Feasibility Study Iron Powder for Energy Cooperatives

Final report

13 March 2024

Agenda

1. Introduction

Introduction

The Deloitte Impact Foundation has assisted Metalot in developing a roll out strategy for iron powder with local energy cooperatives

- **Metalot is** a network organization that focuses on accelerating sustainable, circular developments in the field of metals and renewable energy by combining the knowledge and experience of scientists, government agencies, students, and entrepreneurs

- **A key initiative** is the development of iron powder as a safe carrier of green hydrogen

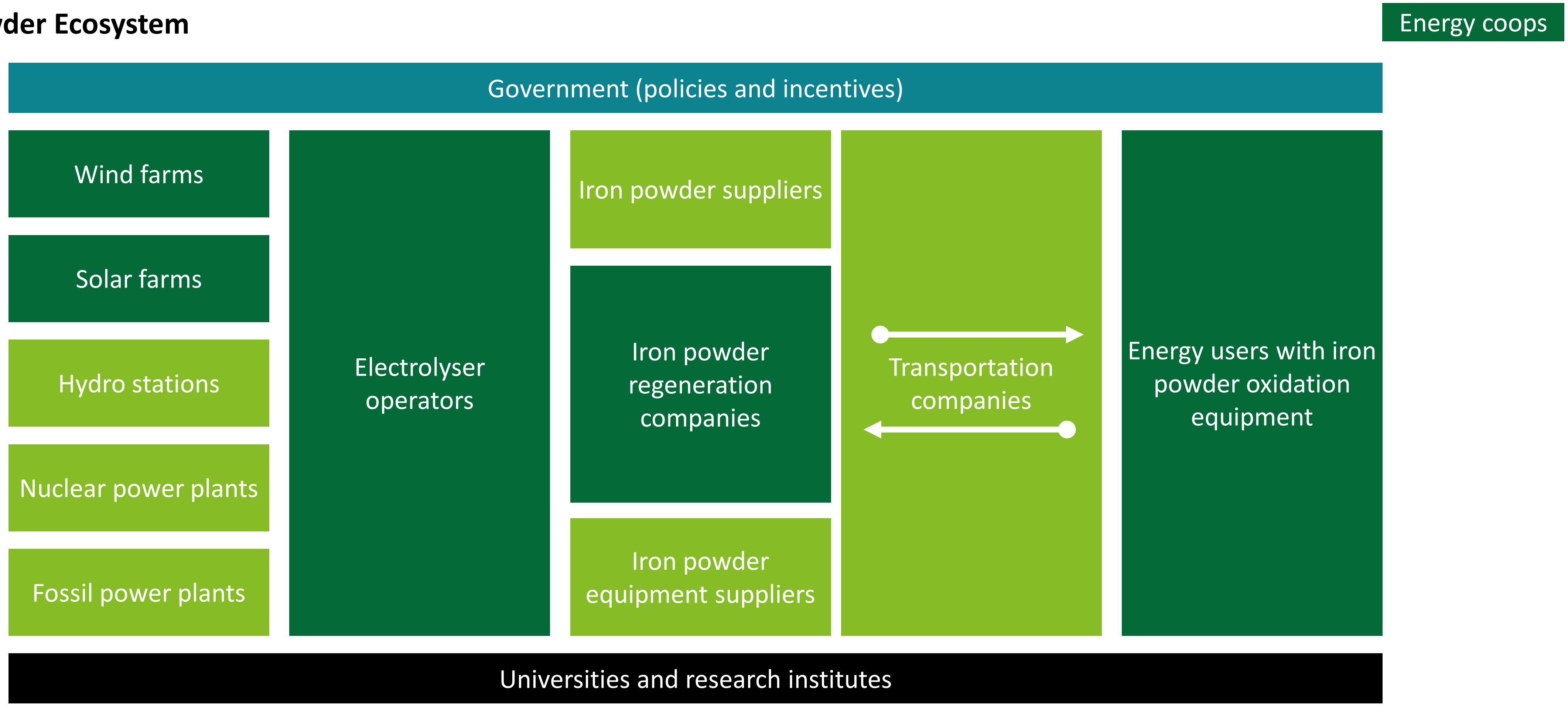
- **Metalot wants** to kick-start the adoption of this technology through pilot projects with local energy cooperatives in the Netherlands

- **The Deloitte Impact Foundation has offered to help Metalot in:**
  - Identifying pilot projects for the energy cooperatives
  - Assessing the relative costs across the entire value chain
  - Suggesting next steps

Introduction

Metalot primarily is as facilitator of the emerging iron powder ecosystem in which the energy cooperatives can take roles as both energy generators and consumers

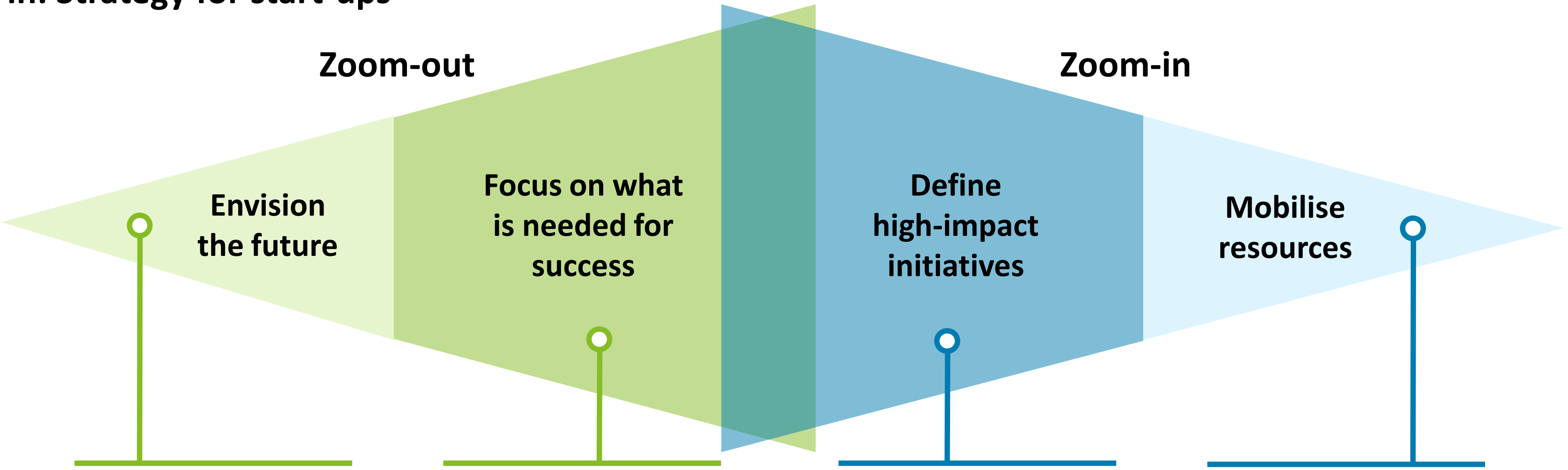
The Iron Powder Ecosystem



Introduction

A local energy cooperative functions as a pilot that allows Metalot to kick-start the ecosystem

Zoom-out/Zoom-in: Strategy for start-ups



Envision
Synthesise a **shared view** of the long-term (**10-20 years**) role of iron powder in the energy system

Focus
Determine **what Metalot will look like**, in terms of its aspirations, where it will play and how it to win and what capabilities it needs

Define
Identify a few **initiatives** for the next **six to 12 months** that accelerate the path toward the long-term destination

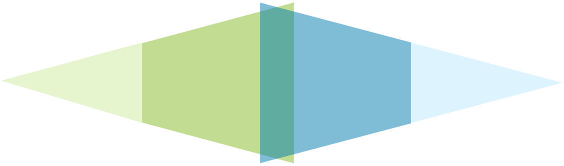
Mobilise
Perform **tests**, measure, **learn**, **reassess** the vision and **redefine** the initiatives

Introduction

In doing so, Metalot can advance the iron powder technology, whilst limiting risk

Stages of a start-up

Problem Solution Fit



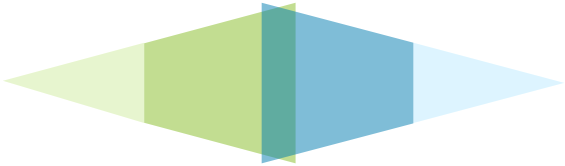
- Create a vision for the future (‘Zoom Out’)
- Raise seed funding and test if the technology solves the problem (‘Zoom In’)
- If yes, attract more capital

Product Market Fit

- Prove that there is a market that wants to pay for the product (‘Zoom In’)
- Check if the vision still holds (‘Zoom Out’)
- If yes, attract more capital

Current stage

Scale-up



- Test if the product works for additional customers (‘Zoom In’)
- Check if the visions still holds (‘Zoom Out’)
- If yes, attract more capital and continue to scale and learn (‘Growth Hacking’)

Introduction

We think iron powder can be a competitive heat source for smaller off-grid users especially with support from subsidies and should be piloted with grass drying

Main conclusions

1. Iron Powder technology offers a **sustainable**, **autonomous**, and **safe** source of dense heat energy, meeting the needs of various industries, including district heating, food processing, and construction
2. Compared to its closest alternative, piped green hydrogen, Iron Powder is **competitive** for **smaller consumers** located **further** from a hydrogen **grid**
3. An optimal operational **threshold** for Iron Powder production equipment is **4,000 FLH**, which can be attained through a combination of multiple energy sources and batteries
4. **Subsidies** can play a crucial role as the **environmental impact** of adopting Iron Powder is **significant**: using 1 ton of Iron Powder can prevent 11 tons of CO_2 emissions when replacing natural gas, and 19 ton when substituting coal
5. **Grass drying in Zeeland** is a cost-effective **pilot** as it needs substantial continuous heat in an off-grid location, with green power supplied by a local energy cooperative
6. Metalot should **engage** with parties in **Zeeland** as well as **grant** and **capital providers** to set up the pilot
7. In our cost analysis, we focused on comparing iron powder to piped hydrogen, given iron powder's distinctive attributes. It's important to note, though, that there are other green energy alternatives that might offer greater financial advantages

2. Long-term vision

Long-term vision

Driven by regulation, customer pressure and internal CSR policies, more and more companies are looking to switch to sustainable energy, including green hydrogen

Drivers for a green energy premium

Regulation	Consumer preference	Investor pressure
First movers: EU, UK, US, CA	First movers: Energy extensive	First movers: Multinationals
Followers: AU, JP, KR, CN	Followers: Energy-intensive	Followers: All others

Long-term vision

Iron Powder is a hydrogen carrier with eight unique characteristics

Iron Powder benefits

Sustainable
Zero SO_x and CO_2 emissions, low NO_x and particular matter emissions

Safe
Zero environmental hazards and toxicity traits
No gaseous or explosive dangers

Autonomous
Suitable for industries that do not have a direct link with grids

Easily transportable
Transport by truck, train, or ship. Minimal loss of energy during transportation

Dense energy storage
Efficient energy storage with high density that could be stored a few months without loses

