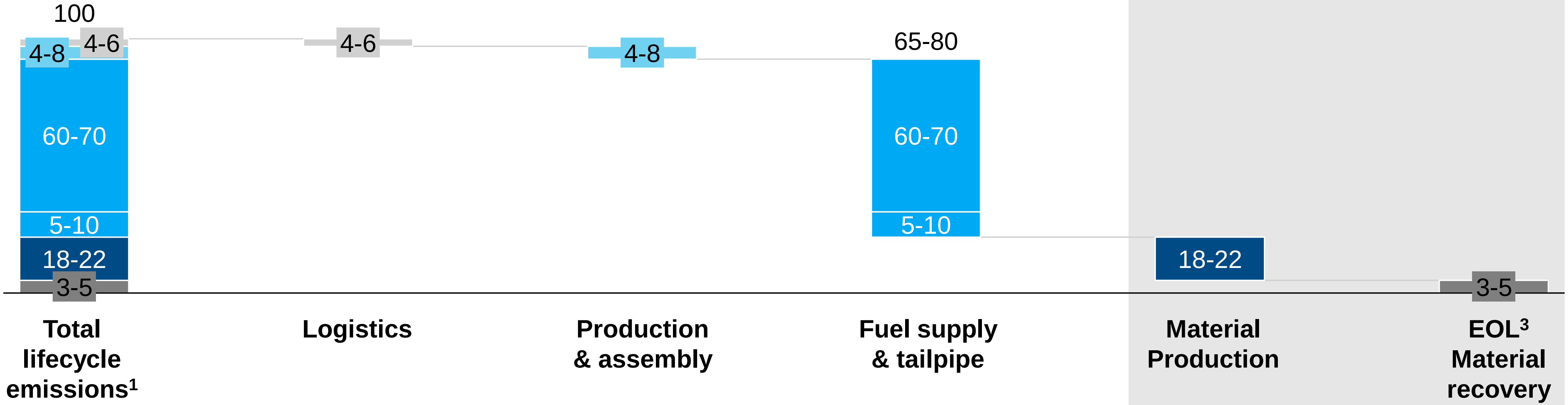
Internal combustion engine vehicles (ICEV) generate 65-80% of their lifetime emissions from exhaust, and another 18-22% from the production of materials

Share of 2019 lifecycle emissions of ICEV, in %

Under more direct Original Equipment Manufacturer (OEM) control and currently addressed

Under less OEM control and not addressed



✓ **Mainly addressed by electrification of vehicles and processes** paired with increased supply of **green electricity**

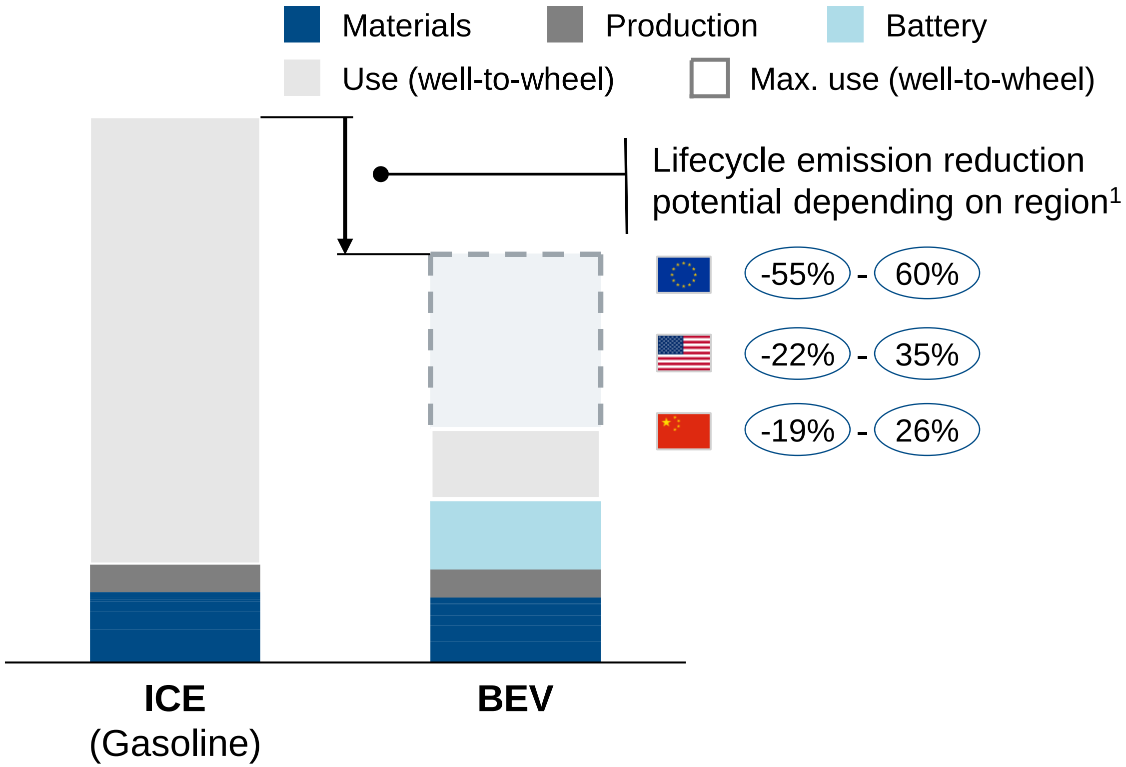
✕ **Not addressed: Requires transparency** and **complex supplier management**

