C contents in the biochar	70	60	50	%
N contents in the biochar	14	12	10	%
P contents in the biochar	5	3	2	%
Biofuels yield from liquid bio-oil	75	65	50	%
Functional biochar from raw biochar	65	55	45	%
CO_2/nutrition uptake and emission parameters and assumptions				
CO_2 uptake during the algae growth	1.75	1.65	1.50	kg CO_2/kg algae
N uptake during the algae growth	0.06	0.05	0.04	kg N/kg algae
P uptake during the algae growth	0.02	0.015	0.01	kg P/kg algae
CO_2 emission during algae decay	1.10	1.20	1.25	kg CO_2/kg algae
CH_4 emission during algae decay	0.15	0.20	0.25	kg CH_4/kg algae
NO_x emission during algae decay	0.003	0.005	0.08	kg NO_x/kg algae
CO_2 emission during algae landfill	0.65	0.75	0.85	kg CO_2/kg algae
CH_4 emission during algae landfill	0.35	0.45	0.55	kg CH_4/kg algae
NO_x emission during algae landfill	0.01	0.015	0.02	kg NO_x/kg algae

Table S8. LCA data inventory for the algae treatments (per ton dry algae biomass)

Stage	Input/output	Utilities/materials	Units	Values
Harmful algae blooms and biomass harvest	Input	CO_2 [a]	ton	1.65
		N [a]	ton	0.05
		P [a]	ton	0.01
		Concrete [b]	kg	2.2×10^{-4}
		Steel [b]	kg	7.5×10^{-7}
		Plastic [b]	kg	5.08×10^{-5}
		Power [c]	kWh-electricity equivalence	3400
	Output	Algae biomass [d]	ton	5.0
Transportation (150 km)	Input	Power	kWh-electricity equivalence	23.0
Drying (From water content 80% to 2%)	Input	Power	kWh-electricity equivalence	85.2
		Algae biomass	ton	5.0
	Output	Algae biomass	ton	1.0
Biorefining	Input	Power	kWh-electricity equivalence	11.2
	Output	Bio-oil	ton	0.25
		Biochar	ton	0.47
Upgrading	input	Power	kWh-electricity equivalence	22.3
		CH_3OH	ton	0.13
		NH_3	ton	0.05
		H_2	ton	0.02
		Water	ton	3.28
		Sulfuric acid	ton	0.09
	Output	Bio-fuels	ton	0.27
		Biochar based functional materials	ton	0.39
		Wastewater	ton	3.98

[a] Uptake directly from the environment

[b] For constructing the infrastructure

[c] Power for algae harvest and on-site dewater

[d] Water content 80%

Table S9. Impacts results of the thermochemical conversion for the biomass treatment

Impact category	Electricity	Transport	Water	Chemicals	Steam	Hydrogen	Total
Agricultural land occupation (m^2a)	95.3	0.76	0.87	12.6	1.32	1.63	112.48
GHG emissions (kg CO_2-Eq)	323.0	10.9	13.6	273.3	16.8	18.9	656.5
Fossil depletion (kg oil-Eq)	96.9	7.36	3.92	53.2	9.23	27.6	198.21
Freshwater ecotoxicity (kg 1,4-DCB-Eq)	0.14	1.52×10^{-2}	4.98×10^{-3}	0.29	5.20×10^{-2}	0.16	0.66
Freshwater eutrophication (kg P-Eq)	1.62×10^{-2}	3.27×10^{-3}	4.65×10^{-4}	2.82×10^{-2}	1.78×10^{-4}	2.39×10^{-3}	4.49×10^{-2}
Human toxicity (kg 1,4-DCB-Eq)	2.56×10^{-2}	4.32×10^{-3}	1.02×10^{-4}	3.62×10^{-2}	2.63×10^{-4}	1.12×10^{-3}	6.21×10^{-2}
Ionizing radiation (kg U235-Eq)	1.23×10^{-3}	6.35×10^{-3}	1.69×10^{-5}	2.96×10^{-3}	1.52×10^{-4}	6.36×10^{-4}	1.06×10^{-2}
Metal depletion (kg Fe-Eq)	0.36	1.65	0.16	0.98	0.36	0.81	4.32
Ozone depletion (kg CFC-11-Eq)	1.78×10^{-5}	3.58×10^{-6}	9.36×10^{-7}	7.86×10^{-5}	2.96×10^{-6}	1.81×10^{-6}	9.72×10^{-5}
Particulate matter formation (kg PM10-Eq)	0.59	1.18×10^{-2}	1.27×10^{-3}	0.36	6.32×10^{-2}	9.65×10^{-2}	1.13
Photochemical oxidant formation (kg NMVOC)	0.11	8.86×10^{-3}	7.62×10^{-4}	5.69×10^{-3}	7.96×10^{-3}	8.39×10^{-3}	0.13
Terrestrial acidification (kg SO_2-Eq)	1.38	0.47	2.31×10^{-2}	0.96	1.15×10^{-2}	1.03×10^{-2}	2.84
Terrestrial ecotoxicity (kg 1,4-DCB-Eq)	1.77×10^{-2}	2.08×10^{-3}	2.20×10^{-4}	2.63×10^{-2}	2.80×10^{-4}	6.18×10^{-3}	4.49×10^{-2}
Urban land occupation (m^2a)	7.32	0.16	0.13	0.26	0.11	9.36×10^{-2}	7.99
Water depletion (m^3)	0.62	1.32×10^{-2}	2.52×10^{-3}	0.21	3.02×10^{-2}	0.11	0.98

Table S10. Impacts results of the landfilling for the biomass treatment

Impact category	Electricity	Transport	Water	Chemicals	Steam	Landfill activity	Total
Agricultural land occupation (m^2a)	35.7	0.12	1.23×10^{-3}	7.89	0.65	11.4	55.76
GHG emissions (kg CO_2-Eq)	112.6	1.23	0.58	156.9	3.62	1362	1636.93
Fossil depletion (kg oil-Eq)	26.9	0.98	0.16	32.5	2.35	0	62.89
Freshwater ecotoxicity (kg 1,4-DCB-Eq)	1.47×10^{-3}	1.02×10^{-3}	8.72×10^{-5}	1.86×10^{-3}	2.12×10^{-3}	1.26	1.28
Freshwater eutrophication (kg P-Eq)	4.72×10^{-3}	2.27×10^{-4}	9.27×10^{-6}	3.26×10^{-2}	3.08×10^{-5}	0	3.31×10^{-2}
Human toxicity (kg 1,4-DCB-Eq)	3.79×10^{-3}	5.78×10^{-4}	7.89×10^{-6}	4.15×10^{-2}	1.97×10^{-5}	2.08	2.13
Ionizing radiation (kg U235-Eq)	5.78×10^{-4}	5.23×10^{-4}	6.32×10^{-7}	3.21×10^{-3}	3.63×10^{-5}	0	6.90×10^{-2}
Metal depletion (kg Fe-Eq)	0.11	9.69×10^{-2}	1.05×10^{-3}	1.03	0.10	0	1.25
Ozone depletion (kg CFC-11-Eq)	2.96×10^{-6}	5.08×10^{-7}	3.52×10^{-9}	5.67×10^{-5}	1.06×10^{-7}	6.39×10^{-4}	6.45×10^{-4}
Particulate matter formation (kg PM10-Eq)	0.13	2.39×10^{-3}	6.08×10^{-5}	0.56	3.92×10^{-3}	0	0.70
Photochemical oxidant formation (kg NMVOC)	3.93×10^{-4}	1.06×10^{-3}	2.13×10^{-6}	1.03×10^{-2}	2.85×10^{-4}	6.25×10^{-4}	1.05×10^{-2}
Terrestrial acidification (kg SO_2-Eq)	0.26	0.10	1.26×10^{-4}	1.02	2.30×10^{-3}	1.69	3.09
Terrestrial ecotoxicity (kg 1,4-DCB-Eq)	2.35×10^{-3}	3.45×10^{-4}	1.08×10^{-6}	2.13×10^{-2}	3.69×10^{-5}	1.83	1.88
Urban land occupation (m^2a)	0.36	4.05×10^{-2}	1.29×10^{-3}	0.33	2.96×10^{-3}	13.2	13.93
Water depletion (m^3)	0.16	3.46×10^{-3}	1.02×10^{-4}	0.19	3.02×10^{-2}	0	0.40

