WORLD ECONOMIC FORUM

The Road Ahead:
A policy research agenda for automotive circularity

CIRCULAR CARS INITIATIVE
POLICY WORKSTREAM

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Cover: Getty Images

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Foreword

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The car has given us freedom. It has accelerated trade and made an indelible mark on modern culture and lifestyles. But cars are also responsible for ~10% of greenhouse gas emissions and a large share of global steel, aluminium, plastic, rubber, glass and increasingly battery material consumption. It is now time for a revolution in automotive sustainability.

The World Economic Forum and the World Business Council for Sustainable Development (WBCSD) jointly formed the Circular Cars Initiative to accelerate this transformation. The Initiative takes a systemic approach – accounting for the build phase as well as the use phase – to automotive sustainability. It looks at how technology and business levers can maximize the resource value of the car, minimize life-cycle emissions and unlock new opportunities.

Within the Circular Car Initiative, 40 companies from the automotive value chain, several research institutes, international organizations, governmental bodies and think tanks are charting the course towards a zero-emission future through new technology, materials innovation, efficient vehicle usage and full life-cycle management.

We wish to thank Accenture under the leadership of Wolfgang Machur and Alexander Holst, and McKinsey under the direction of Fehmi Yüksel and Eric Hannon, for their in-depth analysis and thought partnership on these topics. We are also appreciative of EIT Climate-KIC's Sira Saccani and Kirsten Dunlop, and SYSTEMIQ's Matthias Ballweg, Tillmann Vahle and Martin Stuchtey, for joining early on and for their ongoing work on policy recommendations.

We also would not have come to this point at the end of 2020 without the leadership of Levi Tillemann at the World Economic Forum.

The "circular car" is now on its way to becoming a core component of the automotive future.

Letter from the World Economic Forum

Levi Tillemann
Lead, Circular Cars Initiative,
World Economic Forum

A few short years ago the future of the electric car was highly uncertain. But the confluence of climate emergency and policy-driven innovation has now codified the future of automobility and it is electric. The world now has two light-duty vehicle fleets: an electric fleet that needs to be ramped up in the coming decades; and an internal combustion engine fleet that needs to be efficiently and environmentally scaled down. These electric vehicles (EVs) should dramatically reduce vehicle emissions, but the materials emissions and waste attributable to each EV will increase substantially (to 60% of life-cycle emissions by 2040) unless proactively addressed. The solution is for EVs to join the emerging "circular economy". The Circular Cars Initiative (CCI) includes a diverse community of car manufacturers, policy-makers, materials companies, fleet companies and others collaborating to optimize the use phase of light-duty vehicles and recapture embedded materials value at end of life.

Technology has expanded the potential pathways for doing so beyond electrification. Through mobility as a service, a car that 15 years ago would have been suitable for a single household, can now serve the mobility needs of dozens of people. Digitalization of communication, development of new technology platforms and convenient low-cost geolocation have resulted in the rise of a sharing economy. The prospect of the automobility industry shifting from selling goods to selling services, thus reducing its environmental burden, is very real. Materials decarbonization and closed-loop recycling can also shrink carbon emissions and resource footprints. And full life-cycle management of vehicles and emerging manufacturing paradigms can eliminate waste, extend vehicle life and cut the fat from physical processes and inventories.

The shift towards shared transport and urbanization will be affected by the COVID-19 pandemic in the short term, and the long-term effects are still unpredictable. But what will not change is the importance of decarbonization, electrification, dematerialization and circularity. These are secular, durable and investable trends with potentially profound positive societal implications.

CCI's mission is to achieve an automobility ecosystem aligned with a 1.5ºC climate scenario – no easy task. According to CCI analysis by McKinsey, usage accounts for roughly 80% of current life-cycle automotive GHG emissions while 20% of emissions come from materials and production. But this materials share is poised to grow to 60% by 2040. Both materials and use-phase emissions must be addressed, and there is broad consensus within the CCI community that policy will be a critical part of the solution. This policy research agenda takes stock of relevant policy tools, regulatory strategies and institutions that will likely play a critical role in CCI's future action agenda.

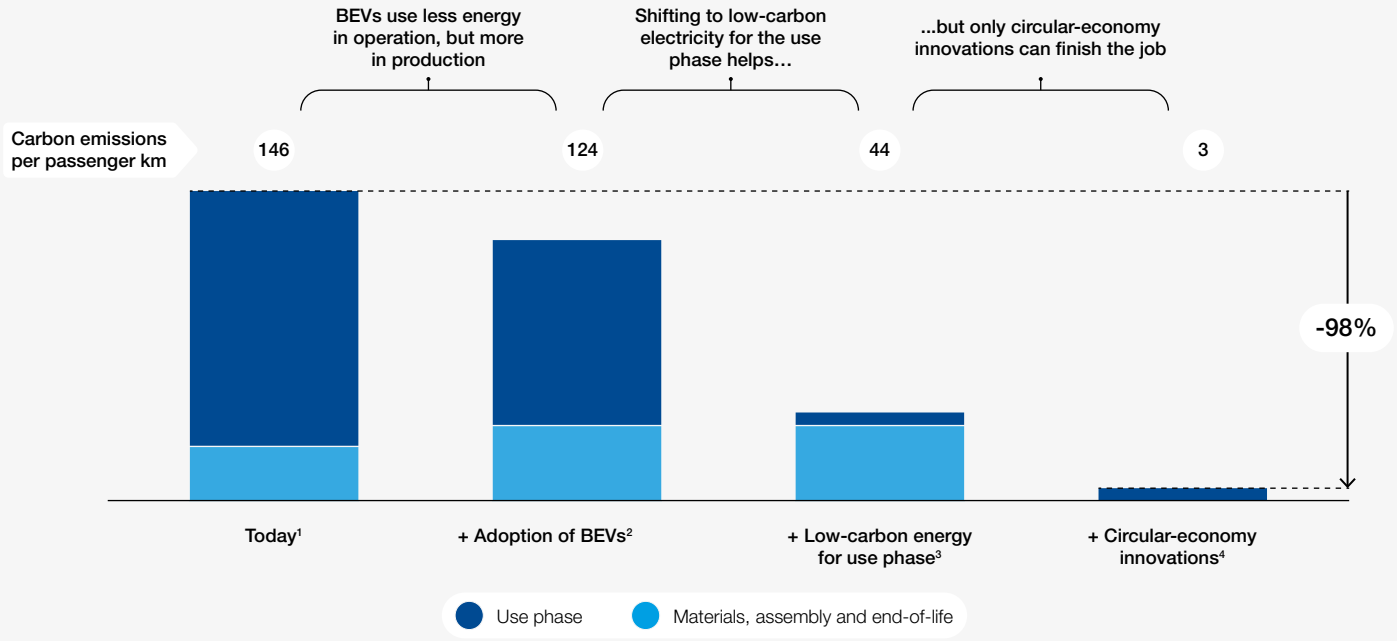
Introduction

Sustainable cars must be powered by green electricity – circular economy principles need to govern both manufacture and use phase.