Flexible
Efficient and fast changing of power received during combustion process

Multiply resources usage cycles
Optimizing resource usage across multiple cycles to enhance sustainability for fuel and water mgt

Can generate high temperatures
Suitable for industries that rely on high-heat production processes

Long-term vision

Based on Iron powder’s unique characteristics, it primarily will have to compete with piped green hydrogen

Iron Powder benefits vs alternatives

	Green hydrogen fuels				Traditional fuels		Power	
	Trucked iron powder	Piped gas	Trucked gas	Trucked ammonia	Biomass	Piped natural gas	Fossil electricity	Green electricity
Sustainable	2	2	2	2	1	0	0	2
Safe	2	1	2	0	2	2	2	2
Autonomous	2	2	2	2	1	0	0	0
Easily transportable	2	1	0	1	2	1	2	1
Dense energy storage	2	2	1	1	1	2	0	0
Flexible	2	2	2	2	2	2	2	0
High Temperatures	2	2	2	2	2	2	0	0
∑	14	12	11	10	11	9	6	5

Next best alternative

Note: Trucked includes transport by rail or ship

Long-term vision

Iron Powder can be cheaper for smaller consumers located further from hydrogen pipelines, as grid expansion becomes increasingly expensive for them

Levelized Cost Of Energy of iron powder -/- piped hydrogen (€/MWh)

Distance from grid (km)	Annual energy consumption (MWh)					
	1000	**2000**	**3000**	**4000**	**5000**	**6000**
1	132	139	142	143	144	145
5	-72	37	74	92	103	110
10	-327	-89,7	-10	28	52	68
15	-583	-217	-95	-35	1	25
20	-838	-344	-180	-99	-49	-16

Key assumptions

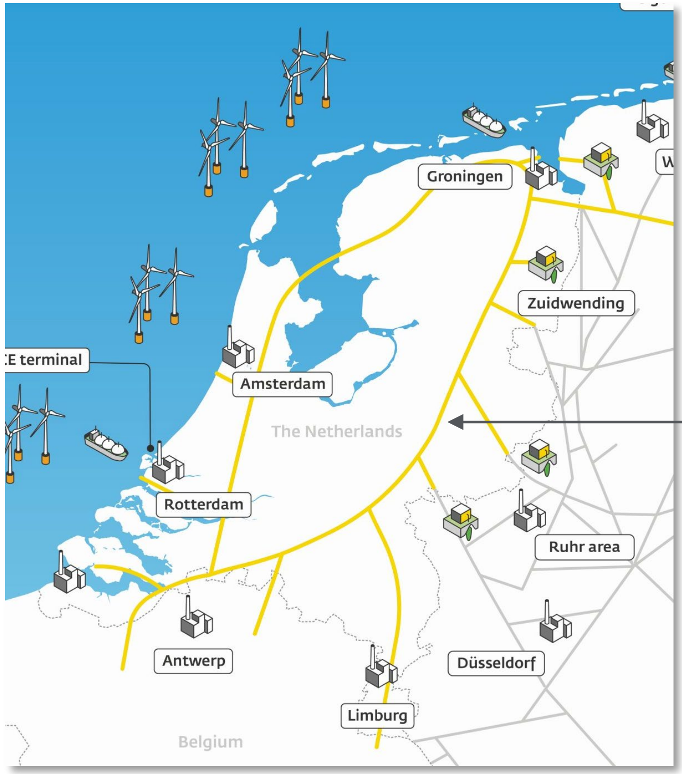
Cost driver	Assumption
Iron burner power	1,00 MW
Electrolyser & Regenerator working hours	4.744 FLH
Distance between IP Regenerator to the Client	57 km
Required return to capital	8,70%
Electrolyser efficiency	70%
Renting of the production building	No

Note: Assumes same cost of hydrogen, differences follow from iron powder oxidation, regeneration and transportation costs versus pipeline costs
Source: Deloitte Iron Powder model

Long-term vision

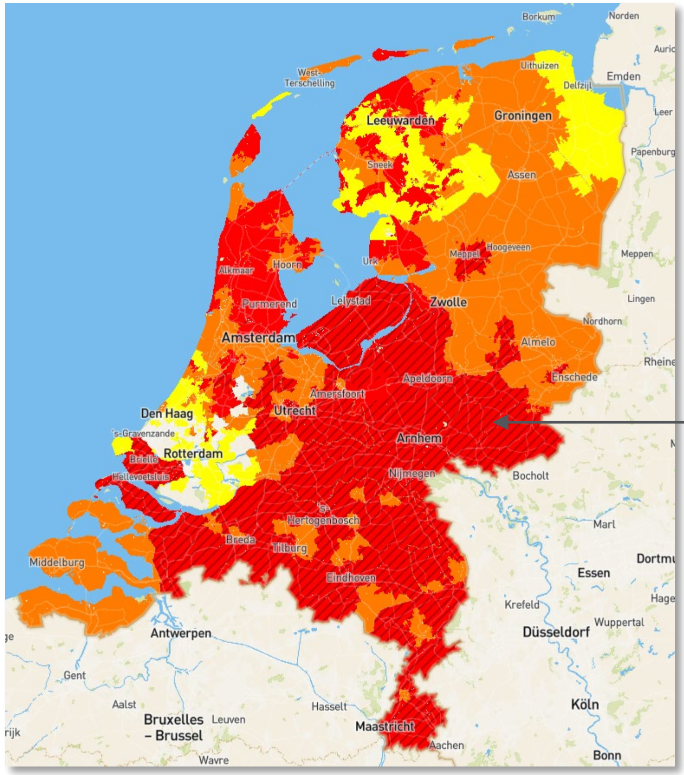
Moreover, competition from the grid will be limited in the mid-term, even in densely populated countries, and everywhere else on the long run

Planned Dutch hydrogen grid



Backbone plus ribs to major demand centres only

Current Dutch electricity grid



Most congested

Source: Gasunie; Technologyreview.com

Long-term vision

Most attractive industries are district heating, food and construction

Iron powder application assessment

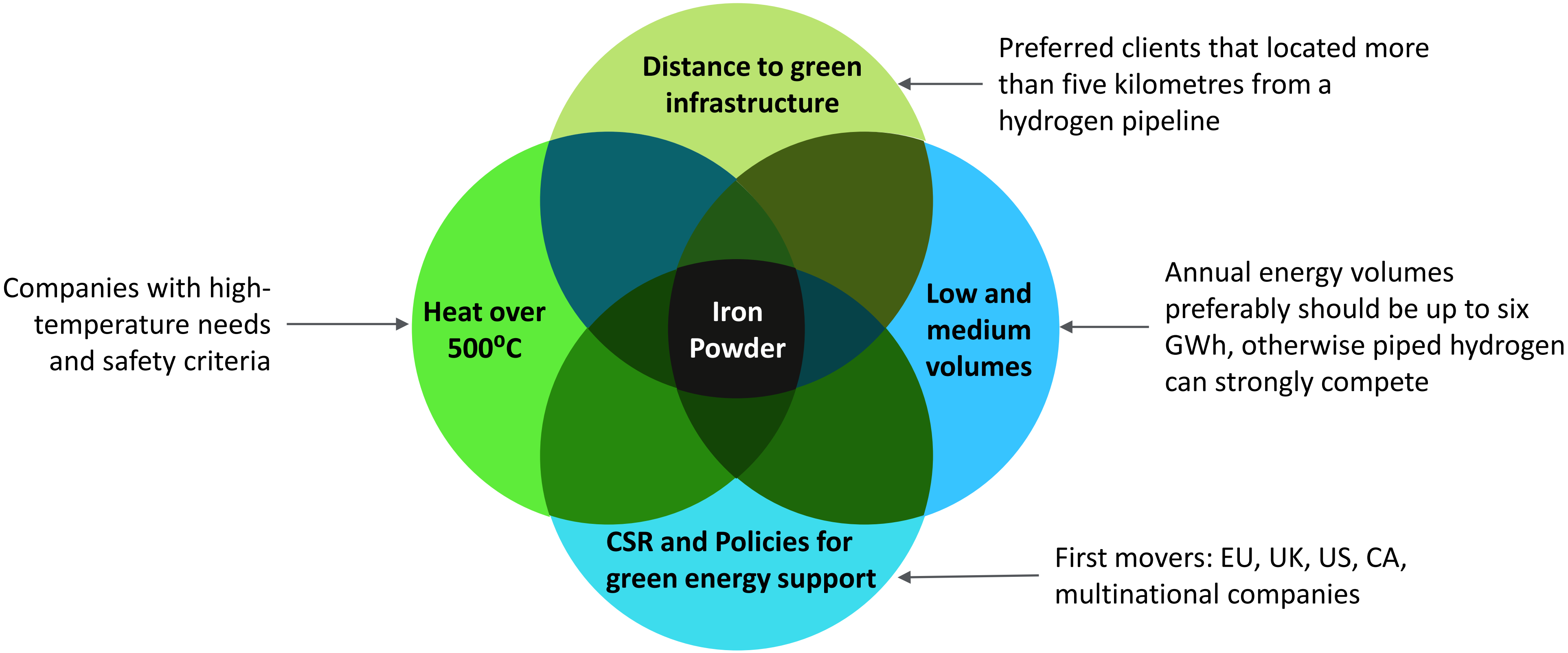
Industry	Autonomous	Easily transportable	Dense energy storage	Multiply resources usage cycles	Safe	Sustainable	Flexible	High temperatures	Current solution	Attractiveness
Ceramics	Industry agnostic					Low	Medium	High	Natural gas Coal	Medium (6)
District Heating					Medium	Low	Medium	Medium	Natural gas Coal	High (7)
Food					Medium	Medium	Medium	Medium	Natural gas Electricity	High (8)
Pulp & Paper						Low		Medium	Natural gas Electricity	Low (3)
Electricity Generation						Medium	Medium	Medium	Natural gas	Medium (6)
Chemicals						Medium	Medium	Medium	Natural gas Electricity	Medium (6)
Data Centres						Medium	Medium	Low	Electricity	Medium (5)
Construction sites					Medium	Low	Medium	Medium	Natural gas Electricity	High (7)
Agriculture					Medium	Medium		Low	Natural gas Electricity	Medium (5)
Build (residential, commercial)					High			Low	Natural gas Electricity	Low (4)
Steel						Medium		High	Coke	Medium (5)
Glass						Low		High	Natural gas Coal	Low (3)
Cement						Medium		High	Natural gas Coal	Medium (5)

Legend: Low (1 point) Medium (2 points) High (3 points)

Long-term vision

The technology's optimal utility emerges for medium energy processes are far from green infrastructure, supported by government green energy incentives

Iron powder technology 'sweet spot'



3. Short-term plan

Short-term plan

In the short term, Metalot should identify pilot use cases with energy cooperatives and conduct a financial analysis of these scenarios to assess their profitability

Analyses

1

Use case identification
- Identify and select a specific use case for the application Iron Powder technology
- Define clear assumptions and explore value chain options, focusing on real-world applicability

