CHALLENGE WINNER:
SPRIN-D
GERMAN FEDERAL AGENCY
FOR DISRUPTIVE INNOVATION

enaDyne

Profitable CO_2 conversion with plasma technology

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TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG

Fraunhofer IMWS

UNIVERSITÄT LEIPZIG

HTWK Hochschule für Technik, Wirtschaft und Kultur Leipzig

RUHR UNIVERSITÄT BOCHUM RUB

SPINLAB THE HHL ACCELERATOR

ENADYNE STANDS FOR ADVANCED AND SUSTAINABLE PLASMA-BASED SOLUTIONS

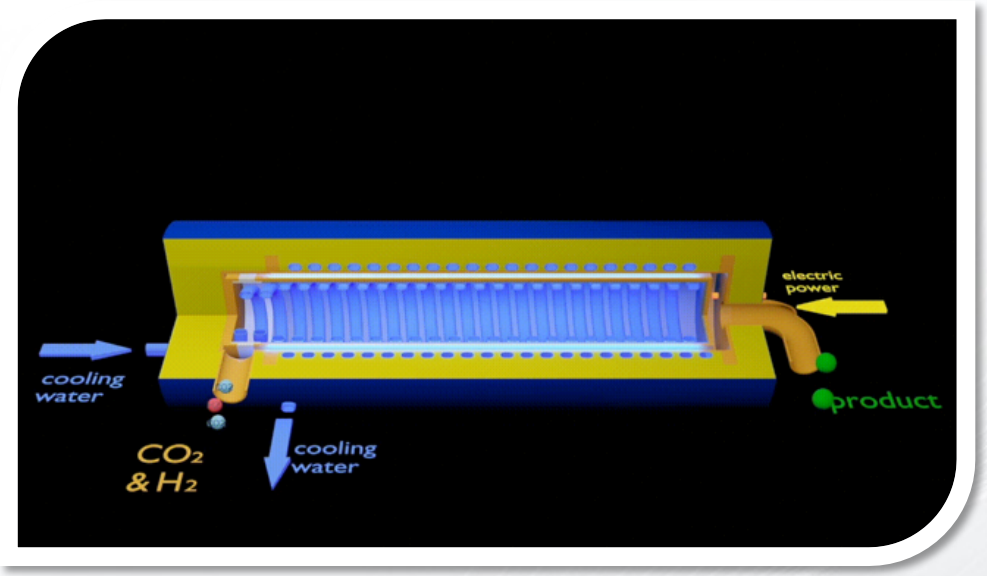
Executive summary

enaDyne stands for plasma reactors that selectively convert CO_2 and a hydrogen source into synthetic base chemicals and e-fuels in a single process step. The core process has an unprecedented energy efficiency, allows complete carbon neutrality and is highly scalable.

The technology solves several critical challenges at the same time:

- The **profitable reduction** of industrial CO_2 emissions.
- The **scalable production** of synthetic fuels.
- The **sustainable replacement** of fossil feedstock with the flexible production of synthetic hydrocarbons.

The electrode material that is key to the technology has been patented several times and the project is supported by a network of renowned R&D partners. Beyond that enaDyne was awarded as one of the most promising projects for the sustainable reduction of CO_2 emissions by the German Federal Agency for disruptive innovation (SPRIN-D) in its recent Carbon-to-Value Challenge.



enaDyne reactor prototype

Click here for a brief video overview.

TO OVERCOME THE CLIMATE CRISIS AT SPEED AND SCALE, TECHNOLOGY MUST MEET THREE CRITERIA

The challenge

Active reduction of CO_2 emissions

Just reducing CO_2 emissions will not allow us to reach net-zero. As certain emissions are not avoidable, there is an urgent need for active carbon dioxide reduction technologies.

Profitable application

Relying on subsidies will not solve the problem. To achieve a widespread application of the technology and its products, it must achieve a profit for its users.

Production of sustainable resources

A sufficient supply of sustainably produced chemicals and fuels is the only way to achieve a lasting independence of fossil oil and gas without hurting existing value chains.

THE ENADYNE TECHNOLOGY PROFITABLY CONVERTS CO_2 INTO GREEN CHEMICAL FEEDSTOCK AND E-FUELS

The solution

Harmful emissions....