The term "circular car" refers to a theoretical vehicle that has maximized materials efficiency. This notional vehicle would produce zero materials waste and zero pollution during manufacture, usage and disposal – which differentiates it from today's zero-emission vehicles. While cars may never be fully "circular", the automotive industry can significantly increase its degree of circularity. Doing so has the potential to deliver economic, societal and ecological dividends.

Indeed, the convergence of technology, environmental and economic megatrends is propelling the modern automotive industry towards just such a transformation. The Circular Cars Initiative has assembled a broad coalition of participants from the automobility ecosystem committed to leading this transformation and increasing the environmental sustainability of global mobility by harnessing the power of new technologies, materials and business models.

FIGURE 1 **Decarbonizing the car**



1. ICEV hatchback (level 1) with 1.70t weight (incl. repair components), 0.90t steel, 0.15t aluminium, 0.29t plastics, 200,000 life-cycle km and average occupancy of 1.5
2. BEV hatchback (level 1) with 1.90t weight (incl. repair components), 0.70t steel, 0.19t aluminium, 0.32t plastics, 0.32t EV battery, 250,000 life-cycle km and average occupancy of 1.5
3. Requires decarbonization of electricity grid with additional renewable energy as per consumption requirement by BEVs
4. Circular-economy innovations consider level 4 circular BEV (fully circular)

Source: Accenture Strategy analysis

The Circular Cars Initiative (CCI) is comprised of three main workstreams:

- The **materials workstream**, led by McKinsey, is focused on the pressing need to decarbonize materials, institute closed-loop recycling and provide materials with a productive second life – capturing value that today is downcycled into other industries (see Figure 2).
- The **business models workstream** is led by Accenture Strategy. Its work lays out a series of strategies for achieving circularity. In collaboration with the World Economic Forum, Accenture Strategy has developed a taxonomy to guide the industry's progress on carbon and resource efficiency. The goal is to maximize the mobility output achieved per unit of resources and emissions expended (see Figure 3).

The taxonomy addresses usage, vehicle lifetime, materials and energy-related aspects of circular business models.

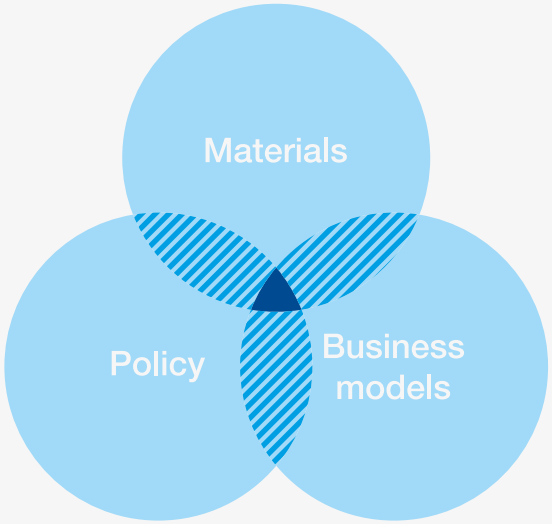
– Finally, the **policy workstream** is under development. It will connect the dots of this ecosystem and address the relevant policy tools to be taken onboard by governments globally.

Each of these workstreams has been supported by our diverse community of stakeholder organizations, including carmakers, materials suppliers, national research institutes, non-governmental organizations (NGOs) and academic institutions. They have contributed their insights through workshops and many dozens of interviews, as well as data and feedback on this multifaceted analytical process. In addition to our analytical partners McKinsey and Accenture, CCI would also like to recognize the valuable support and contributions of our CCI co-founders at the World Business Council for Sustainable Development (WBCSD), EIT Climate-KIC and SYSTEMIQ.

FIGURE 2 **The Circular Cars Initiative (CCI): organizational structure and 2020 deliverables**

CCI deliverables for 2020 include

- A five-level taxonomy for automotive circularity
- A materials transition tool to delineate pathways for material decarbonization in the sector
- Roadmaps (materials, policy and business models) outlining critical investments, milestones and policy-drivers for circularity
- Approach to start circularity-focused pilot projects among member companies



1 A policy research agenda for automotive decarbonization

Many of the technological tools needed to fully decarbonize the automobility system are available today. But most will rely on policy support if they are to inspire swift transformation across this sprawling industry.

