Industrial aluminium pilot at Karmøy – Norsk Hydro ASA

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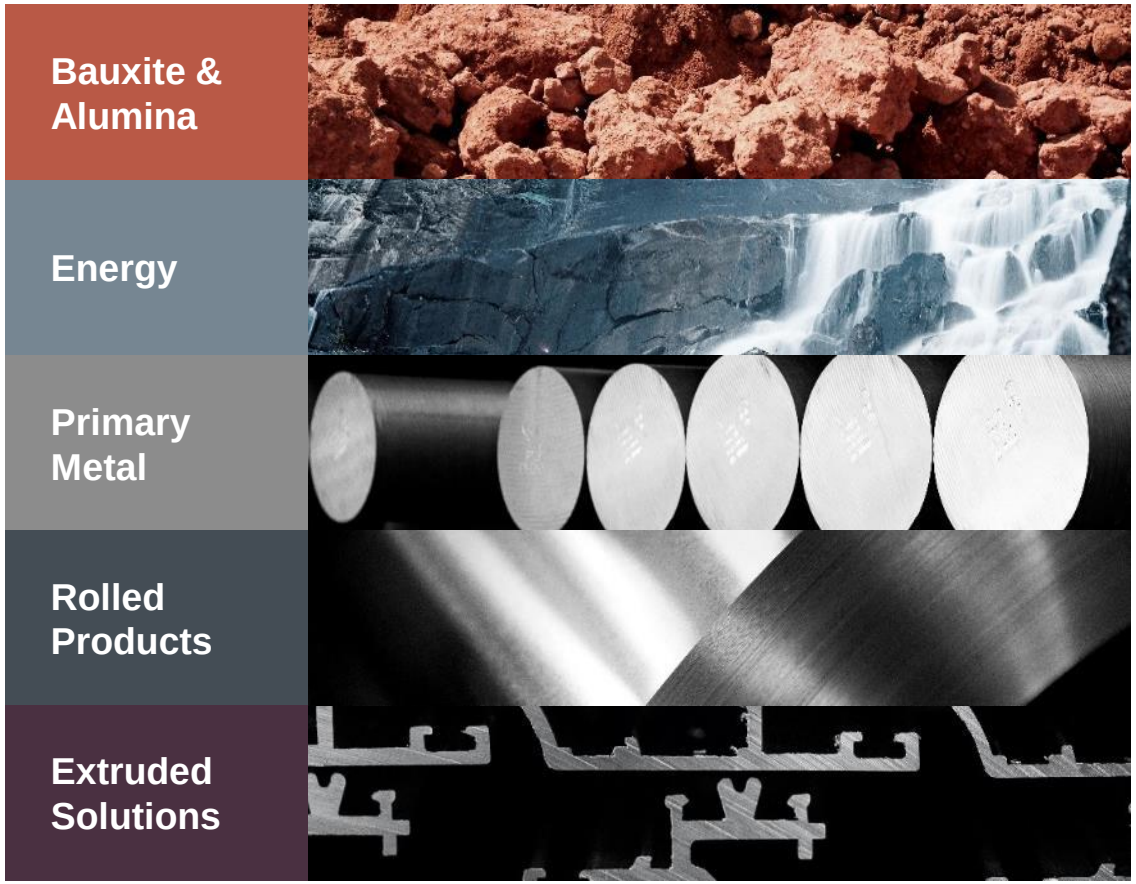
01

Hydro and Karmøy Technology Pilot

An integrated and customer-oriented aluminium company

With robust positions across the entire value chain



- Global provider of alumina, aluminium and aluminium products and solutions
- Leading businesses along the value chain; raw materials, energy, primary metal, rolled products, extruded solutions and recycling
- 35,000 employees at 150 locations in 40 countries
- Market cap ~NOK 70 billion/ ~USD 8 billion
- Annual revenues NOK 160 billion (2018)
- Included in Dow Jones Sustainability Indices, Global Compact 100, FTSE4Good

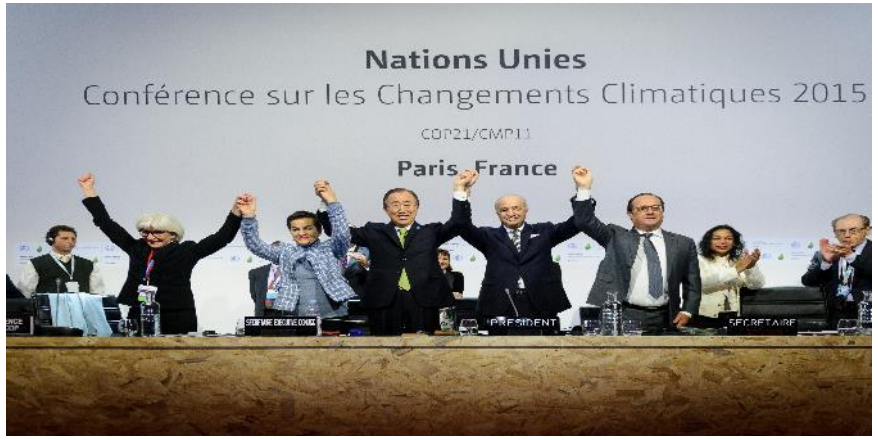
Karmøy Technology Pilot – producing greener aluminium

Hydropower-based and benchmark on energy consumption and emissions

- Annual production of 75 000 mt
  - 48 HAL4e cells, 12.3kWh/kg
  - 12 HAL4e Ultra cells, < 11.8kWh/kg
  - Global average: 14 kWh/kg Al
- Verifying next generation low-energy electrolysis technology
- Spin-offs for existing portfolio
- Total capex BNOK 4.3
  - Enova support BNOK 1.6

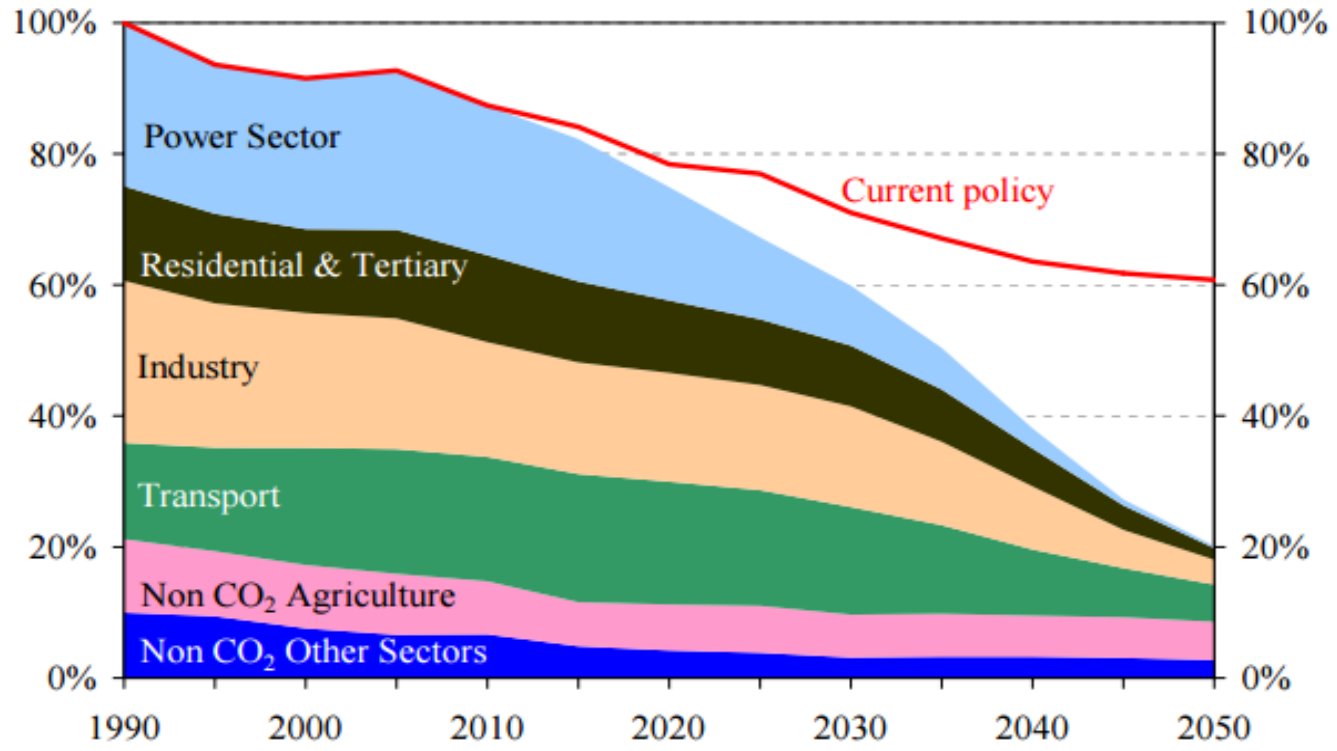
The Paris agreement: ambitious climate targets

