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Centre for an Energy Efficient and Competitive Industry for the Future

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Inert Anode – the Blind Valley to Environmental Friendliness?

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Abstract

The introduction of inert anodes in alumina reduction cells may bring about some advantages, but also a number of serious drawbacks. In view of the developments in the Hall-Héroult process during the last decades, it was considered desirable to make a critical evaluation of the inert anode concept as compared to state-of-the-art electrolysis cells. It was found that the DC energy consumption will be about 3 kWh/kg Al higher with inert anodes, partly because the 1 V higher isothermal cell voltage cannot be fully compensated, but mainly because a cell with inert anodes requires similar heat loss as a cell with carbon anodes. Consequently; the total carbon dioxide footprint will be higher with inert anodes when the power is generated in a coal fired plant, while there is not much difference if the power comes from a gas fired plant. The full carbon dioxide reduction potential with inert anodes can only be realized when using renewable energy sources. However, a Hall-Heroult plant with carbon capture and sequestration will still require less electric power than a plant with inert anodes.

The paper was delivered in 2017. Here is attached the conference presentation performed 13 March 2018 in Phoenix, US.

INERT ANODES – THE BLIND ALLEY TO ENVIRONMENTAL FRIENDLINESS?

Asbjørn Solheim

SINTEF

Contents

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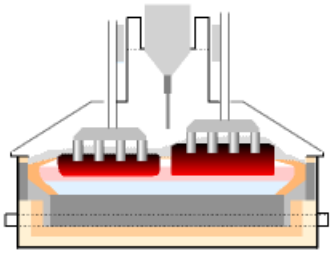
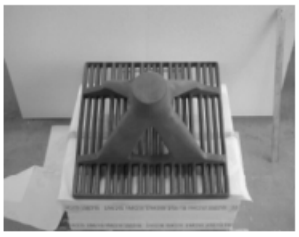
- Cell voltage
- Heat losses
- Energy consumption
- Greenhouse gas emissions
- Carbon capture and sequestration
- Other aspects. Summary





Inert anodes is a very old idea

- Inert anodes was suggested already by Charles M. Hall (1887)
- Most major companies have been working with inert anodes
- Still, no durable material has been developed
  - 800 mill. USD spent during last six decades

"The oxygen goes to the positive electrode, which may be formed of copper, platinum, or other suitable non-carbonaceous material" (1887)

Quoted benefits with inert anodes

- Increased energy efficiency (up to 25 percent has been claimed when combined with a stable, wetted cathode)
- Reduction of greenhouse gas (GHG) emissions, such as CO_2 and perfluorocarbons (PFC)
- Reduced operating costs by eliminating the anode plant, rodding shop, and anode changes
- Increased productivity
- Reduced emissions of harmful substances other than GHG

Purpose of present work: "Why", not "how"

- Are the quoted benefits realistic?
- … remember that many developments necessary for realising IA cells can also be used in HH cells
- It is fair to compare inert anode (IA) cells with state-of-the-art Hall-Héroult (HH) cells!

- Introduction and purpose
- **Cell voltage**
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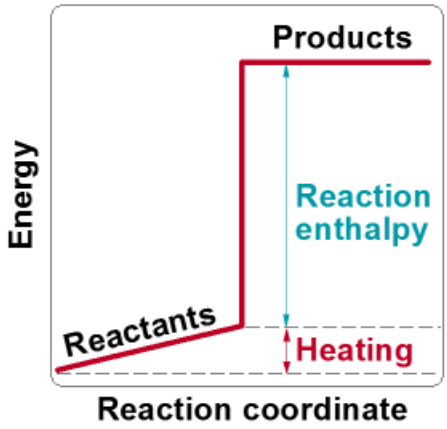
Minimum cell voltage/energy consumption

Principle

- 100 percent current efficiency
- No heat losses, constant temperature
- Reactants added in exact amounts

- Heating of reactants
- Reaction enthalpy



Comparison carbon anodes – inert anodes

	Carbon anodes		Inert anodes	
	kWh/kg	V	kWh/kg	V
Heating of γ-Al_2O_3 (298-1233 K)	0.58	0.19	0.58	0.19
γ-Al_2O_3 to α-Al_2O_3 (1233 K)	-0.12	-0.04	-0.12	-0.04
Heating of C (298-1233 K)	0.13	0.04	-	-
Reaction (1233 K)	5.65	1.90	8.70	2.92
Sum	6.24	2.09	9.16	3.07

Can the cell voltage be reduced with IA?

- Probably somewhat lower anodic overvoltage
- The bubble "overvoltage" may be higher (small bubbles)
- The anode-cathode distance can probably not be reduced
- Low-melting bath containing KF has low conductivity
- Probably no potential for lowering the voltage drop in the anode assembly

The cell voltage will probably be 1 V higher than in the HH process

- Introduction and purpose
- Cell voltage
- **Heat losses**
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Can the heat losses be reduced with IA?