CO_2 Source

Any process that produces relevant CO_2 emissions is suitable as **CO_2 source**. Possible sources are for example:

- Biogas plants
- Cement, Steel- and aluminum production

In the long run direct air capture might be a valid alternative.

H Source

Both green hydrogen and green methane are suitable **hydrogen sources**. Fossil hydrogen sources are possible but yield no decarbonizing effect. The focus is therefore on:

- **H_2** produced via electrolysis
- **CH_4** produced in biogas plants
- In the long term, also **H_2O** is possible

EnaDyne

Plasma catalysis

Energy - Technology is carbon neutral from 80% RE-Share

... become valuable resources

As **primary product,** the reactor selectively produces one out of a variety of hydrocarbons in a single-staged, highly selective process.

- E-Fuels and E-Fuel pre-products
- Feedstock for the chemical industry
- Ethylene, alcohols, aldehydes, etc.

Primary product

As **byproducts,** most synthesis processes create:

- Oxygen
- Pure, solid carbon

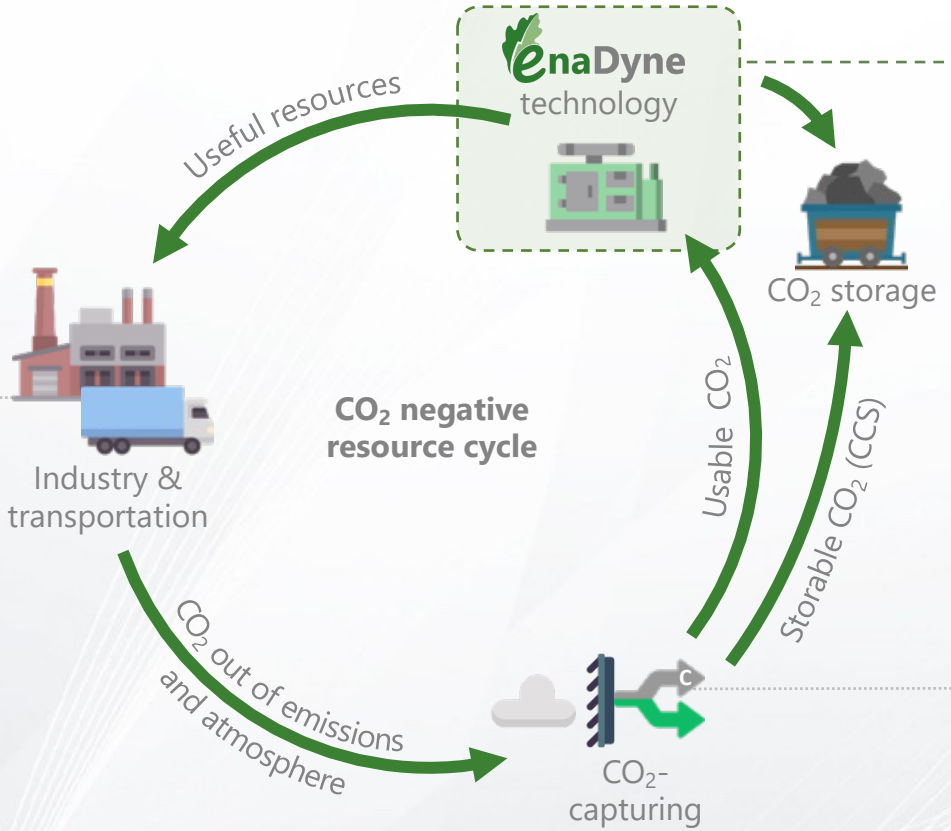
The solid carbon allows permanent carbon sequestration.

Secondary products

Beyond this, several other use cases like the production of ammonia from nitrogen and H_2 are possible.

ENADYNE TECHNOLOGY ESTABLISHES A CARBON NEGATIVE RESOURCE CYCLE

Added value in the context of the energy transition



A large part of the global CO_2 load comes from processes in industry and transport and energy generation.

The CO_2 produced in this way is essentially still emitted as waste gas.

enaDyne's technology allows the direct conversion of CO_2 into chemicals that can be returned to the system. Thus, for the first time, a closed CO_2 cycle can be established.

