Innovation and Development in Technology Upscaling

Bart van den Bosch
Scientist Electrochemistry

Why

- Aspects for upscaling from lab to pilot stage easily overlooked in early stage research

Laboratory

Miniplant (Celbicon project)

Pilot Plant

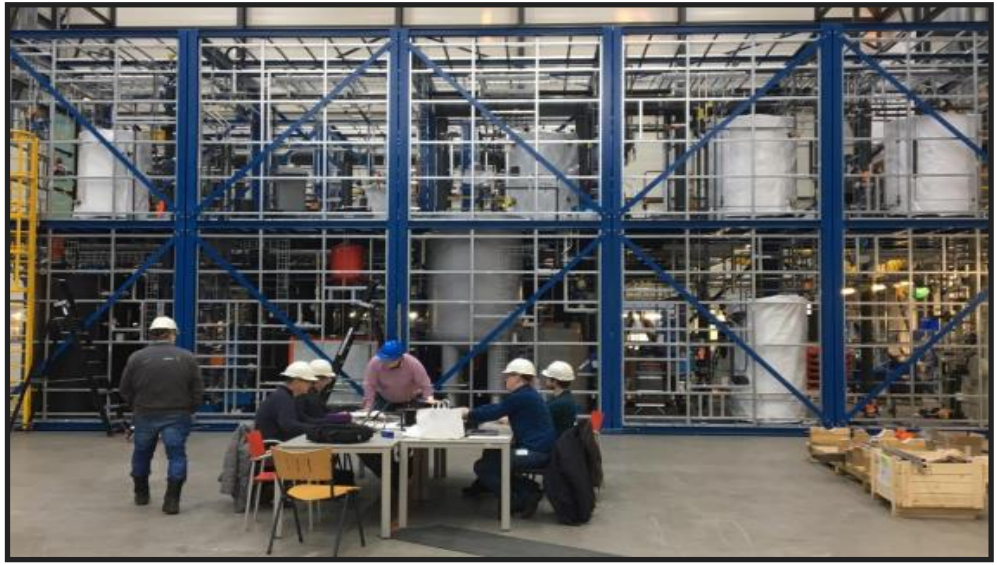
- Important later-stage aspects for early stage research

Avantium's Renewable Chemistries *develops new, industrial chemical technologies*

Ideation/ Feasibility → **Development** → **Piloting** → **Post-Pilot Plant** → **Commercialization**

H-cell testing

Electrochemistry skid at Avantium



Avantium's DAWN pilot plant

Avantium's Renewable Chemistries *develops new, industrial chemical technologies*

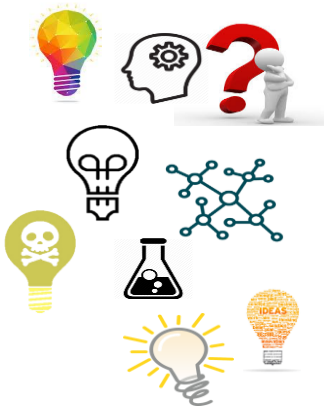
In the chemical industry (..) time (..) to pass from ideation to commercialization is (..) up to about 10 years.[1]

Faster = more risk, slower = less risk

[1]*Specifying Technology Readiness Levels for the Chemical Industry*, Schomäcker, *Ind. Eng. Chem. Res.* **2019**, 58, 6957–6969

Avantium's Renewable Chemistries *develops new, industrial chemical technologies*

Ideation/ Feasibility → **Development** → **Piloting** → **Post-Pilot Plant** → **Commercialization**



3 things that can happen with ideas

A winning idea

A failing idea

Failing fast = failing cheap

A neverending idea

Goal

Research question(s)

Sub-questions

Goal

Research question(s)

Sub-questions

Goal

Research question(s)

Sub-questions

Hypothesis

Goal

Research question(s)

Sub-questions

Hypothesis

Experimental

Goal

Research question(s)

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Conclusion

Goal

Research question(s)

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Hypothesis

Experimental

Conclusion

Put your ideas to the test

- Define Technology Readiness Levels (TRL)
- Industrially relevant conversion process
- Define process from feedstock to product
- Techno-Economic Assessment (TEA)
- Perform Life-Cycle Assessment (LCA)

Put your ideas to the test

TRL

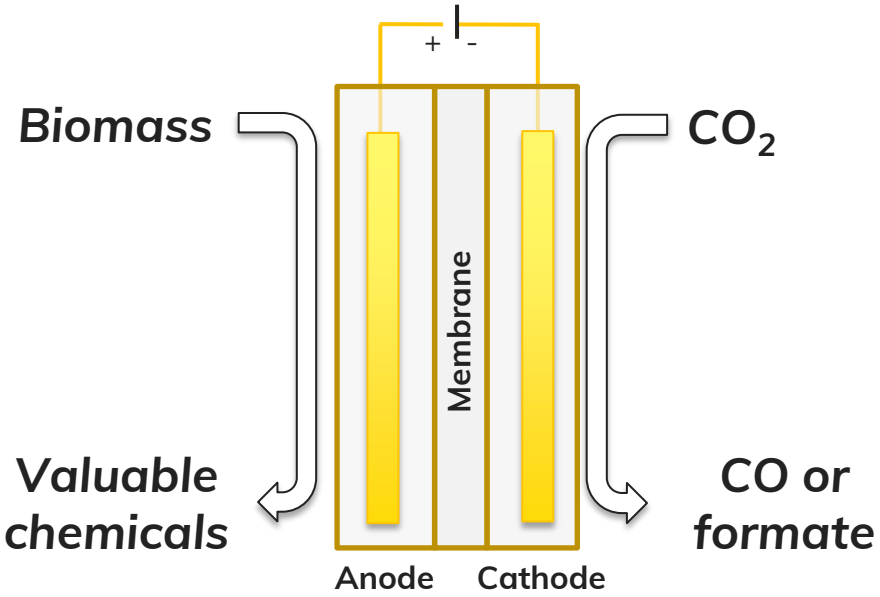
Process from feedstock to product

Continuous conversion process

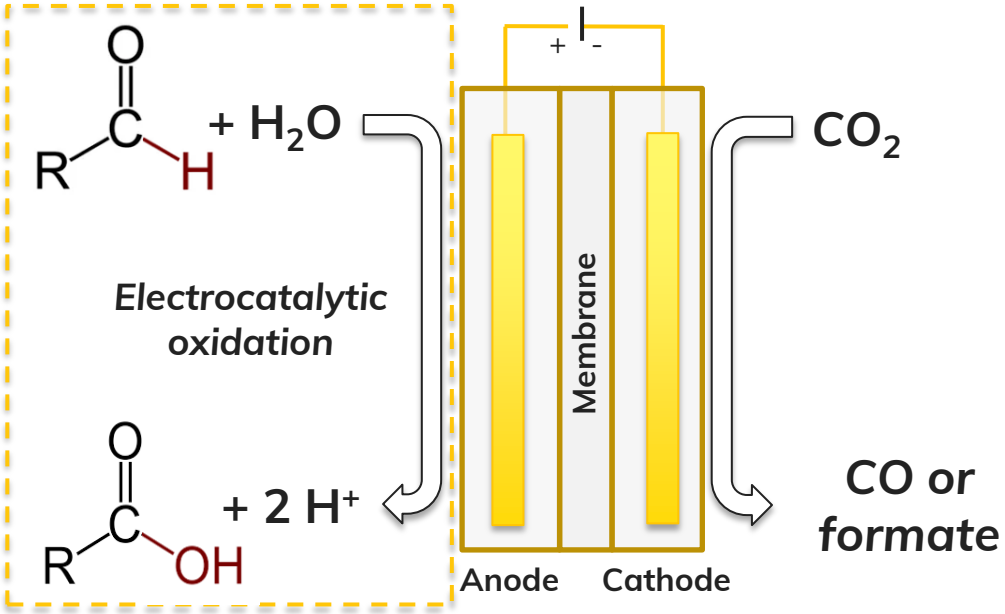
TEA

LCA

Context: oxidation reactions for paired electrolysis



Context: oxidation reactions for paired electrolysis



Define Technology Readiness Levels (TRL)

Industrially relevant conversion process

Define process from feedstock to product

Techno-Economic Assessment (TEA)

Life-Cycle Assessment (LCA)

Technology readiness level[1]

TRL	Title	Typical Workplace
1	Idea	Office
2	Concept	Office/Laboratory
3	Proof of concept	Laboratory
4	Preliminary process development	Laboratory
5	Detailed process development	Laboratory/miniplant
6	Pilot trials	Pilot plant/technical center
7	Demonstration and full-scale engineering	Pilot plant/technical center, demo plant
8	Commissioning	Production site
9	Production	Production site

[1]*Specifying Technology Readiness Levels for the Chemical Industry*, Schomäcker, *Ind. Eng. Chem. Res.* **2019**, 58, 6957–6969

Technology readiness level

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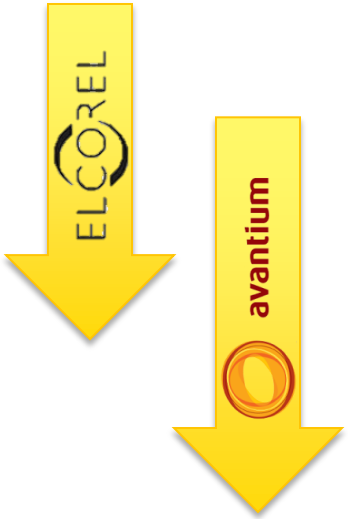
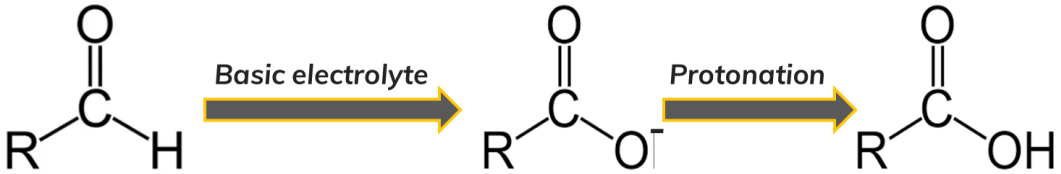


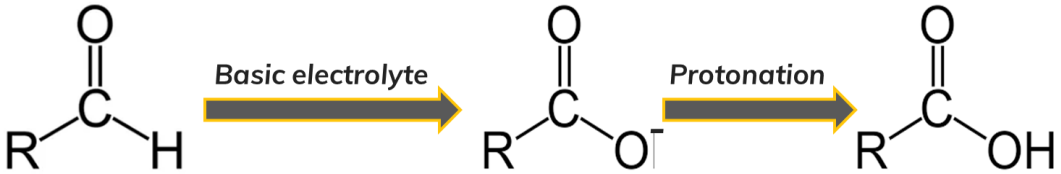
Work at appropriate TRL

Research Strategy

1. 

2. 

Research Strategy

1. 

Literature search: TRL 3

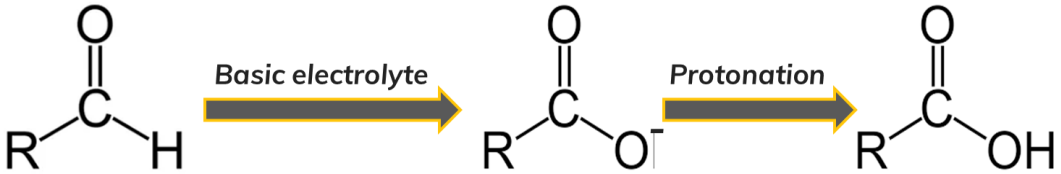
- Well-defined electrocatalyst and catalytic conditions
- Relevant rates and selectivity
- H-cell, batch setup

2. 

Literature search: TRL ≤ 1

- No precedents
- Hints for catalytic materials from other fields (organic chemistry)

Outcome

1. 

Literature reproduced, ready to proceed to TRL 4

2. 

Experiments performed, no catalyst found

Route 2.

Route 1.

TRL 1	Idea
TRL 2	Concept
TRL 3	Proof of concept
TRL 4	Preliminary process development
TRL 5	Detailed process development

Break

Define Technology Readiness Levels (TRL)

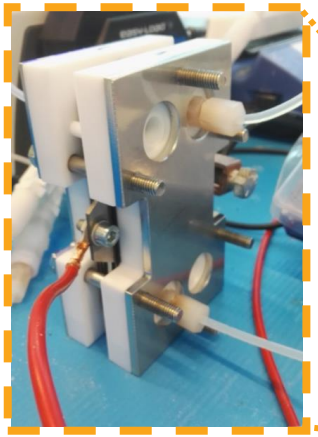
Industrially relevant conversion process

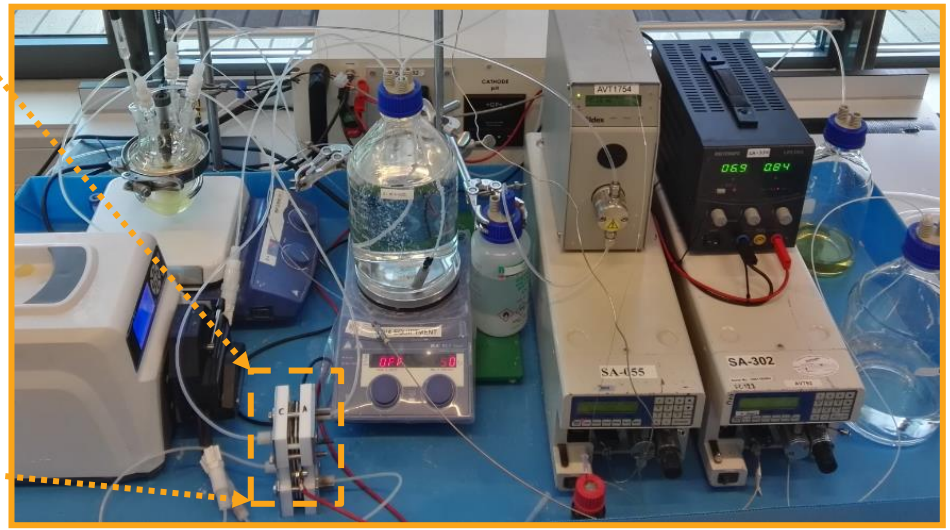
Define process from feedstock to product

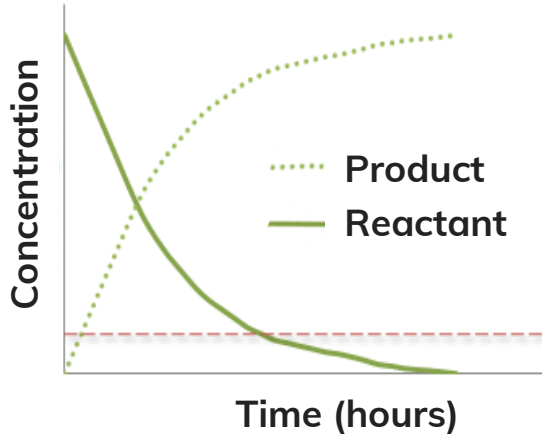
Techno-Economic Assessment (TEA)

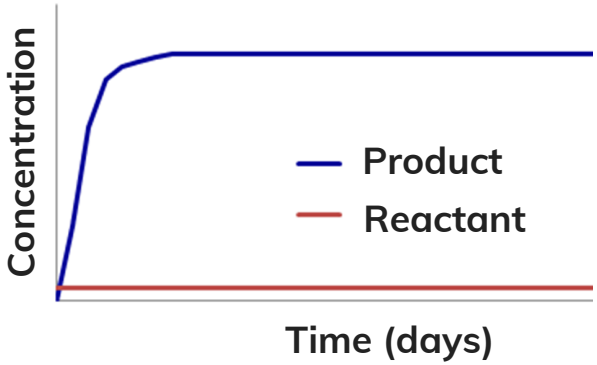
Life-Cycle Assessment (LCA)

Stable, continuous conversion process







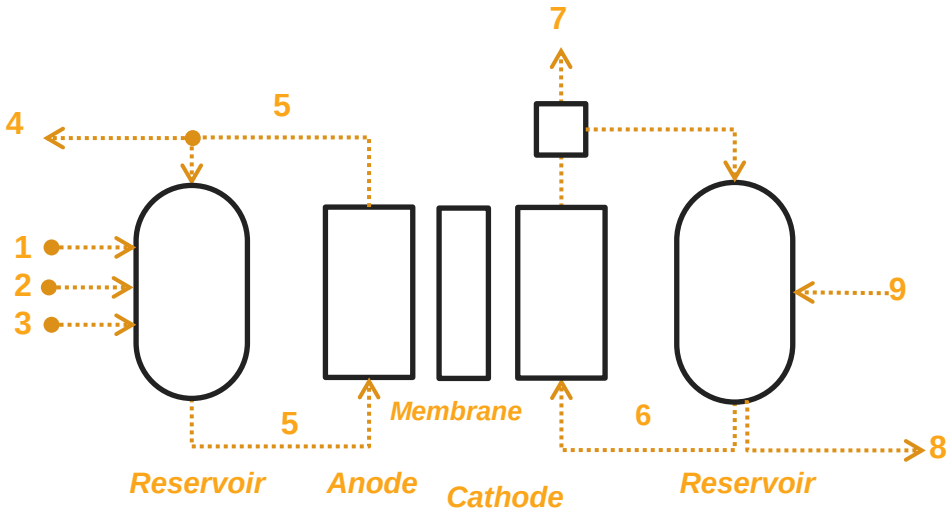


Stable, continuous conversion process

- Demonstrate stability of the process
- Define industrially relevant (continuous) process
- Produce high product concentration and low reactant concentration

Stable, continuous conversion process

Make a Process Flow Diagram (PFD) with mass balances



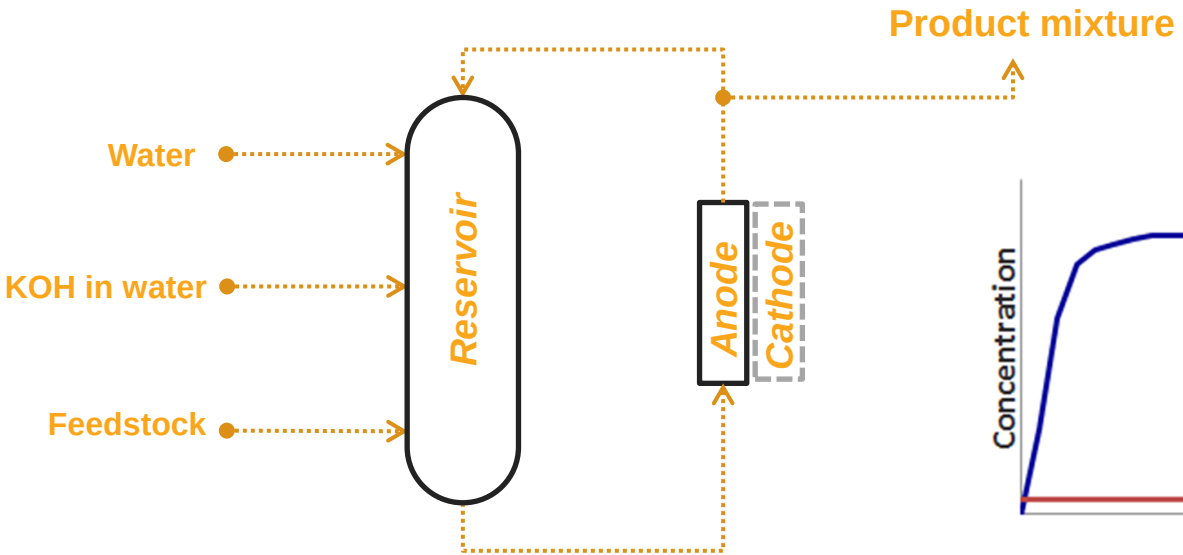
Stream #	Flow (kg/hour)	Composition
1	5	Water
2	1	KOH (10 w%), water (90 w%)
....	....	
9	8	Reactant (0.5w%) Product (10w%) KOH (1 w%) Impurity A (0.5w%) Water (88w%)

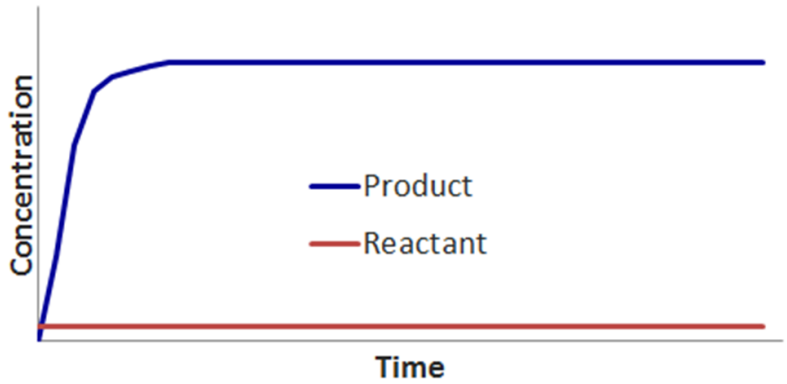
Stable, continuous conversion process

Make a Process Flow Diagram (BFD) with mass balances

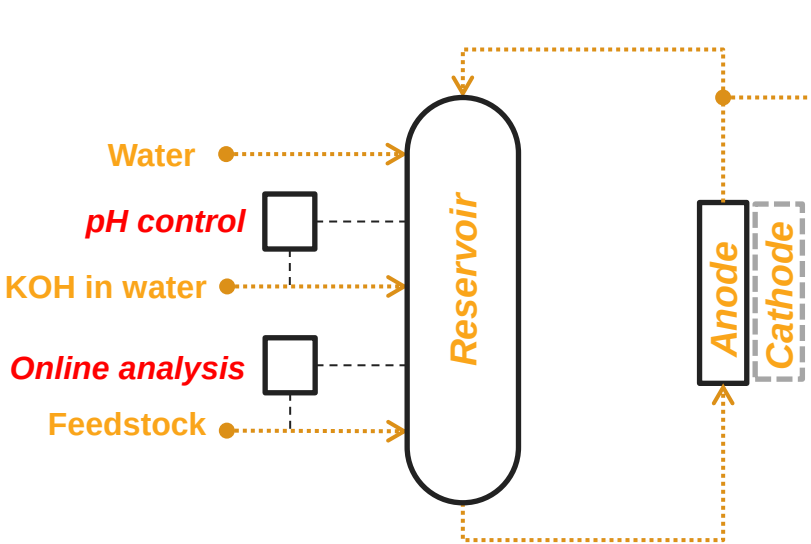
- *Required for selecting equipment and instruments*
- *Input for economic analysis*
- *Input for engineering activities*
- ***Forces to think about process in detail***
- ***Helps in communication***

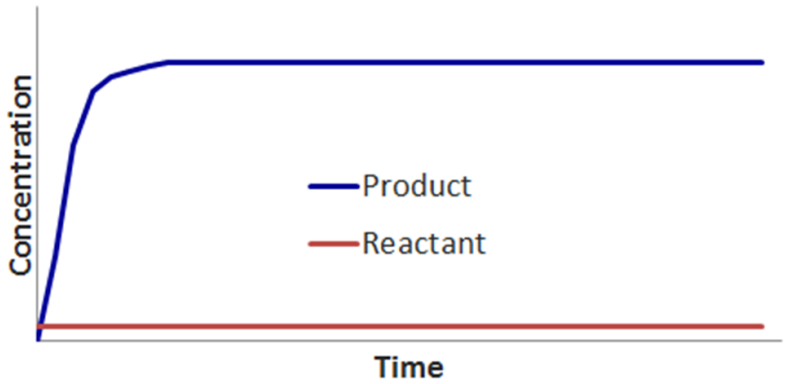
Stable, continuous conversion process





Stable, continuous conversion process





Process automation is essential for long term testing

TRL 4	Preliminary process development	Laboratory
TRL 5	Detailed process development	Laboratory/miniplant

TRL 4	Preliminary process development	Laboratory
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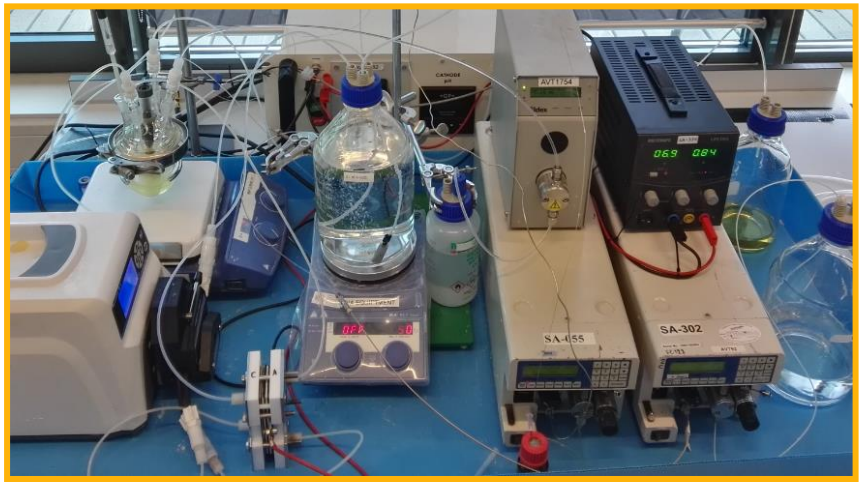
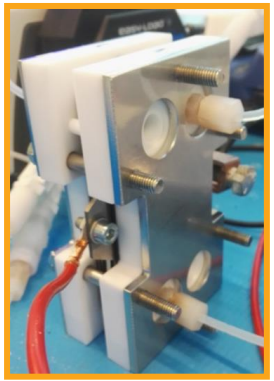
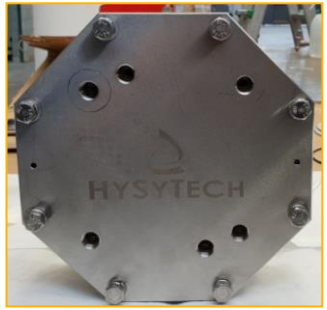
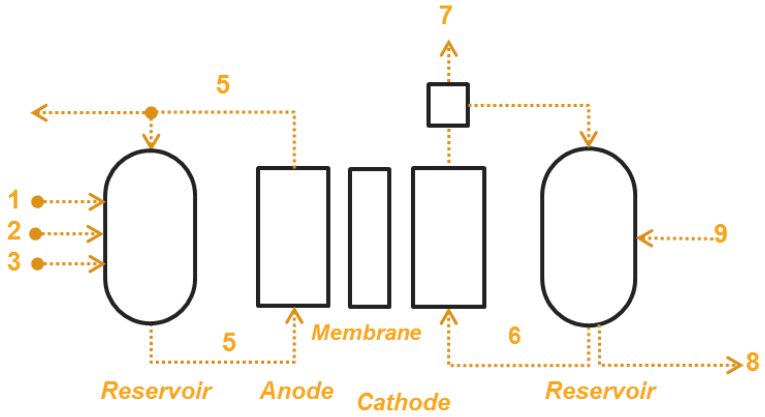




TRL 4: Mostly commerially available equipment

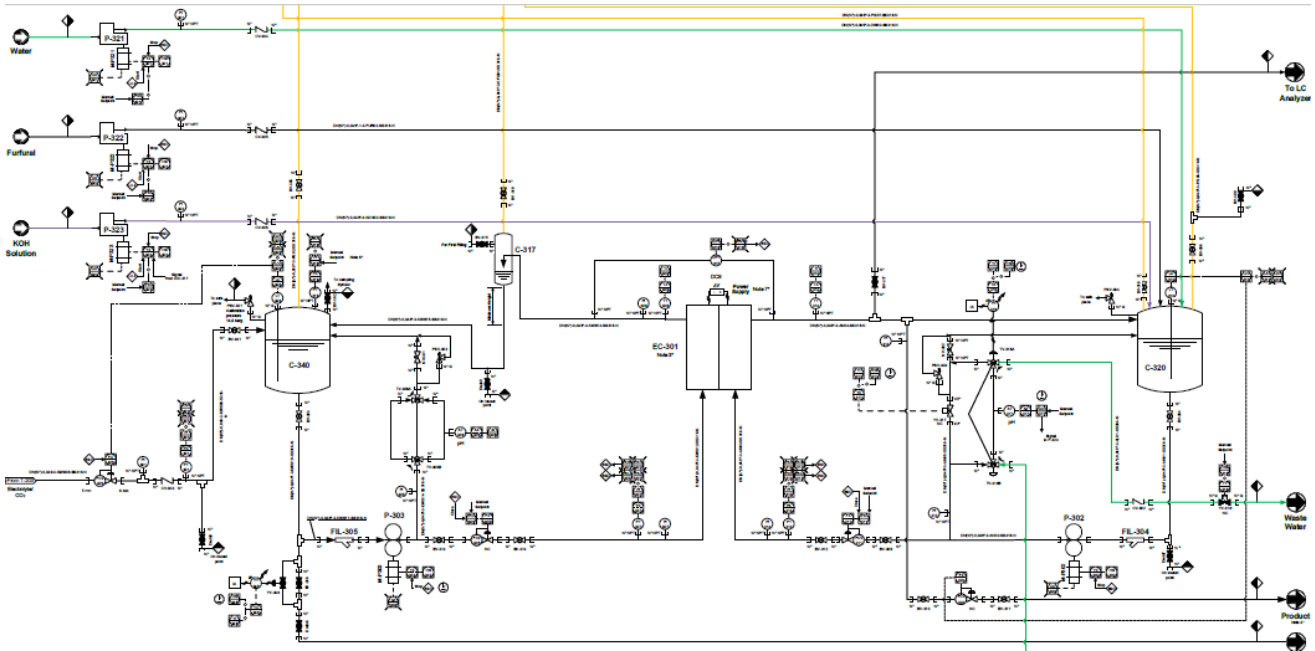


TRL 5: More custom made equipment



From Process Flow Diagram (PFD) to Piping and Instrumentation Diagram (P&ID).

- P&ID is leading technical document for plant building



Define Technology Readiness Levels (TRL)

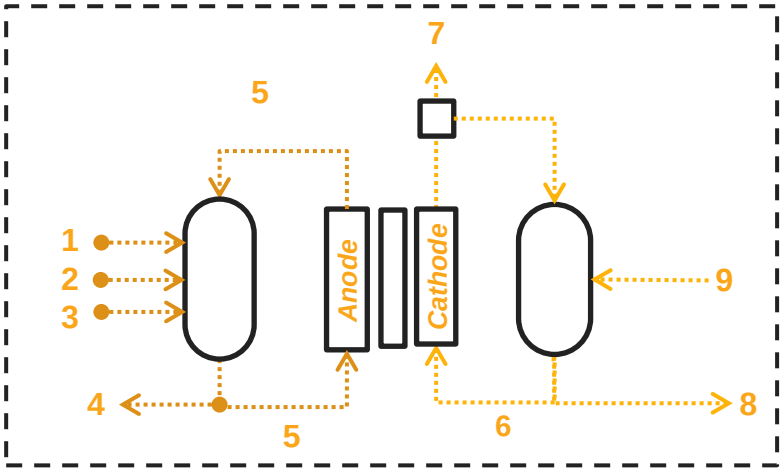
Industrially relevant conversion process

Define process from feedstock to product

Techno-Economic Assessment (TEA)

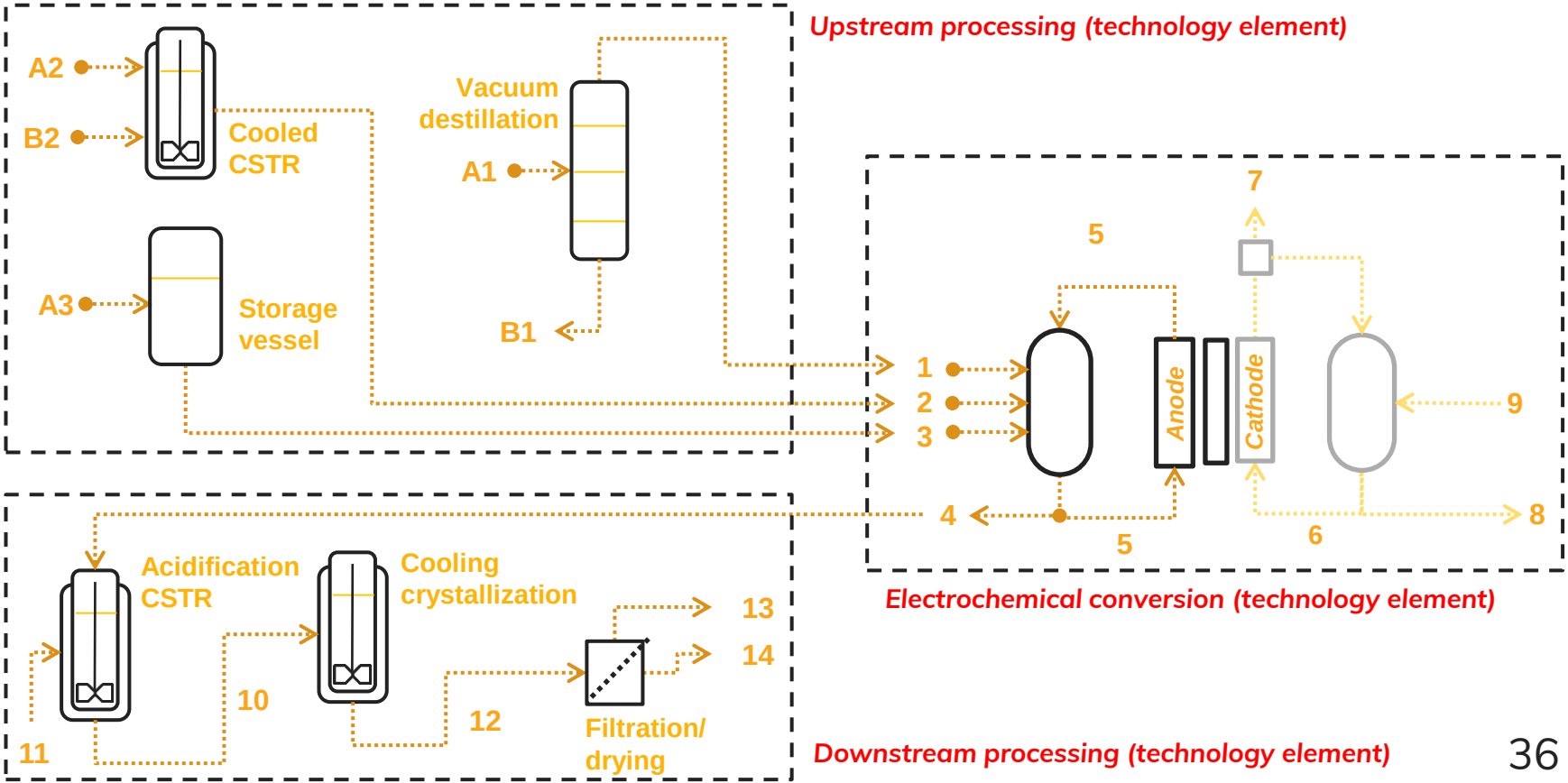
Life-Cycle Assessment (LCA)

Define process from feedstock to product

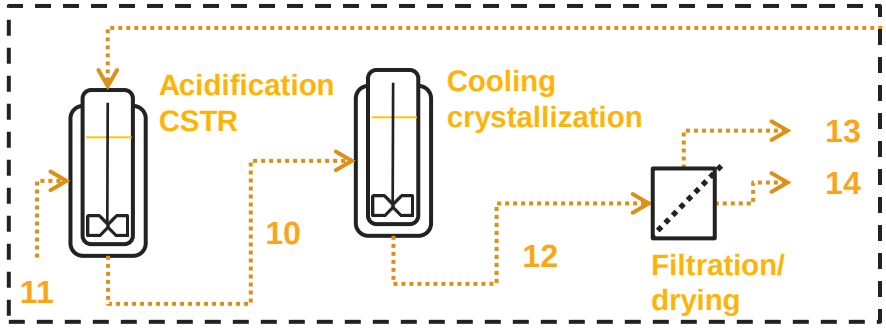


Electrochemical conversion (technology element)

Define process from feedstock to product



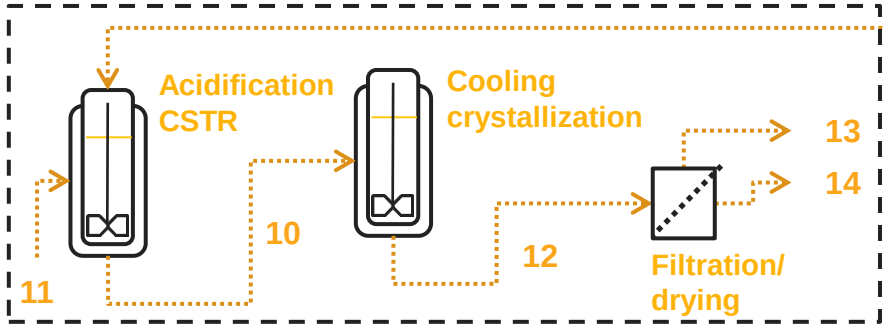
Mass and energy balance



Downstream processing

Stream #	Flow (kg/hour)	Composition
1	10	Water
….	…..	…..
9	20	Water (80w%) Product (10w%) KOH (1w%) Reactant (3 w%) Contaminant x (0.5 w%) Contaminant y (0.5 w%)
10	23	Water (79w%) Product (8 w%) H_2SO_4 (2 w%) K_2SO_4 (2 w%) Reactant (2w%) Contaminant x (0.5 w%) Contaminant y (0.5 w%)
…..	…..	……..

Mass and energy balance



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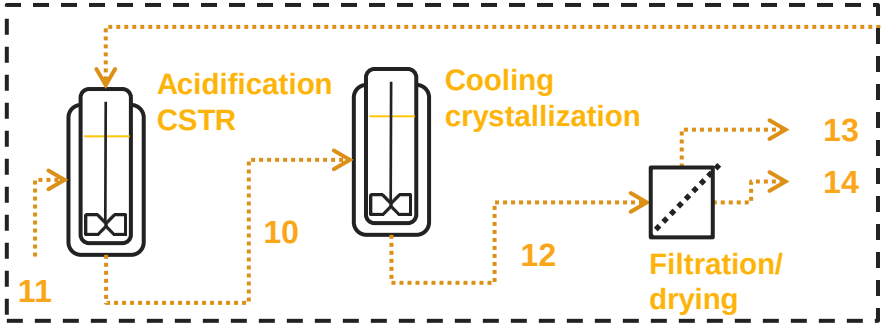
…..	…..	…….

Energy requirement cooling crystallization
Energy to cool water stream
Energy to crystallize product
Energy efficiency unit
Energy consumption for stirrer
…….

Mass and energy balance



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…..	…..	……

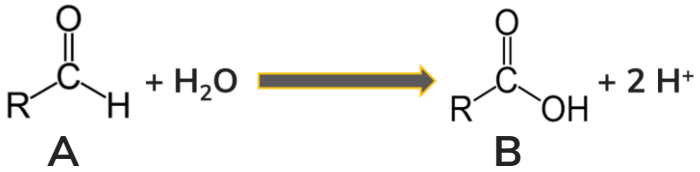
Process simulation software to produce mass and energy balances

Energy requirement cooling crystallization
Energy to cool water stream
Energy to crystallize product
Energy efficiency unit
Energy consumption for stirrer
……

- Define Technology Readiness Levels (TRL)
- Industrially relevant conversion process
- Define process from feedstock to product
- **Perform techno-economic assessment (TEA)**
- Perform life-cycle assessment (LCA)

Detail of TEA is coupled to TRL

TRL	Title
1	**Idea**
2	Concept
3	Proof of concept
4	Preliminary process development
5	Detailed process development
6	Pilot trials
7	Demonstration and full-scale engineering
8	Commissioning
9	Production



- **Costs of A, value of B.**
- **Atom efficiency = + 16 g/mol**
- **....**

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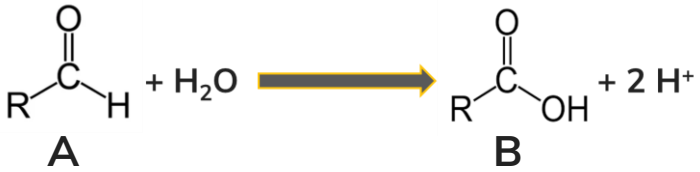

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- **Competitive technologies**
- **Initial market potential identified.**
- **…**

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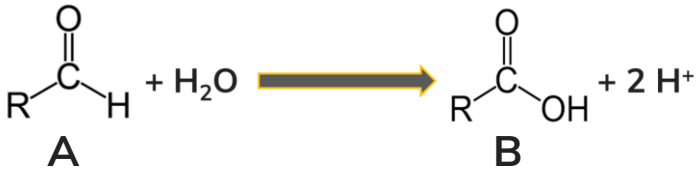

TRL	Title
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5	Detailed process development
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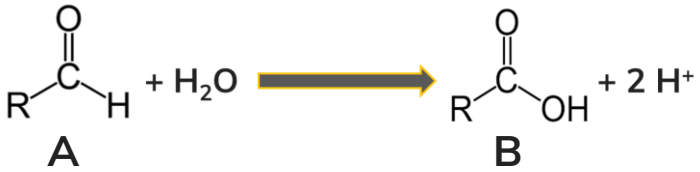
- **Cell potential and current density**
- **Conversion efficiency and selectivity**
- **…**

Detail of TEA is coupled to TRL



TRL	Title
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2	Concept
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4	**Preliminary process development**
5	Detailed process development
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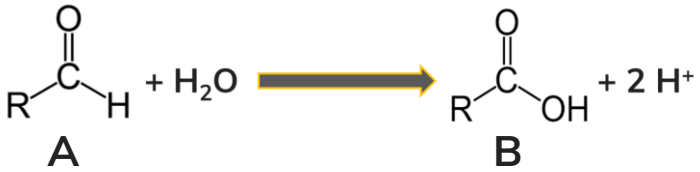
- **Catalytic system stability**
- **Material input /ton product**
- **Unit operations for up-and downstream processing**
- **....**

Detail of TEA is coupled to TRL



TRL	Title
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2	Concept
3	Proof of concept
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5	**Detailed process development**
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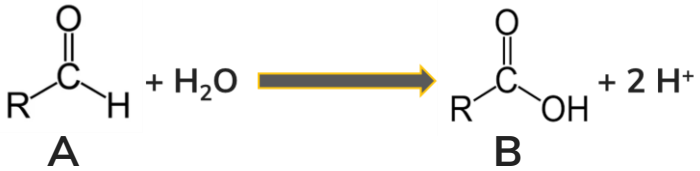
8	Commissioning
9	Production

- **Good estimate of CAPital Expenses (CAPEX)**
- **Power consumption of whole process**
- **Good estimate OPerational Expenses (OPEX)**

Detail of TEA is coupled to TRL

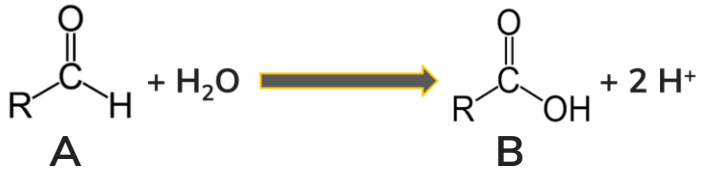


TRL	Title
1	Idea
2	Concept
3	Proof of concept
4	Preliminary process development
5	Detailed process development
6	**Pilot trials**
7	**Demonstration and full-scale engineering**
8	**Commissioning**
9	**Production**

- Define Technology Readiness Levels (TRL)
- Industrially relevant conversion process
- Define process from feedstock to product
- Perform techno-economic assessment (TEA)
- **Perform life-cycle assessment (LCA)**

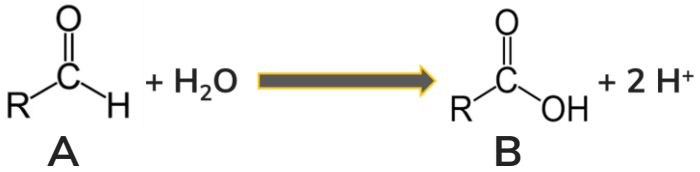
Detail of LCA is coupled to TRL

TRL	Title
1	**Idea**
2	Concept
3	Proof of concept
4	Preliminary process development
5	Detailed process development
6	Pilot trials
7	Demonstration and full-scale engineering
8	Commissioning
9	Production



- **Bio-based compounds**
- **Electrification**
- **…**

Detail of TEA is coupled to TRL



TRL	Title
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2	**Concept**
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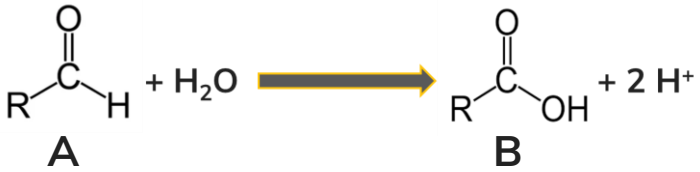
8	Commissioning
9	Production

- **Competitive technologies**
- **Material availability and sustainability**
- **…**

Detail of TEA is coupled to TRL



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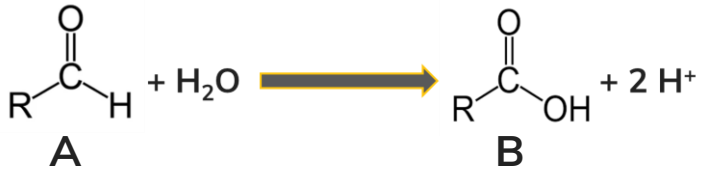
9	Production

- **Cell potential and current density**
- **Conversion and selectivity**
- **Initial down-stream processing**
- **.....**

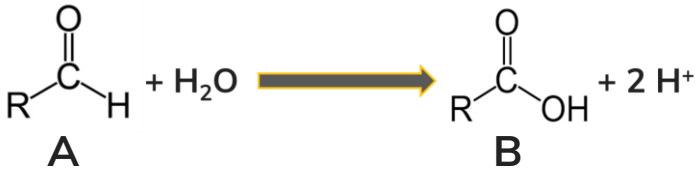
Detail of TEA is coupled to TRL



TRL	Title
1	Idea
2	Concept
3	Proof of concept
4	**Preliminary process development**
5	Detailed process development
6	Pilot trials
7	Demonstration and full-scale engineering
8	Commissioning
9	Production

- **Material input /ton product**
- **Unit operations for up-and downstream processing**
- **....**