Table S11. Impacts results of the without treating for the biomass treatment

Impact category	Electricity	Transport	Water	Chemicals	Steam	Algae emission	Total
Agricultural land occupation (m^2a)	0	0	0	0	0	0	0
GHG emissions (kg CO_2-Eq)	0	0	0	0	0	1789	1789
Fossil depletion (kg oil-Eq)	0	0	0	0	0	0	0
Freshwater ecotoxicity (kg 1,4-DCB-Eq)	0	0	0	0	0	23.6	23.6
Freshwater eutrophication (kg P-Eq)	0	0	0	0	0	45.3	45.3
Human toxicity (kg 1,4-DCB-Eq)	0	0	0	0	0	18.2	18.2
Ionizing radiation (kg U235-Eq)	0	0	0	0	0	0	0
Metal depletion (kg Fe-Eq)	0	0	0	0	0	0	0
Ozone depletion (kg CFC-11-Eq)	0	0	0	0	0	2.91×10^{-3}	2.91×10^{-3}
Particulate matter formation (kg PM10-Eq)	0	0	0	0	0	0	0
Photochemical oxidant formation (kg NMVOC)	0	0	0	0	0	6.25×10^{-4}	6.25×10^{-4}
Terrestrial acidification (kg SO_2-Eq)	0	0	0	0	0	3.29	3.29
Terrestrial ecotoxicity (kg 1,4-DCB-Eq)	0	0	0	0	0	0	0
Urban land occupation (m^2a)	0	0	0	0	0	0	0
Water depletion (m^3)	0	0	0	0	0	0	0

Table S12. List of the economic parameters and assumptions for a 100 kton algae biomass treatment per year

Economic parameters	Values
NH_3 (liquid) price ($ per ton) [1]	300
CH_3OH price ($ per ton) [2a]	250
N_2 (liquid) price ($ per ton)[2b]	90
H_2 price ($ per ton)[2c]	3400
$Fe_2(SO_4)_3$ ($ per ton)[2c]	725
Process water price ($ per ton) [3]	0.22
Electricity price ($ per kWh) [4]	0.07
Low pressure steam price ($ per kWh) [5]	0.021
Cooling water price ($ per kWh) [6]	0.003
Transportation ($ per km per ton algae biomass) [7]	0.55
Economic assumptions	
Cost year basis [8]	USD-2015
Operating hours (hours per year) [9]	4000
Equipment life span (years) [9]	20
Working capital (% of fixed capital investment) [9]	10
Equity (% of fixed capital investment) [9]	40
Loan interest (%) [9]	8
Loan terms (years) [9]	10
Internal Rate of Return (%) [9]	10
Tax rate (%) [9]	35
Depreciation period (years) [9]	7
Replacement interval (years) [10]	7
Specified yearly replacement cost (% of installed cost of electrocatalytic reactor)[10]	15
Unplanned replacement cost (% of FCI of electrocatalytic reactor) [10]	0.5

[1] Taken from online market data (http://jiage.molbase.cn/hangqing/29119)

[2a] Taken from online market data (**http://jiage.molbase.cn/hangqing/1426584**)

[2b] Taken from online market data (**http://jiage.molbase.cn/search?search_jiage=%E6%B6%B2%E6%B0%AE**)

[2c] Taken from online market data (http://jiage.molbase.cn/search?search_jiage=%E6%B6%B2%E6%B0%AE)

[3] Government set industrial water price (http://tazlh.zjzwfw.gov.cn/art/2014/6/16/art_30833_28099.html)

[4] Government set electricity price (http://www.ndrc.gov.cn/gzdt/201905/t20190515_936212.html)

[5] Taken from a book by Seider et al. (Product and process design principles : synthesis, analysis, and evaluation. 2nd ed.; Wiley: New York, United States of America, 2004; p xviii, 802 p)

[6] Government set industrial water price (**http://tazlh.zjzwfw.gov.cn/art/2014/6/16/art_30833_28099.html**)

[7] Distance is 150 km

[8] All costs are updated to 2015 cost levels using the Chemical Engineering Plant Cost Index (CEPCI) and the average Producer Price Index (PPI)

[9] Taken from a study by Humbird et al. (Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol: dilute-acid pretreatment and enzymatic hydrolysis of corn stover; S44 National Renewable Energy Laboratory (NREL): Colorado, US, 2011)

[10] Capital investment is spread over 3 years at a rate of 8%, 60%, and 32% in first, second, and third years, respectively

Table S13. Total direct costs, indirect cost and capital investment for a 100 kton algae biomass treatment per year

Items	Notes	Values ($)	
		Landfill	Biorefinery
Algae biomass harvest	Harvesting the biomass from algae blooms waterbody	635,216	635,216
Equipment cost	The cost of equipment listed in the process flow diagram	2,132,562	5,623,159
Equipment installation	0.47 * Equipment cost	1,002,304	2,642,885
Instrumentation and control	0.36 * Equipment cost	767,722	2,024,337
Piping	0.68 * Equipment cost	1,450,142	3,823,748
Electrical/heating installation	0.19 * Equipment cost	405,186	1,068,400
Utility	Buildings construction + Site development + Service facilities + Delivery	1,769,256	9,289,632
Total Direct costs (TDC)	**Sum of above items**	**8,162,388**	**25,107,377**
Engineering and supervision	10% of TDC	816,239	2,510,738
Construction fee	10% of TDC	816,239	2,510,738
Legal expenses	3% of TDC	244,871	753,221
Project Contingency	10% of TDC	816,239	2,510,738
Construction labor cost	15% of TDC	1,224,358	3,766,107
Other Costs (Start-Up, Permits)	10% of TDC	816239	2,510,738
Total Indirect Cost (TIC)	**Sum of above items**	**4,734,186**	**14,562,280**
Fixed Capital Investment (FCI)	TDC+TIC	12,896,574	39,669,657
Land	10% FCI	1,289,657	3,966,966
Working Capital	5% of FCI	644,828	1,983,482
Total Capital Investment (TCI)	**FCI + Land + Working capital**	**14,831,059**	**45,620,105**
Operating labor	Operating hours * hourly wage * workers	2,520,000	2,520,000
Operating supervision	0.15 * Operating labor	378,000	378,000
Maintenance and repair	0.06 * FCI	773,794	2,380,179
Operating supplies	0.15 * Maintenance and repair	116,069	357,026
Laboratory charges	0.15 * Operating labor	378,000	378,000
Royalties	0.03 * Product sale cost	0	243,256
Variable operating costs	**Sum of above items**	**4,165,863**	**6,256,461**
Property tax	0.02 * FCI	257,931	793,393
Insurance	0.01 * FCI	128,966	396,697
Rent	0.08 * FCI	1,031,726	3,173,573
Depreciation	0.06 * FCI	773,794	2,380,719
Fix operating costs	**Sum of above items**	**2,192,417**	**6,744,382**
Administration	0.20 * Operating labor + supervision + Maintenance and repair	734,358	3,262,179

