Trends and challenges of mega castings: Insights from an aluminium supplier perspective

Presentation at 101st AMAP Colloquium

Dr. Dinesh Thirunavukkarasu, Hydro Aluminium AS

Christian Harter, fka GmbH (now: strato 7 GmbH – the consultants of fka)

1 Profile and Mission of Hydro

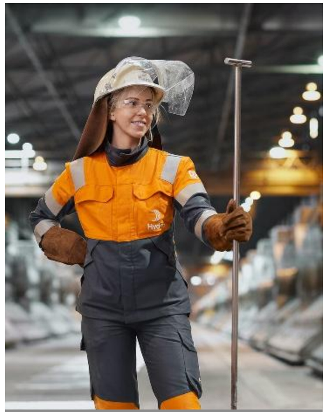
Our value chain is a unique opportunity

Hydro

Traceability in Hydro's own value chain can ensure certified, traceable and low-carbon aluminium

Bauxite mining

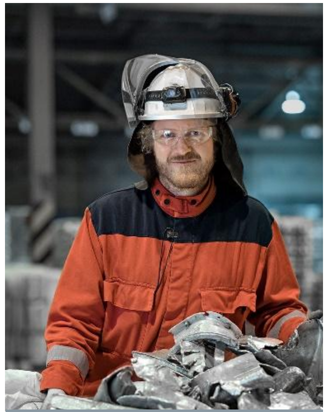
Alumina refining



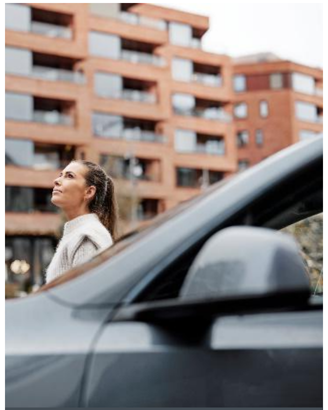
Aluminium primary production

Aluminium casting

Aluminium extruding



Aluminium recycling



Aluminium products in use

32,000 employees

140+ locations

203.6 NOK billion revenue

Powered by **renewable energy**

Strength in primary, growth in recycling

Reducing carbon footprints through primary production and harnessing the benefits of scrap aluminium

Primary

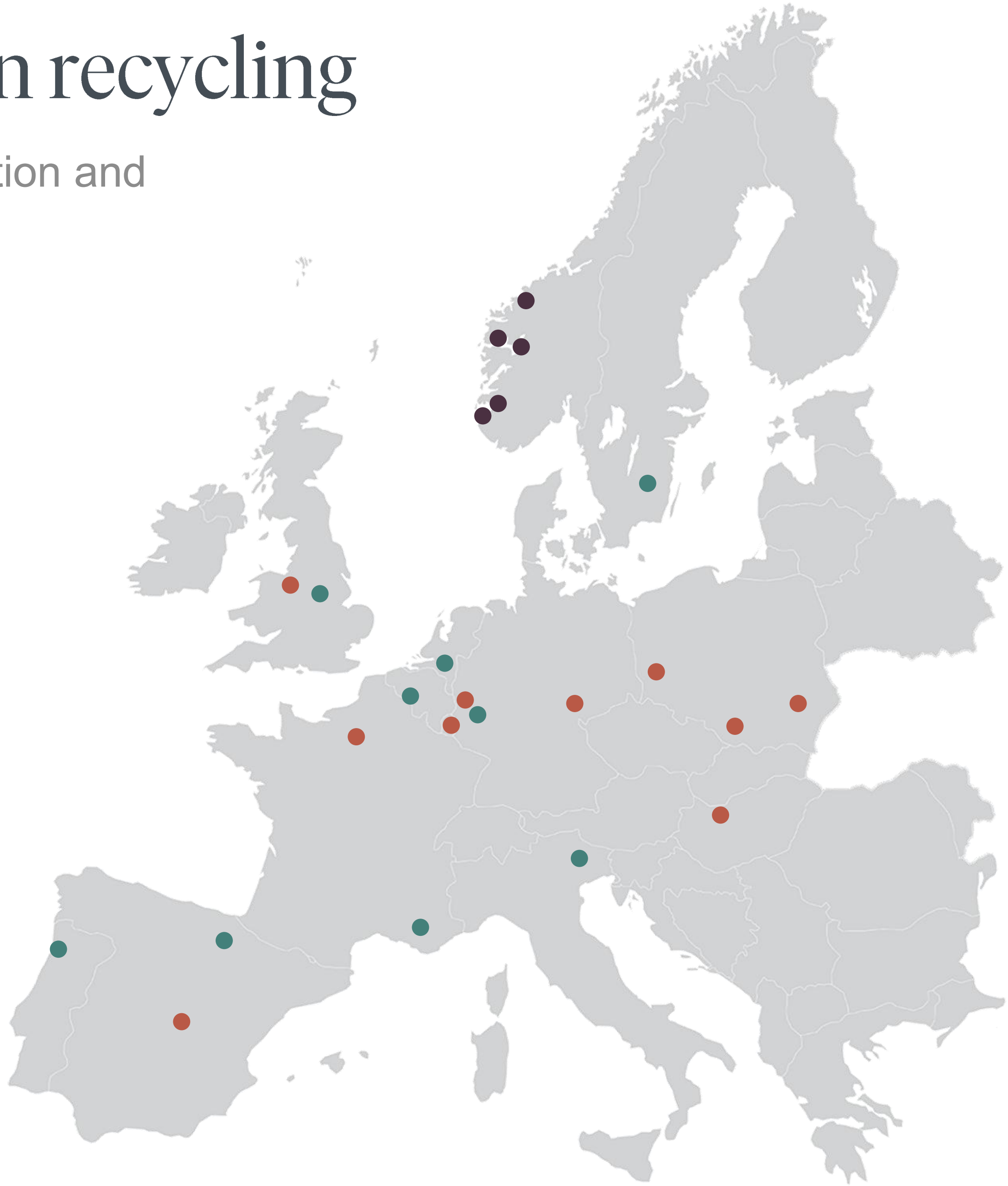
- Husnes NO
- Årdal NO
- Sunndal NO
- Karmøy NO
- Høyanger NO

Recycling (AM)

- Lucé FR
- Clervaux LU
- Azuqueca SP
- Wrexham UK
- Rackwitz DE
- Dormagen DE
- Kęty PL
- Gorzye PL
- Nowa Sól PL
- Komarom HU

Recycling (EE)

- Tibshelf UK
- Drunen ND
- Navarra SP
- Avintes PT
- Feltre IT
- Puget FR
- Ghlin BE
- Sjunnen SE
- Ludensheid DE



Our product portfolio

- Capitalizing on value-added casthouse products portfolio
- Extensive multi-sourcing system including fully and part-owned primary casthouses and stand-alone remelters
- Flexible sourcing system enabling rapid and cost-effective volume adjustments
- Value creation from margin management based on commercial expertise and risk management competence
- Strong market positions in Europe, U.S. and Asia

Casthouse production

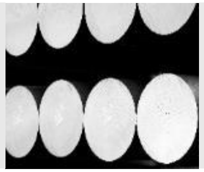
Primary production

Remelting
& recycling

Commercial agreements

Extrusion ingot

1.6 million mt



Leading global position

Unique primary and recycling capacity network

Foundry alloys

0.5 million mt

Leading global position

Strong capabilities in all automotive segments

Sheet ingot

0.3 million mt

Leading European position

Well positioned to capture automotive growth

Wire rod

0.1 million mt

Leading European position

Market attractively supported by copper substitution

Standard ingot

0.3 million mt

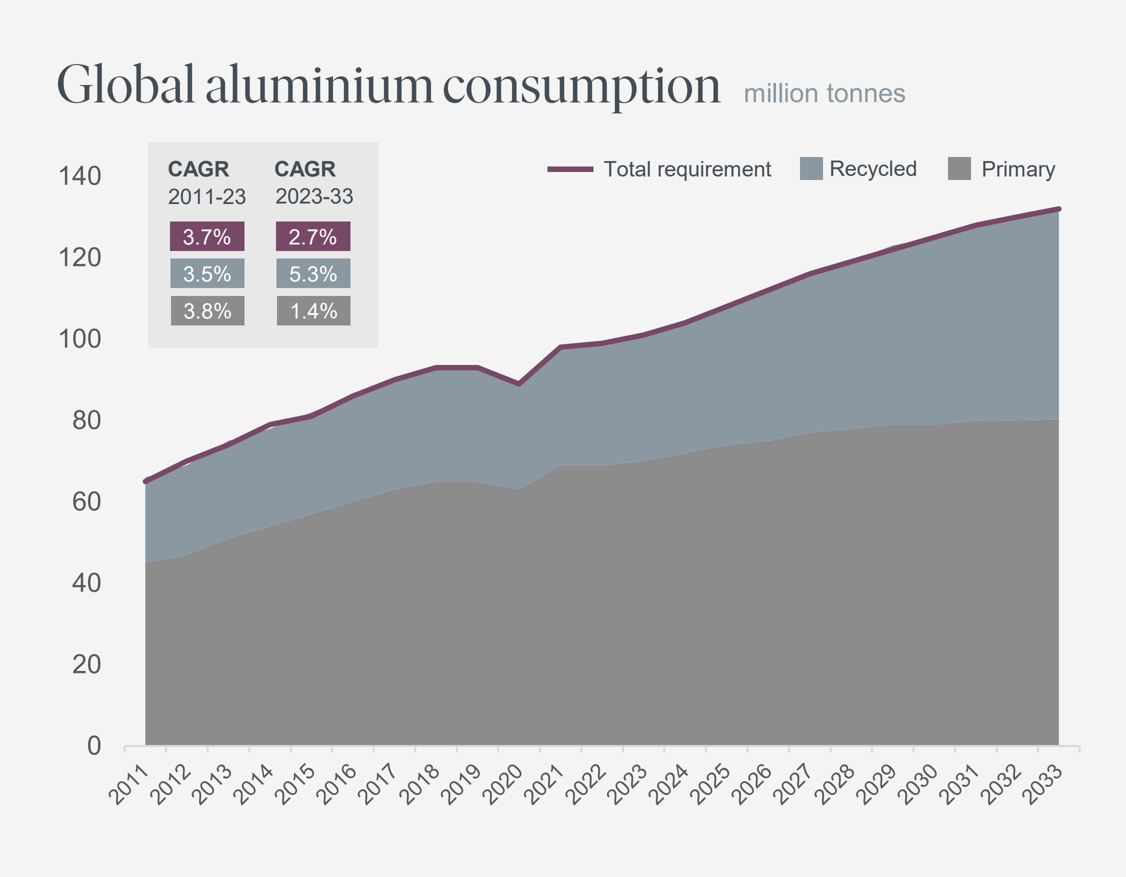
Leading global position

Global flow optimization through key positions

Numbers are based on 2019 Metal Markets sales, including casthouse and remelter production, standard ingot and external sources

