SMELTER OF THE FUTURE

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  Consequences of the Paris climate agreement for the aluminium industry

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  - **Optimizing the Hall-Heroult process**
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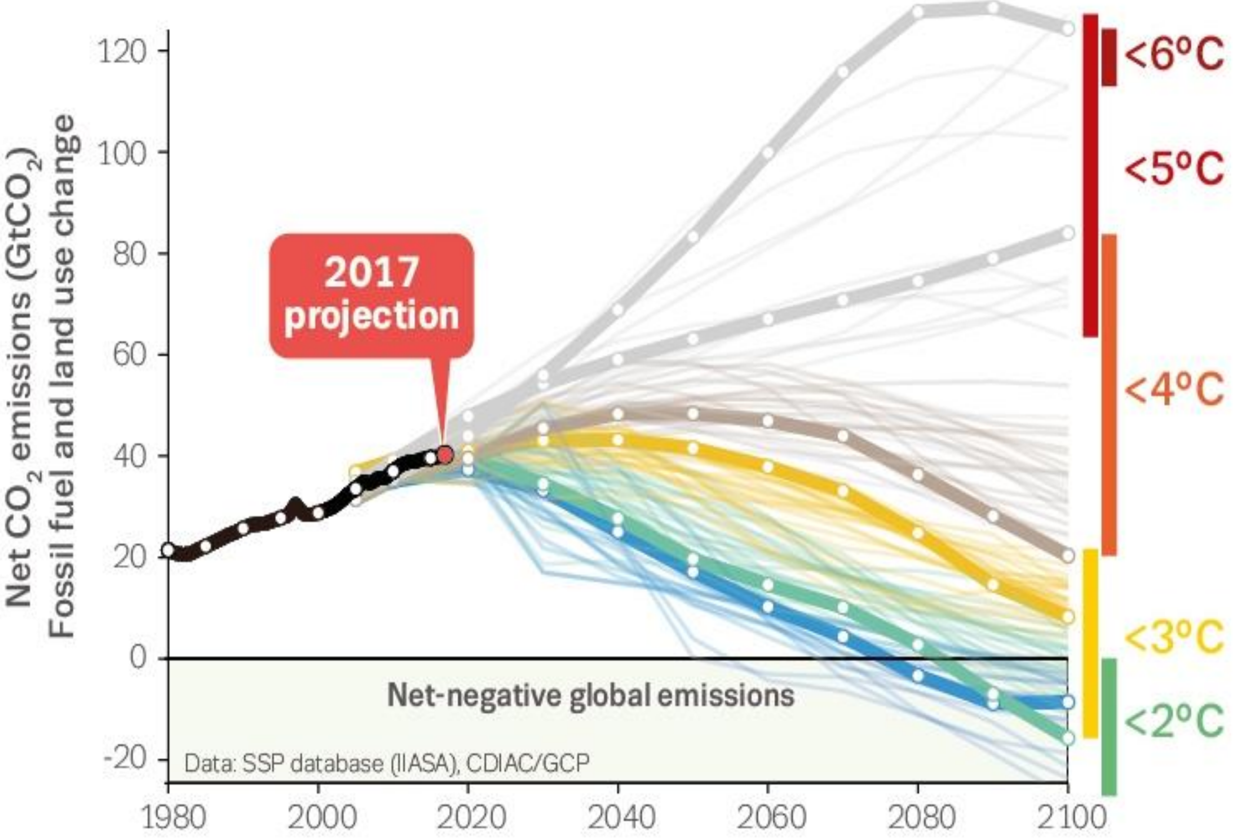
- **Opportunities through Industry 4.0 and digital technology**

01 Introduction

The Paris agreement: ambitious climate targets

The Paris agreement will be instrumental in shaping the future technology development

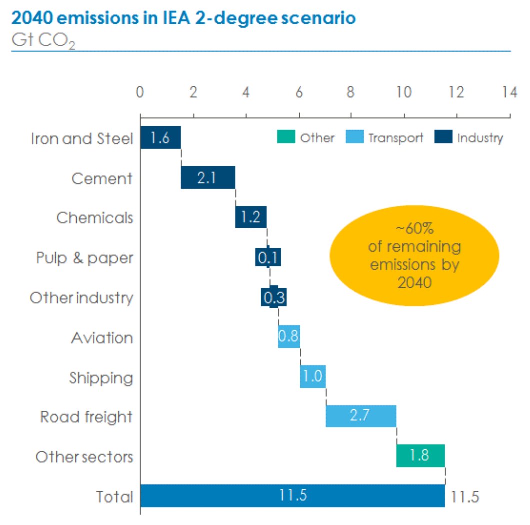
- Target: Reduce global warming to «well below» 2 degrees, aiming for 1.5
- Significant actions will be needed in all sectors
- EU reaction will influence industry politics going forward



Increased urgency and focus on industrial emissions

Reducing industrial CO_2 emissions

- Industry and heavy transport emit 60% of total in 2040 – in 2 degrees scenario
- CO_2 budget (IEA): limited to approx. 11GT/y



Early reductions may hedge future pressure?

Intensified competition among materials

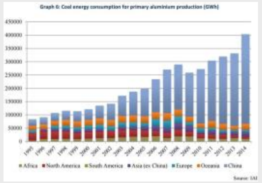
Environmental footprint takes hold as a differentiating quality – competing materials have significant potential for low footprint

Plastics

Steel

HYBRIT
FOSSIL-FREE STEEL

Coal content in Al

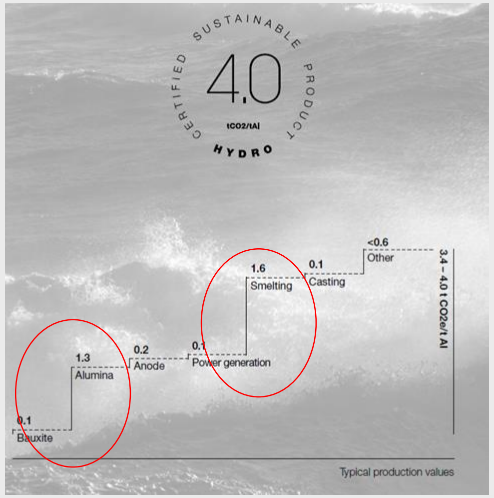


New competitors (e.g. wood)

Environmental credentials are fragile?