1. C-segment vehicle
2. End of Life

Source: NGVA, Expert interviews, Decarbonization in Automotive Material Team Analysis

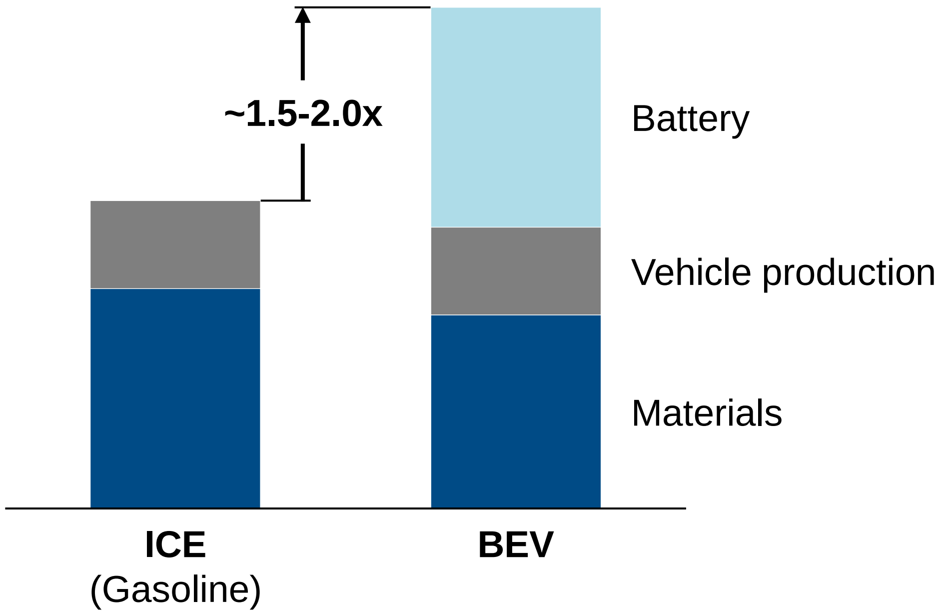
Energy- and emission-intensive production processes of batteries place new demands on decarbonization efforts

Lifecycle emission



Battery Electric Vehicle (BEV) lifecycle emissions could be substantially lower and depend on use of green electricity in power mix

Material emissions



1.5-2.0x higher material emissions for BEV vs. ICEV due to energy-intensive battery production

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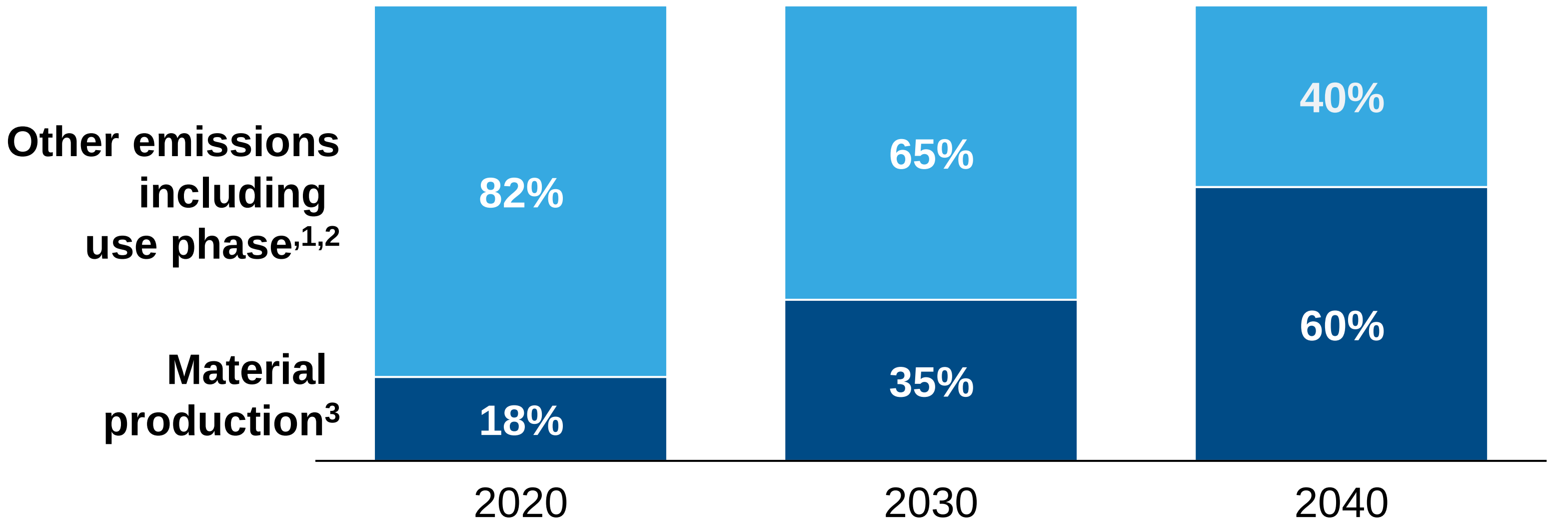
1. Reduction potential also depending on vehicle segment with smaller vehicles with typically higher emission reduction potential

Source: World Economic Forum, Global Batterny Alliance, McKinsey Analysis

Emissions from production materials may reach 60 percent of lifecycle emissions by 2040

% of lifecycle emissions

Emissions from material production will have higher share than other lifecycle emissions
in percent share (based on required sales data)