The world increasingly demands greener aluminium

Future consumption growth increasingly met with recycling



Automotive Market Developments

- The automotive market is a key market for Hydro
- Development trends need to be analyzed in detail to forecast production capacities for value added products
- Regional development plans of key automotive players drive investment decisions
- Scope and ambition towards green transition as well as technical requirements with regard to alloy composition needs to be outlined

Chinese Market Entry & Mega Castings
Study of Norsk Hydro and fka GmbH

1 Technology and Market Strategies for Mega Castings

- Multi-dimensional evaluation of mega castings vs. conventional production processes
- OEM applications and strategies towards Large HPDC and mega castings

2 Scenarios on China and Mega Casting Market Footprint

- Chinese Market Entry
- Quantitative Mega Casting Market

3 Value Chain Structure Opportunities

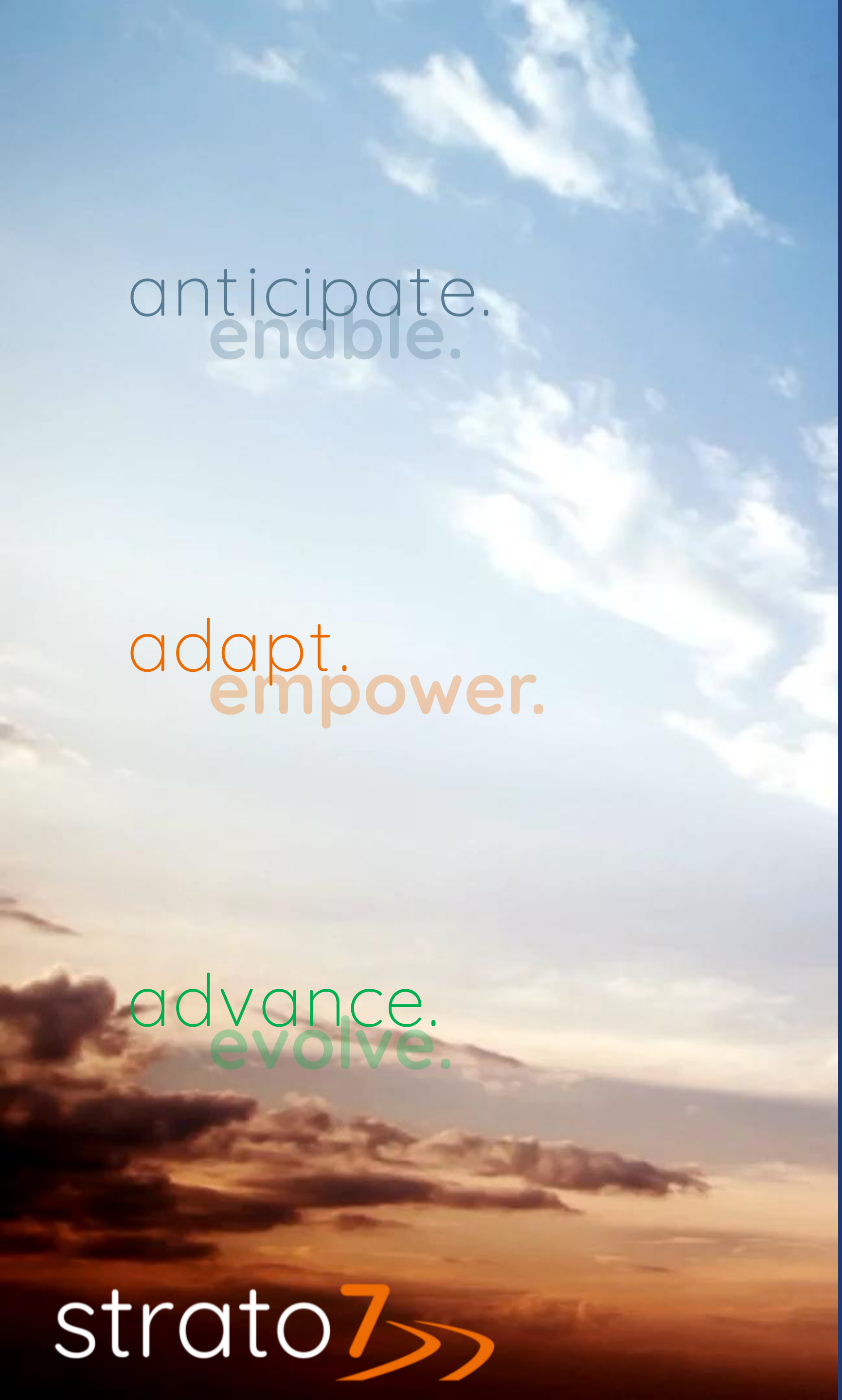
- Value Chain Structure Scenarios
- Stakeholder Interviews
- Internal Perspective: Stakes for Hydro

2 Profile and Mission of fka

Company profile

Since 1981, we are **CREATING IDEAS & DRIVING INNOVATIONS**

- Strategically located in **research & innovation hubs** in **Aachen** and **Silicon Valley**
- An **active innovation partner** for the entire spectrum of the **mobility industry**
- Offering **advanced engineering**, **method & process support** and **data & digital products**
- Counting with a team of over **200 highly skilled professionals**



Our approach.

We envision future mobility technologies that drive our partner's innovative capacities.

We develop adaptation strategies and support their consistent implementation – methodically and practically.

We help to build a technologically and organizationally resilient and innovative organization.

For over 40 years, we have been a leader in groundbreaking mobility solutions, from automated driving to zero-emission.

Our research and development facilities and our team of experts consistently push the boundaries of what's possible in mobility.

Our clients are not just prepared for the future – they help define it. Become a part of the revolution in mobility. Become future proof. Today.

3

Mega Casting Progress and Bottlenecks

Mega Castings & Chinese Market Entry

- » Starting from 2007: The rise of the die cast shock tower accelerated the demand for structural applications
- » Clear increase in large die-casting machines since the rise of structural components
- » Rise of structural components as trailblazer for ever larger castings
- » Machine size was a limiting factor until Tesla decided to adopt mega-casting
- » First application of mega-casting in 2020:
- » At Tesla named “Giga-Casting”
- » Large die casting machines with clamping forces ≥ 55,000 kN / 5,600 ton

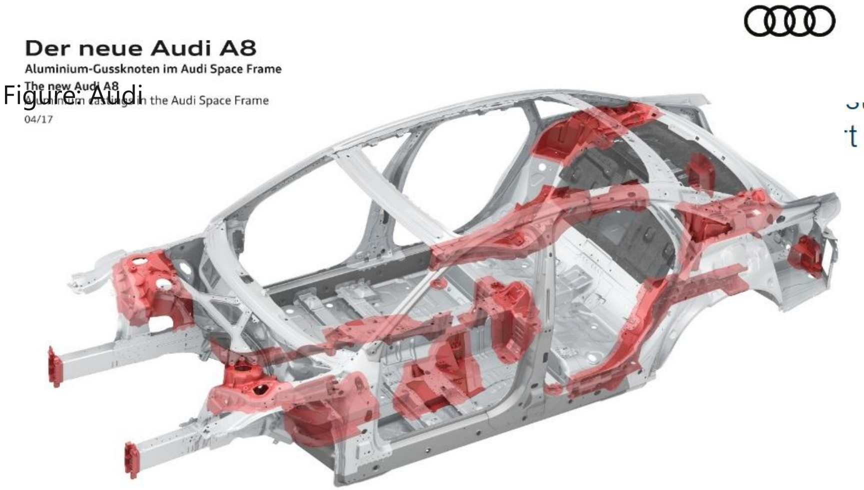
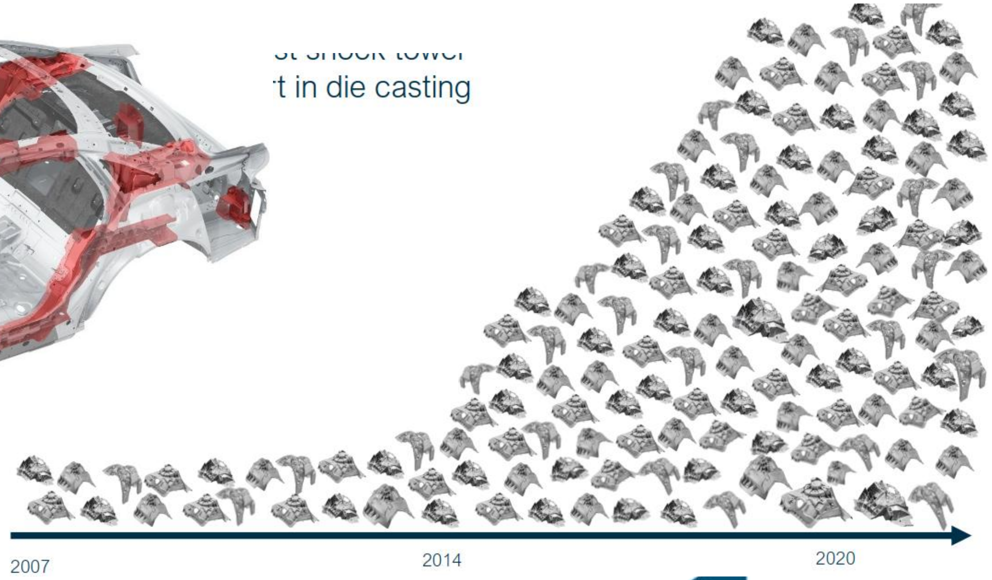
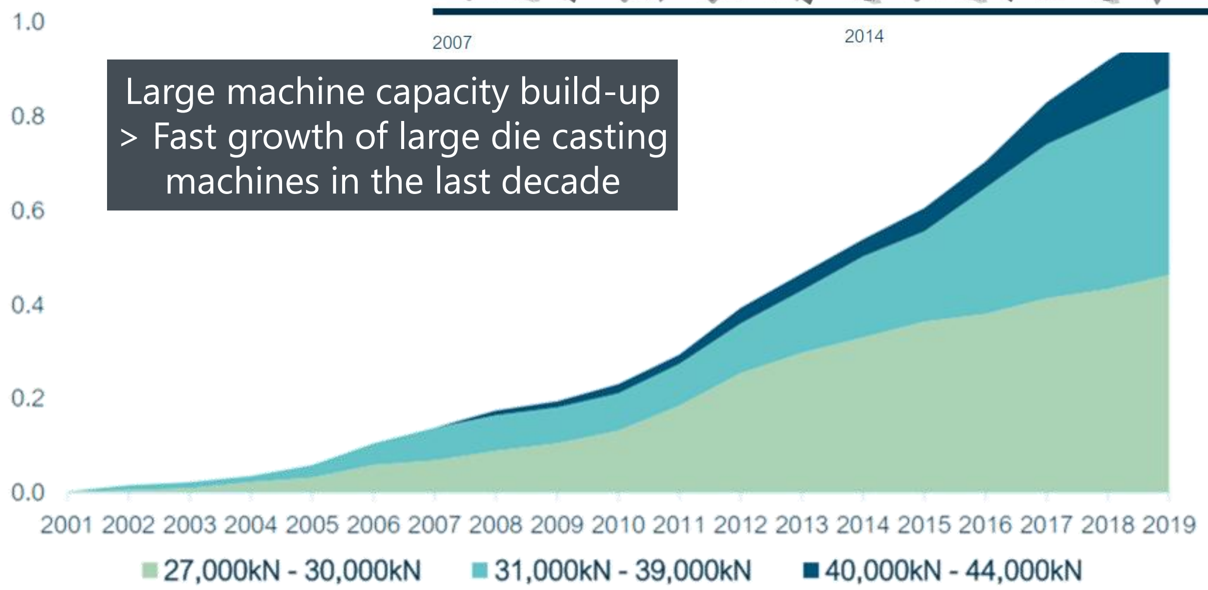