Customer driven competition

- Competition btw peers on footprint
- Requirements from customers on transparency and low footprint

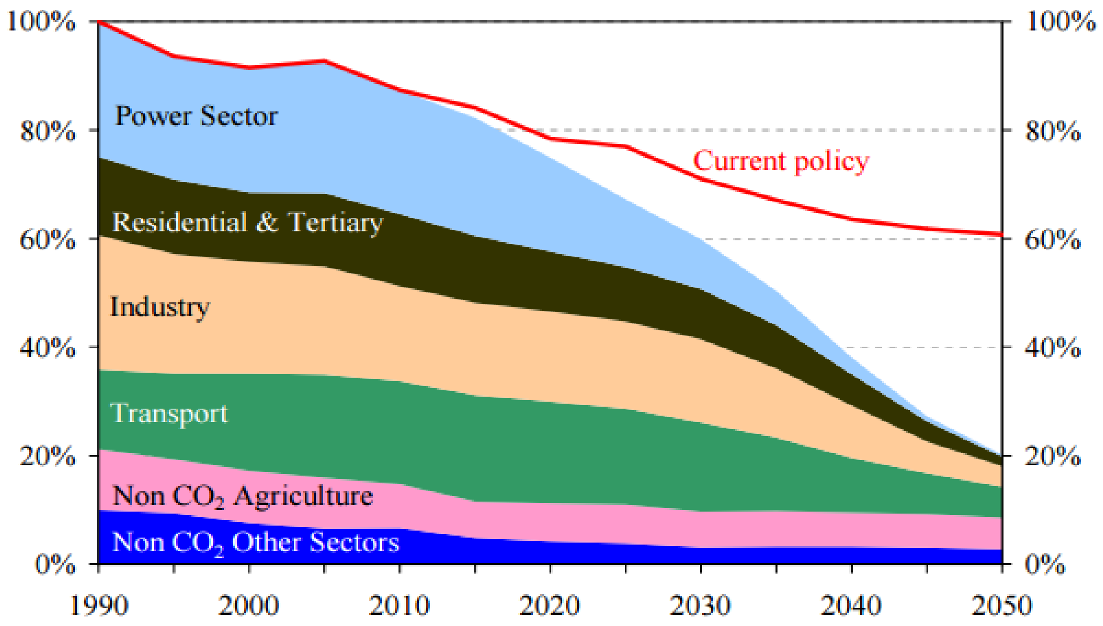


Market positions change and customers increasingly differentiate suppliers?

Energy related emissions and process emissions reductions

- In a 2 degrees scenario, emissions need to be reduced by 50%, compared to Paris pledges
- In a below 2 degrees scenario, emissions need to be reduced by 75%

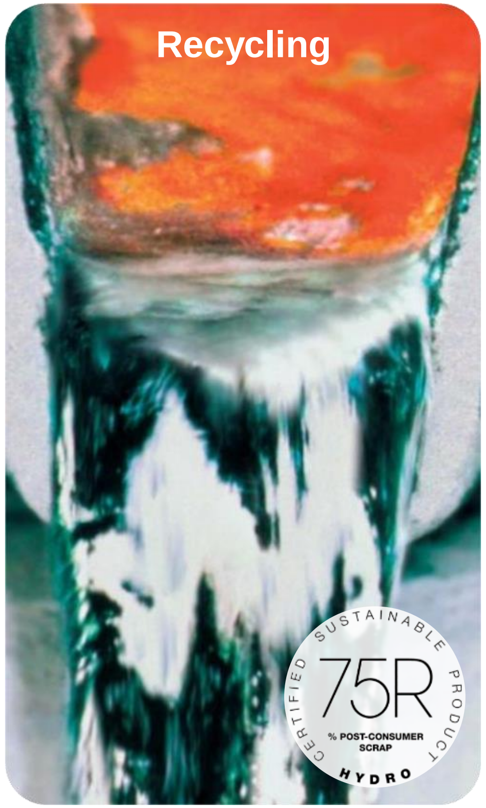
Figure 1: EU GHG emissions towards an 80% domestic reduction (100% =1990)



Our response – global view

Production processes, recycling and aluminium in the use-phase are all important

Reduce energy consumption and emissions in our own processes

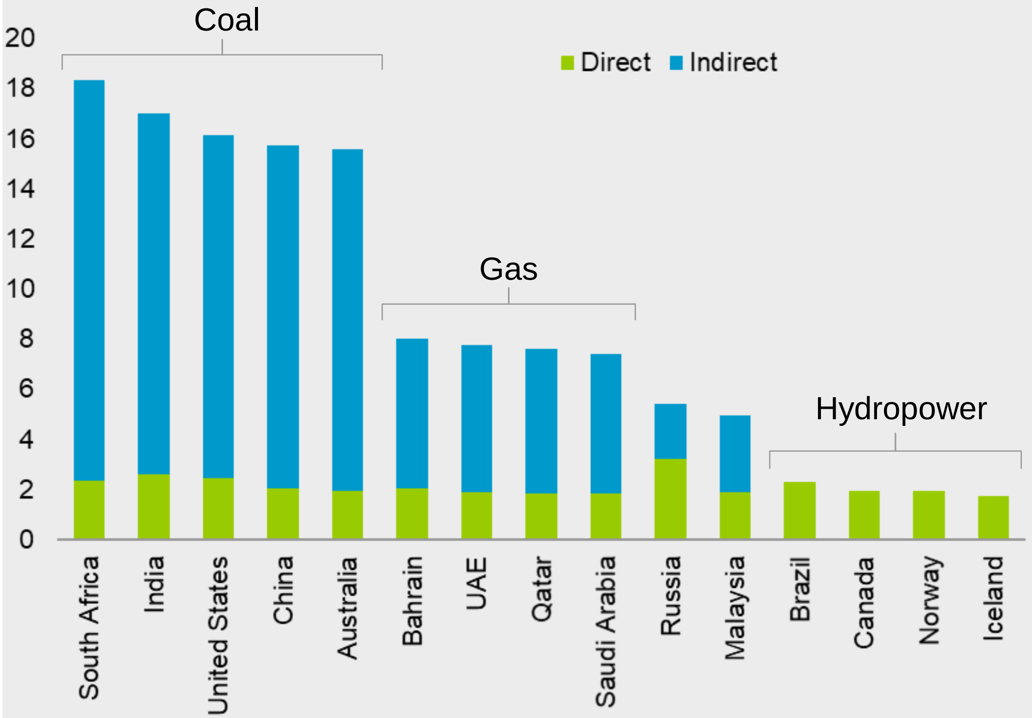


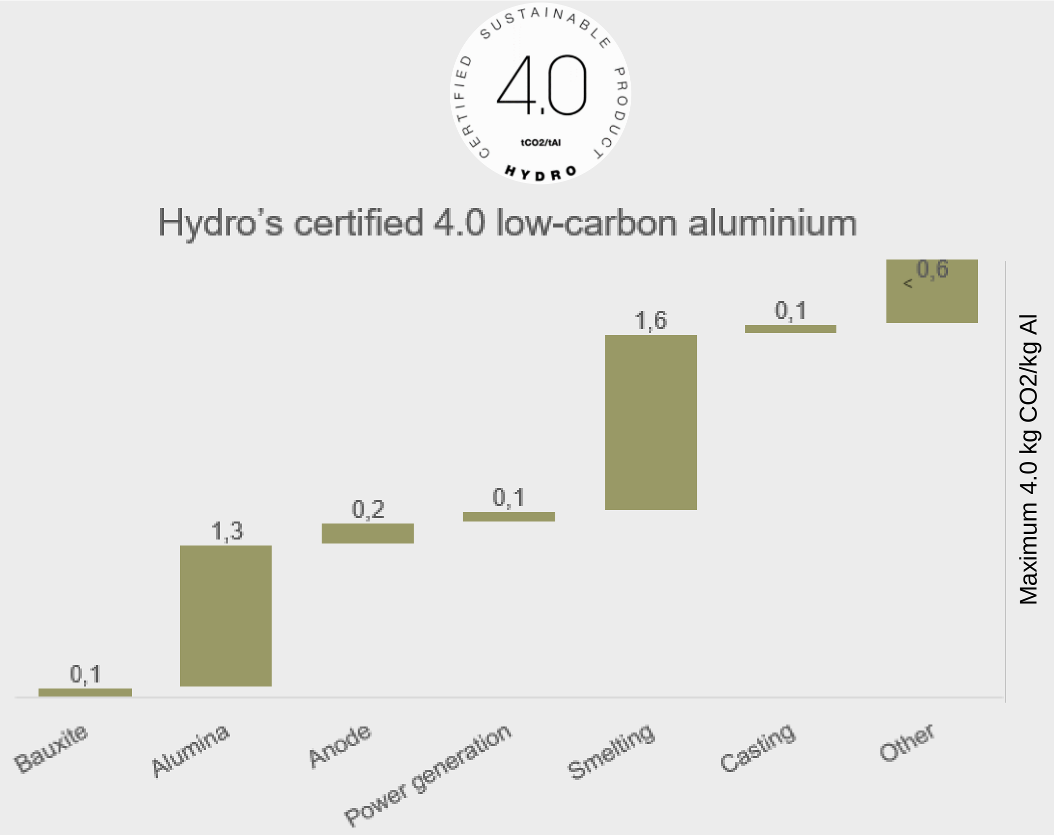
Reduce waste and recover energy value from used products through recycling