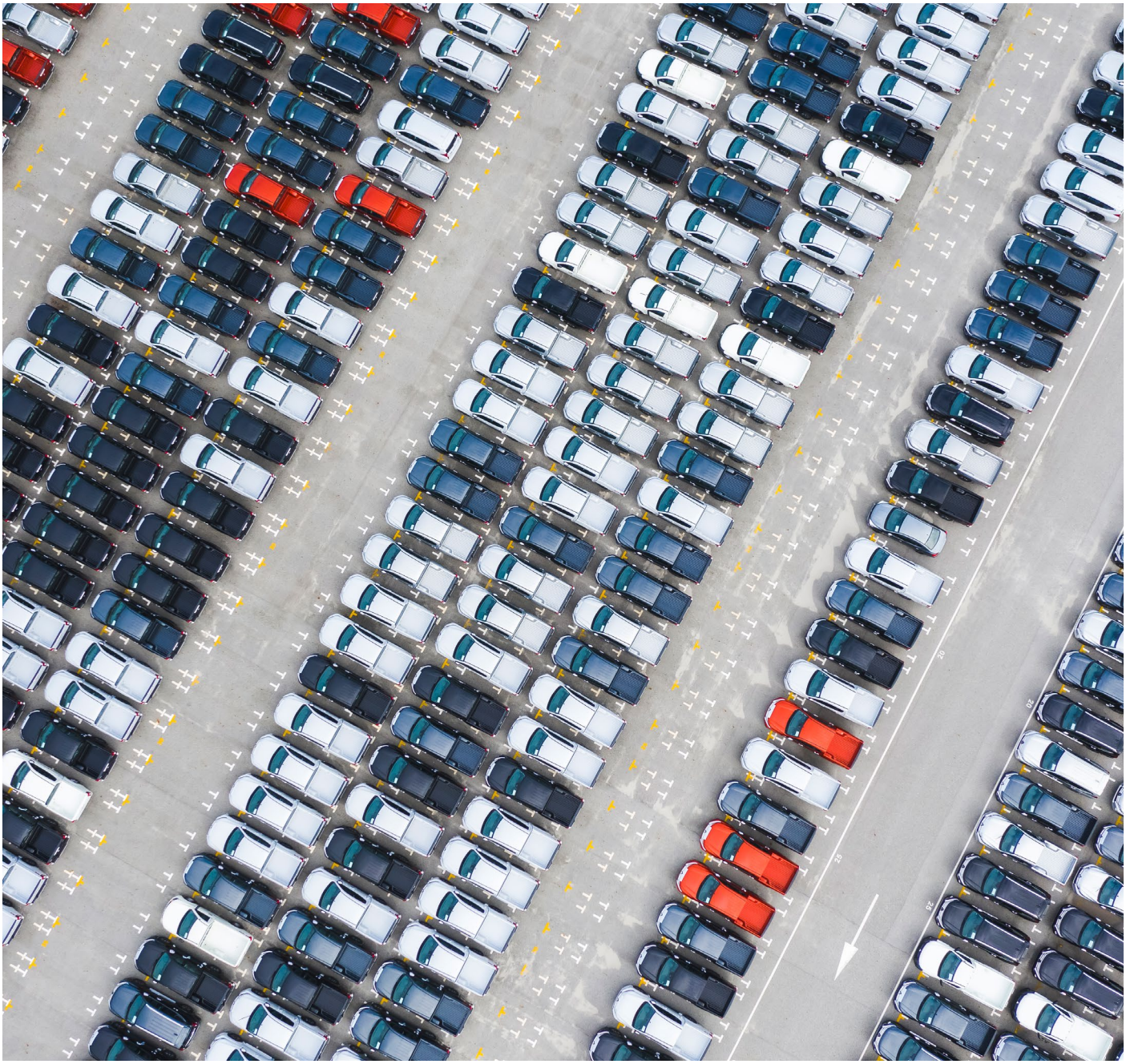
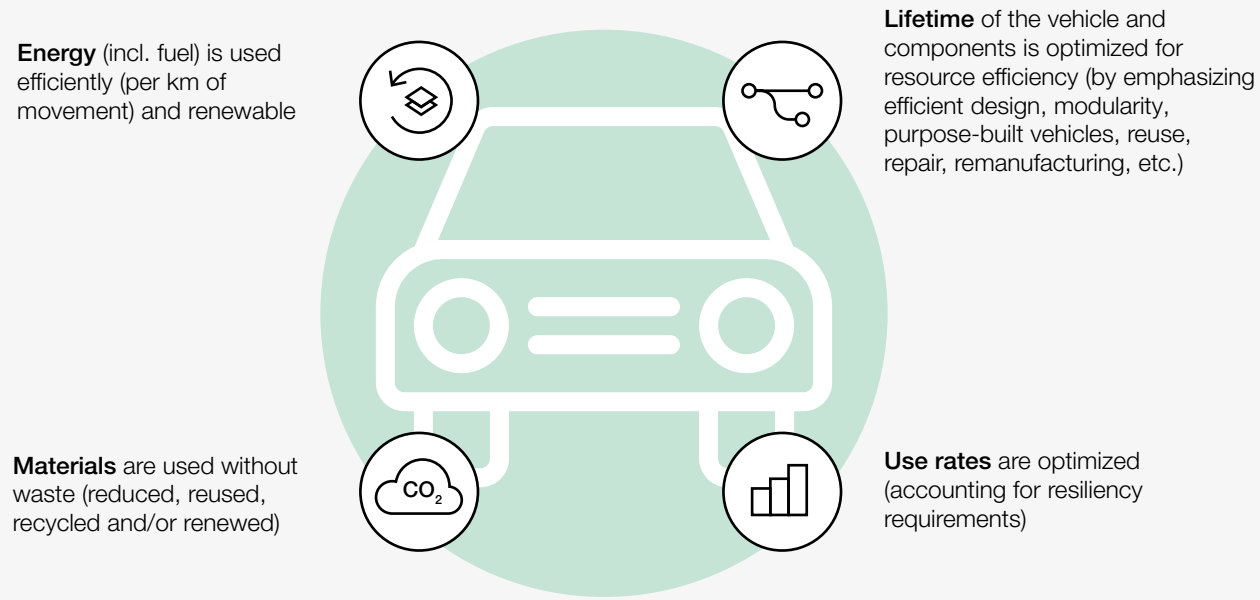


FIGURE 3 | **Definition and elements of a circular car**

A circular car maximizes the value from resource consumption



> [Today] low-carbon commodities and services are largely undifferentiated from carbon-intensive commodities and services.

Some of the most challenging aspects of building a circular automobility system result from the fact that low-carbon commodities and services are largely undifferentiated from carbon-intensive commodities and services.

This document lays out key questions to address in order to advance circularity in the months and years to come. It is informed by hundreds of hours of interviews and analysis from the Circular Cars Initiative community. The CCI has developed two detailed roadmaps as guides to decarbonizing materials production and business models (including mobility-as-a-service, or MaaS). The McKinsey materials carbon abatement cost curve offers a technoeconomic assessment of specific pathways towards materials decarbonization, while Accenture's circularity taxonomy provides a holistic framework that describes the steps necessary to achieve automotive circularity up to 2050. This analysis must be placed within a policy context if the automotive industry is to reduce its emissions by 50% by 2030 and align with goals set in the Paris Agreement.

At a high level, the research questions posed in this document can be grouped into the following categories: adapting existing policy tools to circularity; optimizing materials efficiency and energy consumption through mobility-as-a-service; building capacity for circular materials production; and institutions and institutional characteristics necessary for supporting sustainable markets for circular cars and services.