Figure: Audi

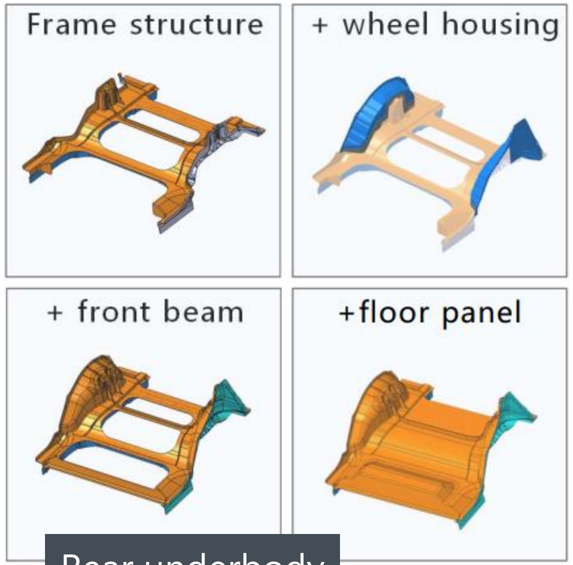




Figures: Bühler

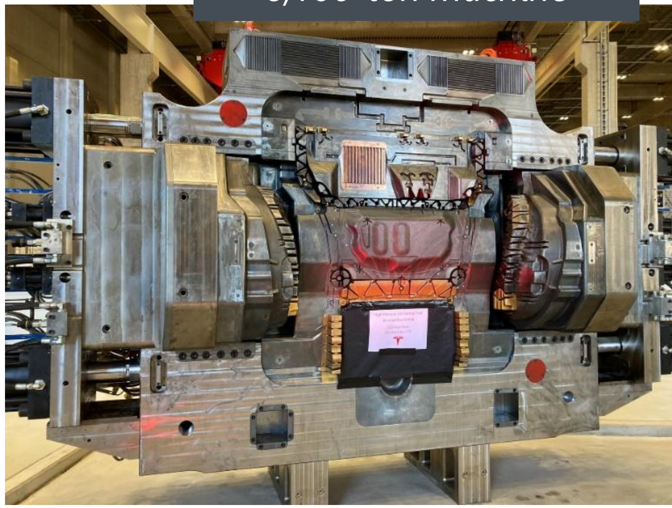
Mega Castings & Chinese Market Entry

- Production of very large (one-piece) structural castings:
  - Fully integrated:
    - For example, entire vehicle rear underbody
- Huge die casting machines (at Tesla named Giga Presses):
  - Length: >19 m, width: >7 m, height: >5 m
  - Weight: >400 t
  - Die-casting tool:
    - Max. die height ≥ 2400 mm
    - Weight per tool side: 50 - 100 t
  - Cycle time:
    - General target figure around 100 s > Tesla already 75 s
  - Rising clamping forces, especially in China:
    - 16,000-ton machine available
  - Special building requirements:
    - Foundations, height, crane, …



Rear underbody mega-casting
Integration levels

Die-casting tool for Tesla Model Y rear underbody
Moving side - 70 t
6,100-ton machine



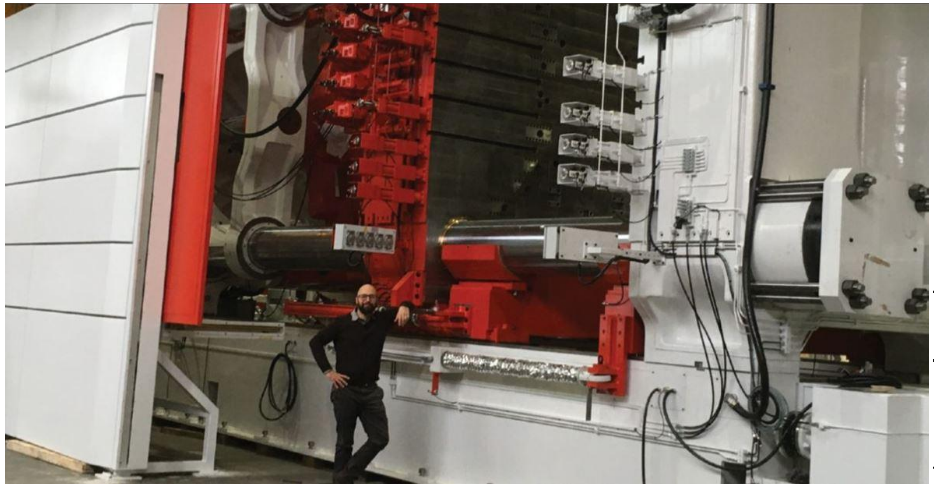


Figure: teslanorth.com

Mega Casting in a nutshell: Evolutionary development, but revolutionary potentials

Clamping forces >5,500 t

Aluminum alloys available, but improvment potential towards mega casting requirements

Principle

- Further evolution of high pressure die castings beyond machine clamping forces of 5,500 t
- Large, single-piece aluminum casting components
- Typically replacing welded steel or aluminum sheets.

Motivation

- Primary: Production Efficiency
  - Part reduction ca. 100 ➔ 1
  - Correspondingly reduction of assembly and joining processes
- Secondary: Supply Chain Efficiency
  - Sustainability
  - Risk / Supplier Management

Limitations

- Machine size / Clamping forces determine max. component size
- Process quality challenges increase with large casting components
- Minimum casting thickness as limitation for sheet-like parts
  ➔ Mass increase
- No multi material approaches

Variety of Applications in Body in White (BiW)

BiW Front Structures | **Underbody / Battery Structures** | **BiW Rear Structures**

Source: fka GmbH

Spotlights on Progress in Mega Casting

Casting Process

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							

- Key targets: Quality improvement and cycle time reduction
- Linked to developments in the field of optimized cooling and optimized mold design
- Reduction of secondary operations
- Part as well as die casting tool design decisive for process quality and cost

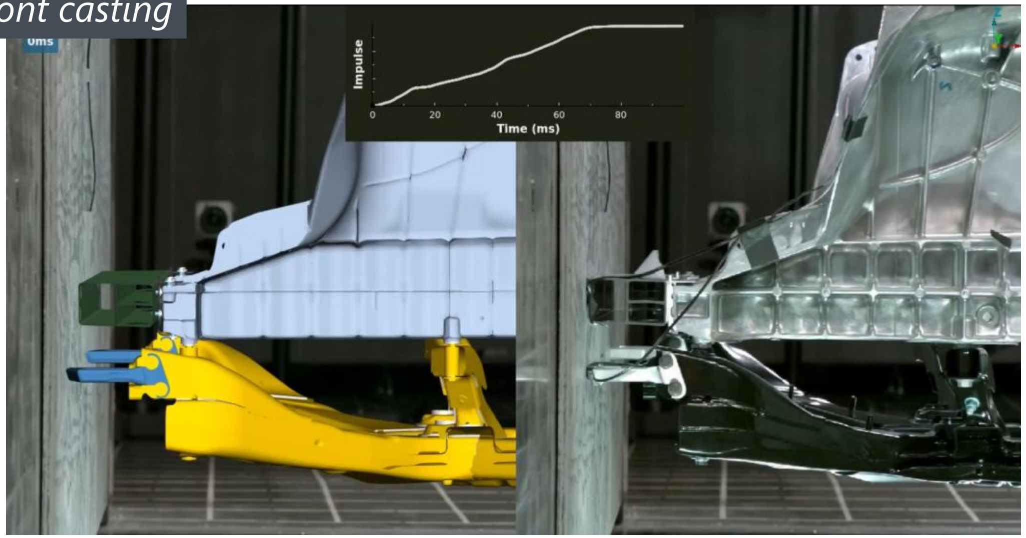
Image Source: Bühler

Spotlights on Progress in Mega Casting

Structural Performance

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							

Cybertruck
Front casting



- Limited ductility of casting alloys remains challenging
- However, optimized design approaches even enable application in crash energy absorption paths
- Principle design advantages of large integrated (casted) parts regarding vehicle stiffness