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

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

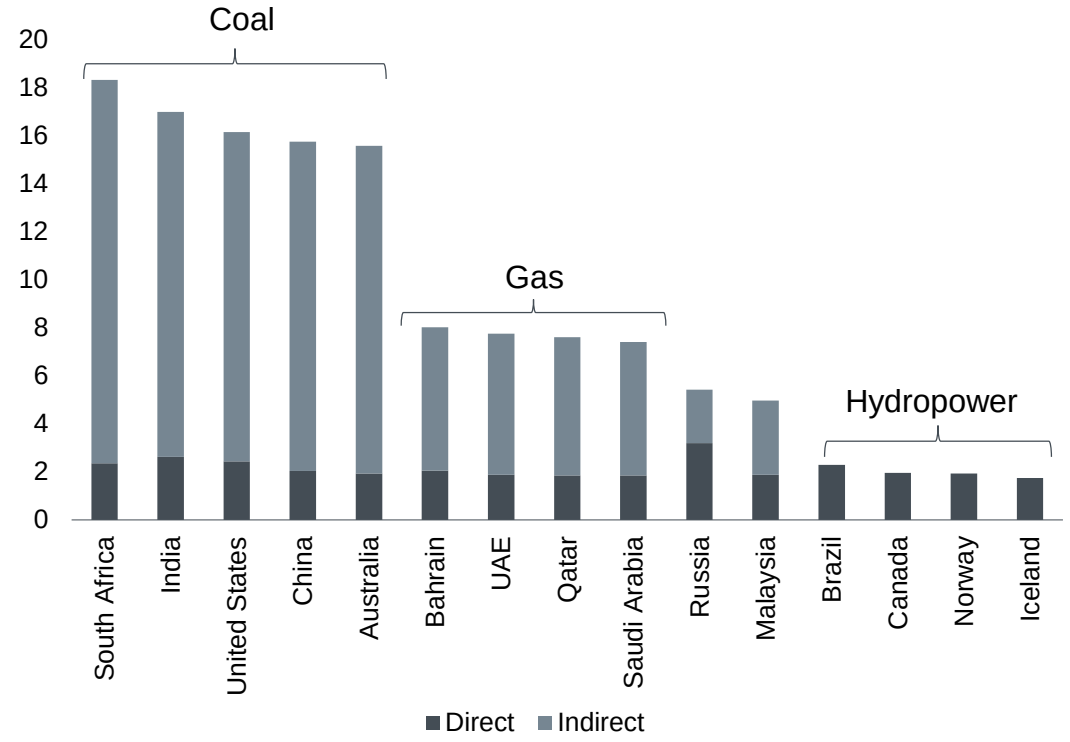


The climate rationale and the climate paradox

Increasing share of aluminium production is coal-based

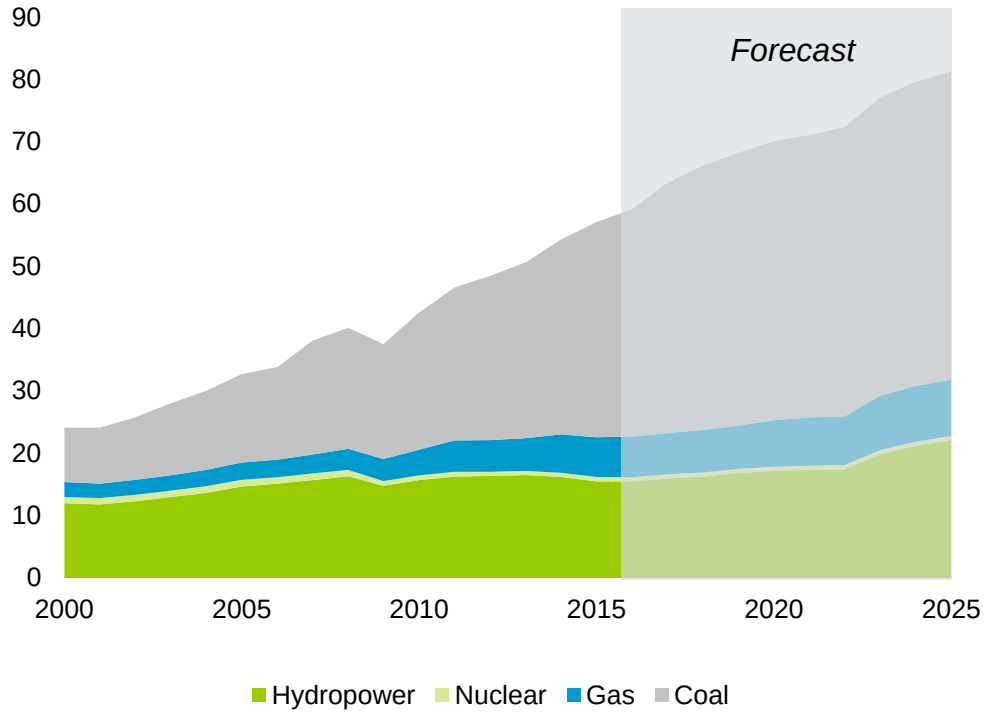
CO2 emissions and main energy source in aluminium production by country