- Heat from sides: Need protective sideledge
  …or an inert side wall, which can also be used in HH
- Heat from the top: Need unwieldy mass of ACM
  …or an inert lid, which can also be used in HH
- Heat from the bottom: Relatively small heat loss, can be reduced using thicker layers
  …which can also be used in HH

It is not easier to reduce heat losses with IA than in HH

- Introduction and purpose
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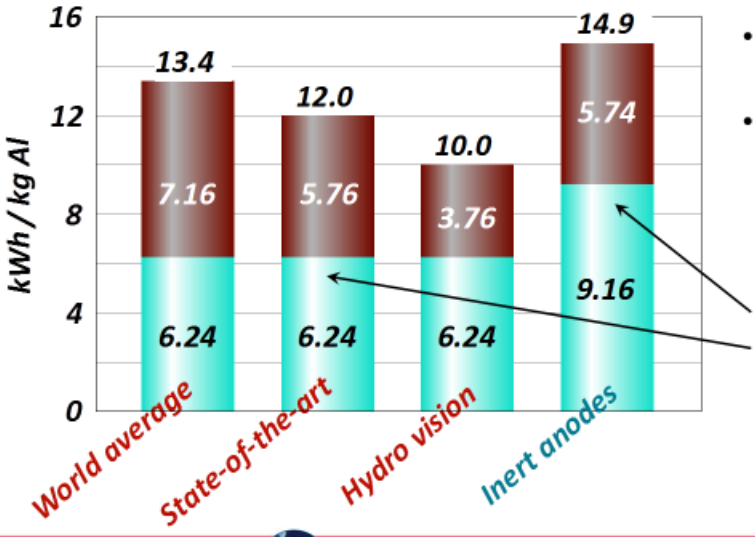
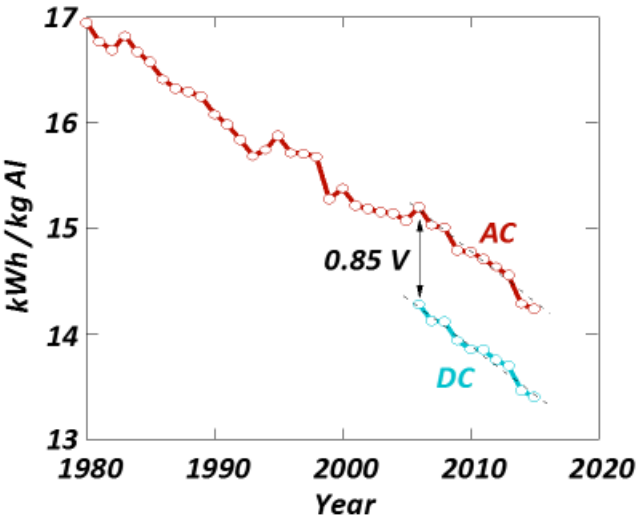
Some examples of energy consumption



- DC power consumption
- Hydro vision may require heat recovery and utilisation

Compare state-of-the-art HH and IA cell with same heat loss

World average energy consumption



- The trend is still linear
- Can get rid of all heat losses in 120 years…?

- Introduction and purpose
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- Heat losses
- Energy consumption
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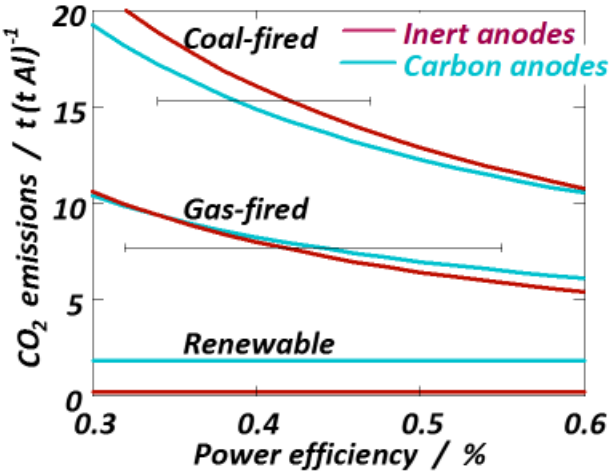
Carbon dioxide emissions in kg CO_2/kg Al

40 % efficient coal fired power generation
12.85 kWh/kg AC for HH, 15.75 kWh/kg for IA

	Hall-Héroult	Inert anodes
Coal-fired power plant, covering AC	12.93	15.85
Electrolytic anode consumption	1.47	-
Production of calcined petroleum coke	0.25	-
Anode production, electric power	0.11	-
Anode production, gas firing	0.15	-
Production of inert anodes	-	0.25
Total	14.91	16.10