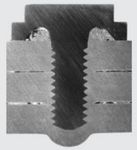
Image Source: X @wmorrill3

Spotlights on Progress in Mega Casting

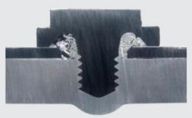
Integration and Joining

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							

Flexible
- One Sided joining
- Two-Sided joining
- C-frame with SPR die



Capable
- Multiple layers of aluminium
- Range of aluminium tempers including T6



Multi Material
- Cast, extruded, sheet aluminium
- Prehole steel to aluminium
- Magnesium
- GFRTP top sheets

Versatile
- Very thick aluminium bottom sheets
- No pre-hole needed for aluminium top sheet

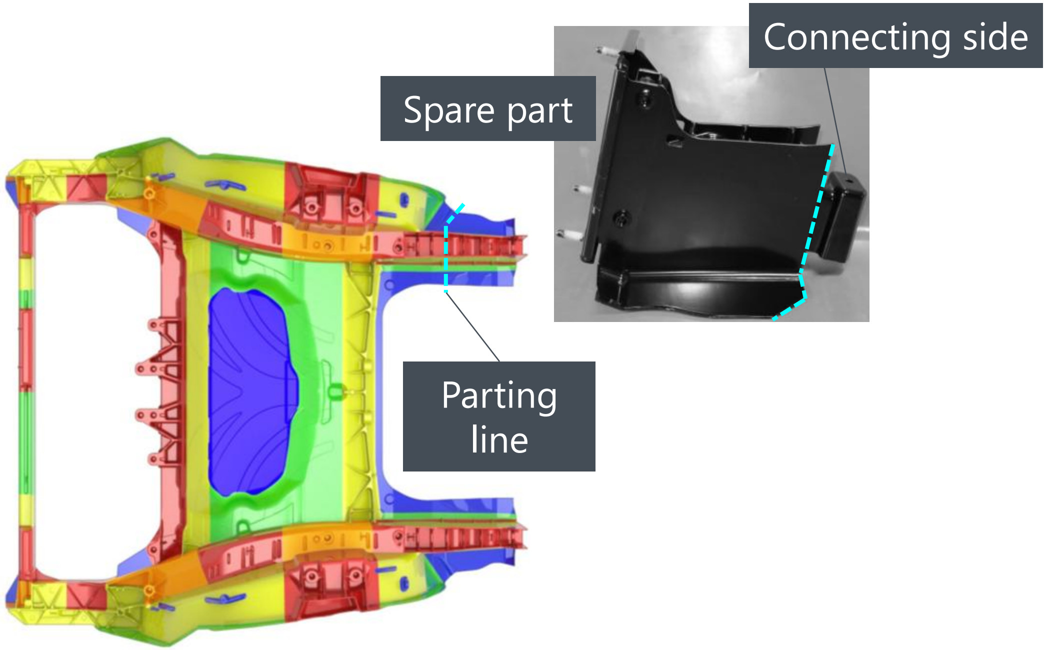
- Mega casting structures enable the reduction of joining operations on a large scale
- Main joining technologies used for mega castings:
  - Self-piercing rivets + Adhesive bonding
  - Resistance spot welding + Adhesive bonding
- Existing joining technologies such as self-piercing rivets have to be adapted to the casting material characteristics (low ductility), which entails new designs and processes

Image Source: Atlas Copco, Munro Live

Spotlights on Progress in Mega Casting

Repairability

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							



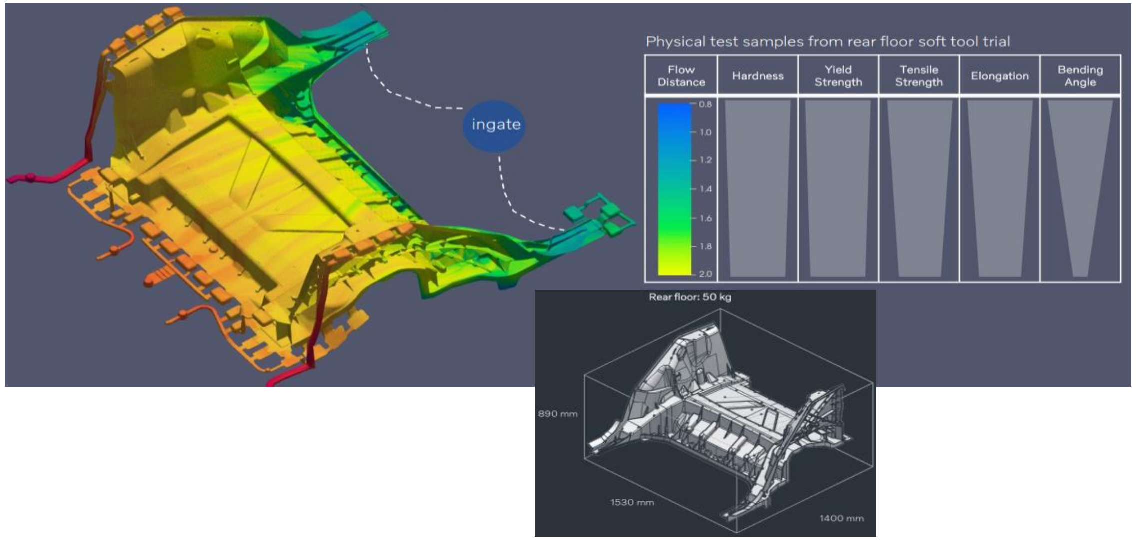
- In principle, repairability of mega castings is considered to be challenging, however repair concepts are exisiting
- Approach 1: Design for repairability
- Approach 2: Protect mega casting
- Well-designed and integrated mega casting not seen critical in terms of insurance rates

Image Source: Tesla, sfvautoparts.com

Spotlights on Progress in Mega Casting

Material Technology

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							



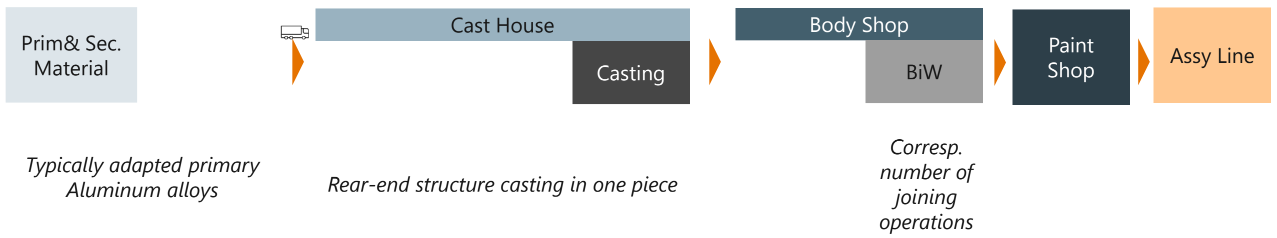
- Commonality: No heat treatment, given the dimensions of the casting parts
- Key parameters of HPDC alloys include fluidity, die sticking resistance, elongation & bending angle, fracture toughness, shrinkage tendency, rivetability & weldability as well as corrosion resistance
- Towards higher circularity, acceptance of impurities is critical for higher shares of secondary aluminum

Image Source: Volvo

Spotlights on Progress in Mega Casting

Economy

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							



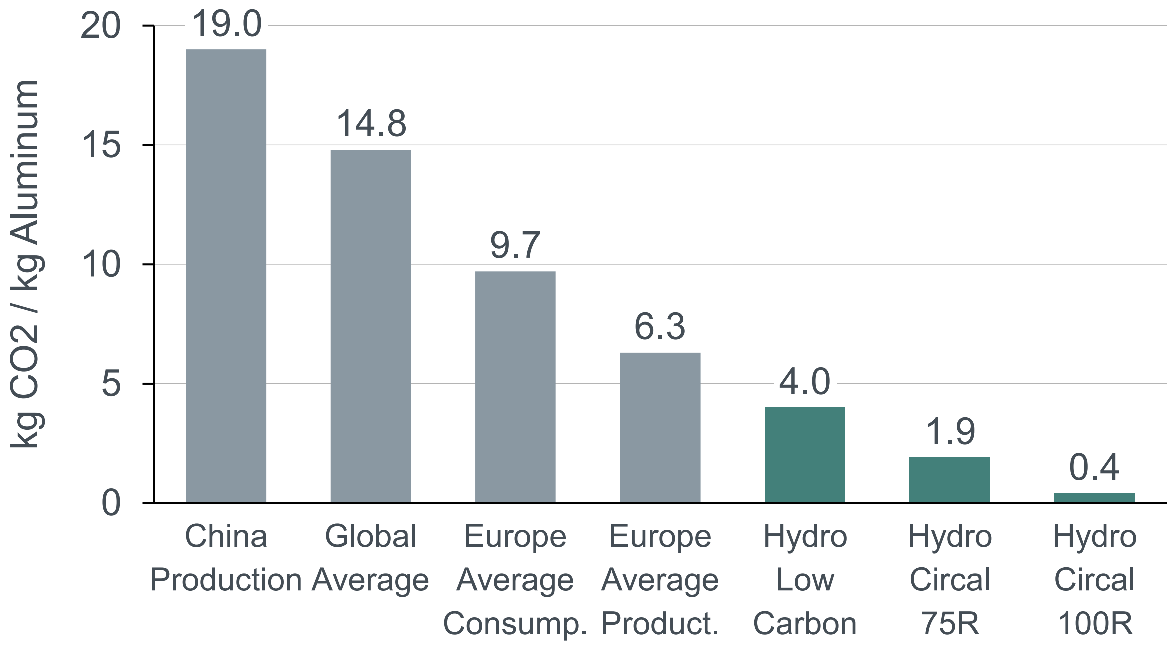
- Mega casting component costs dominated by raw material, investments and tooling
- Typical tooling lifetime currently increasing
- Mega castings can lead to lower costs than conventional steel-based rear end structures
  - when casting component is lighter
  - for medium production volumes per factory side
- Non directly monetary secondary factors include lead times, supply chain management etc.