Fed by renewable green energy or if the products are used in activities with high storage potential like plastics production, the cycle can even be made CO_2 negative.

Several technologies already deal with the capture of CO_2 from exhaust gases and the atmosphere.

In principle, these technologies help to reduce CO_2 emissions. However, the question of what happens to the CO_2 after being captured remains unanswered.

ENADYNE IS THE ONLY TECHNOLOGY THAT COMBINES FOUR VITAL TECHNOLOGY ADVANTAGES

Technology advantages

More efficient

Plasma catalysis technology works just above room temperature and around ambient pressure. This allows the selective conversion of CO_2 to green resources in a single process step with an energy efficiency far above that of common technologies.

More flexible

The technology can selectively and flexibly produce diverse chemical feedstocks and e-fuels. It is also independent of green hydrogen as it can also use biomethane as a hydrogen source. Moreover, its ramp-up time is only a few minutes.

More scalable

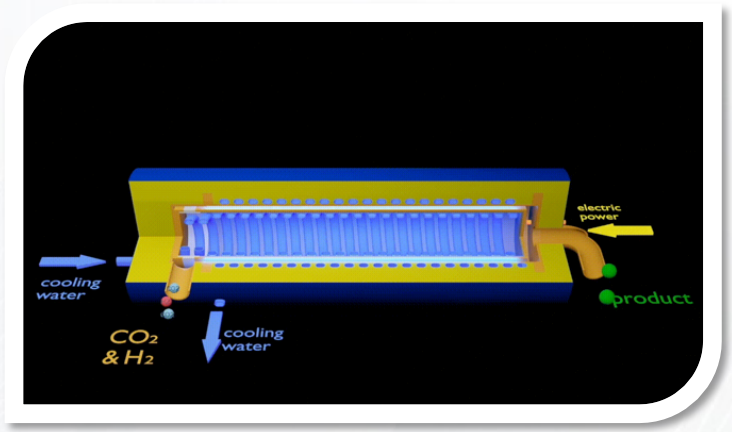
enaDyne pursues a modular approach in which cost-effective reactors are connected in parallel. This enables efficient series production and qualifies the technology for both scaled industrial as well as decentralized applications.

More sustainable

The enaDyne technology can be operated CO_2 neutrally with as little as 80% RE share, since small portions of processed carbon are captured in solid form. Furthermore, no rare earths are required for production and operation of the reactors.

THE TECHNOLOGY IS DEVELOPED AS A MODULARLY SCALABLE CONTAINER SOLUTION

Modular scaling approach



enaDyne reactor design

- The enaDyne reactor is based on our functionalized ceramics material that is **patented several times**.
- The plasma-active properties of the material allow us to build up a **highly selective nonthermal plasma** only slightly above room temperature.
- Depending on how the material is adjusted, the process can be used to yield a **variety of different products**.

enaDyne reactor – modular scaling approach

- Instead of further scaling the reactor, we pursue a **modular approach** in which we cluster up to 250 reactors.
- The chosen approach allows a centralized and **more scalable production** and more flexibility for our customers.
- Most of the peripheral technology[1)] is standard technology that is **enabled by our core material**. This way significant parts of the production can be performed by external partners.

1) For example, gas separation, gas management and power supply.

ENADYNE TECHNOLOGY DIFFERENTIATES ITSELF THROUGH SCALABILITY AT HIGH EFFICIENCY

Competitive Landscape

	enaDyne Plasma catalysis	e.g. KIT Electro catalysis	e.g. sunfire CO-electrolysis	e.g. LanzaTech Microorganisms	e.g. Linde Dry Reforming
Energy efficiency	++	++	-	+	-
Flexibility	+	-	-	-	-
Scalability	++	-	+	-	+
Space requirement	+	+	+	-	-
Product diversity	+	+	-	-	-
Process complexity	+	+	-	-	-
Technology readiness	-	-	+	+	+
	2nd Generation		1st Generation		

- Second-generation power-to-X technologies use advanced catalysis approaches to reduce process complexity and enable higher efficiency in converting CO_2 into green chemical feedstock.
- Compared to the competing electrocatalysis, plasma catalysis ensures a significantly increased scalability.

