DOPS

RECYCLING TECHNOLOGIES

a CO_2 negative technology

DCI™ (Direct Carbon Immobilization)

Technology view

26-3-2025

DCI™, Three-fold great impact 1:

Energy transition, reducing climate change

- Avoiding CO_2 and methane emissions from waste and biomass combustion, composting or landfilling
- Converting up to 90% of carbon from biomass into either solid carbon or methanol

DCI™, Three-fold great impact 2:

(hydro-)Carbon transition, providing alternative for fossil carbon sources

- Producing the syngas from biomass and waste otherwise combusted, composted or land filled
- By producing methanol from this syngas as pre-cursor for plastics and other polymers
- By producing char, active carbon, carbon black and/or graphitic carbon from biomass to replace fossil carbon sources

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Problem

Technology

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DCI™, Three-fold great impact 3:

Metals and minerals raw materials transition

- By freeing metals in E-waste, cables and PCB's from all plastics
- By converting polyesters and epoxies to syngas, keeping glass and carbon fibers as new raw materials
- Separating Ca, P and other minerals in a loose, carbon rich and hydrocarbon-free solid residue

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Climate change, problem scope

Worldwide

> 50 billion ton of CO_2 emissions per year

Netherlands

> 200 million ton of CO_2 emissions per year

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Climate change, problem scope

Worldwide

2.5 billion ton per year of solid waste incinerated, landfilled or dumped

6 billion ton of agricultural biomass per year incinerated, uncontrolled burned or composted

Leading to **> 10 billion ton or 20% of avoidable CO_2** emissions worldwide

Netherlands

10 million ton per year of solid waste incinerated or landfilled

> 20 million ton of agricultural biomass per year incinerated or composted

Leading to **> 30 million ton or 15% of avoidable CO_2** emissions in the Netherlands

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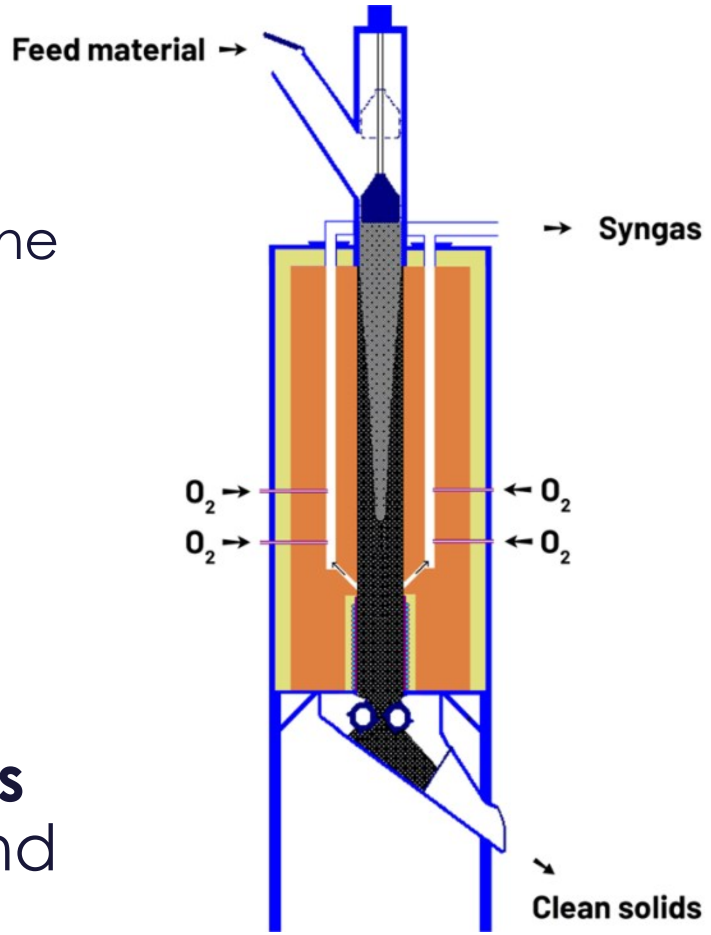
The Solution

DOPS Recycling Technologies developed the

DCI™ Technology

Direct Carbon Immobilization

This is a **high temperature thermolysis** reactor to convert residual waste and biomass into valuable syngas and a solid residue