Image Source: fka

Spotlights on Progress in Mega Casting

Carbon Footprint

Dimension	Casting process	Structural performance	Integration & joining	Repairability	Material technology	Economy	Carbon Footprint
Criticality (Performance X Relevance)							



- CO2e footprint of aluminum creates a massive malus in the overall PCF when using EU average or even global average aluminum for mega castings
- Effect of process energy and supply chain logistics is rather neglectable
- Use phase benefits based on lightweight design can compensate some of the production emissions
- **Availability of secondary material – and its applicability in casting processes – is key to further optimization of sustainability.**
- **Requires circularity with corresponding design and supply chain measures.**

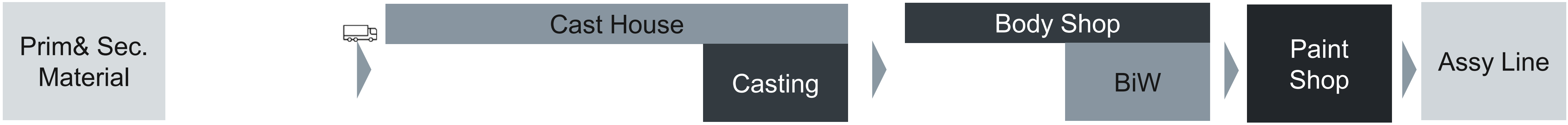
Image Source: fka based on IAE, Hydro

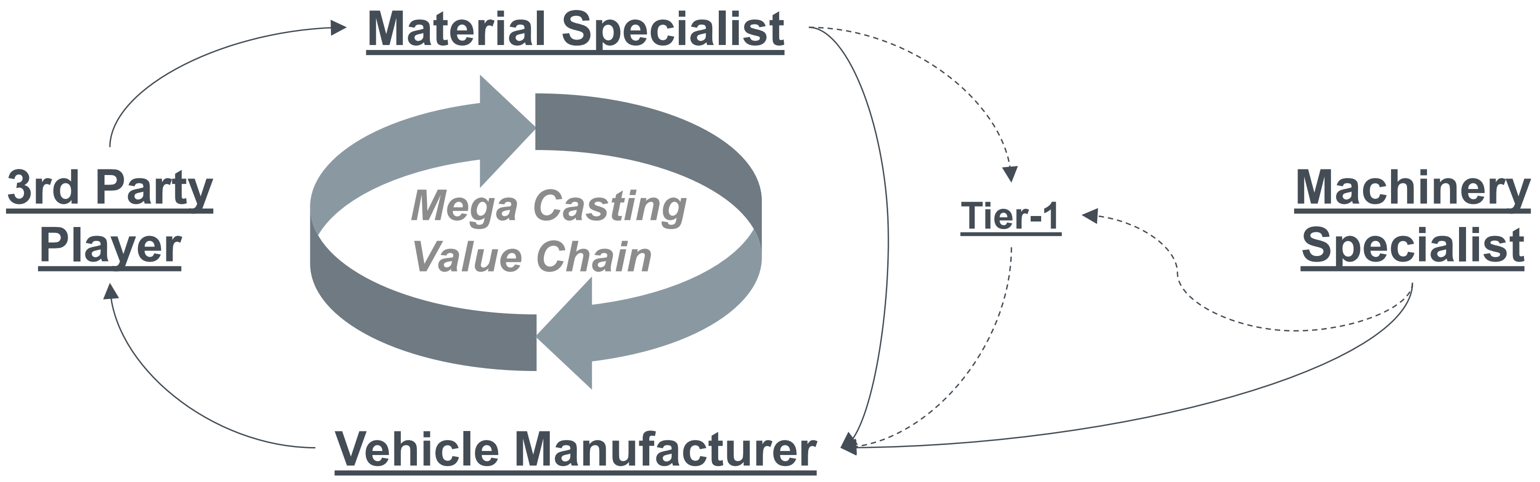
4 Market Impact in Europe

From sheet metal and component driven value chains and indirect relations to OEM...

Source: fka GmbH

...to an unmediated material specialist to OEM collaboration for mega castings.





Source: fka GmbH

Global Users of Mega Castings

Front mega casting

Typically including
- Front Longitudinals
- Wheelhouses
- Firewall (partly)

Rear mega casting

Typically including
- Rear panel
- Rear longitudinal
- Rear underbody
- Rear seat cross member
- Wheelhouses

Underbody mega casting

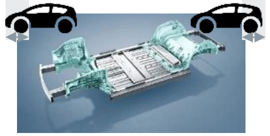
Typically including
- Floor group
- Longitudinal + Tunnel
- Seat cross member
- partly battery housing

Tesla Front & Rear

Volvo Rear

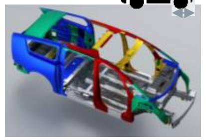
Zeekr Rear

Nio Rear



Xpeng Front & Rear

Xiaomi Rear



LiAuto Rear

Huawei Rear & Side

FAW Rear

Toyota Front / Rear

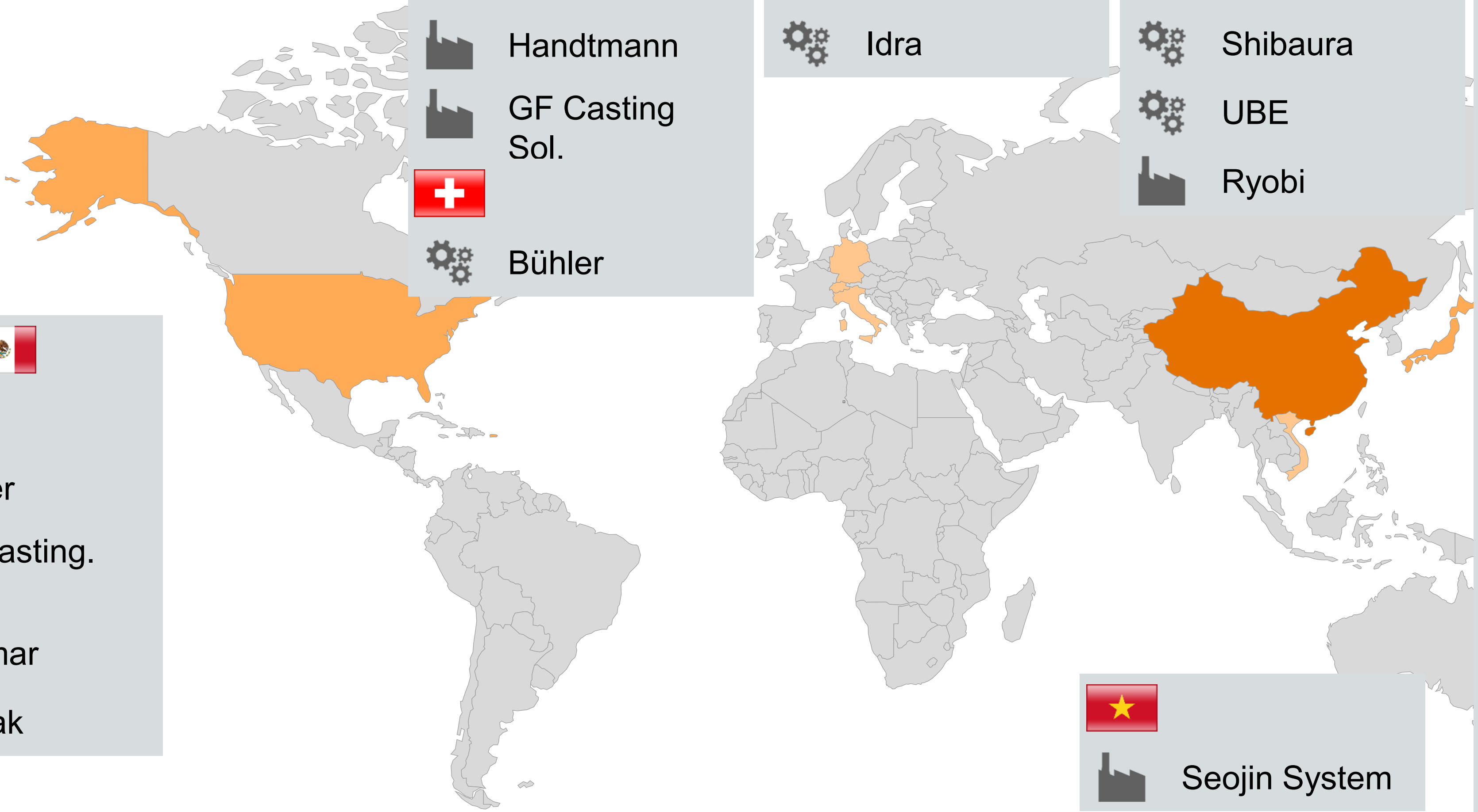
Honda Front, Rear

Chery Underbody

and many more, including announcements on tests / prototypes / evaluations by Mercedes, VW, Ford, Nissan, Hyundai and numerous Chinese OEM

Image Sources: Tesla, Volvo, Zeekr, Nio, Xpeng, Xiaomi, LiAuto, Huawei, FAW, Toyota, Honda, Chery

Global Mega Casting Suppliers



Germany
- Handtmann (Mega Casting Suppliers)
- GF Casting Sol. (Mega Casting Suppliers)

Switzerland
- Bühler (Mega Casting Machinery)

Italy
- Idra (Mega Casting Machinery)

Japan
- Shibaura (Mega Casting Machinery)
- UBE (Mega Casting Machinery)
- Ryobi (Mega Casting Suppliers)

China
- LK Technology (Mega Casting Machinery)
- Haitian (Mega Casting Machinery)
- Yizumi (Mega Casting Machinery)
- Tianzheng Mould (Mega Casting Suppliers)
- Ningbo Tuopu (Mega Casting Suppliers)
- Guangdong Hongtu (Mega Casting Suppliers)
- Wencan (Mega Casting Suppliers)
- GF Casting Sol. (Mega Casting Suppliers)
- Bojun Tech (Mega Casting Suppliers)
- Rongtai (Mega Casting Suppliers)
- Asiaway (Mega Casting Suppliers)
- Anhui Ruimei (Mega Casting Suppliers)
- Duoli Technology (Mega Casting Suppliers)

