SLUTRAPPORT

MUDP forprojekt

Juli 2025 – December 2025

Purifies wastewater, recycles the scarce resource phosphorus and captures CO_2 with biological processes

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Bio Clean Carbon (Clean Carbon ApS)

Miljøteknologisk Udviklings- og Demonstrationsprogram

Projektet, som er beskrevet i denne rapport, er støttet af Miljøteknologisk Udviklings- og Demonstrationsprogram (MUDP) under Miljøministeriet, der støtter udvikling, test og demonstration af miljøteknologi.

MUDP investerer i udvikling af fremtidens miljøteknologi til gavn for klima og miljø i Danmark og globalt, samtidig med at dansk vækst og beskæftigelse styrkes. Programmet understøtter dels den bredere miljødagsorden, herunder rent vand, ren luft og sikker kemi, men understøtter også regeringens målsætninger inden for klima, biodiversitet og cirkulær økonomi.

Det er MUDP's bestyrelse, som beslutter, hvilke projekter der skal modtage tilskud. Bestyrelsen betjenes af MUDP-sekretariatet i Miljøstyrelsen.

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Purifies wastewater, recycles the scarce resource phosphorus and captures CO_2 with biological processes

FAKTA OM PROJEKTET

Projektperiode: Juli 2025 – December 2025
Projektdeltagere: Clean Carbon ApS
Bevilling fra MUDP: 527.740,00 kr.
Projektleder: Anne Karina Filt Asbjørn

PURPOSE

The BioCleanCarbon project aimed to develop and demonstrate a biologically driven wastewater treatment system using cyanobacteria to capture CO_2 and remove nitrogen (N) and phosphorus (P), while producing biomass suitable for circular valorization such as biochar. The project targeted both laboratory and pilot-scale validation to ensure practical feasibility and compliance with regulatory standards.

PROJECT RELEVANCE

The BioCleanCarbon project addresses three urgent and interconnected environmental challenges: (1) reducing nutrient pollution from wastewater, (2) capturing atmospheric CO_2 with biological systems, and (3) enabling circular use of phosphorus—an increasingly scarce global resource. Conventional wastewater treatment relies heavily on energy-intensive aeration and chemical precipitation and often struggles to remove nitrogen (N) and phosphorus (P) efficiently. These challenges contribute to eutrophication, greenhouse gas emissions, and inefficient resource use.
Cyanobacteria-based treatment systems offer a fundamentally different and more sustainable approach. By actively assimilating CO_2 for photosynthesis, they can lower aeration demand and simultaneously capture N and P into biomass. This biomass can then be valorized into biochar or other circular products, enabling resource recovery rather than disposal.
The project is highly relevant in a Danish and European context, where municipalities and industries face tightening discharge standards, rising energy costs, and increasing pressure to adopt nature-based treatment technologies. Furthermore, phosphorus recovery aligns with EU circular economy strategies, and biochar production supports carbon sequestration objectives.
By demonstrating both laboratory and pilot-scale feasibility, the project contributes directly to the development of low-energy, climate-positive wastewater solutions that can reduce eutrophication, lower operational costs, and unlock new circular value chains.

KEY RESULTS

The project successfully validated the core hypothesis that cyanobacteria can remove nutrients and capture CO_2 in both controlled laboratory conditions and real Danish wastewater environments.

Laboratory-scale results

- Cyanobacteria achieved up to 38% phosphorus removal and 80% nitrogen removal within 96 hours, outperforming conventional activated sludge benchmarks.
- Trials in real municipal wastewater confirmed robust growth under non-sterile conditions and >90% biomass recovery using bio-based flocculants.
- Comparative wastewater pond testing showed municipal wastewater with high ammonium concentrations delivered the highest overall nutrient uptake, while balanced sugar-industry wastewater offered strong growth with improved P–N balance.
- Biomass from both wastewater types contained high carbon contents, low contaminants, which makes it very suitable for biochar.

Pilot-scale results

- Pilot systems were deployed at Lolland Forsyning (LF) and NordZucker (NZ) using portable greenwall pond systems.

At Lolland Forsyning:

- Achieved 100% ammonium removal and 95% phosphate removal within ~1 month.
- Demonstrated atmospheric CO_2 uptake, enabling continuation to biochar work.
- Reduced aeration needs by 30–60% during daytime, confirming high energy-saving potential.