2 Adapting existing policy tools to circularity

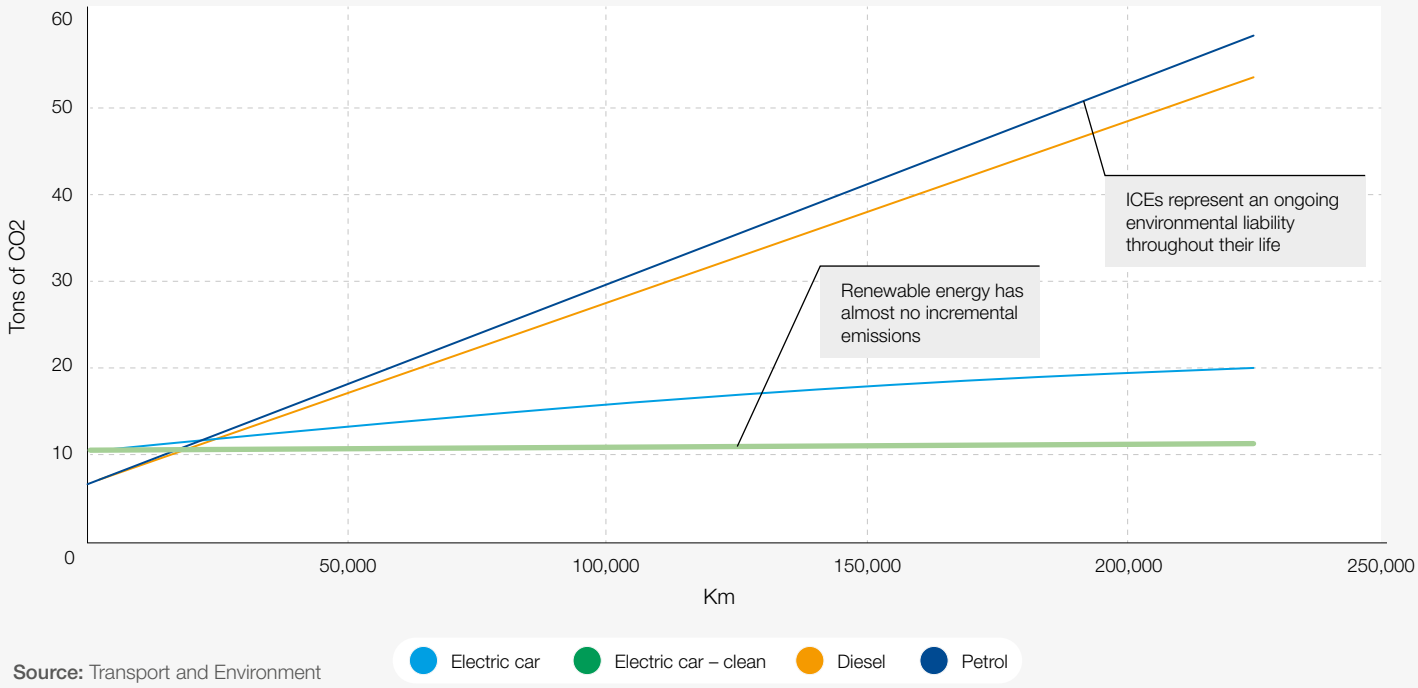
Policy-making for circular cars should draw upon existing policy tools from the renewables, mobility and EV sectors.

“ Pooling helps decarbonize both use-phase and automotive materials (by increasing passenger kilometres per unit of fuel and material).

A wide variety of policy tools have been successfully implemented in China, Europe, the US and other economies to encourage the transition to clean energy and from internal combustion engine (ICE) vehicles to electric vehicles (EVs) and clean mobility – particularly in dense urban environments. The push for circular cars can potentially draw upon learnings from these existing policies. Some of the successes of these policies include: increasing investment in the clean energy sectors as well as achieving scale and reduced unit cost for clean energy technologies. Some relevant areas of inquiry include:

- **How can urban policies successfully used to promote electrification be broadened to promote circularity?** From a decarbonization standpoint, it makes sense to provide incentives not only for electrification but also for pooled mobility in order to reduce use-phase inefficiencies. Pooling helps decarbonize both the use-phase and automotive materials emissions (by increasing passenger kilometres per unit of fuel and material). Pooling also diffuses the additional cost of decarbonizing materials by spreading the cost of each vehicle over an increased number of users and changing design incentives for manufacturers (see *Raising Ambitions: A new roadmap for the automotive circular economy*, Figure 5). EV and clean air policies already implemented in Europe, China and California can also be applied to MaaS going forward. Many of these tools have been well catalogued elsewhere (see the Shared, Electric and Automated Mobility Governance Framework by the Global New Mobility Coalition). These include:
  - Preferential access to premium urban locations and high-priority geographies. In *low- and zero-emission areas* only vehicles achieving certain per-vehicle or per-rider emission levels are allowed into city streets, city centres or other desirable parts (zones) of the city; as of 2019 there were more than 300 low-emission zones in Europe, with a number of major urban centres (e.g. London) instituting zero-emission and pedestrian-only zones.[1] Strategies for achieving decarbonization of mobility in cities through adjusted pricing and access to roads, parking and street space include:
  - *Preferential lane access.* Chinese cities including Shenzhen and Shanghai, the State of California and some European countries and cities have made aggressive use of existing high-occupancy lanes to encourage the use of electric cars and shared-rides (sometimes at a cost to pooled mobility).[2]
  - *Preferential parking locations and fee structures* for MaaS and EVs, or increased parking fees for non-MaaS and non-electric vehicles.[3]
  - *Road-pricing that preferences MaaS and EVs.* In London, where road pricing was implemented in 2003, traffic decreased by 15% and travel time decreased by 30%. More cities, including in the US, are currently considering the introduction of road-pricing policies.[4]
- **How can national policies successfully used to promote electrification be broadened to promote circularity in the use phase?**
  - *Subsidies and taxes.* Beginning in the 1990s, Germany's renewable energy feed-in tariffs paid a premium for every kilowatt hour of renewable electricity delivered to the grid.[5] A feed-in tariff for electric passenger kilometres travelled (which encourages both electrification and pooling) should be examined. Other direct tax incentives and subsidies for MaaS and circular vehicles should also be considered.
  - *Registration rights.* In China, ICE vehicle registrations are both costly and restricted. In cities including Shanghai, Beijing, Shenzhen, Tianjin and Hangzhou, EV registrations are unlimited and sometimes free.[6]
  - *Per-ride sustainability performance reporting* to enable users to make better-informed mobility choices.

FIGURE 4 | **Extending the life of EVs is a climate win: EVs have higher upfront emissions, but with clean electricity they have extremely low use-phase emissions**



Source: Transport and Environment

A feed-in tariff for electric passenger kilometres travelled (which encourages both electrification and pooling) and other incentives for fleet-based vehicle on-demand services should be examined.

- **What are the proper incentive structures to increase EV lifespan? How should end-of-life processing fees be differentially applied to both ICEs and EVs?** Early retirement of ICEs should be encouraged, whereas life extension for EVs should be a major policy focus so as to maximize the use-life of carbon-intensive vehicles. High upfront manufacturing emissions from EVs are environmentally problematic. However, once built, an EV running on clean electricity produces very low emissions. Policy should create incentives to keep these vehicles on the road.

- **In what contexts can hybridized regulatory and economic policy tools (synthetic markets) be effectively applied?**[7] "Synthetic markets" or regulatory credit markets have been used to transfer funds between market participants based on their willingness to fulfil regulations (e.g. fuel economy).