USA / Canada / Mexico
- UBE (Mega Casting Machinery)
- Bühler (Mega Casting Machinery)
- GF Casting. Sol. (Mega Casting Suppliers)
- Linamar (Mega Casting Suppliers)
- Nemak (Mega Casting Suppliers)

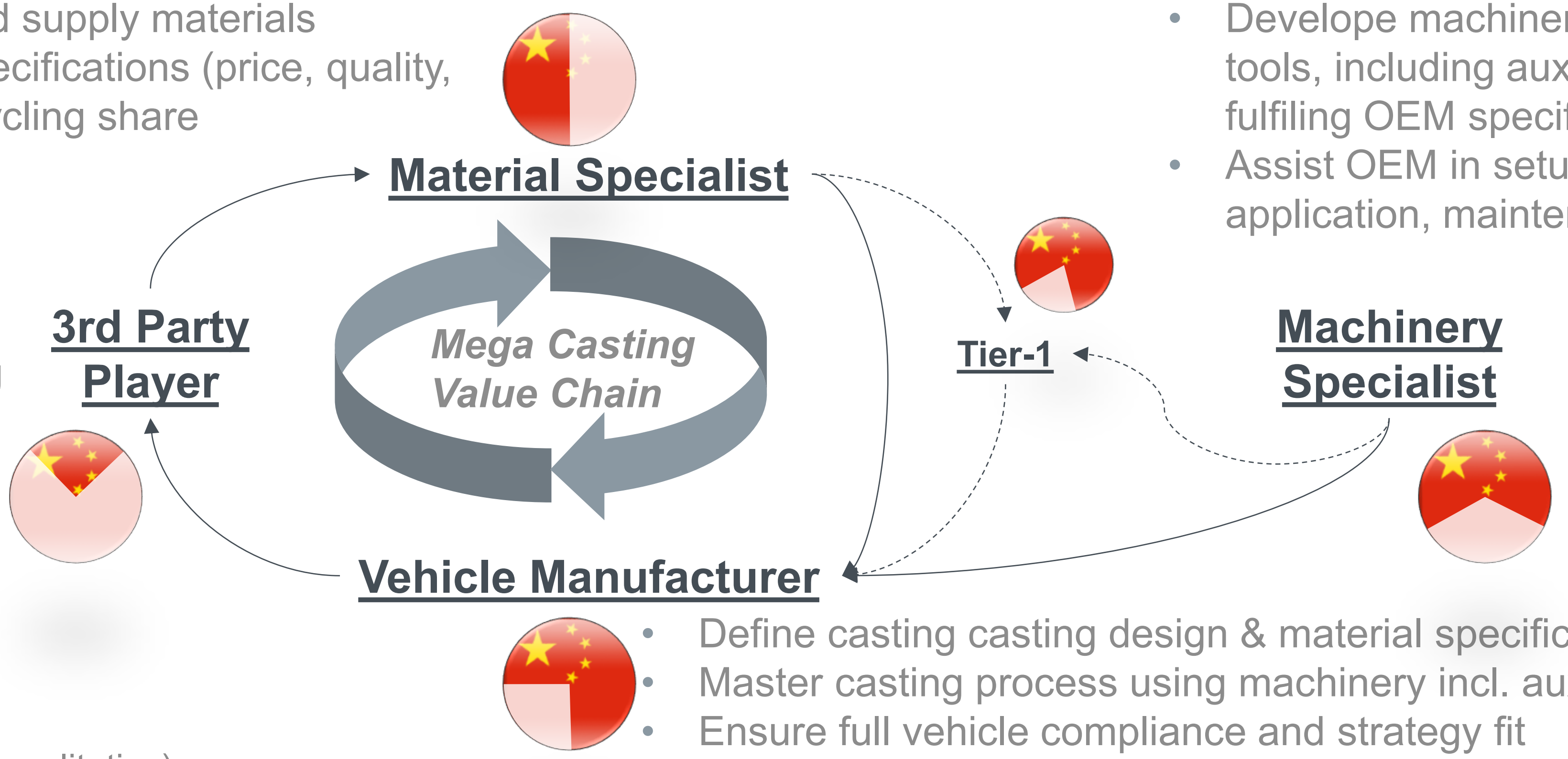
Vietnam
- Seojin System (Mega Casting Suppliers)

Mega Casting Suppliers
Mega Casting Machinery

Strong Chinese position in relevant roles along the OEM-driven mega casting value chain

- Develop, Produce and supply materials according to OEM specifications (price, quality, carbon footprint / recycling share

- Develope machinery and tools, including auxiliaries, fulfiling OEM specifications
- Assist OEM in setup, application, maintenance



- Source EoL vehicles
- Dismantling, recycling
- Market scrap

- Define casting casting design & material specifications
- Master casting process using machinery incl. auxilliaries
- Ensure full vehicle compliance and strategy fit

Degree of Chinese market dominance (qualitative)

Source: fka GmbH

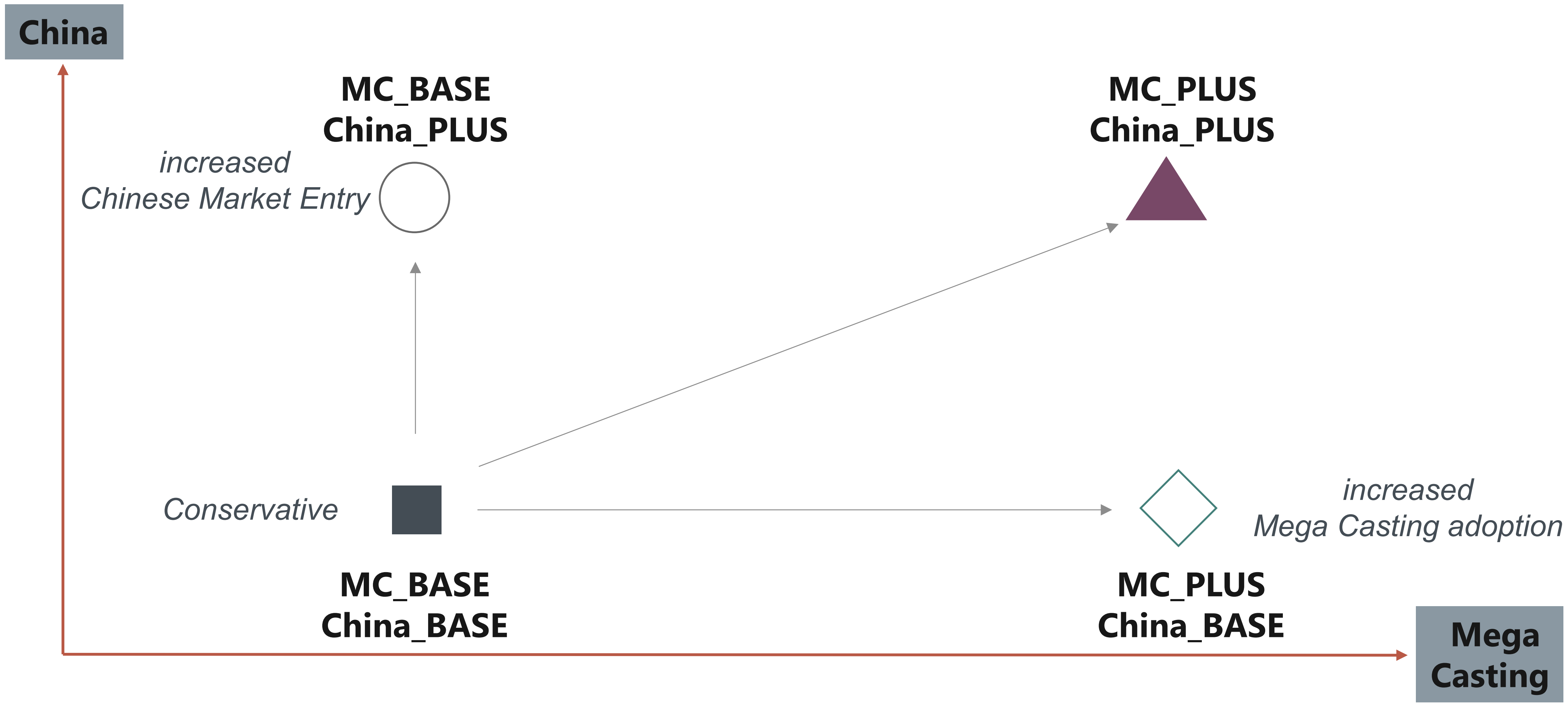
Green Lights for an EU market entry of Chinese mega casting OEM, but ambiguous for domestic production and sourcing

↑ Positive impact ↔ Neutral / ambiguous impact ↓ Negative impact

	Impact on EU Market Entry of Chinese OEM	Impact on EU Vehicle Production of Chinese OEM	Impact on EU Aluminum and Component Sourcing of Chinese OEM
Global Tariffs	↑	↑	↑
EU EV Regulation in general (CO_2 targets, ELV, Battery Regulation etc.)	↗	↔	↑
Carbon Pricing (EU-ETS + CBAM)	↔	↓	↔
Capacity Situation in China	↑	↓	↓
China Aluminum Strategy	n.a.	n.a.	↔
Cost Structure	↑	↓	↓