Tonne CO2 / tonne aluminium



Aluminium production by power source

Mill tonnes

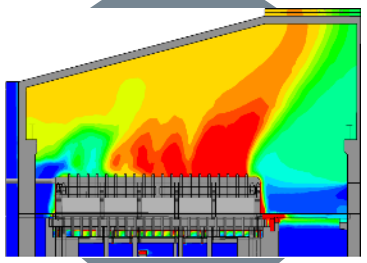


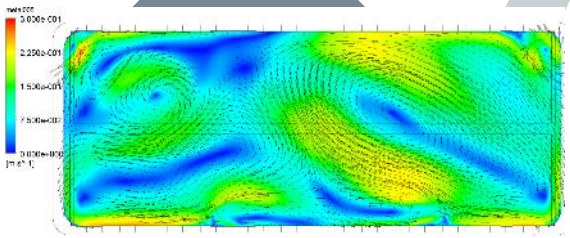
Source: CRU

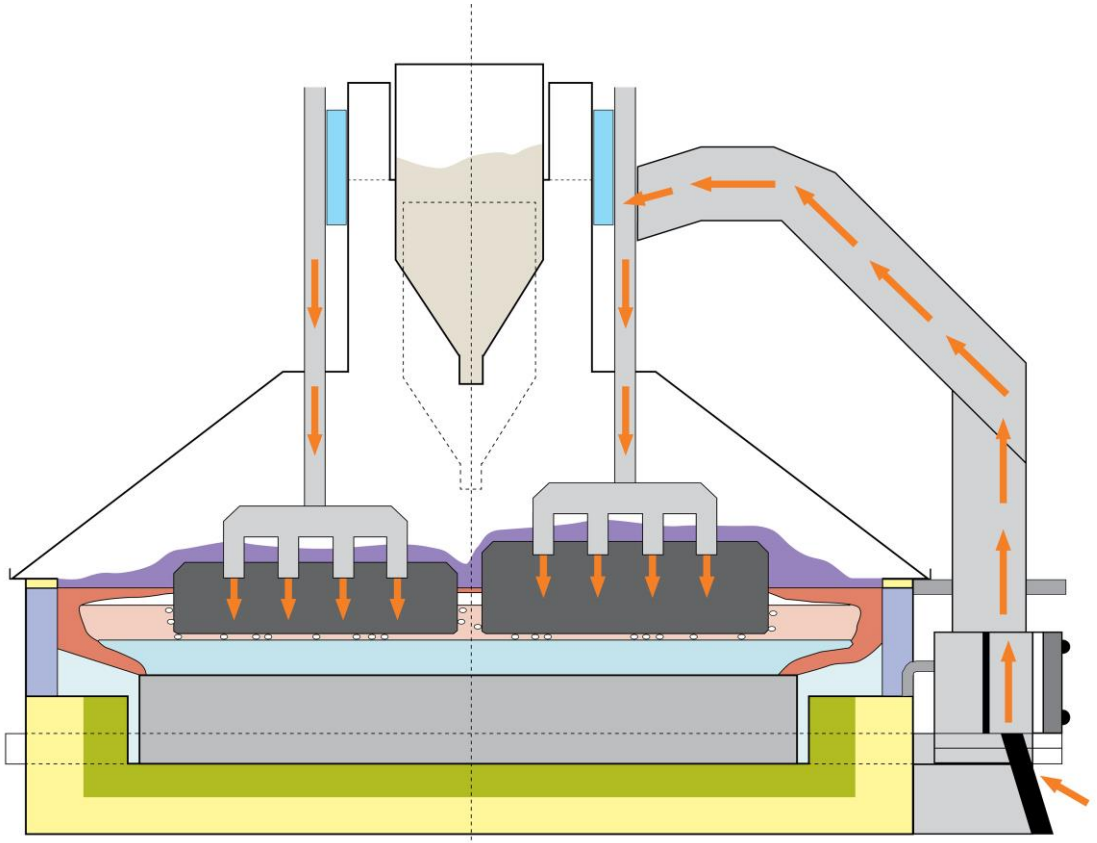
02

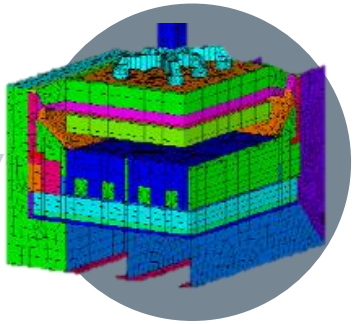
The challenge and the solution

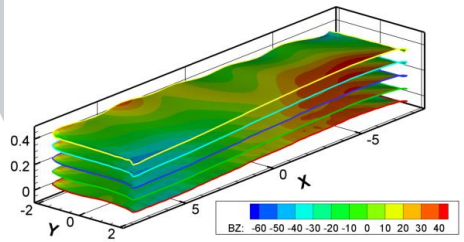
Electrolysis:
Advanced technology and cross-disciplinary skills









