Thermal Solutions
for every challenge.

Upscaling processes for new battery raw materials from laboratory into industrial production

ONEJOON GmbH

Axel Weiand | Peter Vervoort | New Business | September 2020

Agenda

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1 Introduction ONEJOON Group

2 Motivation – What drives us

3 From Laboratory into Industrialization

4 Case Studies - new anode materials

5 Improving performance for CAM

6 Discussion

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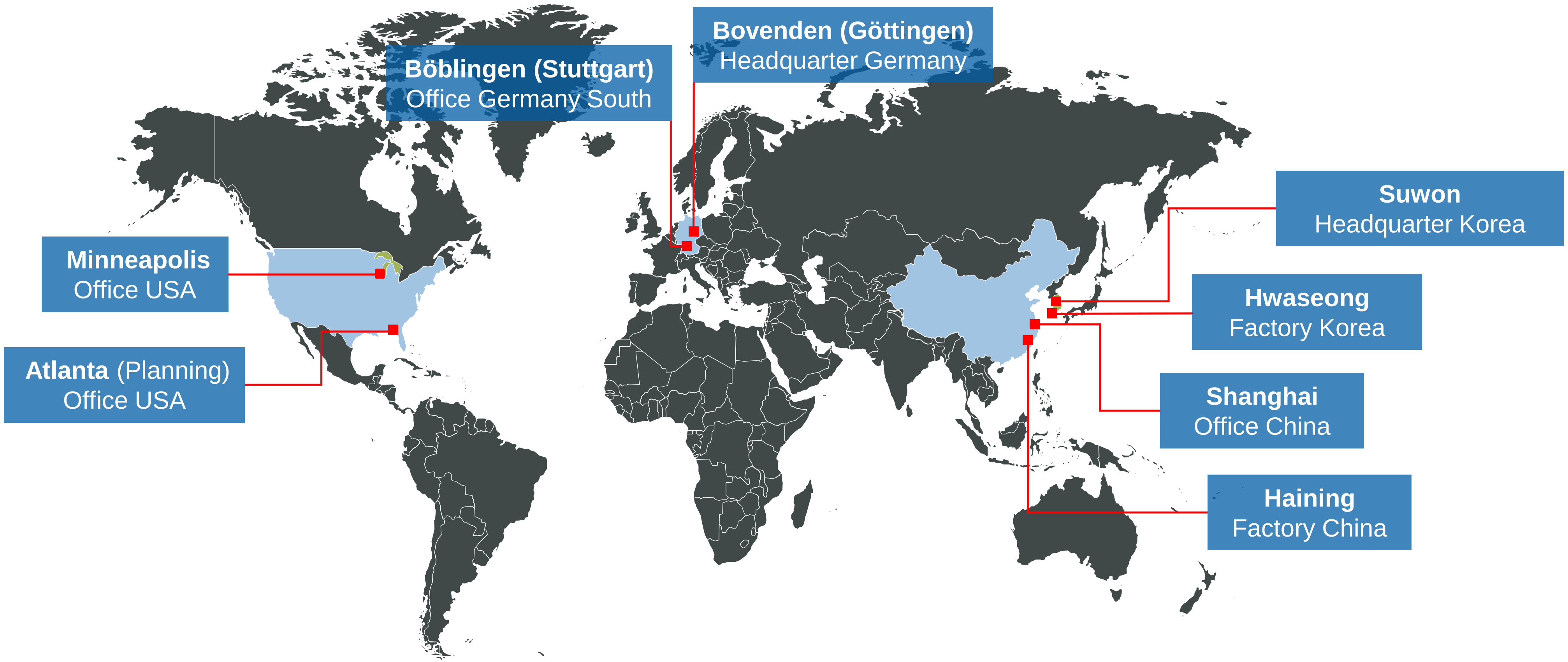
ONEJOON - Your Partner for
Thermal Production Systems

- **Represented in 4 countries** with **9 locations** worldwide
- **240** employees worldwide (2020)
- **More than 100** design engineers, researchers and developers
- **Quality made by ONEJOON** with own factories in Germany, Korea and China
- Ongoing **Culture of Innovation** ensured by **German and Korean Test Center** and **Research & Development** Department
- Experienced Project Management Team with **Project Sizes** up to **50 Mio €**
- **Thermal Process Equipment** up to 3000 ° C and **turnkey Thermal Process Production lines**
- **Pioneer** in electric **high temperature furnaces** Established in year **1888**

Our Locations

we're right where you need us.



Onejoon Core Teams around the globe can handle local projects on their own with an organisation of Sales, Project Management, Basic Engineering, Commissioning, Site Management and Service.

Factories
and Facilities


Headquarter of ONEJOON Co. Ltd. in Suwon, Korea


Production of ONEJOON GmbH in Bovenden, Germany


Headquarter of ONEJOON GmbH in Bovenden, Germany


Test Center of ONEJOON GmbH in Bovenden, Germany

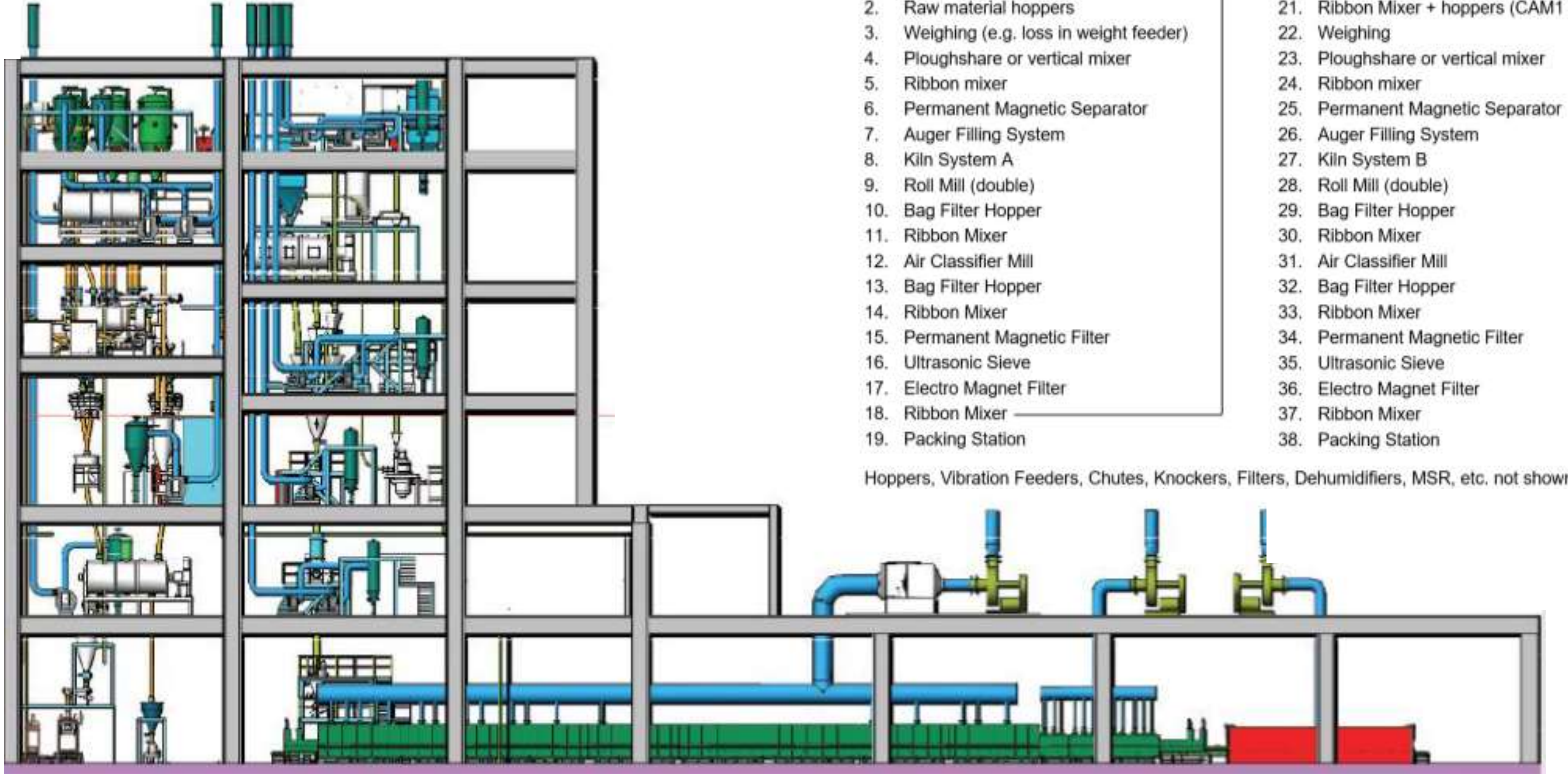

ONEJOON GmbH, Office Germany South


Production of ONEJOON (Zheijiang) Co.Ltd., China

Cathode Active Material
Powder Process Engineering & Equipment

ONEJOON

Example for NCM622 2-firing process



1st Firing Proces

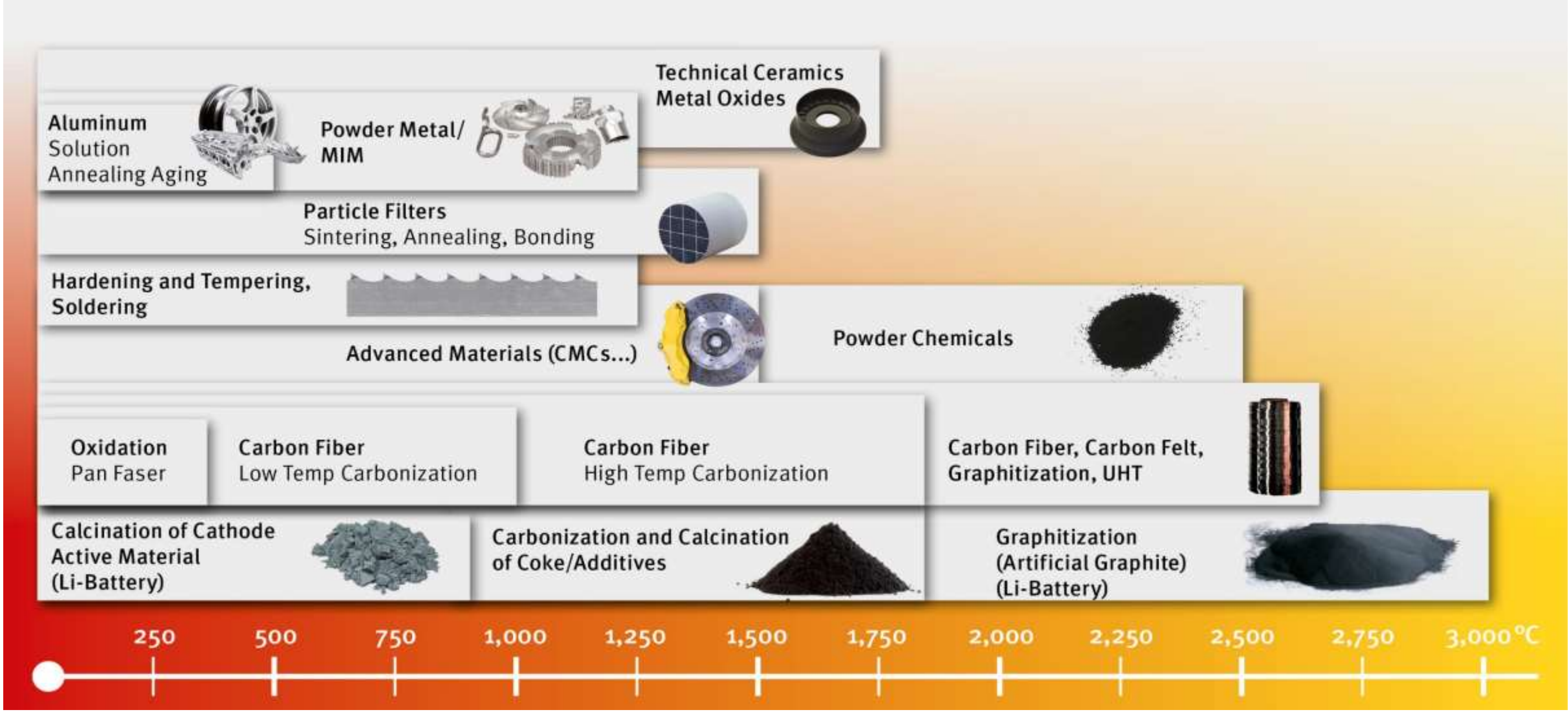
1. Big Bag Unloading
2. Raw material hoppers
3. Weighing (e.g. loss in weight feeder)
4. Ploughshare or vertical mixer
5. Ribbon mixer
6. Permanent Magnetic Separator
7. Auger Filling System
8. Kiln System A
9. Roll Mill (double)
10. Bag Filter Hopper
11. Ribbon Mixer
12. Air Classifier Mill
13. Bag Filter Hopper
14. Ribbon Mixer
15. Permanent Magnetic Filter
16. Ultrasonic Sieve
17. Electro Magnet Filter
18. Ribbon Mixer
19. Packing Station

2nd Firing Process

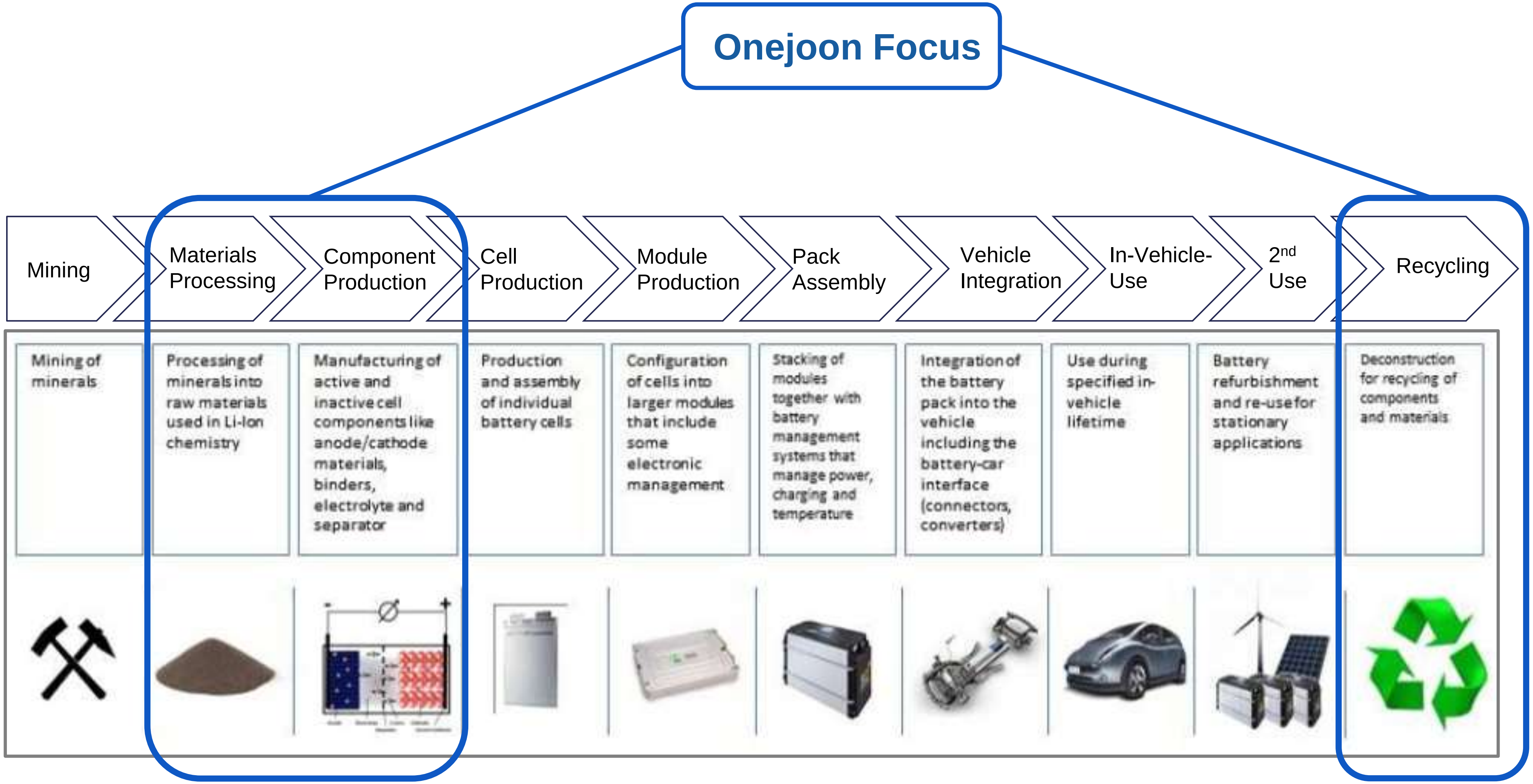
20. Bag Filter Hopper
21. Ribbon Mixer + hoppers (CAM1 + Additives)
22. Weighing
23. Ploughshare or vertical mixer
24. Ribbon mixer
25. Permanent Magnetic Separator
26. Auger Filling System
27. Kiln System B
28. Roll Mill (double)
29. Bag Filter Hopper
30. Ribbon Mixer
31. Air Classifier Mill
32. Bag Filter Hopper
33. Ribbon Mixer
34. Permanent Magnetic Filter
35. Ultrasonic Sieve
36. Electro Magnet Filter
37. Ribbon Mixer
38. Packing Station

Hoppers, Vibration Feeders, Chutes, Knockers, Filters, Dehumidifiers, MSR, etc. not shown in list

Thermal Processes
this is our Expertise



Battery Materials
Overview & Onejoon Focus



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Motivation for future material processing

Lifetime Sustainability: Well to Wheel CO2 emissions

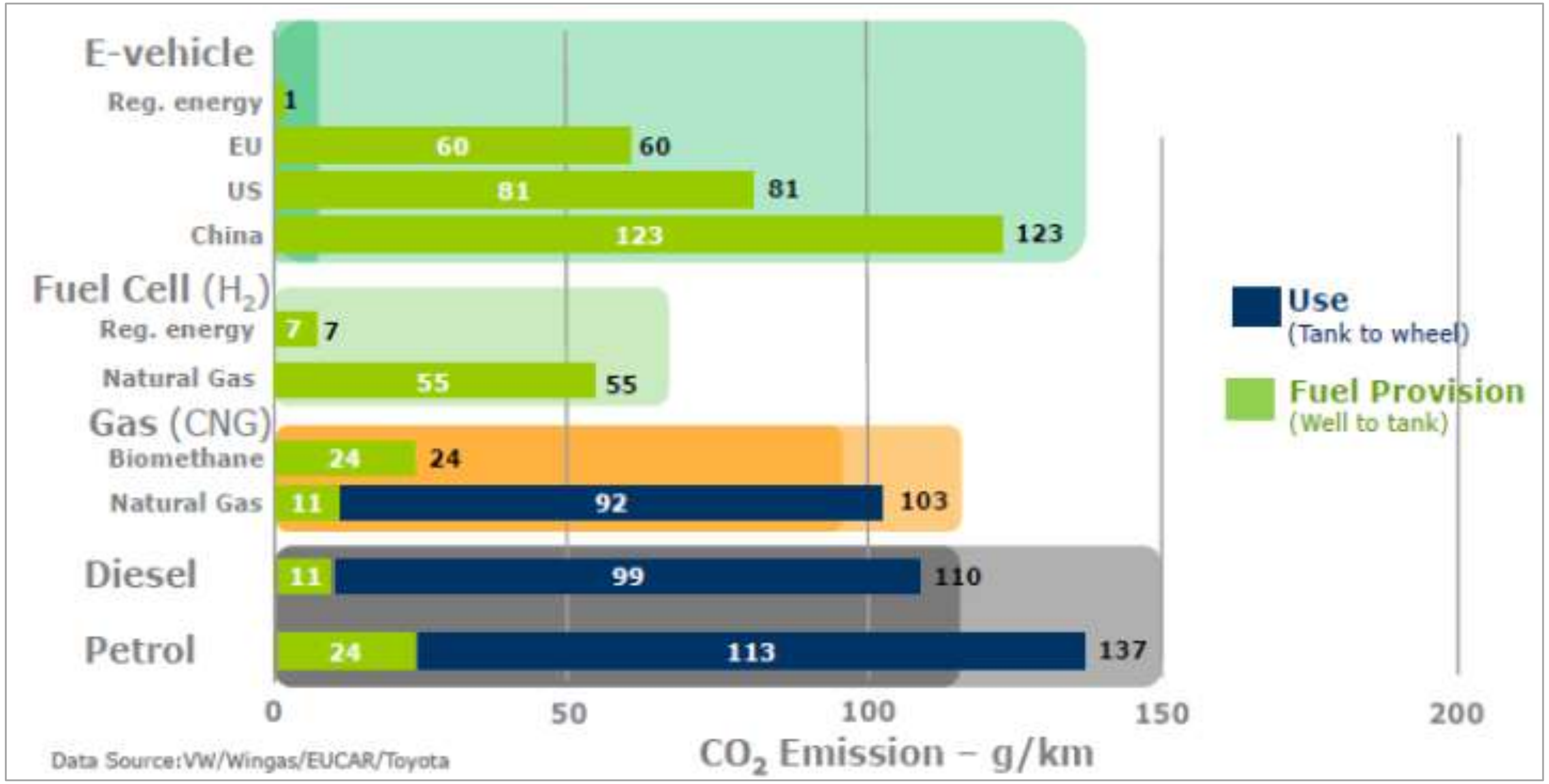


Fig. 9 'Well to wheel' lifecycle CO_2 emission comparisons (From presentation: 'The Powertrain of the Future - The Challenge of CO_2 and Emission Compliance', Michael Reissig, AVL List GmbH)

Motivation for future material processing

Lifetime Sustainability: Lifecycle CO2 emissions

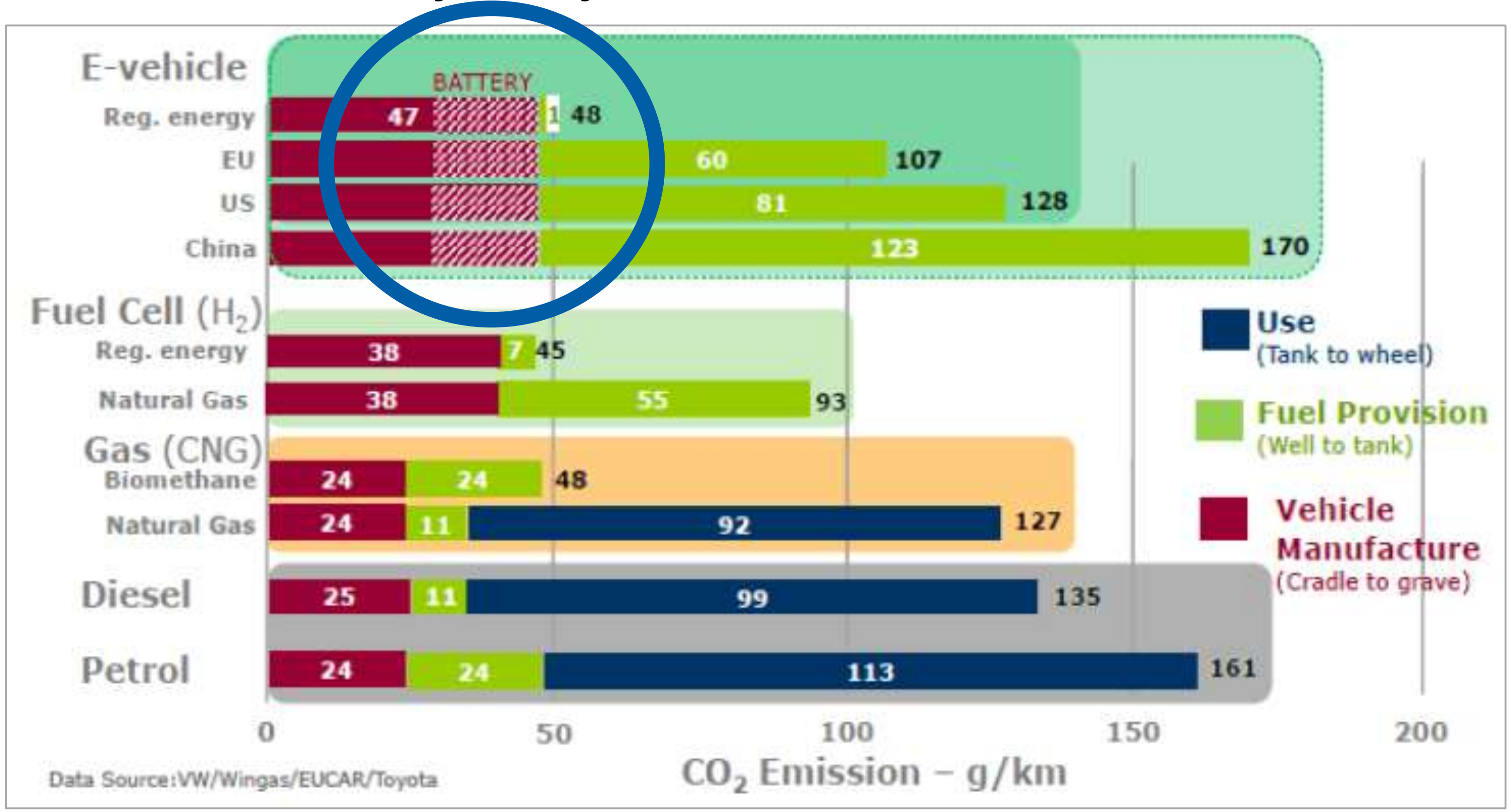


Fig. 10 Lifecycle CO_2 emission comparisons, including 'cradle to grave' data. (From presentation: 'The Powertrain of the Future - The Challenge of CO_2 and Emission Compliance', Michael Reissig, AVL List GmbH)

Motivation: Current Production of Graphites

Acheson Process / Lengthwise Graphitization

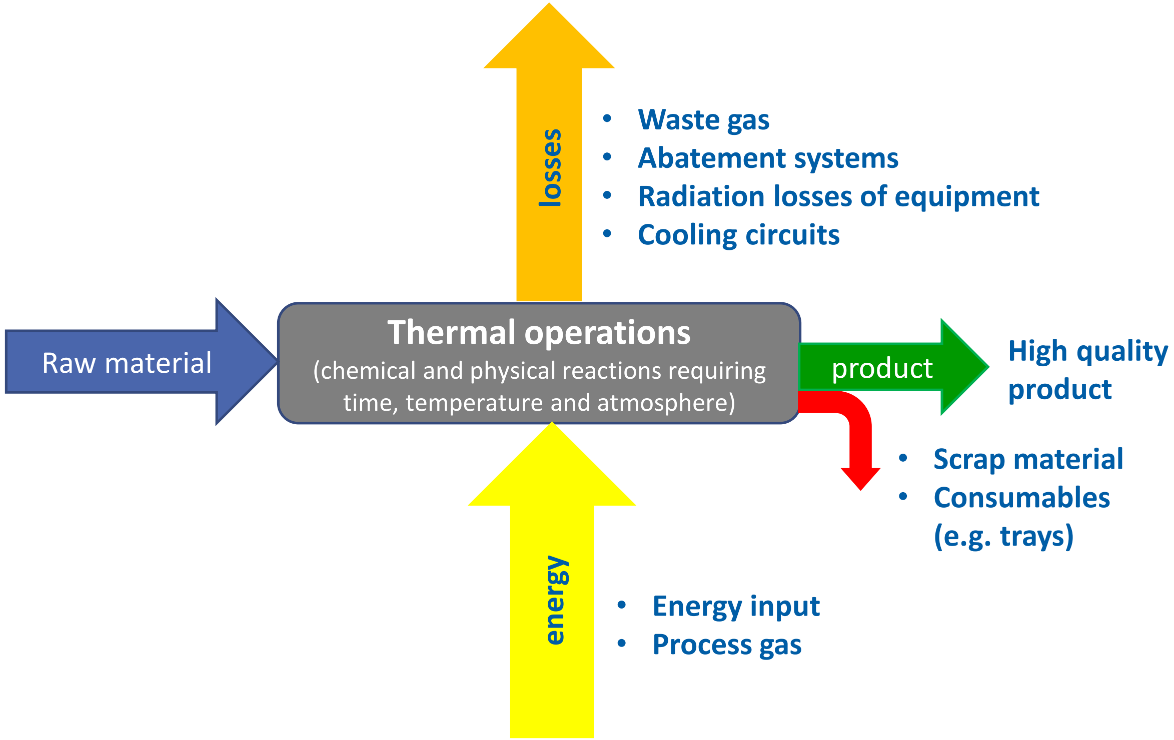
Source: Saint Gobain

Mining

Source: anfre

Target for a sustainable production of raw materials

- **Considerable reduction of the energy consumption and emmissions – Improvement of the lifetime sustainability of e-vehicles**
- **High control over temperature and atmosphere – Improving the yield**
- **Control over the material properties and Improving of the average quality level**
- **Control over the exhaust properties – Continuous exhaust treatment**
- **Reduction of manual operation steps – Integration into an automized production system**



Keep challenging your own solution - continuous review of the complete process

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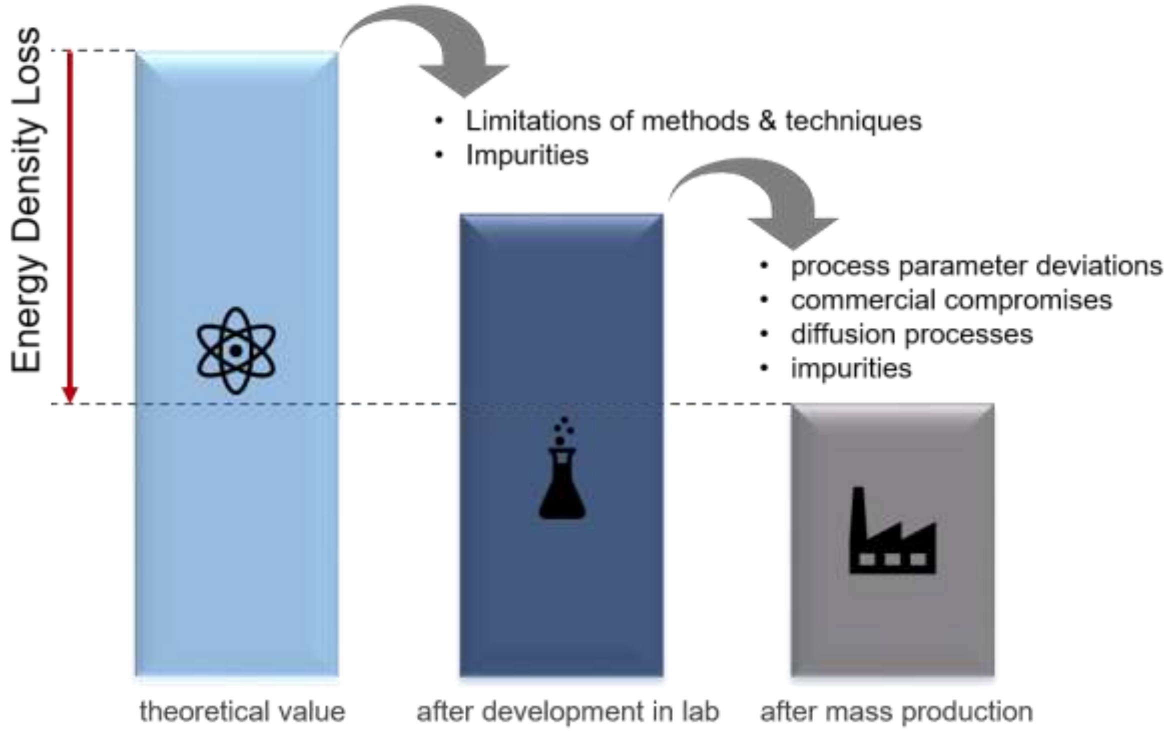
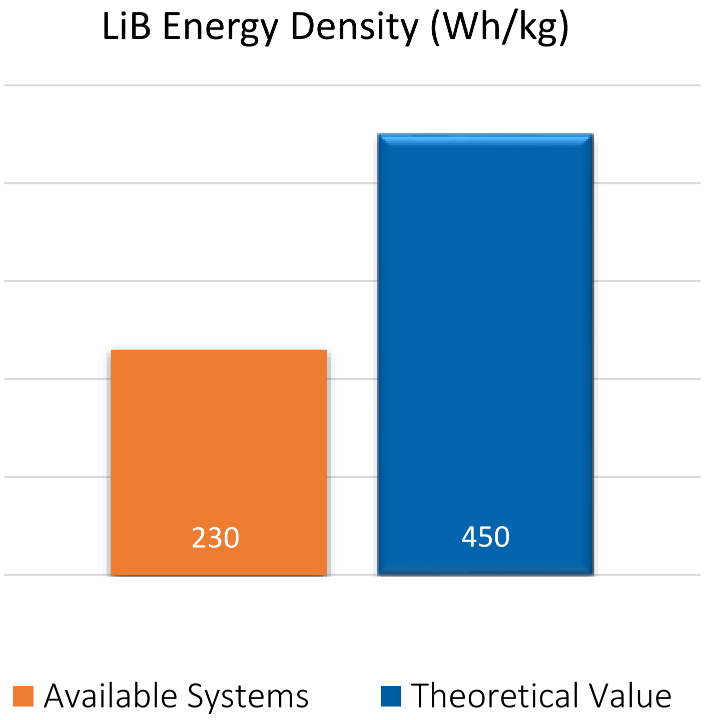
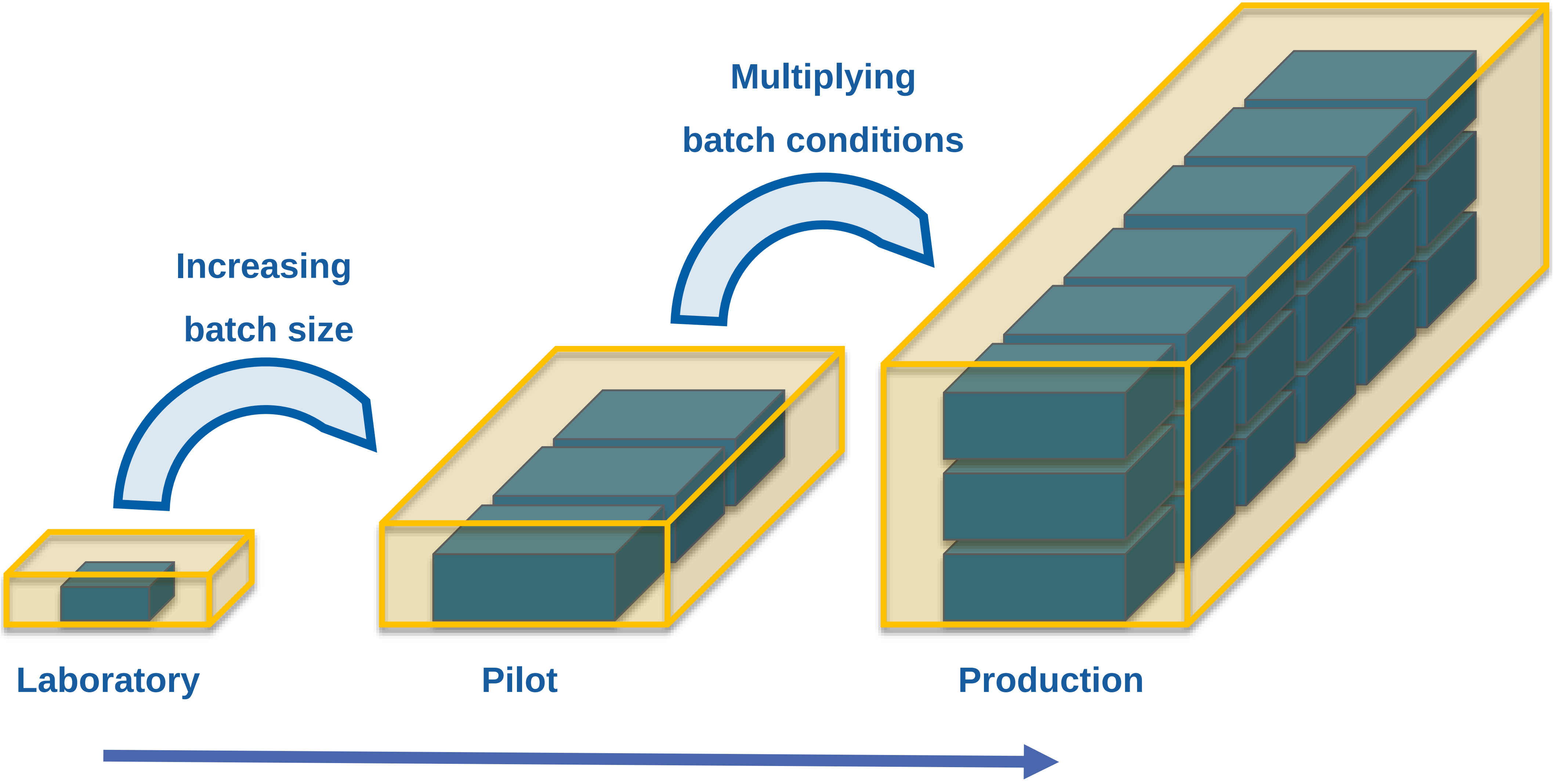
Problem of Upscaling Production



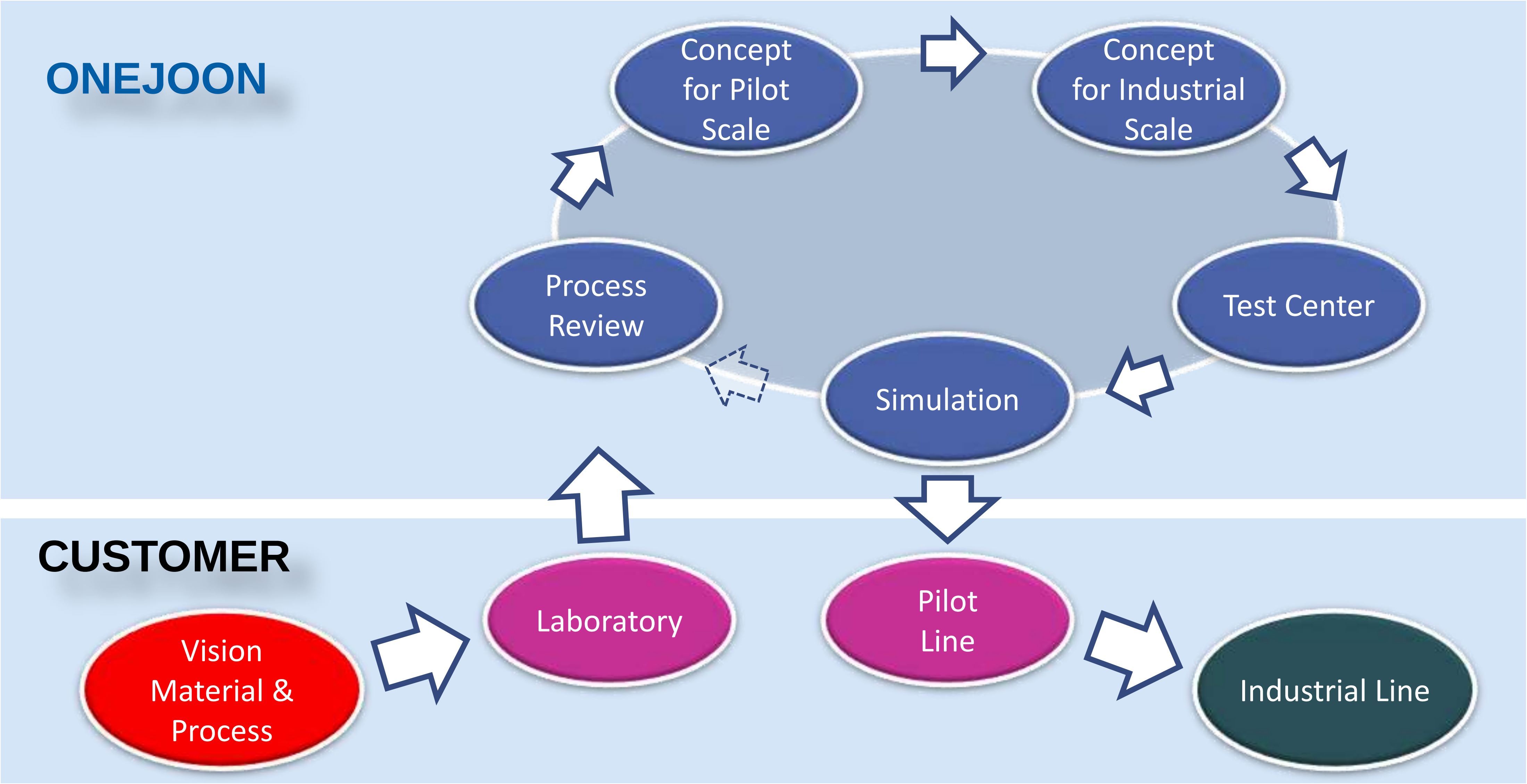


Many of promising new processes fail during industrial upscaling due to their complexity

From lab into large scale production



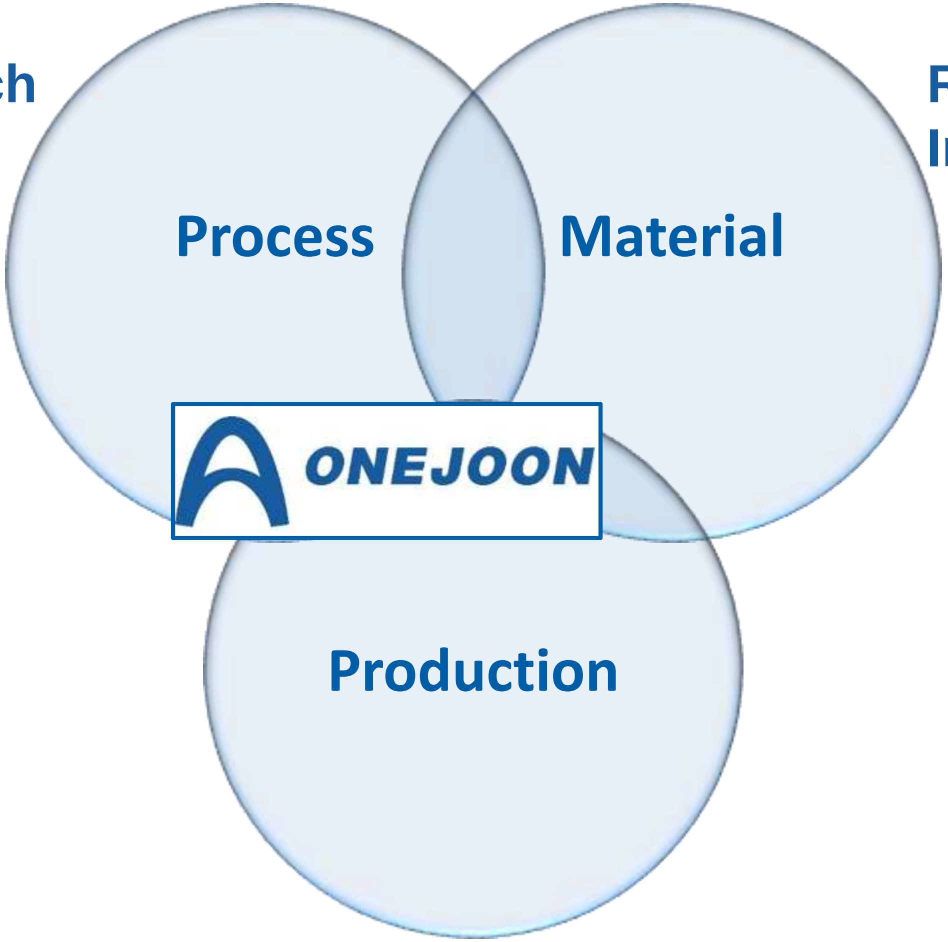
From Laboratory
to industrial scale production



Where furnace suppliers come into account

Corporate Research
& R&D - Groups

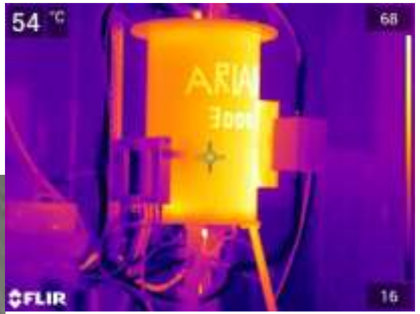
R&D - Groups
Institutes & Laboratories

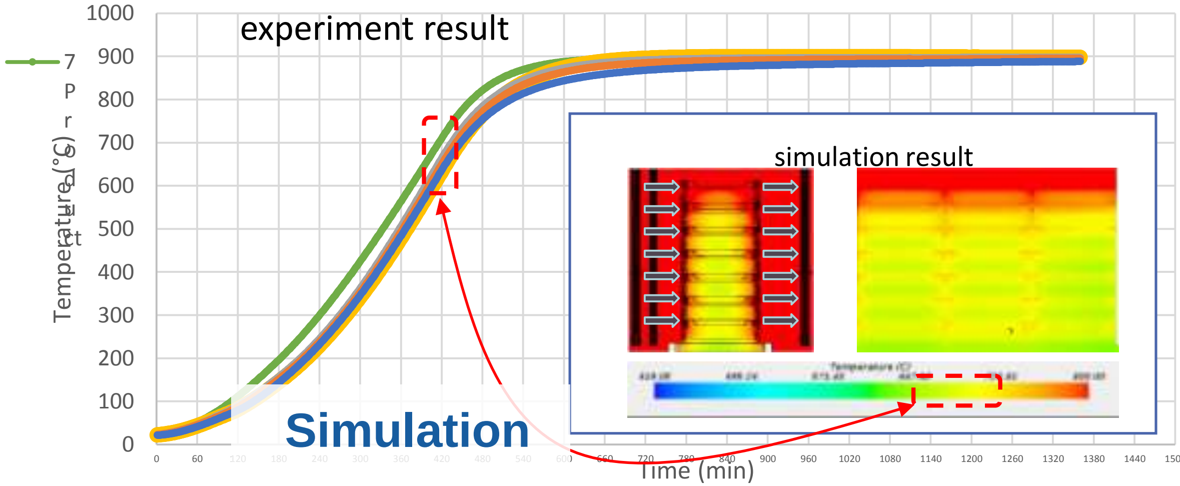


Classical
Furnace supplier

Corporate Engineering
Plant Engineering

Proof of Concept
what does it take….?





Test Kiln „Multifunctional Kiln“

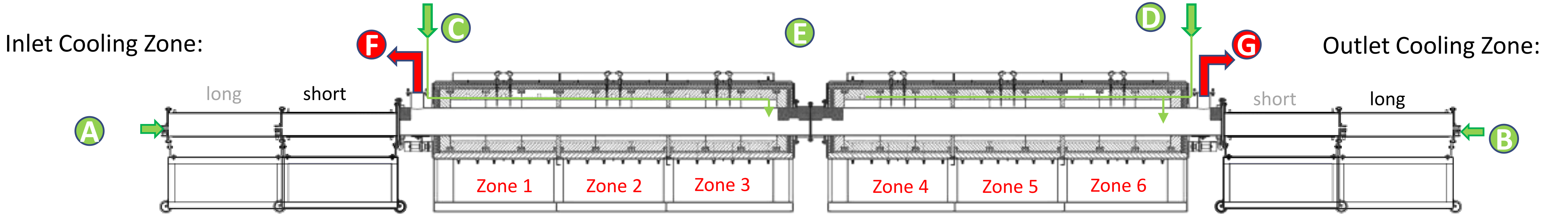
Technical Highlights:

- Versitile functions
- Gas preheating and Gas humidification
- Cooling zones at the inlet and outlet
- Use as conveyor belt or push-through oven possible

Technical Details:

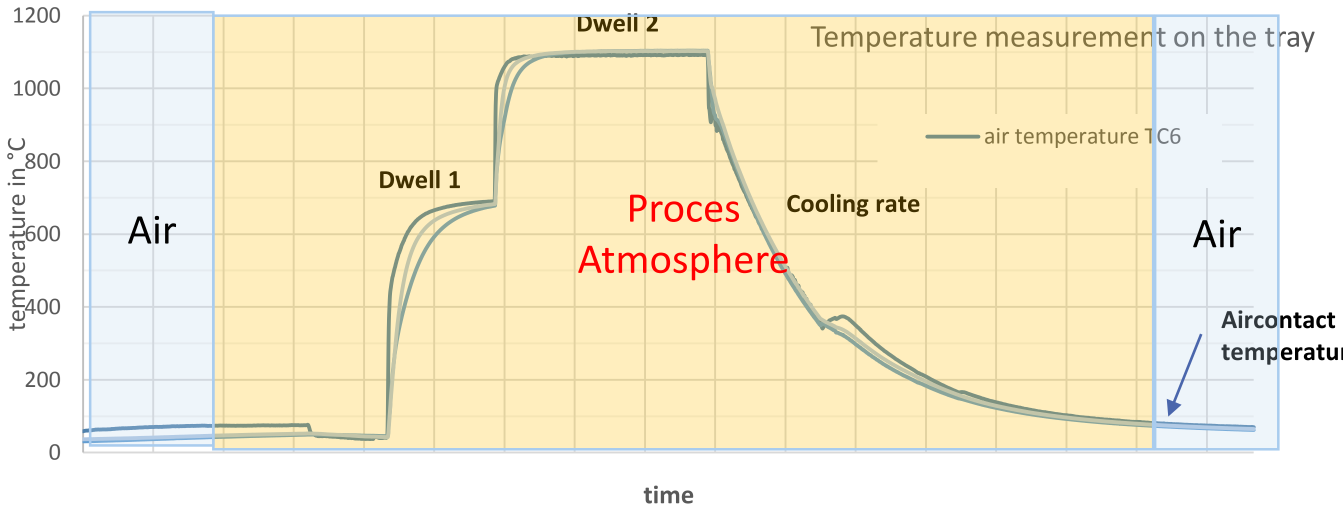
Atmosphere	Air, inert gas, burnable gas
Temperature-Zone 1-3	Up to 700°C
Temperature-Zone 4-6	Up to 1,100°C
Number of seperately controllable heating zones	6
Heated length per kiln segment	Approx. 4400mm
Muffle profile	Width approx. 500mm Height approx. 200mm

What can we adjust



Process variables:

- **Amount of powder /layer thickness**
- **Process atmosphere (Nitrogen, …)**
- **Inlet position gas and direction of gas flow**
- **Flow rate gas (1-20 Nm³/hr)**
- **Gas/powder ratio**
- **Dwell time and temperature zone 1 & 2 independant**
- **Heating and cooling rates (within physical limits)**



Current Testing Portfolio: subject to continuous adoption

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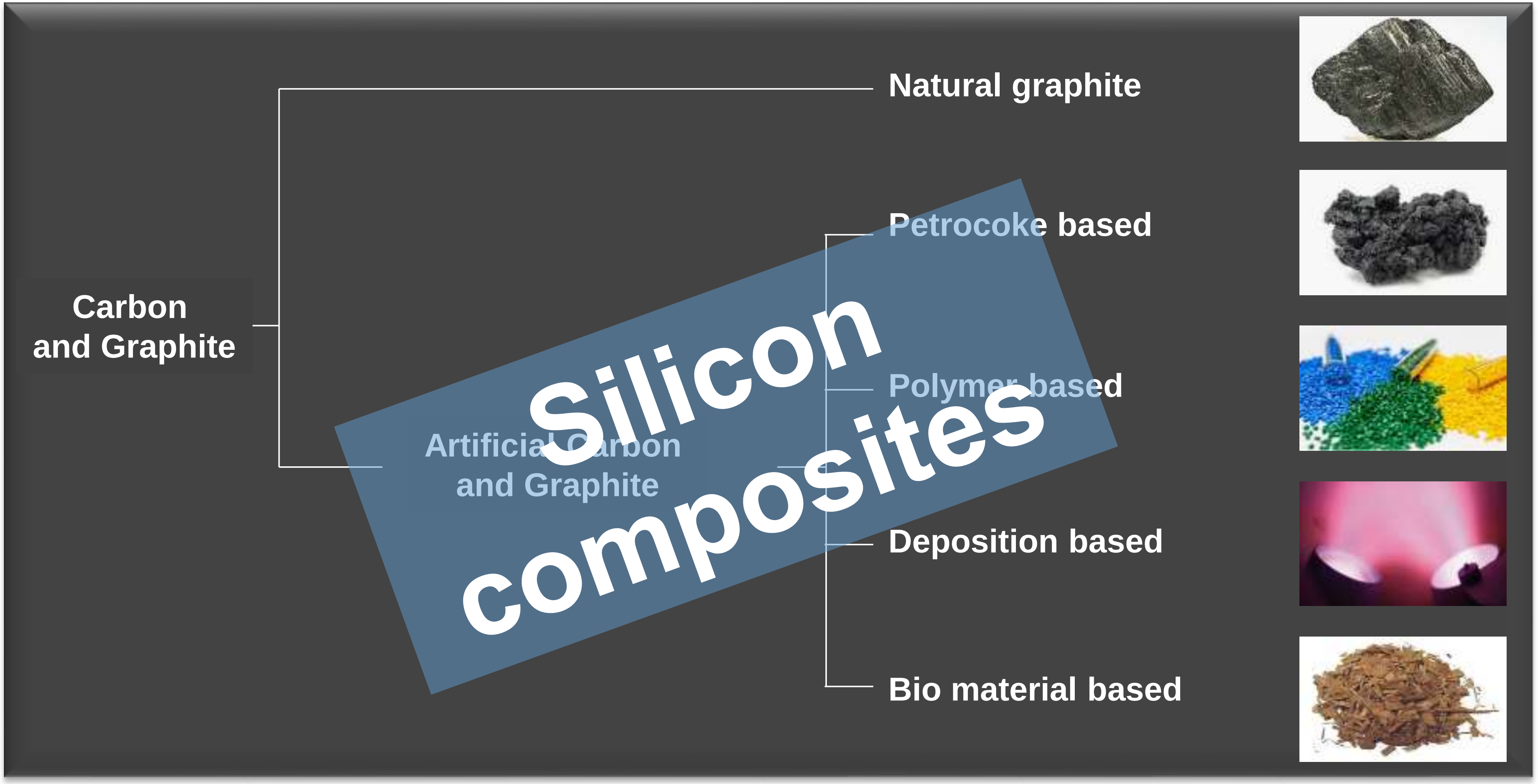
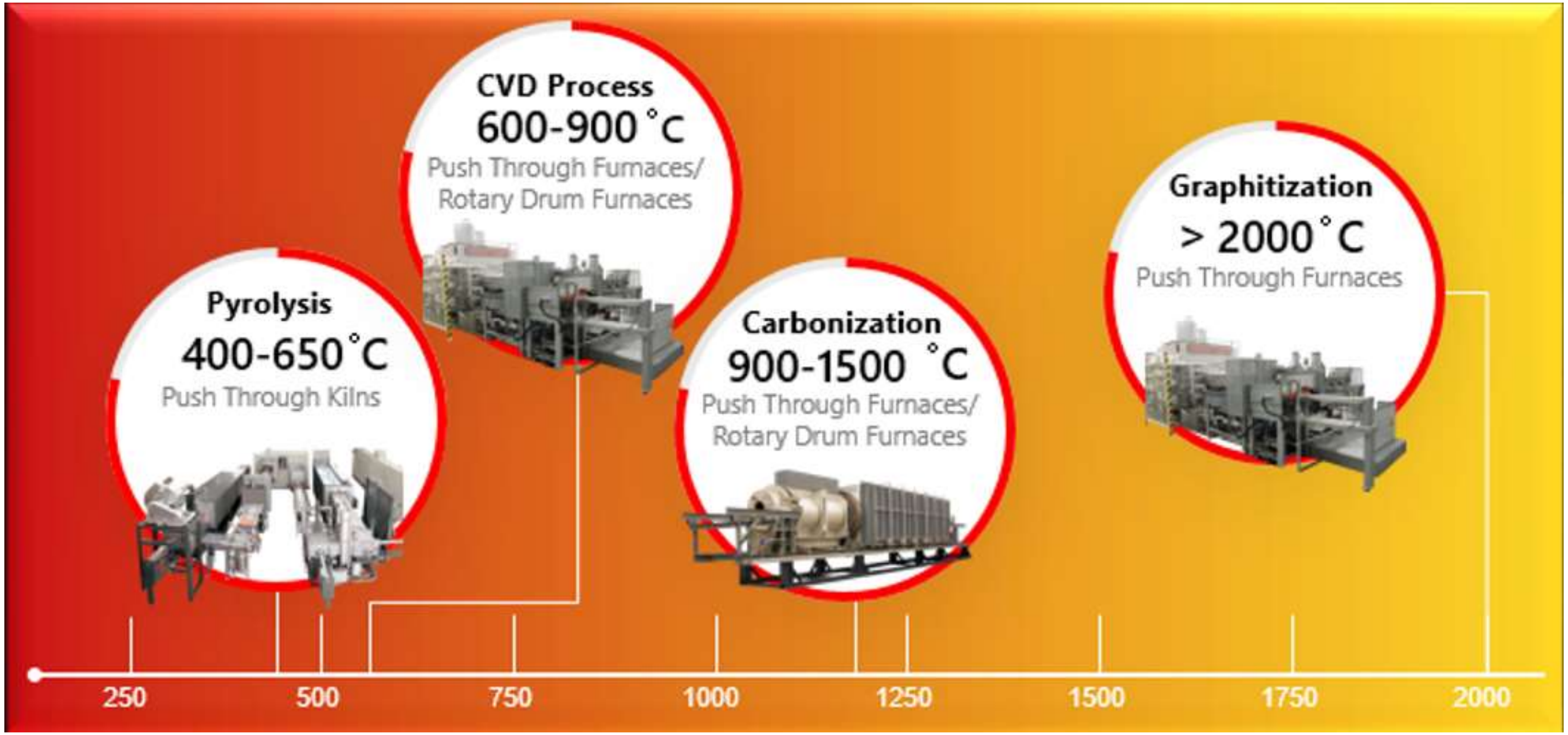
Graphite and Carbon for anode materials



Furnace or Reactor?
Processing of Anode Material.

Typical processes

- Drying
- Vapor release
- Pyrolysis
- Carbonization
- Activation
- Passivation
- Deposition
- Graphitization
- ……



Concepts for Anode Materials
based on experience from different industries.

New battery materials

Processing of Carbon based materials	Processing of Silicon – Ca marbon Based materials	Processing of Graphites	Processing of Solid Electrolyte battery systems

Products

Rotary furnace

Roller furnace

Pusher furnace

Tube furnace

Existing markets

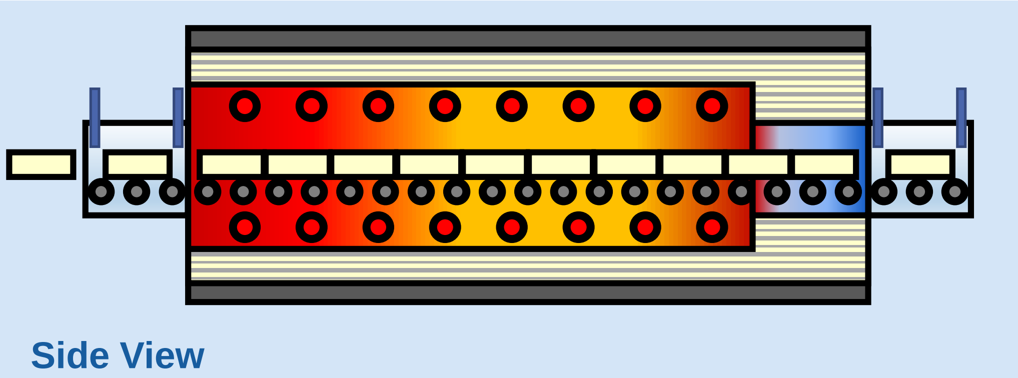
Powder Metals
HT PM parts

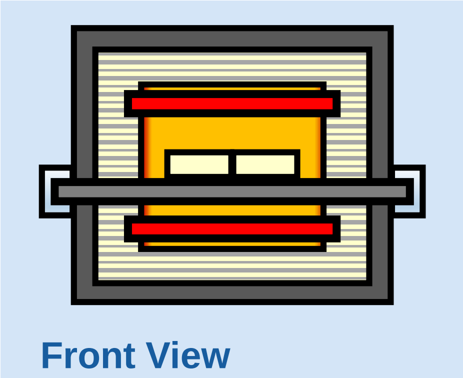
Advanced Ceramics
Filter Ceramics
Piezo Ceramics
Varistors
Ferrites

Powder Chemicals
Catalyst material
Carbides & Nitrides

Battery Materials
Cathode Active Material
Anode Material
Solid State Battery

Roller Furnace

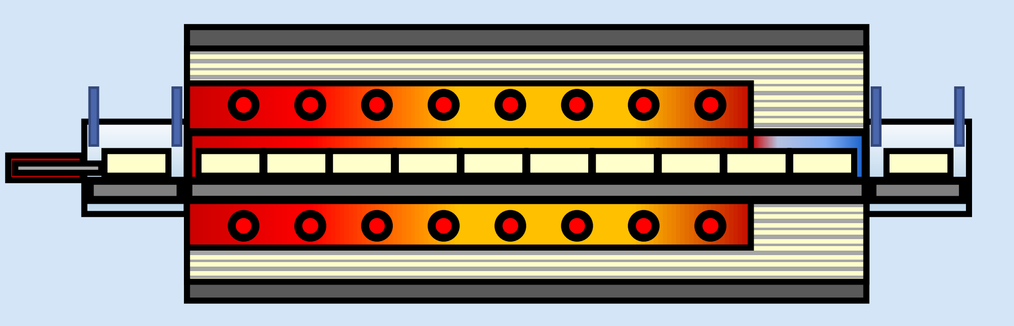




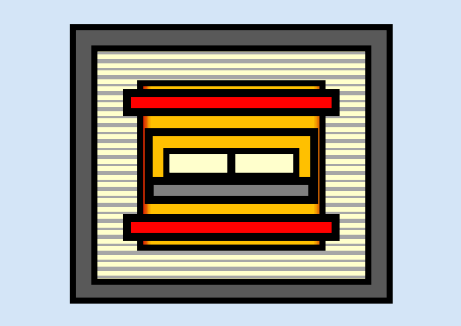
<u>Concept Characteristics:</u>

Concept Complexity	*high*
Gas Tightness	*difficult to achieve*
Temperature Profile	*very high flexibility*
Atmosphere Profile	*high flexibility*
Reaction Control	*depending on carrier / saggar*
Possible Max Temperature	*limited due to roller material*
Energy Efficiency	*low*

Pusher Furnace



Side View

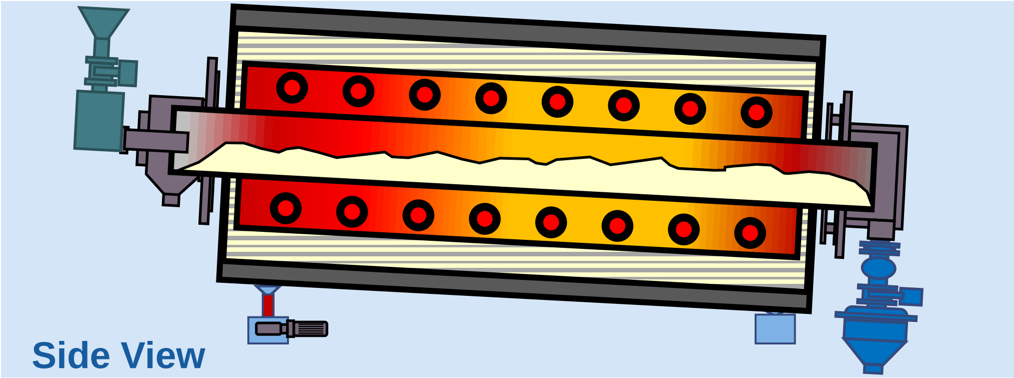


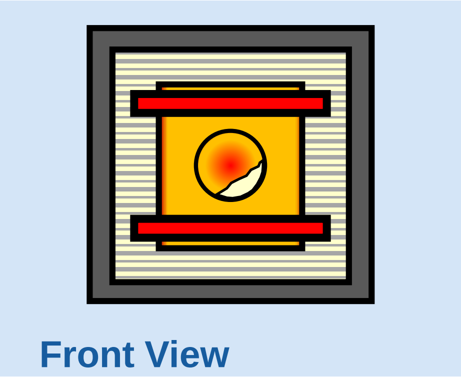
Front View

<u>Concept Characteristics:</u>

Concept Complexity	*medium*
Gas Tightness	*very good*
Temperature Profile	*reasonable flexibility*
Atmosphere Profile	*reasonable flexibility*
Reaction Control	*depending on carrier / saggar*
Possible Max Temperature	*high*
Energy Efficiency	*medium*

Rotary Furnace

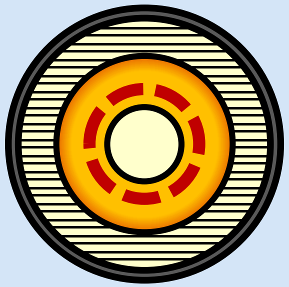




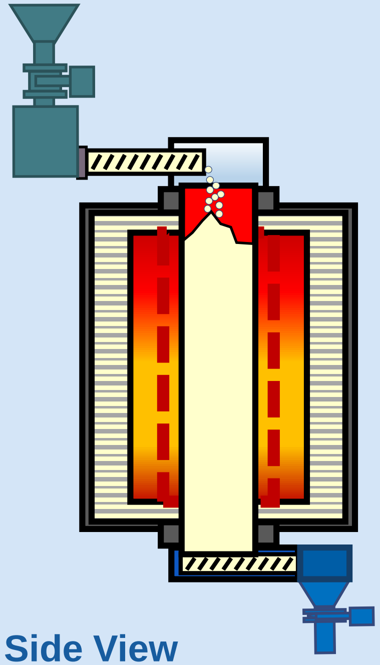
<u>Concept Characteristics:</u>

Concept Complexity	*medium*
Gas Tightness	*difficult to achieve*
Temperature Profile	*very limited flexibility*
Atmosphere Profile	*low*
Reaction Control	*very good*
Possible Max Temperature	*limited due to drum material*
Energy Efficiency	*high*

Tube Furnace



Top View

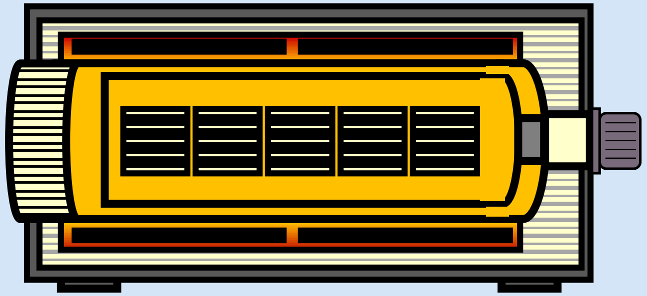


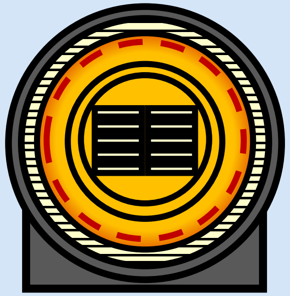
Side View

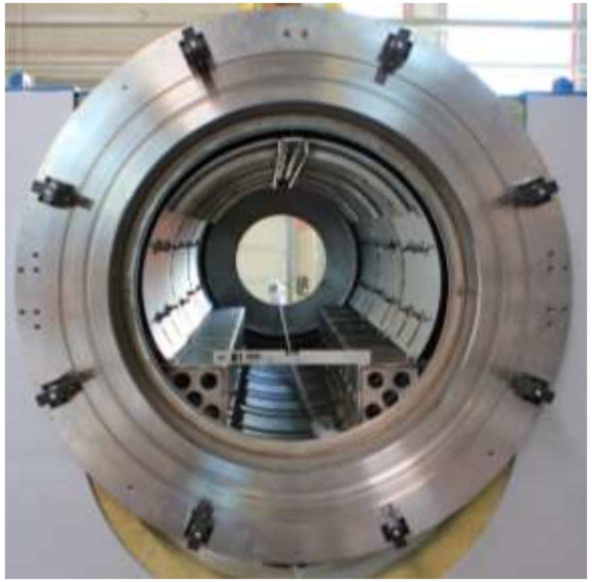
Concept Characteristics:

Concept Complexity	*medium*
Gas Tightness	*very good*
Temperature Profile	*limited*
Atmosphere Profile	*limited*
Reaction Control	*limited*
Possible Max Temperature	*very high*
Energy Efficiency	*high*

Recirculation Furnace







<u>Concept Characteristics:</u>

Concept Complexity	*high*
Gas Tightness	*good*
Temperature Profile	*very high flexibility (batch)*
Atmosphere Profile	very *high flexibility (batch)*
Reaction Control	*very high for flat carriers*
Possible Max Temperature	*low*
Energy Efficiency	*low*

Case Study 1

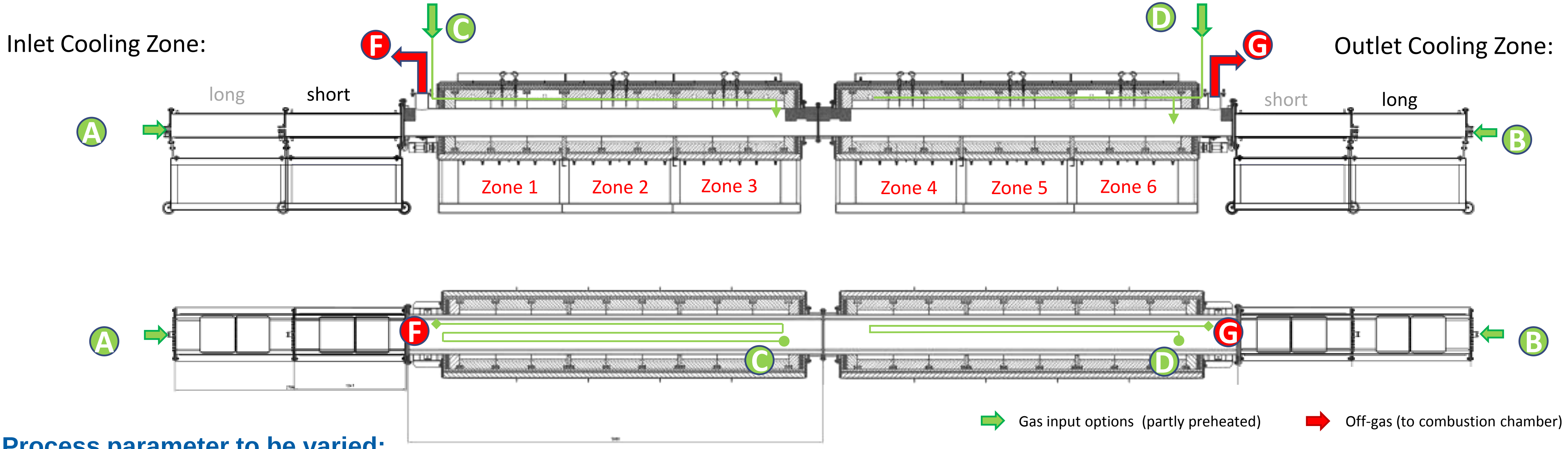
<u>Customer Requirements:</u>

- Throughput, e.g. 4000 tons/a
- Process pyrolysis
- Temperature 1,000 °C
- Atmosphere innert gas
- Focus excellent temperature control and waste gas control

<u>Case study;</u>

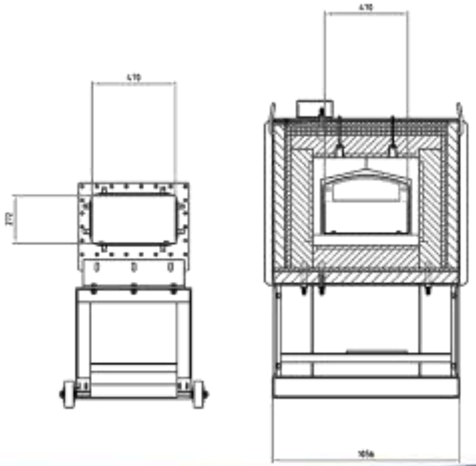
- Rotary furnace not possible due to metal contamination and long process time
- Roller furnace problem of condensation
- Pusher furnace tests showed this is the preferred solution, allowing long process times and good vapor removal

Tests in our test center: relevant aspects



Process parameter to be varied:

- Tray design and filling height
- Temperature profile - typical 1 to 2 dwell temperatures
- Ramp rate (slow, intermediate or fast)
- Dwell time (from minutes to hours)
- Process gas composition
- Process gas flow (direct /counterflow or mixed)
- Input of proces gas either cold (position A,B E) or pre-heated (position C and D)
- Off-gas in either of the 2 ports (F and /or G)
- Short or long cooling zones

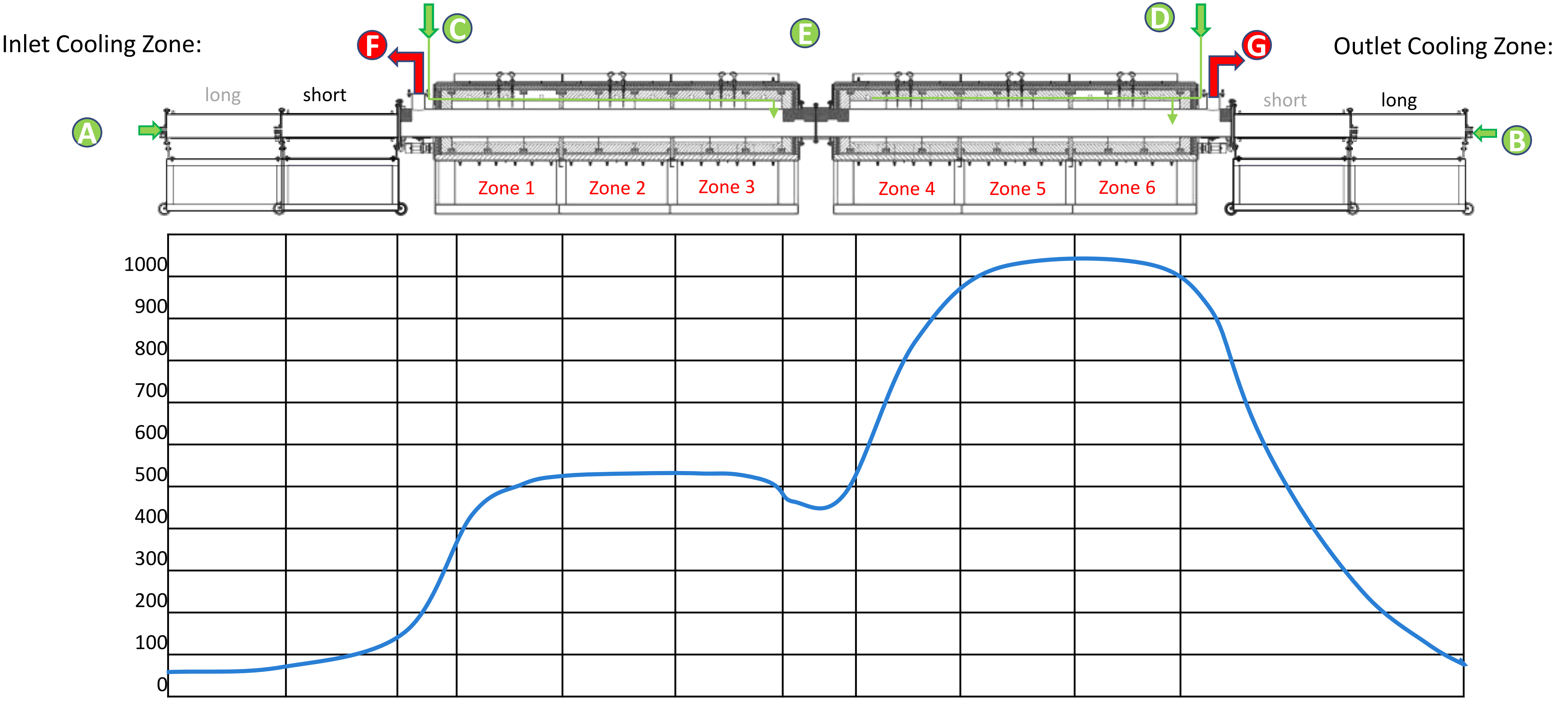


Tests in our test center: relevant aspects

Thermocouple in powder to measure product temperature during test

Muffle to guide gas flow close to product

Example of temperature profile in the furnace



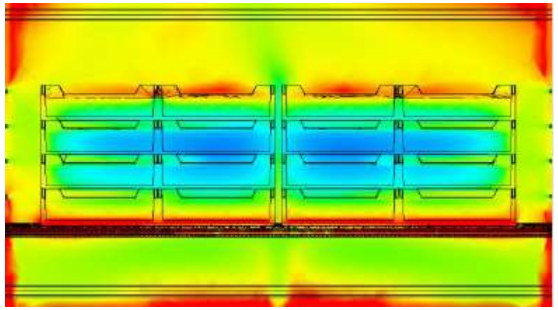
Examples of different Saggar materials for material transport

Stainless steel

Titanium

Ceramic

Graphite

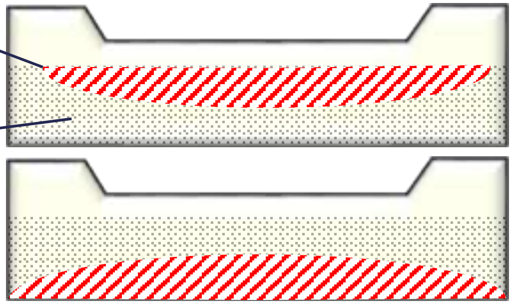


Simulation of Heat Transfer

Effect of Heat Transfer

reaction completed

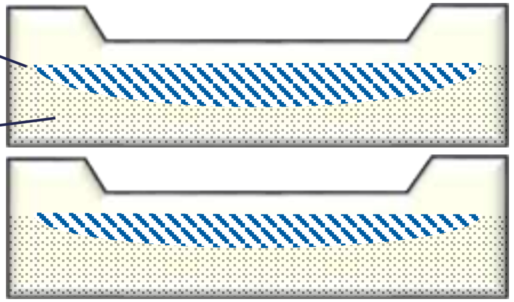
reaction not completed



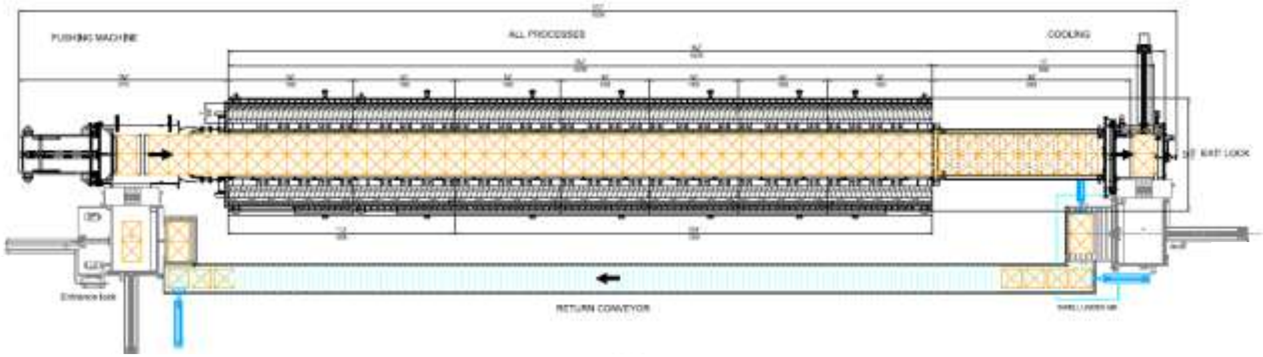
Effect of Gas Saturation

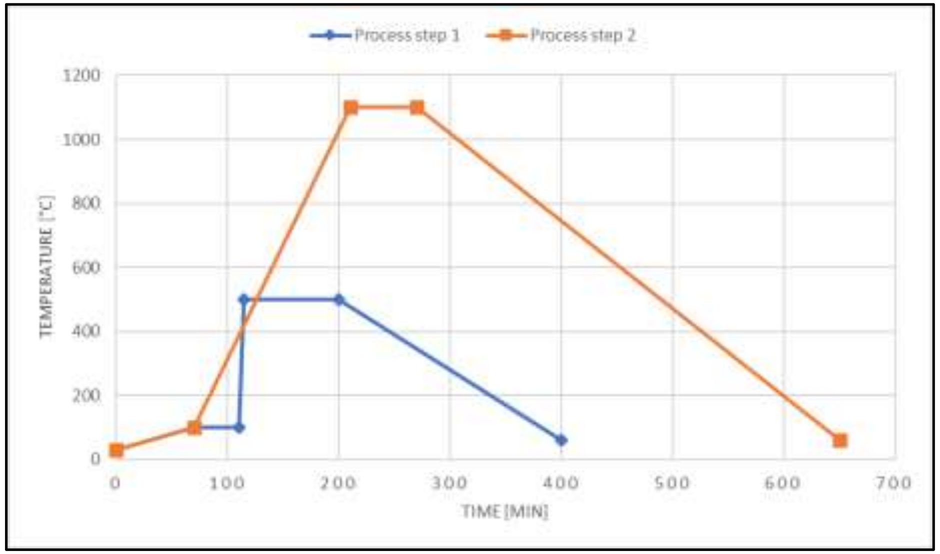
reaction completed

reaction not completed

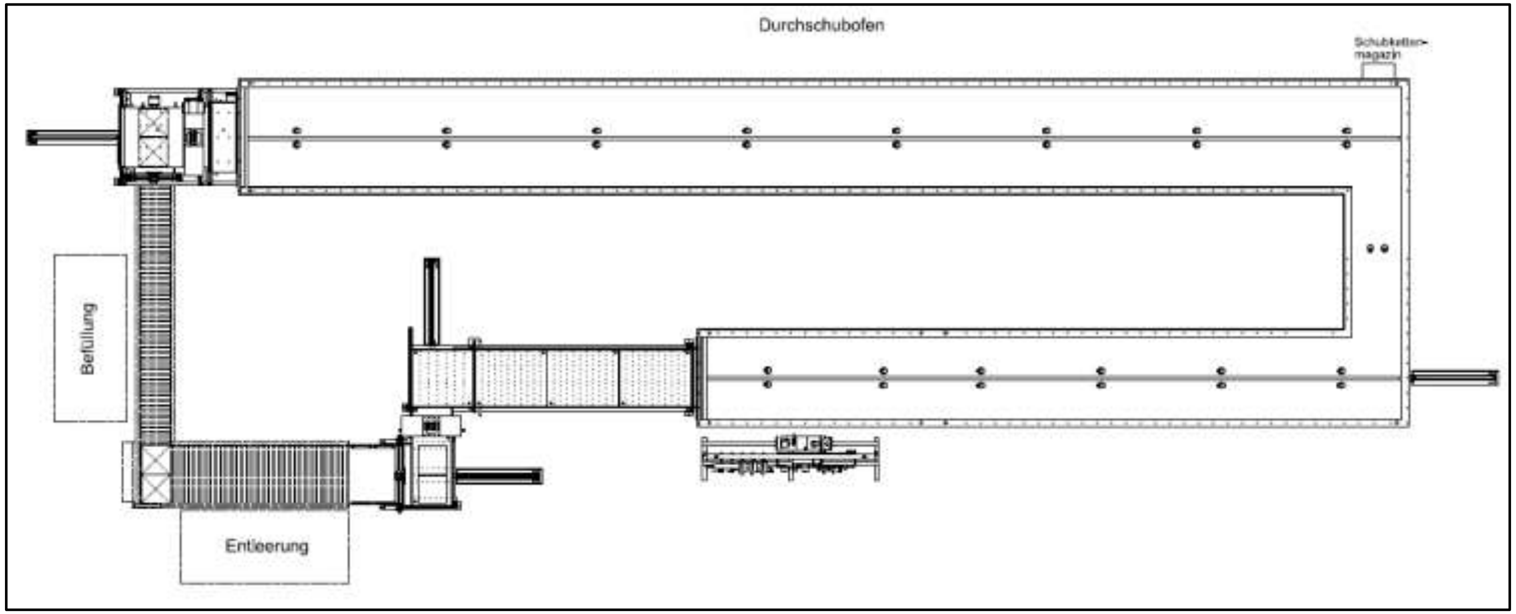


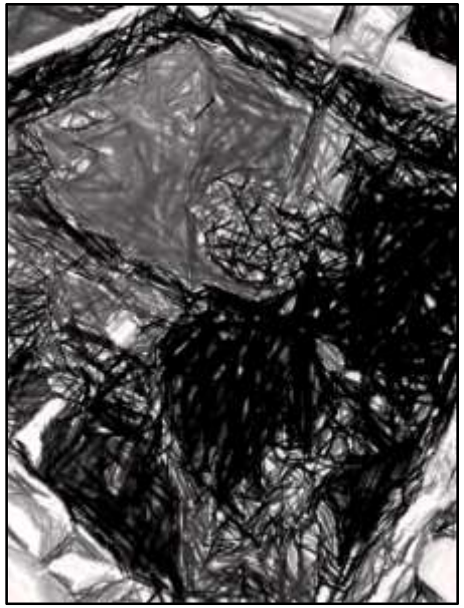
Concept for the production of carbon for batteries

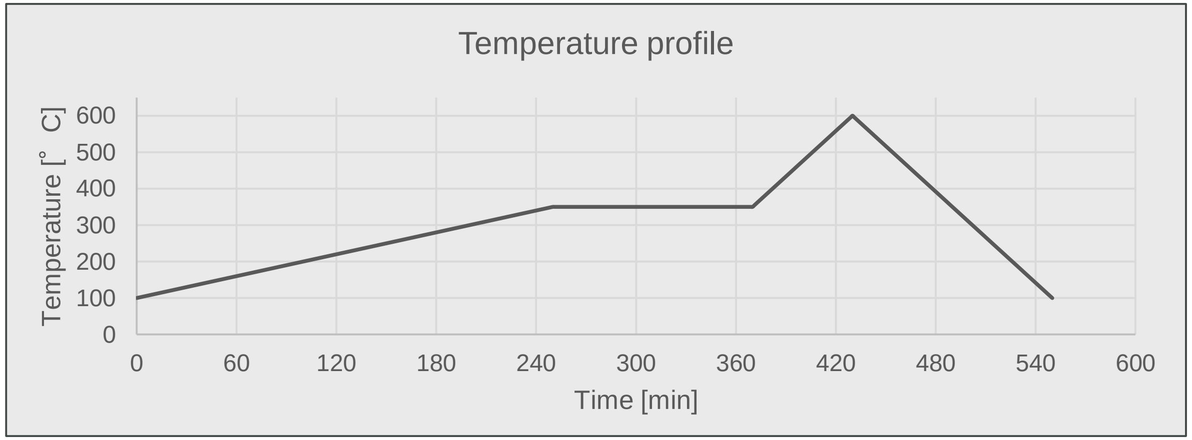


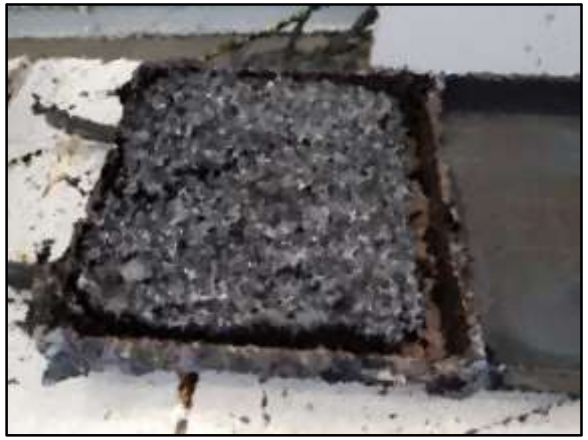


Concept for the production of carbon for batteries









Case study 2 – out of the box approach

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Product tray

Customer Requirements:

- Throughput, e.g. 1000 tons/a
- Process proprietary chemical reaction
- Temperature 900 °C
- Atmosphere Highly flammable gasses
- Reactivity excellent gas – powder interaction

Case study;

- Rotary furnace limited due to dust release
- Roller furnace limited due to gas flow limitation and condensation
- Pusher furnace possible – but study showed complexity of gas injection and off gas
- Recirculation furnace Simulation and tests proofed concept to provide high reaction efficiency

Example of the reactor

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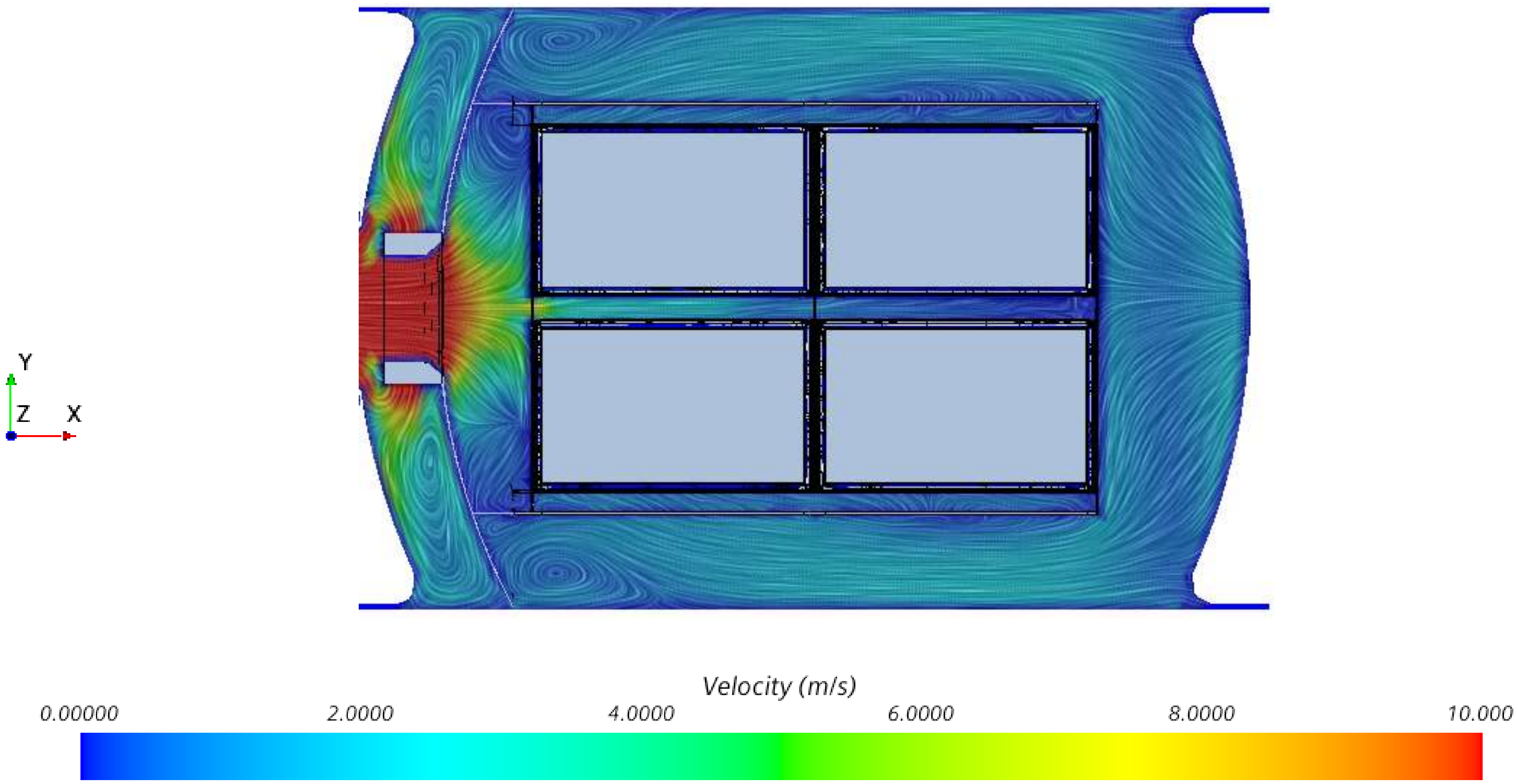
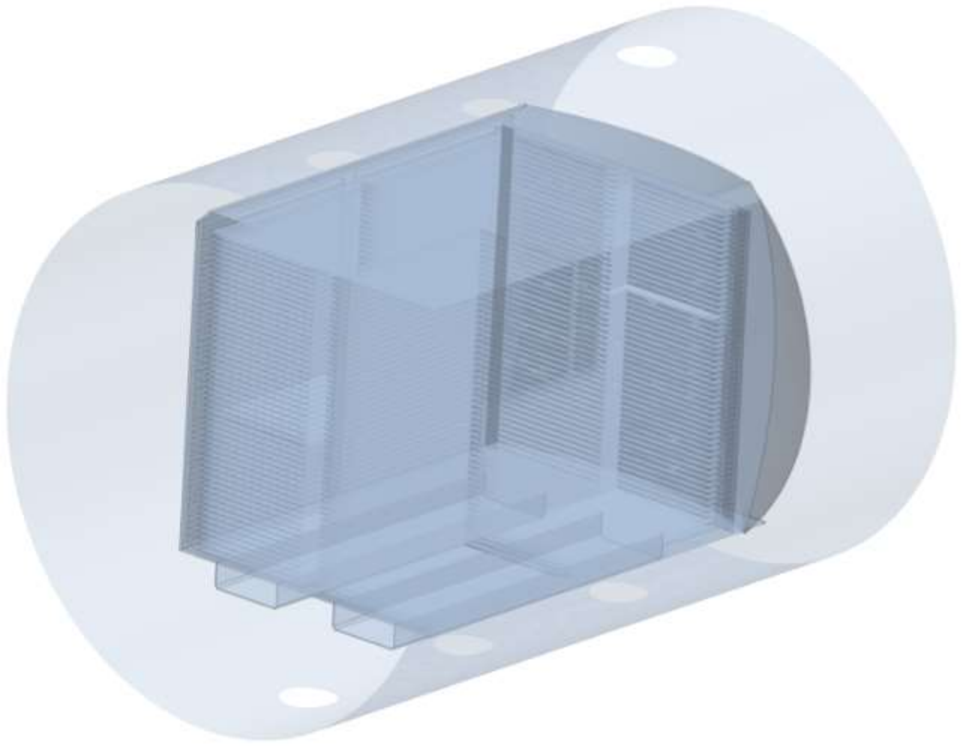
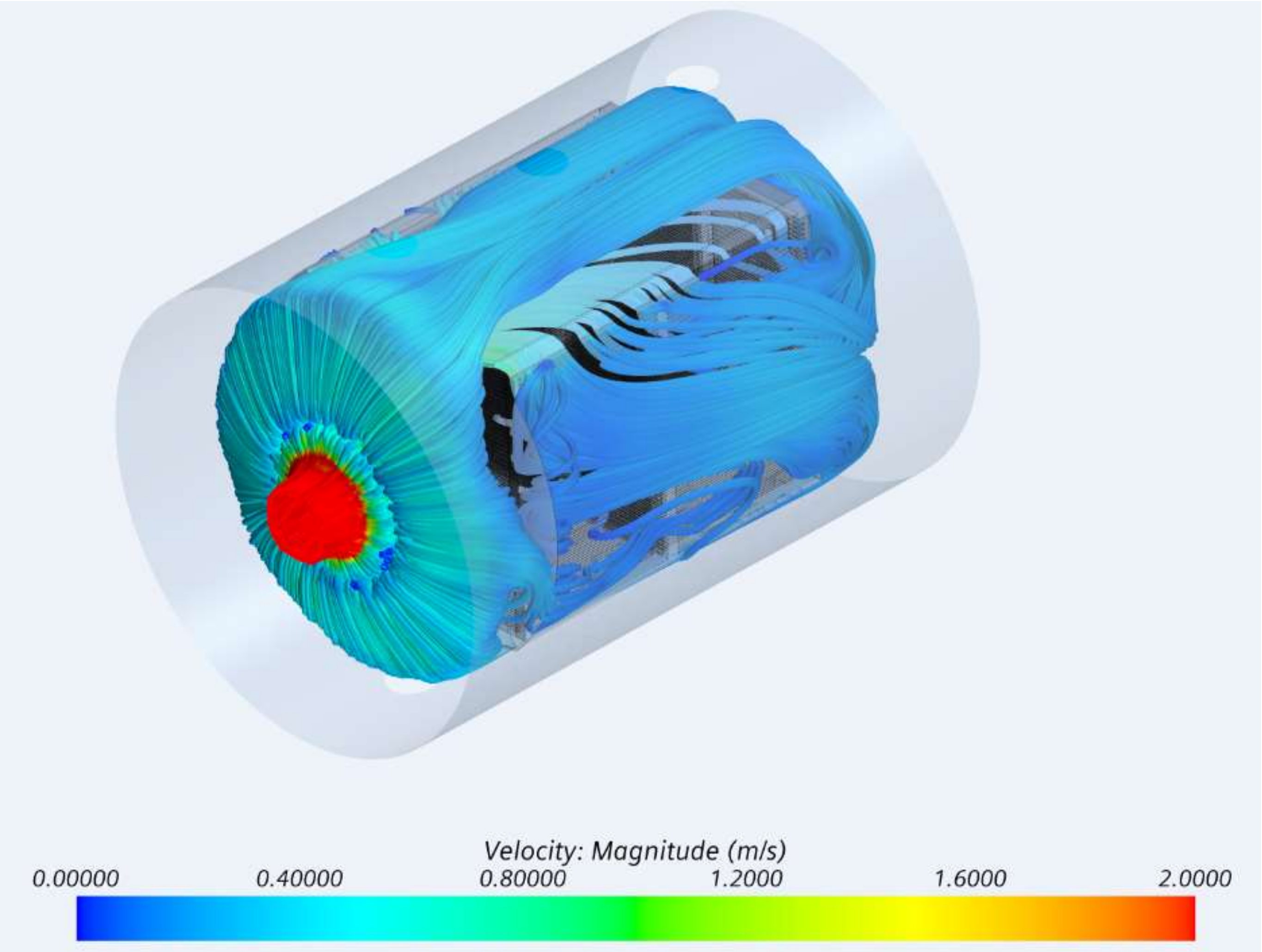
Simulation



Simulation: Concept of the reactor



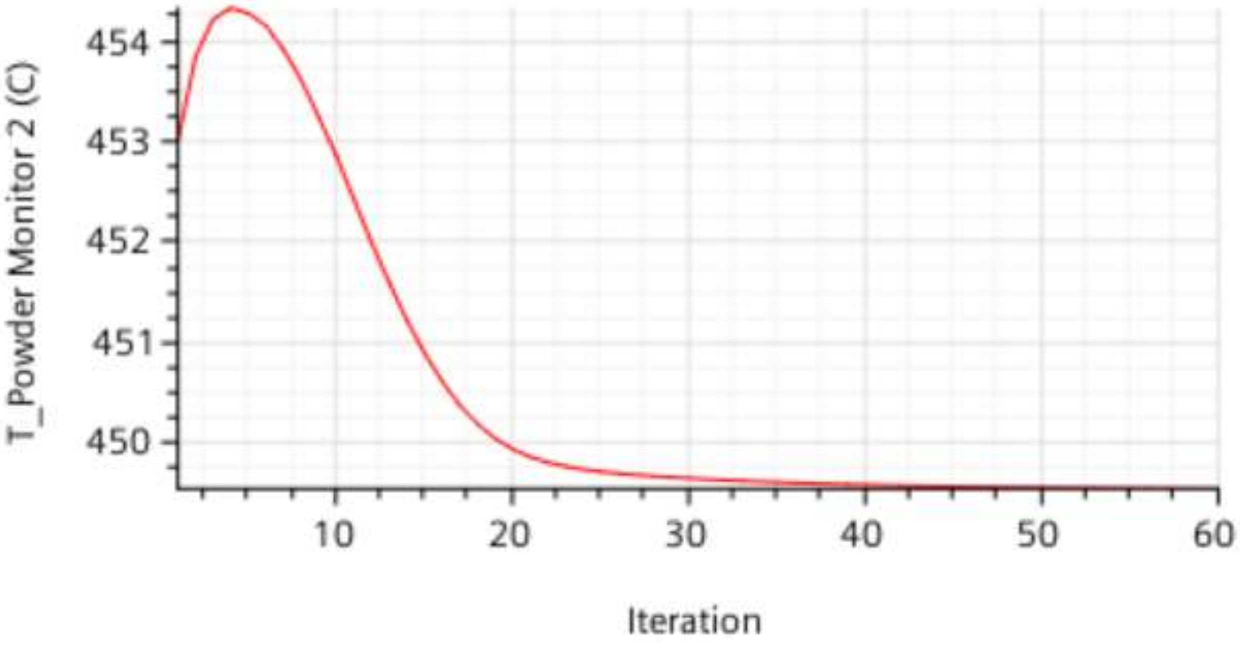


Influence of reaction heat to product temperature

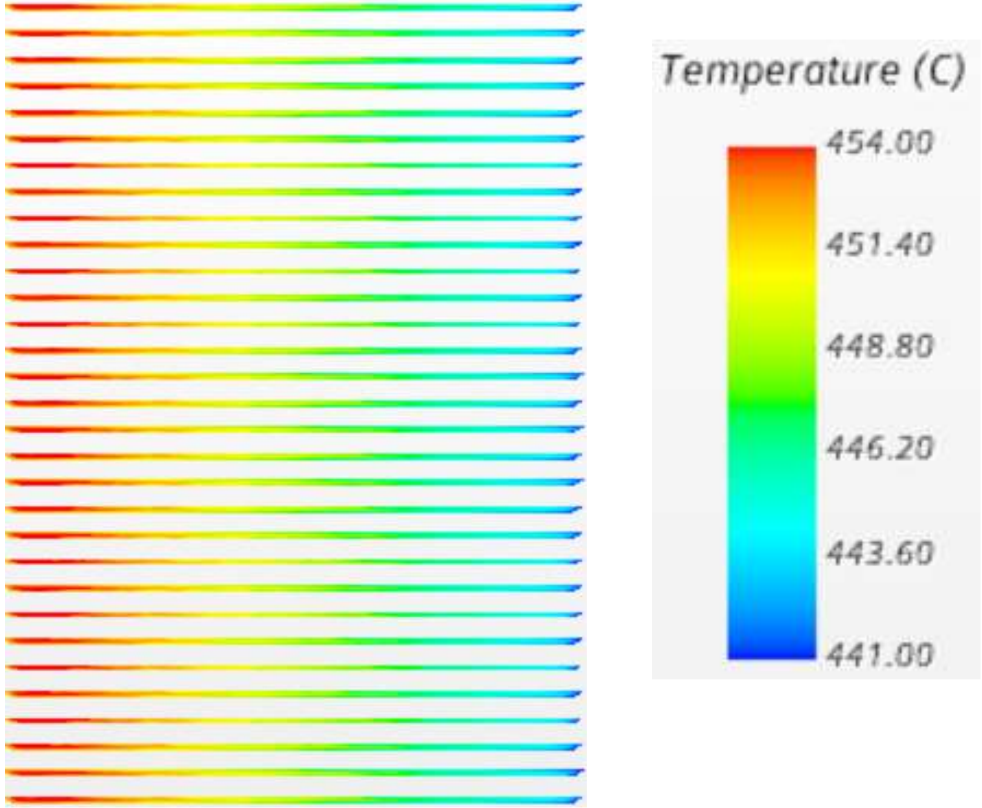
Exothermic reaction under a specific atmosphere

Gap between powder and next tray	**15 mm**
Flow velocity	**0.5 m/s**
Initial temperature gas & product:	**450 °C**

Mean temperature of powder: 449.5 °C



ΔT: 12K

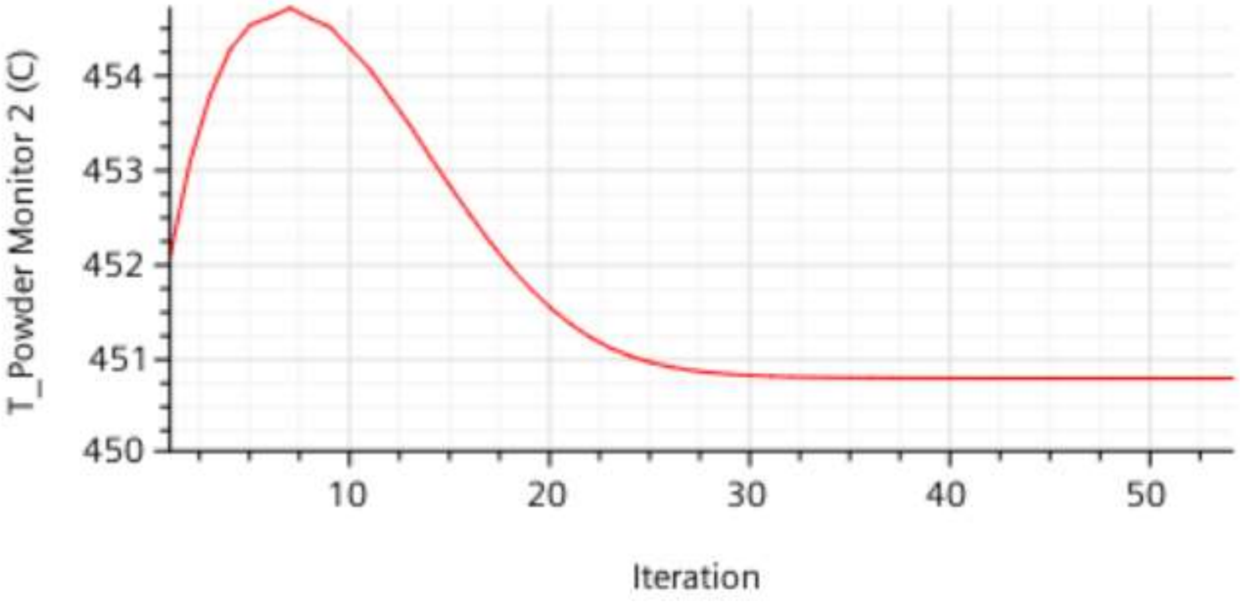


Influence of reaction heat to product temperature

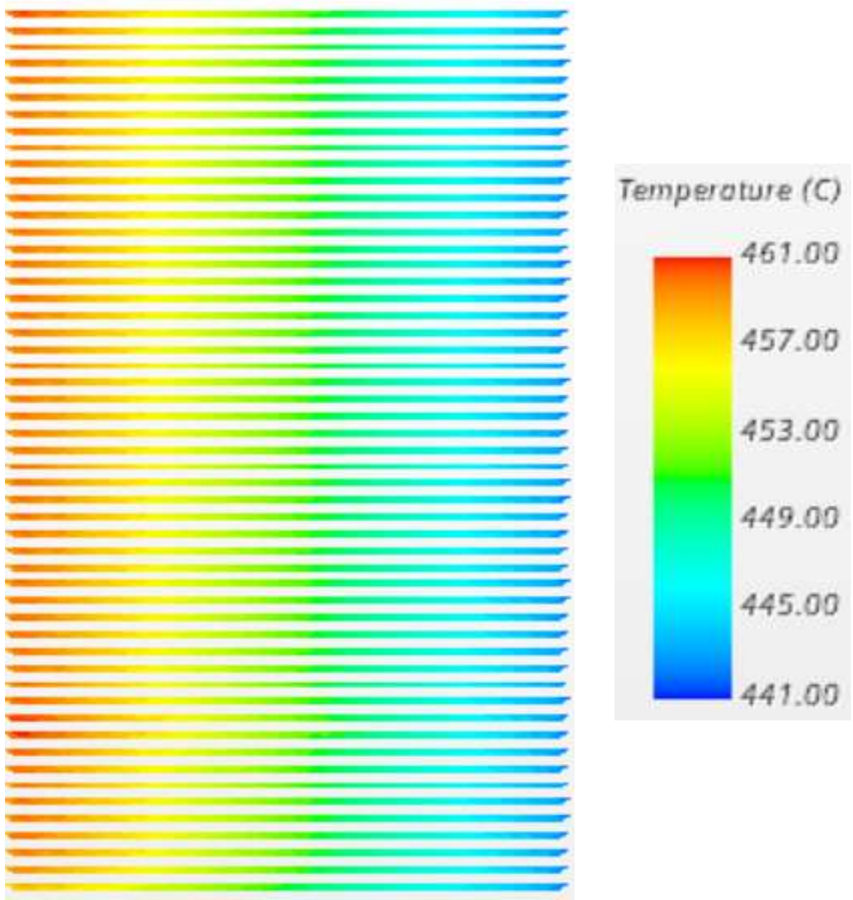
Exothermic reaction under a specific atmosphere

Gap between powder and next tray	**7.5 mm**
Flow velocity	**0.5 m/s**
Initial temperature gas & product:	**450 °C**

Mean temperature of powder: 451 °C



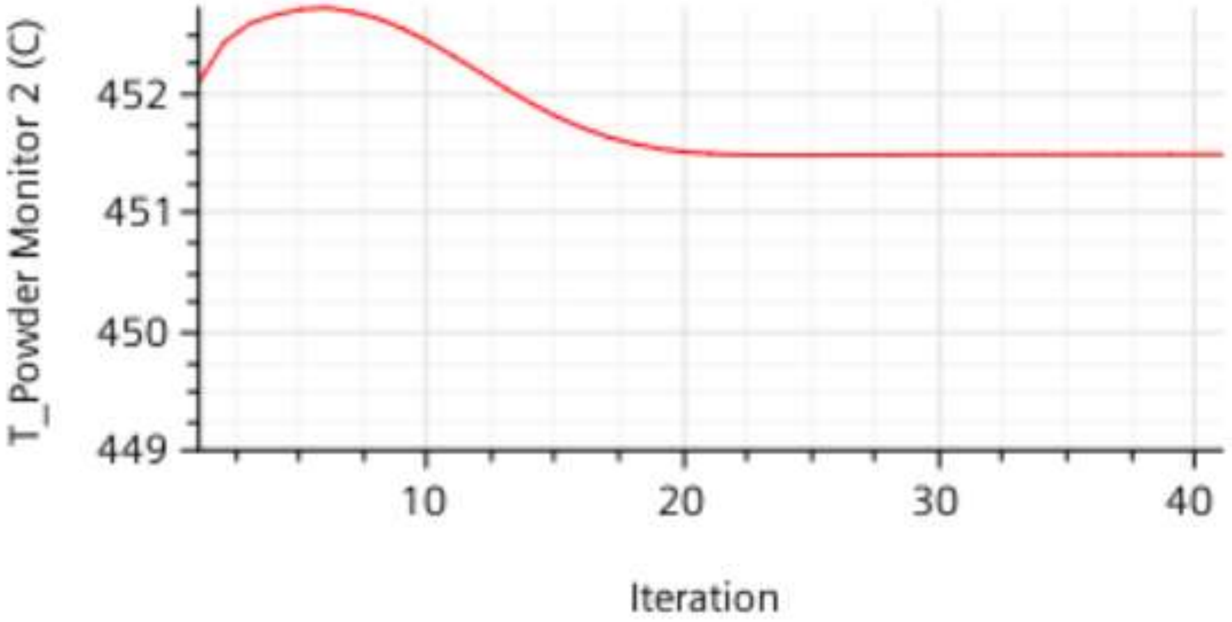
ΔT: 20K



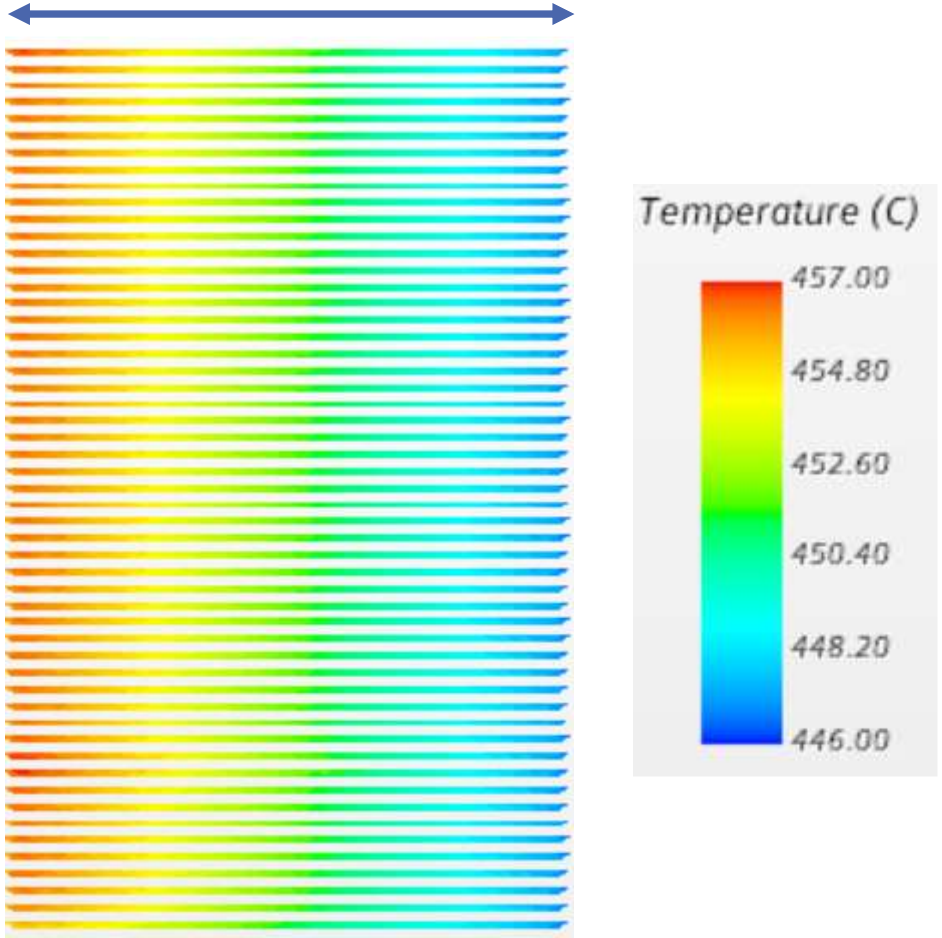
Influence of reaction heat to product temperature

Exothermic reaction under a specific atmosphere	
Gap between powder and next tray	7.5 mm
Flow velocity	1.0 m/s
Initial temperature gas & product:	450 °C

Mean temperature of powder: 451.5 °C



ΔT: 11K



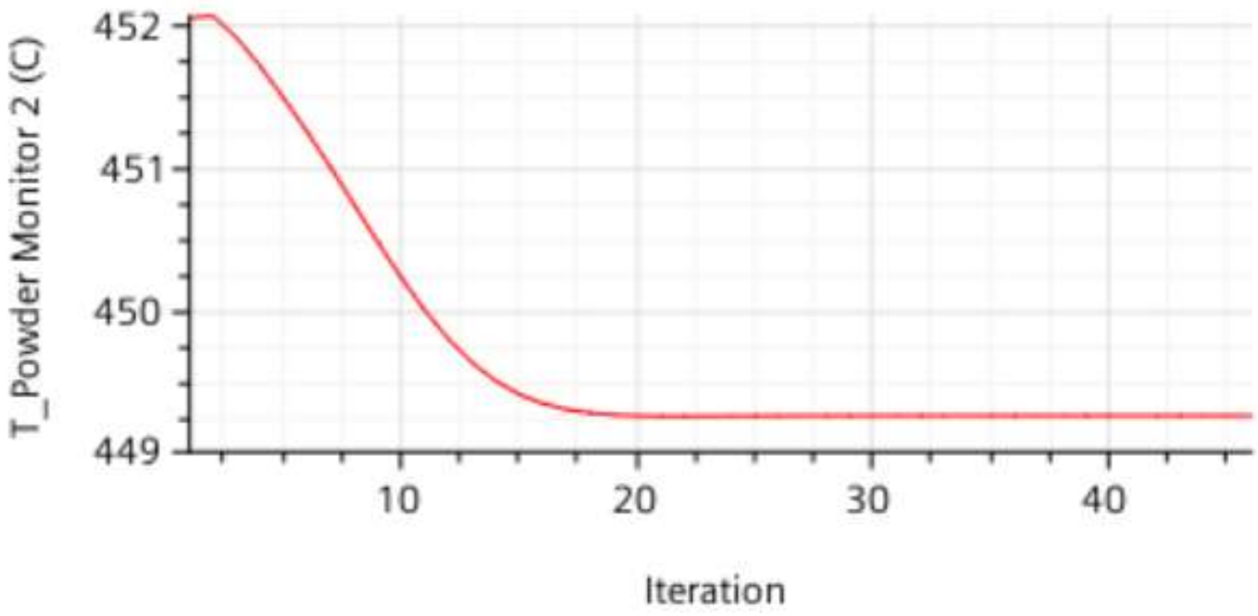
Influence of reaction heat to product temperature

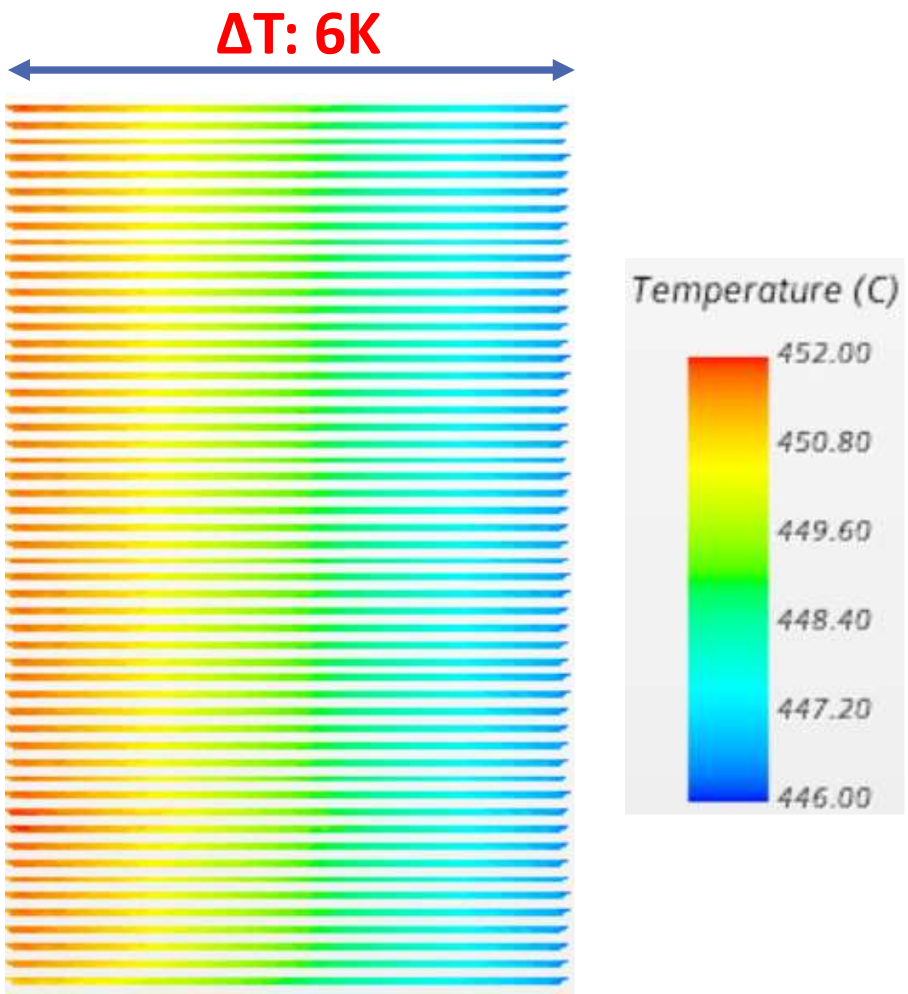
ONEJOON

Exothermic reaction under a specific atmosphere

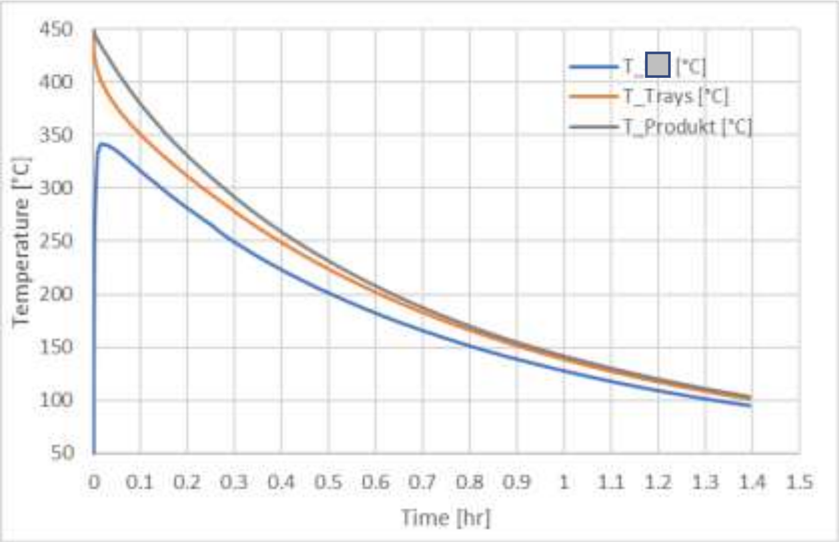
Gap between powder and next tray	**7.5 mm**
Flow velocity	**2.0 m/s**
Initial temperature gas & product:	**450 °C**

Mean temperature of powder: 449 °C

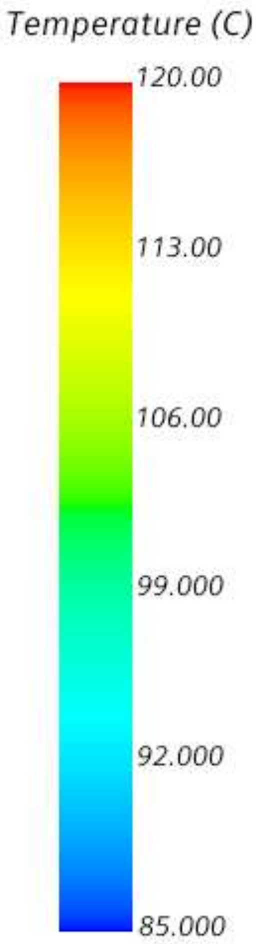




Mean temperatures during cooling phase

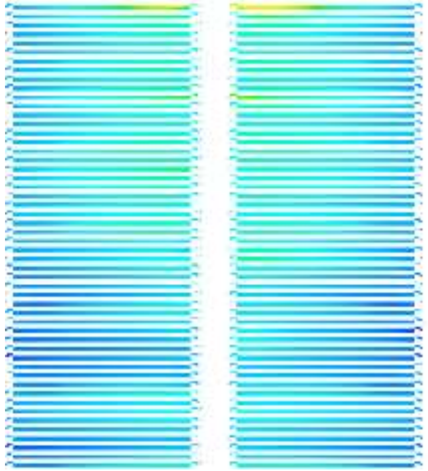


- Reactive atmosphere
- Average product temperature after 1.5 hours: 92°C
- Average ΔT between Trays and Product: ca. 2K

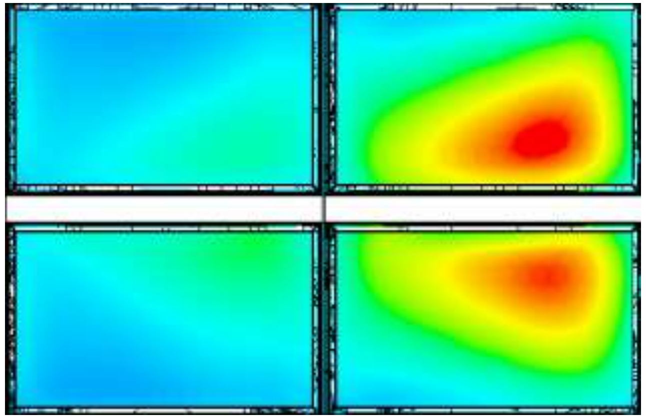


T range = 85 - 120°C

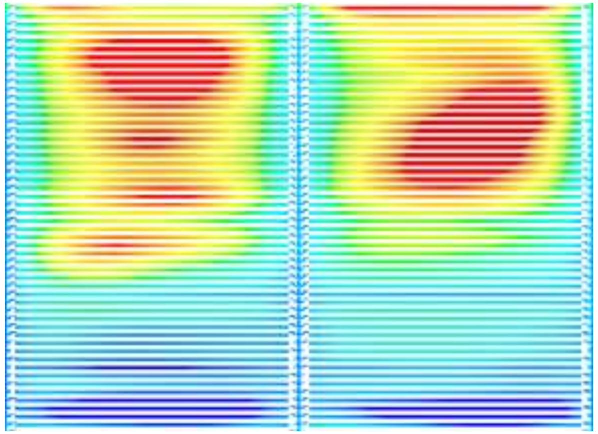
Side view



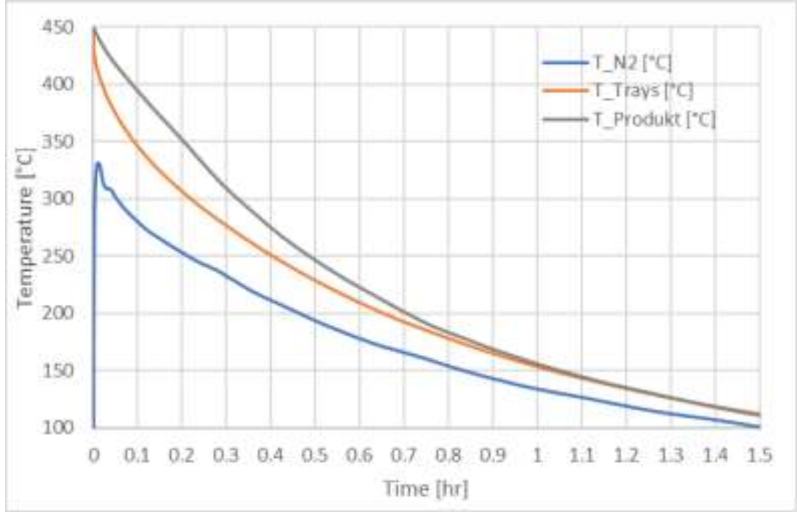
Top view



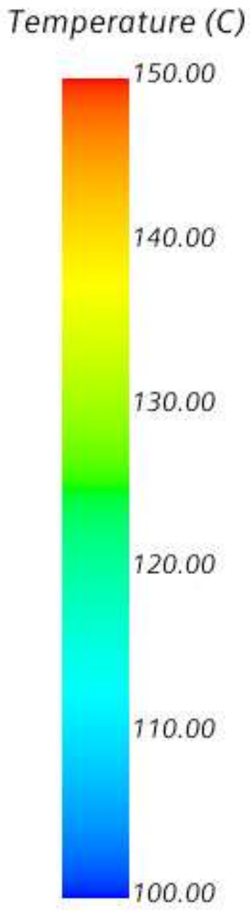
Front view



Mean temperatures during cooling phase

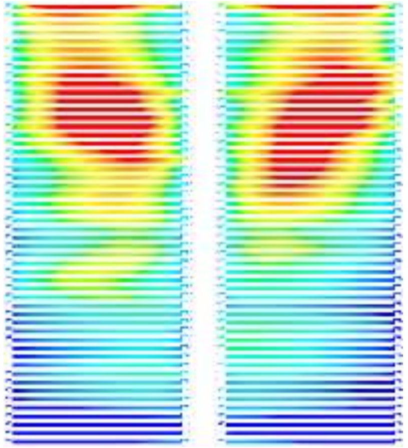


- N2 atmosphere
- Average product temperature after 1.5 hours: 111°C
- Average product temperature after 1.8 hours: ~92°C
- Average ΔT between Trays and Product: ca. 0.5K

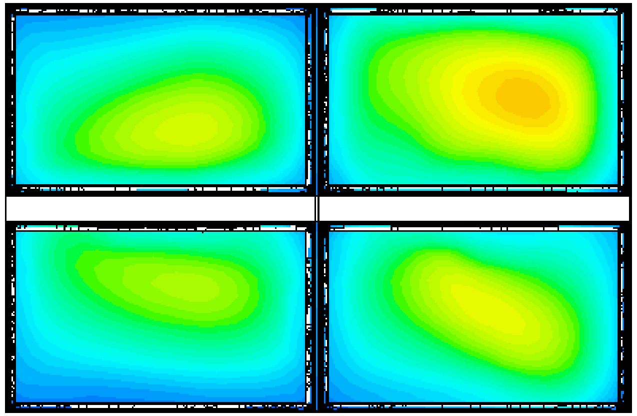


T range = 100 -150°C

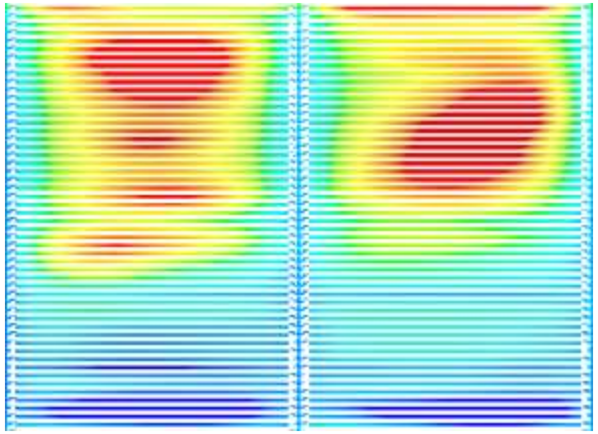
Side view



Top view



Front view



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Agenda

1 Introduction ONEJOON Group

2 Motivation – What drives us

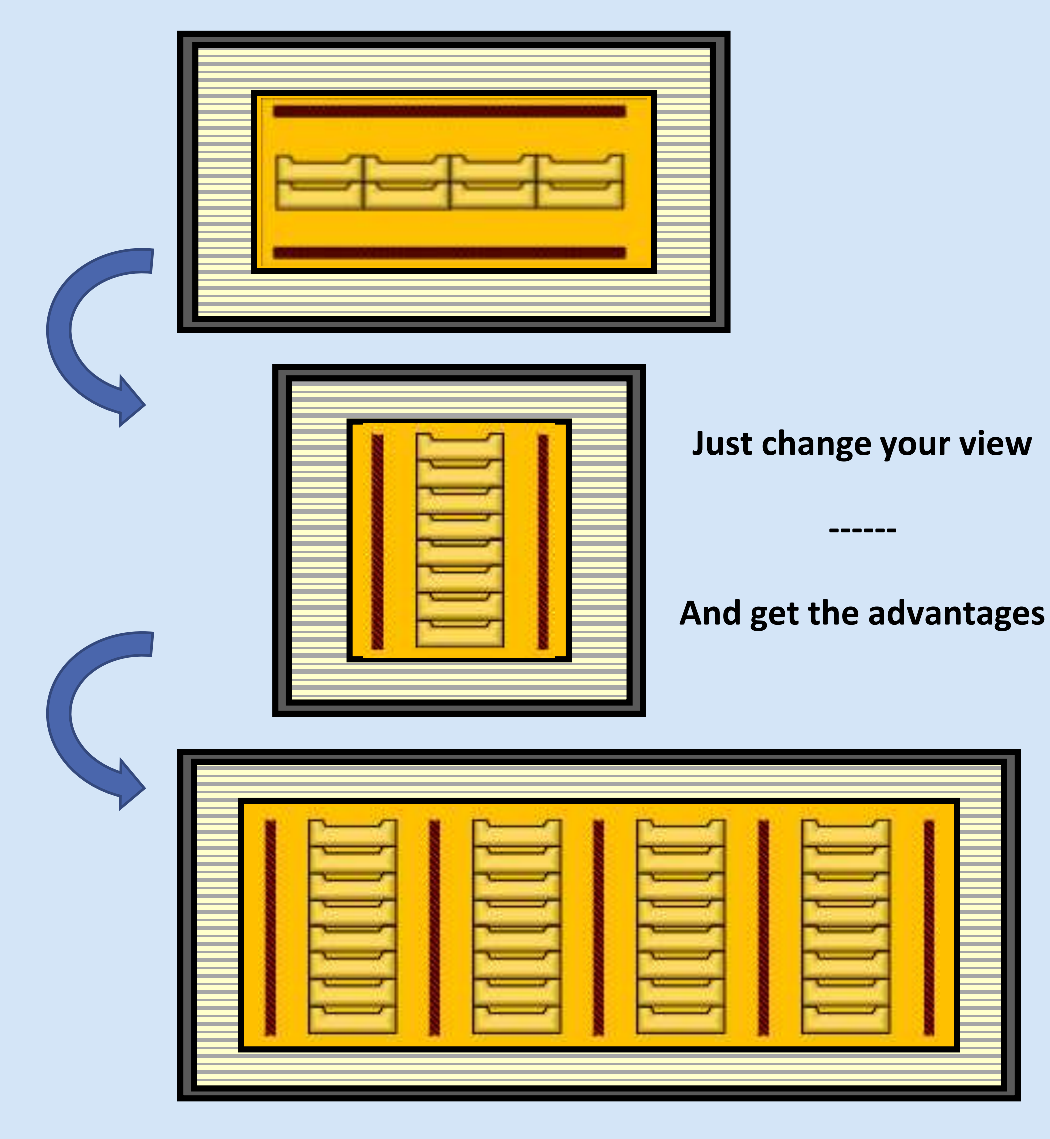
3 From Laboratory into Industrialization

4 Case Studies - new anode materials

5 Improving performance for CAM

6 Discussion

NEW Development Pusher Kiln
Principle & Advantages



Just change your view

And get the advantages

General

- ↑ Throughput (kg/h)
- ↓ Investment ($/kg)
- ↓ Footprint (m^2)
- ↓ Energy consumption (KWh/kg)
- ↓ Process gas consumption (Nm^3/h)

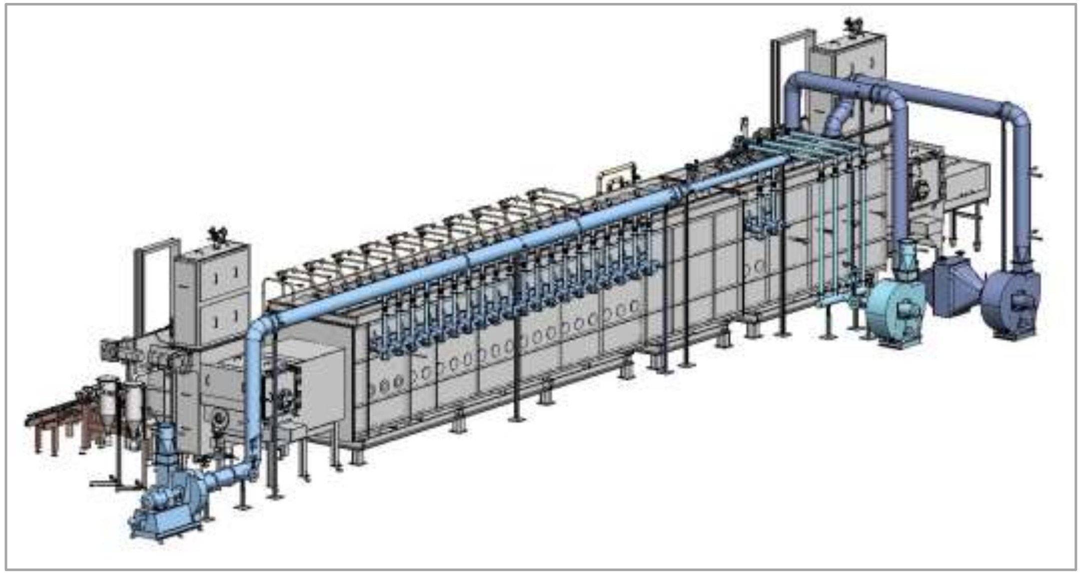
Process

- ↑ Temperature uniformity
- ↑ Adjustability and controllability
- ↑ Same condition situation for all saggars
- ↑ Process gas pre-heating (possible)
- ↑ Product homogeneity and quality

NEW Development Pusher Kiln
Concept Validation by Testing and Simulation

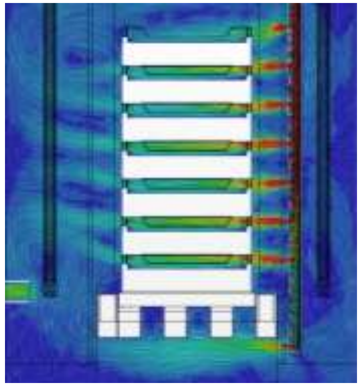
Test Bench

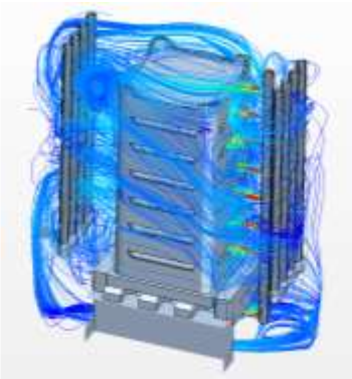
Test Module

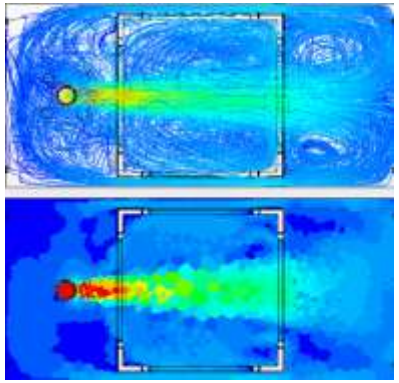


Pusher Pilot Kiln, 1 track, L=13m

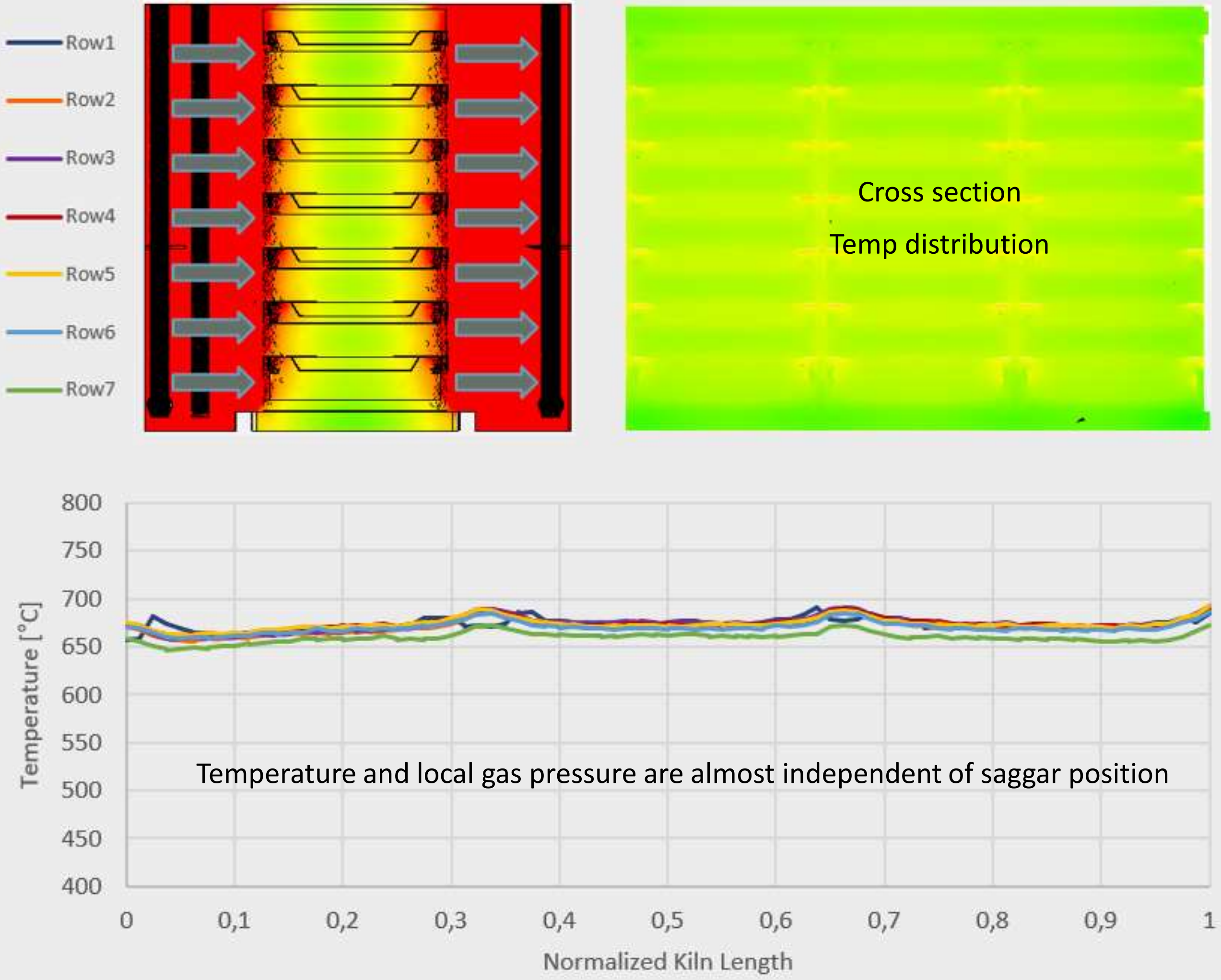
Series of experiments have been done for validation of concept to optimise and validate the CFD simulation model (flow & heating)



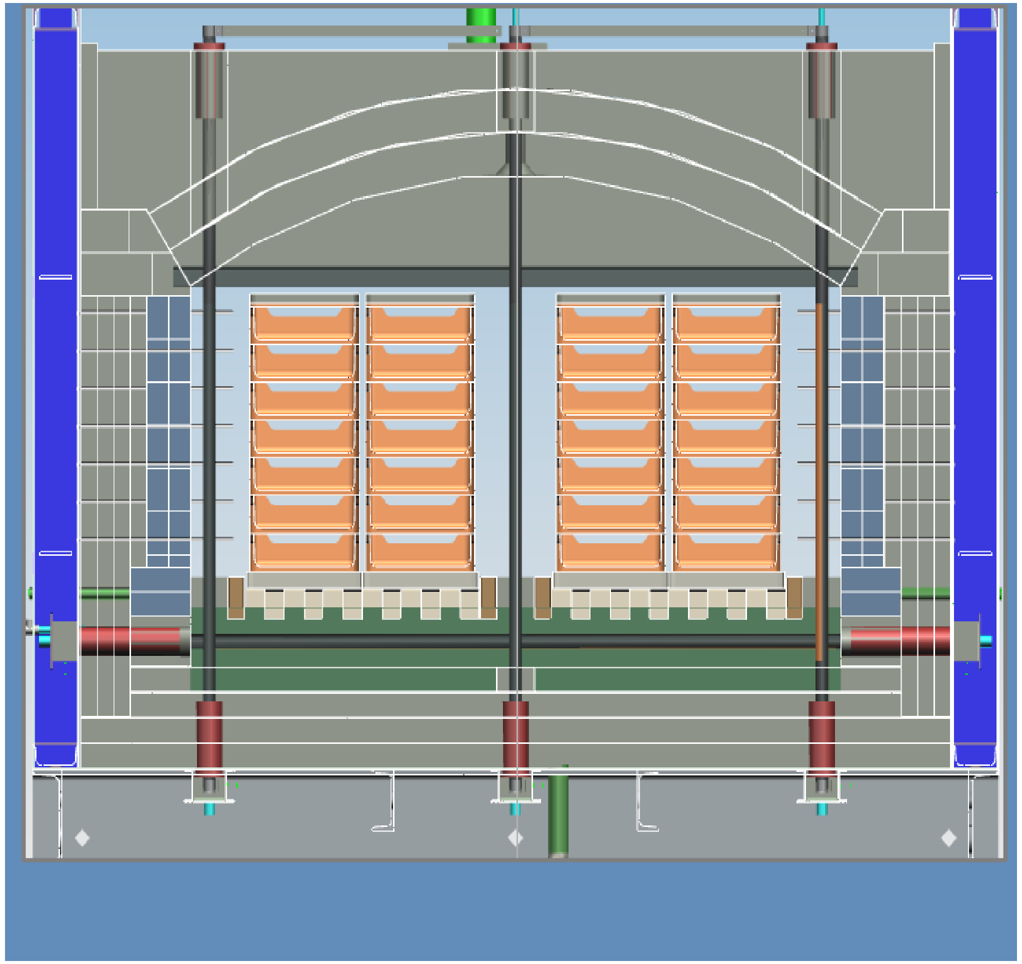




NEW Development Pusher Kiln
Testing and Simulation



NEW Development Pusher Kiln
Current Product with Double Lane)



Battery Pusher Kiln Benefits

- Onejoon mass production kiln:
  - Almost no upscaling drawbacks!
  - ca. ~ 400 % increase of production capacity
  - ca. ~ 70 % reduce of kiln’s footprint
  - ca. ~ 23 % reduce of energy consumption
  - ca. ~ 27 % reduce of Oxygen consumption

  up to 1 Mio €/a saving in production costs*

  * PSK 6x7 compared with a 43.7 m 4x2 RHK; 5 kg filling; 8 ct/kWh; 15 ct/m3 O_2

thus exploiting almost the full potential of CAM powder

Satisfying OEM Targets → longer driving ranges and saving costs!

New battery materials – What is needed?

- **Chemistry between the developing parties**
  - Open relationship with mutual respect and understanding of cultures

- **Extensive Process and Concept Expertise**
  - Extensive experience in regard of special atmosphere processes
  - Wide concept know how
  - Experience with production scale up
  - Test center with good test cababilities

- **Global Company**
  - Manufacturing operations in the main production regions
  - Service capabilities worldwide

Capability to listen to the challenges presented by the producer in order to provide the best solution !!!

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Thank you.

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ONEJOON – we never stop challenging the future.