DCI™, the reactor

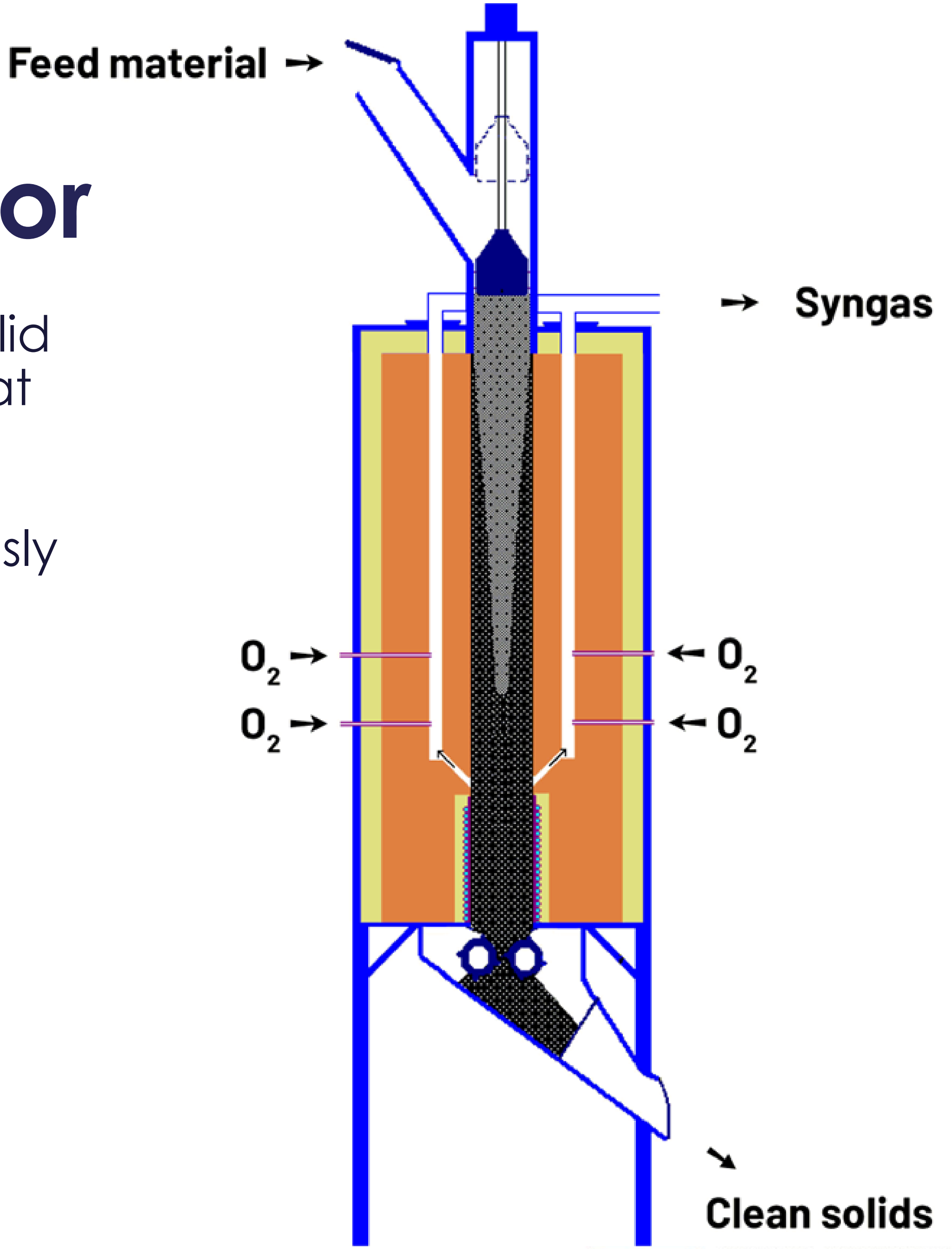
Basis is a shaft reactor where solid materials are continuously fed at the top.

And a solid residue is continuously unloaded at the bottom.

The reactor works at 1000 °C for the solids

at atmospheric pressure

Residence time solids: 2 to 6 hours



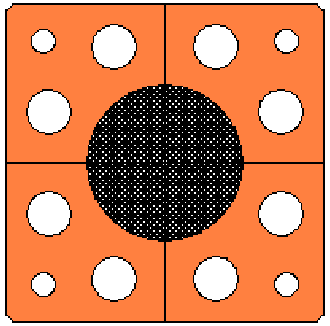
DCI™ How it works

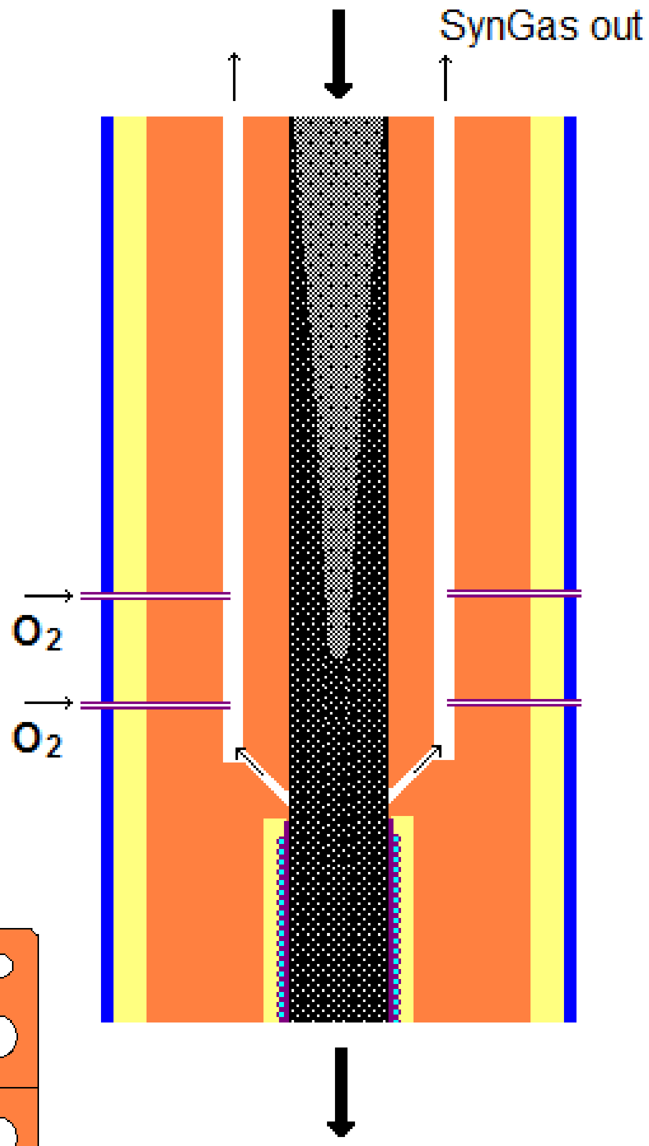
The refractory (fire bricks) that forms the shaft heats the solid feed inside.