  - For instance, "cap and trade" where a progressively decreasing number of "credits" for some undesirable output (e.g. carbon dioxide) is sold or distributed. Those credits can then be bought and sold between participants. This ensures that the most economical abatement options are sought out by market participants (e.g. Corporate Average Fuel Economy [CAFE] credits adopted in the US and China). Similar mechanisms could be applied to commodities ranging from steel to plastics. These could target emissions or virgin resource consumption.

  - Another example of a synthetic market comes from the State of California, where regulators flipped the system on its head and required an escalating percentage of vehicles sold in the state to eliminate exhaust emissions. They awarded credits to makers that sold these vehicles and allowed these credits to be bought and sold – requiring each producer to secure credits proportional to their annual vehicle sales. The system not only propelled the growth of EV manufacturers (e.g. Tesla)[8] but was also expanded to ten more states, which adopted the policy and enlarged the trading market.[9]

Why fleets?

Not only do fleets allow for multiple users of a single vehicle (including concepts such as "breathing fleets" where use case for a vehicle changes over the course of a day), fleet managers are easier to influence via policy measures. Intensive usage by a fleet means more electric miles driven, sooner, and faster vehicle stock turnover than with an equivalent number of privately owned vehicles (in the US the average private car is driven ~11,400 miles per year, while the average fleet vehicle is driven almost 30,000 miles per year). All of this is a big win from the standpoint of circularity.

Source: US Department of Energy Alternative Fuels Data Center: Feasibility Analysis of Taxi Fleet Electrification Using 4.9 Million Miles of Real-World Driving Data

3 Optimizing materials efficiency and energy consumption through mobility-as-a-service

Fleets and mobility-as-a-service are foundational enablers for circularity.

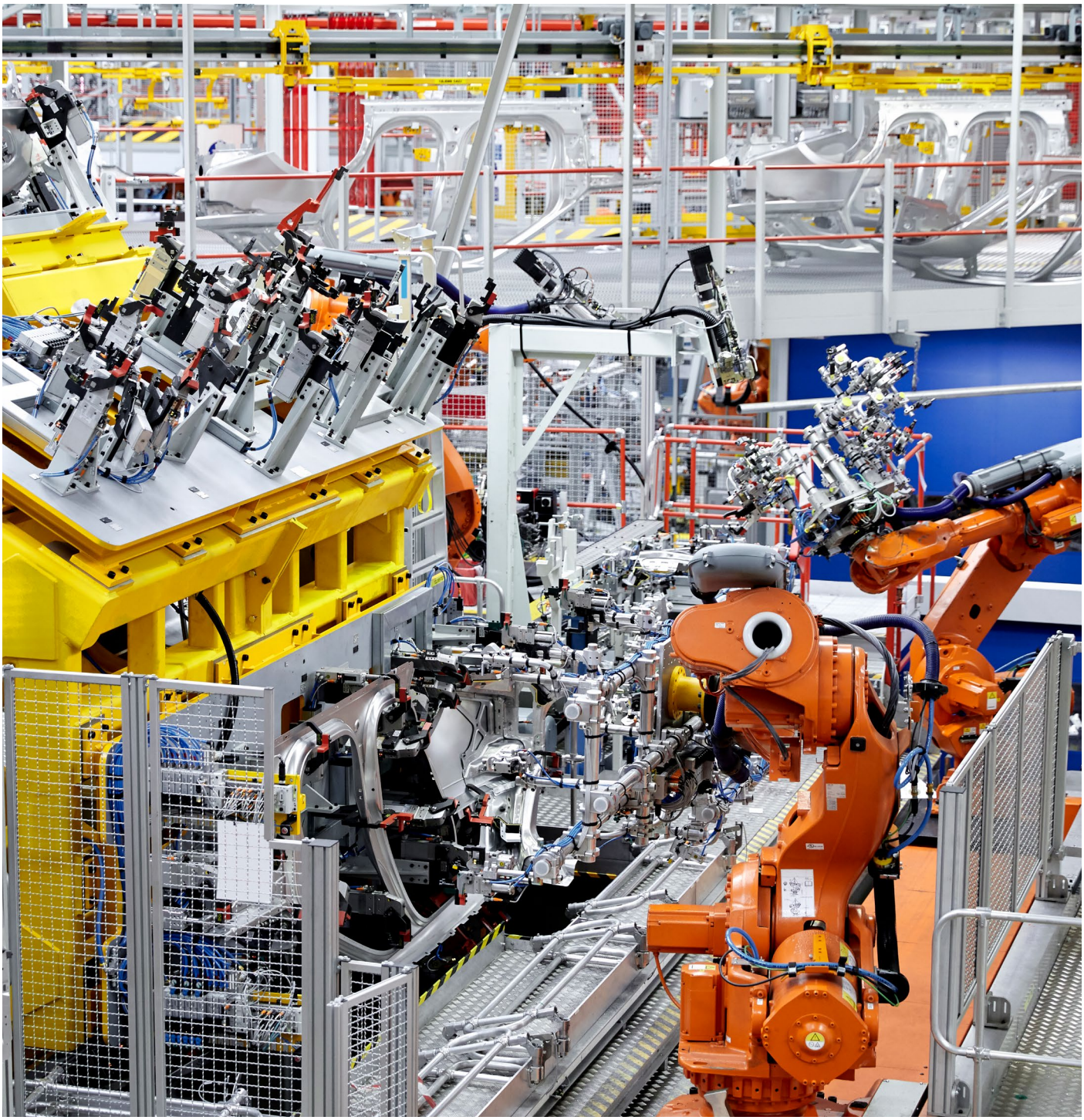
A feed-in tariff-type subsidy for electrical passenger miles would encourage both electrification and pooling by incentivizing MaaS vehicles to go electric and padding margins for multi-rider trips.

Part of this transformation will involve recalibrating the competitive landscape between mobility-as-a-service (MaaS)-related business models and traditional business models (which are built around today's paradigm of personal vehicle ownership). On a theoretical level, mobility-as-a-service has the potential to dramatically reduce emissions through both optimizing the use phase and reducing the total number of vehicles necessary to service a given level of demand. It will be important to understand realistic expectations of the contribution mobility-as-a-service can make to decarbonization. Policy research is urgently needed as a basis for action on the following questions and areas of concern.