1. Assumed constant range of 15,000 km/vehicle per year and 10 year life time as baseline – End of life emissions not considered here
2. 2018 average ~120gCO2/km, target today 95 gCO2/km; Future assumptions: 2030 75 gCO2/km; 2040 50 gCO2/km; 0.10-0.16 kWh/km for xEV
3. Average material emissions: ICE 3,000, EV 7,400, PHEV 5,000, HEV 4,000 kg/CO2 per vehicle as of model (hold constant as decarbonization in focus)
4. Current BEV, PHEV, HEV penetration in relevant regions at 4-8%;2030: BEV 33%, PHEV 12%, HEV 7%; 2040: BEV 60%, PHEV 27%, HEV 13%
5. 2020 US/Germany at average 450 gCO2/kWh; future assumptions: 2030 320 gCO2/kWh (current EU average), 2040 160 gCO2/kWh, 2050

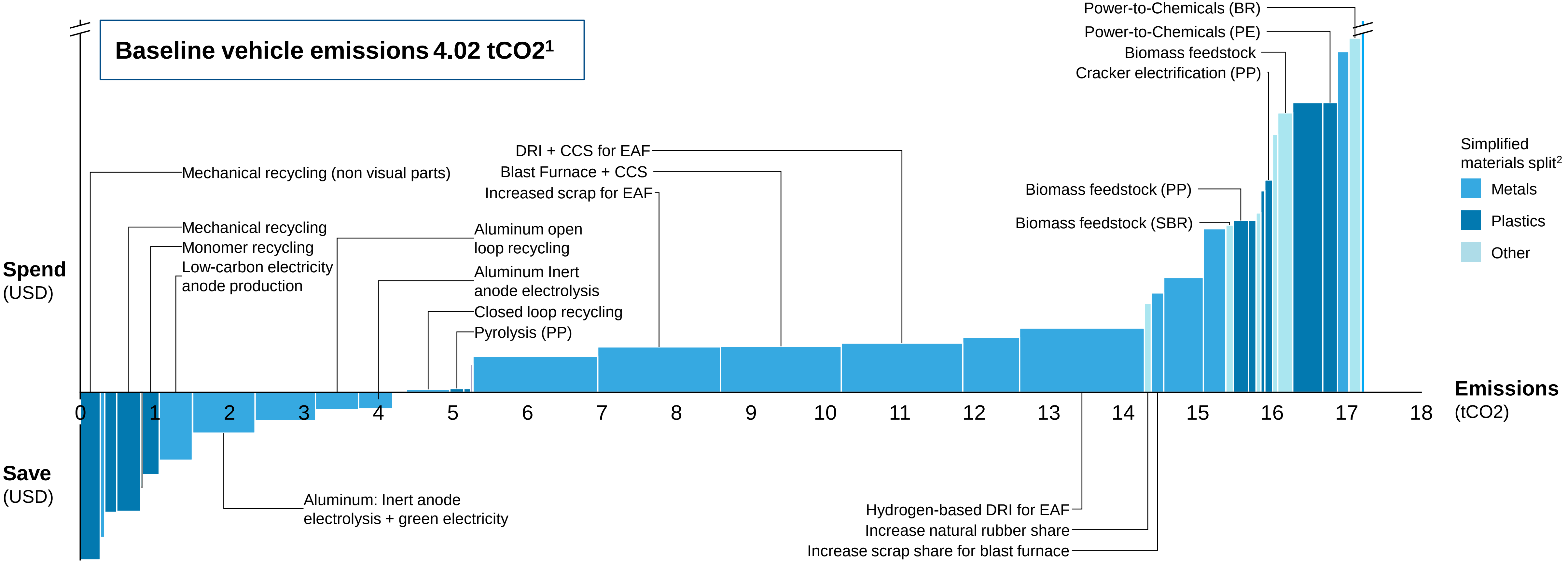
Source: High level estimation of Circular Cars Initiative (2020) for ambitious EV adoption scenario

For a typical ICEV, powering processes with green electricity offers decarbonization potential while reducing material costs

in USD/ tCO2 (2030)

