CREATING VALUE WITH GREEN HYDROGEN BY INTEGRATING SOEC WITH DOWNSTREAM PLANTS

BA2C

zero emission molecules
project development

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WHO IS BA2C AND WHAT IS BA2C DOING

SUMMARY

BA2C
zero emission molecules
project development

SPECIALIZED:

H_2 | MeOH | SAF | DRI - IRON FUEL | NH_3 - FERTILIZER

WHAT DO WE DO

- Technology development
- Project development
- Advisory (mainly investors & colleague project developers & EPC)

REGIONS

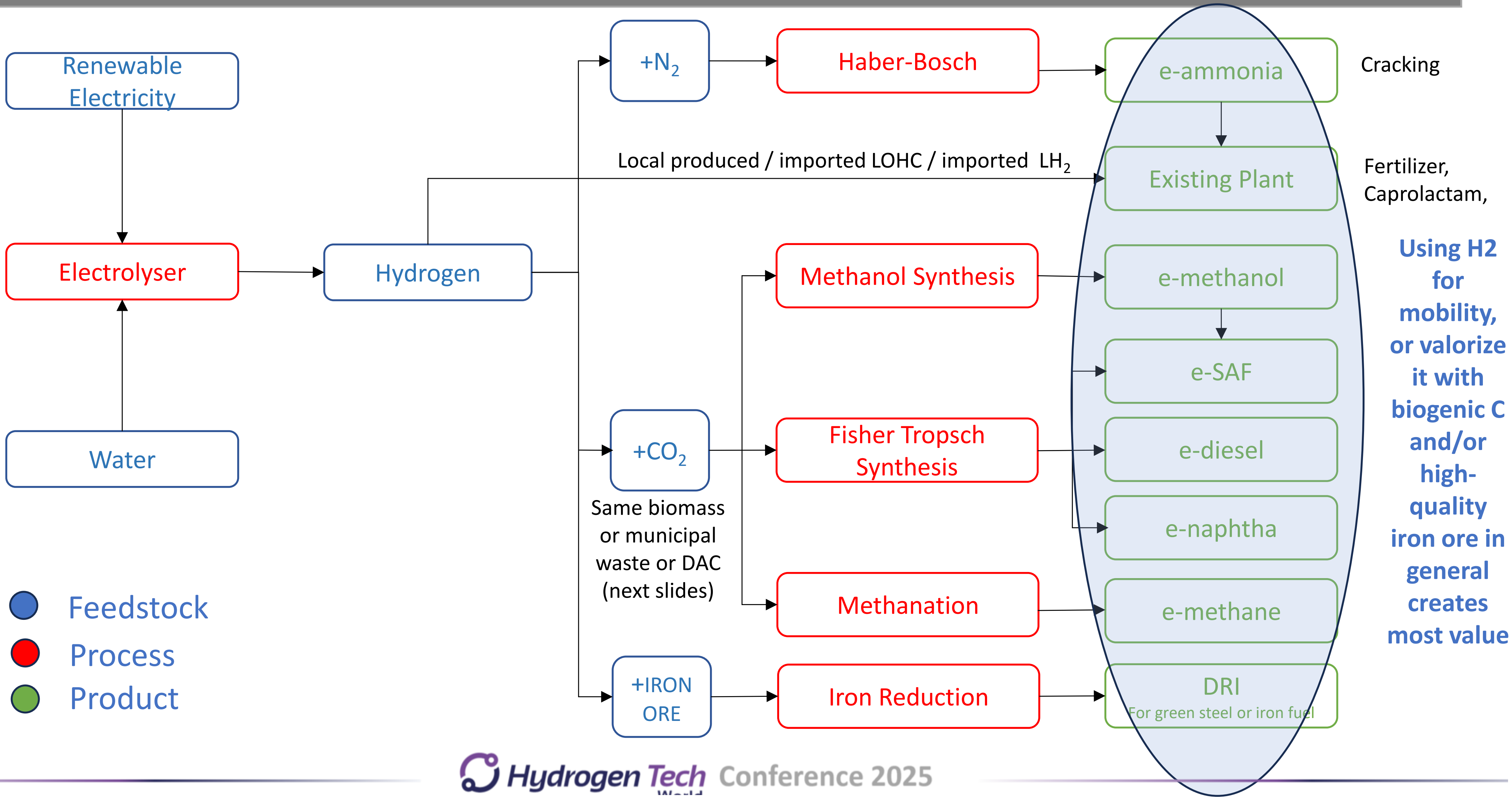
- Latin America
- Africa
- North Europe, Iberian Peninsula & CEE

(GREEN) HYDROGEN VALUE CREATION

PRODUCTS WITH PREMIUM

HOW TO ADD VALUE TO GREEN HYDROGEN

USE IT TOGETHER WITH BIOGENIC CARBON AND/OR IRON ORE



Using H2 for mobility, or valorize it with biogenic C and/or high-quality iron ore in general creates most value

BANKABLE PROJECTS

WHAT DO YOU HAVE TO DEAL WITH?

- RENEWABLE PRODUCTS TECHNOLOGIES (H_2/NH_3-FERTILIZER/MeOH/DME/DRI)
- GHG SAVINGS DUE TO PROJECT AND CALCULATING THE VALUE
- CERTIFICATION
- RIGHT TIME TO MARKET
- POLICY SUPPORT
- FEEDSTOCK
- OFFTAKE AGREEMENT

WHY SOEC + DOWNSTREAM PLANTS

TO OVERCOME CHALLENGE OF GREEN HYDROGEN (DERIVATIVES)