Develop products and solutions that reduce energy consumption and emissions in the use-phase

Our response - industry production view

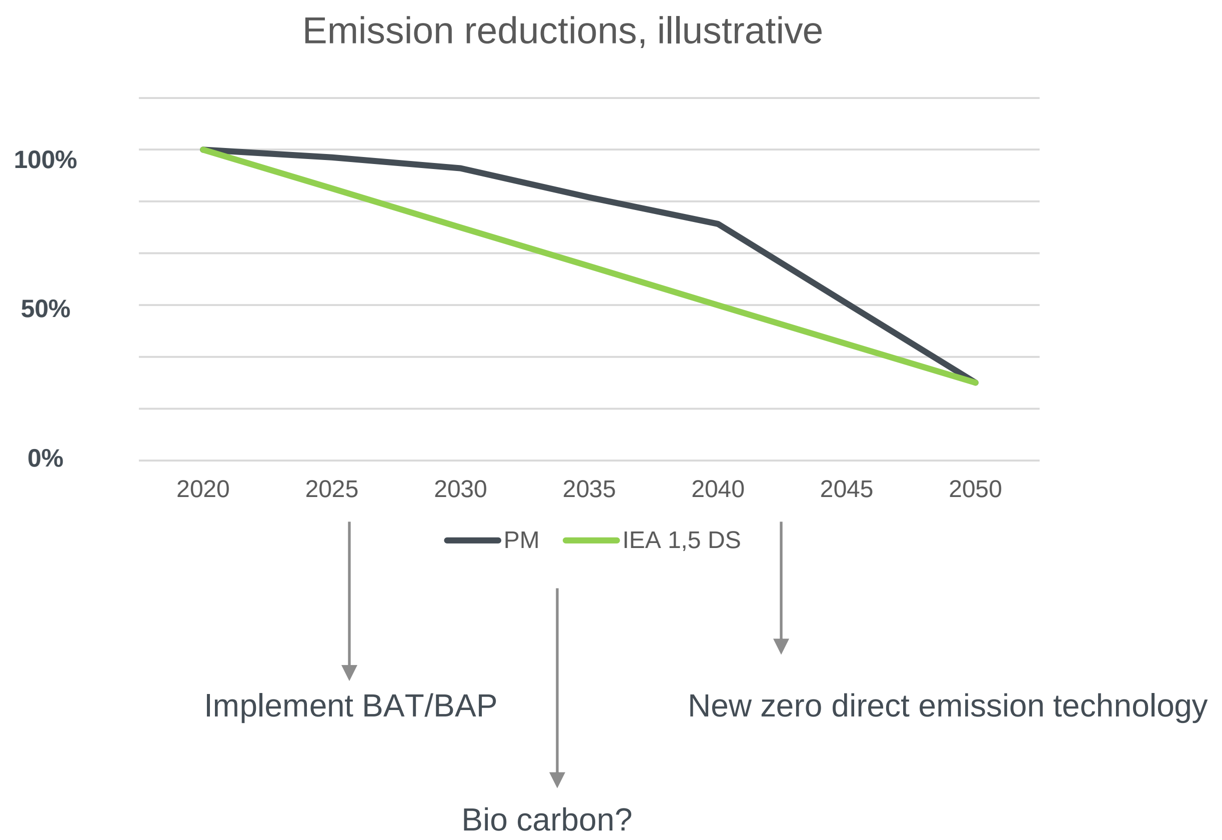
Emissions from production steps in the whole value chain