OUR TARGET CUSTOMERS ARE OWNERS OF CO_2 EMITTING PROCESSES

Customers

Biogas plants

- enaDyne processes raw biogas
- Output is upgraded
- Plant becomes CO_2 negative

Heavy emitters

- Cement
- Steel
- Gas-fired power plants

Energy sector

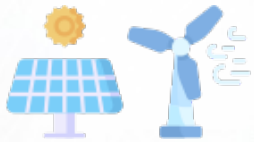
- Energy transport/storage
- Grid stability solutions
- Alternative to feeding into grid

IN OUR BIOGAS USECASE, ENADYNE TURNS BIOGAS PLANTS INTO ACTIVE CO_2-SINKS

Example usecase – Biomethane & CO_2 to usable resources

Higher RE-Share increases carbon negativity.

No separate H_2 source required in Biogas usecase!



RE-Energy

CO_2 reduction

CO_2 reduction

As biogas is already carbon neutral, the combination of enaDyne and biogas acts as an active CO_2 sink!

With CH_4 and CO_2, the unseparated biogas provides all required resources

Biogas Plant

Biogas (CO_2 & CH_4)

enaDyne

Plasma catalysis

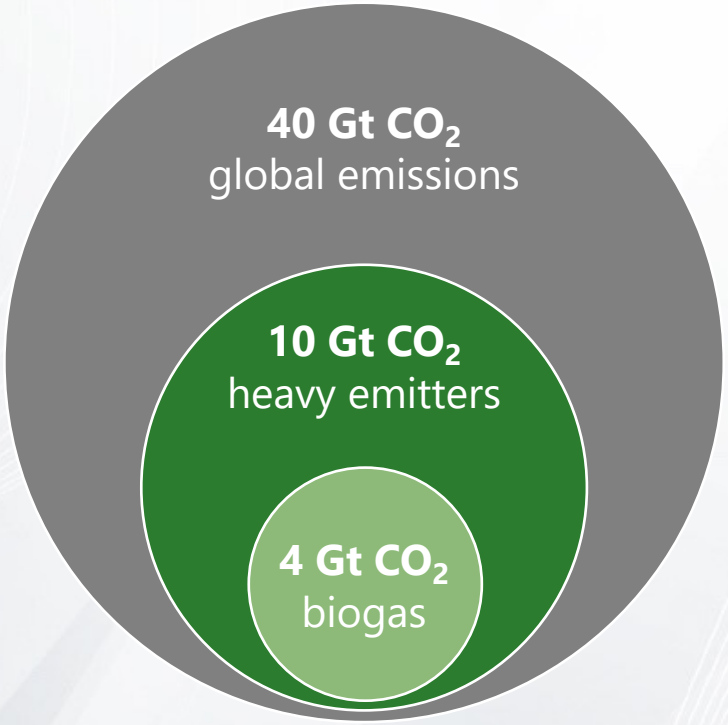
Products

Green hydrocarbons or e-fuels.

Ethylene, methanol and other hydrocarbons could be produced in a mostly identical setup.

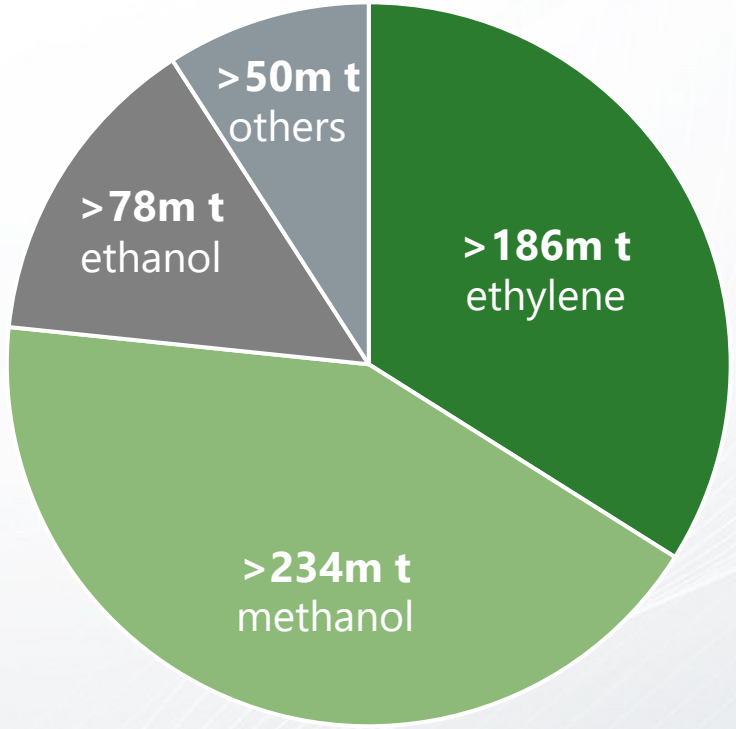
OUR MARKET IS A COMBINATION OF ADRESSABLE CO_2 AND DEMAND FOR GREEN CARBON-BASED CHEMICALS

