American Chemistry Council | Plastics Division

# AUTOMOTIVE PLASTICS & POLYMER COMPOSITES
# A ROADMAP FOR FUTURE MOBILITY



February 2020

AUTONOMY
CONNECTIVITY
CIRCULARITY
ELECTRIFICATION
SHARED MOBILITY
SUSTAINABILITY

# Contents

# Advanced plastics and polymer composites are essential to the personal mobility REVOLUTION

**Advanced plastics and polymer composites are integral to automotive design**. Nearly every quality of the modern vehicle—from safety and performance to efficiency and aesthetics—relies on plastics and, increasingly, polymer composites to meet ever-evolving consumer expectations.

Now, **the revolution underway in personal mobility** is driving automakers to rapidly invent mobility solutions suited to **an autonomous, connected, electrified, and environmentally responsible automotive future**. To do so, automotive designers need new material solutions. **Advanced plastics and polymer composites will continue to be essential on this journey to the future of mobility**.

The American Chemistry Council (ACC) has continually recognized and promoted the potential of advanced plastics and polymer composites to deliver automotive innovation since it first published a roadmap in 2001 outlining a vision for the application of plastics as key solutions for the automotive industry. The 2014 version of this roadmap, *Plastics and Polymer Composites: A Technology Roadmap for Automotive Markets*, offered an industry-wide strategy to accelerate innovation in advanced plastics and polymer composites through 2030 to help the automotive industry cost-effectively enhance safety, reduce weight, and improve the performance of vehicle designs.

Since then, **the plastics and polymer composites industries, automotive stakeholders, and state and federal governments have invested hundreds of millions of dollars into collaborative research and development (R&D) efforts** to implement roadmap priorities and benefit the nation's energy and economic security. For example, the U.S. Department of Energy invested $70 million in partnership with industry and researchers to establish the Institute for Advanced Composites Manufacturing Innovation (IACMI)—a national, industry-driven consortium that works to reduce technology implementation risk and develop a robust supply chain to support a growing advanced polymer composites industry.

While much of the 2014 roadmap remains relevant, the radical changes in the automotive landscape since then demand an updated strategy to ensure automakers are equipped with the necessary materials solutions. This **2020 roadmap** describes the megatrends shaping the future of automotive design and provides an **industry-led perspective on the research, technology, and workforce development necessary to ensure automakers have access to the advanced plastics and polymer composites they need to transform mobility in the next five years and beyond**.

The ACC Plastics Division led this roadmapping effort, guided by the ACC Auto Team under the leadership of Gina Oliver, Senior Director, ACC Plastics Division. Vital contributions were made by the Auto Team members and experts from the polymers and automotive communities; see Appendix A for a complete list of contributors. Nexight Group provided stakeholder engagement and roadmap development support to ACC and prepared this document.

# *What's driving the* REVOLUTION?

Radical change is happening in the role of the vehicle and the ways people move from one place to another. **Transformative technological, cultural, and economic megatrends are converging to reshape "personal mobility," creating a demand for new material solutions that plastics and polymer composites are ready to provide**.

# PERSONAL MOBILITY

### *Convergence of IT & AUTO INDUSTRIES*

Vehicles are rapidly evolving into **computers on wheels**, a change similar to events in the computer industry 20 years ago and the cellphone industry 10 years ago.[1]

### *Improved BATTERY TECHNOLOGY*

Steady improvements continue to be made in the cost and energy density of battery technology. The volume weighted-average **lithium ion pack price declined 85%** between 2010 and 2018.[4]

### *Increasingly URBAN POPULATIONS*

For the first time in human history, **more than 50% of the global population lives in urban centers** as of 2016,[2] led by dramatic urbanization in China. According to the US Census, 80% of Americans live in urban areas.[3]

### *Proliferation of ARTIFICIAL INTELLIGENCE*

Unit shipments of artificial intelligence systems used in infotainment and advanced driver assistance systems are expected to rise from just **7 million in 2015 to 122 million by 2025**, according to IHS Inc.[7]

### *Growing global ENVIRONMENTAL CONCERNS*

A rise in concern about the effects of climate change and the need to embrace a more circular economy are **influencing consumer purchasing habits**. The cross-value chain Alliance to End Plastic Waste (AEPW) has committed over $1 billion with the goal of investing $1.5 billion over five years to develop and promote technologies, business models, and entrepreneurs that prevent ocean plastic waste, improve waste management and recycling, and promote solutions for used plastics by helping to enable a circular economy.[8]

### *Emergence of ALTERNATIVES TO PERSONAL VEHICLES*

Ridesharing, fractional ownership, and novel urban mobility solutions are increasing in popularity. Some projections expect **1 in 5 cars sold in the US and EU will be part of a subscription service by 2025**.[5]

### *Rise in AUTOMOTIVE-BUYING POPULATIONS in growing economies*

The rise of massive, automotive-buying middle class populations in rapidly growing economies, most notably **China (world's largest automotive sales since 2009) and India (4th largest automotive sales in the world since 2018)**, is increasing global demand for small, lightweight vehicles that can operate where transportation infrastructure is limited.[6]

### *Modernization of regulations and standards to enable SELF-DRIVING VEHICLES*

To date, **29 states have passed regulations for self-driving cars**[9] and the U.S. Department of Transportation's guidance document, AV 3.0, now outlines voluntary guidance, policy recommendations, and best practices from state and local government agencies in testing and operating autonomous technologies.[10]

### *Implementation of FUEL ECONOMY STANDARDS encouraging automotive lightweighting*

The Environmental Protection Agency determined that the **National Highway Traffic Safety Administration's (NHTSA) 2025 Corporate Average Fuel Economy standards have contributed to the innovation and adoption of lightweighting technologies**, and that further mass reduction is projected to reduce fatalities per vehicle mile traveled.[11]

# >> The ACCESS Framework

The technological, cultural, and economic megatrends driving the personal mobility revolution require new ways of thinking about automotive innovation. This roadmap offers a new framework for capturing the opportunities created by today's automotive transformation.

## AUTONOMY

*Advanced driver-assist safety technologies and other technological breakthroughs are helping to gradually relieve human drivers from controlling passenger vehicles.*

## CONNECTIVITY

*Future vehicles will offer greater levels of connectivity and communications, driven not only by in-vehicle comfort and convenience but also by safety considerations.*

## CIRCULARITY

*Principles of a circular economy emphasize recovering materials at the end of their usable life, refurbishing and repairing materials to extend product lifecycles, and remanufacturing and reusing them in new products.*

## ELECTRIFICATION

*Electric vehicle (EV) sales are accelerating and projected to represent between 30% and 50% of worldwide vehicle sales by 2040, up from just 1% of worldwide vehicle sales in 2016.*[12,13]

## SHARED MOBILITY

*Adoption of ridesharing has grown from 15% of U.S. consumers having used ridesharing in 2015 to as many as 43% of U.S. consumers in 2018, helping to reduce travel costs and environmental impact of passenger vehicles.*[14]

## SUSTAINABILITY

*Automakers are working to achieve sustainable automotive design that reduces environmental impacts and improves the efficiency of products throughout their lifecycle.*

# *Ready for the Revolution:* ADVANCED PLASTICS & POLYMER COMPOSITES

**Advanced plastics and polymer composites offer an unparalleled combination of properties** that are essential to achieving the opportunities outlined in the ACCESS framework. As automakers rapidly invent mobility solutions suited to an autonomous, connected, electrified, and environmentally responsible automotive future, advanced plastics and polymer composites are the materials they can rely on to push the boundaries of their designs and wow consumers.

The advanced plastics and polymer composites industry is hard at work developing and rethinking materials and ways of creating them that can make automakers' even most radical ideas a reality sooner rather than later. The examples that follow are just a few of the ways these materials can already help the automotive industry capture the opportunities in the ACCESS framework and shape the personal mobility revolution.

## > *Safely add sensors, electronics, and batteries to vehicles*

**Provide signal transparency** required for active safety systems and sensors including radar, Light Detection and Ranging (LIDAR), and acoustics

**Protect sensors, electronics, and batteries** from transmission interference, noise, vibration, harshness, elevated temperatures, impact shock, and other hazards

Interactive display screen

**Protect passengers and pedestrians from potential hazards** from the increased prevalence of sensors, electronics, and batteries

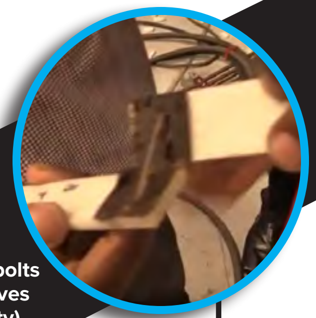
**Prevent marring and prolong life** of interactive display screens

**Protect occupants from fire hazards** (flame-retardant adhesives, fabrics, and battery pack assemblies)

## > *Offset added weight from additional features*

Carbon fiber frame with honeycomb impact panels

**Fast fact:** Using carbon fiber reinforced polymer composites for mixed-material designs could **reduce the weight of some automotive components by 50-75%**[15]



Reversible bonding (replaces bolts and improves repairability)

Plastic battery assembly

**Provide high strength-to-weight ratio** to offset added weight increases and improve vehicle efficiencies

## Enable design and seamless integration of high-value electronic content

Additively printed control button

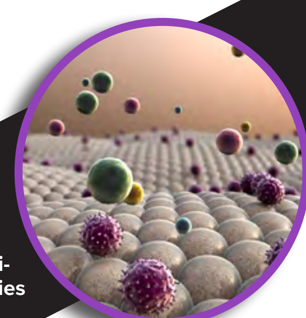
Plastic grille with hidden sensors

**Allow manufacture of grilles and front fascia to meet styling design requirements** while **allowing hidden sensors to properly transmit** radio frequency transmissions from vehicle to vehicle

**Enable signal transparency** for outgoing sensors, **signal reflectivity** to facilitate detection of other vehicles and infrastructure, **robust performance** in harsh vehicle operating conditions, and **design freedom** to consider styling, form, and function

**Enable design of emerging vehicle electronics** including transparent displays, touch-sensitive switches, ambient lighting aesthetics, and voice-enabled internet of things (IoT) devices

## Support a reimagination of vehicle interiors



Materials with anti-odor and anti-microbial properties

Seating concept

**Improve ability of interiors to stand up to the wear and tear of use as a shared vehicle** (e.g., scratch-resistant materials to protect expensive displays and touchscreens; high-durability components that are easy to repair, replace, refurbish, and recycle; and hygienic materials with self-cleaning, anti-odor, and anti-microbial properties for improved passenger experience and comfort)

**Provide options for more equitable and inclusive vehicle interiors** that expand transportation access for elderly and disabled passengers

**Enable more modular and multi-configurable interior components for autonomous vehicles** such as reversable seats, desks, tables, or entertainment consoles for more dynamic and customizable commuting modes



## Help modernize transportation infrastructure

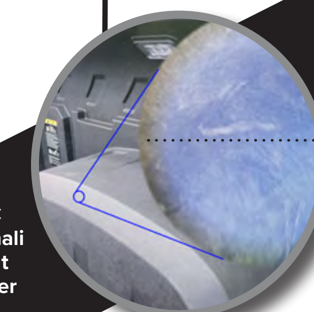
Plastic infrastructure components that can enable connectivity

Plastic network vehicle charging stations

**Enable durable infrastructure that can communicate with vehicles to maintain safety and traffic flow** (e.g., plastic vehicle charging stations, traffic flow monitors, stoplight timers, lane-diversion signals, temporary barriers, travel direction signs, and emergency vehicles)[16]

**Design for disassembly, repair, and replacement** to extend useful product lifetimes, and **efficient recycling and re-insertion of materials** back into new vehicles and other useful applications

## Promote sustainable design and supply chain



2019 GMC Sierra Denali lightweight carbon fiber composite truck bed

Includes pocket reinforcements made from recycled carbon fiber thermoplastic materials[17]

**Fast fact:** A study recently conducted by ACC's Economics & Statistics Department found that investing in new chemical recycling facilities and operations could produce $9.9 billion in economic output and could generate more than 38,000 jobs in local communities across the country.[18]

**Advances in polymer recycling technologies,** multi-material joining methods, end-of-life vehicle dismantling and recovery approaches, and comprehensive lifecycle assessment (LCA) tools with high-quality data are **allowing plastics to transition toward a more circular economy**

# The Path Forward: Collaborative Activities

Although automotive plastics and polymer composites companies are already providing material solutions that can capture the areas outlined in the ACCESS framework, **there are still many major opportunities that are too large and far-reaching for any one company to devote all the resources needed to respond**.

Progress in these areas requires the advanced plastics and polymer composites industry to work together and with automotive partners, government agencies, and academic researchers to conduct pre-competitive research, development, demonstration, and commercialization activities. Supplementing the proprietary R&D efforts of individual companies with these collaborative efforts will produce the novel materials solutions automakers need to deliver the personal mobility of the future.

The pages that follow identify **collaborative, pre-competitive activities in each of the ACCESS areas** as well as suggested timeframes for addressing them. Some of the activities can largely be accomplished by the advanced plastics and polymer composites industry, while others require leadership and engagement from those outside of the industry. The top ten highest priority of these activities are bolded and numbered throughout the following pages and outlined in the adjacent table; they have been identified as such because tackling these activities will significantly accelerate the advancement of plastics and polymer composites and enable their integration into future mobility design through 2030.

# Top 10 Priority Activities

NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030)

## AUTONOMY

**1** Demonstrate and prove the effectiveness of plastic and polymer composite components for increasing the ability of autonomous vehicles to detect surroundings during poor weather conditions

**2** Establish materials-agnostic automotive industry standards to permit the use of innovative materials for lightweight mixed-material assemblies

## CONNECTIVITY

**3** Define material performance requirements required to safeguard electrical and electronic system components

## CIRCULARITY

**4** Establish an industry group or committee to identify and set LCA standards for automotive materials

**5** Pursue high-speed nondestructive testing and evaluation (NDT/NDE) techniques for end-of-life sorting to rapidly identify grades of plastics and polymer composites for reuse and remanufacturing

**6** Collaborate with state and local economic development groups and the automobile salvage industry on effective chemical and mechanical recycling strategies for non-commodity/mixed plastics

## ELECTRIFICATION

**7** Increase collaboration efforts among NHTSA and key advocacy groups to develop collision test methods for vehicle battery systems

## SHARED MOBILITY

**8** Conduct a demonstration project for durable interior automotive plastics and polymer composites with high usage rates

## SUSTAINABILITY

**9** Demonstrate the performance benefits of structural adhesive joining techniques or plastics-based fasteners as a means for ease of maintenance, repair, and disassembly

**10** Develop embedded non-destructive failure and damage detection systems (e.g., structural health monitoring) suitable for all polymeric materials systems

# AUTONOMY

Advanced driver-assist safety (ADAS) technologies and other technological breakthroughs are helping to gradually relieve human drivers from controlling passenger vehicles. Because they will be able to process more information and react faster than humans, it has been estimated that autonomous vehicles will help to reduce the 94% of serious automotive crashes caused by human error.[19]

Once the most significant barriers to adoption—including consumer acceptance, regulations, and economics of alternative car ownership models—have been overcome, fully autonomous vehicles will offer significant advantages and value, including:

- Allowing passengers to safely participate in non-driving activities like resting or working while traveling
- Reducing road congestion and traffic delays
- Improving fuel efficiency

The trend toward embracing autonomous vehicle technology presents a broad range of opportunities for advanced plastics and polymer composites in the following areas:

## > Flexible Interiors

## > Safety

## > Sensors/Light Detection and Ranging (LIDAR)

**LEVELS OF AUTONOMY**
The Society of Automotive Engineers (SAE) has proposed a classification scale for autonomous vehicles:

**Level 0: No automation**
Driver performs all driving tasks

**Level 1: Driver assistance**
Vehicle is controlled by driver but some driving assist features may be included in the design

**Level 2: Partial automation**
Vehicle has combined automated functions like acceleration and steering but driver must remain engaged and monitor the environment

**Level 3: Conditional automation**
All safety functions are automated, but the driver is still needed to take over in an emergency

**Level 4: High automation**
Vehicle is capable of performing all driving functions under certain conditions but driver may have the option to control the vehicle

**Level 5: Fully autonomous**
Vehicle is capable of performing all driving functions under all conditions but driver may have the option to control the vehicle

Source: NHTSA.gov

# Flexible Interiors

## DESIGN IMPACTS

Interiors are likely to feature **numerous sensors and biometrics** for vehicular access, safely monitoring driver behavior, and personalized riding experiences **without sacrificing style or aesthetics**.

Higher levels of autonomy could improve the comfort and modularity of vehicle interiors including more **flexible seating configurations.**

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Engineered automotive plastics can enable **surface- and fabric-embedded flexible sensors** without interfering with radio signals.

Protective plastic screens, coatings, and projection surfaces can provide **scratch-, chemical-, and shatter-resistance for entertainment and information display screens**.

Fleet and rideshare vehicles will require **anti-microbial plastic surfaces** to accommodate multiple passenger trips.

Lightweight polymers can enable **unique vehicle interiors customized for specific customer needs** such as desks for business commuters or built-in entertainment and gaming consoles for families while providing **durability, tactility, and natural appeal** in new automotive interior materials.

Lightweight, durable advanced plastics and polymer composites could **maximize cabin space and enhance sound isolation** while permitting the **integration of various sensors and electronics**.

### INTEGRATED SENSORS/ BIOMETRICS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Define materials requirements in terms of transparency and opacity for state-of-the-art biometric sensors | ● | | |
| Design additively manufactured thermoplastic composite tooling configuration for fabricating interior components | ● | | |
| Conduct benchmark study of sensor technologies used in advanced safety systems for driver monitoring | ● | ● | |
| Establish materials-agnostic automotive industry standards for interior sensor systems | | ● | |
| Establish industry-wide indirect measurement methods for monitoring driver health and behavior; include mapping and scoping parameters for safety, comfort level, driving experience, etc. | | ● | |
| Design engineered automotive plastics for flexible sensors that are integrated into interior fabrics and surfaces | | ● | ● |

### RECONFIGURABLE SEATING

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Standardize test methods to assess the performance of materials with high daily usage rates | ● | ● | |
| Develop next-generation automotive seating with innovative composite materials and engineered plastics | ● | ● | ● |
| Define materials specifications for materials with high daily usage rates | | ● | |
| Investigate passenger comfort requirements using human finite element (FE) models | | ● | |
| Demonstrate modularity of lightweight seats to create new spaces and configurations | | ● | |
| Increase collaboration efforts between NHTSA and the automotive industry to upgrade existing safety standards to account for flexible seating configurations | | ● | ● |
| Upgrade existing safety standards and crashworthiness test methods and countermeasures for reconfigurable seating | | ● | ● |

# Safety

Lightweight roof that lowers center of gravity for improved safety.

## DESIGN IMPACTS

While autonomous driving technologies are expected to reduce human-caused crashes over time, automakers still require advanced materials to **improve the crashworthiness of windows, airbags, and other energy-absorbing components**. Regulations tailored for incumbent legacy materials could potentially inhibit the integration of new or novel materials for automotive applications.

Future vehicle designs may **substitute lighter weight alternatives** for systems such as glazing closures, body structures, and interior components.

**Automotive exteriors must be externally detectable** for a broad range of sensor wavelengths and fully functional in difficult weather conditions while meeting consumer demand for styling and brand differentiation.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

A recent vehicle mass reduction study demonstrated that B-pillar structural components made with thermoplastic-based carbon fiber composites can **satisfy side-impact crash requirements and deliver a 60% weight reduction** compared with the steel baseline.[20] Composite front-end structures can provide the same crash protection in less space than a steel one.[21]

**Low-density polymeric glazing materials** could help reduce vehicle weight while providing increased acoustic damping performance for improved passenger comfort. Hard-coated polycarbonate is a beneficial alternative to traditional automotive glazing due to its **high transparency and clarity, low weight, huge freedom of design, and strong impact resistance.**[22]

Sensor-embedded exterior surfaces will use **signal-transparent plastics to enable two-way connectivity** with other vehicles and infrastructure (i.e., vehicle to vehicle [V2V], vehicle to infrastructure [V2I]).

**Visually transparent, UV-resistant, and shatter-resistant windows, roofs, and frames** could remove blind spots and reduce pedestrian collisions for driver-controlled operations.

Thermoplastic polyolefins and other advanced plastics can be molded into complex shapes to **make vehicles quieter and more ergonomic.**[23]



## DETECTABLE EXTERIORS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **1 Demonstrate and prove the effectiveness of plastic and polymer composite components for increasing the ability of autonomous vehicles to detect surroundings during poor weather conditions** | ● | ● | |
| Coordinate with original equipment manufacturers (OEMs) to define application specifications and requirements for highly durable, weather-resistant exterior body panels including consideration for embedded sensors and displays | ● | | |
| Define material property requirements to enable multi-modal sensing (e.g., LIDAR, radar, camera) | ● | | |
| Investigate enhanced plastic or polymer composite materials and coating for exterior surfaces with high reflectivity and signal transparency | ● | | |
| Develop sensor-detectable colors to expand options for styling and differentiation | | ● | |
| Examine potential solutions to increase visibility of autonomous vehicle exteriors to visually warn pedestrians (i.e., similar to EV warning sounds to alert nearby pedestrians) | | ● | |
| Establish industry-wide test methods and standards for automotive exterior surfaces for reflectivity, visibility, and connectivity (e.g., coatings, pigments) | | ● | |
| Explore a composite exterior molding process that avoids the need for secondary painting | | ● | |
| Develop highly visible reflective pigments with infrared (IR) capabilities (e.g., use IR signals to make vehicle "glow") | | | ● |

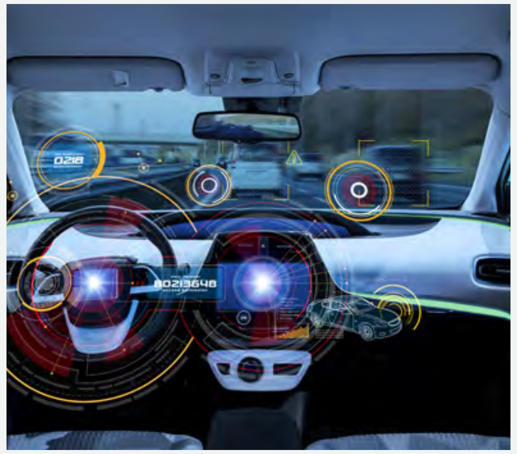
## WINDSHIELD & GLAZING CLOSURES

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Investigate polymeric glazing materials with dimmable curvatures to customize interior lighting | ● | | |
| Identify structural requirements for large-span windows and panoramic roof structures with limited pillar support | ● | | |
| Develop predictive numerical material models for windshield and glazing materials | ● | ● | |
| Conduct integrated analysis of windshield safety and performance | ● | ● | |
| Demonstrate high modulus adhesives of large window components for reduced noise, vibration, and harshness (NVH) and improve passenger comfort | ● | ● | |
| Develop photoactive engineered polymers (i.e., semi-transparent or variable-transparency) required for passenger safety | | ● | |
| Develop application requirements of functional window-display materials (e.g., heads-up passenger display, pedestrian warning systems) for Level 4 autonomous vehicles | | ● | |
| Design windshields that enhance nighttime visibility for drivers | | ● | ● |
| Upgrade industry standards to accommodate photoactive materials to improve driver vision and safety (Level 1-4 autonomy) | | ● | ● |
| Increase lifespan of transparent windshield glazing materials via improved impact- and weather-resistance (Level 0-4 autonomy) | | ● | ● |
| Integrate electronic display systems to replace select transparent glazing materials (Level 5 autonomy) | | | ● |

## CRASHWORTHINESS REQUIREMENTS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **2 Establish materials-agnostic automotive industry standards to permit the use of innovative materials for lightweight mixed-material assemblies** | | ● | |
| Engage key industry organizations to achieve consensus on realistic materials-agnostic performance standards | ● | | |
| Develop predictive numerical material models to improve the energy absorption of structural automotive composites | ● | | |
| Identify a range of crash scenarios to inform performance and failure prediction models for structural composites | ● | | |
| Identify required test methods and standards to evaluate structural composite test specimens using dynamic loading rates | ● | ● | |
| Coordinate with appropriate federal agencies to re-evaluate interior crash protection requirements including countermeasures for rear- and side-facing seating configurations | ● | ● | |
| Upgrade existing safety standards and standardize crashworthiness test methods (e.g., rollover, side-impact) to validate structural rigidity of large window components and electrical energy storage systems | | ● | |
| Design composites with optimized fiber-matrix interfaces to maximize their energy absorption capabilities | | ● | |
| Establish and maintain a database of automotive specifications and materials properties to evaluate the safety and performance of advanced composites | | ● | |
| Conduct technical analysis of automotive composites safety and performance to support regulatory standards development activities | | ● | |
| Investigate automotive chassis designs to permit interchangeable polymer and composites panels that balance crashworthiness with aesthetic design | | ● | |
| Enhance performance and failure prediction models for carbon fiber composite parts | | ● | ● |

# Sensors/LIDAR



## DESIGN IMPACTS

Self-driving vehicles will require some combination of embedded sensors such as camera, radar, satellite, and light-based (e.g., LIDAR) detection methods. **Standardizing automotive sensor systems** will be challenging due to both competitive market forces as well as a limited understanding of which combinations of sensor types will eventually be most in demand.

The sharp increase in total sensors per vehicle will require **additional electronics protection** to ensure the safe and continued operation of life-saving safety features.

Increased number of on-board sensors and algorithm computing devices will **demand improved heat management solutions** to ensure safe, continuous operation.

Encapsulant materials must offer **physical protection for sensors while permitting full signal transparency** for detecting pedestrians, animals, obstructions, and other communications devices.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Automakers will require **radio frequency-transparent plastics for all cameras, radar, LIDAR, and sensors** on vehicles to "see" conditions further ahead.

Integrating electronic sensor systems will require **humidity and temperature resistant plastic materials** for connection harnesses, housings, and wiring.

**Advanced polymeric materials permit both light and imaging transparency** and can hide multimodal sensor systems behind body panels, bumpers, and grilles.[24]

Vehicle systems will require **thermally conductive and electrically insulative polymers** including adhesives, separators, and housings to maintain safe operation.

| | | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|---|
| ELECTRONIC INSULATORS | Gather reliable information on a broad range of realistic ambient conditions for superabsorbent materials to inform appropriate test methods | ● | | |
| | Conduct a demonstration project for humidity and temperature resistant adhesive technologies for electronics protection | | ● | |
| | Define materials specifications based on sensor detection and data processing requirements | | ● | |
| RADIO FREQUENCY TRANSPARENCY | Define application specifications and requirements for radio-frequency transparency and/or shielding | ● | | |
| | Design automotive composite panels with integrated clips or brackets to accept custom wiring and sensor configurations | ● | | |
| | Design aesthetic embedded sensor systems (e.g., hidden behind plastics such as logos and front-end components with a glossy or shiny appearance) | ● | | |
| | Standardize material characterization methods for sensor-friendly exterior material surfaces including substrates and fillers | ● | | |
| | Design advanced polymer and composite-intensive automotive concepts with optimum integration and concealment of sensor hardware | | ● | |
| SENSOR STANDARDS | Increase education and advocacy efforts to publicize the necessity of advanced plastics for enabling sensor-to-sensor communication | ● | | |
| | Define performance-based specifications and requirements for sensor/LIDAR systems | ● | ● | |
| | Standardize communication protocols for interoperability, security, and reliability of multimodal sensor systems (e.g., standardization of input/output signals, data bus, diagnostics software); focus on single consolidated data transmission standard | | | ● |

# CONNECTIVITY

Future vehicles will offer greater levels of connectivity and communications, driven not only by in-vehicle comfort and convenience but also by safety considerations.

Advanced software and multimodal sensor systems will facilitate:

- V2V collaborative behavior
- Interaction with V2I interaction
- Congestion mitigation via cellular and/or satellite

The continued growth of sensor technology adoption and proliferation of advanced driver-assist safety technologies, coupled with anticipated 5G mobile networks and a growing demand for high-tech displays (e.g., touchscreens, augmented reality features), will enable the addition of more electronic content to vehicles while increasing the value of vehicle software systems. The growing addition of electronics, sensors, and data processing to future vehicles creates opportunities for advanced plastics and polymer composites in the following areas:

## > Artificial Intelligence

## > Cybersecurity

## > Infotainment

## > Software and Data Management

## > Transportation Grid

# Artificial Intelligence


## DESIGN IMPACTS

**Artificial intelligence (AI)-driven techniques** will help to optimize travel routes based on traffic conditions, guide electric vehicles to recharging stations, and classify driver health and attentiveness.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Advanced plastics and polymer composites can **protect expensive electronics and computing hardware** from harmful physical vibrations and dangerously high temperatures.

## HEAT AND SHOCK PROTECTION

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **3 Define material performance requirements required to safeguard electrical and electronic system components** | ● | ● | |
| Build public perception of advanced plastics and polymer composites as a key enabler for reducing NVH (i.e., squeaks, rattles, roughness of ride quality) | ● | | |
| Establish standardized test methods for evaluating NVH performance and thermal stability of automotive parts and materials | ● | ● | |
| Demonstrate non-conductive, vibration-damping adhesives for joining automotive electronic applications | ● | ● | |
| Increase participation across advocacy groups and key standards committees to permit the integration of nanosensor-embedded advanced plastics and polymer composites | ● | ● | |
| Develop highly durable plastic insulators for safeguarding automotive electronics | | ● | |
| Establish integrated test methods (e.g., heat management, shielding, flammability) to aid in the development and certification of automotive electronic components | | ● | ● |

# Cybersecurity


## DESIGN IMPACTS

Future connected vehicles **may rely on a 5G mobile internet infrastructure for over-the-air updates of onboard software systems**. However, the proliferation of sensor-based safety systems raises cyberattack vulnerability concerns for both vehicles and smart infrastructure technologies.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Shared vehicles, in particular, will require **tamper-resistant polymer exclosures to help reduce physical damage** to expensive vehicle electronics without impeding radio signals.

### TAMPER-RESISTANT COMPONENTS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Compile and document best practices for the repair of plastic and polymer composite automotive components for sensors/vehicle to everything (V2X) devices | | ● | |
| Demonstrate easy-to-access (i.e., for repair, maintenance, disassembly) polymeric automotive components that are designed to prevent theft, vandalism, and damage to sensors/V2X devices | | ● | |

# Infotainment

## DESIGN IMPACTS

Higher levels of vehicle autonomy and connectivity are **encouraging the integration of electronic displays for more a personalized in-transit driving experience**. Information and entertainment systems integrated on the vehicle's outer surface could function as public displays or potentially change surface color.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Protective plastic screens, coatings, and projection surfaces can provide scratch-, chemical-, and shatter-resistance for electronic displays** on both the vehicle's interior and exterior surfaces.

### ELECTRONIC DISPLAYS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Increase collaboration among OEMs, suppliers, and universities to establish standards for scratch-, chemical-, UV-, and shatter-resistant electronic display materials for automotive interiors and exteriors | ● | | |
| Demonstrate benefits of commercial scratch- and abrasion-resistant coatings for glass and plastic surfaces | ● | | |
| Establish gloss, reflectivity, transparency, and optical purity standards for safety and entertainment displays | | ● | |
| Increase collaborative efforts in legislative, regulatory, and voluntary consensus standard development to enable outer surface display technologies for automotive applications | | ● | ● |

# Software and Data Management

## > DESIGN IMPACTS

**Sensor-based safety systems will generate enormous volumes of data** from detecting and classifying the vehicle's surroundings. Advanced data storage and processing solutions are required to support safe and successful operation of self-driving vehicles.

## >> OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Solid-state plastic RAM devices have low power requirements and elevated thermal resistance** necessary for maintaining higher data generation rates of ADAS.

## DATA-PROCESSING DEVICES

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Define application specifications and requirements for electronic materials and components of ADAS | ● | | |
| Conduct a demonstration project for solid-state RAM devices to enable high data generation rates in ADAS | | ● | |

# Transportation Grid

## DESIGN IMPACTS

Sensors for autonomous vehicles and transportation infrastructure components must be **free from electromagnetic interference (EMI)** to facilitate consistent and reliable transmission of real-time information including traffic and congestion data.

**Extreme weather conditions** could affect the real-time performance of automotive sensors while causing accelerated degradation and aging of automotive materials.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Advanced polymeric materials **permit both light and imaging transparency and can hide multimodal sensor systems** behind body panels, bumpers, and grilles.[25]

**Plastic and polymer composite materials with tailorable shielding properties can help reduce electromagnetic interference** for V2X technologies.

**Plastics that resist weather, road salt, and UV exposure can prolong vehicle life** and protect driver visibility and safety.



**NEAR** (2020–2022) | **MID** (2023–2025) | **LONG** (2026–2030)

## EMI PROTECTION

- Demonstrate effectiveness, tailorability, and durability of advanced plastics-based radio-opaque materials for conduits, cable jacketing, and other EMI shielding components
- Characterize the shielding attenuation behavior of polymeric EMI shielding components to create and validate predictive models
- Foster development of multifunctional materials for housing and protecting sensors from physical damage and signal interference
- Develop models that can simulate EMI behavior of advanced plastics and polymer composites in “fully assembled” vehicle designs
- Coordinate with automakers and autonomous component developers to establish materials-agnostic test methods and industry standards for EMI and electromagnetic shielding (e.g., wavelengths, acceptable interference)

## WEATHER/UV-RESISTANCE

- Develop accelerated aging tests for long-term weathering of automotive plastics and polymer composites to road chemical treatments and UV exposure

# CIRCULARITY

Principles of circularity emphasize not only recovering materials at the end of their usable life but also reusing them in new products, refurbishing them to extend product lifecycles, and reducing the demand for finite raw materials.

Globally, the automotive community is increasingly focused on making it easier to disassemble end-of-life (EOL) vehicles, boosting EOL material recovery rates, and increasing the amount of recycled and reused material in new vehicle designs. For example, 50 of the 280 kilograms of plastics used in a Renault Espace come from recycled sources including closed-loop EOL plastics.[26] Advanced plastics and polymer composites have the opportunity to play a significant role in improving automotive circularity in the following areas:

## > Collection and Dismantling

## > Lifecycle Assessment

## > Recovery and Sorting

## > Remanufacturing

# Collection and Dismantling

## DESIGN IMPACTS

The current **recycling infrastructure** is not optimized for the collection and sorting of end-of-life automotive polymers. Coordination across the recycling supply chain is needed to understand and demonstrate the value proposition of nationwide collection platforms for retrieving dismantled vehicles and automotive components.

Automakers are increasingly focused on **designing vehicles for increased recyclability as well as easy and economic disassembly** to extend vehicle lifespan through refurbishment, and to remanufacture materials into new automotive components (closed-loop) or into alternative applications (open-loop).

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Broadening participation in nationwide recycling initiatives, establishing new markets for recyclate materials, and streamlining activities between waste collection and manufacturing** could help to reduce landfilling and improve the recyclability rate of post-consumer automotive advanced plastics and polymer composites.

**Lifecycle tools and other long-term design strategies** could help reduce technical and logistical barriers for EOL vehicle disassembly and improve recycled material recovery rates for automotive plastics and polymer composites.

| | | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|---|
| RECYCLING INFRASTRUCTURE | Engage existing automotive material recovery facilities to benchmark progress and motivate research in effective automotive disassembly/dismantling approaches | ● | | |
| | Benchmark efforts in Europe to establish a nationwide closed-loop manufacturing infrastructure for effective retrieval of dismantled vehicles/components and post-consumer sorting and separation of recyclable plastics and polymer composites | ● | | |
| | Collaborate with dismantlers on a study to quantify the value proposition for open-loop collection approaches of plastic parts (e.g., new recycle stream, feed for chemical recycling plants) | ● | ● | |
| | Identify high-value secondary applications for upcycled EOL polymers | ● | ● | ● |
| | Launch a collaborative, holistic effort across multiple technology sectors to optimize the automotive EOL recycling infrastructure; determine funding requirements and create a unified voice and strategy for EOL vehicles | ● | ● | ● |
| | Fund (or enhance an existing) disassembly and remanufacturing shared R&D facility to demonstrate the feasibility of large-scale dismantling operations for EOL automotive plastics and polymer composites | | ● | |
| | Develop industry-wide vehicle fleet maintenance standards to ensure the consistent testing, refurbishment, replacement, and collection of end-of-life seating materials (i.e., for Level 5 autonomous vehicles) | | ● | |
| | Identify seed funding opportunities to demonstrate small-scale/regional collection platforms and advanced sorting technologies for EOL auto plastics / polymer composites | | ● | |
| RECYCLABILITY AND DISASSEMBLY DESIGN | Coordinate an industry-wide series of competitions, grants, and other creative and publicity-building efforts to demonstrate automotive designs which help improve the recovery rate of EOL automotive plastics and composites | ● | ● | |
| | Establish industry standards to better define how the “recycled content” of a vehicle is quantified | | ● | |
| | Demonstrate high performance recycled plastics-intensive automotive designs | | ● | |
| | Design plastic and polymer composite automotive components for ease of disassembly/dismantling | | ● | |
| | Pursue innovative design approaches that fully account for ease of disassembly/recovery of advanced polymer and composite parts including plastic-metal-hybrid parts | | ● | ● |

# Lifecycle Assessment

## DESIGN IMPACTS

Future shared and autonomous vehicles are expected to have higher usage rates and shorter lifespans which will increase the need for designs and materials solutions that extend overall vehicle service life. **LCAs** will help provide automakers with a clearer understanding of the **cradle-to-grave energy use, environmental impacts, service life, and recyclability requirements** of new automotive materials options.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Using advanced plastics and polymer composites instead of alternative materials could **save 89 million US gallons of gasoline and diesel over the lifetime of vehicles** in North America produced in one year.[27]

**Rigorous LCAs** could help determine the environmental benefits of plastics manufacturing technologies—including conventional, bio-based, chemically recycled, and other recycled plastics technologies—which offer an opportunity to reduce lifecycle greenhouse gas emissions across the entire value chain.[28]

## MODELING AND IMPACT ANALYSIS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **4 Establish an industry group or committee to identify and set LCA standards for automotive materials** | ● | ● | ● |
| Allocate funding for LCA benchmarking studies to understand the full lifecycle environmental and economic impacts of various cradle-to-grave scenarios | ● | | |
| Determine if the lack of accepted and reliable LCAs addressing advanced plastics and polymer composites is a true barrier or just a perceived barrier by soliciting feedback from OEMs on existing LCAs | ● | | |
| Create standardized LCA methods that are easier to use for automotive designers | ● | | |
| Conduct an LCA study to understand the potential impact of environmental regulations and strategies to improve the sustainability of recycled and reused automotive advanced plastics and polymer composites | ● | ● | |
| Create a technoeconomic model to study alternative open-loop remanufacturing pathways that convert recovered advanced plastics and polymer composites into fuels | ● | ● | |
| Coordinate with OEMs to establish a shared database for gathering anonymized manufacturing data (e.g., energy use) to increase the robustness of LCA prediction tools | | ● | |
| Develop and apply AI tools within design and optimize software packages to accelerate materials discovery and deployment for automotive plastics and polymer composites | | ● | |
| Conduct a comparative LCA demonstration study on a plastic or polymer composite component (e.g., liftgate, exterior body panel, truck bed, seat system) and metallic counterpart; evaluate durability, serviceability, repairability, cost, etc. | | ● | |
| Create a technoeconomic model to assess the feasibility of end-of-life vehicle dismantling processes for plastics-/composites-intensive automotive designs | | ● | ● |
| Launch a collaborative effort among key plastics recycling associations and facilities (e.g., Association of Postconsumer Plastic Recyclers) to conduct LCAs on behalf of automotive OEMs | | ● | ● |

# Recovery and Sorting

## DESIGN IMPACTS

Without a clear value proposition or regulatory driver to recycle EOL vehicles, **recycling organizations are unlikely to invest in technologies** to identify and sort automotive materials.

Retrieved EOL materials must exhibit adequate aesthetic quality and mechanical performance to be remanufactured into automotive components. Automotive recyclers will require **effective reprocessing technologies** for extracting chemical additives and separating materials grades as well as best practices and **guidelines for separating and recovering EOL parts** for recycling.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Advanced sorting technologies** such as image recognition, near-infrared spectroscopy, and marker technologies (e.g., barcodes, invisible chemical markers) can enable high purity materials streams needed for remanufacturing vehicles with high levels of recycled plastics content.[29]

Industry-wide guidelines for collecting, sorting, and separating plastic from metal vehicle components can **improve batch quality and reduce contaminant levels**.[30]

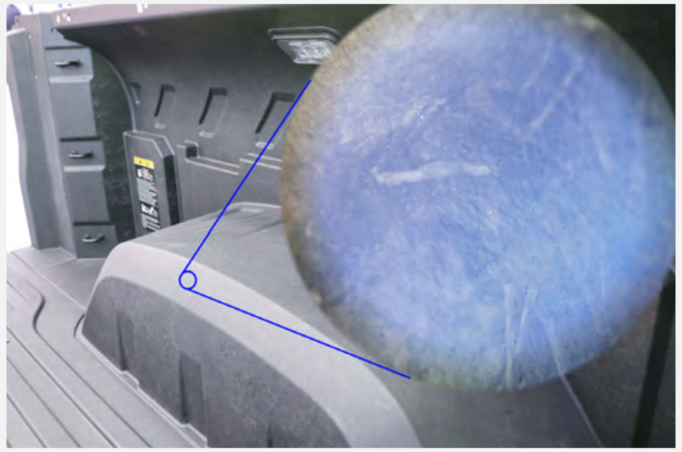
### IDENTIFICATION AND SORTING

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **5 Pursue high-speed NDT/NDE techniques for end-of-life sorting to rapidly identify grades of plastics and polymer composites for reuse and remanufacturing** | | ● | |
| Increase advocacy efforts to help OEMs/consumers understand differences between "low-cost" and "recycled" materials grades | ● | | |
| Support the development and funding of shared recycling centers to enable new techniques for material identification and sorting of end-of-life vehicles | ● | ● | |
| Launch a task force across automotive stakeholders and state and federal agencies to standardize test standards (i.e., high-speed NDE techniques) for rapid identification of end-of-life materials grades | | ● | |
| Increase collaborative efforts in legislative, regulatory, and voluntary consensus standard development to ensure gradual shift toward advanced sorting strategies for vehicle recycling | | ● | ● |

### MATERIALS RECOVERY

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| **6 Collaborate with state and local economic development groups and the automobile salvage industry on effective chemical and mechanical recycling strategies for non-commodity/mixed plastics** | ● | ● | |
| Conduct a study to quantify the potential impact of innovative chemical recycling techniques for a broad range of automotive advanced plastics and polymer composites | ● | | |
| Seek inputs from interior automotive materials producers on common or standardized end-of-life materials recovery approaches; examine lessons learned from non-automotive sectors on establishing end-of-life recycling strategies | ● | | |
| Demonstrate recycling technologies that seek to maximize the recoverable energy and value of end-of-life plastics and polymer composites | ● | ● | |

# Remanufacturing



2019 GMC Sierra Denali lightweight carbon fiber composite truck bed with pocket reinforcements made from recycled carbon fiber thermoplastic materials.

## DESIGN IMPACTS

Global automakers use closed-loop recycling approaches to reduce material waste and manufacturing energy consumption by replacing virgin materials with recycled materials in the same production cycle. **Closed-loop manufacturing approaches are not yet broadly adopted** due to insufficient scale, supply chain coordination, and recyclate quality.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Recyclable thermoplastics** can be reprocessed and remanufactured into new automotive components.

Most automotive manufacturers, including Ford and Toyota, **recycle old or damaged parts and reuse them in new vehicle components** (e.g., old bumpers in new bumper reinforcement cores).[31]

Some advanced plastic recycling and recovery (APRR) technologies **can convert used plastics into new products**, chemicals and chemical feedstocks, and transportation fuels without the need for pre-cleaning treatments.[32]

## CLOSED LOOP APPLICATIONS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Conduct a study of closed-loop manufacturing models to remanufacture automotive components using recycled plastics; identify critical application areas | ● | | |
| Coordinate with OEMs to define application/material specifications, property standards, and targets for automotive components with high levels of recycled content | ● | | |
| Increase collaborative efforts among OEMs/Tier 1-2 suppliers to review best practices for remanufacturing with more recovered materials content | ● | | |
| Launch a demonstration program for novel automotive concepts that use end-of-life plastics and polymer composites (i.e., designed for ease of disassembly, repair, reuse) | ● | ● | |
| Conduct a demonstration project for the end-of-life disassembly and remanufacturing of multimaterial assemblies and components (e.g., seating) | ● | ● | |
| Standardize disassembly and remanufacturing approaches to make EOL automotive plastics and polymer composites easier to recycle; focus on high-volume applications (e.g., seats, instrument panels, air intake manifolds, body panels, air ducts) | | ● | ● |

# ELECTRIFICATION

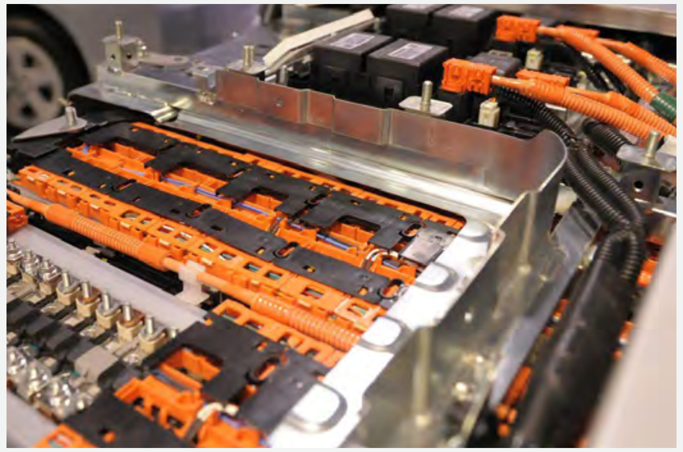
Since 2010, alternative powertrain options such as battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) have begun to penetrate the automotive market while federal agencies have increased investments in electric/hybrid vehicles and battery technologies.

Acceptance for EVs continues to rise as $CO_2$ emissions standards drive increased electrification and hybridization. By 2030, electrified propulsion vehicles are expected to meet or surpass internal combustion engines in vehicle sales.[33] Vehicle electrification provides a variety of opportunities for advanced plastics and polymer composites in the areas that follow:

## > Hybridization

## > Propulsion Systems

# Hybridization



## DESIGN IMPACTS

The proliferation of vehicle battery systems with higher energy densities creates a greater need for increased **occupant protection from fire hazards**.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Flame-retardant polymers, including adhesives and fabrics**, could help reduce the risk of fires from spreading.

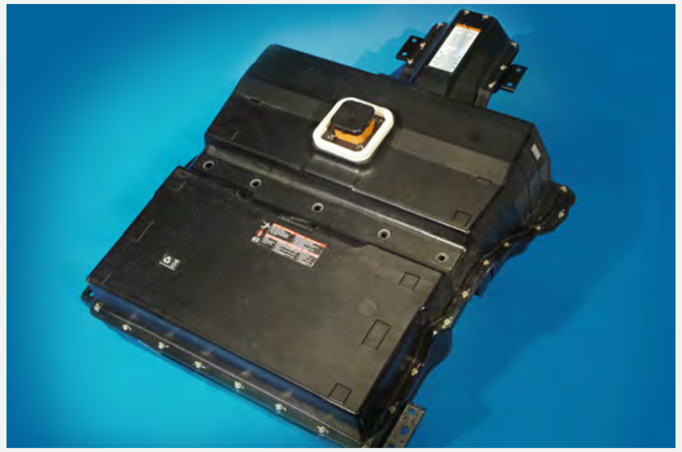
**Engineered thermoplastics**, which can meet the growing demand for electrical connectors and housings, can be designed to withstand the high heat and electrical currents generated by EVs.[34]

The 2016 Chevrolet Volt featured an **all-plastic battery pack** which enabled a 15% **weight reduction** compared to its previous steel end plate design.[35] The all-plastic battery pack also features a new design circuit which **increases battery safety** by reducing the risk of short circuits.

## FLAME RETARDANCY

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Coordinate across automotive stakeholder groups to achieve consensus on flame-retardance safety standards and performance requirements for HEVs/EVs (e.g., flame spread, smoke, or heat generation) | ● | ● | |
| Demonstrate the performance benefits and repairability of adhesives for HEV/EV battery pack assemblies | ● | | |
| Conduct a demonstration project for evaluating the ability of flame-resistant advanced polymers to protect HEV/EV battery pack assemblies | ● | ● | |
| Upgrade flame retardance performance standards that are exclusively designed for automotive applications (i.e., different than other industries to avoid over-design/ undue constraints) | | ● | |
| Demonstrate tailorable battery pack assemblies for variable battery geometries (i.e., integrated battery systems that conform to unique vehicle structures) | | ● | ● |

# Propulsion Systems



Composite EV battery enclosure that protects the EV's battery components in the event of a catastrophic event

## DESIGN IMPACTS

Active or passive **thermal management and impact protection systems and materials** are designed to increase passenger safety, battery efficiency, and battery lifetime of hybrid and electric vehicles.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

EVs have different cooling requirements than internal combustion engines, which may render certain types of vehicle grilles and front fascia obsolete, thereby creating opportunities for new advanced **plastics-based front-end vehicle designs**.[36]

Lightweight, corrosion-resistant, and **thermally conductive polymers** including adhesives, battery pack assemblies, and lithium-ion separators could improve vehicle safety and increase battery lifetime. Advanced polymer-based battery separators for lithium ion batteries can boost battery power by up to 30%, maintain temperature stability, and extend EV range under a single charge.[37]

Advanced polymer-based **battery pack protection systems** can protect vehicle batteries during impact events.

## THERMAL MANAGEMENT AND IMPACT PROTECTION

NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030)

7 **Increase collaboration efforts among NHTSA and key advocacy groups to develop collision test methods for vehicle battery systems**

Define application specifications and property requirements (including temperature, thermal conductivity, impact, fatigue, etc.) for plastic and polymer composites used in automotive thermal management and battery protection technologies

Demonstrate benefits of commercial thermally conductive adhesives and gap-fillers for HEV/EV battery pack assemblies

Develop a set of guidelines for selecting appropriate thermal conductivity test methods for specific plastics/composites grades

Coordinate with automakers and battery developers to define long-term design needs for increased under-the-hood EV performance and increased vehicle range

Develop coupled multi-physics simulations (i.e., solid, fluid, thermal, electromagnetic) to improve the safety and efficiency of battery protection systems

Establish industry-wide standards or calibration steps to reduce the variability of thermal conductivity test results across different types of characterization instruments

Standardize test methods to assess both the safety and performance of materials used in automotive thermal management and impact protection technologies for batteries and electronics

Identify industry-wide R&D demonstration opportunities to develop new types of low-cost structural thermally conductive polymers for the manufacture of thermal management battery systems

# SHARED MOBILITY

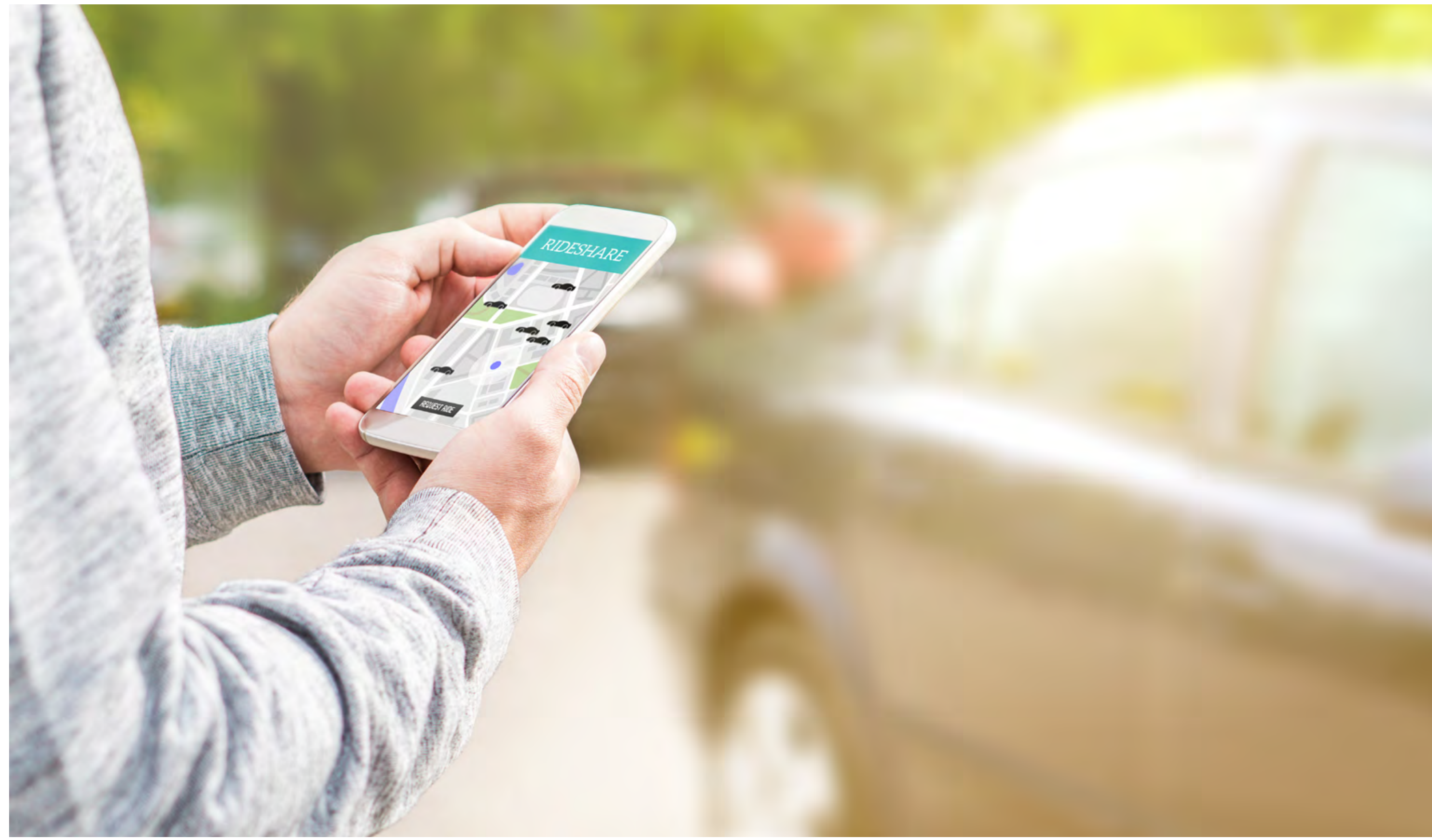
Shared mobility could help reduce travel costs and overall environmental impact of passenger vehicles. A reported 43% of U.S. consumers use ridesharing at least once per week.[38]

To date, most ridesharing vehicles are repurposed personal vehicles, although the U.S Department of Transportation has also developed federal guidelines to help cities and municipalities add low-speed automated shuttles to their transportation fleets to help solve first- and last-mile travel issues for those who rely heavily on public transportation.

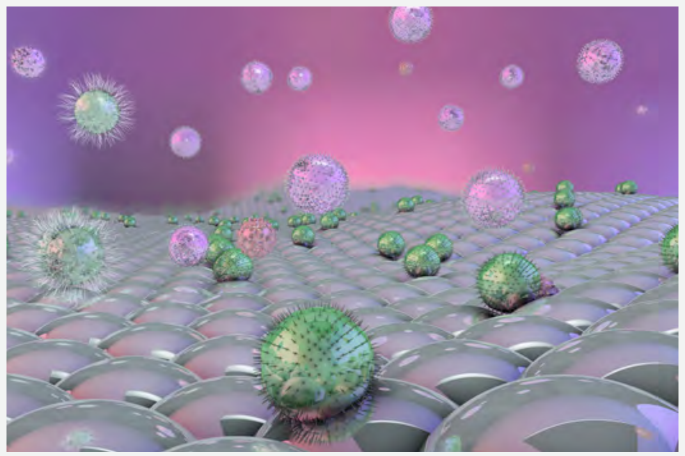
The growth of ridesharing and car-sharing services will continue to significantly influence individual mobility behavior while introducing changes to automotive systems—particularly vehicle interiors. Riders will continue to expect advancements such as durable, hygienic materials as well as accessible interiors, an enhanced in-transit experience, and innovative display materials. Shared mobility is also expected to reduce average vehicle lifespans due to increased usage rates, which could encourage the use of longer-lasting automotive materials that are more durable, recyclable, repairable, and replaceable. Advanced plastics and polymer composites could play a major role in the following areas:

## > Anti-Odor, Self-Cleaning, and Antimicrobial Materials

## > Shared, Fractional Ownership and Ridesharing



# Anti-Odor, Self-Cleaning, and Antimicrobial Materials



## DESIGN IMPACTS

Like mass transit seating, shared vehicle interiors will **require durable, hygienic, and odor-free surfaces** to accommodate multiple passenger trips.

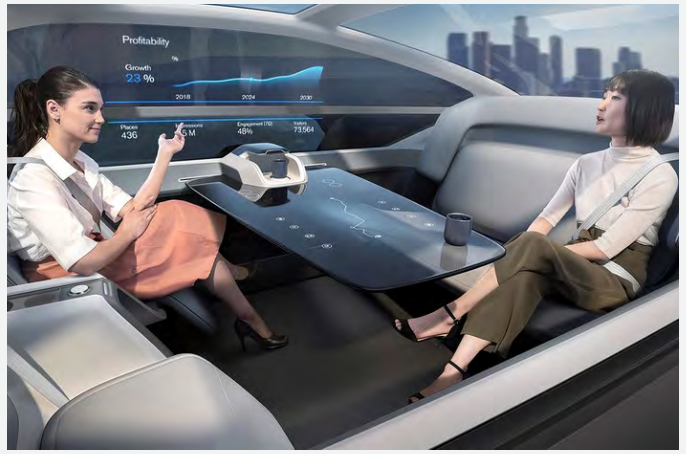
## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Contact-activated polymeric interiors** can resist odors and microbial growth.[39]

### HYGIENIC MATERIALS

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| Demonstrate novel automotive interior prototypes that are specifically designed for easy cleaning and disinfecting of plastics and polymer composites | | ● | |
| Identify compatible materials systems (i.e., additives) to enable plastics and polymer composites with desired functional properties for shared vehicle interiors (i.e., anti-odor/-static/-microbial, self-cleaning) | | ● | |

# Shared, Fractional Ownership and Ridesharing



## DESIGN IMPACTS

Shared and autonomous vehicles will require **resilient and highly durable materials** designed to withstand increased usage rates and improve vehicle lifecycle performance.

Shared vehicles can enable equitable transportation access for the elderly and individuals with sensory, physical, or intellectual disabilities in both rural and urban regions. **Universal design principles for accessibility** could significantly impact interior vehicle configurations.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

Advanced plastics and polymer composites can provide **wear- and scratch-resistance** to meet the increased usage rates of shared automotive interiors.

Advanced plastics and polymer composites offer **superior design flexibility and lightweighting benefits** for both reconfigurable and custom-made automotive interiors.

| | | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|---|
| HIGH-DURABILITY INTERIORS | **8 Conduct a demonstration project for advanced interior automotive plastics and polymer composites with high usage rates** | ● | ● | |
| | Define durability requirements of materials for automotive interiors (e.g., shared vehicles with high usage rates) including characteristics of cleanability and resistance to wear, UV, and scratches | ● | | |
| | Design soft-touch surfaces that cover structural composites for improved aesthetic appearance and durability | | ● | |
| ACCESSIBLE VEHICLE DESIGN | Coordinate across automotive stakeholder groups to explore likely future scenarios for consensus-based principles for accessible vehicle design | ● | | |
| | Examine accessible vehicle design principles or frameworks to define vehicle safety requirements for interior automotive plastics and polymer composites; coordinate with regulating agencies | ● | ● | |
| | Demonstrate innovative lightweight systems (e.g., retractable composite ramps) to enable accessibility for disabled users | | ● | |

# SUSTAINABILITY

Automakers and their suppliers are exercising a variety of methods to help achieve sustainable automotive design to reduce environmental impacts and improve product lifecycle efficiencies.

- Lightweighting to boost fuel economy and reduce greenhouse gas emissions
- Process technology improvements that lower cycle times and reduce energy usage
- Reducing manufacturing waste to impact both the environment and the embodied energy of wasted material
- Computational design methods that optimize product shape to reduce material usage

Advanced plastics and polymer composites can address key sustainability objectives in a variety of ways, including by serving as the lightweight materials of choice for replacing metals; offsetting the additional weight of advanced components such as electric batteries and sensors; offering vehicle longevity and performance benefits through mixed material assemblies; enabling the greater use of nondestructive, software-based modeling and testing to support safe and reliable vehicle operation; and delivering more design flexibility needed to enhance durability, end-of-life vehicle recyclability, and circularity. Specific vehicle design elements and requirements that will be impacted include:

## > Lightweighting

## > Multimaterial Joining

## > Nondestructive Evaluation

# Lightweighting

Plastic honeycomb floor rocker reinforcement

## DESIGN IMPACTS

Several components including batteries, sensors, electronics, motors, and wiring harnesses are expected to increase the average weight of future vehicles by hundreds of pounds. On average, the components required for Level 4 and 5 autonomy may add 300-400 pounds to vehicles.[40] Automakers will **require high strength-to-weight materials to offset added weight** increases and improve vehicle travel ranges and efficiencies.

Automakers are unlikely to rely on single material solutions to offset the added weight of batteries and autonomous safety systems. Instead, automakers **incrementally replace or introduce new materials and components** as a low-cost, low-risk approach to reduce vehicle weight.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Fiber-reinforced polymers** (including glass and carbon fiber composite and intermediate materials) can enable complex aerodynamic shapes while improving automotive safety, fuel economy, and performance.

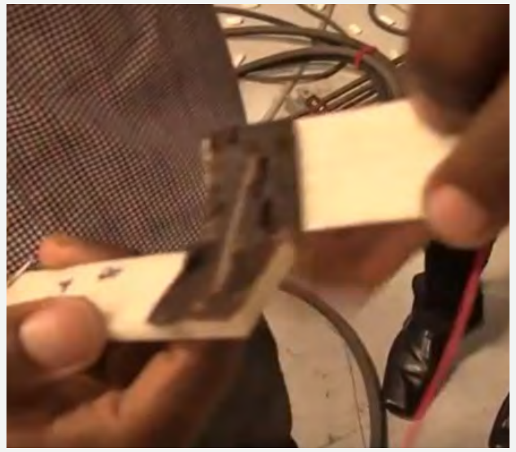
Advanced plastics and polymer composites reduce automotive weight by an average of 500 pounds.[42] Using **carbon fiber reinforced polymer composites for mixed-material designs** could reduce the weight of some automotive components by 50-75%.[43]

**Thin-walled composites and honeycomb materials** could help reduce vehicle weight and increase interior cabin space for passenger comfort.[41]

**Transparent polymers for window and glazing systems** can provide up to 40% weight reduction compared to glass systems, while also providing additional design freedom.[44]

| | | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|---|
| HIGH-PERFORMANCE MATERIALS | Continue sponsorship of critical R&D demonstration programs for polymer composites-intensive automotive designs | ● | | |
| | Demonstrate carbon fiber composite-intensive structures for battery electric vehicle chassis | ● | ● | |
| | Increase education and advocacy efforts to communicate automotive lightweighting benefits (e.g., environmental, vehicle range, safety); and increase public awareness on the safety, performance, and lightweighting attributes of advanced plastics and polymer composites | ● | ● | |
| | Demonstrate the performance benefits of advanced structural adhesives including low specific gravity adhesive systems for lightweight mixed-material assemblies | ● | ● | |
| | