

Closed-loop Enhancement of Plant Photosynthesis via Biomass-derived Carbon Dots in Biohybrids

Wenbo Cheng^{1,2,3#}, Xueyun Wang^{1#}, Haitao Hu^{1#}, Yu Yang^{4#}, Xuemeng Yu^{5#}, Wei Xiang Chao⁶, Min Yu^{1, 3}, Jianwei Ding⁷, Yiliang Lin⁷, Wei Zhao¹, Qiao Zhao¹, Rodrigo Ledesma-Amaro⁸, Chao Zhong¹, Lu Lu⁶, Xihan Chen⁵, Junzhong Liu⁴, Chen Yang^{2,9*}, Xiang Gao^{1*}

¹Key Laboratory of Quantitative Synthetic Biology, Shenzhen Institute of Synthetic Biology, Shenzhen Institutes of Advanced Technology, Chinese Academic of Science, Shenzhen 518000, P. R. China

²Key Laboratory of Plant Carbon Capture, CAS-Key Laboratory of Synthetic Biology, CAS Center for Excellence in Molecular Plant Sciences, Shanghai Institute of Plant Physiology and Ecology, Chinese Academy of Sciences, Shanghai, 200032, China

³University of Chinese Academy of Sciences, Beijing, 100049, China

⁴Center for Life Sciences, School of Life Sciences, State Key Laboratory of Conservation and Utilization of Bio-Resources in Yunnan, Yunnan University, Kunming, 650500, China

⁵SUSTech Energy Institute for Carbon Neutrality, Department of Mechanical and Energy Engineering, Southern University of Science and Technology, Shenzhen, Guangdong, 518055, China

⁶State Key Laboratory of Urban Water Resource and Environment, School of Civil and Environmental Engineering, Harbin Institute of Technology, Shenzhen, China

⁷Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore, 117585, Singapore

⁸Department of Bioengineering and Imperial College Centre for Synthetic Biology, Imperial College London, London, UK

⁹State Key Laboratory of Microbial Metabolism, and School of Life Sciences and Biotechnology, Shanghai Jiao Tong University, Shanghai, 200240, China

These authors contributed equally to this work.

*Correspondence to: yang.c@sjtu.edu.cn, gaoxiang@siat.ac.cn

Supplementary Methods

Photoluminescence quantum yield (PLQY) of C-CDs

The PLQY of C-CDs under 365 nm was measured on HORIBA Fluorolog[®]-3 Spectrofluorometer using a quantaphi-2 quantum yield accessory including an integrating sphere. The PLQY was calculated using the equation:

$$\varphi = 100\% \times \frac{Em_{sample} - Em_{solution}}{r \times k \times (Ex_{solution} - Ex_{sample})}$$
$$Ex = \int_{360}^{370} I(\lambda) d\lambda$$
$$Em = \int_{630}^{720} I(\lambda) d\lambda$$

where **Ex** is the integrated intensity of the excitation spectra from 360-370 nm, **Em** is the integrated intensity of the emission spectra from 630-720 nm, **r** is the ratio of the integration time used to collect **Em** and **Ex**, **k** is the attenuation factor used to collect **Ex**.

Supplementary Information for TEA

Demonstration of routes synthesizing materials for plant cultivation.

This work compares the synthesis cost of different materials for plant yield enhancement, specifically biomass-based carbon dots (CDs), with several other potential photosynthesis-enhancing materials. These include non-biomass carbon dots derived from chemicals, and transition metal oxides (e.g., ZnO, Fe₃O₄, TiO₂). The comparison underscores the cost advantages of these materials in synthesis and their application in agricultural yield improvement. This section demonstrates the primary synthesis processes of these materials. The following [Supplementary Tables 3-8](#) provide specific data on materials, reagents and electricity consumption for the synthesis of these material, cost of consumables, and increase ratio of plant biomass when these materials are applied.

The primary synthesis process of this work includes the full immersion of biomass,

such as *Cyano*, mulberry leaves, weeds, and straw, in ethanol to collect the leachate. This leachate undergoes solvothermal synthesis, extraction with an equal volume of water-organic extractant (recyclable), and drying purification (using nitrogen to dry the residual organic phase) to yield CDs. These biomass CDs are subsequently re-dispersed in ethanol for plant (e.g., *A. thaliana*) cultivation.

Route 2 engages a synthesis process that employs citric acid as the carbon source and ethylenediamine as the nitrogen source. Following mixing in water and heating, nitrogen-doped carbon dots are synthesized. Non-biomass carbon-based CDs are obtained after post-dialysis and freeze-drying purification. These non-biomass CDs are then dispersed in ethanol for crop cultivation^{1, 2}.

Route 3 encompasses a synthesis process utilizing transition metal salts and reductants as precursors for the fabrication of transition metal oxides. This typically involves mechano-chemical processes, precipitation, sol-gel methods, and gas-phase synthesis. Herein, typical ZnO, Fe₃O₄, and TiO₂ are employed to enhance plant growth³⁻⁸. Given their widespread commercial application, detailed inventory for their synthesis is omitted here. Instead, prices from chemical trading market are used for economic evaluation.

Comparison of evaluated parameters by normalization.

All evaluated terms in Fig. 6d are computed for basic scenarios without uncertainty definition of input parameters. Specifically, the scores of comparable parameters (**Score**, dimensionless) displayed in Fig. 6d are normalized using the following equation to amplify their differences and eliminate comparison difficulties due to differing units and numerical ranges.

$$Score = \left[AF \times \frac{\ln(P_{i,j})}{\ln(Max_{i,j})} \right]^2$$

where the subscript *i* represents comparable parameters. The subscript *j* represents technical routes using various nanomaterials. *AF* (dimensionless, 10) is the amplification factor, *P_{i,j}* is the parameter value with different specific units and numerical values, *Max_{i,j}* is the maximum value among a cluster of classified

parameters. For the specific values of evaluated terms, photosynthetic efficiency derives from the data exhibited in Fig. 6b, production cost derives from the data exhibited in Fig. 6c, values of resource accessibility for biomass CDs (8), non-biomass CDs (6), and metal oxides (5) are qualitatively allocated based on the level of their spatiotemporal resource distribution and processing convenience, while values of human/animal toxicity (ozone formation-human health, human carcinogenic toxicity, human non-carcinogenic toxicity) and environmental toxicity (terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity) are determined upon certain environmental indicators by life-cycle assessment, which are evaluated using the ReCiPe-2016-Midpoint-(H) methods and the consumable inventories used for these evaluations are provided in Supplementary Tables 3-8. Notably, these evaluation parameters are computed as their average values, and are normalized to scores ranging from 0 to 100, corresponding to classes 1 to 4 with increasing score as shown in Fig. 6d.

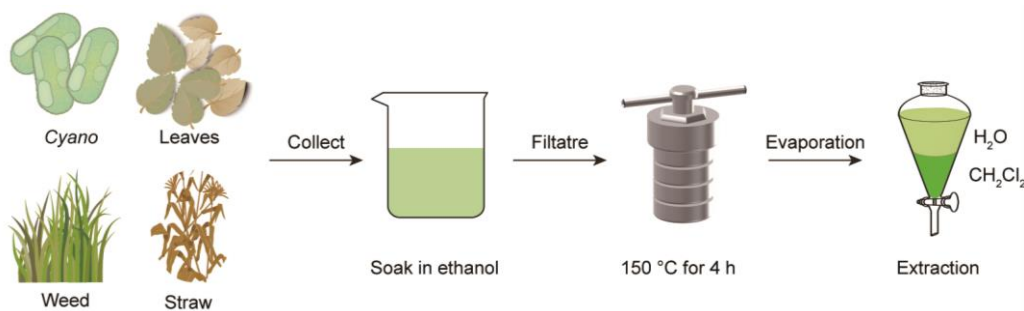
Uncertainty analyses.

In this work, all input parameters in the evaluation procedures are defined with uncertainty, based on collected data. To quantify result uncertainty, Monte Carlo simulations with Latin hypercube sampling propagate the input uncertainty of parameters. These parameters are summarized in Supplementary Table 7 and typically follow a triangular distribution with minimum, most probable, and maximum values. Data clusters in this study are displayed as mean $\pm$ standard deviation in a 5-95% confidence interval, based on 10,000 Monte Carlo simulation trials, as depicted in Fig. 6c, Supplementary Fig. 15

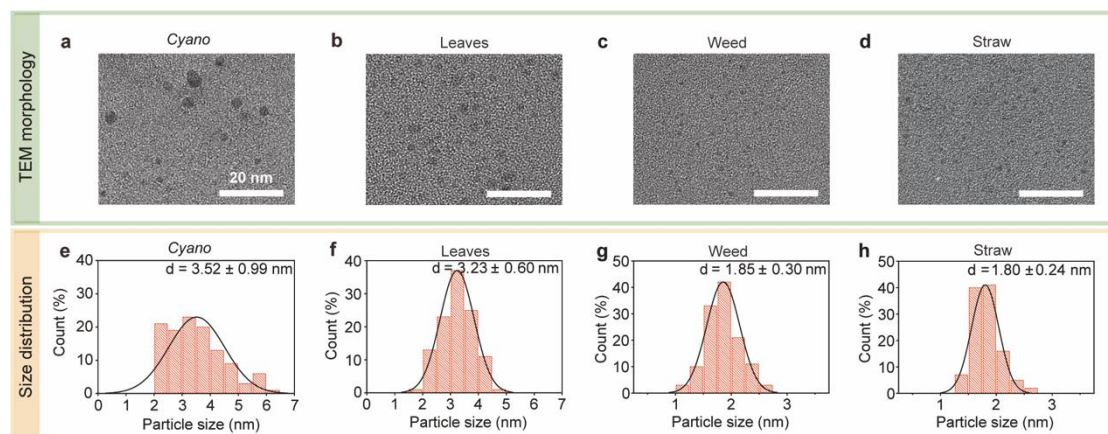
The growth of cyanobacteria with the addition of ethanol

To test whether ethanol has an effect on the growth of cyanobacteria, we tested the growth curve of cyanobacteria in sealed bottles. Given that we used a CDs concentrate that was about 0.1% of the volume of the medium, we tested 0.1% ethanol on the growth of cyanobacteria. There were four biological replicates.

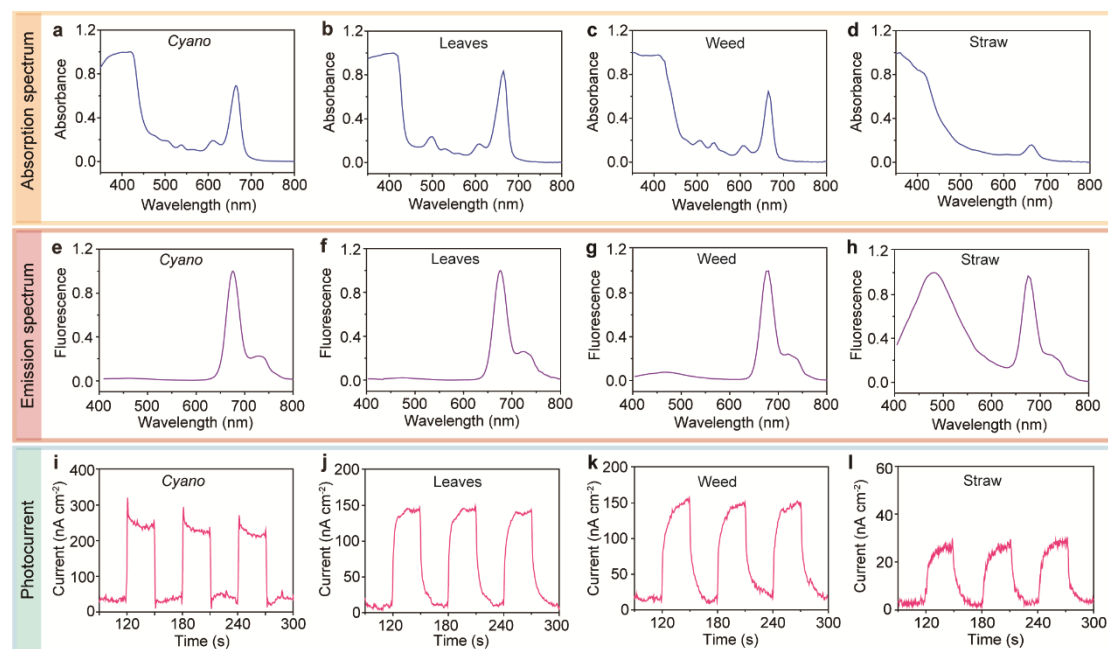
Supplementary Figures



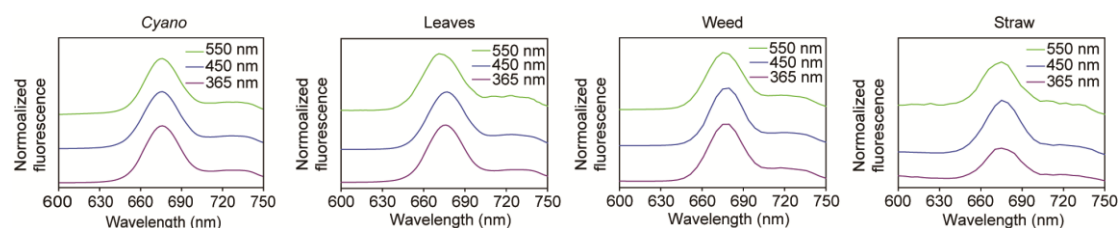
Supplementary Figure 1: The production processes of CDs. Schematic of CDs synthesis by solvothermal method from Cyano cell pellet, leaves, weed and straw.



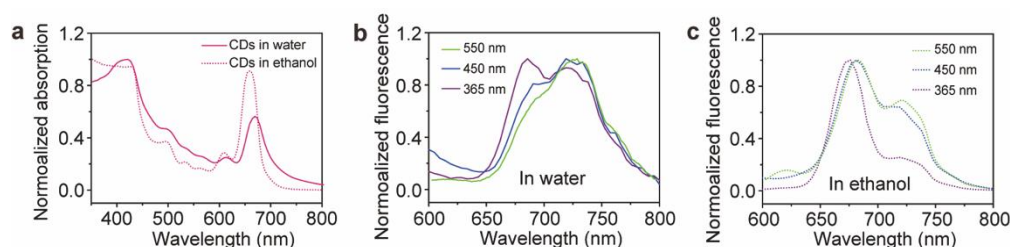
Supplementary Figure 2: Morphology and size of four types of CDs. a-d. The TEM morphology and e-h. particle size of CDs produced from four different raw biomass.



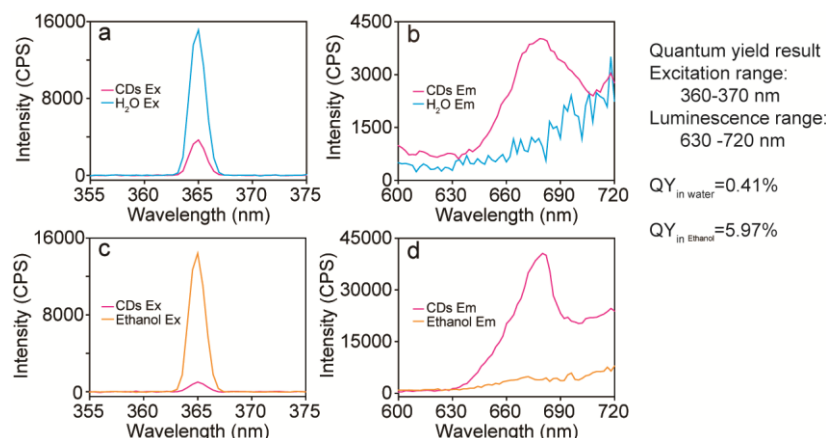
Supplementary Figure 3: The absorption, emission and photocurrent characterizations of CDs. a-d. The normalized absorption spectra in ethanol, e-h. normalized emission spectra (excited with 365 nm) in ethanol and i-l. photocurrent of four types of CDs (200 μ L of 1.25 mg mL⁻¹ CDs, dropped and dried on a FTO electrode (1 $\times$ 1 cm²)).



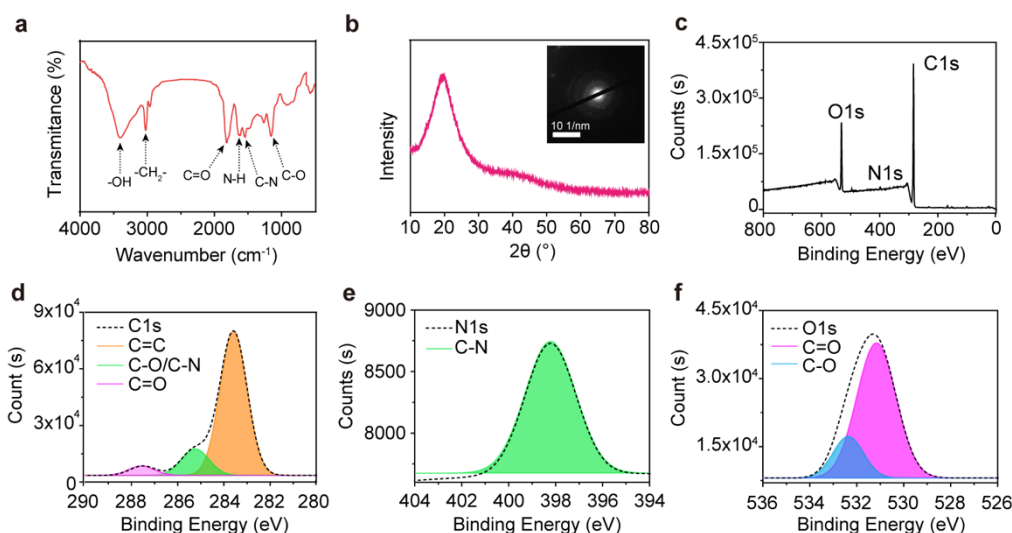
Supplementary Figure 4: The fluorescence emissions of four CDs are independent with the different excitation wavelength. The emission $\lambda_{\max}$ remained nearly constant with excitation wavelengths of four CDs in ethanol at 365 nm, 450 nm and 550 nm, respectively.



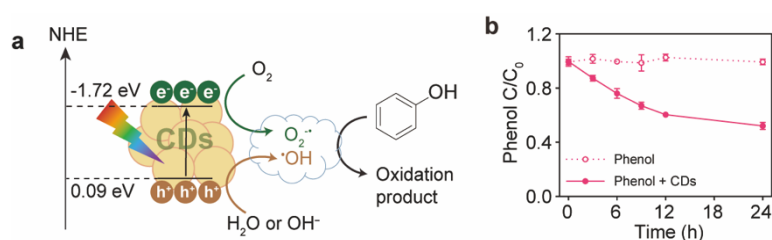
Supplementary Figure 5: The optical properties of C-CDs in ethanol and water. **a.** The normalized absorption spectra of C-CDs in different solvents. The normalized fluorescence emission spectra under excitation at 365 nm, 450 nm and 550 nm **b.** in water and **c.** in ethanol.



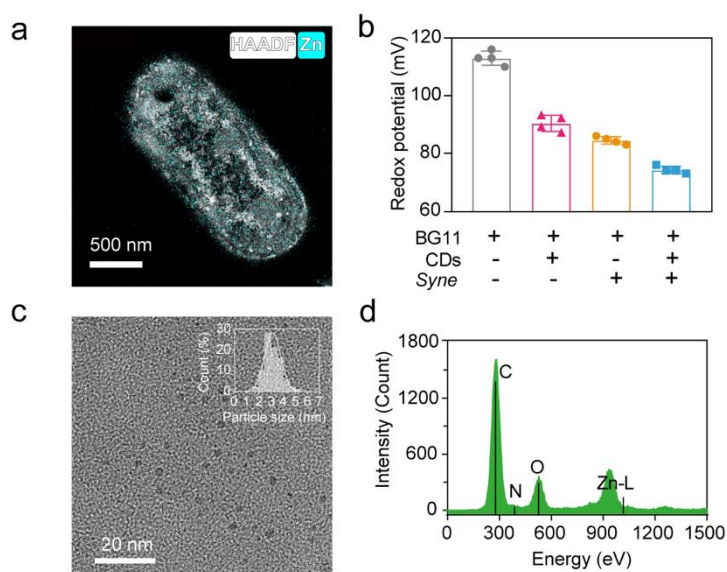
Supplementary Figure 6: The absolute PLQY measurements of C-CDs in water and ethanol under 365 nm excitation. **a.** The excitation spectra of C-CDs in water and water. **b.** The emission spectra of C-CDs in water and water. **c.** The excitation spectra of C-CDs in ethanol and ethanol. **d.** The emission spectra of C-CDs in ethanol and ethanol. The spectra were used to measure the PLQY.



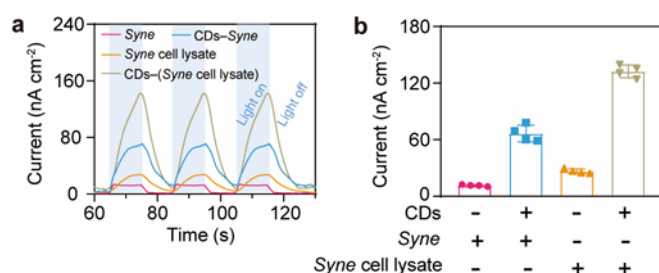
Supplementary Figure 7: The FTIR, XRD and XPS characterizations of C-CDs. **a.** The FIRT of C-CDs. **b.** The XRD spectrum of C-CDs, and the insert image is the TEM diffraction patterns, indicate C-CDs have the amorphous structure. **c-f.** XPS survey spectra of C-CDs. Deconvolution spectra of **d.** C1s, **e.** N1s and **f.** O1s for C-CDs.



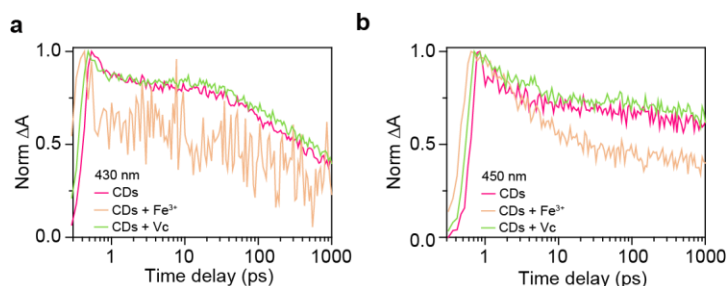
Supplementary Figure 8: The photoelectric effect of C-CDs. **a.** The mechanism of photo-generated electrons from C-CDs for phenol degradation. **b.** The phenol degradation curve in the presence or absence of C-CDs under light condition. C_0 is the initial concentration of phenol, 100 mg L^{-1} . Degradation rate is about 50% after 24 h of illumination with 1 mg mL^{-1} C-CDs. The data are presented as the mean values $\pm$ standard deviation of four replicates.