Market potential



>14 Gt addressable CO_2 supply p.a.

The enaDyne technology is the only one that can use CO_2 to address demands for multiple chemical products at scale.



>548m tons demand for green chemicals p.a.[1)]

1) Estimate 2021 – Expected to massively increase over time.

THE TECHNOLOGY IS PROVEN, PATENTED AND WILL BE MARKET READY IN A MAXIMUM OF 4 YEARS

Status quo

2

working prototypes.

First **demonstrator** projects in planning phase.

2

registered patents.

6 additional patents in pipeline!

12

renowned R&D and industrial partners.

To support **development** and production **scaling**.

4

years time-to-market.

Earlier revenues possible with other applications.

THE TECHNOLOGY'S HIGH PROFITABILITY ALLOWS BOTH A SALES APPROACH AND A TAAS MODEL

Business model

>30-50%

profit margin

We currently estimate a sales price for the container version of around € 1.3m at a production cost of € 0.8-1m.

4-5

years to positive ROI

The investment in an enaDyne container solution will pay off after 4-5 years. Therefore, also technology-as-a-service approaches are feasible.

90%

commodity technology

As most of the container solution's periphery are standard components, we will focus on our core material and final assembly.

In a first step, we will produce and sell our reactor solution and work with partners to scale production and maintenance. Later, licensing or technology-as-a-service models are also viable.

WE HAVE BUIT A STRONG NETWORK OF INDUSTRIAL AND ACADEMIC PARTNERS

Partner Network

Industry

MCR ENGINEERING LAUSITZ / LEAG
Electrical engineering & specialized containers

EDL PÖRNER GRUPPE
Gas handling, separation & engineering

ARCANUM ENERGY
Value chain development & biogas

BALANCE Ein VNG Unternehmen
Biogas & value chain

enaDyne
Core technology & electrode material

Academia

TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG
Enamel & Machinelearning

UNIVERSITÄT LEIPZIG
Catalysis

Fraunhofer IMWS
Measurement technology

HTWK Hochschule für Technik, Wirtschaft und Kultur Leipzig
Measurement technology

RUB
Plasma science

Our partners increase our pace by giving us access to resources, know-how, industrial testing possibilities and production scaling.

ENADYNE WAS FOUNDED BY AN INTERDISCIPLINARY TEAM AND IS SUPPORTED BY STRONG ADVISORS

Team

Torsten Lorenz
Material Science

Christian Koch
Co-Founder Science

Martin Drössiger
Electrical Engineering

Dr. Dave Arens
IT / Machine Learning

Philipp Hahn
Co-Founder Business

Dr. Juliane Titus
Advisor Catalysis

Dr. Martin Kilo
Advisor Material Science

Teambackground:

IN OUR NEXT TWO FINANCING ROUNDS, WE LOOK FOR FUNDS TO BUILD PROTOTYPES AND DEMONSTRATORS

Financing rounds

€ 1.5m

Seed round
Late 2022 (closing soon)

Team setup, infrastructure, materials development, prototype development,

€ 4-8m*

(Pre-)Series A round
Mid/Late 2023

Team extension, infrastructure, industry demonstrator,

Beta-Prototype Design Biogas → Methanol	**Goals**	Industry demonstrator Modular Scalability

* Depends on availability of public funding

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enaDyne

We are ready to change the world!
If you are, join us!

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