The resulting syngas can only escape from the shaft by channels around the main shaft.

Within those channels, a small amount of the syngas is combusted to keep the refractory structure at its high temperature.

Within the bottom section of the shaft, the solid material cools down again.





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DCI™, multiple processes in one

In the solids shaft:

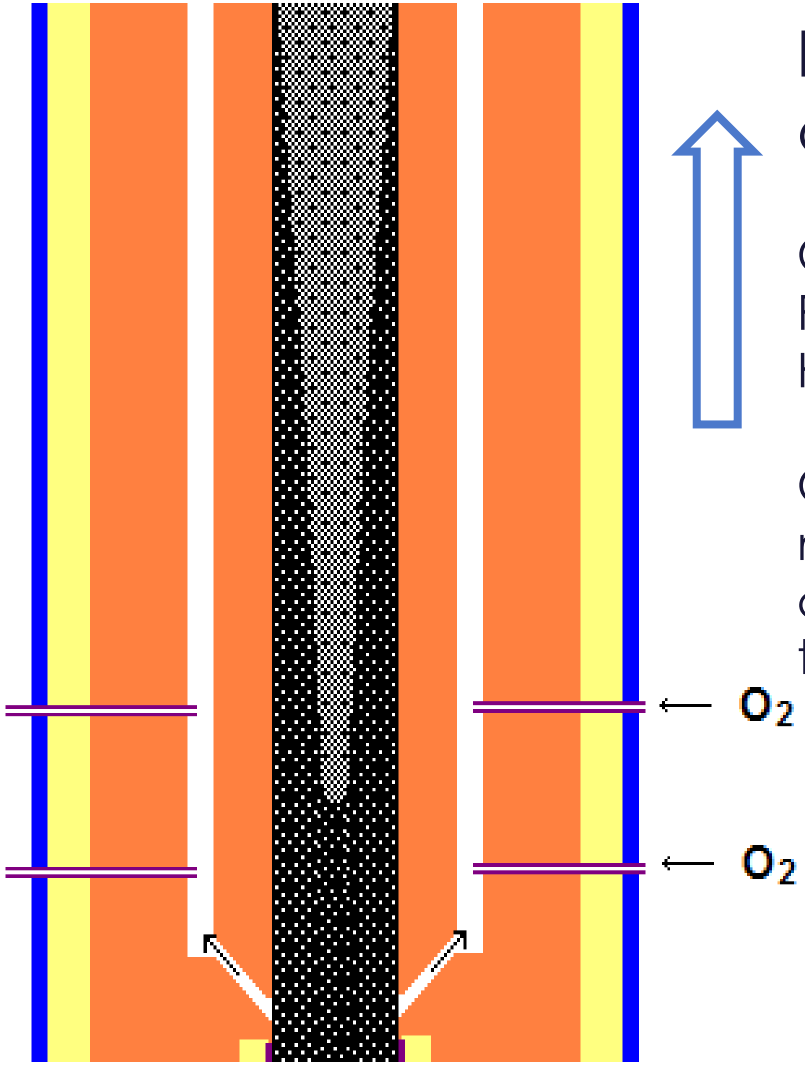
Torrefaction/ volatilisation

Depolymerization/ Pyrolization

HT Thermolysis of small molecules

Boudouard equilibrium:
$CO_2 + C \Rightarrow 2CO$
at **1000 °C**

Gas filtration in moving carbon bed (soot captured!!)



In combustion channels:

Chemical equilibrium
Reverse watergas shift:
$H_2 + CO_2 \Rightarrow H_2O + CO$

Cracking of persistent molecules: (fluor-carbons, dioxins) at up to **1500 °C**

Partial combustion by O_2 injection

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Waste processing hierarchy:

• Mechanical recycling	
• Pyrolysis	Partial cracking of hydrocarbons
• **HT Thermolysis**	**Full cracking of hydrocarbons into H_2, CO and solid C**
• Gasification	Thermolysis plus partial oxidation of hydrocarbons
• Combustion/ Incineration	Thermolysis plus full oxidation of hydrocarbons

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DCI™, differs from standard gasification technology

- No air or (external) oxygen is admitted to the solid phase within the reactor shaft
(therefore, more carbon is retained within the solids)
- Heat is added to the material by radiation from the refractory shaft wall, the high temperature of refractory wall prevents fouling by tars etc.
- The gas phase is internally filtrated by produced char
- Carbon rich solid residue is without slagging