2

Cost assessment and relative position
- Conduct a detailed cost analysis across all segments of the Iron Powder value chain
- To identify the levelized cost of energy (LCOE) for Iron Powder technology consumers
- Identify potential CO_2 emissions reduction and identify how it can influence the LCOE
- Assess the economic viability and potential emission savings of iron powder technology
- Compare iron powder technology with other green energy alternatives in terms of costs

3

Subsidies application
- Research possible subsidies and identify most applicable
- Identify how they can influence the results of the calculations

Short-term plan – Use case identification

Based on the developed criteria for the technology sweet spot, including Industry preference and small to medium energy needs, it was decided to have two use cases: coffee roasting and grass drying

Use case inputs

	Coffee roasting (Option 1)	Grass Drier (Option 2)
Company	Peze	Timmerman Groenvoederdrogerij
Location	Arnhem	Kortgene
Power needs	10-20 MW	1-2 MW
Type of energy needs	Hot air	Hot air
Stability of the process	Batch processing, 10 hours/day 260 days per year	24/7 operation Seasonal, 7 month per year
Distance to Hydrogen backbone	10 km	15 km
Current solution	Natural gas	Coal
Iron burner power	1 MW	1 MW
Green energy source	Solar energy	Wind energy
IP Regenerator location	Uden	Goedereede
Annual energy needs	2.418 MWh	4.776 MWh

Key locations

Production facilities location   Chosen customer's locations

Short-term plan – Use case identification

Considering pilot stage of the Iron Powder technology, we use the decentralised model with two different green energy sources photovoltaic systems and onshore wind farms

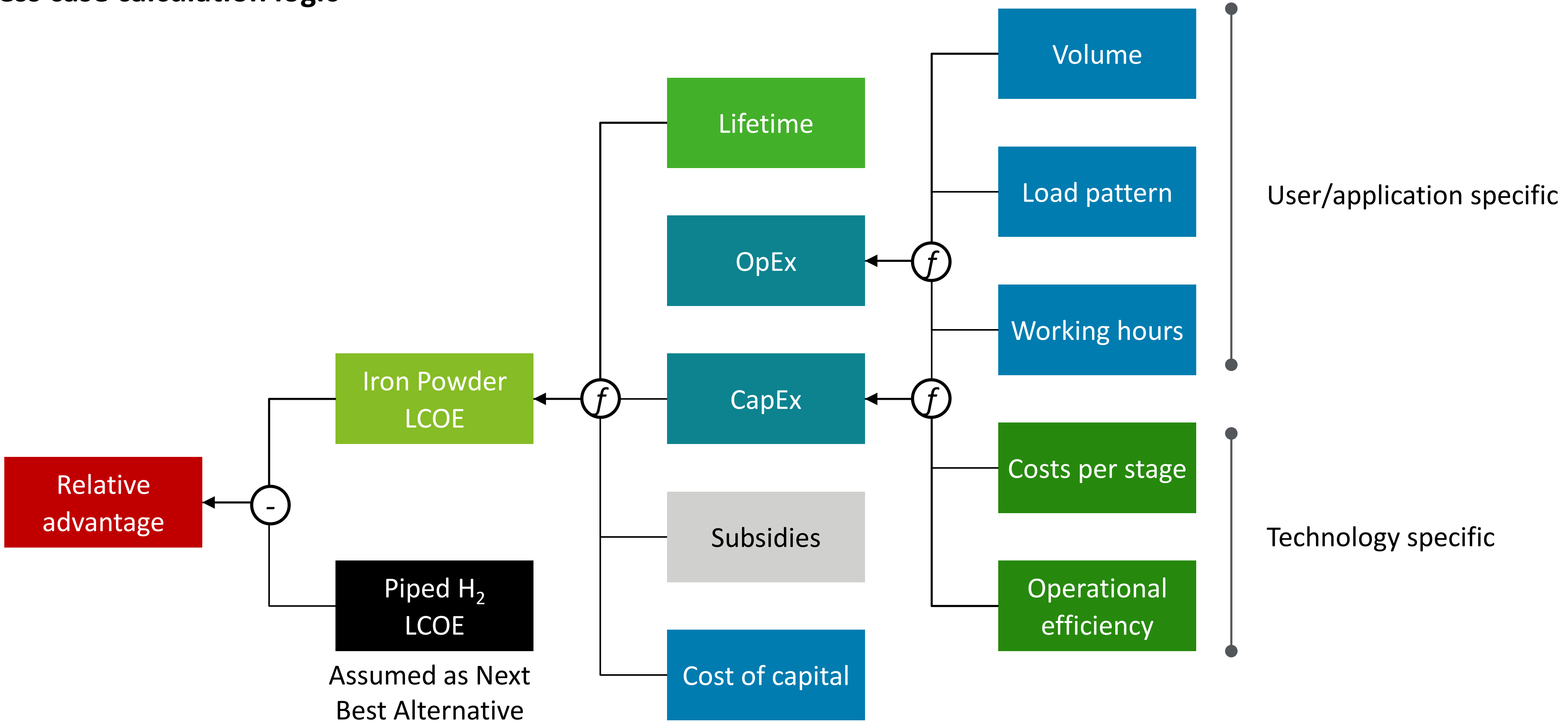
Potential supply chains

	Green energy generation	Hydrogen production	Regeneration	Short-term storing	Transportation	Long-term storing	Combustion
Centralised Iron Powder production	Concentrated solar power	Purchase green hydrogen	Hydrogen Reduction	Shipping Containers	Trucks	Silos	Hot water
	Offshore wind farms	Alkaline electrolysis	Blast Furnace	Barrels / Drums	Trains	Barrels / Drums	Steam
	Floating wind turbines	PEM electrolysis			Ships	Shipping Containers	Hot air
	Hydropower	SOE electrolysis			E-Trucks	Ventilated Warehouse	Electricity
	Geothermal	Thermochemical water splitting					
Decentralised Iron Powder production	Photovoltaic systems	Purchase green hydrogen	Hydrogen Reduction	Bags	Trucks	Bags	Hot air
	Onshore wind farms	Alkaline electrolysis	Microwave Reduction	Barrels / Drums	E-Trucks	Silos	Electricity
	Biomass	PEM electrolysis	Direct Reduced Iron Process	Mini silos (4-5 m^3)		Barrels / Drums	Hot water
						Ventilated Warehouse	Steam
						Mini silos (4-5 m^3)	

Short-term plan – Cost assessment

We have created a model that compares the LCOE in €/MWh for iron powder with that of green hydrogen supplied via a new pipeline

Business case calculation logic



Assumed as Next Best Alternative

Short-term plan – Cost assessment

The model comprises around 90 parameters and various modules, including a dashboard, energy model, financial model, cash flow analysis, and subsidies

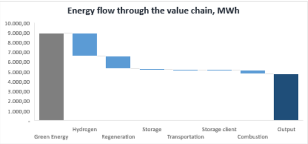
4.2. Overall summary

Grass Dryer / Wind farms

Energy delivered after Combustion,	4776,48

Energy flow through value chain

Phase	Input, MWh	Output, MWh	Reduction, MWh	[%]
Green Energy production	38937	8.955,41	29.981,16	-
Hydrogen production	7764	5.435,11	2.329,33	56%
Regeneration	6626	5.293,21	1.332,87	32%
Production-side storing	5293	5.240,28	52,93	1%
Transportation	5240	5.187,88	52,40	1%
Client-side storing	5188	5.136,00	51,88	1%
Combustion	5136	4.776,48	359,52	9%
Overall by system	**8955**	**4.776,48**	**4.178,93**	**53%**



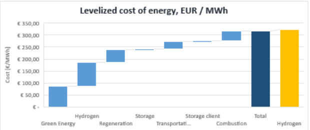
Subsidies options

Subsidy	Value [I]
☐ DEI+: Energy & Climate	872.027,50
☐ DEI+: Hydrogen	153.796,87
☐ VEKI	55.800,00
☐ MOOI	927.027,50
☐ EIA	872.027,50
☐ MIA/VAMIL	1.514.274,13
Total subsidies	########

CO2 allowances	Indicator	Measurement units
☐ Emissions allowance (natural gas)	94.893,12	[EUR] / [Year]

Levelized cost of energy, EUR per MWh

Phase	Accumulated LCOE	Increase	[%]
Green Energy production	86,29	86,29	27%
Hydrogen production	185,41	99,11	31%
Regeneration	239,68	54,28	17%
Production-side storing	242,11	2,42	1%
Transportation	273,47	31,37	10%
Client-side storing	276,53	3,06	1%
Combustion	315,94	39,41	12%
Overall by system	**315,94**	**315,94**	**100%**
LCOE of Piped Hydrogen	**321,45**	321,45	**102%**



Key factors	Indicator	Measurement units
Iron burner capacity	1,00	[MW]
Iron burner's hours per day	24,00	[hours per day]
Iron burner's number of working days	214,00	[days per year]
Electrolyser & Regenerator working hours	4.743,95	[hours per year]
Distance between IP Regenerator and Client	57,00	[km]
Subsidies covering level	10%	[%]
Required return to capital	8,70%	[%]
Distance from Hydrogen grids	15	[km]
Electrolyser efficiency	70%	[%]
Renting of the production building	No	

Total project costs for the 1-st year

Phase	Combined	OPEX	CAPEX (as D&A)
Green Energy production	356.401	71.280	285.121
Hydrogen production	165.949	26.684	139.265
Regeneration	188.604	120.249	68.354
Production-side storing	-	-	-
Transportation	150.043	150.043	-
Client-side storing	1.087	767	320
Combustion	62.724	35.224	27.500
Total	**924.808**	**404.249**	**520.560**

Costs per MWh delivered

Phase	Combined	OPEX	CAPEX (as D&A)
Green Energy production	74,62	14,92	59,69
Hydrogen production	34,74	5,59	29,16
Regeneration	39,49	25,18	14,31
Production-side storing	-	-	-
Transportation	31,41	31,41	-
Client-side storing	0,23	0,16	0,07
Combustion	13,13	7,37	5,76
Total	**193,62**	**84,63**	**108,98**

Other indicators

Phase	Product	Value [I]	Units
Green Energy production	Green electric	86,29	[EUR] / [MWh]
Hydrogen production	Hydrogen	7,24	[EUR] / [kg]
Regeneration	Iron Powder	492,69	[EUR] / [Ton]
Combustion	Iron Powder	603,97	[EUR] / [Ton]

5.2.1. Inputs subsidies

Type of costs	Measure units	Target year(s)	Green Energy generation	Hydrogen production	Regeneration	Production-side storing	Transportation	Client-side storing	Combustion	Total CAPEX
CAPEX	EUR	Y0 - 2024	7.128.015,20	1.592.259,80	1.537.968,75	0,00	0,00	8.000,00	550.000,00	10.816.243,76