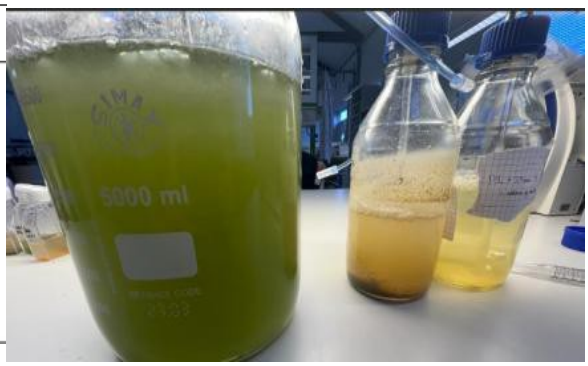
	14 B			
	OD (750 nm)	**NH4**	**NO3**	**PO4**
22/08/2025	0.093	32.54	4.21	3.18
27/08/2025	0.39	0.06	3.76	0.17
	OD increase %	Removal efficiency		
	NA	16%	-602%	23%
	76%	100%	-470%	95%

At NordZucker:

- First water source caused biomass collapse due to low phosphorus and seasonal pH fluctuations, but Plan B was deployed.
- Second wastewater type supported full strain adaptation and successful scale-up during November.

Table 1. OD results.

Date	OD750
14/11/2025	0.417
17/11/2025	0.720
18/11/2025	0.254
19/11/2025	0.315
20/11/2025	0.434



Biochar and certification readiness

- 313 g dried biomass was converted to 150 g biochar and submitted for full DIN/ISO chemical analysis, including heavy metals, PAHs, and PFAS.
- A comprehensive feedstock assessment identified sugar-industry wastewater as the optimal long-term EBC certification pathway.
- Registration with Carbon Standards International (CSI) was completed and pre-audit documentation initiated.

Overall outputs from LF and NZ

- Demonstrated robust biological nutrient removal and CO_2 capture.
- Validated scalability from Erlenmeyer flasks to 1000 L pilot ponds.
- Produced and analyzed pilot-scale biomass and biochar.
- Achieved full documentation basis for EBC certification.
- Secured strong partnerships with municipal, industrial, and academic stakeholders.

PROJECT COURSE AND LESSONS LEARNED

The project progressed according to plan, with several adaptive measures implemented to ensure delivery of all milestones.

Project course

Laboratory work (WP1) was frontloaded due to summer shutdowns at the partner lab. This enabled early optimization of cultivation systems, nutrient assays, and biomass analysis. Once lab validation was complete, pilot systems were deployed at LF and NZ, supported by active collaboration with facility staff. Weekly partner meetings maintained alignment between technical, regulatory, and certification tasks.

Work Package 3 (EBC readiness) and WP4 (project management) proceeded smoothly, including the transition from Krüger to new collaborators (GCL and DTU) without affecting milestones.

Challenges and solutions

- Variability in wastewater composition:
  Fluctuating nutrient levels and pH in municipal and industrial effluent required adaptive experiment design and sometimes necessitated repeated trials. At NZ, this caused strain collapse, which was resolved by restarting with an alternative wastewater type.

- Harvesting inefficiency:
  Hand-centrifugation proved insufficient at pilot scale; the team decided to adopt automated centrifuges for later testing.
- Regulatory complexity:
  Transport and classification of biomass required extensive coordination with regulators. Early engagement reduced risks for pilot continuation.
- Partner change:
  Replacement of Krüger with new technical collaborators was managed without interruption due to strong project coordination and contingency planning.

Key lessons learned

- Wastewater selection is critical—balanced N:P ratios strongly influence culture stability.
- Cyanobacteria systems can be highly resilient but require rapid operational flexibility in variable wastewater environments.
- Early regulatory alignment and certification planning are essential for circular biochar products.
- Strong collaboration with wastewater utilities accelerates troubleshooting and scale-up success.

CONCLUSION AND PERSPECTIVES

The project successfully met its core objectives and demonstrated that cyanobacteria-based treatment can efficiently purify wastewater, recover scarce phosphorus, and capture atmospheric CO_2 while producing biomass suitable for circular valorization streams.
The results show that:

- Nutrient removal efficiency exceeded expectations, with near-complete ammonium and phosphate removal at pilot scale.
- CO_2 assimilation was verified, supporting future development of carbon-negative treatment systems.
- Created Biochar quality met safety and compositional requirements required for the Agri European Biochar Certificate for DK.
- **Compared with raw sludge, cyanobacteria biomass has higher carbon and lower accumulated heavy metals**
- The technology is ready to advance from TRL 3–4 to TRL 5, supporting larger outdoor demonstrations and industrial-scale testing in different wastewater types.