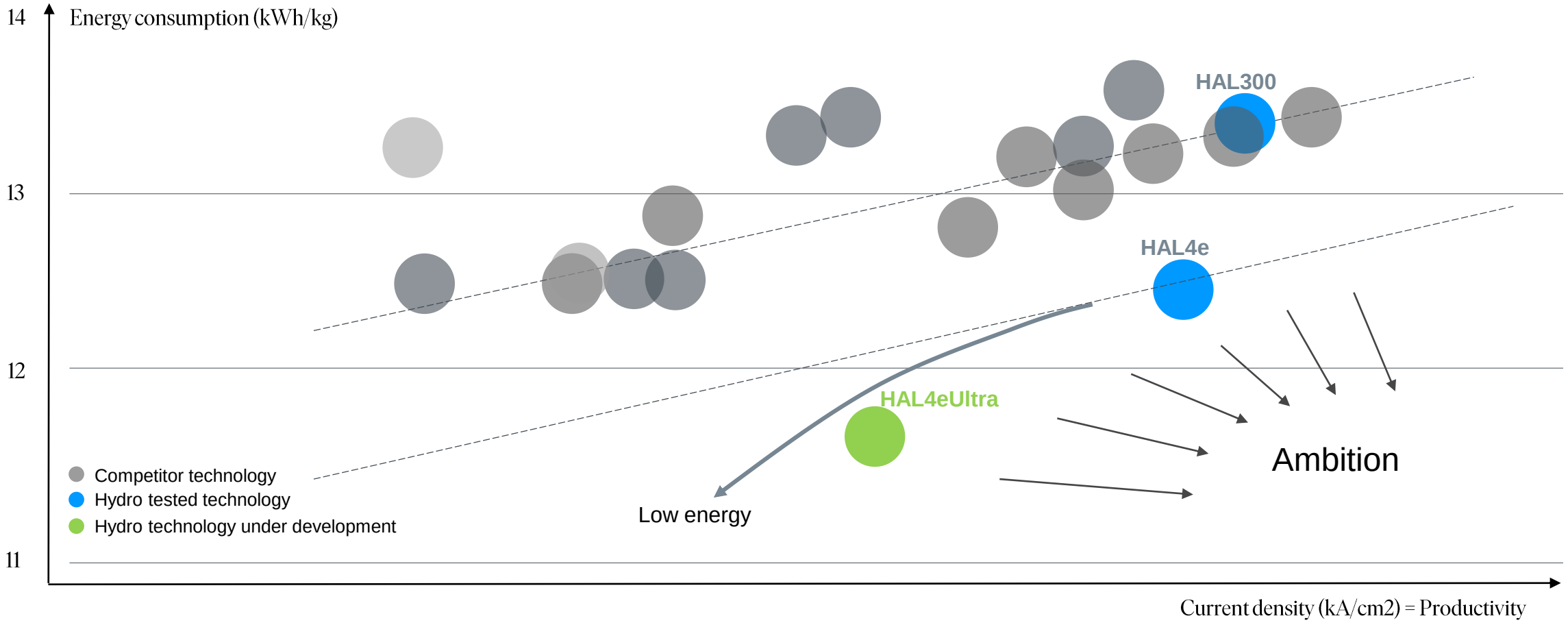


$Al_2O_3 + {}^3/_2\ C + Energy = 2Al + {}^3/_2\ CO_2$

Electrolysis technology – challenging the laws of nature

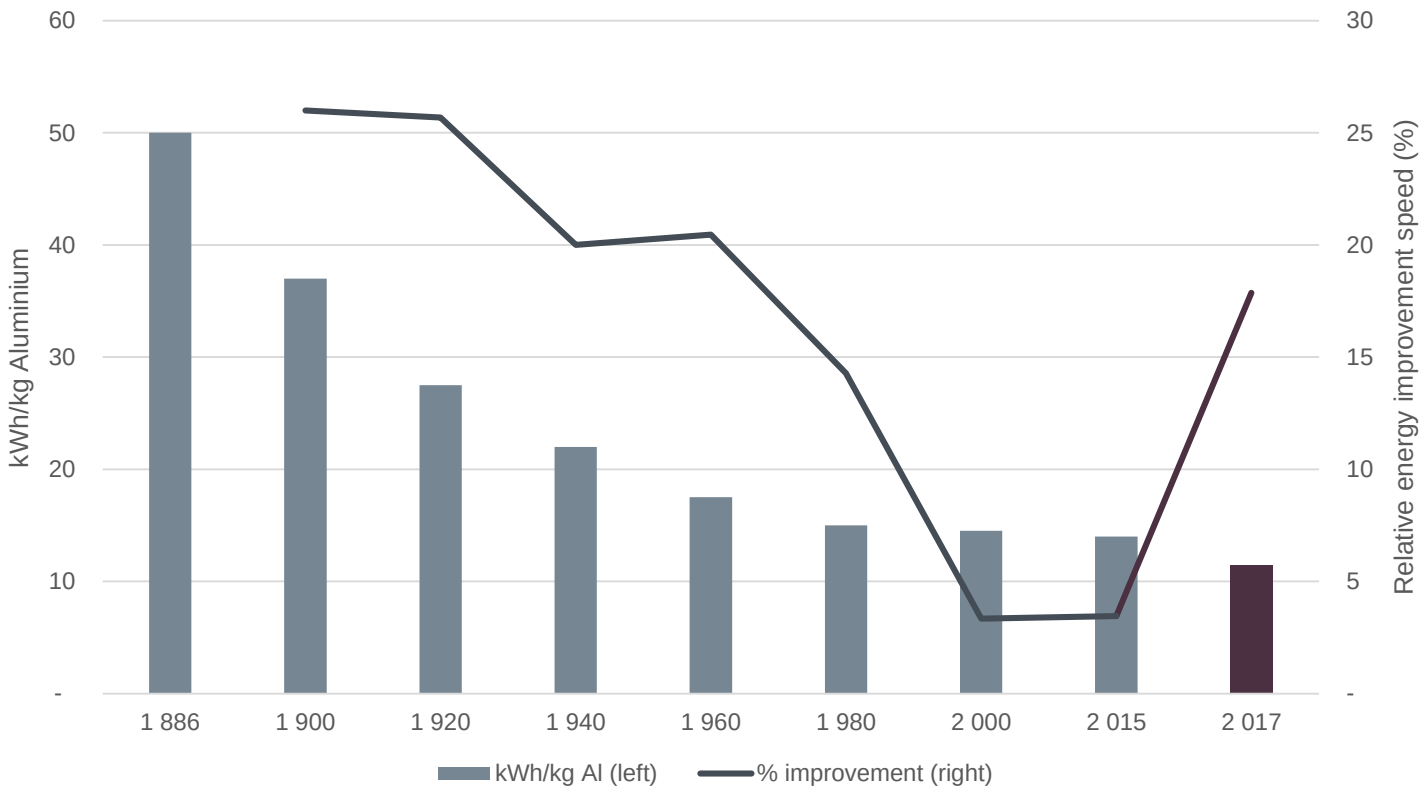
Hydro

Hydro with benchmark combination of energy consumption and productivity



Karmøy Technology Pilot

A huge step for a mature production technology

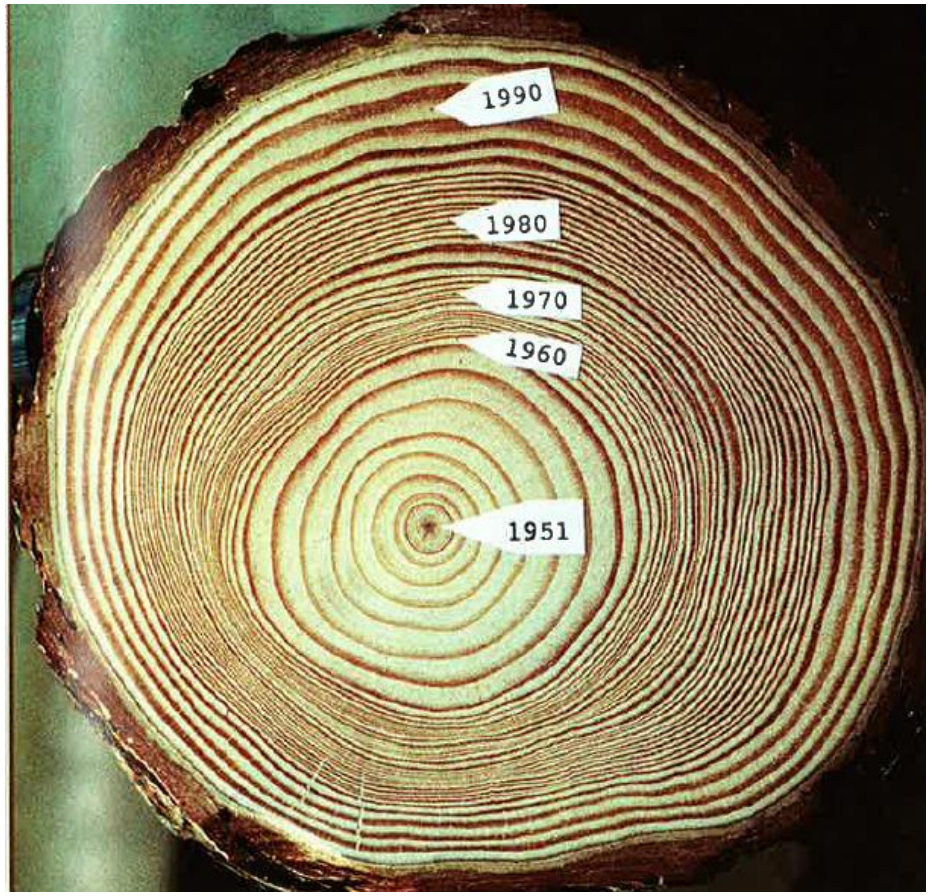


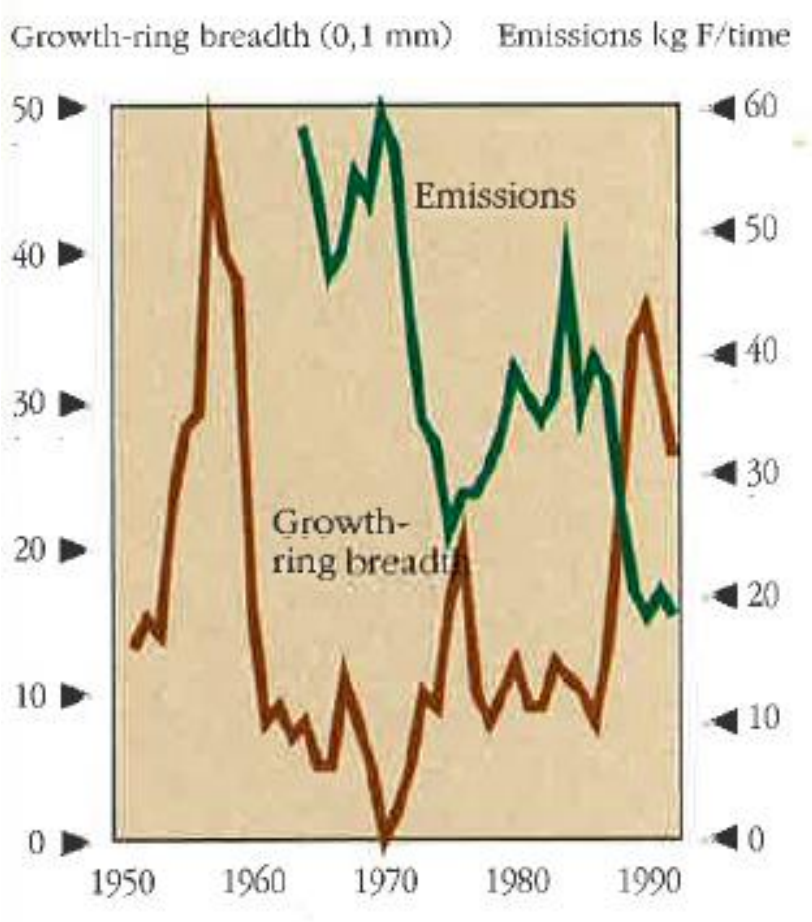
- More than low energy consumption
- World-leading combination
  - Energy consumption
  - Productivity
  - Capex
  - Environmental footprint