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DCI™, plus of high temperatures

- The high temperatures prevent any tars to remain in the char, resulting in clean, loose solid residues;
- They activate the carbon (in combination with some steam from humidity of feedstock);
- They break down also very persistent hydrocarbons;
- Less CO_2 in syngas (< 4%) (First Boudouard reaction, subsequently reverse Water-gas-shift)
- Faster heat transfer by radiation (4^{th} power of temperature);

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DCI™ Target materials

All residual materials containing hydrocarbons:

- Mixed Municipal Waste;
- Low value biomass;
- Paper waste (recycling residues);
- Dried sewage sludge;
- Residues from mechanical recycling, pyrolysis heavy tars;
- (crude) Oil and tank residues, asphalt, roof coverings;
- E-Waste, Printed Circuit Boards, cables, solar panels, PVC;
- Car deconstruction residues, used car tires;
- Fiber reinforced plastics (windmill blades, aircraft components).

Everything currently incinerated, land filled or composted.

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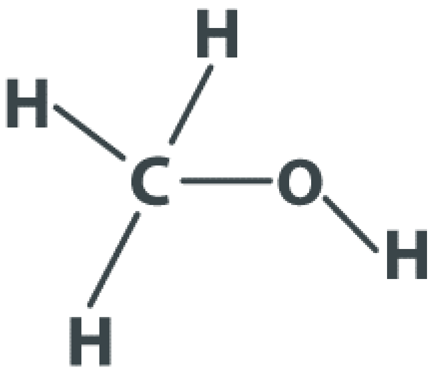
Products DCI™ produces:

Gas phase:

- Syngas (**H_2** and **CO** in tuneable ratio's) to produce:
  - Methanol
  - Olefines (gasoline, SAF, diesel, waxes)



Solid phase:

- Carbon:
  - Char, activated carbon as absorbent or as growth substrate;
  - Amorphous, Carbon Black (clean soot);
  - Graphitic carbon;
- Minerals:
  - CaO (e.g. from paper);
  - Particulates (glass, stone, pottery remains, etc);
  - P and S – minerals, salts, sand;
- Metals:
  - Particulate (nuts & bolts, connectors, wires, foils);
  - Molecular bound to carbon.

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DCI™ Use Case 1

Syngas ($CO + H_2$) from DCI™ reactor to **replace** natural gas in high temperature furnaces and kilns (brick industry, tiles, ceramics, glass industry)

Opportunities:

- Furnaces remain unaltered
- Limited foot-print (m^2) for installations
- DCI™ process is not critical for feedstock
- **Independency of fossil gas price**

DCI™ Use Case 2

Syngas ($CO + H_2$) from DCI™ reactor to produce **methanol** as feedstock chemical industry

Opportunities:

- Tuneable relation between H_2 and CO
- Requires far less energy compared to reaction $H_2 + CO_2$
- **Green Methanol to Green Olefines**

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DCI™ Use Case 3

Producing **active carbon** from woody biomass

Opportunities:

- Char production and activation **in one step**
- Replaces fossil carbon made from coal
- Saves 50% energy

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DCI™ Example wood pellets

Wood pellets and active char pellets

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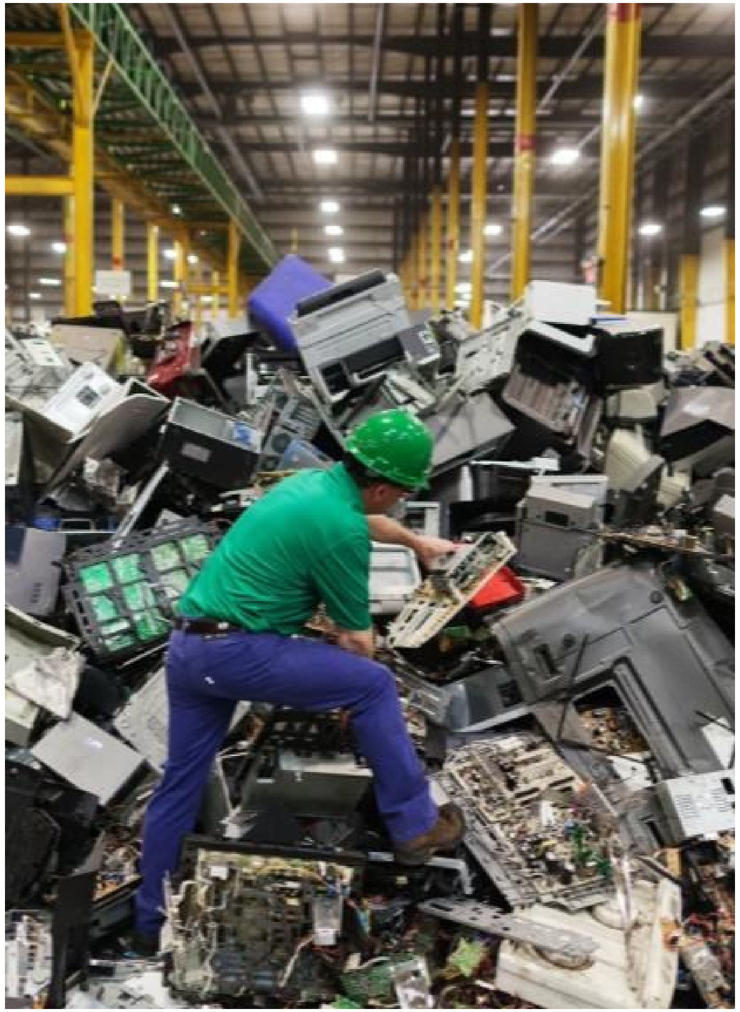
DCI^{TM} Use Case 4