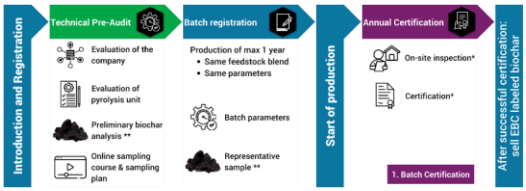
The strong performance at Lolland Forsyning, combined with successful Plan B adaptation at Nord-Zucker, confirms that the system can operate in diverse wastewater environments. Business development activities have already triggered new collaborations with Envafors, Bornholm Forsyning, and Kalundborg Forsyning, creating a clear pathway for future development.

Next steps include:

- TRL 5 testing with larger-scale trials using raceway ponds to further reduce aeration energy use in municipal and industrial wastewater treatment plants.

- Larger scale Biochar production with contract manufacturing partners
- Full EBC certification and Biochar as fertilizer market testing with large farmers.
- Moving into TRL 6 with industrial implementation at LF and expansion to additional municipal and agro-industrial partners.

Overall, the project has achieved its intended purpose and built a strong foundation for a full development and commercialization phase.



DISSEMINATION

Throughout the project, BioCleanCarbon shared results and progress across professional networks, industrial partners, and international events.

Events & Outreach

- Ocean Exchange Global Program – Finalist presentation
  Selected among 158 global applicants to present the solution for reducing eutrophication and nutrient runoff impacts.

- Rockstart Forward 2025 – Biochar ecosystem networking

  Participated in expert discussions on biochar innovation and certification pathways.

- Slush 2025 – Climate innovation track

Engaged with investors, corporates, and regulators to showcase climate-positive wastewater treatment technology.

Industry & stakeholder engagement

- Shared project results with:
- Collaboration with Sugar Company:

BCC has shared recent laboratory findings with the partner sugar company. Thanks to this collaboration, we have jointly analyzed the complex characteristics of the refinery's effluent to define the optimal operating pathway for the successful development of the strain. After demonstrating its viability in the wastewater of interest to the project, the pilot implementation plan has been adapted to address the plant's peak production season. This strategy focuses on validating the system's efficacy and resilience during the most critical seasonal period.

  - **LF business business plan and scale-up proposal:** Based on the success of pilot scale at Lolland Forsyning, we built a business case proposal on how we can move to industrial scale. The decision sits with the LF leadership team. If they chose to continue the collaboration they will pay 50% of the further scale-up costs.

Wastewater discharges cause reputational damage and costs high fees

Source: Wildlife Conservation Society, 2023

Utilities discharges N, P, BI-5 and have high energy-bills.

→ pays ~610.000 DKK on average in fees yearly for emissions of P, N and BI-5
→ pays ~ 390.000 DKK on average in energy bills for current process
→ Reputational risk: Driving coastal pollution and dead zones and high emissions of CO2, N2O, PFAS, CH4

Performance Targets: ≥96% phosphate removal; ≥100% ammonium removal; 60% BI-5; 79% reduction in aeration energy use.

Can be front-runner on CO2, N2O, PFAS, CH4 emissions.

The coming decade will bring sharp increases in costs due to regulations

Nutrients : 2030–2035 Waste Framework Directive targets **require significant N-reduction upgrades**.

PFAS : Immediate Pressure

- **DK & EU are pushing for sweeping PFAS limits.** ECHA restriction proposal that targets over **10,000 PFAS substances** - Miljøstyrelsen calls this a "very important milestone."
- **PFAS treatment costs could reach millions for utilities.** Miljøstyrelsen's PFAS-handling studies show that full-scale PFAS decontamination (flocculation + granular media) could cost on the order of **40–50 mio. DKK over 20 years (~ 2–2.5 mio DKK/yr for a medium utility)**.

CO_2, N_2O, CH_4 : New Cost Drivers

- Miljøstyrelsen is preparing GHG regulation for wastewater plants.
- CO_2 shadow price rising toward **4,000+ DKK/t**.

Impact: Utilities face **rapidly rising OPEX & compliance costs**. Must **future-proof operations now**.

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Sources: Miljøstyrelsen+1 ; MST

- Conducted interviews and workshops with multiple Danish wastewater companies.
- Initiated new pilot dialogues with Envafors (Næstved), Bornholm Forsyning, and Kalundborg Forsyning.

Investor communication

- Engaged more than 40 venture capital firms to evaluate scaling potential and funding pathways for subsequent development phases.

These dissemination activities helped position the technology within Denmark's growing circular wastewater and biochar ecosystem and facilitated the establishment of important partnerships for future scale-up.

Læs mere om MUDP på vores hjemmeside