Source: International Aluminium Institute, Hydro analysis

Fluoride emissions and the effect on the environment

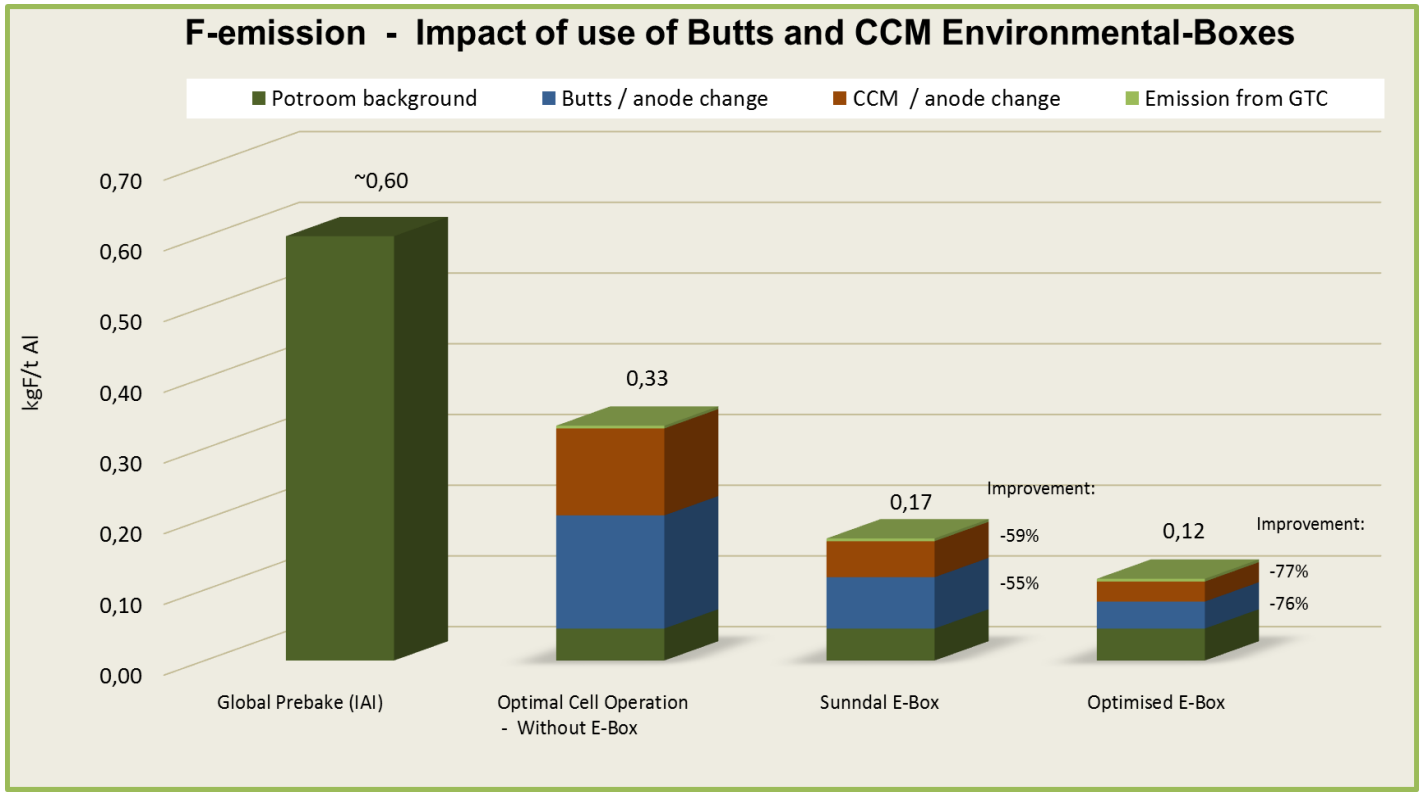
Illustrated by historical fluoride emissions in Årdal





Fluoride emissions – Impact of operations and environmental boxes

Karmøy technology pilot with optimized design of environmental box for benchmark performance



Source: IAI, Hydro

03

Agile adoption: digital transformation

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

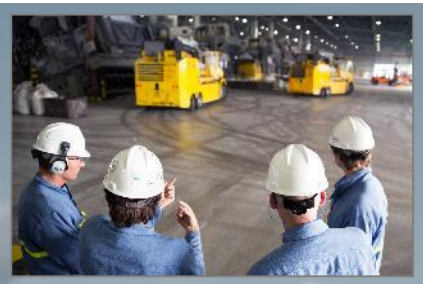
Connectivity
Asset data management
Predictive maintenance
Augmented reality

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

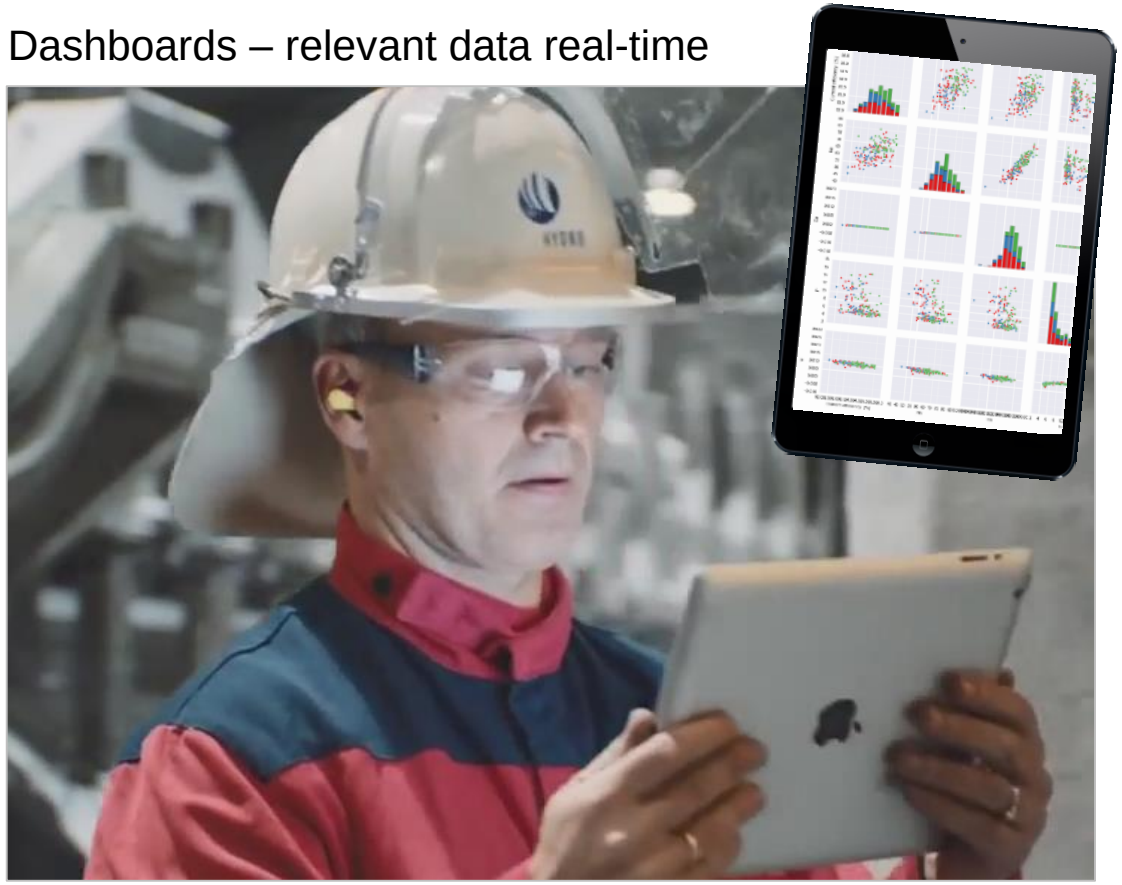
Key topics: autonomous processes – connectivity - automation