- **In practice, to what extent can increased capacity factors facilitate decarbonization?** Other factors being equal, it is possible to achieve significant decarbonization through increasing the capacity factors (proportion of seats filled) over the automotive fleet. While the theoretical gains are impressive, the practical goals for decarbonization through increased capacity factors need to be better understood. For instance, a recent study by the Union of Concerned Scientists found that today's ride share actually currently increases emissions by 70% on a passenger basis.[10] It is important to note that today's ride share system is still nascent and can be shaped by policy in order to optimize environmental outcomes.
- **How can MaaS spread the increased cost and carbon footprint of circular cars and EVs (respectively) over more riders?** Compared to private ownership, increased utilization through MaaS could help defray the increased materials costs and carbon emissions associated with circularity and battery production.[11]
- **How can "as-a-service" mobility reduce overall demand without decreasing quality of service?** Rather than paying for insurance, parking or mobility in a lump sum (by buying a car) and then consuming without limit, products and services can be paid for incrementally (e.g. car insurance, battery use or vehicle cost), potentially providing a market signal to consume less.
- **Are current tax regimes incentivizing emissions?** Today professional commuters in the US are provided with a "mileage allowance". In the US, the standard tax deduction for use is 58 cents per mile.[12] Reducing/eliminating use-phase tax incentives for ICE vehicles (e.g. tax write-offs for ICE mileage) could help eliminate incentives. Instituting subsidies for electric miles could play a role in incentivizing the shift towards electromobility and MaaS.

4 Building capacity for circular materials production

Policy support will be critical to decarbonizing automotive materials. Batteries, aluminium and steel are priorities.



Building a sustainable ecosystem for circular materials will require investment in a clean materials supply chain, building market demand for these materials and designing vehicles so that their materials can be easily disassembled, sorted and reused at end of life. According to analysis from the McKinsey automotive marginal abatement cost curve model, more than three-quarters of emissions will come from batteries, aluminium and steel (BAS materials). Many abatement options should be economical by 2030, but others (e.g. hydrogen-based steel production) will cost significantly more than current production methods in the absence of a carbon tax.

4.1 Batteries

Three-quarters of emissions will come from batteries, aluminium and steel (BAS materials). Many abatement options should be economical by 2030.

Electromobility will be responsible for roughly 90% of battery demand in 2030[13] and roughly 50% of automotive manufacturing emissions will be attributable to batteries.[14] So battery decarbonization is an urgent challenge. BEVs are also expected to reach point-of-sale cost parity with ICE vehicles by 2025, and new battery plants are being built at a rapid pace to support this emergent demand. The goal of policy-makers should be to significantly address battery-related carbon emissions before production surges (see *Forging Ahead: A materials roadmap for the zero-carbon car* for details). In light of the high carbon footprint of BEVs, maximizing the usage of every automotive battery produced is a priority. Critical policy considerations include:

- **How to maximally extend the life of EV batteries (see Figure 4)?** Policymakers should seek avenues to extend the life of EV batteries both on and off the road. Incentives for modular design, "right to repair" and end-of-life processing requirements will be part of this process. The utility of certain policies (e.g. extended warranties in the State of California) should be examined, while taking into account second-life applications.
- **How to best reduce the number of kilowatts per passenger kilometre travelled?** Reducing the total quantity of batteries required per passenger kilometre travelled will yield direct reductions in cost and carbon emissions. Pooled mobility-as-a-service potentially allows for more passenger kilometres to be provided by the same battery. Another and potentially synergistic route is rapid battery swap refuelling, which facilitates fleet EV deployment by reducing downtime for fleet vehicles. Battery swap also allows battery packs to be matched for duty cycle – allowing shorter-range batteries to be used for local transport and longer-range batteries to be reserved for extended trips – potentially reducing the total number of batteries required in the system despite the requirement for external battery banks. In general, technology and business models that address the lack of dedicated parking and charging infrastructure in cities and the storage challenges associated with massive renewable energy deployment should be investigated.
- **What requirements should be placed on batteries to facilitate second-life use and end-of-life recycling?** Currently, regulations surrounding second-life use for EV batteries and end-of-life recycling requirements are embryonic in many markets. As the industry builds scale it will be critical to ensure that standardized best practices be applied in both these spaces. However, overly prescriptive policies may have the unintended consequence of hindering innovation.
- **What is the pathway to a self-sustaining end-of-life recycling regime for batteries?** It is highly likely that battery recycling will require financial support until both technology and scale improve. The ultimate requirements for profitable recycling and necessary support for the recycling industry should be investigated.

4.2 Aluminium

The carbon intensity of aluminium production can range from "as little as 1t CO2e/t Al [1 ton of CO2 per ton of aluminium] of recycled aluminium… and up to 20t CO2e/t Al [20 tons of CO2 per ton of aluminium] for less modern technology powered by coal-based electricity".[15] The carbon intensity of electricity used to make aluminium is a critical factor in the material's overall carbon intensity. Therefore, economies with a heavy reliance on coal (e.g. China and India) are at a disadvantage for decarbonization of aluminium production. Another key factor is the quality of the material feedstock. Aluminium produced with current technology from recycled content can have a roughly 95% lower carbon footprint than production from low-quality virgin bauxite (the major feedstock for aluminium production) found in places such as China. (Today China accounts for roughly 60% of global aluminium production.[16]) A final source of emissions comes from the production

process itself. Most aluminium is produced in electric furnaces using carbon anodes. In standard aluminium production, roughly 400 kilograms of carbon-based anodes are consumed for every ton of aluminium produced. This carbon binds to the oxygen released by the bauxite feedstock, creating CO2. A potential solution to these emissions is the use of "inert anodes" that do not release carbon and have the potential essentially to eliminate CO2 production from the smelting process.[17]

Some policy questions that will need to be addressed include:

- **What critical capital and R&D investments need to be subsidized and on what timeline to decarbonize aluminium in line with a 1.5ºC climate scenario (e.g. inert anodes)?**
- **How can standards, quotas or government purchase requirements for green aluminium be used to create markets and support capital investments?**
- **What domestic, regional or multilateral regulations can be used to encourage international suppliers to invest in low-carbon steel (e.g. carbon tariffs)?**
- **What design and end-of-life specifications will be required to allow car manufacturers to achieve "same-level" collection and recycling (as opposed to downcycling)?**

4.3 Steel

The most complete decarbonization pathways for steel involve either advanced carbon capture and sequestration, or a combination of substituting hydrogen for coking coal and using electric arc furnaces powered with clean electricity for finishing (see *Forging Ahead: A materials roadmap for the zero-carbon car*).[18] Iron and steel are the largest source of materials emissions in the global economy today. Decarbonization of steel and iron is complicated by the fact that more than 60% of global steel production takes place in China – where the energy mix is heavily biased towards coal.