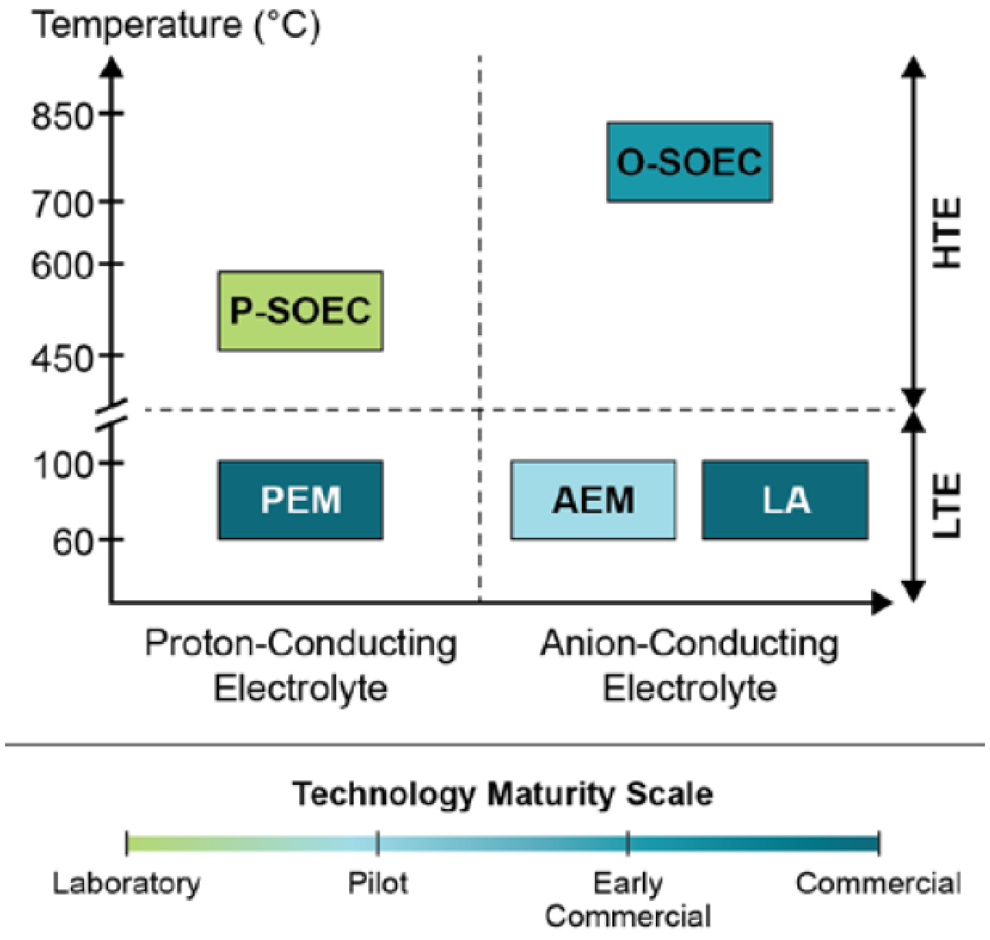
- **SOME TECHNOLOGIES NOT EFFICIENT ENOUGH**
  - We need more efficient technologies. More emphasis on research in upcoming technologies
- **GREEN PRODUCTS ARE MORE EXPENSIVE THAN FOSSIL PRODUCTS**
  - More efficient technologies needed to make products cheaper
  - Include real cost (due to GHG emission) to fossil products
- **TO DEAL WITH THESE CHALLENGES WE NEED (WORLDWIDE) REGULATIONS AND EMPHASIS ON DEVELOPING & MATURING TECHNOLOGIES**

TECHNOLOGIES

ADVANTAGES SOEC TECHNOLOGY

GREEN HYDROGEN

EACH TECHNOLOGY HAS ITS ADVANTAGES & DISADVANTAGES



Source: Energy Earthshots, U.S. Department of Energy, Hydrogen Shot – Water Electrolysis Assessment

GREEN HYDROGEN

EACH TECHNOLOGY HAS ITS ADVANTAGES & DISADVANTAGES

Source: Hydrogen Research Europe

Expected Status 2024 (based on 100MW system)			
	Alkaline	PEM	SOEC
SYSTEM*			
Electrical consumption (kWh/kg)	49	52	39
Heat demand steam (kWh/kg)	n.a.		9,0
Capex[1] €/kW €/(kg/d)	 1000 480	 1550 700	 2000 1250
O&M cost (€/(kg/d)/y)[1]	43	30	130
Hot idle ramp time (sec.)	30	1	300
Cold start ramp time (sec.)	900	10	8 hours
Footprint (M^2/MW)[2]	60	40	150
STACK			
Degradation (%/1000h)	0,11	0,15	1,0
Current density (A/cm^2)	0,7	2,4	0,85
Critical raw materials (mg/W)	0,3	1,25	n.a.

Expected Status 2030 (based on 100MW system)			
	Alkaline	PEM	SOEC
SYSTEM*			
Electrical consumption (kWh/kg)	48	48	37
Heat demand steam (kWh/kg)	n.a.	n.a.	8,0
Capex[1] €/kW €/(kg/d)	 800 400	 1000 500	 800 520
O&M cost (€/(kg/d)/y)[1]	35	21	45
Hot idle ramp time (sec.)	10	1	180
Cold start ramp time (sec.)	300	10	4 hours
Footprint (M^2/MW)[2]	40	25	50
STACK			
Degradation (%/1000h)	0,1	0,12	0,5
Current density (A/cm^2)	1,0	3,0	1,5
Critical raw materials (mg/W)	0,0	0,25	n.a.

ISPT 1GW 2030 prognostication: 1GW Alkaline: EUR 730/kW, 1GW PEM: EUR 830/kW. All construction and electricity items included. Source ISPT 2022

*Standard boundary conditions that apply to all system KPIs: input of AC power and tap water; output of hydrogen meeting ISO 14687-2 at a pressure of 30 bar and hydrogen purity 5.0. Correction factors applied if actual boundary conditions are different.

1) Capital cost are based on 100 MW production volume for a single company and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital cost in O&M. Cost are for installation on a pre-prepared site (fundament/building and necessary pre-prepared site (fundament/building and necessary connections are available, Transformers & rectifiers not included.
2) Average specific space requirement of a MW system comprising all auxiliary systems to meet standard boundary conditions in 1) and built up as indoor installation

GREEN HYDROGEN

EACH TECHNOLOGY HAS ITS ADVANTAGES & DISADVANTAGES

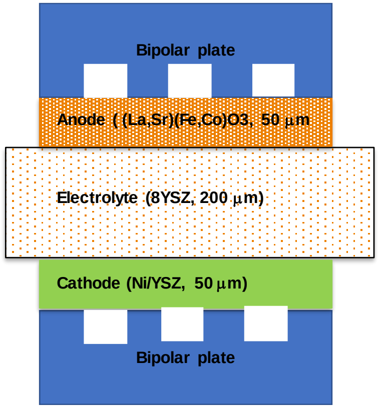
	Parameter	Units	PEM			LA			O-SOEC		
			Status	Interim Targets	Ultimate Targets	Status	Interim Targets	Ultimate Targets	Status	Interim Targets	Ultimate Targets
Stack	Total platinum group metal (PGM) content[15]	mg/cm^2	3.0	0.5	0.125	-	-	-	-	-	-
Stack	Total platinum group metal (PGM) content[15]	g/kW	0.8	0.1	0.03	-	-	-	-	-	-
Stack	Performance	A/cm^2 @V/cell	2.0 A/cm^2 @ 1.9 V	3.0 A/cm^2 @ 1.8 V	3.0 A/cm^2 @ 1.6 V	0.5 A/cm^2 @ 1.9 V	1.0 A/cm^2 @ 1.8 V	2.0 A/cm^2 @ 1.7 V	0.6 A/cm^2 @ 1.28 V	1.2 A/cm^2 @ 1.28 V	2.0 A/cm^2 @ 1.28 V
Stack	Electrical efficiency	kWh/kg H_2	51	48	43	51	48	45	34	34	34
Stack	Lifetime	Operation hours	40,000	80,000	80,000	60,000	80,000	80,000	20,000	40,000	80,000
Stack	Average degradation rate	mV/kh	4.8	2.3	2.0	3.2	2.3	2.1	6.4	3.2	1.6
Stack	Capital cost	$/kW	450	100	50	250	100	50	300	125	50
System	Energy efficiency[16]	kWh/kg H_2	55	51	46	55	52	48	47	44	42
System	Uninstalled capital cost	$/kW	1,000	250	150	500	250	150	2,500	500	200