Our technology pilot is also a significant digital step

Important steps towards an autonomous cell

More automation than any other potline

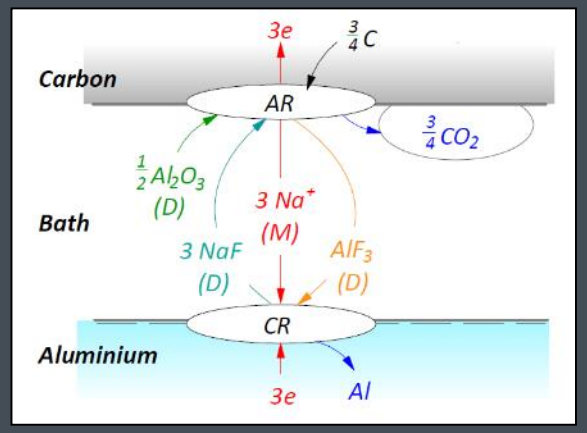
Dashboards – relevant data real-time

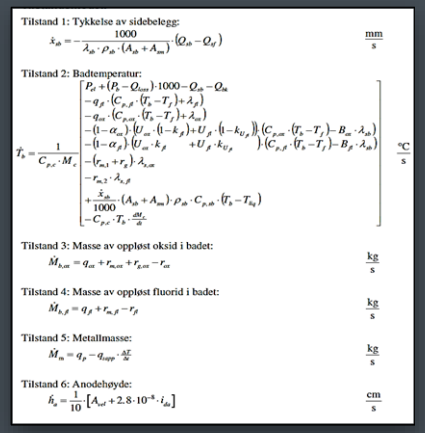


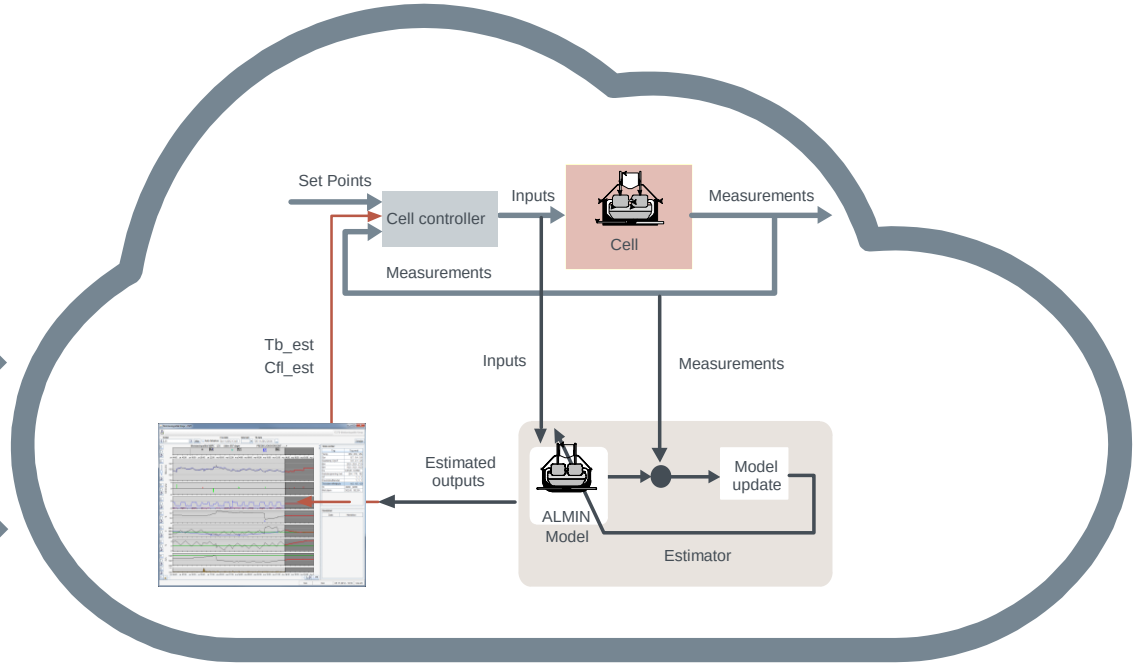
Advanced control platform and digital twin

Process data

Domain competence







Optimizing production by combining:

- Physics-based models
- Sensor data
- Advanced analytics algorithms

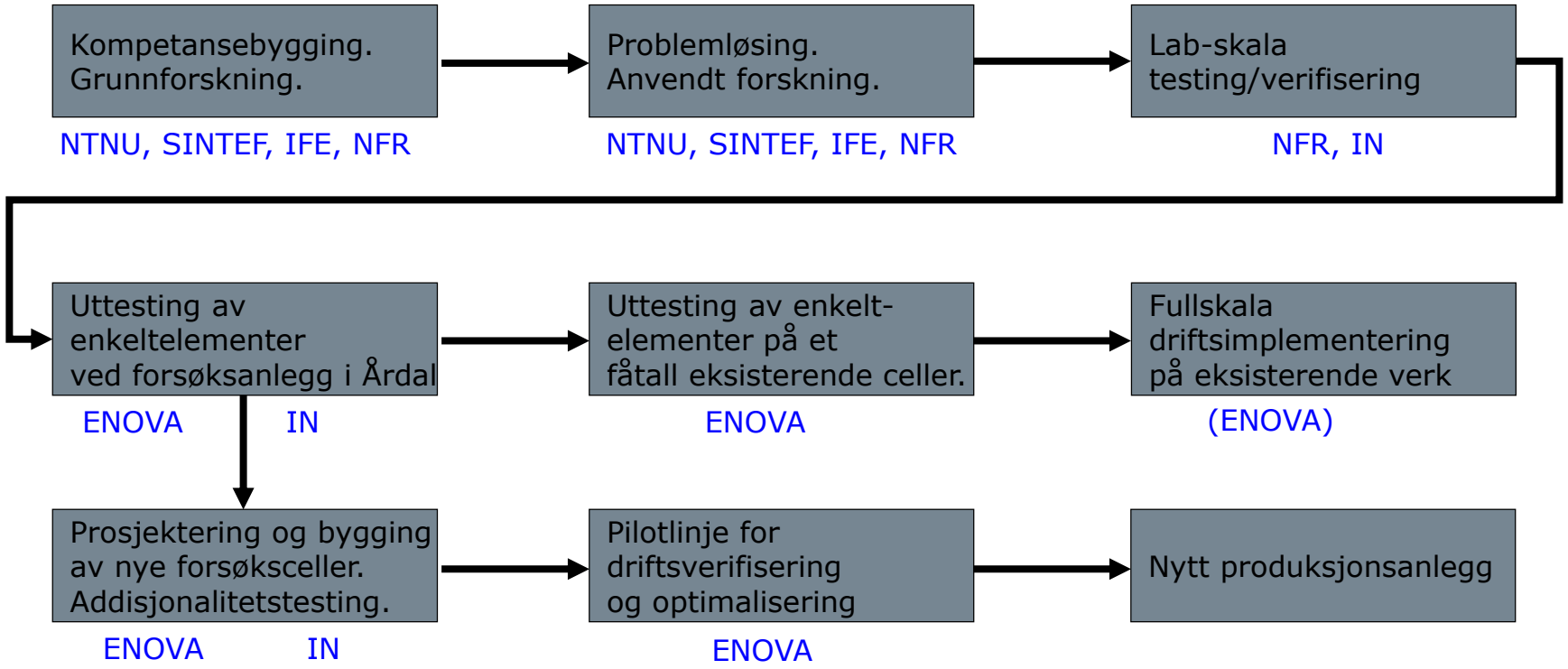
04

From research to industrial scale

Strategiske samarbeidspartnere og virkemiddelapparatet

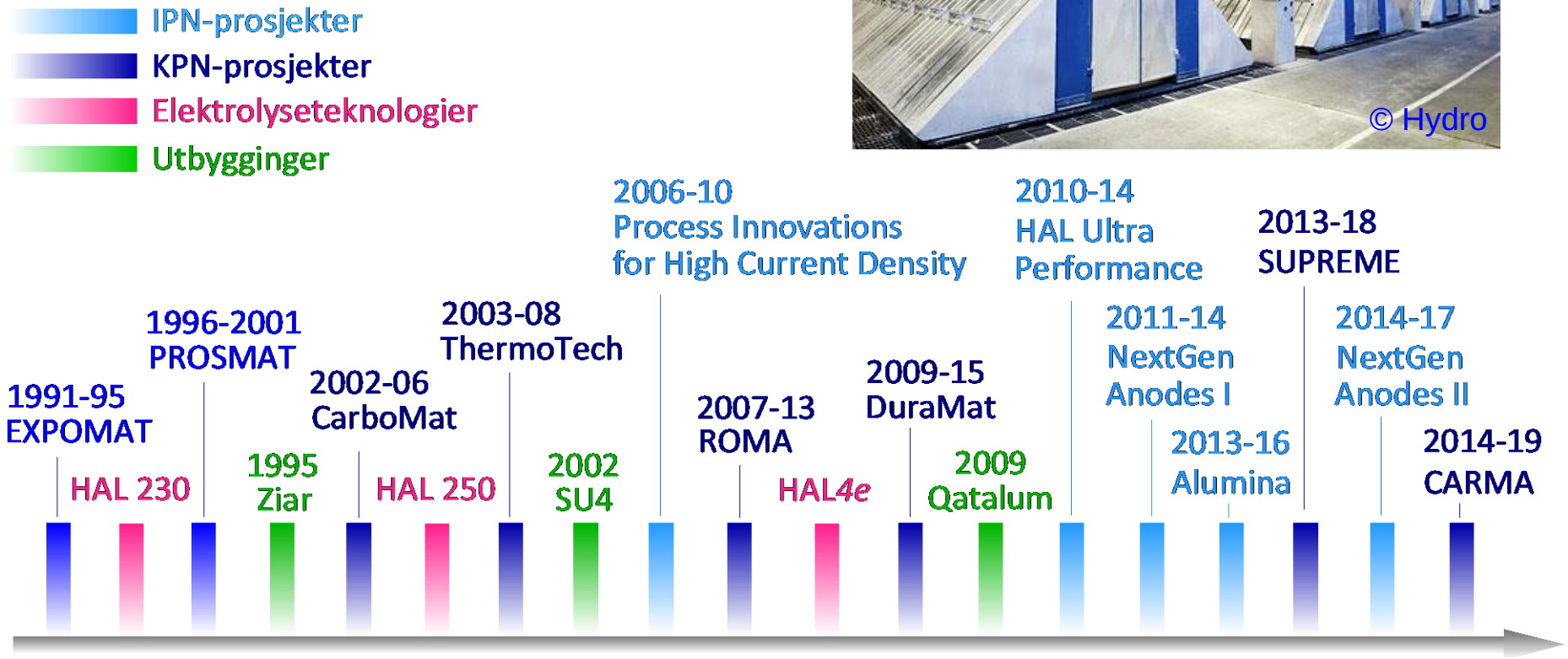
Teknologiutvikling – fra kompetansebygging til industrialisering

Det norske akademiske miljøet og det norske virkemiddelapparatet representerer vesentlige bidragsytere for teknologiutvikling og energieffektivisering



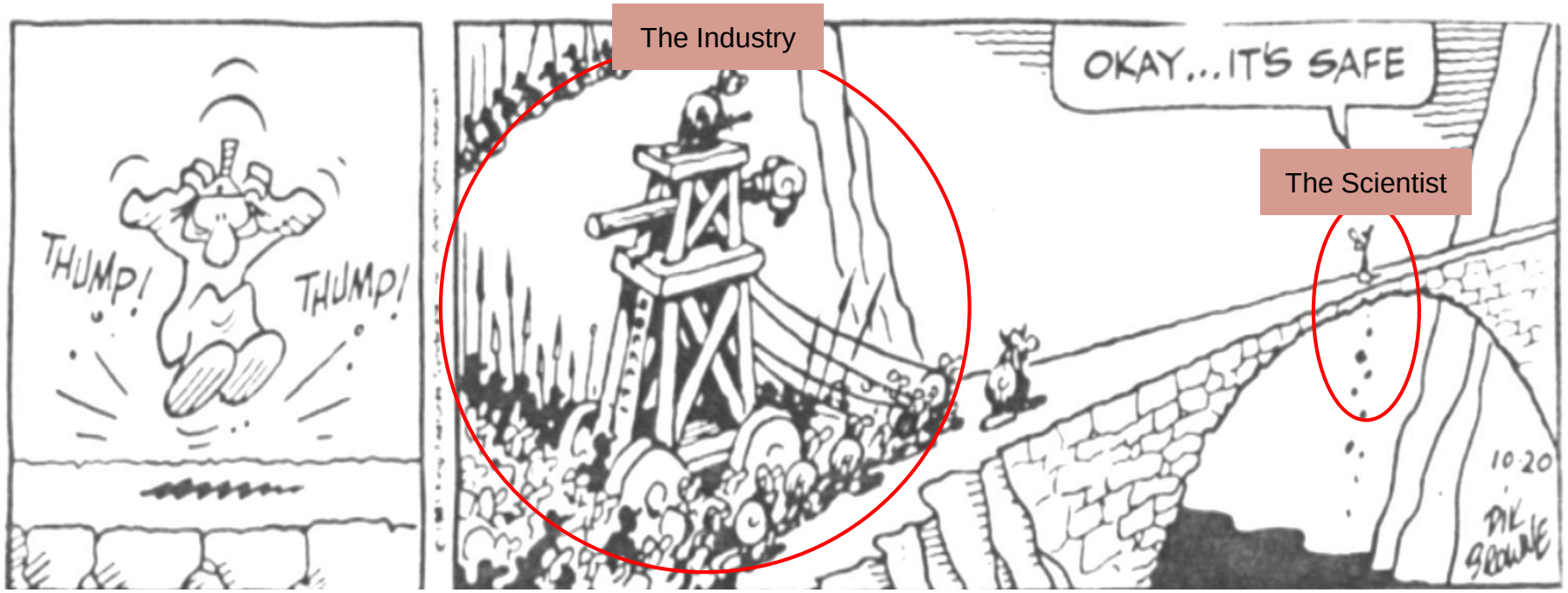
Fra kompetansebygging til industrialisering: +/- 20 år

RCN funding key enabler to create research volume and innovation speed



Why do we need a pilot?