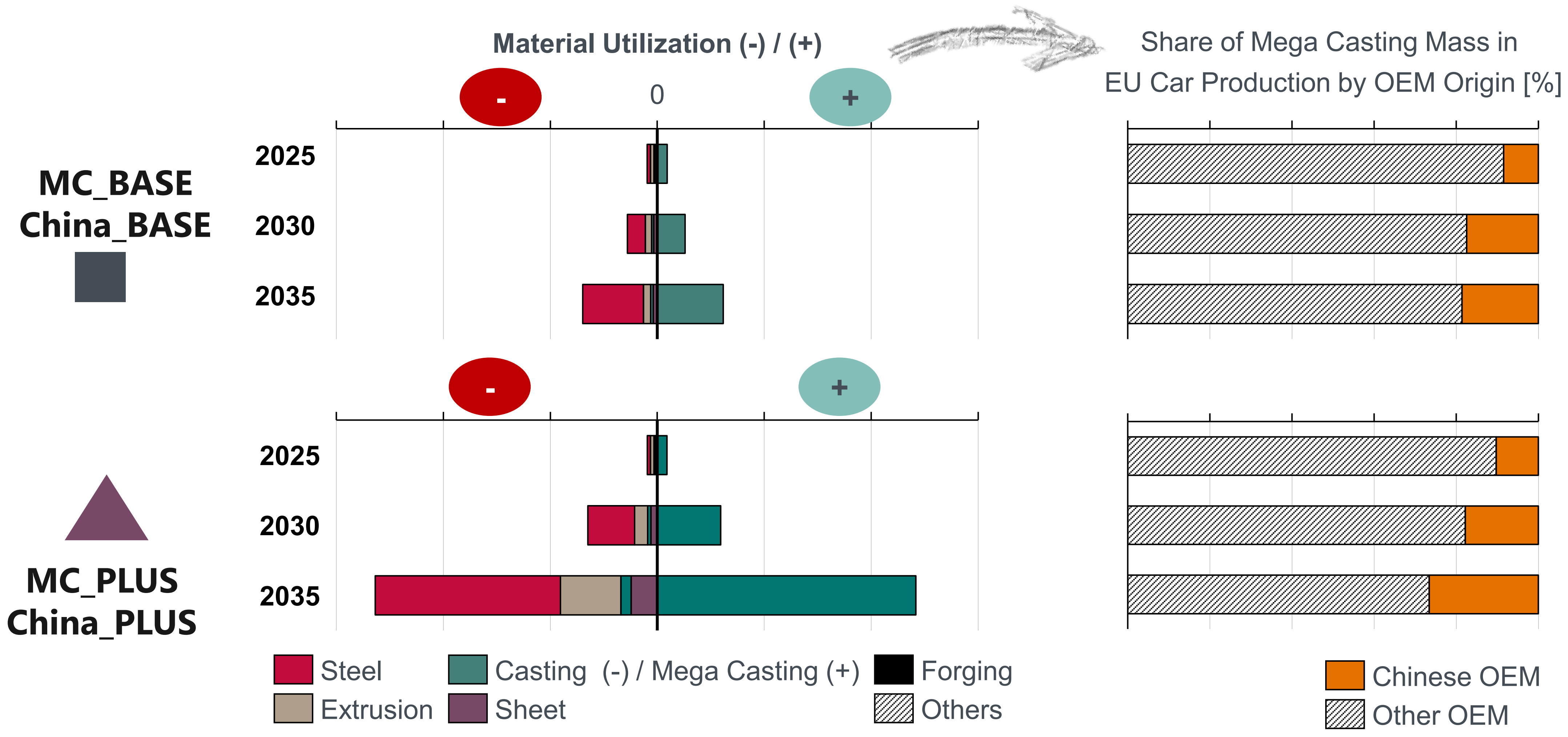
Source: fka GmbH

We defined four scenarios to quantitatively determine the EU market impact of mega castings



Source: fka GmbH

Mega Castings create significant market growth, but partially substitute other alu process types



Source: fka GmbH

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Hydro‘s Strategy towards Green and Circular Aluminum

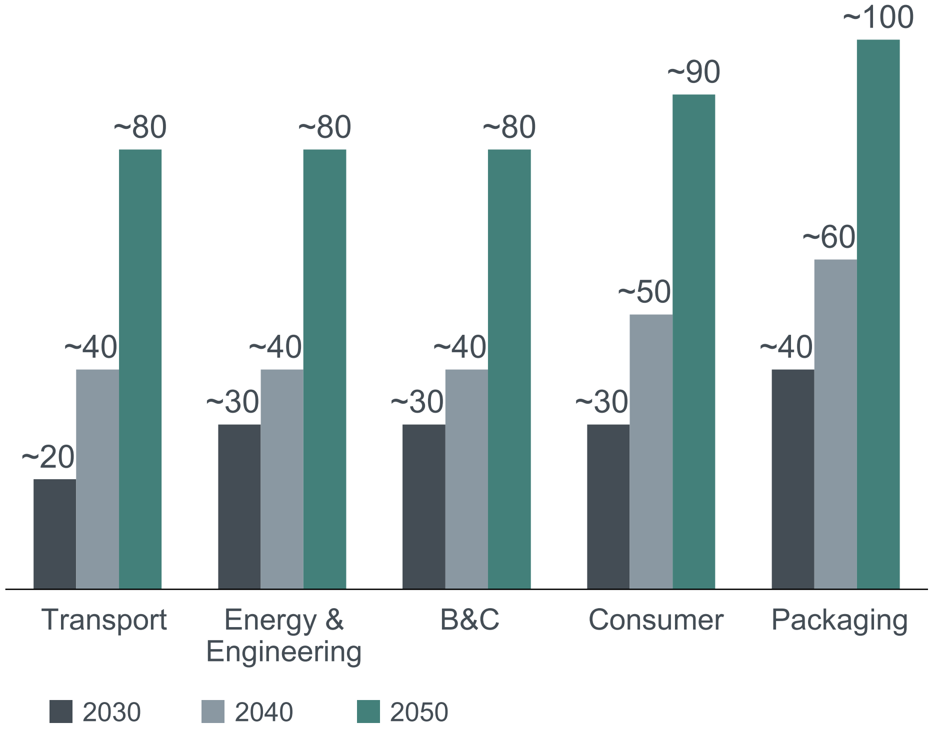
Expecting strong demand for greener aluminium

Hydro

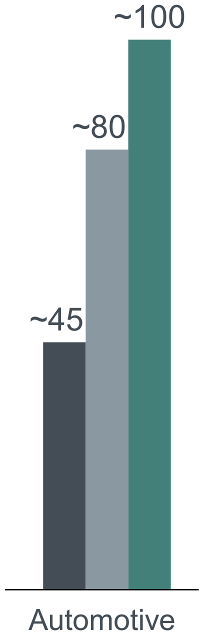
Ambitious abatement targets driving demand in all sectors but especially Automotive OEMs

Share of greener [1] aluminium demand per segment

% greener of total aluminium demand



OEMs are pushing for ever more ambitious life-cycle decarbonization targets



	Timeline to achieve target	Decarbonization target: Scope 1 & 2	Decarbonization target: Scope 3 upstream
PORSCHE	2030	100%[1]	100%[1]
gm	2040	100%[1]	-
Ford	2050[1]	100%[1]	100%[1]
Mercedes-Benz	2039	100%[1]	100%[1]
BMW	2030	80%	22%
VW	2050[1]	100%[1]	100%[1]
VOLVO	2025	40%[1]	25%[1]
TOYOTA	2050	90%[1]	100%[1]
PSA GROUPE	2034	20%	-

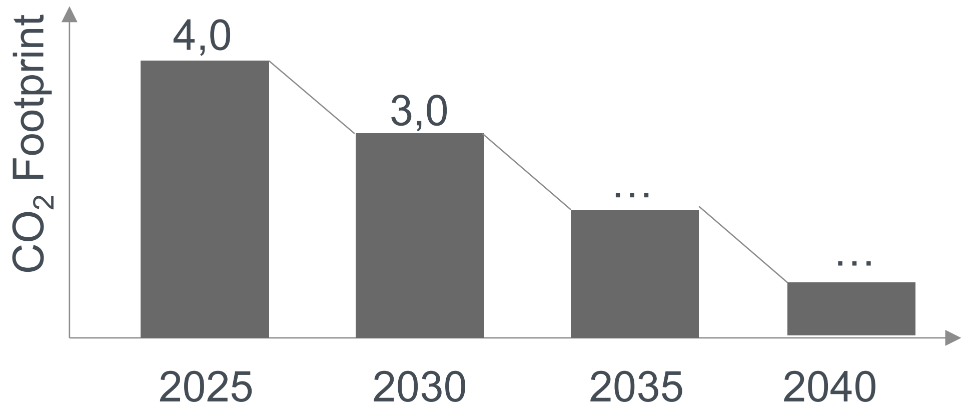
1) Greener aluminium includes “near-zero” tCO2/t, <2 tCO2/t and 50%+ PCS-aluminium
Source: McKinsey market analysis (high level estimate)

Pathways towards Zero

The OEM approach

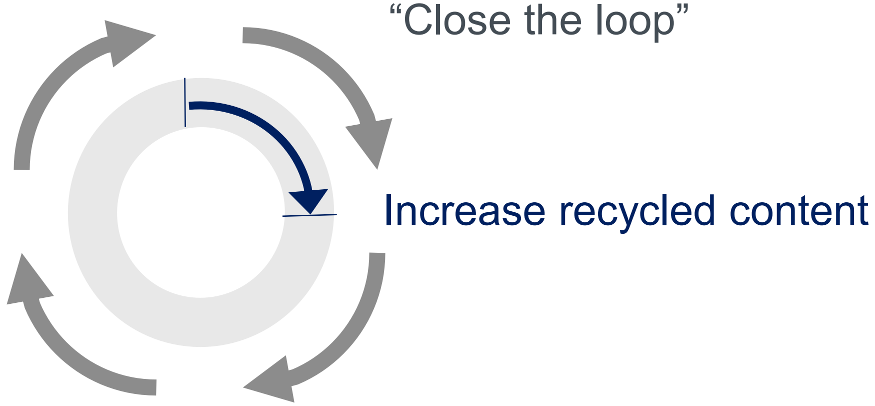
1. Decarbonization of primary production

→ Decarbonization front-runners continuously increase primary CO_2-footprint targets in future vehicle awarding