Subsidies	Focus on	Description	Max subsidy	Level of coverage	Green Energy generation	Hydrogen production	Regeneration	Production-side storing	Transportation	Client-side storing	Combustion	Total
DEI+: E&C	CAPEX	Max €30 mln for a pilot or demonstration project in energy saving or CO2 reduction	€ 30.000.000,00	10%	712.801,52	159.225,98						872.027,50
DEI+: H2	CAPEX	Max €30 mln for innovation in hydrogen production, transport, storage, and use	€ 30.000.000,00	10%			153.796,87					153.796,87
VEKI	CAPEX	Max €15 mln for a go-to-market project of a proven innovation, applicable to a single company	€ 15.000.000,00	10%						800,00	55.000,00	55.800,00
MOOI	CAPEX/OPEX	MOOI – Max €4 mln for a project that makes industrial production processes and products of industry more sustainable, collaboration of at least 3 ventures	€ 4.000.000,00	10%	712.801,52	159.225,98					55.000,00	927.027,50
EIA	CAPEX	Tax-allowance for investment in assets that result in less CO2 emissions, up to 10% of investment	10% of CAPEX	10%	712.801,52	159.225,98						872.027,50
MIA/VAMIL	CAPEX	Tax-allowance for investment environmentally friendly business assets and techniques, up to 14% of investment	14% of CAPEX	14%	997.922,13	222.916,37	215.315,62	0,00	0,00	1.120,00	77.000,00	1.514.274,13
				Total	3.136.326,69	700.594,31	369.112,50	0,00	0,00	1.920,00	187.000,00	4.394.953,50

6.2. Energy model

		Value	Calculation methodology	2024	2025	2026	2027
Green Energy production							
INPUTS							
	Wind energy	[MWh]	[Total electrisity needs, MWh] / [Capacity factor * 365,25*24]	38.936,57	38.936,57	38.936,57	
OUTPUTS							
	Green electricity produced	[MWh]	[Wind energy, MWh] * [Wind turbine efficiency, %] * [System reductic	8.955,41	8.955,41	8.955,41	
	incl. for Hydrogen production	*[MWh]*	*Reference*	*7.764,44*	*7.764,44*	*7.764,44*	
	incl. for Regeneration	*[MWh]*	*Reference*	*1.190,97*	*1.190,97*	*1.190,97*	
	System reduction factor	[%]	1-[System reduction rate, %]+[Sustaining investments rate, %]	100%	100%	100%	
KEY INDICATORS							
	Remaining energy after step 1	Index	[Wind energy, MWh] / [Green electricity produced, MWh]	0,23	0,23	0,23	
	Green Energy needs	[MWh]	[Electricity needs for Hydroden production, MWh] + [Electricity need	8.955,41	8.955,41	8.955,41	
	Energy deficit	*[MWh]*	*[Green Energy needs, MWh] - [Green electricity produced, MWh]*	-	-	-	
Hydrogen production							
INPUTS							
	Green Electricity	[MWh]	[Electrolyser Power, MW] * [Working hours, hours]	7.764,44	7.764,44	7.764,44	
	Top-up Water	[litres]	[Hydrogen produced, kg] * [Top-up water, liters per kg hydrogen]	1.227.727,17	1.227.727,17	1.227.727,17	
	Water leakages	[litres]	[Water leakage rate, %] * [Top-up Water, litres]	12.277,27	12.277,27	12.277,27	
OUTPUTS							
	Hydrogen produced	[MWh]	[Capacity of electoliser, MW] * [Alkaline electrolyser efficiency] * [W	5.435,11	5.435,11	5.435,11	
	Hydrogen produced	[kg]	[Hydrogen produced, kg] * [System reduction factor]	137.946,87	137.946,87	137.946,87	
	System reduction factor	[%]	1-[System reduction rate, %]+[Sustaining investments rate, %]	100%	100%	100%	
KEY INDICATORS							
	Remaining energy after EG	Index	[Hydrogen produced, MWh] / [Green Electricity, MWh]	0,70	0,70	0,70	

7.2. Financial model

		Value	Calculation methodology	2024	2025	2026	2027
Green Energy production							
CAPEX				€ 7.128.015	€ 53.460	€ 53.460	€ 53.460
	Renewable energy infrastructure	[EUR]	[Required installed capacity, MW] * [Onshore wind farm 1MW benchma	7.128.015,20			
	Sustaining investments - wind turbine	[EUR]	[Sustaining investments rate, %] * [CAPEX, EUR]		53.460	53.460	53.460
	Realization value	[EUR]	[CAPEX, EUR] - [D&A, EUR]				
D&A				€ -	€ 285.121	€ 287.259	€ 289.397
	Renewable energy infrastructure	[EUR]	[CAPEX] / [Lifetime equipment]		€ 285.121	€ 285.121	€ 285.121
	Sustaining investments - wind turbine	[EUR]	[CAPEX] / [Lifetime equipment]			€ 2.138	€ 4.277
OPEX					€ 71.280	€ 71.280	€ 71.280
	Maintenance of energy generation equipment	[EUR]	[Maintenance rate, % of CAPEX] * [CAPEX Wind system, EUR]		71.280	71.280	71.280
SUBSIDIES				€ -			
	DEI+: E&C	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
	DEI+: H2	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
	VEKI	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
	MOOI	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
	EIA	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
	MIA/VAMIL	[EUR]	[Maximal amount of subsidy, EUR] * [Coverage of CAPEX by subsidy, %]	€ -			
KEY ANALYTICS INDICATORS							
	MWh produced	[MWh]	Reference		8.955,41	8.955,41	8.955,41
	Total costs per MWh produced	**[EUR] / [MWh]**	**([OPEX, EUR] + [D&A, EUR])/ [MWh produced, MWh]**		**39,80**	**40,04**	**40,27**
	CAPEX per MWh produced	[EUR] / [MWh]	[D&A, EUR] / [MWh produced, MWh]		31,84	32,08	32,32
	OPEX per MWh produced	[EUR] / [MWh]	[OPEX, EUR] / [MWh produced, MWh]		7,96	7,96	7,96

Short-term plan – Cost assessment

The use case calculations are based on several technical …

Key technical assumptions

Item	Description	Option 1 (Solar)	Option 2 (Wind)
Annual energy needs	The total amount of energy required to be supplied by the iron burner during the company's operational hours	2.418 MWh	4.776 MWh
Green energy facilities capacity factor, %	Measure of how much energy is produced by energy production facilities compared to its maximum output. Based on the NL statistics	9,95%	23%
Initial Green energy facilities Power, MW	Power of PV-panels and onshore wind farm that needed to satisfy energy needs for Electrolyser and Regenerator	5,20	4,44
FLH for Electrolyser and Regenerator, hours	Based on the green energy availability, what total hours of utilization the equipment	1.195	4.745
Electrolyser Power, MW	Based on the energy needs, efficiency and FLH, calculated requested power of electrolyser	3,29	1,64
Regenerator Power, MW	Based on the energy needs, efficiency and FLH, calculated requested power of regenerator	2,49	1,24
Number of IP cycles	How many cycles Iron Powder can be used before it should be sold	15	15
Iron burner power, MW	The power of client-site Iron Burner, taken as an constant based on current maximum capacity	1	1
Distance from Hydrogen grids, km	Distance of client to the hydrogen backbone	10	15

Short-term plan – Cost assessment

… as well as general assumptions

General model assumptions

- The **model is based on the Value chain** specified for every option
- Initial use cases are selected at the Status Meeting on February 23
- The model **spans a 20-year period**
- It is assumed that **ownership of assets is necessary to operate** and derive benefits, except for truck transportation, where third-party electric trucks are utilised
- Green **energy production facilities** (Electrolyser and Regenerator), **are co-located**
- **Green energy is the single type of energy** source for IP production
- **The Electrolyser and Regenerator are operational only during green energy production hours**; Short-term storage of green energy (batteries) is not included in the value chain
- **Cost estimations are based on public sources as of March 1, 2024**, and could be subject to change.
- Technical parameters of Iron Powder equipment (electrolyser, regenerator, iron burner) were provided by Metalot
- **Equipment works automatically and doesn't need additional personnel** on top of maintenance
- **It is presumed that there will be no significant technological breakthroughs** or market shifts that could make the proposed technology obsolete or introduce a disruptive competitor during the projection period

Short-term plan – Cost assessment

The main costs for energy from iron powder are investments in equipment and further maintenance across its operational lifespan

Investments in the Iron Powder equipment

Major investments	Option 1 (€)	Option 2 (€)	Comments
CAPEX Renewable energy infrastructure	4.088.845	7.128.015	Investments needed for production green energy for Electrolyser and Regenerator
CAPEX Electrolyser	3.196.782	1.590.714	For Option 1, the required investments in the Electrolyser and Regenerator are notably higher due to the limited number of peak solar hours available to generate electricity, which restricts the operational time for these systems
CAPEX Regenerator	3.090.781	1.537.968	
CAPEX Combustion machine	550.000	550.000	Investments in 1 MW Iron Burner
Total CAPEX in major equipment	**10.926.408**	**10.806.697**	

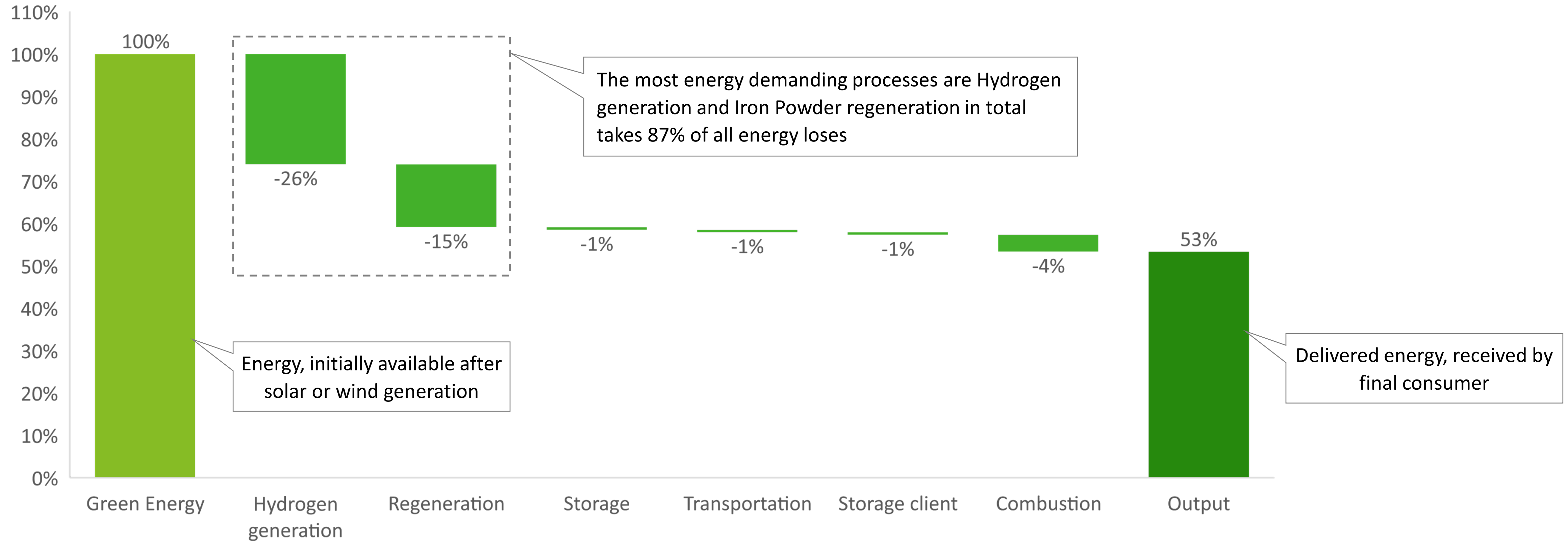
Key operational costs and D&A

Other expenses	Option 1 (€)	Option 2 (€)	Comments
Maintenance of equipment	160.304	127.101	Maintenance vary based on they equipment type in range between 1 and 4,5%
Annual purchase of virgin IP	60.833	120.170	Assumed that Iron Powder can operate 15 cycles and then should be sold
Annual transportation costs	64.826	150.043	Costs for transportation IP and used Iron powder between Clients and a Regenerator