Bringing research to industrial application – one experiment may not be conclusive …



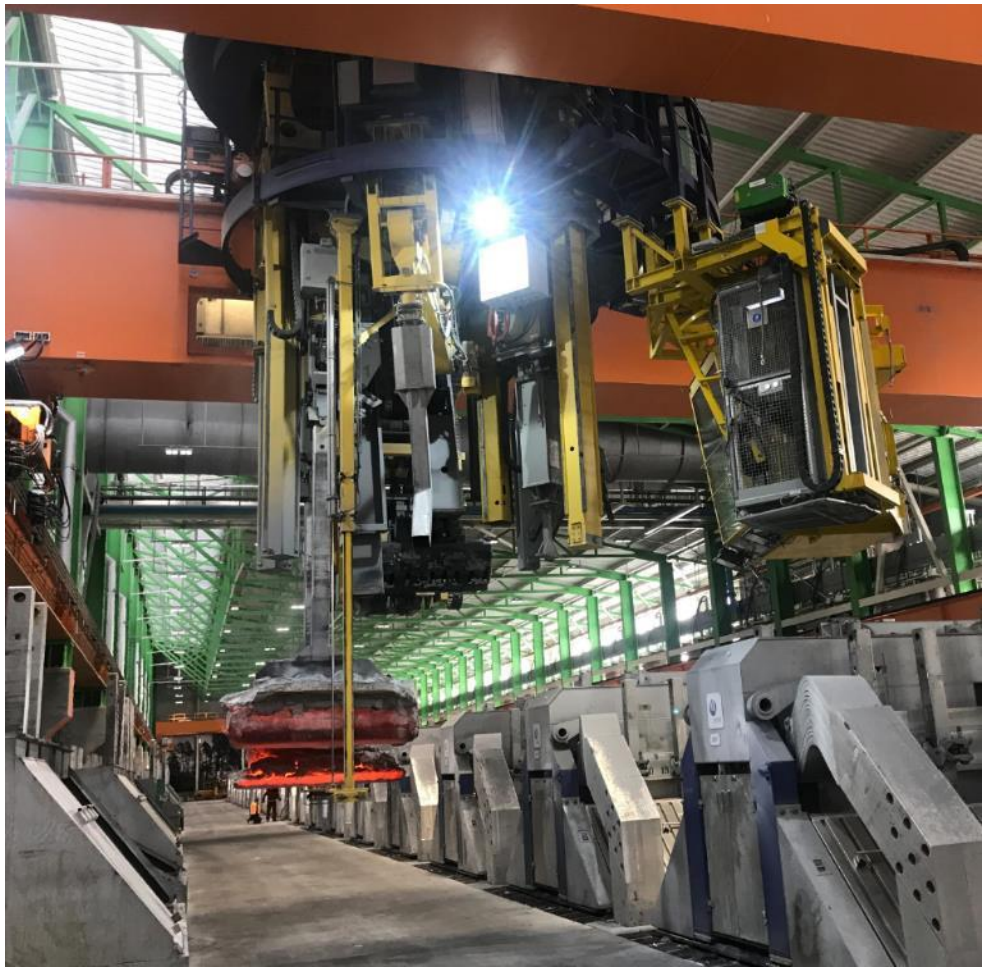
05

Results so far and the value of a pilot

Energy consumption - Karmøy Technology Pilot

60 HAL4e cells in operation – stabilizing operational performance

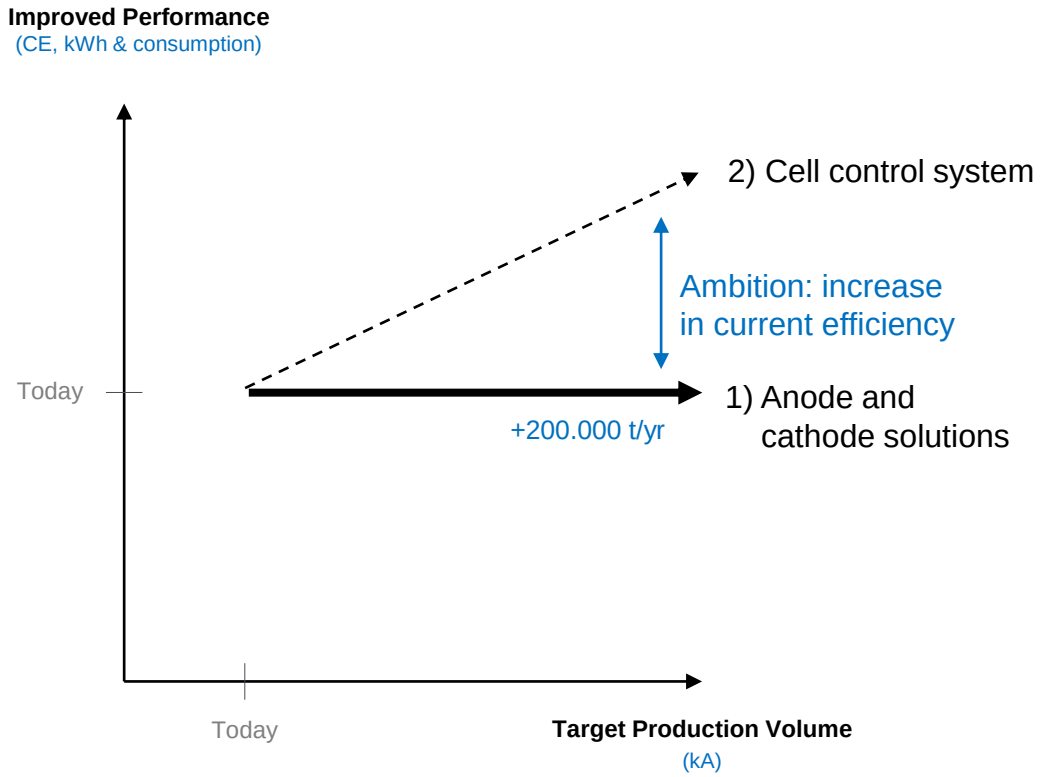
- 1st cell started January ‘18, all 60 cells by June ‘18
- Current efficiency and energy consumption on track towards verification of targeted values
- Optimization ongoing for performance
- Cathode performance according to expectations
- Digital Twin based control system fully implemented and performing well
- Several Industry 4.0 elements under implementation
- Early operational challenges largely solved



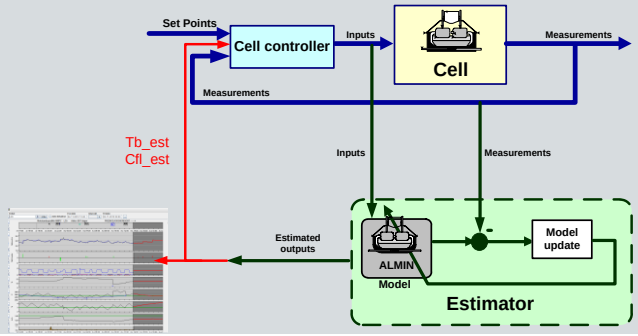
Utilising the Karmøy pilot technology for higher performance

Hydro

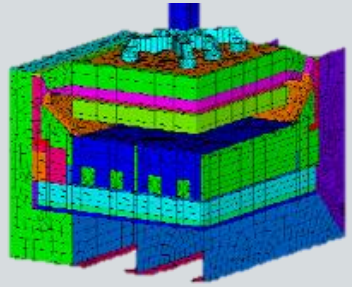
Cathode solutions, anode elements and cell control system



Cell control system



Anode and cathode solutions



Technology spin-offs to existing smelters

Very important for pay-back of R&D and pilot investment

- Structured projects for implementation in all existing smelters
  - Amperage increase has traditionally been a good business case
  - New technology elements can be used for amperage increase or energy consumption
  - For mature smelters, using technology elements to reduce energy consumption is a good alternative to avoid infrastructure investments
- Ex: Husnes idled line

06

Concluding remarks

Karmøy Technology Pilot

Long developing lines, cross-discipline teamwork, academic collaboration, top management commitment and public support to fundamental work and piloting

Hydro

We are aluminium