2. Increase in secondary material share

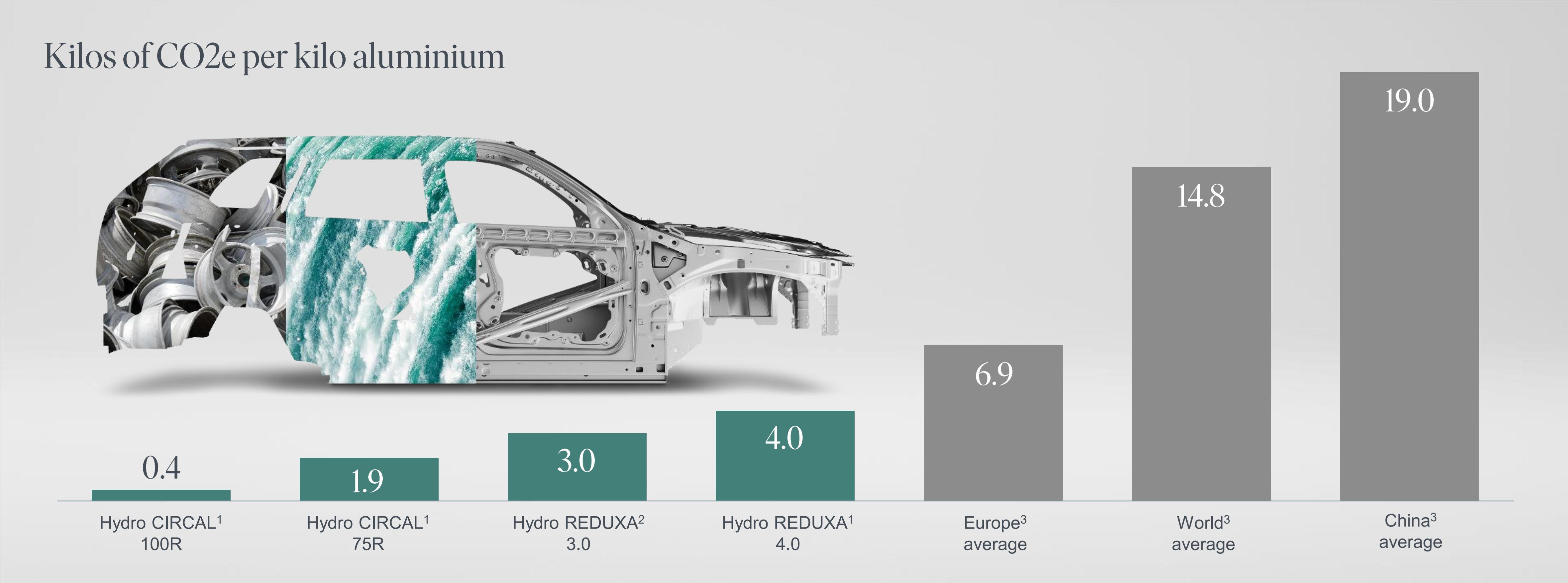
→ Continuous increase of secondary material share to fully “close the loop” throughout all product areas



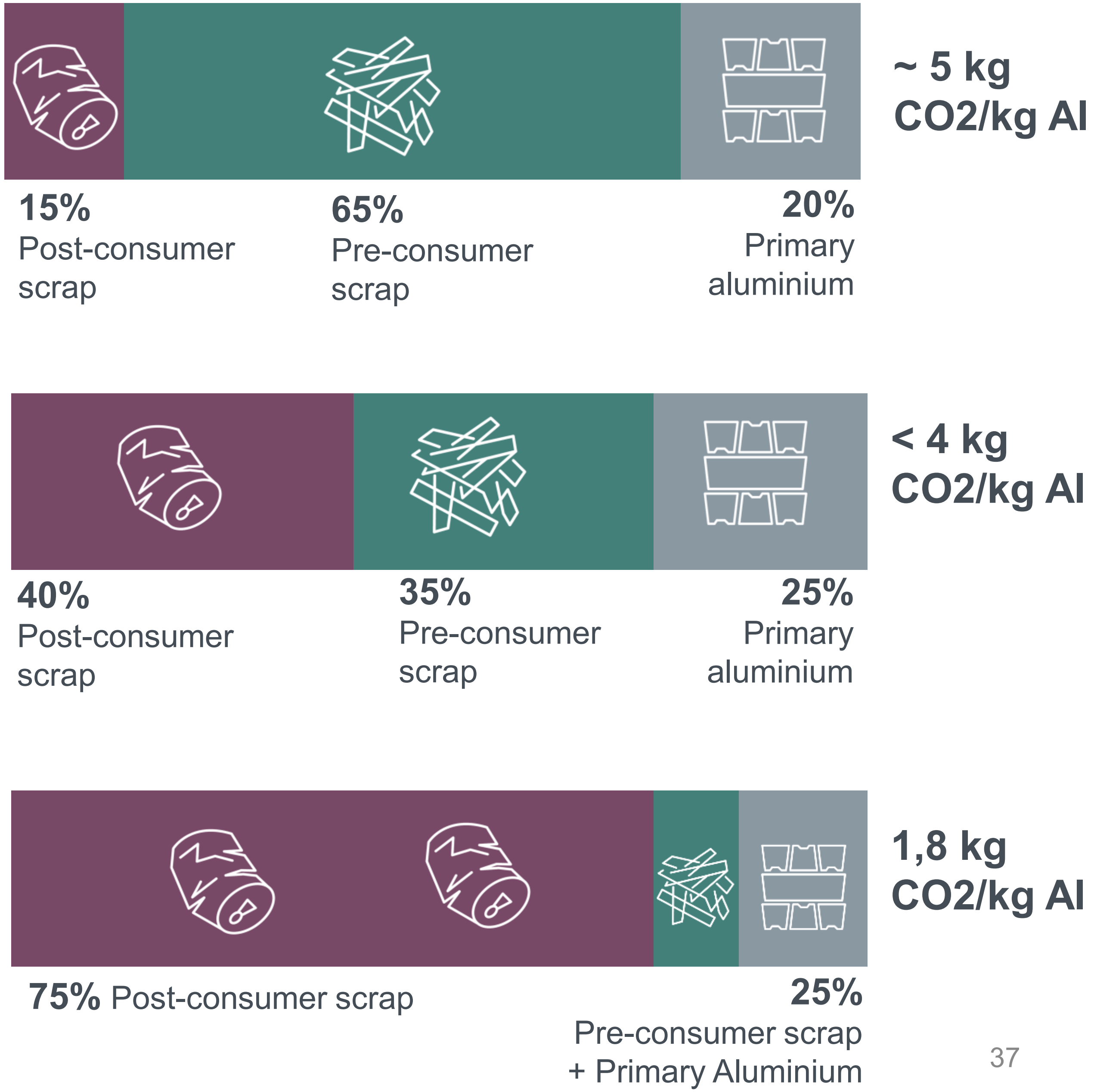
→ Decarbonization of aluminium in future vehicles is mainly driven by streamlined and continuously increasing targets in future vehicle awarding

It matters where and how aluminium is produced

CO_2 emissions from almost zero to more than 20 kilos

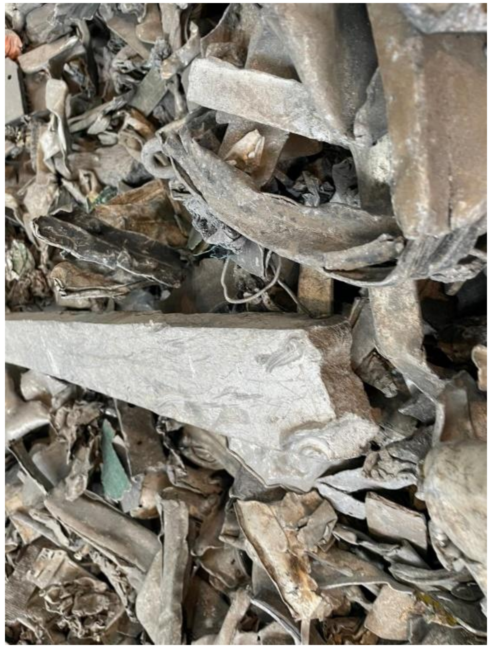


[1] Verified by DNV and certified according to EPD EN 15804+A2 on a per-batch level [2] Hydro internal estimates [3] Source: International Aluminium Institute (2024)


~ 5 kg CO2/kg Al
15% Post-consumer scrap
65% Pre-consumer scrap
20% Primary aluminium
< 4 kg CO2/kg Al
40% Post-consumer scrap
35% Pre-consumer scrap
25% Primary aluminium
1,8 kg CO2/kg Al
75% Post-consumer scrap
25% Pre-consumer scrap + Primary Aluminium

Typical alloy composition – Example B&C

	% Si	% Mg	% Fe	% Cu	% Mn	% Zn	% Cr	% Ti
EN AW-6060 (acc. EN 573-3)	0,30-0,6	0,35-0,6	0,10-0,30	-0,10	-0,10	-0,15	-0,05	-0,10
Hydro standard 6060/6063 alloy	0,40-0,45	0,45-0,50	0,18-0,22	-0,02	-0,03	-0,02	-0,02	-0,02
Scrap	0.35-0.55	0.35-0.55	0,23-0,30	0.035-0.06	0.04-0.07	0.035-0.07	0.01-0.03	0.01-0.03
Hydro RFA variant	0,40-0.45	0,45-0.50	0,20-0.28	0,01-0.05	0,04-0.06	-0,05	-0,03	-0,03



- Standard Hydro alloy established 30 years ago from primary production
- All alloying elements from Hydro alloys are below maximum requirements from EN 573-3
- Increased maximum level of trace elements (Fe, Cu, Mn, Zn, Cr and Ti) is needed based on the scrap received at the recycling plant.

The concentration of trace elements is often the limiting factor for increasing recycling content.

Strong portfolio built on experience & expertise

Hydro

Just a glance at our extensive customer base built over 50 years including OEMs & Tier suppliers

Strategic Partnerships

OEM customers*

Tier Supplier Customers*

Logos are listed in no particular order
*this list is not extensive, just a selection of our customer logos

Summary & Conclusion

Key-Takeaways

- Initial technological challenges are being addressed resulting in an increased attractiveness of mega castings.
- Therefore, mega castings will be a part of the solution in future vehicles – also driven by Chinese OEM entering Europe with sales or production.
- Finding a strong position in value chains of Chinese OEM is a key enabler to profit from opportunities that mega castings promise for aluminium specialists.
- However, the carbon footprint of mega castings remains challenging, requiring secondary material offerings.
- Mega castings strengthen the direct supply relations of material specialists and OEM and open opportunities for new collaboration models, also with other stakeholders, to accelerate circularity.

Hydro