Increased scrap recovery and higher-quality, more efficient recycling will play a critical role in decarbonization.[19] Massive supplies of clean electricity will be critical for many industrial processes – including the production of green hydrogen. Policy questions related to steel decarbonization include:

- **What are the critical capital investments and research and development (R&D) elements necessary to deploy low-carbon steel technologies (e.g. production of green hydrogen) and on what timeline?**
- **How can standards, quotas or government purchase requirements for green steel be used to create a market and support capital investments?**
- **What domestic, regional or multilateral regulations can be deployed to encourage international suppliers to invest in low-carbon steel (e.g. carbon tariffs)?**
- **What design and end-of-life specifications will be required to allow car manufacturers to achieve "same level" collection and recycling?**

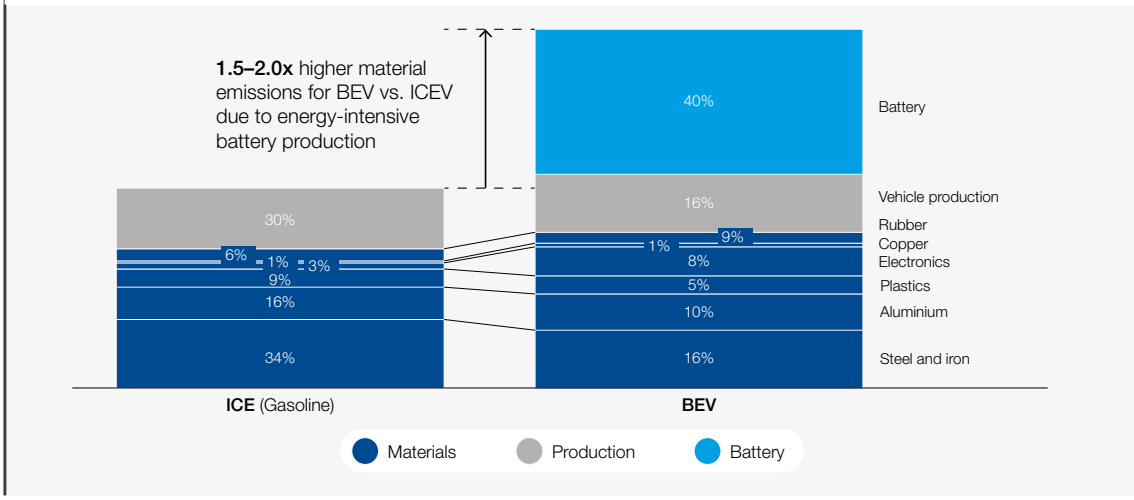
4.4 Overarching research questions on materials decarbonization

> Reducing the diversity of materials used to build cars could simplify end-of-life sorting and lay the groundwork for high-grade recycling.

In addition to the industry-specific questions above, there are more generalized design and capacity issues that will need to be addressed to promote materials circularity. These include:

- **How can end-of-life disposal responsibility for producers or initial buyers be used to promote circularity?** What can we learn from current models of end-of-life producer responsibility (e.g. glass bottle deposit return schemes, oil well reclamation and nuclear waste management and reprocessing)?
- **How can modular construction be encouraged?** Done properly, modular construction has the potential to lead to standardized repair criteria and easy life extension for EVs. However, asserting uniform regulations with regard to modular construction will be challenging and fraught.
- **What are the critical regulatory requirements regarding design for disassembly?** Today, disassembly is generally not taken into account when designing vehicles. The shift to EVs can lay the foundations for simplified construction techniques that are material-efficient, low-carbon and facilitate closed-loop manufacturing processes.
- **Is it possible to build scale in end-of-life commodities markets by reducing the complexity of various alloys and grades of plastic, aluminium and steel used in vehicles?** Today, much of the steel recycled from cars ends up being downcycled to lower-quality applications. Reducing the diversity of materials used to build cars could simplify end-of-life sorting and lay the groundwork for high-grade recycling.
- **From an emissions perspective, how big an opportunity is remanufacturing?** Theoretically, remanufacturing (e.g. retreading tyres) is superior to recycling. But how significant is the actual opportunity? Can the opportunity be expanded through applying best practices at the design phase?
- **What data standards and regimes are necessary to trace material origins and facilitate reliable end-of-life sorting?**
- **How can the supply of clean industrial precursors (particularly electricity and hydrogen) be accelerated?** Clean electricity and hydrogen will be critical in eliminating both use-phase and industrial emissions. They have cascading life-cycle benefits.
- **What role can taxes and fees (e.g. $/tons CO2) play in disincentivizing production of emissions-intensive materials and products?** While market price signals are traditionally viewed as an efficient means of reallocating resources within an industry, the speed of the transition required to decarbonize automobility might require taxes and fees that are prohibitively high.[20]
- **Where should new regulatory standards be applied to decarbonize materials?** Requiring that a product achieve certain baseline performance requirements (e.g. fuel economy) is a broad but blunt policy strategy. Such standards are effective but can be expensive to implement.[21] Further, the automotive industry exists within an industrial context. It accounts for less than 25% of aluminium and steel output. The merits of directly regulating upstream materials industries should be examined.

FIGURE 5 **Materials emissions**



5 Critical institutions and institutional characteristics

Well-designed institutions support successful policy implementation.

In building policy frameworks for circularity, it is also important to consider implementing institutions and their specific characteristics, strengths and restrictions. For instance, frameworks should emphasize outcome-focused flexibility – instead of textual legalism. The European Commission's DG MOVE and DG GROW, Japan's Ministry of Economy, Trade and Industry, China's Ministry of Industry and Information Technology and California's Air Resources Board are good examples of mission-focused organizations with the flexibility to adapt policies to changing circumstances. These bodies are empowered to adjust implementation of industrial policy in order to ensure policies are achieving the desired outcomes and not being gamed by market participants.[22] For instance, in the case of California's Air Resources Board, regulations regarding EVs are regularly re-examined and data is gathered from a wide range of industry-relevant organizations, including actors as diverse as original equipment manufacturers (OEMs) and clean-air advocacy groups, to ensure that policy tools are functioning effectively, not imposing unnecessary economic burdens and not being gamed. It is critical that institutions avoid both regulatory capture and politicization.[23]

One essential element of laying the groundwork for full decarbonization of the car industry will be for key regulatory actors to study existing policies and authorities and how they can be applied to circularity.

5.1 The European Commission

> The overarching goal of the Green Deal is for Europe to reach carbon neutrality by 2050 – which it is estimated will cost roughly $260 billion annually.

- **What role should the various European Commission directorates play in promoting circularity?** Coordinating the actions of bodies such as the Directorate-General for Mobility and Transport (DG MOVE) and the Directorate-General for Growth, Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) will be critical to implementing circularity policies that combine both materials and use-phase aspects of circularity.