Recycling E-waste and PCB's to regain **precious metals**



Opportunities:

- Little pre-processing
- All plastics converted to syngas
- Separation of fibre glass, ceramics and metals
- **No melting**, metals don't mix

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DCI™ Example residue from PCB's

Printed Circuit Boards

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DCI™ Other examples, paper

High quality paper produces quicklime

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DCI™ Example, mixed plastic

Mixed plastic waste

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DCI™ Example residues, glass fibre reinforced epoxy

Glass reinforced epoxy

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DCI™ Example, copper wire

Copper wire

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DCI™ Example, sewage sludge

Dried sewage sludge

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DCI™ how we test now:

Our laboratory reactor

Separate solids and gas shaft

Electrical heated (2x three zones)

2 – 6 kg/hr

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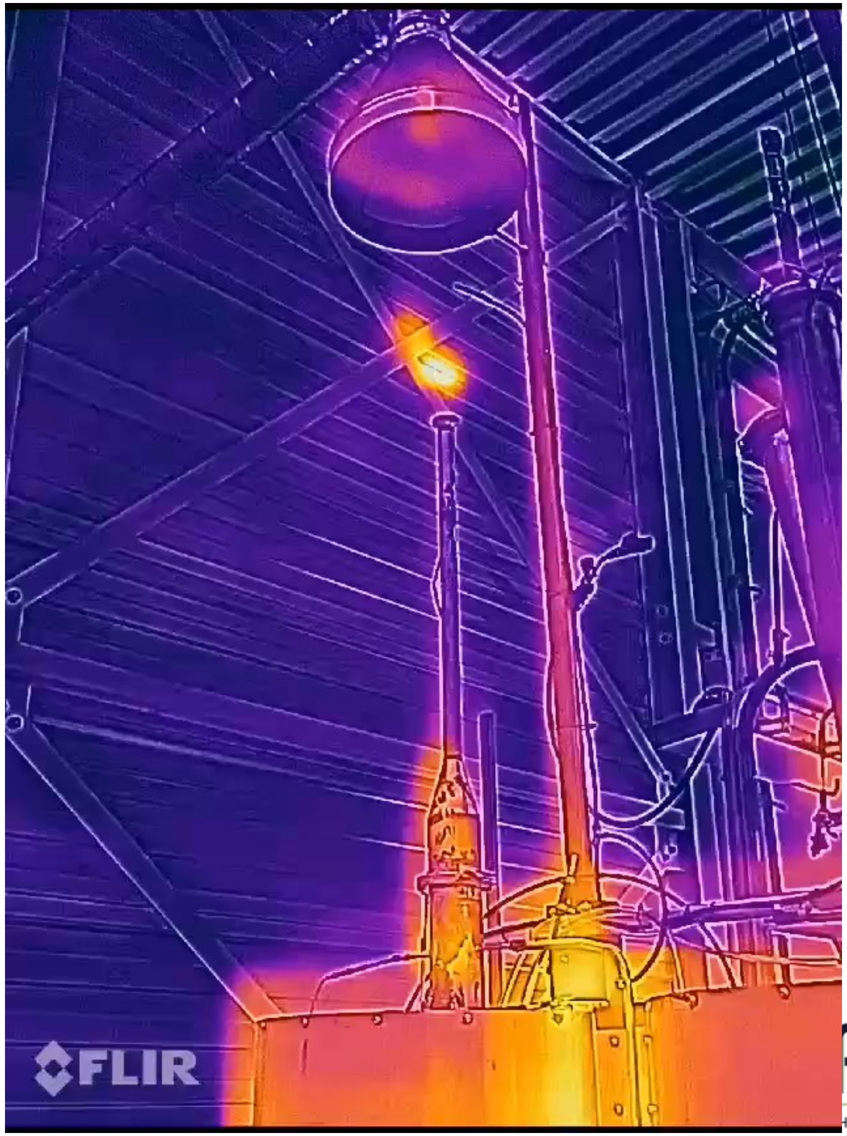
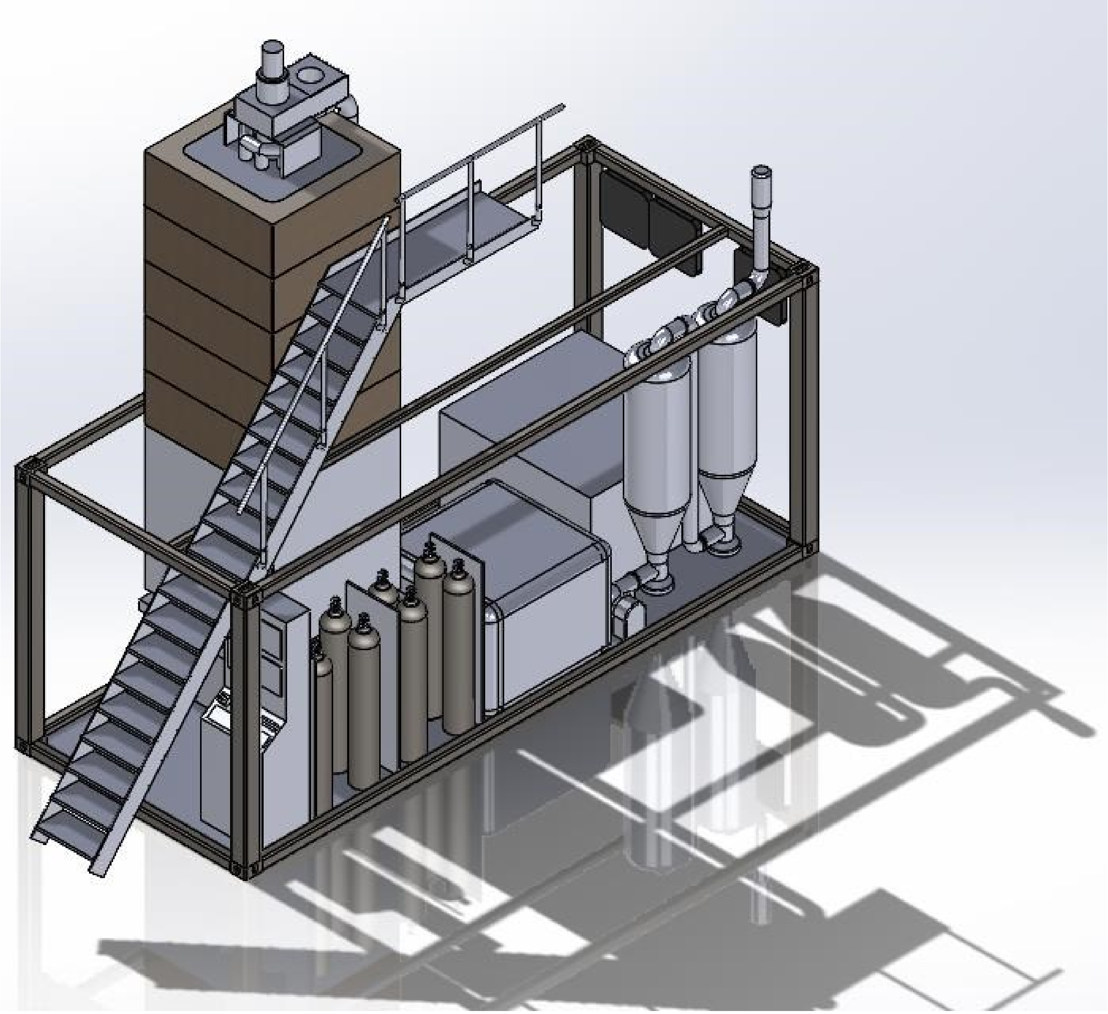
DCI™ Gas produced:



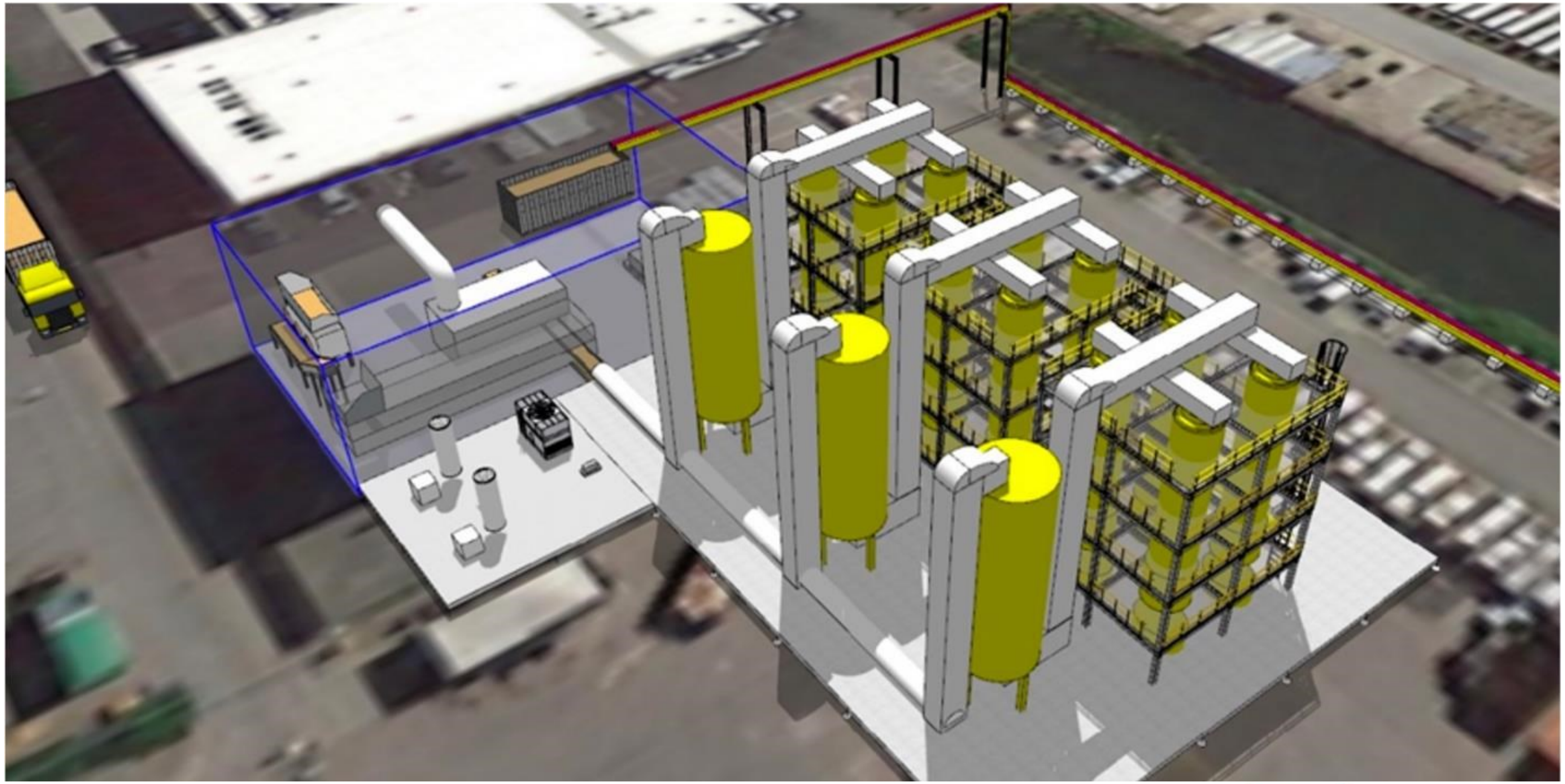
DCI™ 50% scale single shaft



Currently in development:

- 50+ kg/h
- Fully automated
- Operational 2025

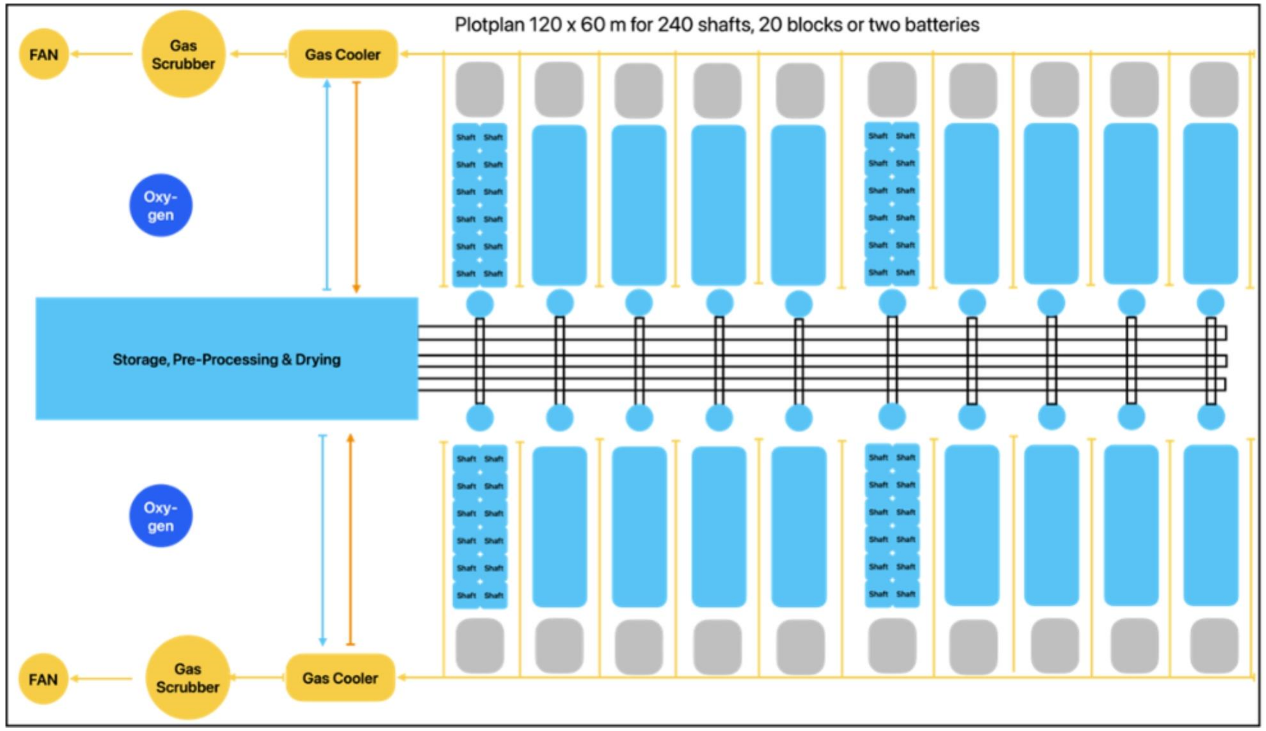
DCI™ Demo plant 2027-28

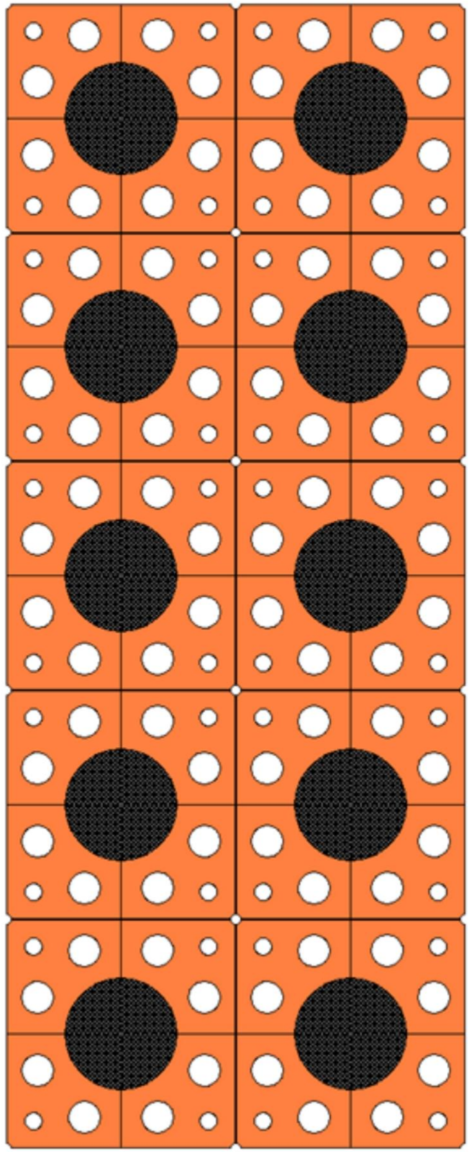


FEL2 started

DCI™ Scaling up

350,000 ton/year per soccer field





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DCI™ Comparison

	DOPS DCI™ thermolysis	Pyrolysis	Traditional gasification	Plasma thermolysis
Tolerance for feedstock	√	X	√	√
No pre-processing for feedstock	√	X	√	√
Energy efficiency	√	√	√	X
CO_2 emissions	√	√	X	X
Value of oil / syngas	√	√	X	√
Value in solid residues	√	X	X	X
Breaks down persistent chemicals	√	X	X	√
Low CAPEX intensity	√	X	√	X
Mature technology available	X	√	√	√

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DCI™ Summary