Short-term plan – Cost assessment

Throughout the entire value chain, almost half of the energy is lost during transformations of iron powder versus about a quarter for piped hydrogen

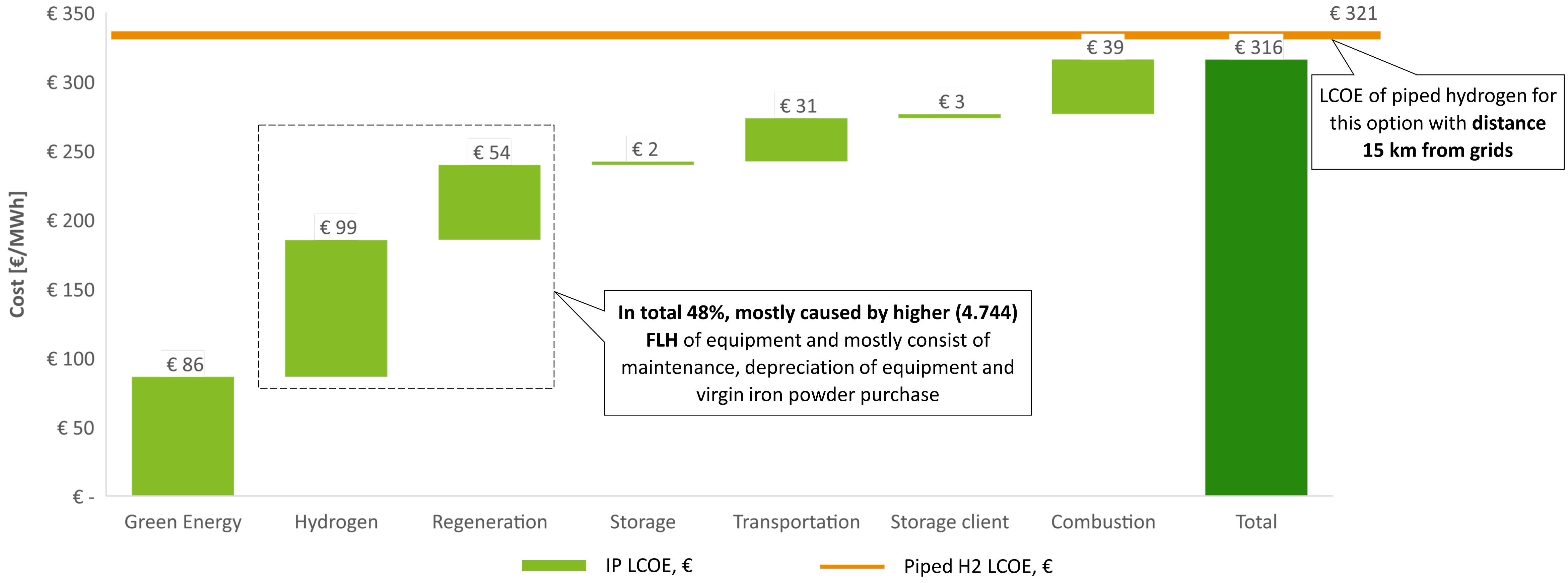
Energy flow through value chain, %



Short-term plan – Cost assessment

Nevertheless, for grass drying, with onshore wind as the primary energy source, the iron powder LCOE is competitive due to a mix of high load hours and distance from the grid

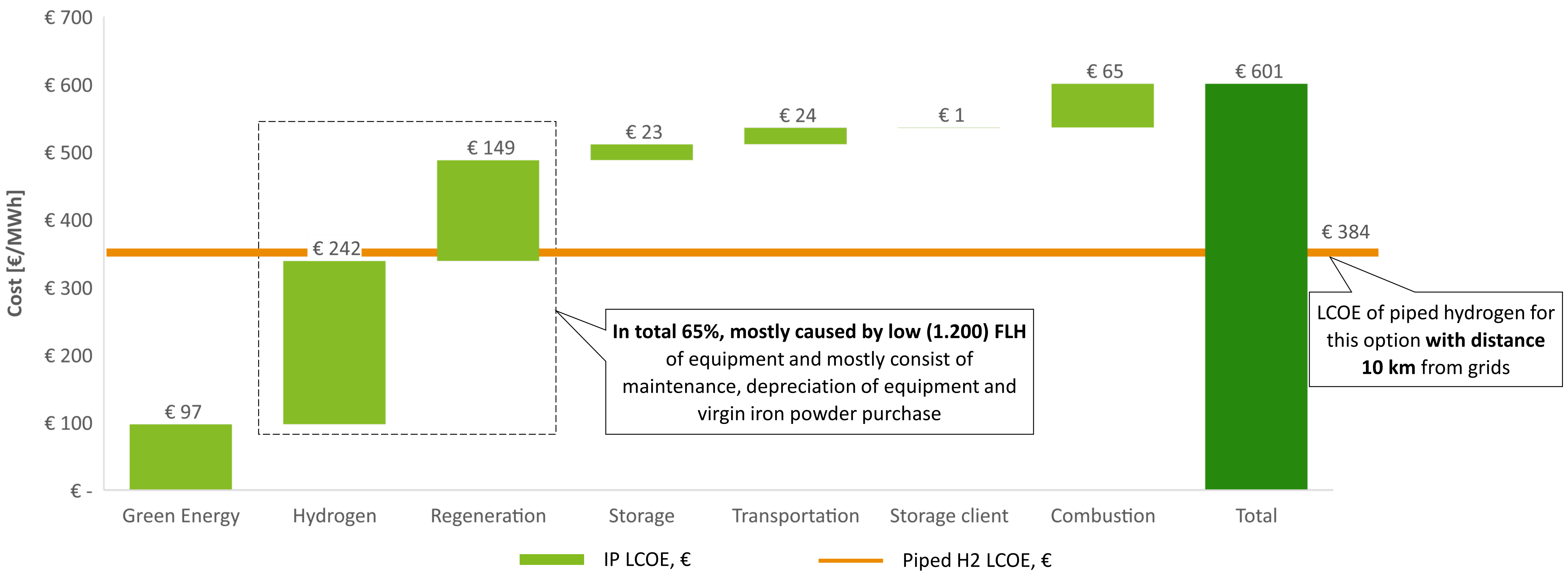
Levelized cost of energy for grass drying



Short-term plan – Cost assessment

Iron powder LCOE for coffee roasting with solar PV-panels as the primary energy source is about 50% higher than piped hydrogen primarily due to low load hours

Levelized cost of energy for coffee Roasting

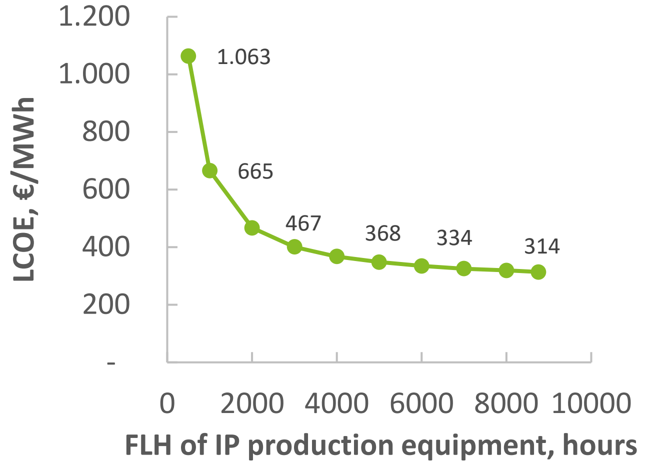


Short-term plan – Cost assessment

But costs can be driven down substantially by increasing load hours of both production equipment and the burner itself

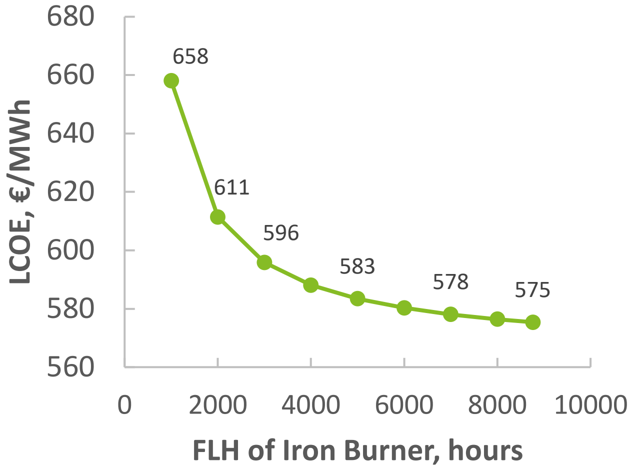
Scale impact of Coffee Roaster LCOE

LCOE vs FLH of IP production equipment



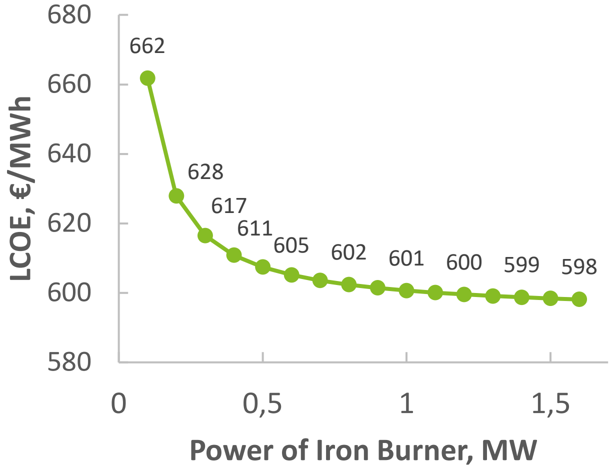
- 1% of changes in FLH of Regenerator and Electrolyser changes 4,3% of LCOE for Option 1 and 4,4% for Option 2
- In our opinion, the optimal interval for FLH for Regenerator and Electrolyser should be between 4000 and 8000 FLH