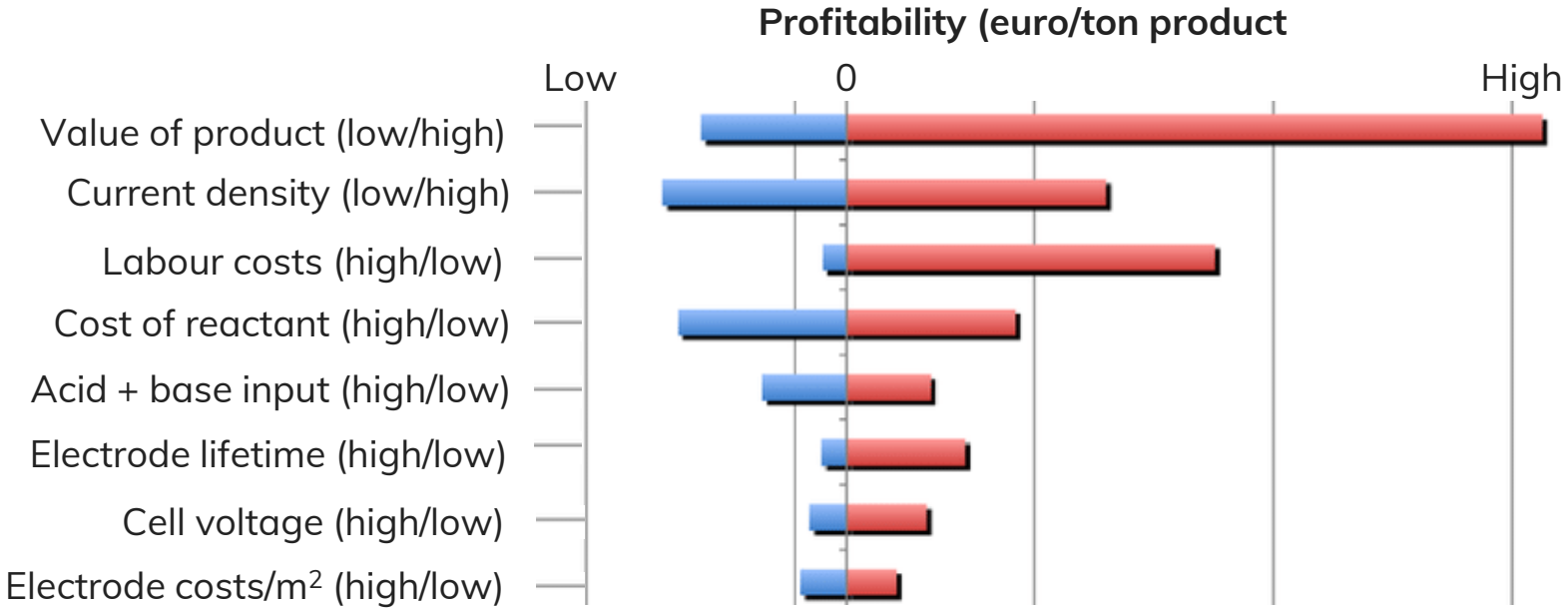
Detail of TEA is coupled to TRL



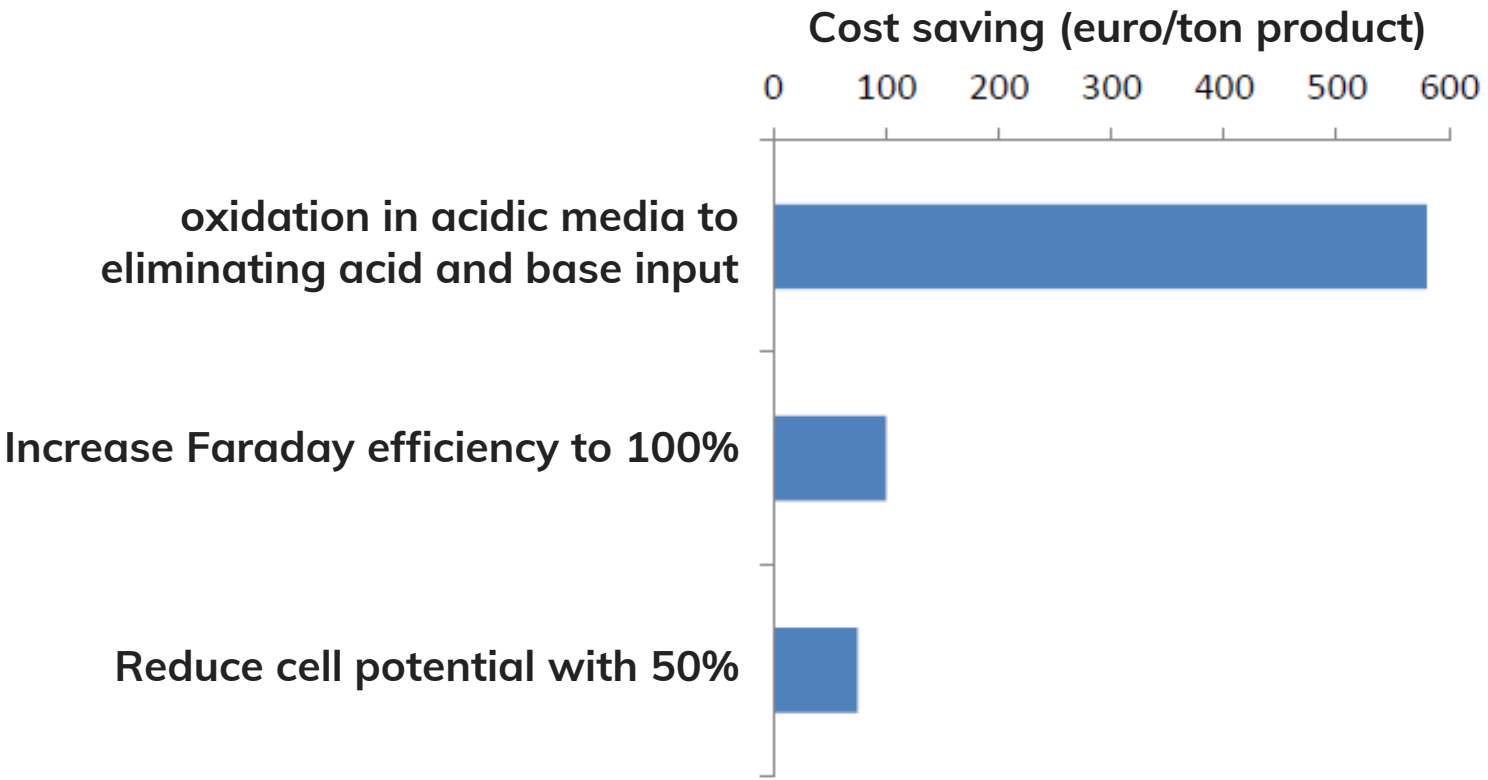
TRL	Title
1	Idea
2	Concept
3	Proof of concept
4	Preliminary process development
5	**Detailed process development**
6	Pilot trials
7	Demonstration and full-scale engineering
8	Commissioning
9	Production

- **Power consumption of whole process**
- **Material input**
- **.....**

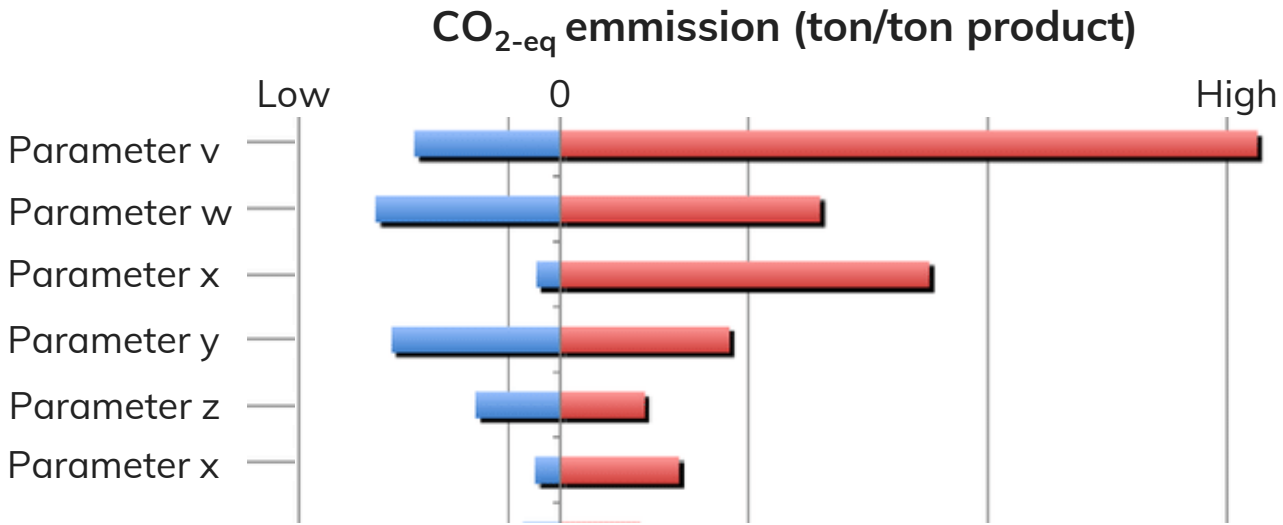
TEA and LCA are tools to prioritize research topics




O
C
R
H
+ H2O
O
C
R
OH
+ 2 H+


Cost saving (euro/ton product)
0
100
200
300
400
500
600
oxidation in acidic media to eliminating acid and base input
Increase Faraday efficiency to 100%
Reduce cell potential with 50%

TEA and LCA are tools to prioritize research topics



Put your ideas to the test

Appropriate TRL?

Industrially relevant conversion process

Process from feedstock to product

TEA

LCA

Talk about your ideas

Technology upscaling requires interdisciplinary team

Technologists, chemists, operational manager, chemical engineers, proces engineers, automation engineers, mechanical engineers, analytics, project management, bussines development

Talk about your ideas

Volta