Source: Energy Earthshots, U.S. Department of Energy, Hydrogen Shot – Water Electrolysis Assessment

SOEC IS FRAGILE… BUT

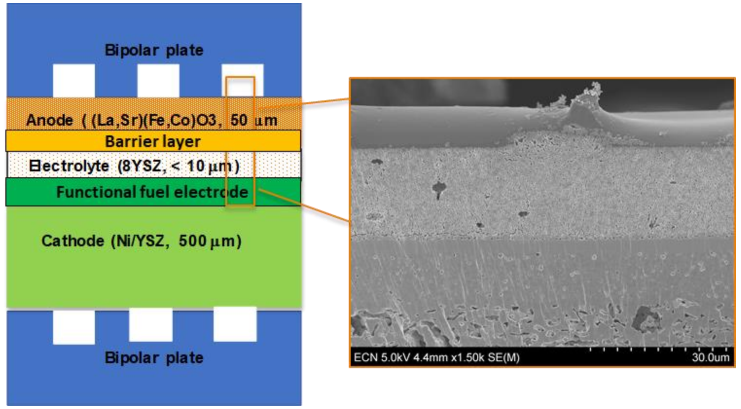
VARIOUS OEM's ARE LOOKING FOR SOLUTIONS (EXAMPLE CERES)

Electrolyte supported SOE
(ESC, T>800^{o}C)



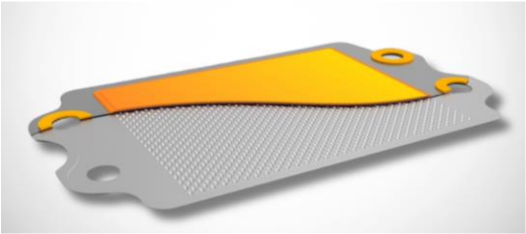
"Sunfire" type

Electrode (Anode) supported SOE
(ASC, 600-850^{o}C)



"other OEM" type

Source TNO Voltachem



- Thin ceramic sandwich on low cost perforated stainless steel
- Electrolyte (ceria based) reduce operating temperature 450-630^{o}C
- Metal support enables robust, laser welded seals

Source Ceres Hydrogen

NEW TYPE: METAL SUPPORTED SOEC

INTEGRATING SOEC WITH eSAF

MAXIMIZING ENERGY EFFICIENCY IS NEEDED

$$3\ H_2O + \text{energy} \longrightarrow 3\ H_2 + 1{,}5\ O_2$$

$$CO_2 + 3\ H_2 \longrightarrow -(CH_2)- + 2H_2O$$

$$H_2O + CO_2 + \text{energy} \longrightarrow -(CH_2)- + 1{,}5\ O_2$$

eSAF production is reverse combustion

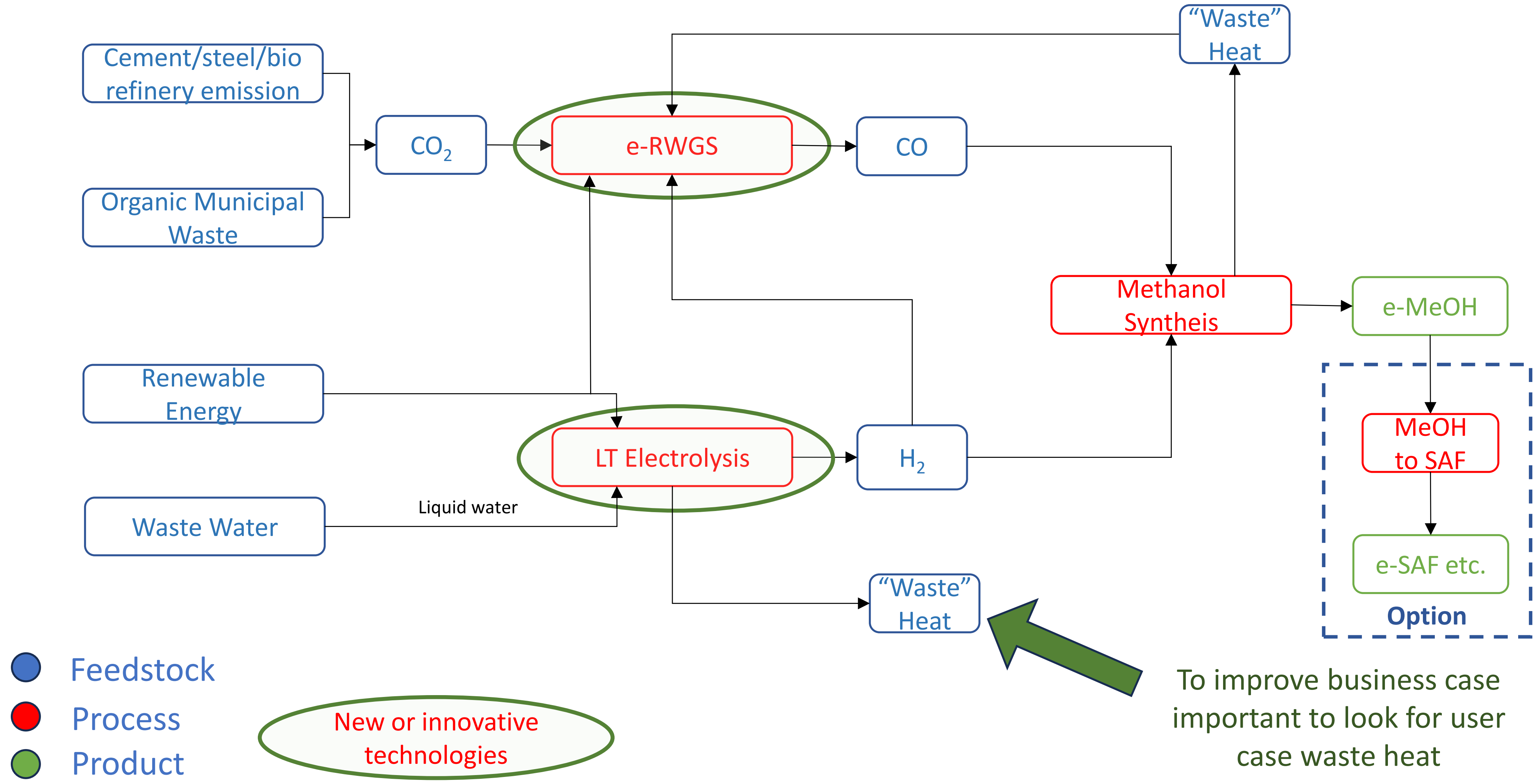
$$-(CH_2)- + 1{,}5\ O_2 \longrightarrow H_2O + CO_2 + \text{energy}$$