Selected levers **Internal combustion engine vehicle (ICEV)**

Full set of all possible levers and cost of implementation



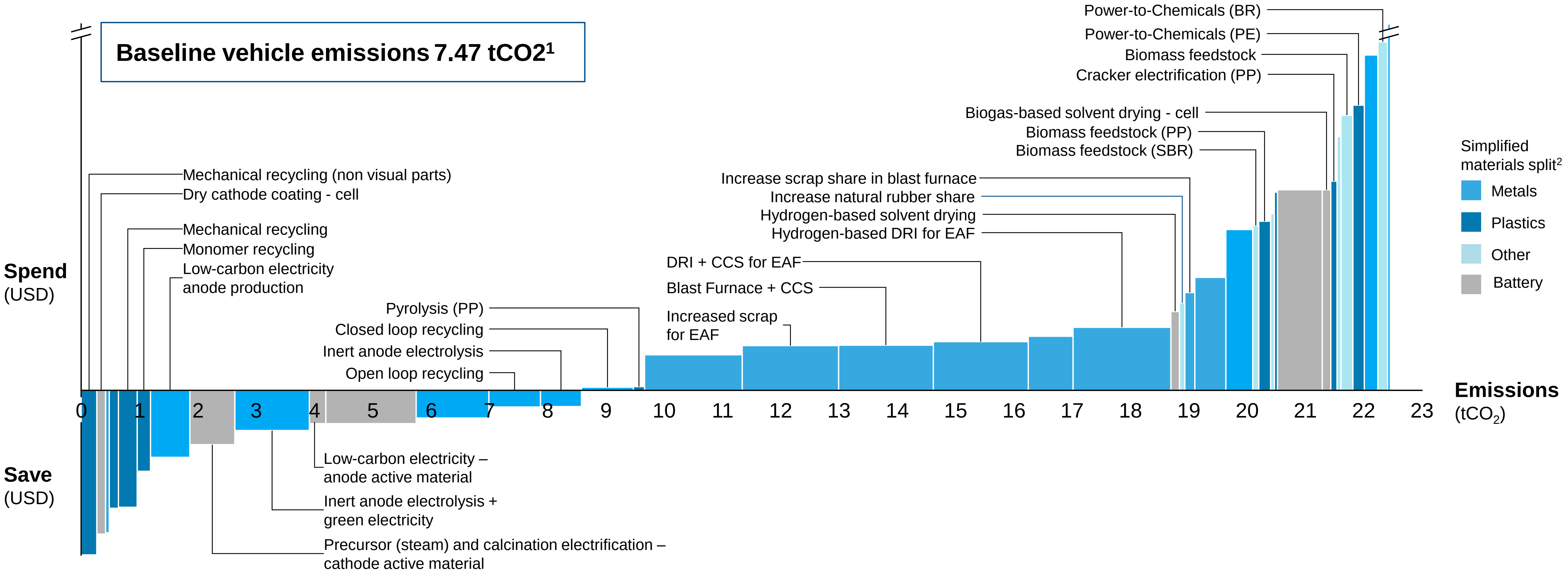
1. In this analysis, a premium C-segment vehicle with 1.95 t vehicle weight: 1.04 t steel; 0.29 t aluminum,0.10t Rubber, 0.07t PP, 0.03t PE, 0.05t Glass is considered
2. Metals including steel, high-strength steel, aluminum, alumina; Plastics including polypropylene, polyethylene, polyamide 6, Others including rubber, glass

Source: McKinsey Analysis (Team, McKinsey Decarbonization Pathways Optimizer)

The BEV abatement curve shows, several levers reduce embedded carbon emissions and material costs at the same time

in USD/ tCO2 (2030)

Full set of all possible levers: Basis for selection for integrated scenario-perspective



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1. In this analysis, a premium C-segment vehicle with 1.95 t vehicle weight: 1.04 t steel; 0.29 t aluminum,0.10t Rubber, 0.07t PP, 0.03t PE, 0.05t Glass, and 92 kWh battery is considered
2. Metals including steel, high-strength steel, aluminum, alumina; Plastics including polypropylene, polyethylene, polyamide 6, Others including rubber, glass

Source: McKinsey Analysis (Team, McKinsey Decarbonization Pathways Optimizer)

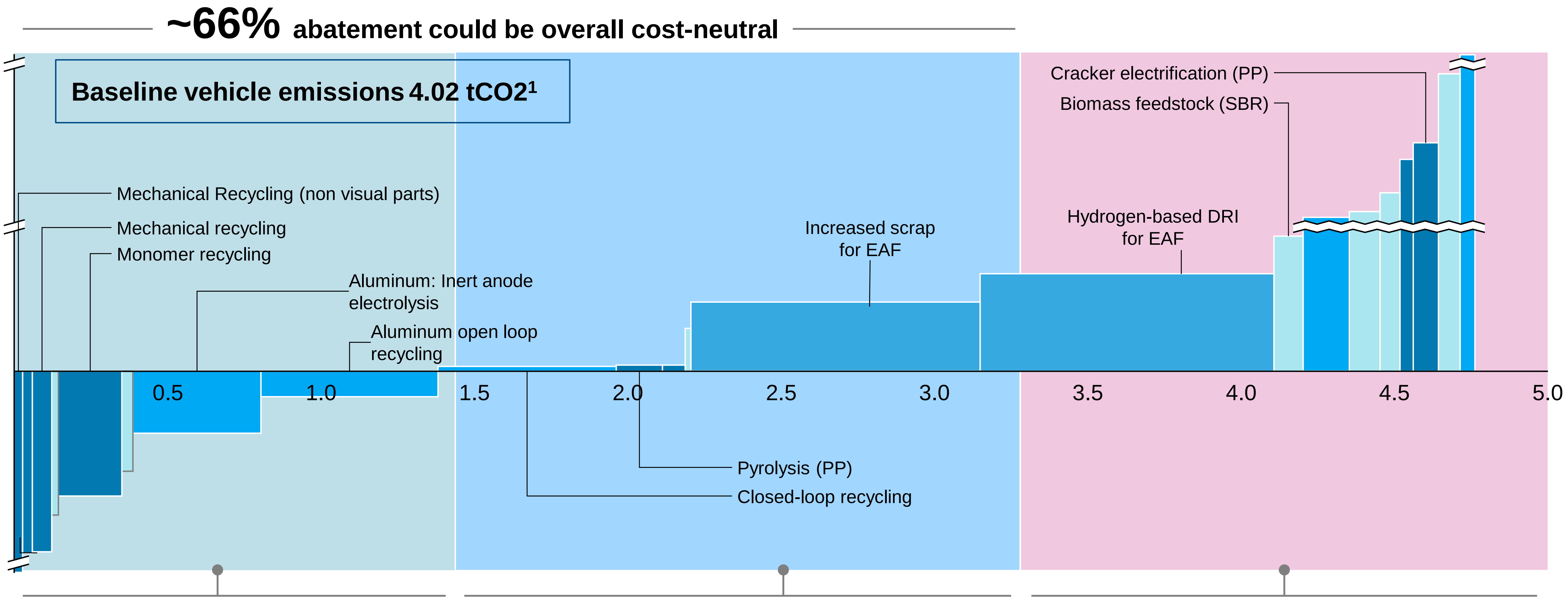
By 2030, 66% of a typical ICEVs materials emissions can be decarbonized at no additional cost

in USD/ tCO2 (2030)