LCOE vs FLH of 1 MW Iron Burner



- FLH of Iron burner indicates the amount of energy provided by a 1 MW Iron Burner
- 1% of changes in FLH of Iron Burner changes 1,6% of LCOE for Option 1 and 2,7% for Option 2
- From the LCOE perspective, the optimal amount of FLH of Iron Burner starting from 5000 FLH

LCOE vs Iron Burner Power

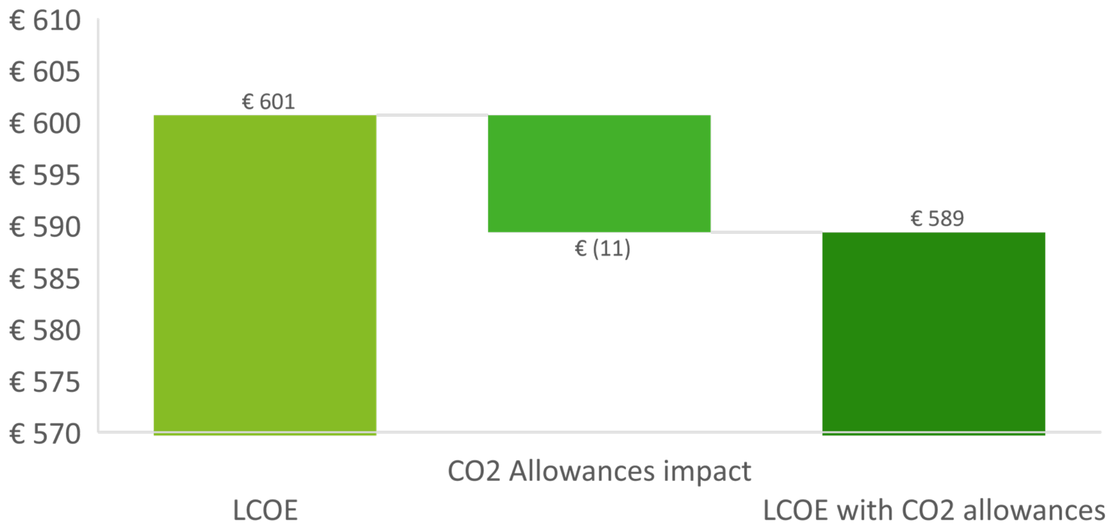


- An increase in Iron Burner capacity by 1% is correlated with a 0,6% decrease in LCOE for both options 1 and 2
- The data suggests that scaling-up burner power yields a marginal gain in efficiency, indicating a diminishing return on investment as the power increases

Short-term plan – Cost assessment

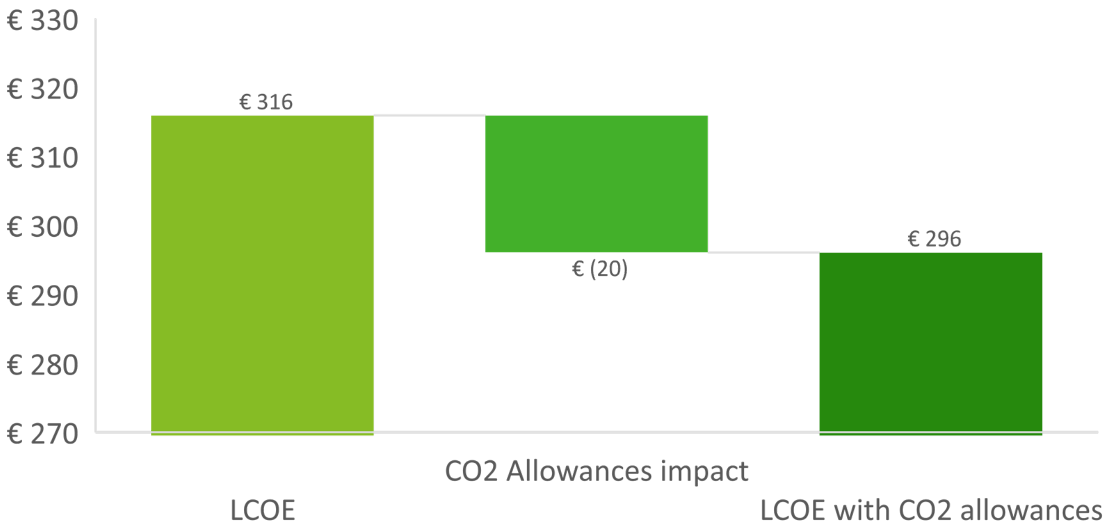
Also, CO_2 emission allowances can reduce LCOE by 2% and 6% for both coffee roasting and grass drying, however, it won't improve the Iron powder positioning related to other green fuels

CO_2 emission allowances impact on Coffee Roasting LCOE



- For Option 1, **delivering 2,4 GWh** of energy is required to substitute **natural gas** as the primary fuel source
- Annually, using iron powder can **prevent 525 tones of CO_2 emissions** and **generate €27,415 in CO_2 emission allowances**
- This results in a **reduction of the LCOE by €11 per MWh**, which is roughly equivalent to a 2% decrease

CO2 emission allowances impact on Grass Drier LCOE

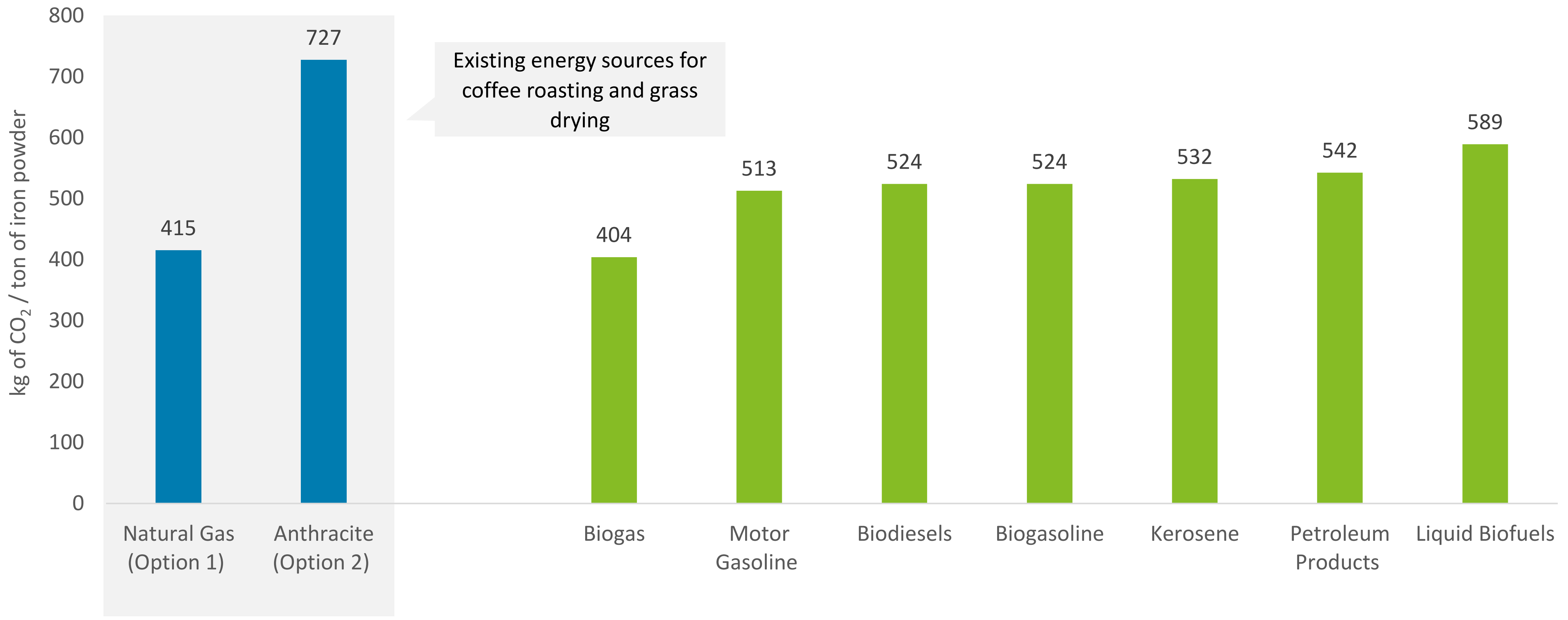


- For Option 2, **delivering 4,8 GWh** of energy is required to substitute **coal** as the primary fuel source
- Annually, using iron powder can **prevent 1,817 tones of CO_2 emissions** and **generate €94,893 in CO_2 emission allowances**
- This results in a **reduction of the LCOE by €20 per MWh**, which is roughly equivalent to a 6% decrease

Short-term plan – Cost assessment

This is because using iron powder as a fuel alternative significantly reduces CO_2 emissions compared to traditional fuels and not to other green alternatives

Reduction of CO_2 tonnage per ton of iron powder used



Source: https://ourworldindata.org/

Short-term plan – Subsidies

Furthermore, there are subsidy programs oriented on renewable energy and sustainability …

General sustainability-oriented subsidies

Name	Description	Application Status	Requirements
TSE Industries studies	Innovative pilot or demonstration project	Deadline: 24 March (budget already spent)	- Pilot project to decide whether to continue or not - Innovative tech
SDE++	Use of techniques for the generation of renewable energy	Temporarily closed	Closed
DEI+: Energy and Climate	Demonstrate innovation to reduce CO_2	Deadline: 29 August	- End-user needs to request subsidy
VEKI	Fund to accelerate climate investments in industry	Closed, reopens half March 2024	- Proven technology - Exclusive with DEI+ - Payback period longer than 5 years
MIA/VAMIL	Tax-allowance for sustainability-related invest.	Continuous	- Investment must be on the “Milieulijst”
EIA	Tax-allowance for green energy / efficiency investments	Continuous	- Investment must be on the “Energielijst”
NIKI	Planned fund to accelerate innovative sustainable investments	Planned, expected to open 2024	Unknown
MOOI	Fund for mission-oriented R&D and innovation in a consortium	Deadline: 18 April	- Collaboration with min. 3 enterprises
HER+	Renewable energy subsidy to support innovation	Closed (might reopen)	Closed

Subsidy is not active

Short-term plan – Subsidies

… as well as hydrogen-specific ones

General sustainability-oriented subsidies

Name	Description	Application Status	Requirements
National Growth Fund	Fund for projects with economic growth potential	Planned, expected to open 1 April	- Large projects (ca. 50 million minimum)
MIT: R&D Collab.	Fund for collaborative innovation	Temporarily closed	- Min. 2 SMEs - R&D Project
WBSO	Tax-allowance for R&D	Continuous	- R&D has to take place

Hydrogen-specific subsidies

Name	Description	Application Status	Requirements
Scaling-up (OWE)	Fund for electrolyser from 0.5 to 50 MW	Temporarily closed	- Hard to combine with other subsidies - Produce and use H2
IPCEI	Fund for hydrogen related investments and projects	Closed	Closed
DEI+: Hydrogen	Fund for innovations in renewable H2 production or H2 carriers	Deadline: 25 June	- Innovation in renewable H2