Production cost SAF = 10 times production cost conventional aviation fuel

THEREFORE WE NEED MORE EFFICIENT PROCESSES

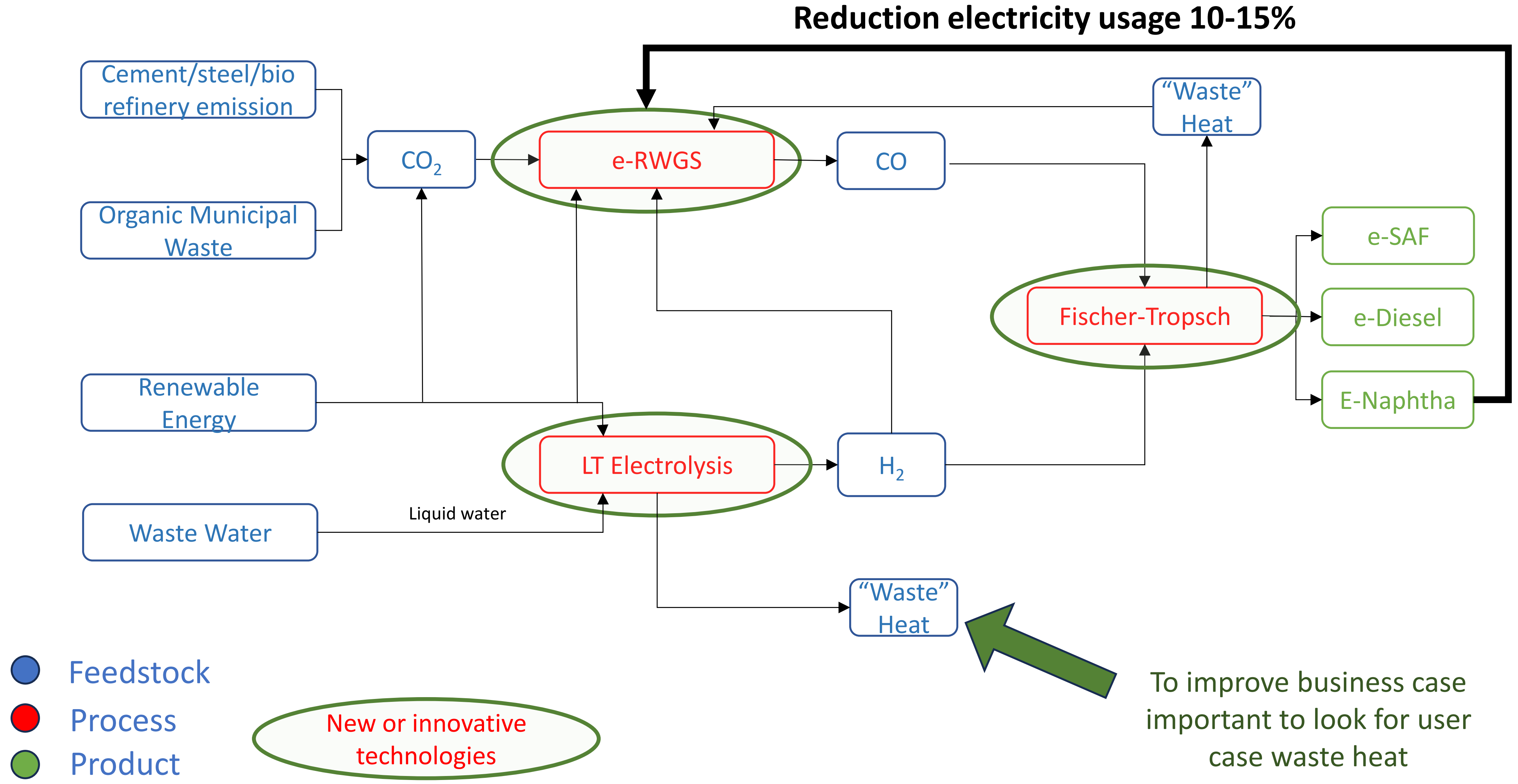
e-MeOH AS FEEDSTOCK FOR e-SAF (1/2)

STEP 1: GREEN HYDROGEN THROUGH LOW TEMPERATURE ELECTROLYSIS



e-SAF USING FISCHER - TROPSCH (1/2)

STEP 1: GREEN HYDROGEN THROUGH LOW TEMPERATURE ELECTROLYSIS



e-MeOH AS FEEDSTOCK FOR e-SAF (2/2)

STEP 2: INTRODUCTION SOEC

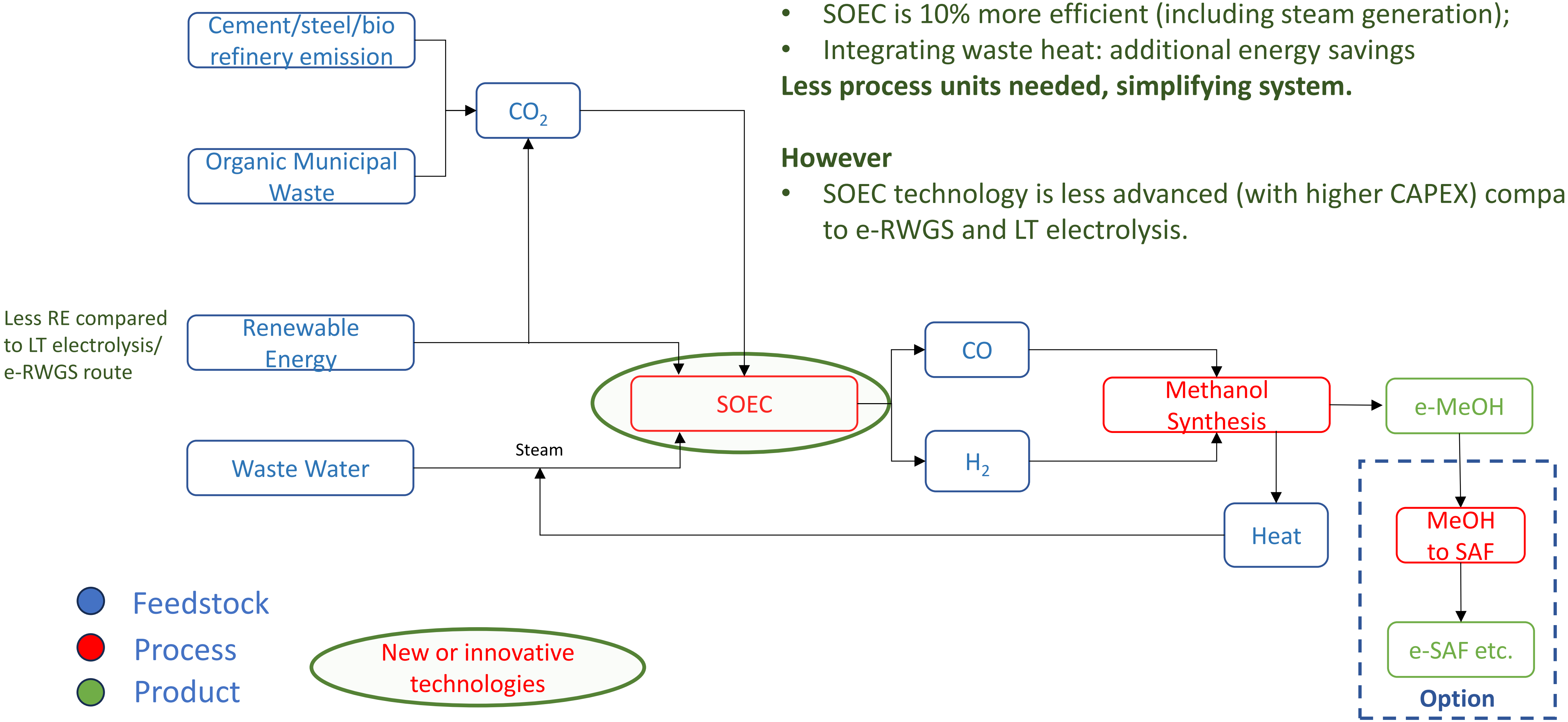
Improved efficiency:

- SOEC is 10% more efficient (including steam generation);
- Integrating waste heat: additional energy savings

Less process units needed, simplifying system.

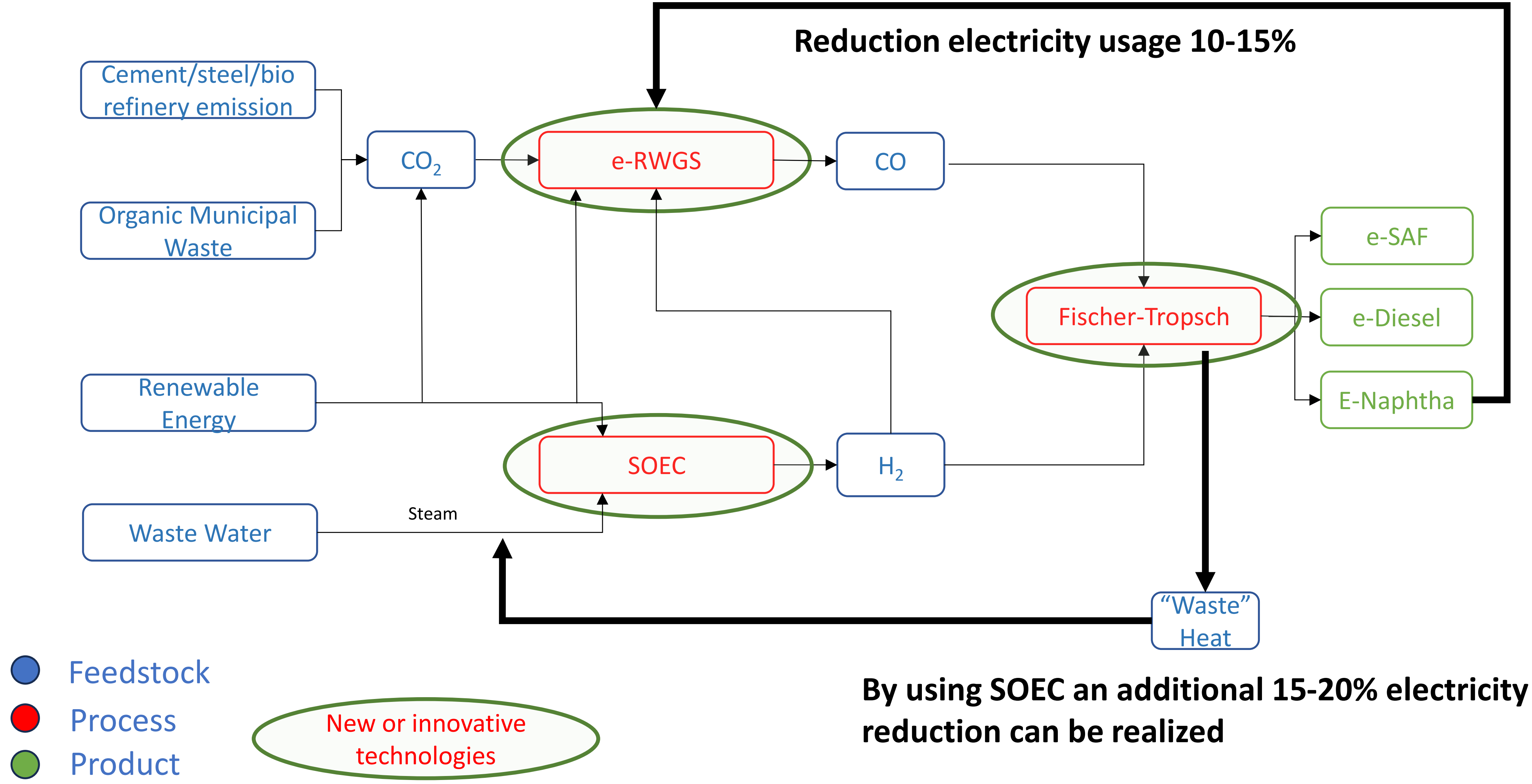
However

- SOEC technology is less advanced (with higher CAPEX) compared to e-RWGS and LT electrolysis.



e-SAF USING FISCHER - TROPSCH (1/2)