Internal combustion engine vehicle (ICEV)[1]

Simplified materials split[2] 🟦 Metals 🟦 Plastics 🟦 Others

~66% **abatement could be overall cost-neutral**



~29% abatement (1.38 tCO2) **long-term cost-saving**

Additional **~37%** (1.76 tCO2) at additional cost but **still overall cost-saving**

~34% (1.61 tCO2) require **additional costs**

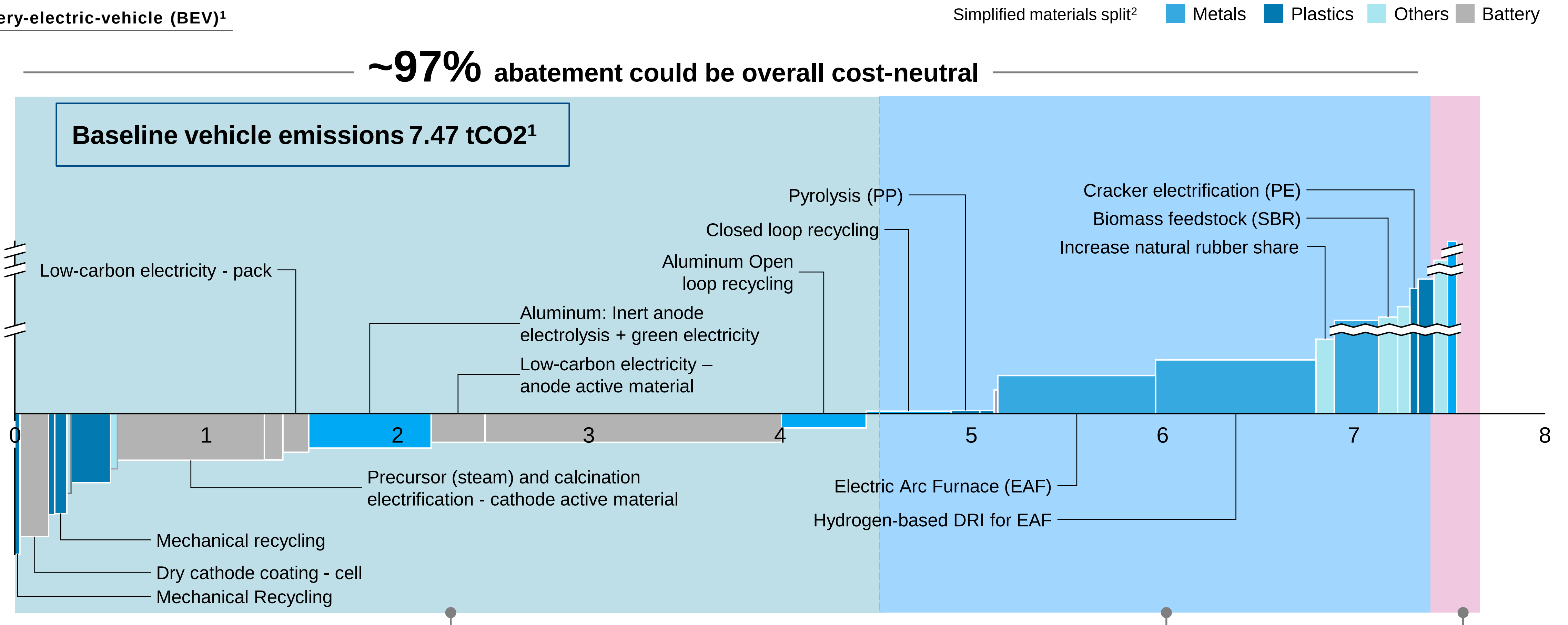
1. In this analysis, a premium C-segment vehicle with 1.95 t vehicle weight: 1.04 t steel; 0.29 t aluminum,0.10t Rubber, 0.07t PP, 0.03t PE, 0.05t Glass is considered
2. Metals including steel, high-strength steel, aluminum, alumina; Plastics including polypropylene, polyethylene, polyamide 6, Others including rubber, glass

Source: McKinsey Analysis (Team, McKinsey Decarbonization Pathways Optimizer)

By 2030, 97% of BEV material emissions could be abated at no net increase of material costs

in USD/ tCO2 (2030)

Battery-electric-vehicle (BEV)[1]