DCI™ is one of many recycling / gasification / thermolysis technologies in development.

Highlights of DCI™ technology are:

- Simplicity of the reactor, very scalable;
- Ease of control of the process;
- Most flexible and forgiving for input materials;
- Produces clean, high value syngas;
- Produces high value solid residues;
- DCI™ is the most carbon – negative conversion technology available with a conversion > 90%

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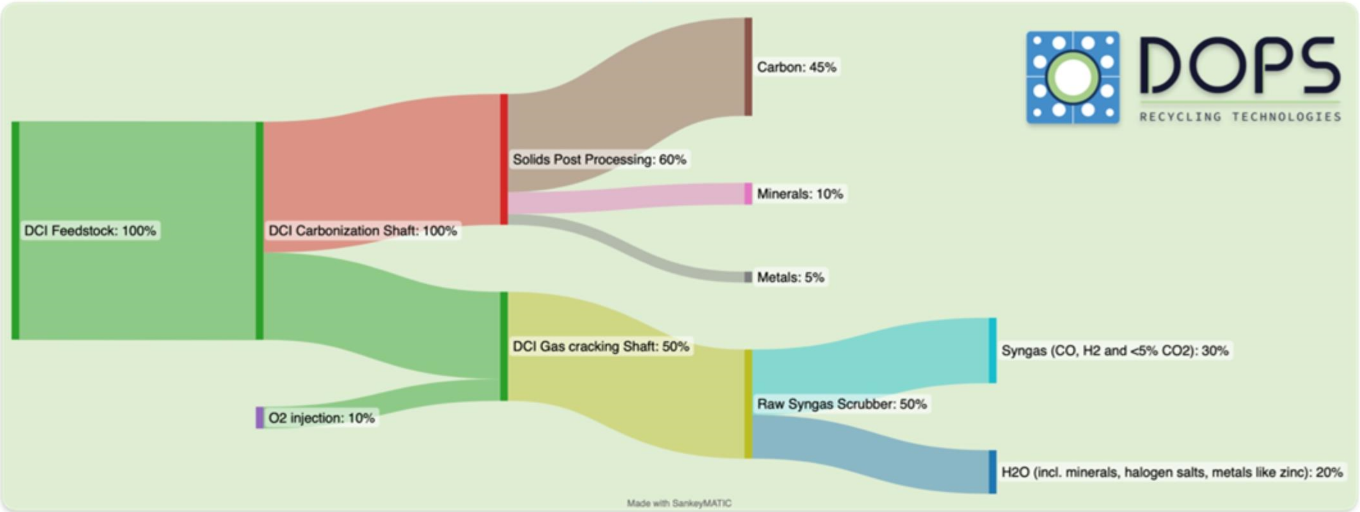
a CO_2 negative technology

Turn Waste into Wealth

www.dops-rt.com

DCI™ Output flexibility

Typical DCI™ Process
Focus on Solid optimized output



Typical DCI™ Process
Focus on Gas optimized output