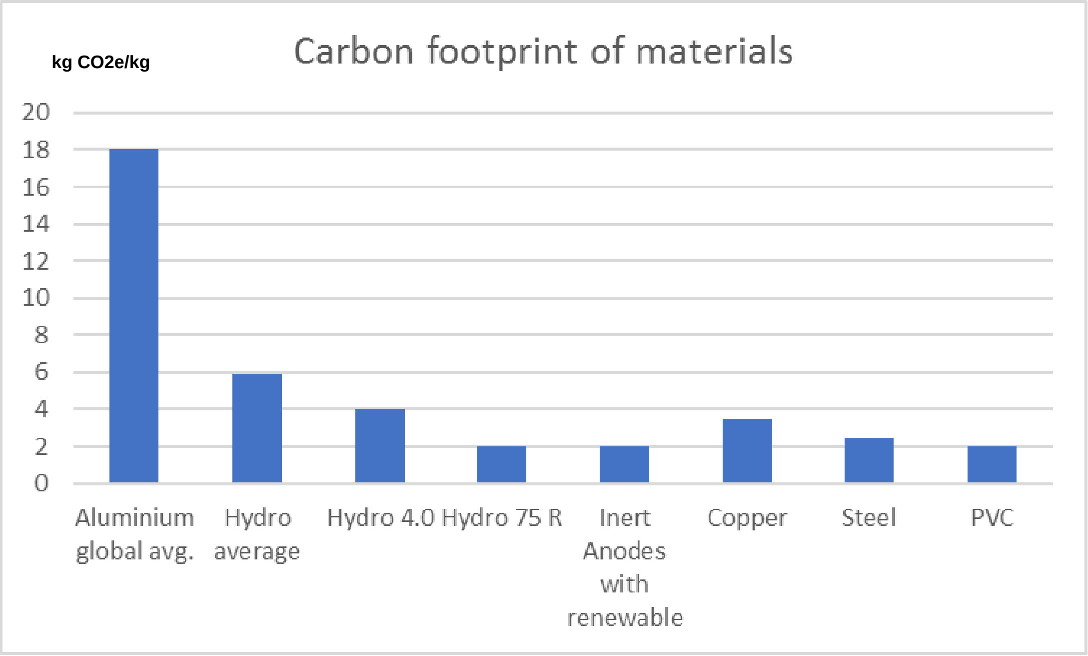
Our response – smelter view

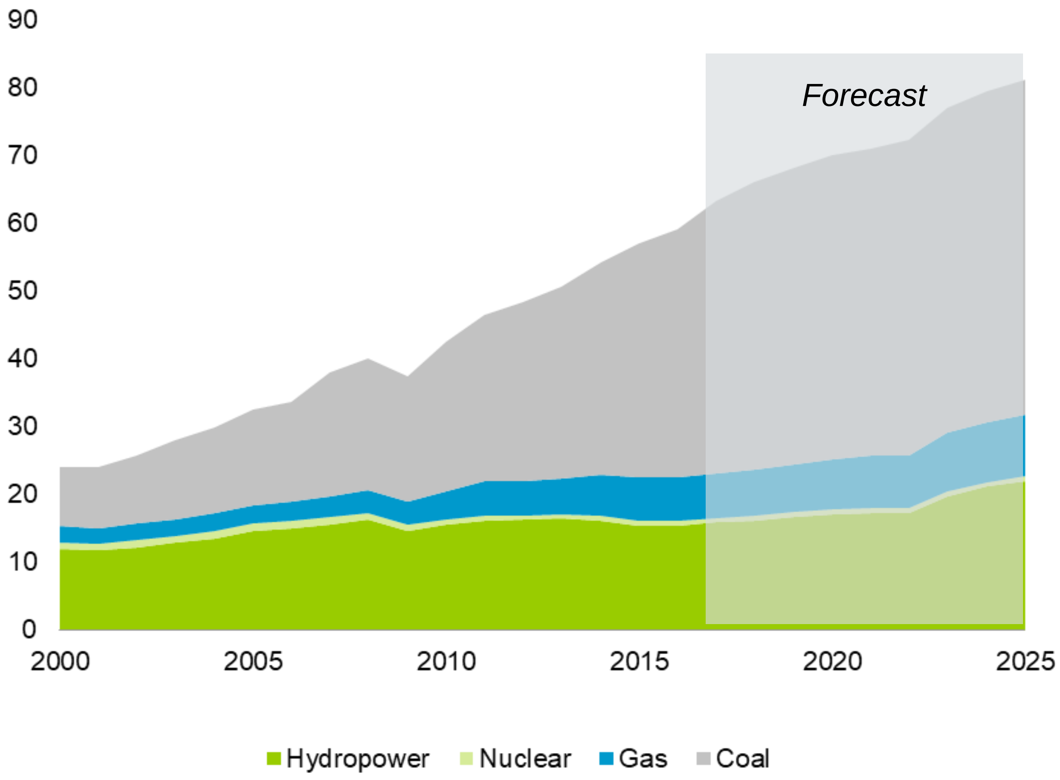
Probably not one solution, but several initiatives spread out in time



Primary aluminium production can come under pressure

Aluminium industry going in the wrong direction – action needed





02

Smelter technology response

Is it possible to produce aluminium with 0 carbon footprints?

Prerequisite: All energy sources must be based on renewable energy

<u>New technology in «new» plants</u>:

- Inert anodes
- Chloride process
- Other exotic processes

New technology:

6000 $/t
70 Mt
400 B$

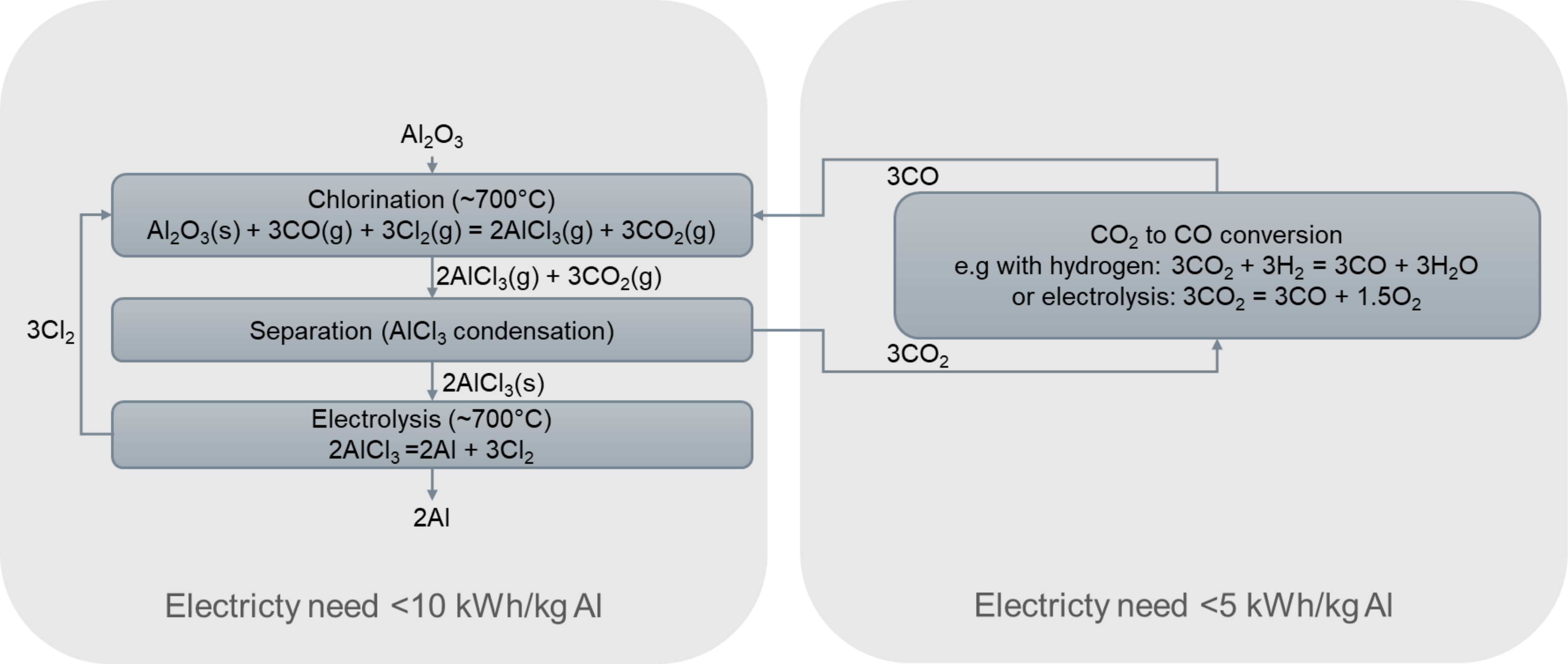
We will probably have Hall-Heroult plants for decades

<u>Build on the HH-process and existing plants</u>:

- Optimise operations
  - Digital/I4.0 stability
  - PFC control
- Energy consumption
- Bio carbon
- CO_2 capture – CCS/CCU

A new approach to the chloride process

Combine the chloride process with recycling of CO_2



CO_2 capture and use – an option for HH smelters

CCU is immature, but a wide range of options may become relevant

CO_2 capture concepts

Low concentration capture
Direct air capture concepts may be adapted to smelter off-gas - BHP recent investment in start-up

MEA capture
Capture concepts developed for higher CO_2 concentrations are maturing

CO_2 utilisation concepts

Mineralisation
Mineralisation of CO_2 using local minerals to stabile substances (e.g. carbonates) for use in products or to storage

Chemicals
Conversion or inclusion of CO_2 into commodity chemicals, plastics or fuels

Biologic conversion
Conversion of CO_2 in biological processes. Algea processes producing bio mass e.g. for fish farming feed

Solutions will be smelter-specific

Definition of options driven by

- Local resources
- Potential technology and value chain partners
- Smelter size, -configuration and – age