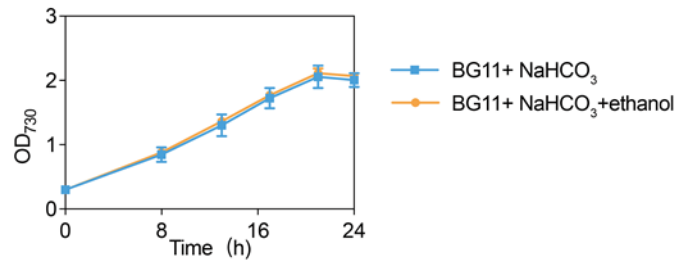
Supplementary Figure 9: The characterizations of CDs-Syne. **a.** The distribution of CDs in CDs-Syne hybrid system. High-Angle Annular Dark Field (HAADF)-STEM and energy dispersive x-ray spectroscopy (EDS) mapping showing that CDs were mainly distributed in the cells. Zn-doped-CDs was used to prepare hybrid system, and EDS imaging was based on Zn element. **b.** The redox potential of BG11 medium, CDs, Syne and CDs-Syne. The potential of CDs-Syne is higher than that of Syne or CDs, indicating the formation of hybrid system. **c.** TEM morphology and size distribution of Zn-doped-CDs, with diameter of 3.15 ± 0.67 nm. **d.** EDS mapping of Zn-doped-CDs.



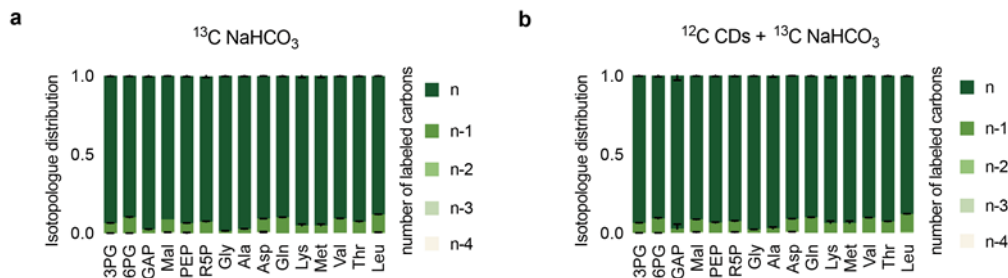
Supplementary Figure 10: The photocurrent of Syne cell and Syne cell lysate with and without CDs. **a.** A representative photocurrent curve and **b.** the quantitative photocurrent of Syne cells, CDs-Syne hybrids, Syne cell lysate, and CDs-Syne cell lysate. Syne cells were lysed and then incubated with CDs for 1 h.



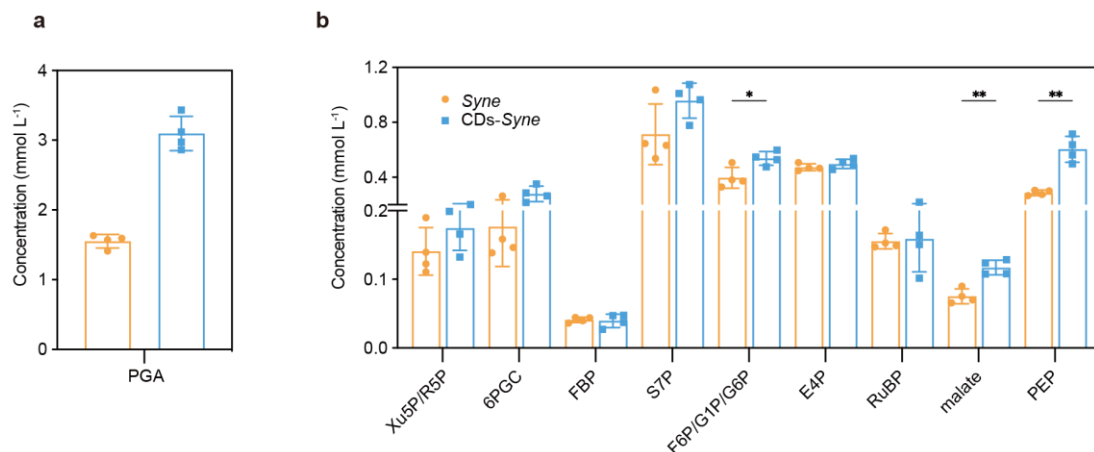
Supplementary Figure 11: The transient absorption spectroscopy analysis of C-CDs. **a.** and **b.** TA spectra of CDs with Fe³⁺ or vitamin c (Vc). Vc serves as a hole trapping agent, while Fe³⁺ is used for electron capture. The similar spectra of CDs and CDs with Vc suggested that the photocarriers of CDs are mainly electrons, with a relatively small proportion of holes.



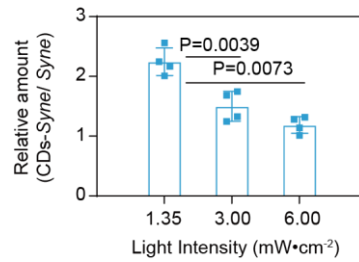
Supplementary Figure 12: The growth of cyanobacteria with the addition of ethanol. 0.1% ethanol had no observed inhibition on the growth of *Syne* cells. The data are presented as the mean values $\pm$ standard deviation of four replicates.