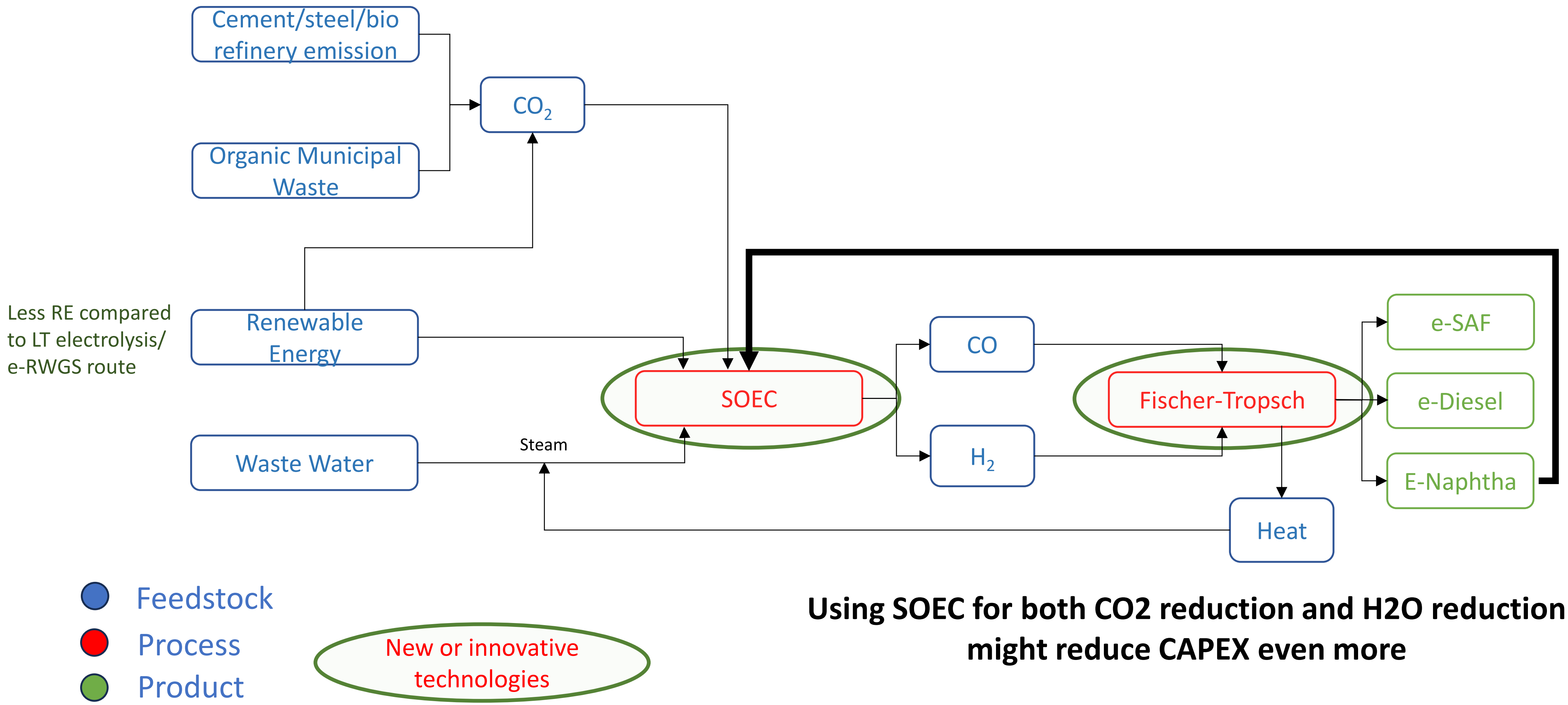
STEP 1: GREEN HYDROGEN THROUGH LOW TEMPERATURE ELECTROLYSIS



By using SOEC an additional 15-20% electricity reduction can be realized

e-SAF USING FISCHER - TROPSCH (2/2)

STEP 2: INTRODUCTION SOEC

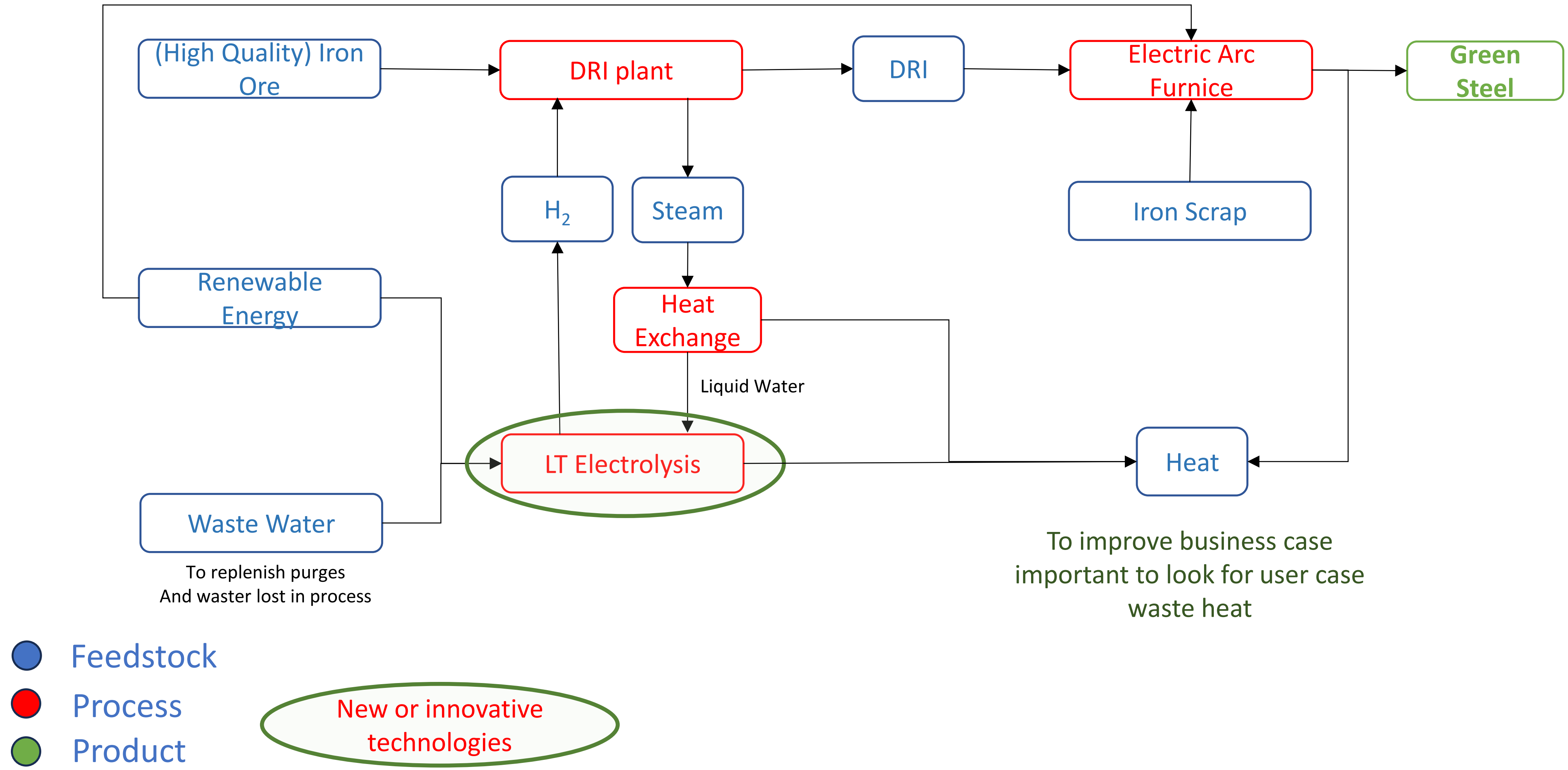


Using SOEC for both CO2 reduction and H2O reduction might reduce CAPEX even more

INTEGRATING SOEC WITH DRI OR IRON FUEL

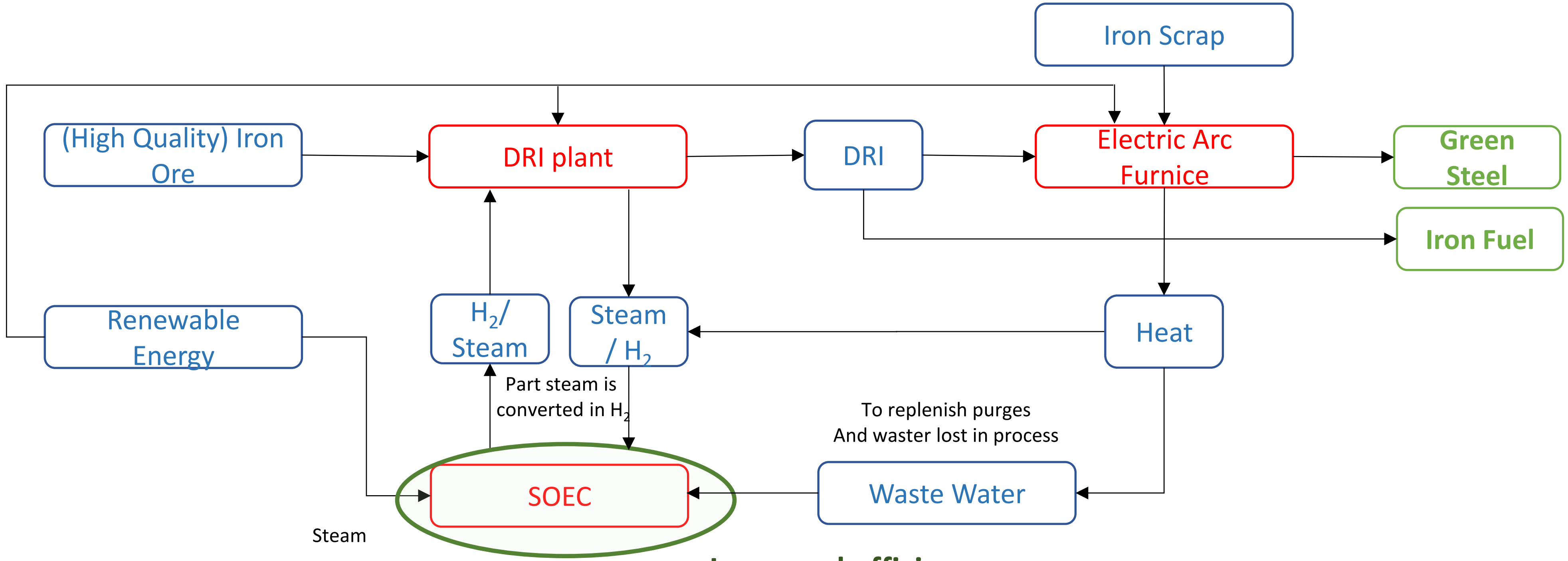
DRI / IRON FUEL (1/3)

STEP 1: GREEN STEEL PRODUCTION



DRI / IRON FUEL (2/3)

STEP 1: INTRODUCING SOEC TO PRODUCE GREEN STEEL MORE EFFICIENT



Improved efficiency:

- SOEC is 10% more efficient (including steam generation);
- Integrating waste heat: additional 20% energy reduction SOEC;
  - ➢ **Two points above reduce energy consumption with 30%;**
- Less process units needed, simplifying system.

However

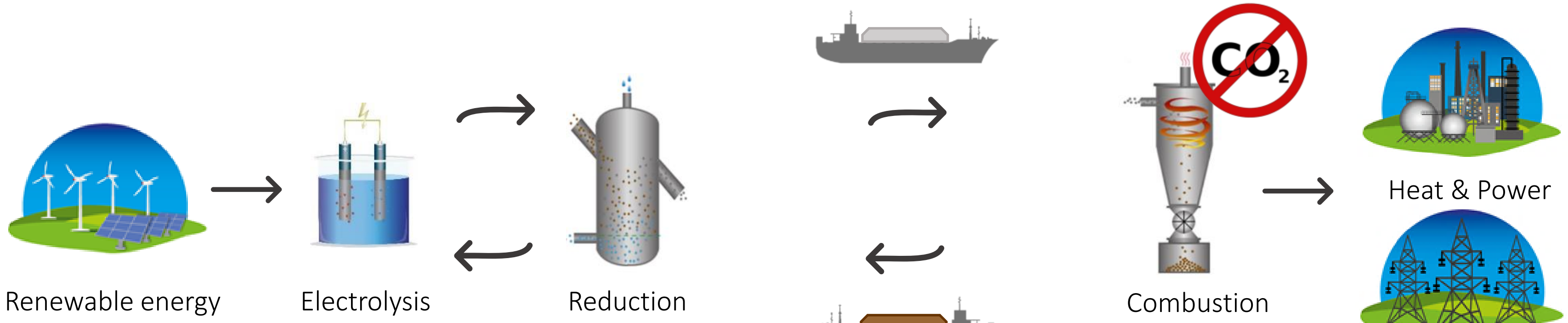
- SOEC technology is less advanced (with higher CAPEX) compared to e-RWGS and LT electrolysis.

Feedstock
Process
Product

New or innovative technologies

DRI / IRON FUEL (3/3)

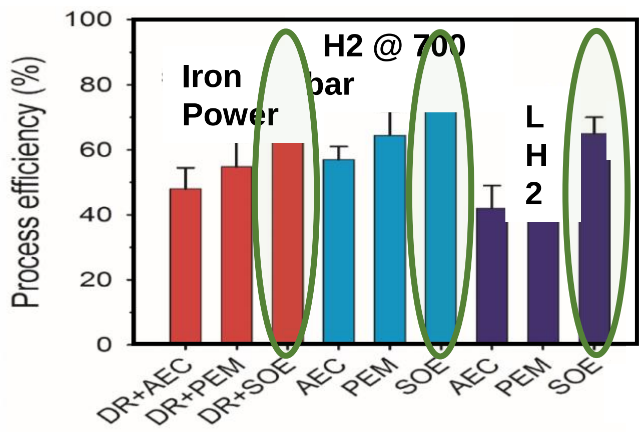
INNOVATIVE WAY FOR CHEAP, SAFE & EASY TRANSPORT & STORAGE OF RENEWABLE ENERGY



$Fe_2O_3 + 3\,H_2 \rightarrow 2\,\mathrm{Fe} + 3\,\mathrm{H_2}O$

$4\,\mathrm{Fe} + 3\,\mathrm{O_2} \rightarrow 2\,Fe_2O_3$

SOEC will improve efficiency (versus PEM or Alkaline) of iron fuel technology system