~59% abatement (4.4 tCO2)
long-term cost-saving

~38% abatement (2.9 tCO2)
possible staying overall **net cost-neutral**

~3% (0.12 tCO2)
with high additional costs

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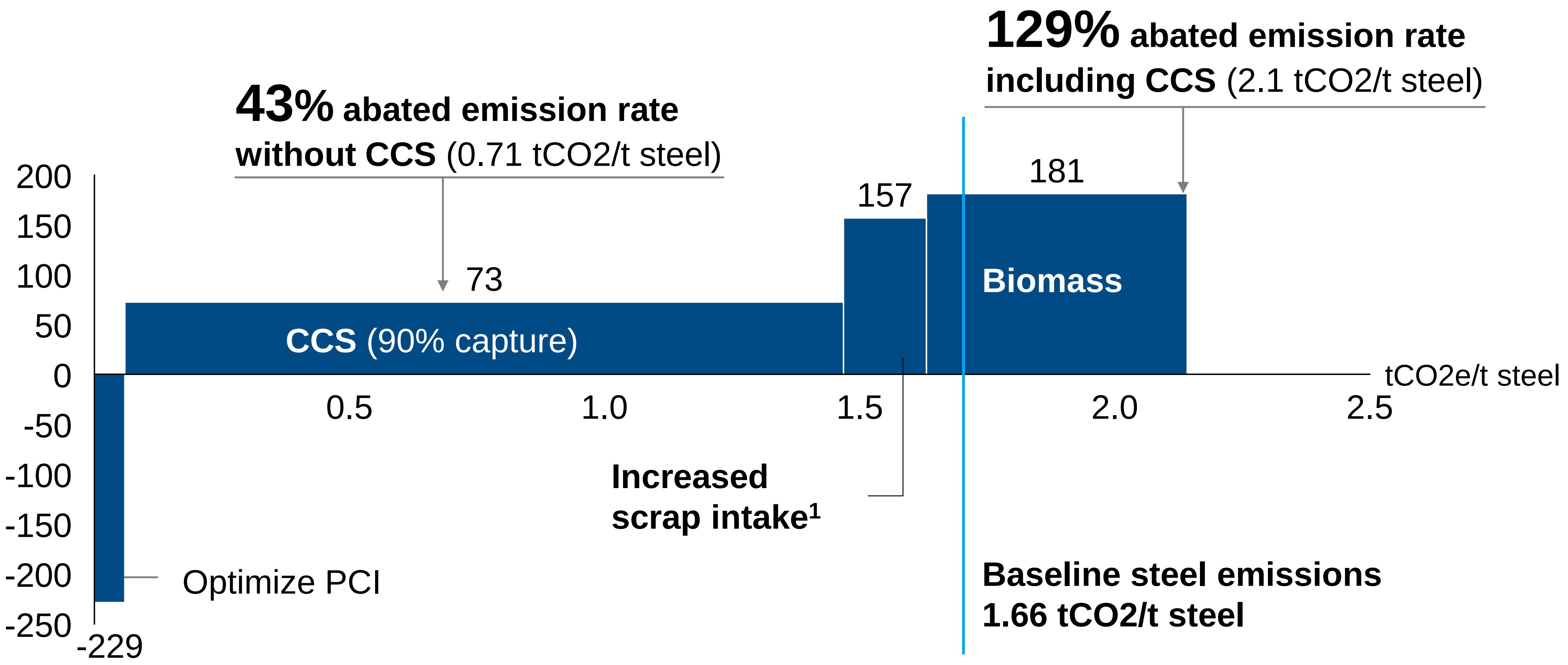
1. In this analysis, a premium C-segment vehicle with 1.95 t vehicle weight: 1.04 t steel; 0.29 t aluminum,0.10t Rubber, 0.07t PP, 0.03t PE, 0.05t Glass, and 92 kWh battery is considered
2. Metals including steel, high-strength steel, aluminum, alumina; Plastics including polypropylene, polyethylene, polyamide 6, Others including rubber, glass

Source: McKinsey Abatement Model Analysis

Emissions from steel production can be reduced through two main paths: low-carbon traditional steelmaking …

in USD/t CO2, Abatement cost vs. blast furnace (2030)