Subsidy is not active

Short-term plan - Subsidies

We assumed five programmes relevant for iron powder

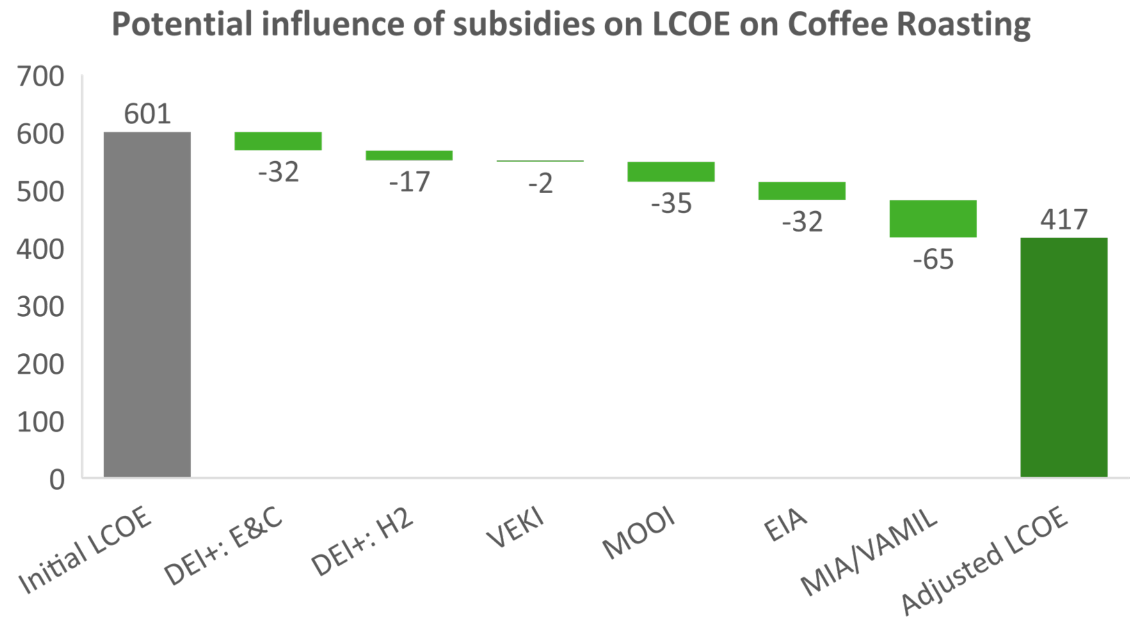
Subsidy assumptions in financial model

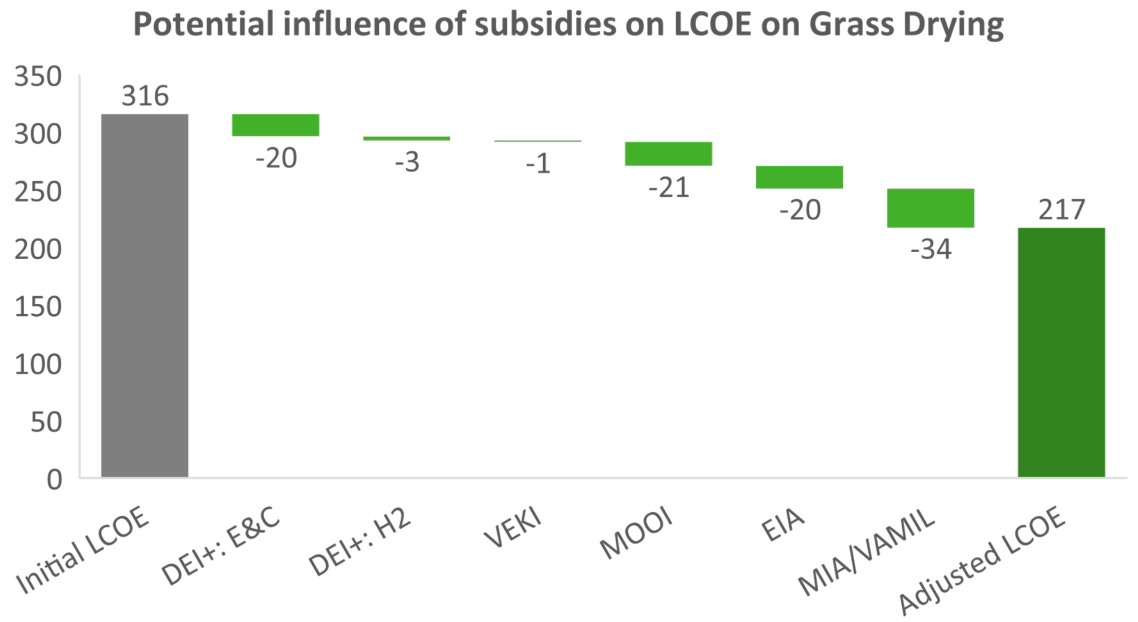
	Green energy generation	Hydrogen production	Regeneration	Production-side storing	Transportation	Client-side storing	Combustion
DEI+: E&C	Max €30 mln		Mutually exclusive with VEKI				
DEI+: H2			Max €30 mln				
VEKI				Mutually exclusive with DEI+: E&C		Max €15 mln	
MOOI	Max €4 mln						Max €4 mln
EIA	Up to 10% of investment		Mutually exclusive with MIA/VAMIL				
MIA/VAMIL	Up to 14% of investment						

Short-term plan - Subsidies

With a coverage of up to 10%, these can lower the LCOE by a further 30%

Key financial modelling assumptions





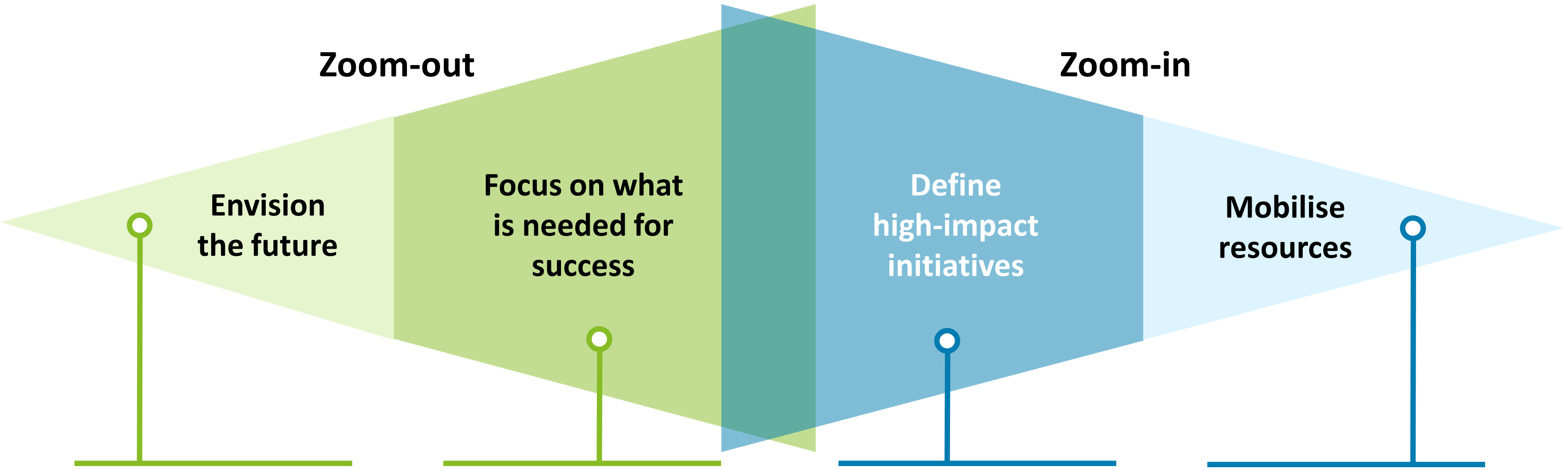
- Assuming that each subsidy can contribute a maximum of 10% to the CAPEX for a specific segment of the value chain, the mentioned subsidies have the potential to decrease the LCOE by up to 30%. Nonetheless, the selection of applicable subsidies and the extent of their coverage can significantly alter this estimate
- Up to now, the most attractive subsidies have been identified as MIA/VAMIL, MOOI, and DEI+
- Additionally, EU subsidies could offer further advantages to the LCOE of Iron Powder technology

4. Implications and next steps

Implications and next steps

With both the zoom-out vision and the zoom-in economics confirmed, Metalot now needs to mobilize the resources to make the grass drying pilot happen

Scale-up strategy Metalot



Envision
Iron powder will play a role in supplying green hydrogen to smaller off-grid high-heat users

Focus
Scale is critical, slow hydrogen grid expansion offers a window of opportunity

Define
A pilot with grass drying already offers a competitive net-zero solution today

Mobilise
A green energy cooperative in Zeeland, subsidies and capital, launching, learning and scaling

Implications and next steps

This means reaching out to Timmerman Groenvoederdrogerij, creating local cooperatives and relentlessly drive down costs

High level roadmap

Engage with Timmerman Groenvoederdrogerij

- Initiate **communications** to pilot Iron Powder technology
- **Collaborate** with RIFT/Iron+ to seek support from Zeeland local authorities
- **Fine tune the model** based on specified information
- Work with RIFT/Iron+ to **design** a project
- **Get subsidies** for the project to compensate extra costs

Create energy cooperatives

- Compile a list of **companies** (energy < 6 GWh, > 10 km from the pipeline) with access to wind power
- Identify **candidates** for energy cooperatives, and negotiate deals
- Initiate discussions with **subsidy** providers

Drive down costs

- **Integrate** mixed green energy sources to achieve over 4000 FLH
- Consider **purchasing** green H_2 as backup
- Evaluate the use of **PEM electrolysers**
- Explore the feasibility of **battery storage** solutions

5. Appendix

Use case options

Use case selection

Based on the criteria defined in the Long-term vision, we propose you to choose the case for further calculations

We need your decision what use case you would like we focus on in the business case:

Ceramics production

Coffee roasting

Chosen Option 1

District Heating

Grass dryer

Chosen Option 2

Use case selection

Ceramics factories in the Netherlands operate within a competitive market, facing energy-related challenges while serving diverse clients both domestically and internationally

Proposed use case Option 1: Ceramics factory

Description: The ceramics industry in the Netherlands comprises diverse manufacturers serving construction, household goods, industrial, and artistic sectors. Products include tiles, bricks, sanitaryware, tableware, and decorative items. Competition drives a focus on innovation, sustainability, and quality to meet both local and global demand.

Energy pain points:

- Energy-intensive processes like firing and kiln operations lead to high energy consumption and costs
- Challenging competitiveness and sustainability goals, including emissions reduction

Client locations: Limburg, Gelderland, North Brabant, and South Holland

Iron Powder facilities

Location: Decentralised, based in North Brabant, local farms

Key energy needs

Criteria	Indication
Energy needs	Medium: 30-50 MW
Working temperature	Very high: 900°C - 1,400°C
Type of energy needs	High-temperature heat
Stability of the process	Continuous: 24/7 operation with peaks during a day
Territory where located	Industrial zones
Grids limitations	Possible high demand
Current solution	Natural gas, Coal

Key locations

★ Chosen Option 1

Use case selection

Coffee beans roasting business can be a good initial client for the Iron Powder Technology

Proposed use case Option 2: Coffee roasting

Description: The country's coffee roasting industry produced an estimated 136,000 tones of roasted, showcasing its significant production scale.