Carbon dioxide emissions

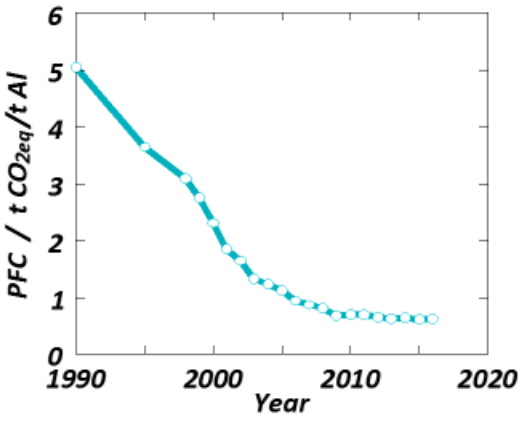
Effect of power generation efficiency



- Potential of CO_2 reduction can only be realised with renewable power sources
- Currently, 60 % of the World's aluminium is produced with coal power

PFC emissions

- High voltage anode effects are nearly eliminated
  - An extremely successful environmental initiative, but not well known in the public
- Currently: Concern about non-reported PFC, stemming from low voltage AEs
- No PFC from IA cells
  - No carbon present!



PFC and alumina concentration

- IAs need to be operated close to alumina saturation to avoid "catastrophic corrosion"
- Need more efficient alumina feeders
  - …which can also be applied in HH
- Somewhat higher and more uniform alumina concentration will eliminate all PFC
- Logical implication: If it's possible to operate an IA cell, it's also possible to eliminate PFC from HH cells

- Introduction and purpose
- Cell voltage
- Heat losses
- Energy consumption
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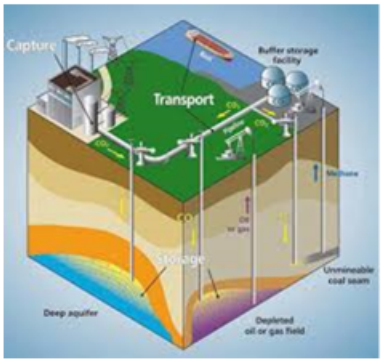
Carbon capture and sequestration

- Arguably, more mature technology than inert anodes
- Energy intensive
  - Separation
  - Compression
  - Frictional pressure drop (pipelines, rock structure)
  - Displacement of ground water



- Still, the energy needed to get rid of HH CO_2 is less than the difference between IA and HH!

- Introduction and purpose
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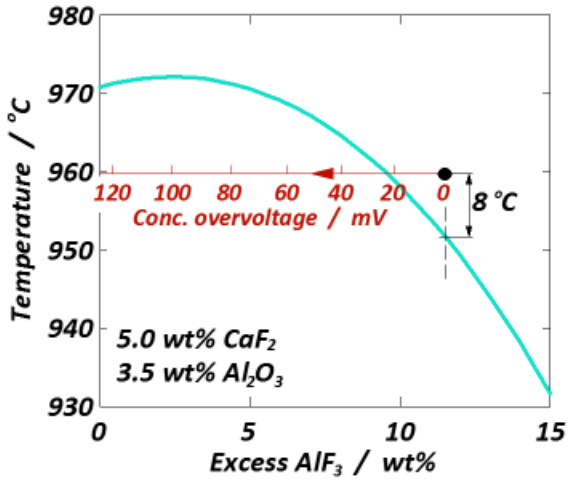
Wetted cathodes

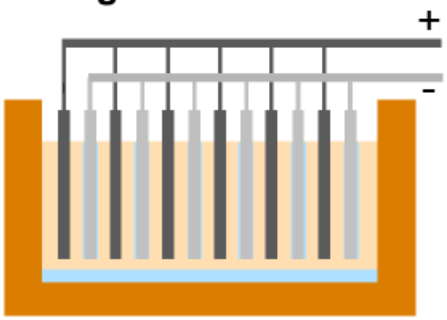


- Less acid bath at metal surface due to cathode reaction
- Solid cryolite will form, which cannot sink away
- Can be avoided by high enough superheat, or bath close to cryolite composition (but this gives low current efficiency)

On the positive side

- IAs eliminates frequent anode changes
  - No carbon anode plant
  - No rodding shop
  - No work-intensive handling
- May have smaller geometric footprint

  … when combined with wetted cathodes



Summary

- IA will consume 3 kWh/kg Al more than HH
- More CO_2 with IA than HH with coal power
- Better feeders, *not IAs*, may eliminate PFC
- Clean processes: IA, or HH with CCS (both with renewable energy)
  - HH with CCS will have lower power consumption
- IAs eliminate carbon anode manufacture and handling
- IA may have smaller geometric footprint (combined with wetted cathodes)

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Thank you for your attention

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