- **How can considerations of automotive circularity be integrated into the EU's Green Deal?** The European Union (EU) is currently in the process of designing and defining a complex series of policy directives aimed at increasing sustainability under the umbrella framework of the "Green Deal". The overarching goal of the Green Deal is for Europe to reach carbon neutrality by 2050 – which it is estimated will cost roughly $260 billion annually.[24] Transport accounts for about 25% of European emissions and the Green Deal targets a 90% reduction in emissions by 2050.[25] Automotive circularity has been addressed, as part of the Green Deal, through the new Circular Economy Action Plan and the Sustainable and Smart Mobility Strategy. A circular economy is positioned as a key driver of sustainable transport modes, with a focus on end-of-life vehicles and batteries. Research and innovation in circular products and services for mobility will be supported by the European Commission in the coming years. The scope of the approach and implementation strategy still require further refinement.

- **What are the key EU directives from the standpoint of automotive circularity and how can their planning efforts be integrated?** Currently, the EU is in the process of reviewing its Battery Directive and a number of other relevant directives. The End of Life Vehicle Directive, a key piece of policy, will govern disposal of EV batteries as well as the European Union's 258 million registered vehicles (2016 numbers). New and revised regulations should consider a strong focus on accelerating the retirement of existing ICE vehicles and implementing a new regulatory system for EVs that will both promote their deployment and use.

5.2 China

- **What are the key policy-making bodies that promote circularity?** China's aggressive electrification standards are primarily overseen by the Ministry of Industry and Information Technology (MIIT). These are in part an effort to curb air pollution and GHG emissions, but they are also aimed at reducing oil imports and increasing industrial competitiveness internationally. China's National Development and Reform Commission, Ministry of Science and Technology, Ministry of Ecology and Environment, local governments and perhaps public-private partnerships such as EV100 may also play an important role.

FIGURE 6 | **Global regulatory bodies**

Four regulatory bodies are positioned to lead on automotive circularity globally.

– **What are the impacts of China's heavy reliance on coal with respect to both electrification and circularity?** The environmental implications of technology shifts in China are complicated by the fact that such a large proportion of China's electricity mix still comes from coal. This amplifies the carbon intensity of EVs along every single step of the automobility value chain. China's GHG emissions (~12 Gt/yr) are roughly double those of the United States,[26, 27] and unless China greens its electricity supply, both use phase and the materials production will have an outsize carbon footprint. Certain use-phase circularity approaches such as pooling will have a positive impact on emissions regardless of energy source characteristics. However, transitioning electricity supply to clean energy sources and decommissioning coal-fired power plants as soon as possible will have a major impact on China's ability to achieve sustainability targets.

5.3 The United States

– **What will be the role for federal agencies as opposed to forward-leaning states?** The most likely avenue by which US federal policy may address embedded CO2 emissions and circularity is through the Clean Air Act's requirement to regulate carbon emissions – administered by the Environmental Protection Agency (EPA). However, the EPA has a history of politicization that can reduce its efficacy in promoting long-term industrial and regulatory initiatives. New legislation could be passed to regulate EVs and ICEs outside the framework of the Clean Air Act.[28] However, without unified control of Congress and the executive branches, such legislation seems unlikely. All this leaves the role of the US federal government uncertain.

– **Can the California Air Resources Board play a leadership role?** Just as relevant to US policy is the California Air Resources Board (CARB), which has played a catalytic role in shifting the automotive manufacturing base towards electrification.[29] CARB's authority derives from Section 177 of the 1970 Clean Air Act allowing it to set its own clean air standards – and allowing other US states to adopt those standards. The US Supreme Court has ruled that this authority also applies to carbon dioxide. The primary policy tool used to stimulate early EV sales and production was a synthetic market for zero-emission vehicle "ZEV" credits, which vehicle manufacturers, including Tesla, leveraged to fund early EV development efforts. As the country's largest automotive market, California has now become something of a shadow regulator for the US automotive industry. In September 2020 the state's governor, Gavin Newsome, announced that all new vehicle sales would be electric by 2035. This shift towards electrification adds urgency to efforts supporting decarbonization of materials and energy supply.

5.4 Generalized national policy considerations

There are a number of top-line policy issues that will need to be considered when promoting decarbonization and circularity in all countries.

- **How can domestic circularity policies be aligned with international trade considerations?** Imports of vehicles from economies that lack stringent environmental and circularity requirements must not be given an uneven playing field.
- **How should leakage of high-emissions vehicles and polluting technologies to geographies with less stringent environmental regulations at end of life be addressed?** Today, many older vehicles from rich economies migrate to developing economies as they age. Fleet-based mobility can play a significant role in reducing leakage of dirty vehicles abroad; so can designing vehicles that are easily disassembled and retain their materials value at end of life. Requiring producer responsibility for end-of-life processing and deregistration may also be part of the solution.
- **How should the import/export of materials, components and waste for carbon content be audited?**
- **How can we build scale for advanced end-of-life processing and increase the quality of scrap output?** "Green workshops" equipped to collect materials and components and advanced disassembly facilities will be critical to enabling low-carbon materials production.
- **What is the most economically efficient and environmentally sustainable pathway towards winding down the ICE fleet, and replacing it with an EV fleet?** EVs have a high manufacturing carbon footprint, but potentially a near-zero operational carbon footprint (as long as they are powered by zero-carbon energy).

6

The time to start is now

The challenge of full decarbonization cannot be postponed and should not be underestimated.

Many questions will need to be answered before a rational and holistic framework for a circular automotive system can be built. One overarching theme for regulation and policy should be to consider ecosystem-wide effects – and not stovepipe regulations that are interrelated. These efforts should begin now, particularly as public funding is channelled towards economic recovery from the COVID-19 pandemic. CO2 and resource consumption per passenger kilometre should be considered as key performance indicators for abatement opportunities. Policy-makers and regulatory actors will have to implement circularity policies within distinct national and regional frameworks. As far as possible, regulators should endeavour to align with like-minded actors internationally on implementation, tracking and enforcement. Aligned international standards will help build scale in key technologies and ease the compliance burden on vehicle manufacturers. Incentives for companies to be proactive with respect to circularity should be predictable, with long time horizons, and enable companies to invest confidently in new production facilities and technologies. Regulatory entities should start building the consensus required to begin implementing circularity-focused efforts and immediately begin examining their own authorities and how to apply them to holistically address both use-phase and materials emissions. Given the urgency of the climate challenge and the necessary economic transformation ahead, there is no time to waste.

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