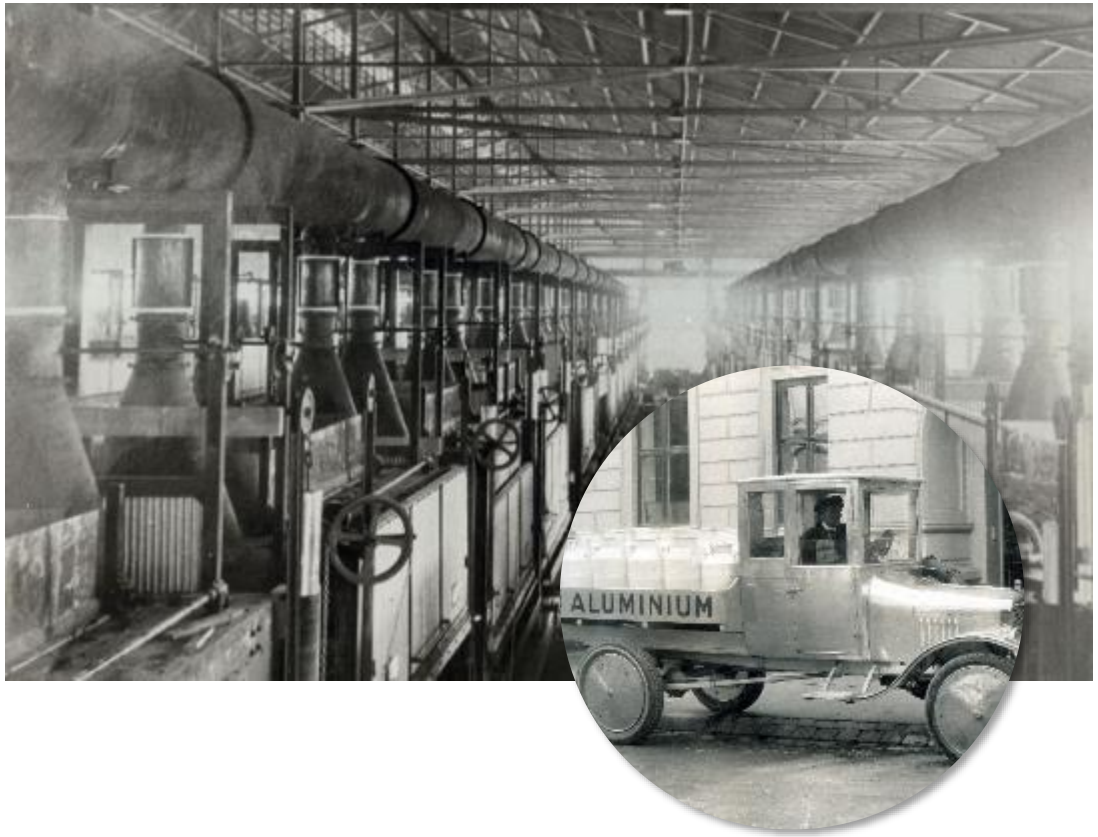
Energy consumption - Karmøy Technology Pilot

60 HAL4e cells in operation – stabilizing operational performance

- 1st cell started January '18, all 60 cells by June '18
- Current efficiency and energy consumption on track towards verification of targeted values
- Optimization ongoing for performance
- Cathode performance according to expectations
- SoftSensor (Digital Twin) fully implemented and performing well
- Several Industry 4.0 elements under implementation
- PTM functionality not yet fully implemented, but being resolved (cover handling)
- Early operational challenges largely solved

03 Industry 4.0

We all seem to have the same vision of an autonomous Smelter 4.0

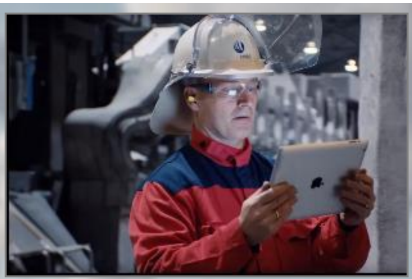


Smelter 4.0 vision – the autonomous smelter of the future

Karmøy technology pilot is step 1 towards the vision - control platform, connectivity and automation

Autonomous cells

Continuous sensor-based measurements
Artificial intelligence
Big data
Automation



Connected operator & maintenance

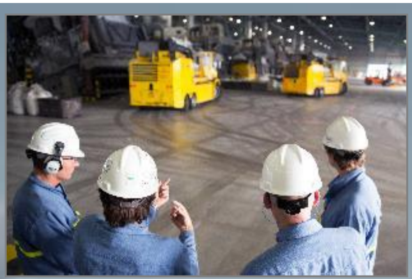
Connectivity
Asset data management
Predictive maintenance
Augmented reality

Connected plants

Connectivity
Virtual control room
Remote operations
Real-time optimisation
Big data

Automated cranes

Sensors
Automation
Safety
Accuracy



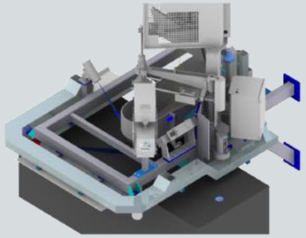
Automated transport

Safety
Autonomous vehicles
Fleet control
& logistics

Exploring improvement opportunities within automation

A substantial part of the portfolio targets HSE – a good way to create engagement and support

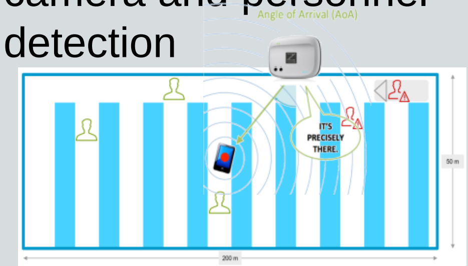
Automatic casting of anode



Automatic charging and skimming

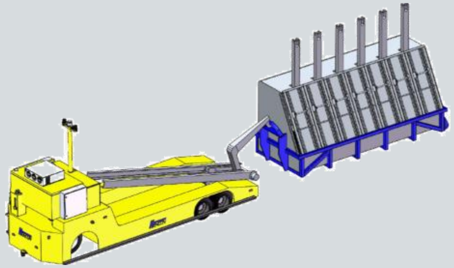
Pit monitoring

Safe zone monitoring – camera and personnel detection

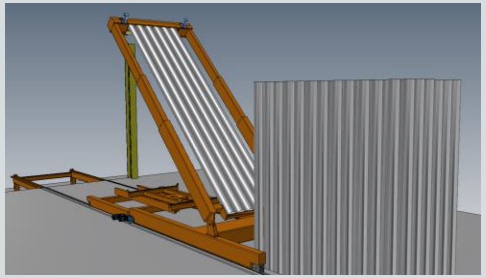


Butts cleaning by robot and 3D scan

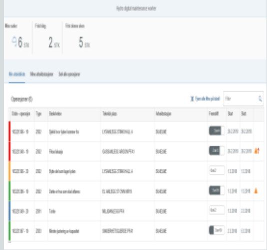
Automated Guided Vehicles (AGV)