Distribution and selling	0.05 * (Variable operating costs + Fix operating costs)	317,914	650,042
Research and development	0.04 * (Variable operating costs + Fix operating costs)	254,331	520,033
General expenses	**Sum of above items**	**1,306,603**	**4,432,254**
Chemicals	NH_3, CH_3OH, H_2, $Fe_2(SO_4)_3$	986,325	10,796,258
Process water	Water for the hydrothermal treatment and other reactions	0	325,014
Steam	For drying and dewatering	256,982	812,632
Cooling water	For cooling	0	136,985
Electricity	For all the process using electricity	186,324	6,983,652
Wastewater treatments	-	169,326	762,589
Total raw materials	**Sum of above items**	1,598,957	19,817,130
Bio-fuel revenues	Selling price * bio-fuel amount	0	24,300,000
Carbon materials revenues	Selling price * carbon materials amount	0	35,100,000
Total Revenues	**Bio-fuel revenues + Carbon materials revenues**	**0**	**59,400,000**

Items	Data source	Data range
Algae concentration in HAB	ISSHA, WRMS, NPMSO	1.5×10^{8} – 2.5×10^{9} cells/L
Weight of a single algae cell	(Hu and Wenna: Dry weight and cell density of individual algal and *cyanobacterial cells* for algae research and development. University of Missouri-Columbia, 2014)	0.8×10^{-9} – 6.0×10^{-9} g/cell
Total HAB water area	IOC, ISSHA, WRMS	1.3×10^{5} – 2.5×10^{5} km^2
Deep of HAB water	ISSHA, NPMSO, WRMS	1.0 – 5.0 m
Frequency of HAB per year	ISSHA, NPMSO, WRMS, ICES	1 – 20 times per year
Total algae biomass amounts produced in HAB	Calculated from the above data	2.34×10^{6} – 3.75×10^{8} tons per year

Figure S1. The data source of the current status of HAB.

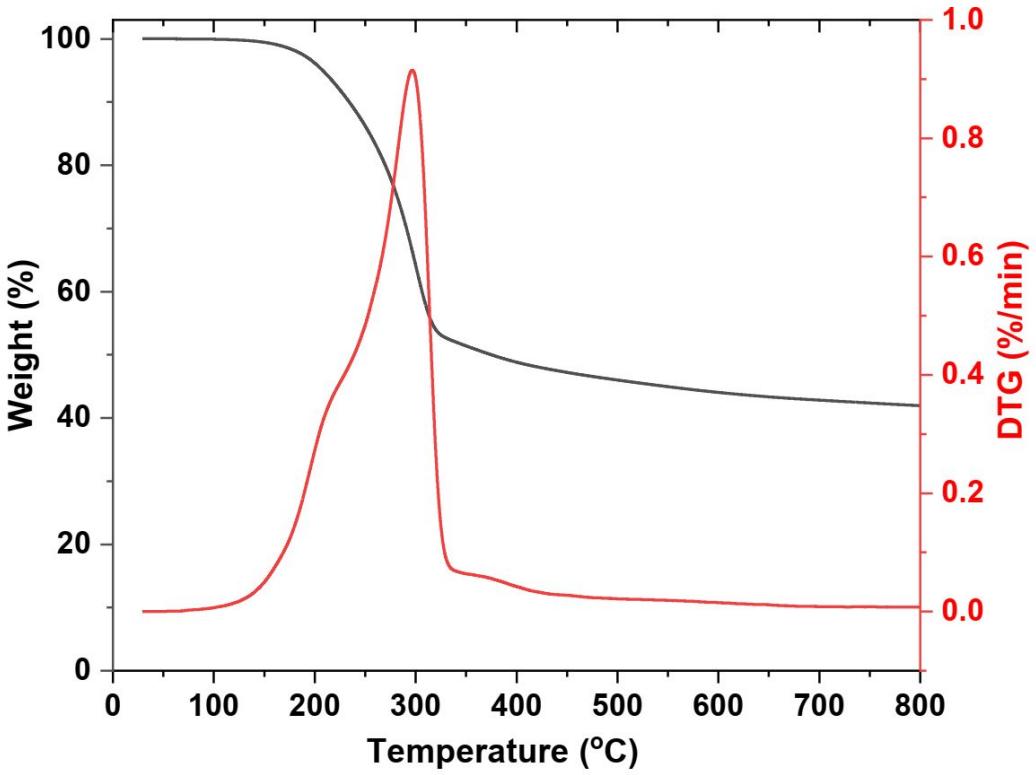

Figure S2. TG and DTG profiles for the thermochemical treatment of the NaCl-activated hydrochar.