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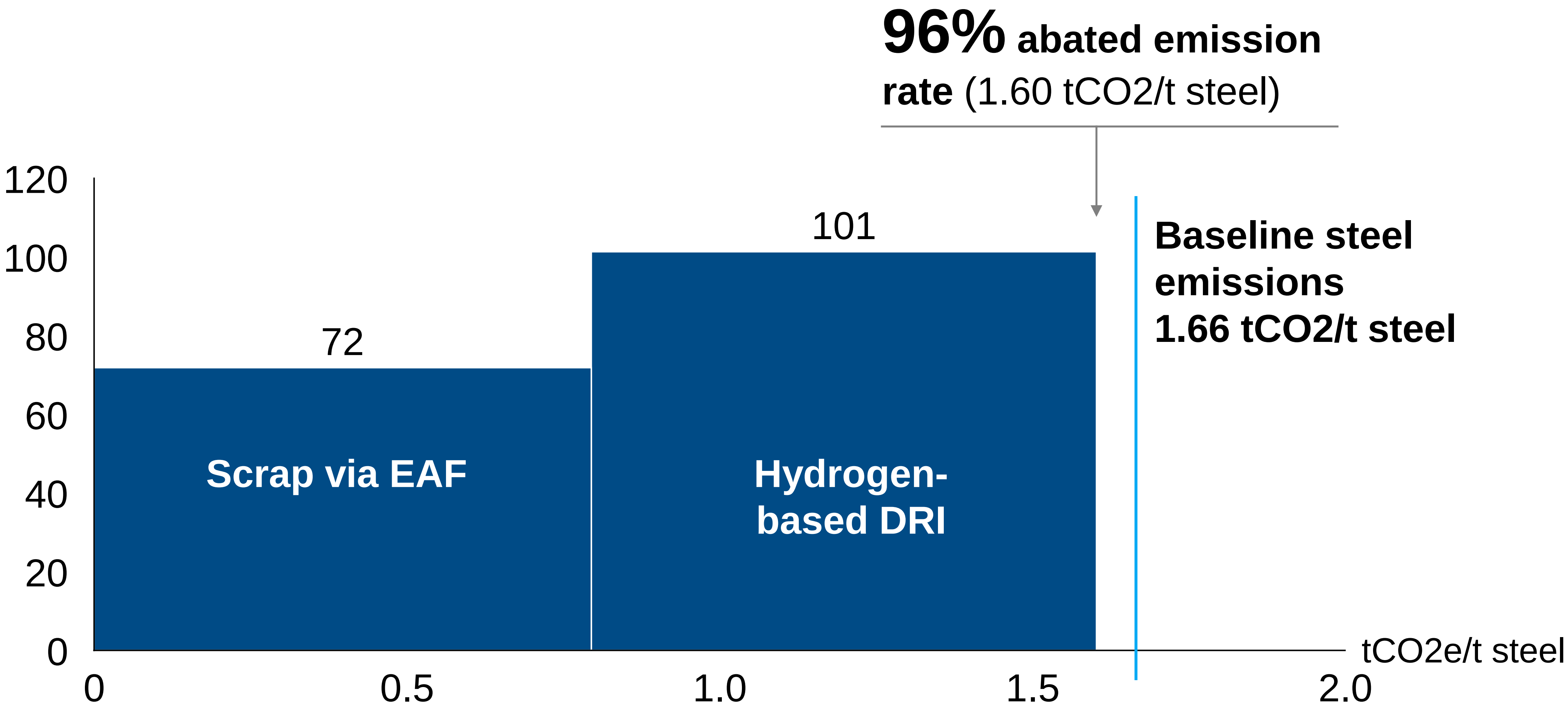
1. from average 12% to 30%

Source: McKinsey Analysis

… and hydrogen-based DRI-EAF steelmaking, which reduces emissions by 96% compared to current production processes

in USD/t CO2, Abatement cost vs. blast furnace (2030)[1]



96% **abated emission rate** (1.60 tCO2/t steel)

Baseline steel emissions 1.66 tCO2/t steel

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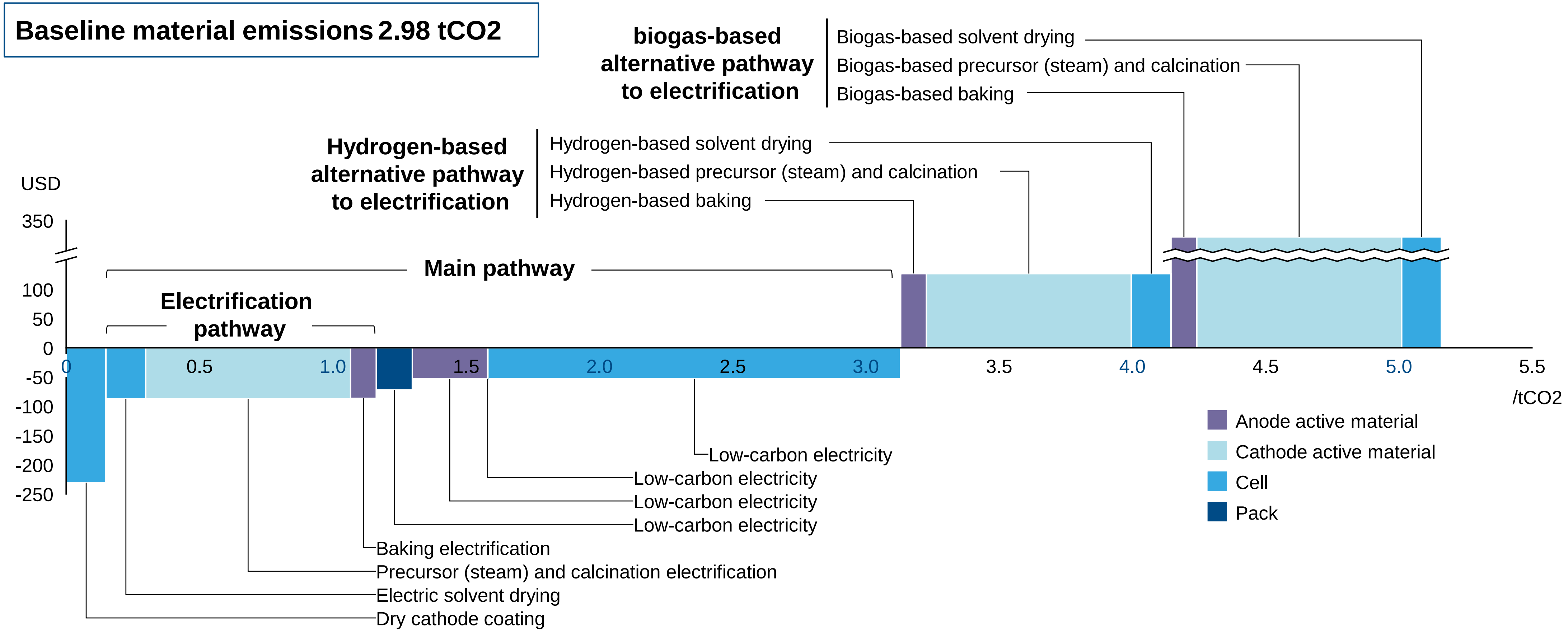
[1] Key assumptions: 50% from each production route; Sharp fall of green hydrogen price to 22 USD/GJ by 2030