Pit stripping



Mobile maintenance worker



Machine learning/AI-engine/advanced analytics

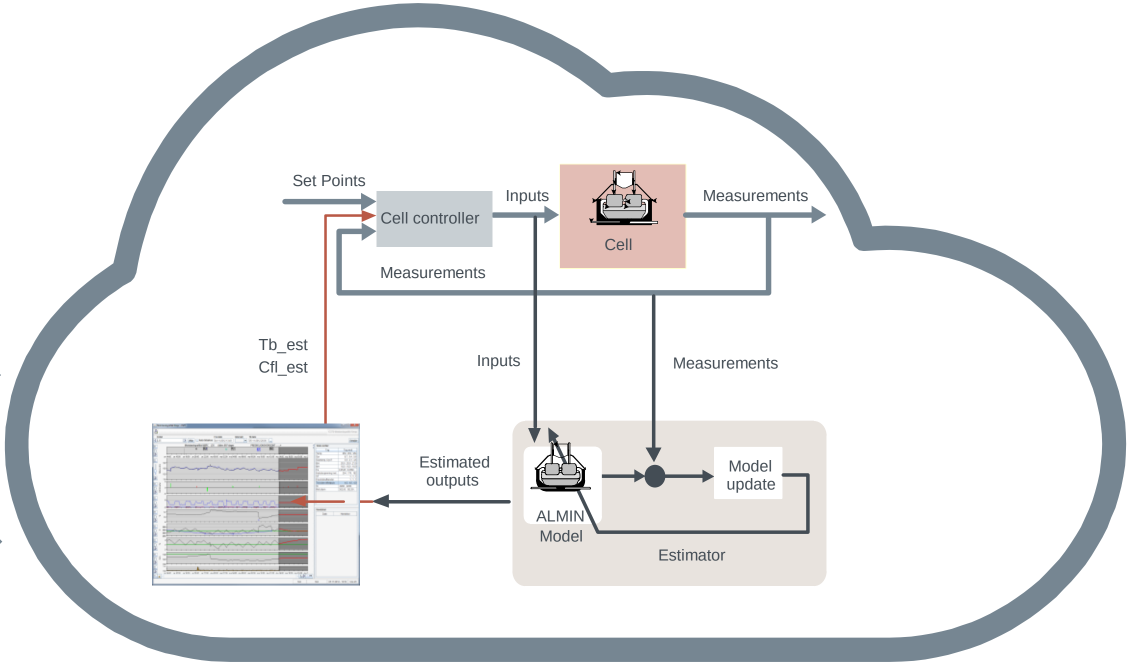
-Many nice examples demonstrating the power of machine learning

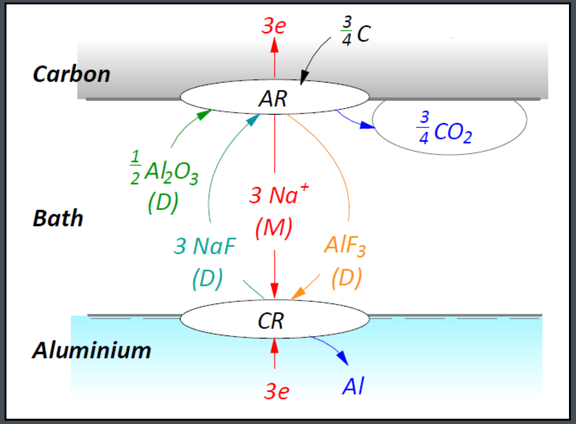
-Will these techniques replace the need for domain competence?

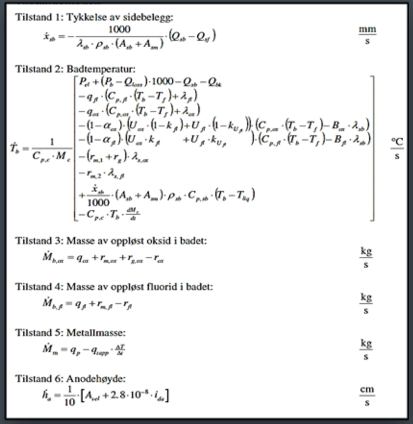
Digital twins

Process data

Domain competence







Tilstand 1: Tykkelse av sidebelegg:

$$\dot{x}_{sb} = -\frac{1000}{\lambda_{sb} \cdot \rho_{sb} \cdot (A_{sb} + A_{sm})} \cdot (Q_{sb} - Q_{sf}) \quad \frac{\text{mm}}{\text{s}}$$

Tilstand 2: Badtemperatur:

$$\dot{T}_b = \frac{1}{C_{p,c} \cdot M_c} \begin{bmatrix} P_{el} + (P_b - Q_{loss}) \cdot 1000 - Q_{sb} - Q_{bk} \\ -q_{fl} \cdot (C_{p,fl} \cdot (T_b - T_f) + \lambda_{fl}) \\ -q_{ox} \cdot (C_{p,ox} \cdot (T_b - T_f) + \lambda_{ox}) \\ -(1-\alpha_{ox}) \cdot (U_{ox} \cdot (1-k_{fl}) + U_{fl} \cdot (1-k_{U_{fl}})) \cdot (C_{p,ox} \cdot (T_b - T_f) - B_{ox} \cdot \lambda_{sb}) \\ -(1-\alpha_{fl}) \cdot (U_{ox} \cdot k_{fl} + U_{fl} \cdot k_{U_{fl}}) \cdot (C_{p,fl} \cdot (T_b - T_f) - B_{fl} \cdot \lambda_{sb}) \\ -(r_{m,1} + r_g) \cdot \lambda_{s,ox} \\ -r_{m,2} \cdot \lambda_{s,fl} \\ + \frac{\dot{x}_{sb}}{1000} \cdot (A_{sb} + A_{sm}) \cdot \rho_{sb} \cdot C_{p,sb} \cdot (T_b - T_{liq}) \\ -C_{p,c} \cdot T_b \cdot \frac{dM_c}{dt} \end{bmatrix} \quad \frac{^\circ\text{C}}{\text{s}}$$

Tilstand 3: Masse av oppløst oksid i badet:

$$\dot{M}_{b,ox} = q_{ox} + r_{m,ox} + r_{g,ox} - r_{ox} \quad \frac{\text{kg}}{\text{s}}$$

Tilstand 4: Masse av oppløst fluorid i badet:

$$\dot{M}_{b,fl} = q_{fl} + r_{m,fl} - r_{fl} \quad \frac{\text{kg}}{\text{s}}$$

Tilstand 5: Metallmasse:

$$\dot{M}_m = q_p - q_{tapp} \cdot \frac{\Delta T}{\Delta t} \quad \frac{\text{kg}}{\text{s}}$$

Tilstand 6: Anodehøyde:

$$\dot{h}_a = \frac{1}{10} \cdot [A_{vel} + 2.8 \cdot 10^{-8} \cdot i_{da}] \quad \frac{\text{cm}}{\text{s}}$$

Optimizing and stabilizing production by combining physical models and advanced analytics of process data

Trusted Data Layer

Do not underestimate data storing and handling

Intelligence Layer

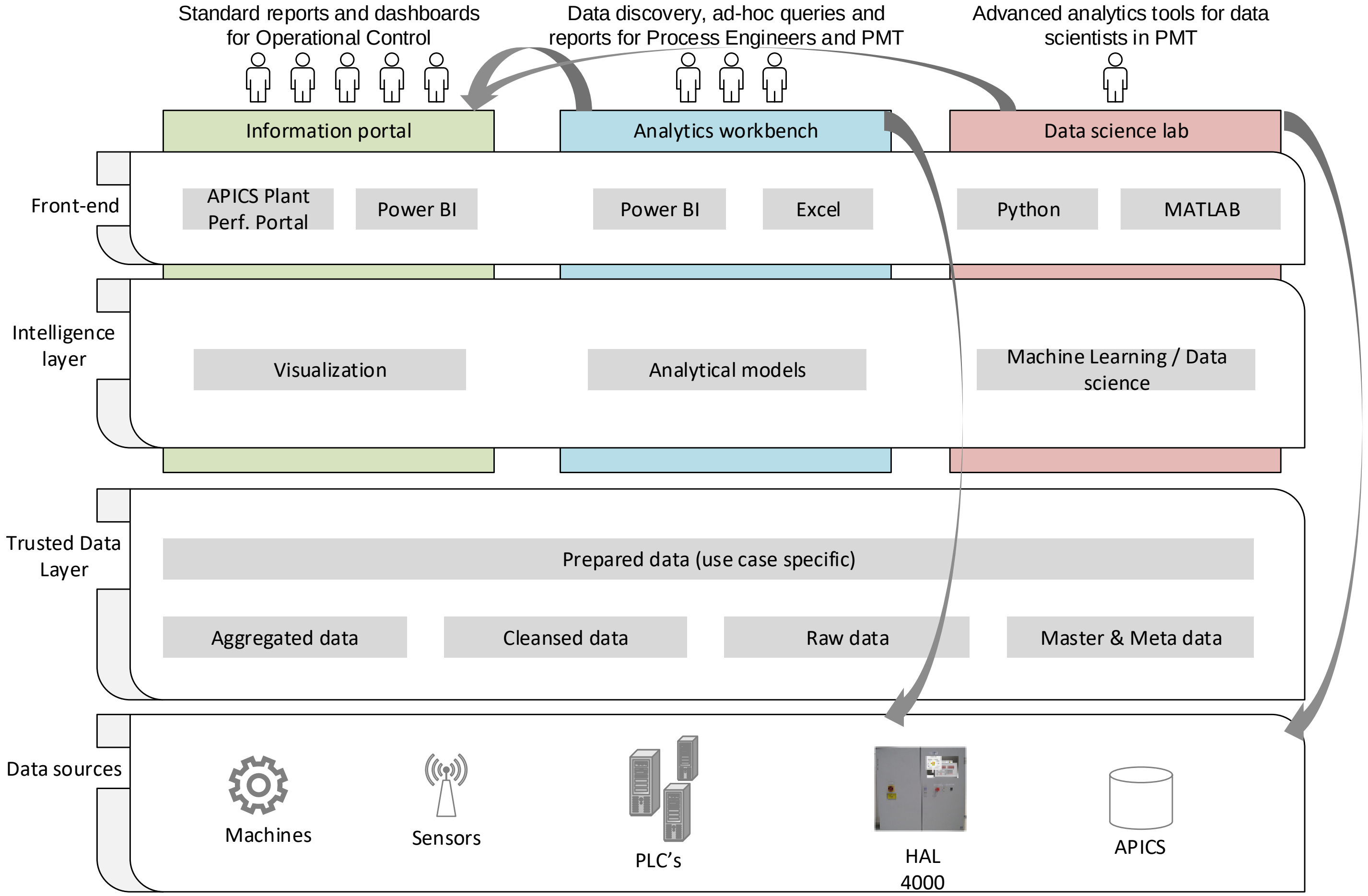
Data and results from analytics is made available for managers, operators, maintenance resources, process engineers and researches through Information portals, Analytics workbenches and Data science tools.

Trusted Data Layer

Data layer where data is managed and stored long term for use in various analytics use cases. Data transfer from source system are implemented based on use cases, but re-used to support new use cases.

Data sources

Data from APICS, cell control systems, sensors etc. are securely transferred to the cloud either real time or in batch (e.g. hourly or daily)



Autonomous Cell

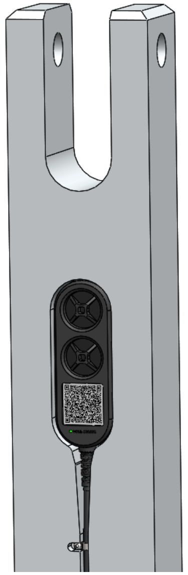
Sensors & Measurement

Manual ACDM

In-house version being implemented in all smelters

IACM

In-house version being piloted in 2 smelters



Fiberlab/Starprobe

Vendor-solutions implemented in all smelters

Smart breakers

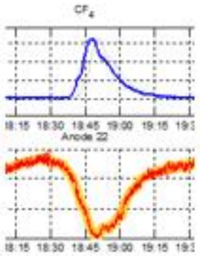
Development work to utilise breaker signals

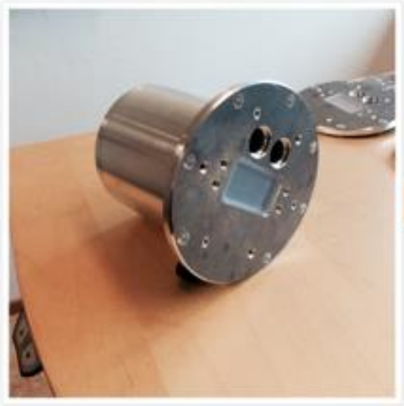
PTM and indirect

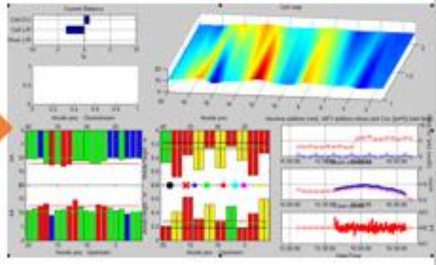
Development on how to utilise PTM and use indirect measurements

IACM - Individual Anode Current Measurements

If installed on every anode: tool to control PFC & big data insight – but needs to be low-cost!







ALOUETTE

alu Québec
Aluminium Cluster

CeAL
Centre d'expertise sur l'aluminium

Equibras

DYNAMIC CONCEPT
ISO 9001-2015

RioTinto

Alcoa ®

MECFOR
Operational Engineering. Optimized Fabrication.

HATCH

STAS

mæstria
SOLUTIONS

AD

Morin Énertech, inc
Projets / Service Conception / Énergie

REGAL
REGROUPEMENT ALUMINIUM
CENTRE DE RECHERCHE SUR L'ALUMINIUM
ALUMINIUM RESEARCH CENTRE

National Research Council Canada
ALTec industrial R&D group

20 ans
CEE-UQAC
Centre d'entrepreneuriat et d'essaimage
Université du Québec à Chicoutimi

The role of suppliers

- Technology development:
  - Fast, innovative, disruptive
  - New players (start-ups and vendors from other industries)
  - Traditional suppliers with pure mechanical solutions not competitive
- Consequence: Difficult to be at the forefront
- Will this lead to innovations in business models and collaboration models?
  - More pre-competitive collaboration
  - Development consortia of suppliers and producers
  - Cross-licensing of IP
  - Industry standards (Alu industry is small and scale is needed to bring down cost of sensors etc.)