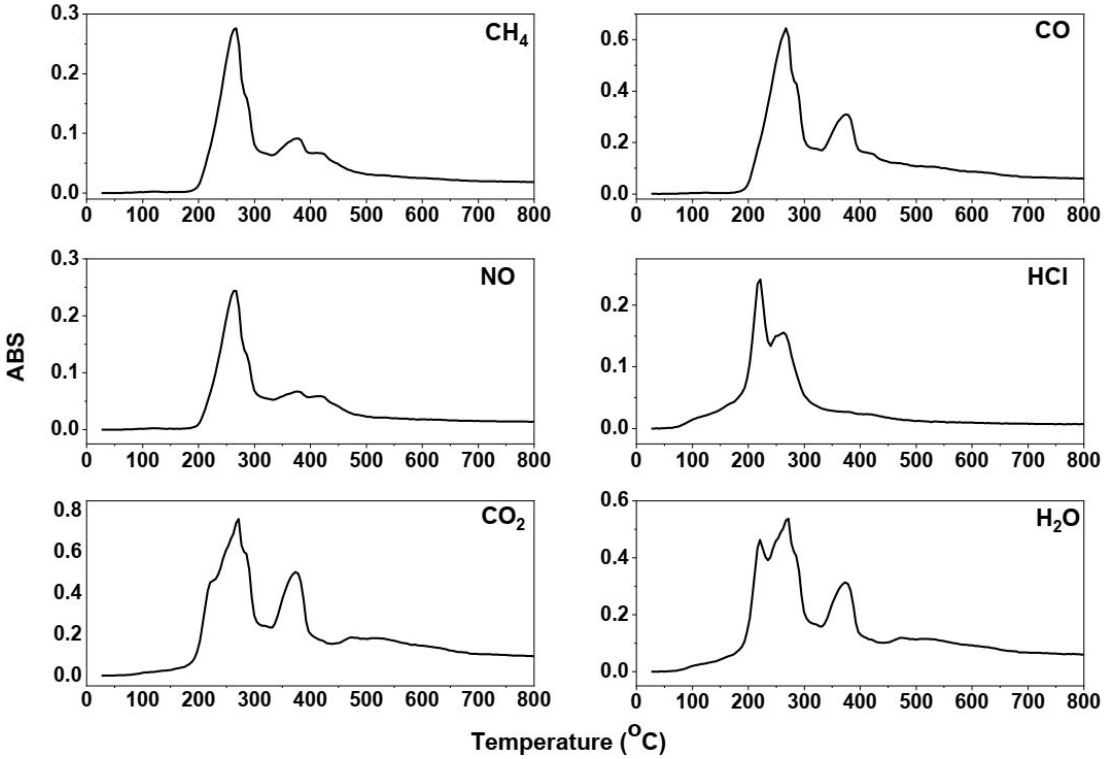

Figure S3. FTIR response of six gas compounds formed during the thermochemical treatment of the NaCl-activated hydrochar.

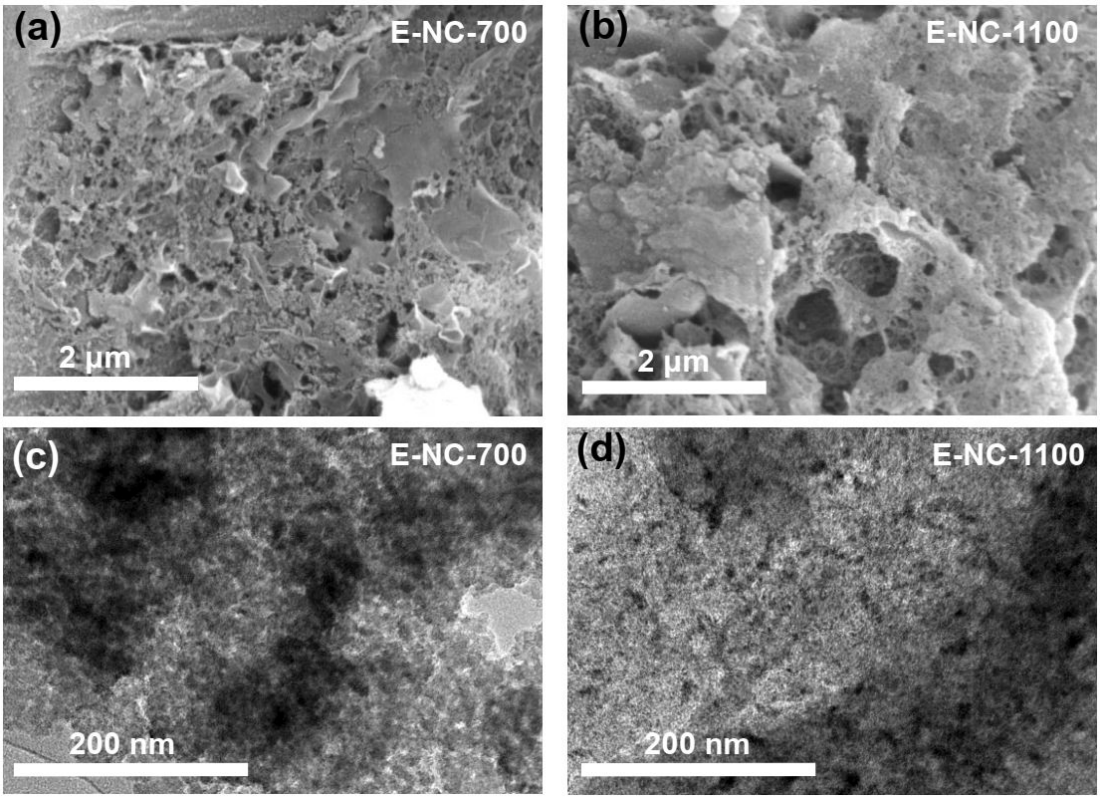

Figure S4. SEM and TEM images of the E-NC materials prepared at different temperatures.

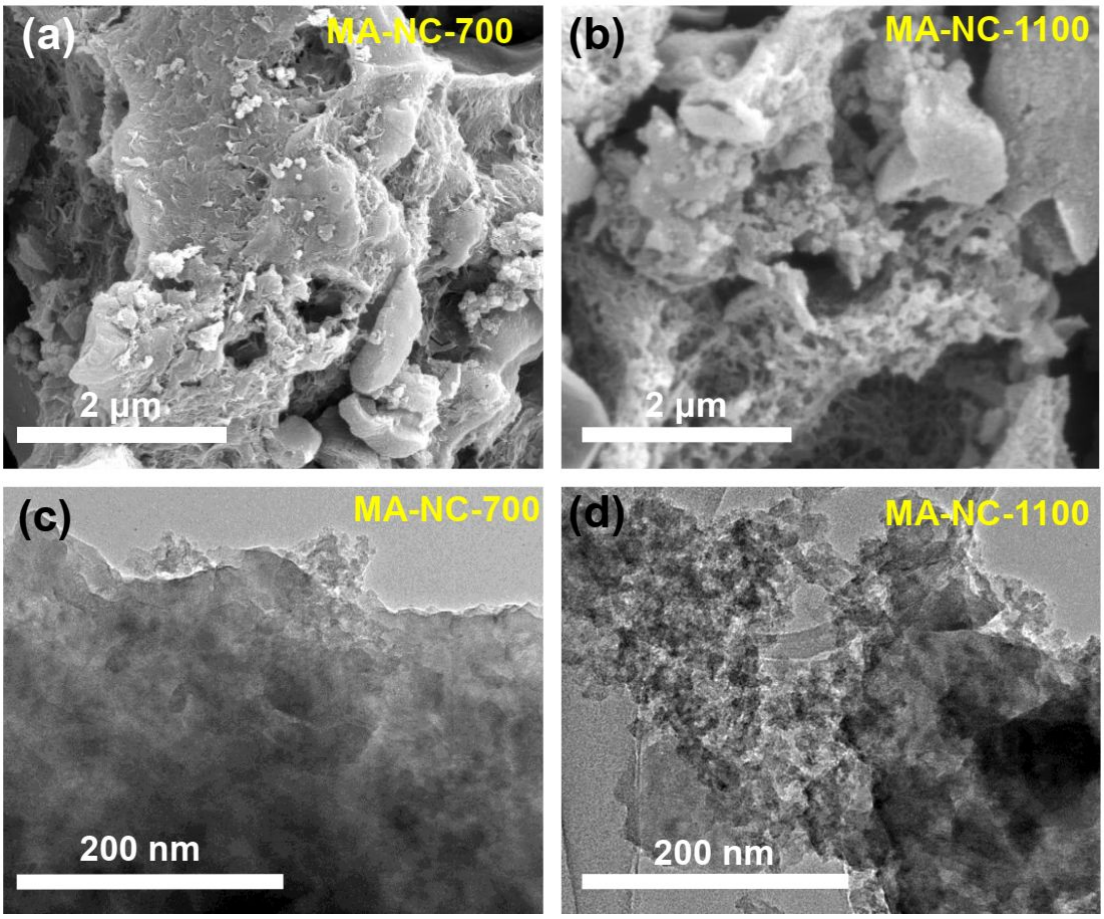

Figure S5. SEM and TEM images of the MA-NC materials prepared at different temperatures.