Large-scale coffee roasting consumes considerable energy, primarily for the roasting process. These operations often incorporate energy efficiency and sustainability measures.

Energy pain points: High energy consumption; cost of energy; energy efficiency and sustainability

Client locations: Zaandam, Dordrecht, Utrecht, Arnhem

Production facilities info

Location: Decentralised, based in North Brabant, local farms
Energy source: Photovoltaic systems

Key energy needs

Criteria	Indication
Energy needs	Low: 10-20 MW
Working temperature	Medium : 180°C - 240°C
Type of energy needs	Hot air, Steam
Stability of the process	Batch processing, 8-12 hours/day
Territory where located	Rural/Urban
Grids limitations	Possible limitations
Current solution	Natural gas, Electricity

Key locations

Customer's locations Production facilities location Chosen customer's locations

Use case selection

The Netherlands is a potentially growing market for district heating. There is an urgent need for changing the existing heating source from natural gas into something different and greener

Proposed use case Option 3: District heating

Description: The market emphasizes sustainability and energy efficiency, providing centralized heating solutions to residential, commercial, and industrial properties. Utilizing diverse energy sources like waste heat, geothermal, biomass, and solar thermal energy, it serves as an alternative to individual heating systems.

Energy pain points:

- Balancing heat supply with varying demand, particularly at peak times, poses a challenge for producers.
- Aging networks require maintenance and upgrades, leading to heat losses and inefficiencies.
- Switch to renewables while ensuring reliable and affordable heat supply remains a difficult task for producers.

Client location: Producers operate district heating networks across various municipalities in the Netherlands

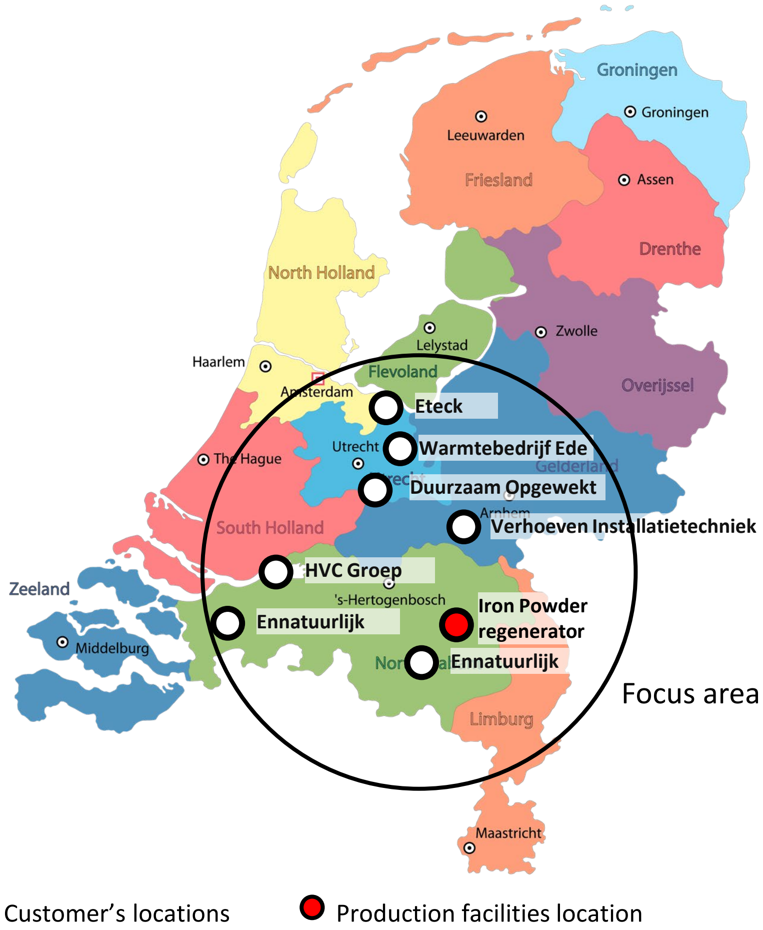
Iron Powder facilities

Location: Centralised, based in North Brabant, local farms

Key energy needs

Criteria	Indication
Energy needs	High: 100-200 MW
Working temperature	Low: 70°C - 130°C
Type of energy needs	Hot water, Steam
Stability of the process	Seasonal with daily peaks, 24/7 base load
Territory where located	Urban/Rural
Grids limitations	High demand for stability
Current solution	Natural gas, Coal

Key locations



Chosen Option 2

Use case selection

Grass dryer factories in the Netherlands are part of the agricultural machinery sector, catering to farmers and agricultural businesses involved in hay and grass production

Proposed use case Option 4: Grass dryer

Description: These factories manufacture equipment used for drying grass, hay, and other forage crops to preserve nutritional value and prevent spoilage. The market for grass dryers is influenced by factors such as weather conditions, agricultural policies, and technological advancements in drying technologies.

Energy pain points:

- Energy consumption due to the energy-intensive nature of the drying process.
- Need for more energy-efficient drying technologies and renewable energy sources to power the equipment.

Client location: In regions with a strong agricultural presence and access to transportation networks

Iron Powder facilities

Location: Based in Zeeland
Energy source: Onshore wind farms

Key energy needs

Criteria	Indication
Energy needs	Low: 1-5 MW
Working temperature	Low: 40°C to 80°C
Type of energy needs	Hot air, Steam
Stability of the process	Continuous: 24/7 operation but seasonal
Territory where located	Agrarian (for the use case - North Brabant, Limburg)
Grids limitations	Difficulties with electricity grids extension
Current solution	Natural gas, electricity, coal

Key locations

Customer's locations Production facilities location Chosen customer's locations

5. Appendix

Active subsidies overview

Deep dive into recommended subsidies (1/2)

After deep dive, DEI+, VEKI, MOOI and EIA are recommended as likely subsidies to obtain

DEI+: Energy and Climate

Deadline: 29 August 2024

Budget: €141 mln total; Max €30 mln

Characteristics

- Subsidy either for *pilot project* or *demonstration project*
  - Pilot project: small-scale, temporary test of a ***new*** initiative. It cannot have been done before
  - Demonstration project: investment initiative employing new or innovative technologies in the Netherlands, where the installed technology remains operational after the project period
- CAPEX/OPEX:
  - Pilot project: CAPEX and OPEX
  - Demonstration project: CAPEX
- For demonstration project: end-user needs to request. The end-user needs to stay owner of the installation and it needs to be kept in use after the demonstration project is completed
- Iron powder might fall under the category "Flexibilization of the energy system", for which only pilot projects get subsidy
- Value Chain: all
- Potentially mutually exclusive with VEKI

DEI+: Hydrogen

Deadline: 25 June 2024

Budget: €40 mln total; Max €30 mln

Characteristics

- Subsidy for innovation in:
  - Production of hydrogen
  - Transport and storage of hydrogen (carriers)
  - Utilization of hydrogen (carriers) and green electrons
- Subsidy for pilot project, demonstration project, or R&D project
- CAPEX/OPEX:
  - Pilot project: CAPEX and OPEX
  - Demonstration project: CAPEX
- Value Chain: hydrogen production
- Potentially mutually exclusive with VEKI

VEKI

Expected to open: half March 2024

Budget (previous round): €138 mln total; Max €15 mln

Characteristics

- Subsidy for systems that are ready to go-to-market, proven technology
- Projects with a payback period longer than 5 years (without subsidy)
- Subsidy only for individual companies in industry
- The project has to result in CO_2 reduction for the company
- CAPEX/OPEX:
  - Mainly CAPEX
- Value Chain: Client-site storing, Combustion
- Potentially mutually exclusive with DEI+

Deep dive into recommended subsidies (2/2)

After deep dive, DEI+, VEKI, MOOI and EIA are recommended as likely subsidies to obtain

MOOI

Deadline pre-registration: 18 April 2024

Budget: €61 mln total; Max €4 mln

Characteristics

- At least three ventures, that are not united in a group
- At least €2 mln in costs
- Subsidy for a project that makes industrial production processes and products of industry more sustainable
- Project needs to fit in one of the themes
    - Iron Powder might fit under: *"Innovation theme 1: Process innovation through electrification and supply chain innovations"*
- CAPEX/OPEX:
    - Both
- Value Chain: all

EIA

Continuous

Budget: €259 mln total; Ca. 10% of investment

Characteristics

- Tax-allowance for investment in assets that result in less CO_2 emissions
- Max 40% of investment deductible from profit
- The asset has to be on the "Energielijst"
    - Iron Powder machines are not on there
        - Application can be made for next year
    - Other systems are, e.g. solar panels, electric boiler, electrolyser
- Each asset invested in has to be listed on the application
- CAPEX/OPEX:
    - CAPEX
- Value Chain: all except transport
- Mutually exclusive with MIA/VAMIL for the same asset

MIA/VAMIL

Continuous

Budget: €217 mln total; Ca. 14% of investment

Characteristics

- Tax-allowance for investment environmentally friendly business assets and techniques
- MIA: investment deduction of up to 45% of your investment amount, in addition to usual investment deduction
- VAMIL: depreciate 75% of the investment costs at a time of own choosing. Gives a liquidity and interest advantage
- Asset or technique has to be on the "Milieulijst"
- Each asset or technique invested in has to be listed on the application
- CAPEX/OPEX:
    - CAPEX
- Value Chain: all except transport
- Mutually exclusive with EIA for the same asset

Subsidies allocation across the value chain

VEKI, MOOI, EIA, and DEI+: H2 can cover CAPEX and OPEX in different parts of the value chain

Selected subsidies for the business case

	Green energy generation	Hydrogen production	Regeneratio n	Production-side storing	Transport-ation	Client-side storing	Combustion
DEI+: E&C	CAPEX/OPEX		Mutually exclusive with VEKI				
DEI+: H2			CAPEX				
VEKI				Mutually exclusive with DEI+: E&C		CAPEX	
MOOI	OPEX						OPEX
EIA	CAPEX		Mutually exclusive with MIA/VAMIL				
MIA/VAMIL	CAPEX						

Likely   Less likely   Unlikely

- **DEI+: E&C** – Max €30 mln for a pilot or demonstration project in energy saving or CO_2 reduction
- **DEI+: H2** – Max €30 mln for innovation in hydrogen production, transport, storage, and use
- **VEKI** – Max €15 mln for a go-to-market project of a proven innovation, applicable to a single company
- **MOOI** – Max €4 mln for a project that makes industrial production processes and products of industry more sustainable, collaboration of at least 3 ventures
- **EIA** – Tax-allowance for investment in assets that result in less CO_2 emissions, up to 10% of investment
- **MIA/VAMIL** – Tax-allowance for investment environmentally friendly business assets and techniques, up to 14% of investment