Virtual control room

RTA

Aluminium Operations Centre

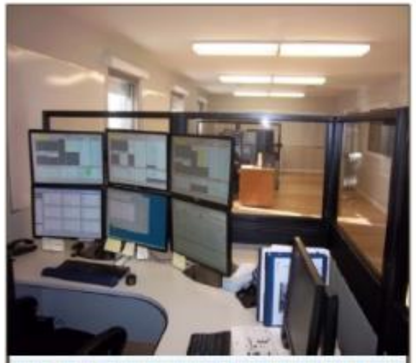
- Reduction:
  - 3000 cells managed from the Saguenay region (Quebec, Canada)
  - Technical support to Rio Tinto’s smelters worldwide, 24/7
  - Optimizing output of the different existing technologies
- Centralized metal management for Saguenay area
- Best practice sharing
- Synergies implementation
- Operations standardization

oTinto

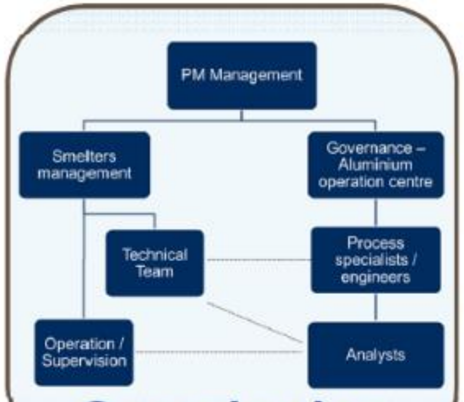
AOC activities and organization

Analysts real-time technical support

- ❑ Monitor continuously (24/7) pots of all supported smelters. (Graphs, alarms, measures, etc.)
- ❑ Identify deviations, diagnose issues, and prioritize actions.
- ❑ Provide coaching and technical support to operators.
- ❑ Remotely participate in technical meetings / LEAN info centers of supported sites.



AOC workstation



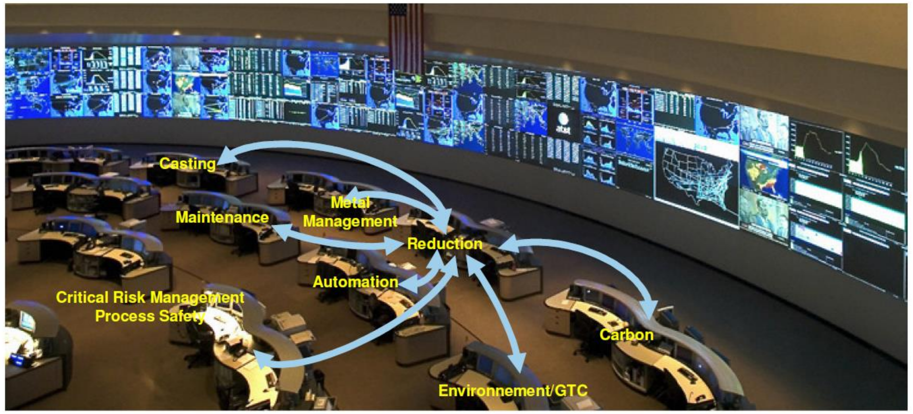
Organization

“Remote” Plant Info Center

RioTinto

AOC in the near future …

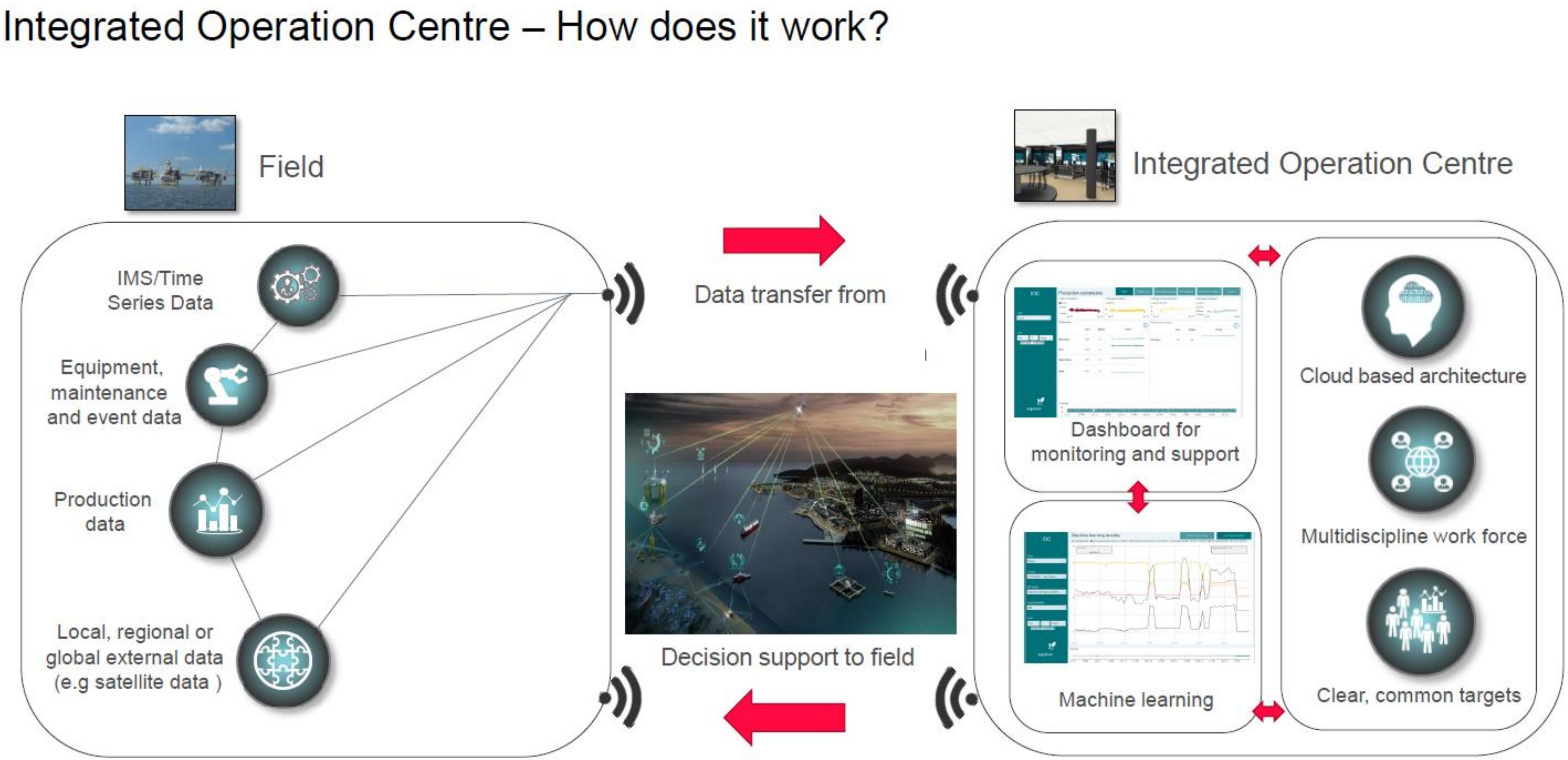
Maximize synergies between disciplines



Source: Data Connectivity - a Key Feature of the Smelter of the Future, RTA, ICSOBA 2016

Virtual control rooms in other industries

Similar thinking in the oil & gas industry



Concluding remarks

- **Elements of the "Smelter of the future"**
  - **Zero direct CO_2 emissions**
    - **Probably more than 1 solution and a step-wise approach**
  - **Autonomous**
    - **No manual interference**
    - **Autonomous control system (digital twin)**
- **Short/medium-term development focus**
  - **Various approaches to reduce direct CO_2 emissions**
  - **New process measurement sensors**
  - **More automation like anode change and AGVs**
  - **Digital twins combining domain competence and data science**

Hydro

We are aluminium