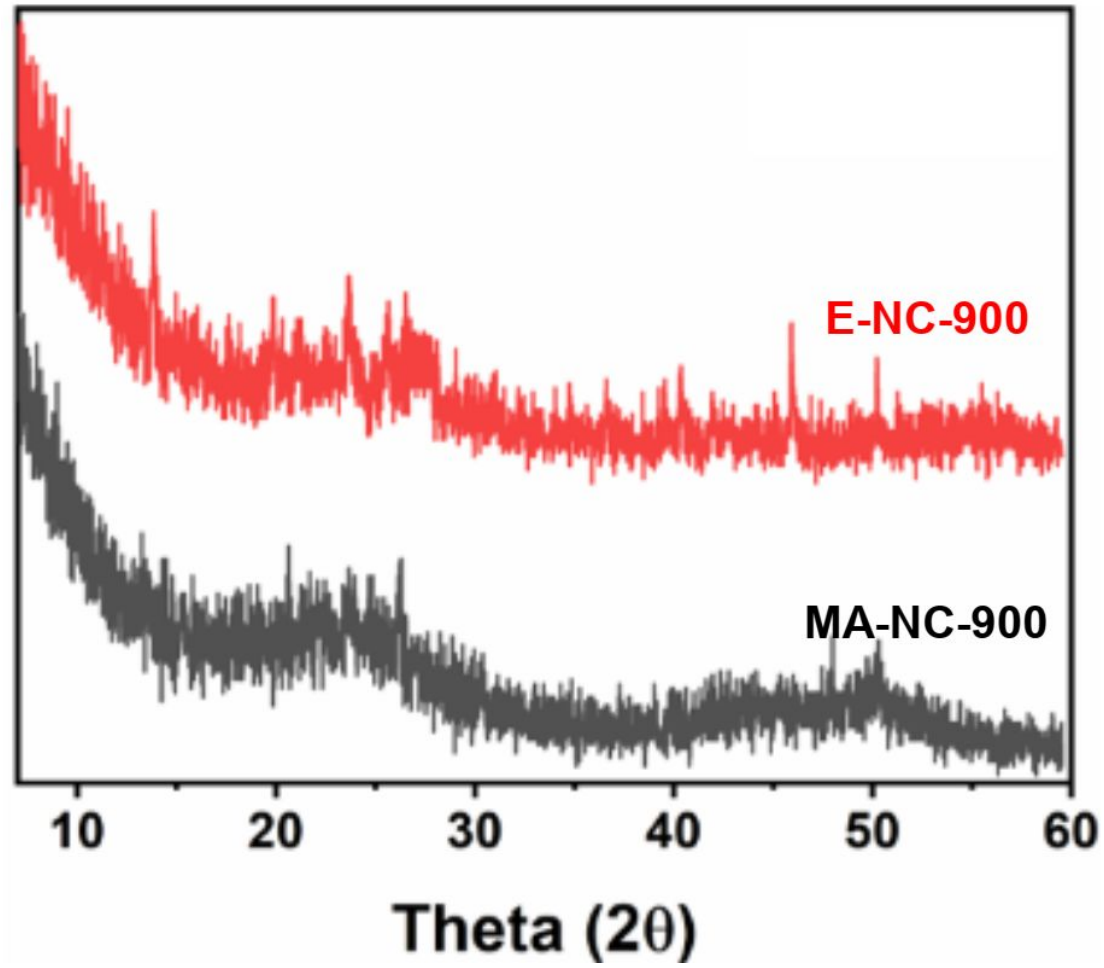

Figure S6. XRD patterns of the E-NC-900 and MA-NC-900 carbon materials. The XRD patterns of E-NC-900 and MA-NC-900 materials show two broad peaks at 25° corresponding to the (002) characteristic peak of carbon. The broad peaks of two samples display obviously low intensity, which is indicative of low crystallinity and high degree of structural disorder due to the etching of NH_3 and NaCl.

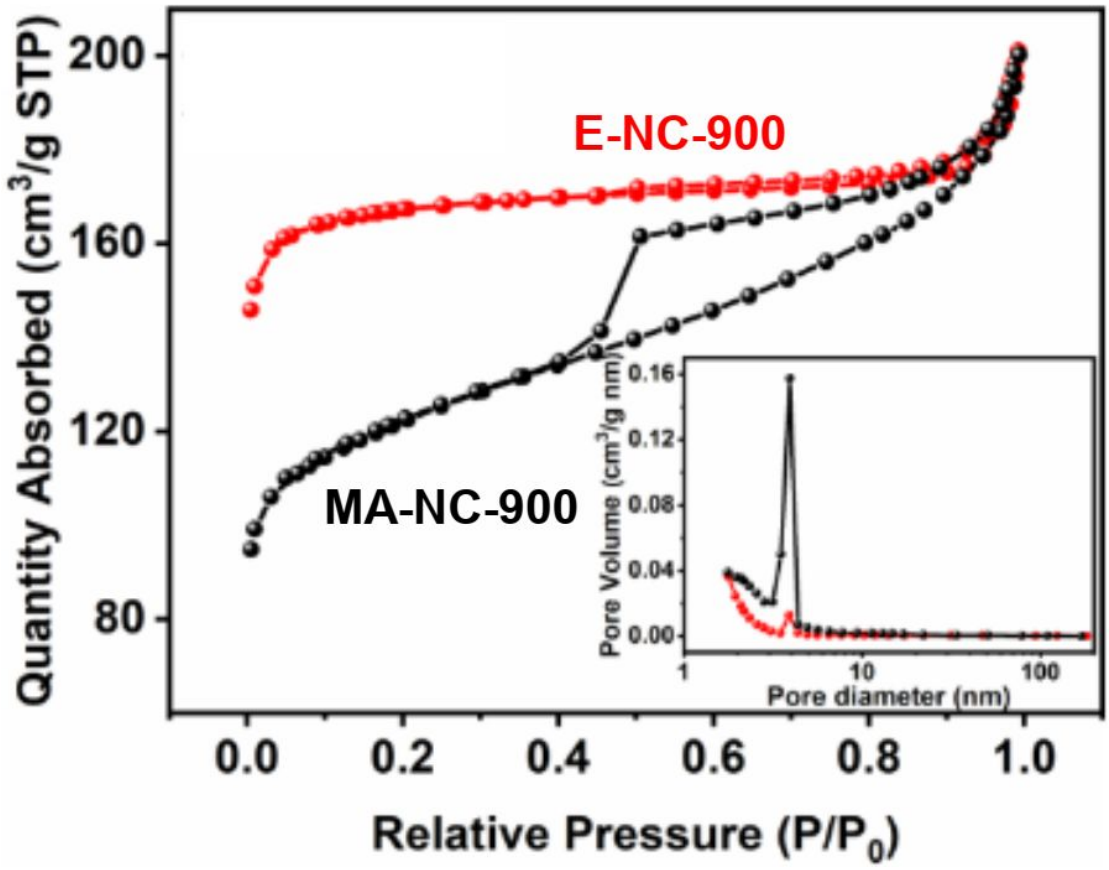

Figure S7. N_2 adsorption-desorption isotherms of the E-NC-900 and MA-NC-900 carbon materials