DR = Direct Reduction (Regeneration plant)

AEC = Alkaline Electrolysis Cell (Electrolyser)

PEM = Proton Exchange Membrane (Electrolyser)

SOE = Solid Oxide Electrolyser

CH2 = Compressed hydrogen @ 700 bar

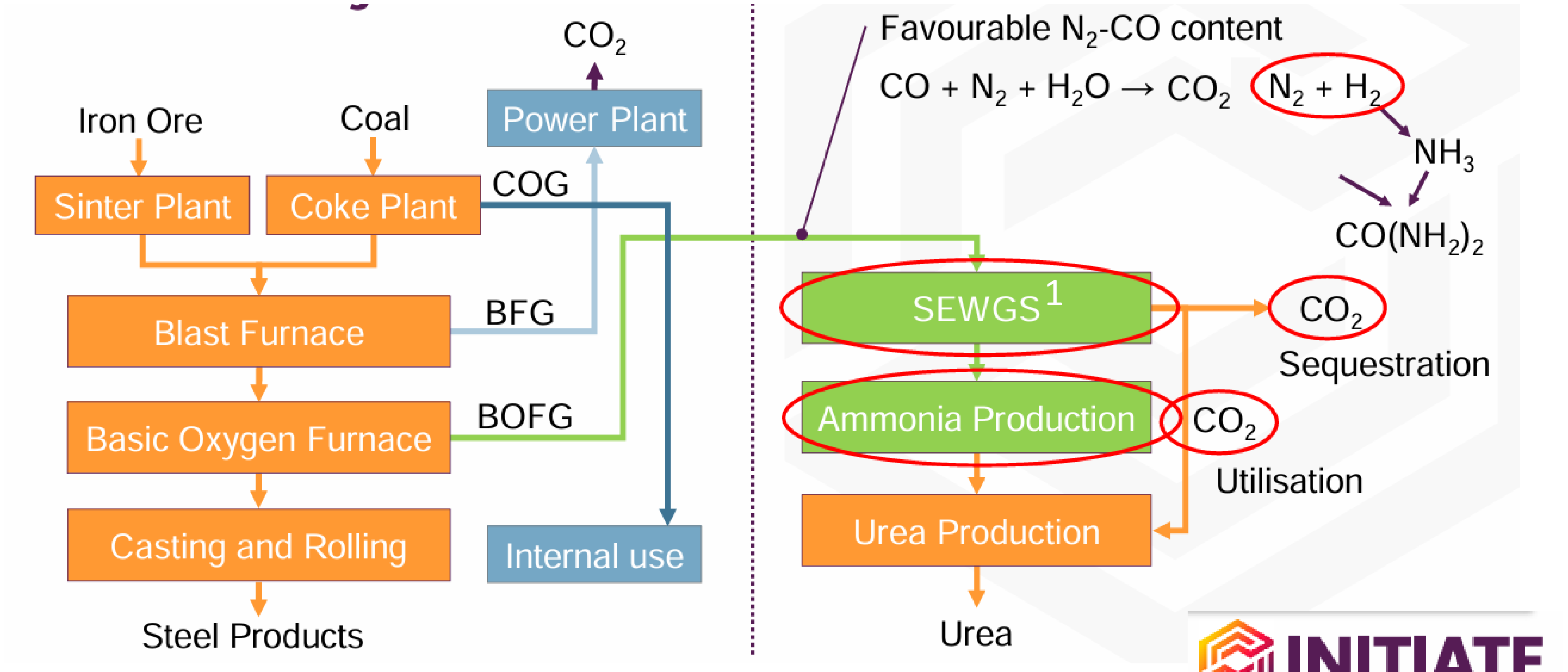
LH2 = Liquified hydrogen

Source: Metalot

INDUSTRIAL INTEGRATION (FUTURE POSSIBILITIES)

JOINT RESEARCH INDSUSTRY PROJECT INITIATE: INDUSTRIAL SYMBIOSIS STEEL & FERTILIZER

Create bankable case for a first commercial size demonstrator at a scale of 50 kt/y urea production capacity on the basis of BOF



1) SEWGS = Sorption enhanced water gas shift reaction

INDUSTRIAL INTEGRATION (FUTURE POSSIBILITIES)

JOINT RESEARCH INDSUSTRY PROJECT INITIATE: INDUSTRIAL SYMBIOSIS STEEL & FERTILIZER

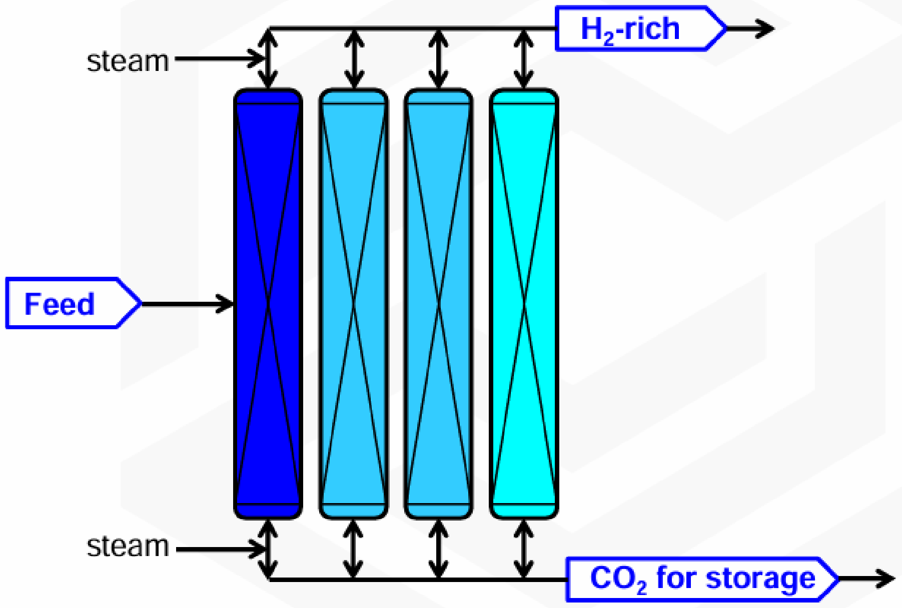
Enabling technologies

Sorption Enhanced Water Gas Shift - SEWGS

- TNO development
- Industrially sourced solid adsorbent
- Combining CO_2 separation with WGS reaction
- Optimizing N_2/N_2 while removing CO_2
- Minimization of energy requirement

Sub-stoichiometric NH_3 synthesis

- NextChem development
- Suitable for variable H_2/N_2 ratio
- Simplification of knock-out and recycle
- More suitable for dynamics



INITIATE
A STEPWISE PROJECT

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Smart invest today, Lower cost tomorrow

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