Source: McKinsey Analysis

The main levers for decarbonizing battery production processes lie in the use of low-carbon electricity and electrification

Full battery abatement levers, in USD/ tCO2

Baseline material emissions 2.98 tCO2



Note:

1. In this analysis a 92kWh battery per vehicle is considered, only direct and indirect process emissions from fuels and electricity in the modelled production steps are included (mining or transport excluded);
2. Levers also dependent on location. EU-angle esp. on immerse battery manufacturing growth and advanced regulation

Source: McKinsey Analysis (Team, McKinsey Decarbonization Pathways Optimizer)

For manufacturers: A systemic collaboration model with three overarching strategies creates the right incentives for decarbonizing materials

	Levers of strategic advantage	Levers too too big for individual players alone	Levers outside direct control but led by other industries
	Lead	**Share**	**Engage**
	Be in the **driver's seat** and take **active role and investment** to take decarbonization lead in value chain	**Share knowledge** and collaborate to **coordinate decarbonization** of customers, suppliers, and value chain	**Engage with supply chain** and **create demand** for breakthrough technologies
Example Steel	**Secondary steel.** Use limited by specification and not cost Use opportunity to work with key suppliers to differentiate	**Closed loop recycling.** Limited by controlled access to high-quality volumes **H2-based DRI[1] and EAF[2].** Limited by development and ramp up time of H2 Use a shared strategy to orchestrate ecosystem and transition to DRI-EAF	**CCS.** Limited by capture rate, costs, and long-term environmental risks Use and engagement strategy to encourage others to embark on decarbonization pathway to implement new technologies

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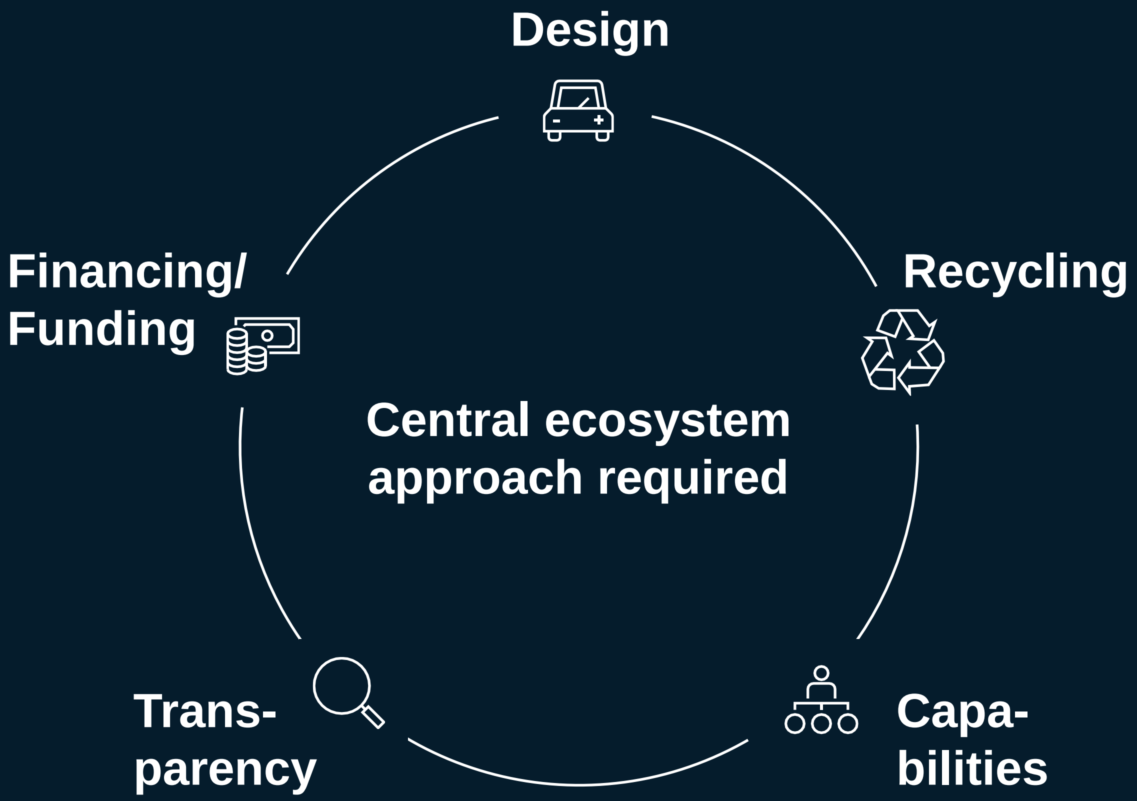
1. Direct reduced iron | 2. Electric arc furnace

5 key enablers for ecosystem materials decarbonization towards the zero-carbon car



Source: World Economic Forum – CCI – Cluster interviews and summer workshop

What action tracks could achieve

- Assist in promoting design for sustainability approaches and standards for circularity across manufacturers
- Coordinate material design approaches and build up of full recycling value chain to step change circularity levels
- Provide a platform to interact with key investors and 3rd parties required to unlock funding

  Have an industry-wide thought partner for regulators
- Promote common standards in accounting, labeling, reporting as well as target setting across the industry
- Promote knowledge sharing and capability building on decarbonization strategies across organizations