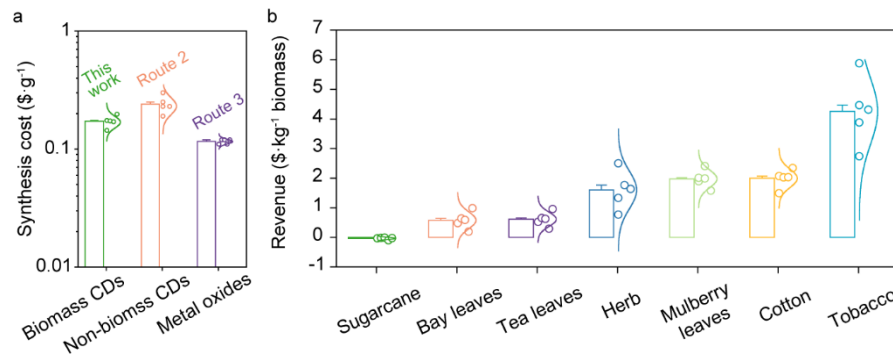
Supplementary Figure 13: The ^{13}C labeled experiments. *Syne* cells were cultured in sealed flasks containing BG11 medium with added ^{13}C NaHCO_3 , under conditions **a.** without or **b.** with ^{12}C CDs. Isotopologue distributions were determined for central carbon metabolites and amino acids by LC-MS. *n* refers to the fully labeled molecule and *n*-1, *n*-2, etc. to molecules with one, respectively two, etc., unlabeled carbon atoms. The data are presented as the mean values $\pm$ standard deviation of four replicates.



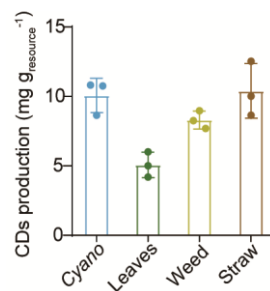
Supplementary Figure 14: The intracellular metabolites concentration in *Syne* and CDs-*Syne*. **a** and **b.** Concentration of intracellular metabolites of central carbon metabolism in *Syne* and CDs-*Syne*. CDs material is from *Syne*. PGA, 3-phosphoglyceric acid; Xu5P, xylulose 5-phosphate; R5P, ribose 5-phosphate; 6PGC, 6-phospho-gluconate; FBP, fructose 1,6-bisphosphate; S7P, 7-phosphosedoheptose; F6P, fructose 6-phosphate; G1P, glucose 1-phosphate; G6P, glucose 6-phosphate; E4P, erythrose 4-phosphate; RuBP, ribulose-1,5-bisphosphate; PEP, phosphoenolpyruvate.



Supplementary Figure 15: The effect of light intensity on glycerol production in CDs-Syne. Relative glycerol production by CDs-Syne hybrids compared to that by Syne cells under different light intensities (1.35, 3, and 6 mW cm⁻²). CDs material is from Syne.



Supplementary Figure 16: Techno-economic assessment of nanomaterials for enhancing plant cultivation. **a.** Synthesis cost of various nanomaterials. **b.** Revenues generated from a 1 kg increment in plant biomass when the biomass-based CDs are applied to several economic plants. Bar charts, error bars, and data distributions (n = 5, with base, maximum, minimum, median, and mean values presented as dots alongside lognormal distribution lines) were derived from 100,000 Monte Carlo simulation trials with a 5%-95% confidence interval.



Supplementary Figure 17: The production of CDs from different raw biomass. Measurement the conversion yield of CDs synthesized from 1 g of raw biomass (wet weight of Cyano, fresh weight of leaves and weed, and dry weight of straw were used for the calculation).

Supplementary Table 1: The summary of materials enhanced natural photosynthesis.

Material type	Material	Organism	Mechanism	Assessment parameter	Fold changes	Ref.
Metal-based material	CdS	<i>R. rubrum</i>	Photosensitizer	Biomass	1.371	9
	InP	<i>N. sphaeroides</i>		Chemical	1.78	10
	Au NPs	<i>S. elongatus</i>		Chemical	1.146	11
	Au NPs	<i>S. elongatus</i>		Biomass	1.106	11
	CdS	<i>R. palustris</i>		Biomass	2.53	12
	CdS	<i>R. palustris</i>		Biomass	1.39	13
	GOQDs	<i>C. pyrenoidosa</i>	Light converter	Biomass	1.17	14
	UCNPs	Lettuce		Biomass	1.4517	15
	Au NPs	<i>C. zofingiensis</i>		Chemical	1.427	16
Carbon-based material	OF/TPT	<i>R. palustris</i>	Photosensitizer	Chemical	1.56	17
	Lev-CDs	<i>C. pyrenoidosa</i>		Biomass	1.5859	18
	PBF	<i>C. pyrenoidosa</i>	Light converter	Biomass	1.145	19
	CDs	<i>Brassica chinensis</i>		Biomass	2.52	20
	CDs	Rice		Biomass	1.6431	21
	CDs	<i>C. regularis</i>		Biomass	1.115	22
	Mg,N-CDs	Rice		Biomass	1.706	23
	N-CDs	Tomato		Biomass	1.383	24
	Far-red CDs	lettuce		Biomass	1.246	25
	CDs	Mung bean		Biomass	1.1539	26
	PVA-CDs	Lettuce		Biomass	1.1451	27
	CDs	Lettuce		Biomass	1.36	28
	N-CDs	Corn	Coupled	Biomass	1.5575	29
	CDs	<i>A. thaliana</i>		Biomass	1.8	This work
	CDs	<i>S. elongatus</i>		Chemical	2.2	This work

Supplementary Table 2: The time constants and relative weight for the two components in CDs and CDs-Syne.

	CDs (ps)	CDs-Syne (ps)
y0	0.11009	0.16417
A1	0.44614	0.44915
tau1	7.3032	6.6109
A2	0.47892	0.38764
tau2	64.485	39.523
tau ave	36.90723396	21.85731361

Supplementary Table 3: Consumed inventory of biomass-based CDs (this work).

Cyano cultivation		
Inputs	Amount (range)	Unit
Deionized water	20	L
Solid <i>Cyano</i> culture medium	1.7	g L ⁻¹
Electricity (centrifugation)	10.20	kWh kg _{wet Cyano} ⁻¹
Outputs	Amount (range)	Unit
Centrifugated wet <i>Cyano</i>	80-85	g
Biomass-based CDs synthesis		
Inputs	Amount (range)	Unit
Centrifugated wet <i>Cyano</i>	1/10	g _{biomass} mL _{ethanol} ⁻¹ a
Leaves ^c	1/3	g _{biomass} mL _{ethanol} ⁻¹ b
Weed ^c	1/5	g _{biomass} mL _{ethanol} ⁻¹
Straw ^c	1/12.5	g _{biomass} mL _{ethanol} ⁻¹
Electricity (solvothormal)	0.35	kWh kg _{wet biomass} ⁻¹ d
Dichloromethane ^e	10-15	mL
Deionized water ^e	10-15	mL
Nitrogen gas ^f	0.01-0.02	L
Electricity (drying)	0.47	kWh kg _{wet biomass} ⁻¹
Outputs	Amount (range)	Unit
Biomass-based CDs	10-15	mg

Note: **a.** The quantity of biomass immersed in ethanol is determined by its wet weight. **b.** Various types of biomasses are immersed in a corresponding volume of ethanol. **c.** The utilized biomass, including economically viable leaves, weed, and straw (these biomass precursors are nearly cost-free), share similar properties and structure with *Cyano*, and are also used to fabricate CDs. **d.** The electricity consumed for the solvothormal synthesis of CDs from biomass is evaluated based on the classical allocation principles of life-cycle assessment, which assesses the electricity consumption when the equipment is at its highest utilization efficiency. **e.** Dichloromethane and deionized water are served as extractants for CDs' purification, employing the same volume of solvothormal solvents, most of which are recycled after post-purification. **f.** Nitrogen gas is utilized to obtain CDs products by air drying the residual organic solvents and water.

Supplementary Table 4: Consumed inventory of non-biomass-based CDs (Route 2).

Inputs	Amount (range)	Unit
Deionized water	10	mL
Citric acid	1.05	g
Ethylenediamine	0.5	mL
Electricity (heating) ^a	1.68E-02	kWh
Electricity (purification) ^a	3.36E-02	kWh
Outputs	Amount (range)	Unit
Non-biomass-based CDs	0.42-0.62 ^b	g

Note: **a.** The electricity consumption for the synthesis of CDs from chemicals is evaluated based on the classical allocation principles of life-cycle assessment, assessing the electricity consumption when the equipment operates at its maximum utilization efficiency. **b.** The yield of non-biomass-based CDs is estimated using the reported conversion ratio of citric acid to CDs in the reference, as collected in Supplementary Table 8.

Supplementary Table 5: Quantitative situations of plant biomass increase when different photosynthesis-enhancing materials are applied.

Terms	Plant wet biomass (before applied)	Plant wet biomass (after applied)	Unit
Biomass-based CDs ^a	0.19-0.27	0.37-0.42	g/p ^b
Chemical carbon-based CDs ^c	0	29.2-50.6	% ^d
Transition metal oxides ^e	0	32.8-55.1	% ^f

Note: **a.** and **b.** Approximately 4-6 mL (50-100 mg L⁻¹) of biomass-based CDs are sprayed on the leaves of an individual *A. thaliana* over 10-15 days. **c.** and **d.** Approximately 1.75 mg of chemical carbon-based CDs are applied to the leaves of an individual *A. thaliana* over 7-10 days, resulting in a 29.2% to 50.6% increment in plant biomass. **e.** and **f.** Empirical principles for agricultural production suggest that 50-200 L of pesticide suspension is typically applied to the leaves within one hectare of crop plants. This results in a harvest of 30-80 kg of dry weight crop biomass in the absence of any photosynthesis-enhancing materials, while the application of transition metal oxides yields a 32.8% to 55.1% average increment in crop biomass. Specifically, ZnO suspension (80-300 mg L⁻¹) can enhance crop biomass by 49.0%-59.0%, Fe₃O₄ suspension (300-500 mg L⁻¹) by 15.0%-25.0%, and TiO₂ suspension (250-450 mg L⁻¹) by 34.3%-81.2%. Biomass weight, including the entire part above roots, is considered in its wet form.

Supplementary Table 6: Price sources of chemicals and reagents consumed in this work, route 2, and route 3.

Supplier	Released date	Sources
ChemNet, Global Chemical Network ^a	2024	https://www.chemnet.com/
World Bank Open Data, The World Bank ^b	2023	https://data.worldbank.org/
Merck, Sigma-Aldrich ^c	2024	https://www.sigmaaldrich.cn/
Aladdin, Aladdin Scientific ^c	2024	https://www.aladdinsci.com/
Macklin, Macklin reagent ^c	2024	http://www.macklin.cn/en/

Note: **a.** This source provides prices of bulk chemicals. **b.** This source provides electricity prices in global average. **c.** These sources provide prices of certain fine chemicals.

Supplementary Table 7: Market prices of several economic plants.			
Terms	Prices range ^a	Unit ^b	Distribution
Sugarcane	0.31-0.37	\$ kg ⁻¹	Triangular
Bay leaves	0.17-2.73	\$ kg ⁻¹	Triangular
Tea leaves	0.26-2.21	\$ kg ⁻¹	Triangular
Herb	0.33-6.20	\$ kg ⁻¹	Triangular
Mulberry leaves	1.43-3.40	\$ kg ⁻¹	Triangular
Cotton	2.23-2.48	\$ kg ⁻¹	Triangular
Tobacco	1.18-10.94	\$ kg ⁻¹	Triangular

Note: **a.** The price range follows a triangular distribution with minimum, most probable, and maximum values, as depicted in Supplementary Table 8. **b.** The unit is dependent on the wet weight of economic plants, while the costs of the dry weight of bay leaves, tea leaves, herbs, tobacco, etc., are significantly higher, as shown in Supplementary Table 8.

Supplementary Table 8: Parameters and probability distribution used in TEA evaluation.		
Parameters	Unit	Values, triangular distribution (minimum, probable, maximum)
Global electricity prices	\$ kWh ⁻¹	0.067-0.070-0.074
Global DI water prices	\$ L ⁻¹	0.071-0.092-0.128
Solid <i>Cyano</i> culture medium prices	\$ g ⁻¹	0.085±10% ^a
Global ethanol prices	\$ L ⁻¹	0.661-0.717-0.762
Recycle ratio of solvents ^b	%	85-90-95
Recycle ratio of organic extractants ^c	%	85-90-95
Global dichloromethane prices	\$ L ⁻¹	0.451-0.508-0.583
Global nitrogen gas prices	\$ L ⁻¹	0.062-0.074-0.087
Dehydration ratio of leafy crops	%	90-95-98
Market sugarcane prices	\$ kg ⁻¹	0.31-0.34-0.37
Market bay leaves prices	\$ kg ⁻¹	7.15-17.03-28.28
Market tea leaves prices	\$ kg ⁻¹	12.53-17.94-22.83
Market herb prices	\$ kg ⁻¹	14.21-34.06-63.75
Market mulberry leaves prices	\$ kg ⁻¹	1.42-2.27-3.40
Market cotton prices	\$ kg ⁻¹	2.23-2.44-2.48
Market tobacco prices	\$ kg ⁻¹	56.9-85.15-113.39
Citric acid prices	\$ kg ⁻¹	82.31±10%
Ethylenediamine prices	\$ L ⁻¹	55.34±10%
Conversion ratio of citric acid to CDs	%	40-50-60
ZnO prices	\$ kg ⁻¹	204.61±10%
Fe ₃ O ₄ prices	\$ kg ⁻¹	116.92±10%
TiO ₂ prices	\$ kg ⁻¹	19.16±10%
Empirical pesticides spaying amount	L hectare ⁻¹	50-120-200
Empirical biomass harvest	(dry) kg hectare ⁻¹	30-50-80
ZnO concentration	mg L ⁻¹	80-100-300

Fe ₃ O ₄ concentration	mg L ⁻¹	300-400-500
TiO ₂ concentration	mg L ⁻¹	250-350-450
Crop increase by ZnO	%	49.0-54.0-59.0
Crop increase by Fe ₃ O ₄	%	15.0-19.0-25.0
Crop increase by TiO ₂	%	34.3-69.6-81.2

Note: **a.** For the price value without a distribution range, a fluctuation of 10% is assumed. **b.** Most solvents and organic extractants in this work, as well as in Route 2 and Route 3, are assumed to be recycled to minimize synthesis costs, which would decrease the reagents consumption demonstrated in Supplementary Table 2 and 3.

235

Supplementary Table 9: The summary of materials enhanced the biomass of photosynthetic organisms.					
Material type	Material	Organism	Assessment parameter	Fold changes	Ref.
Metal-based material	Au NPs	<i>Synechocystis</i> sp. PCC 6803	Biomass	1.65	30
	ZnO NPs	Wheat	Biomass	1.59	6
	SiO ₂ NPs	Soybean	Biomass	1.437	31
	Fe ₃ O ₄ NPs	Barley	Biomass	1.88	7
	CeO ₂ NPs	Sorghum	Biomass	1.31	32
	MoS ₂	Rice	Biomass	1.2817	33
	TiO ₂ NPs	Garlic	Biomass	2.449	8
	CeO ₂ NPs	Soybean	Biomass	1.45	34
	Cu NPs	Mung bean	Biomass	1.2307	35
	TiO ₂ NPs	Tomato	Biomass	1.696	8
Carbon-based material	CDs	Maize	Biomass	2.18	36
	CDs	Soybean	Biomass	1.215	37
	Mg,N-CDs	Lettuce	Biomass	1.4081	38
	NIR-CDs	<i>N. benthamiana</i>	Biomass	2.47	39
	CDs	Maize	Biomass	1.375	2
	CDs	<i>A. thaliana</i>	Biomass	1.2	40
	CDs	<i>C. vulgaris</i>	Biomass	1.17	41
	MWCNTs	Wheat	Biomass	1.63	42
	CDs	Rice	Biomass	1.148	43
	MWCNTs	Barley	Biomass	1.60	44
	CDs	Mung bean	Biomass	1.735	45

The summary of materials enhanced ATP synthesis or Electron transport rate of photosynthetic organisms.					
Carbon-based material	PPE	<i>C. pyrenoidosa</i>	ATP synthesis	2.15	46
	AIEgens	Chloroplast	ATP synthesis	1.5	47
	CD-AIEgens	Chloroplast	ATP synthesis	4	48
	PFP	<i>Synechococcus</i> sp. PCC7942	ATP synthesis	1.272	49
	CPNs-TAT	<i>R. palustris</i>	ATP synthesis	1.4956	50
	CDs	Chloroplast	ATP synthesis	8.7	51
	CDs	Chloroplast	ATP synthesis	2.8	52
	SWNTs	Chloroplast	Electron transport rate	1.49	53

236

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