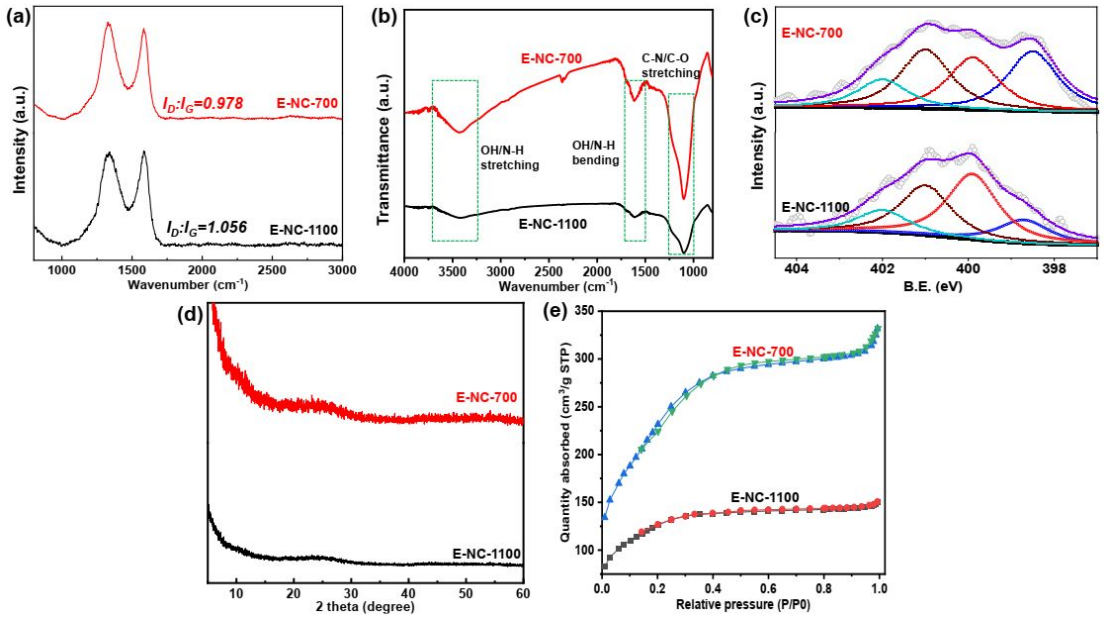

Figure S8. Structure features of the E-NC materials prepared at different temperatures. (a) Raman spectra; (b) FTIR spectra; (c) XPS spectra; (d) XRD patterns; (e) N_2 adsorption-desorption isotherms.

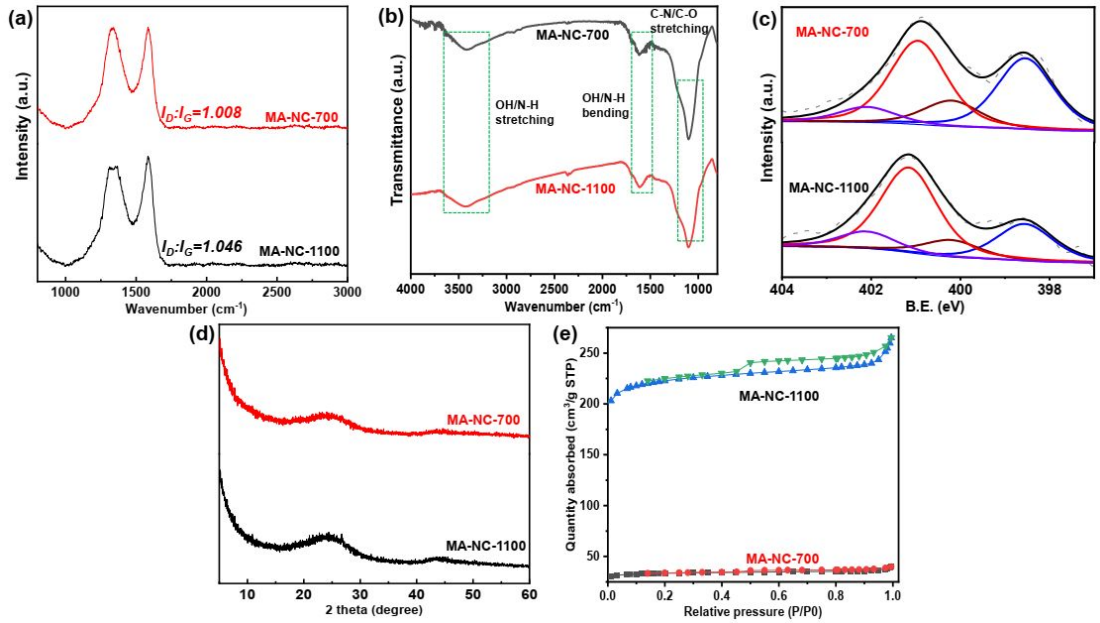

Figure S9. Structure features of the MA-NC materials prepared at different temperatures. (a) Raman spectra; (b) FTIR spectra; (c) XPS spectra; (d) XRD patterns; (e) N_2 adsorption-desorption isotherms.

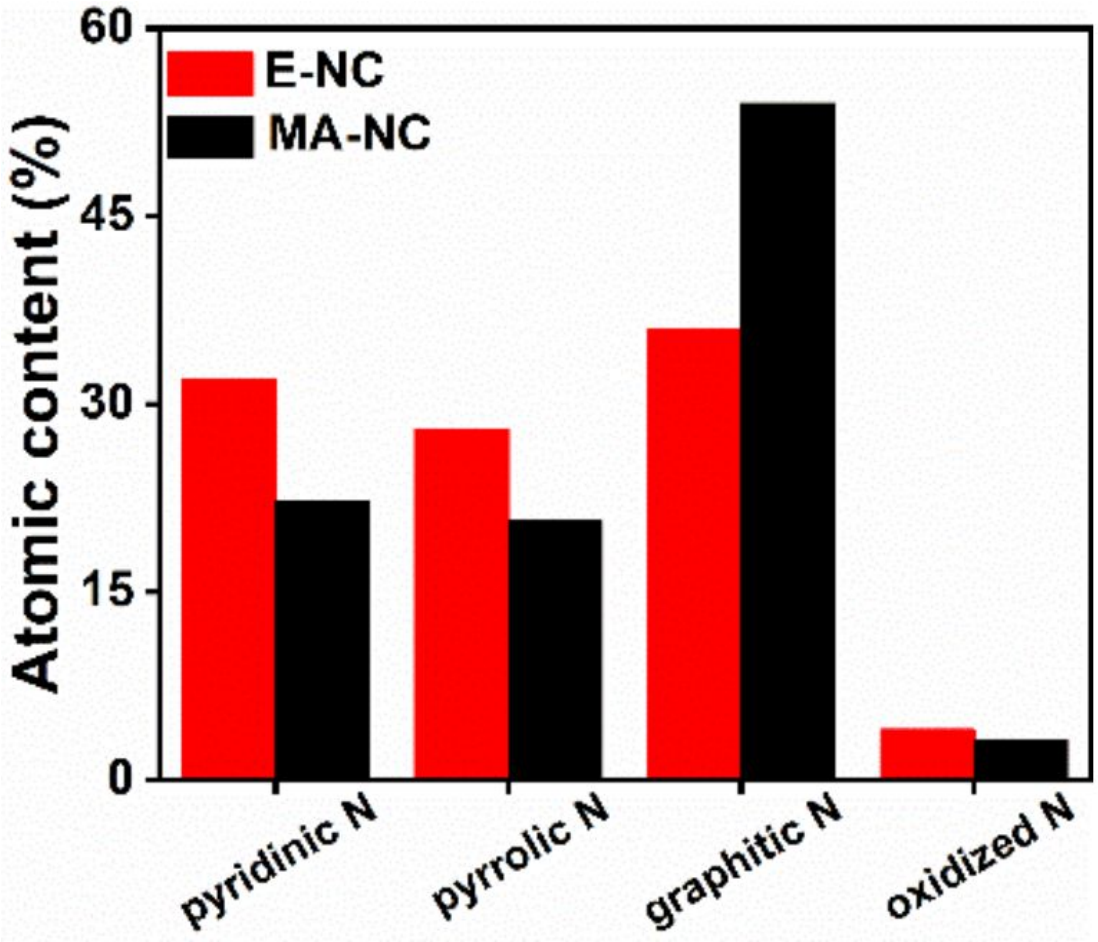

Figure S10. Contents of the four types of nitrogen species in E-NC-900 and MA-NC-900.

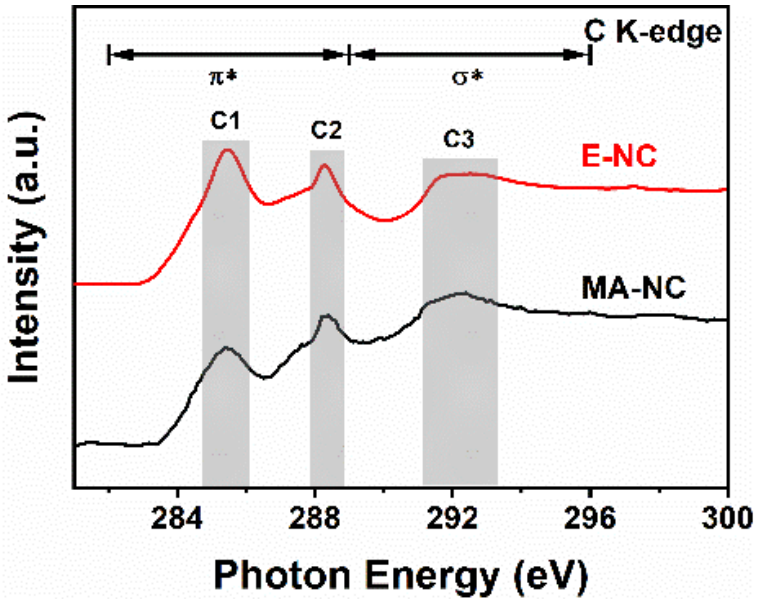

Figure S11. C K-edge NEXAFS spectra of E-NC-900 and MA-NC-900.

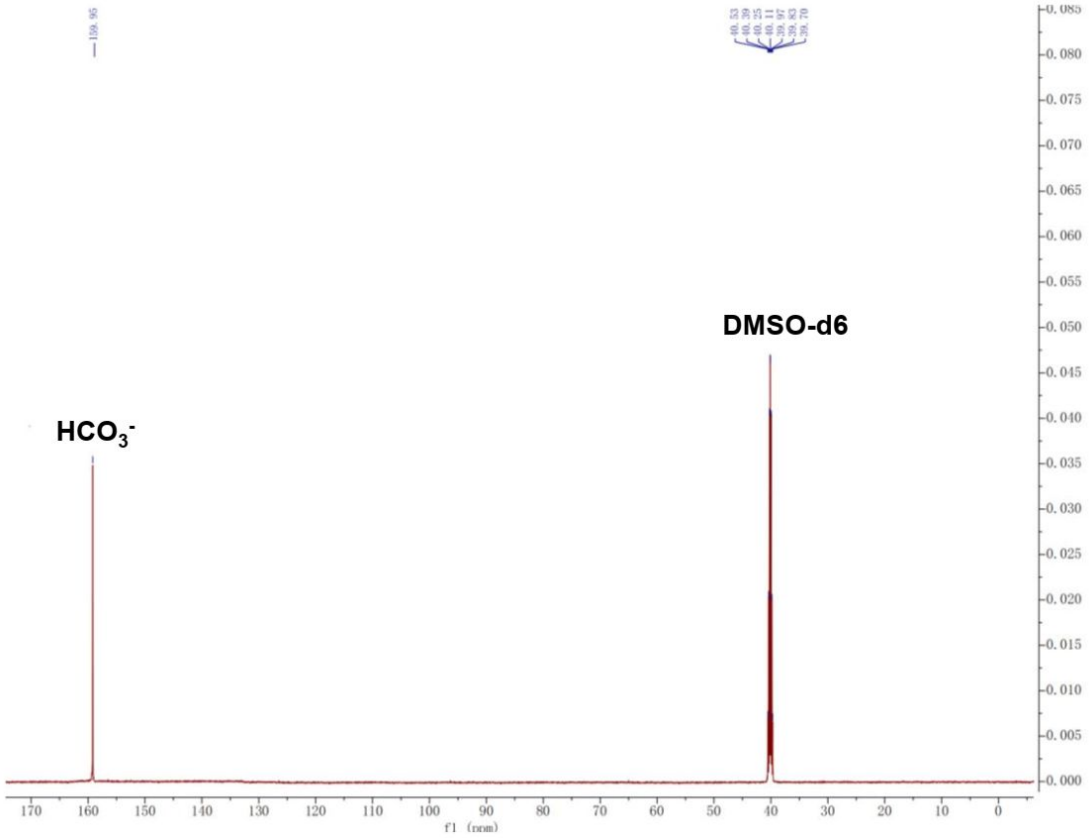

Figure S12. ^{13}C-NMR of the electrolyte after electrocatalytic CO_2 reduction with the catalysis of E-NC-900 material.

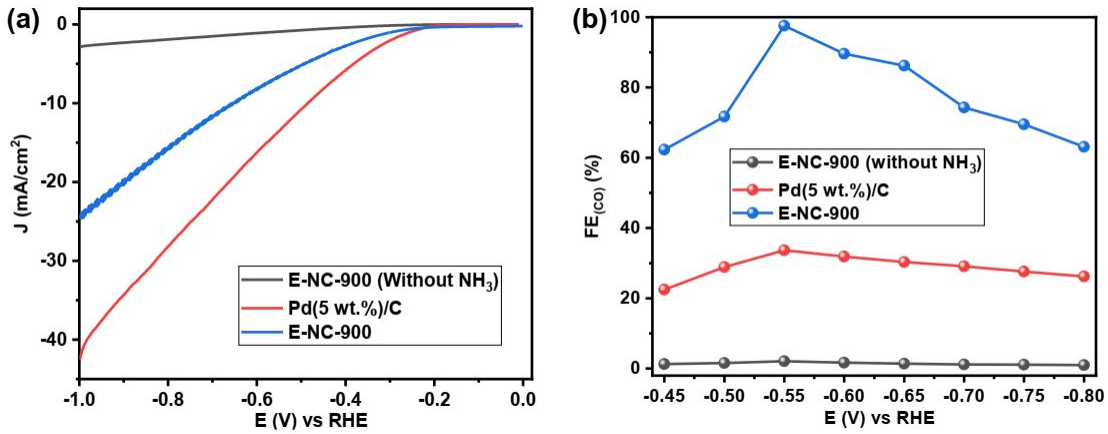

Figure S13. (a) LSV curves of E-NC-900 materials with and without NH_3 activation, as well as the benchmark Pd/C catalyst acquired in CO_2-saturated 0.5 M $KHCO_3$ solution. (b) Faradaic efficiency (FE) of the E-NC-900 materials with and without NH_3 activation, as well as the benchmark Pd/C catalyst at different potentials.

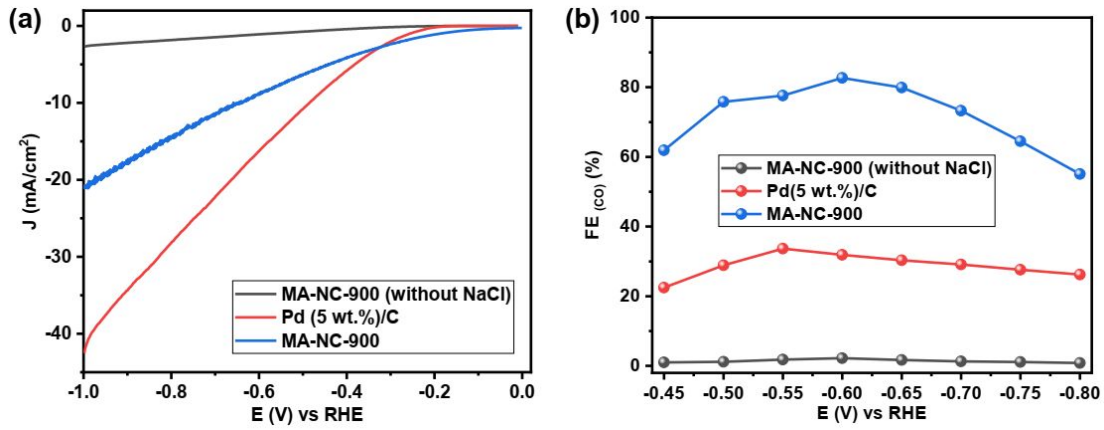

Figure S14. (a) LSV curves of MA-NC-900 materials with and without NH_3 activation, as well as the benchmark Pd/C catalyst acquired in CO_2-saturated 0.5 M $KHCO_3$ solution. (b) Faradaic efficiency (FE) of the MA-NC-900 materials with and without NH_3 activation, as well as the benchmark Pd/C catalyst at different potentials.

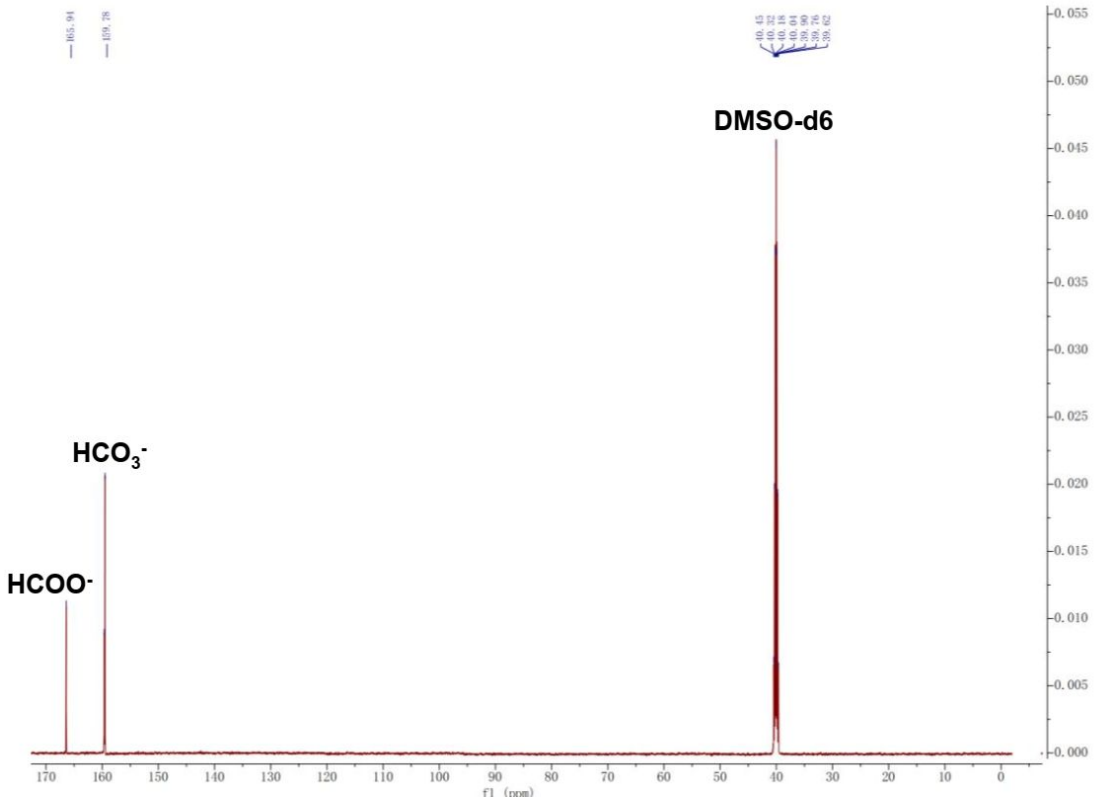

Figure S15. ^{13}C-NMR of the electrolyte after electrocatalytic CO_2 reduction with the catalysis of Pd/C material.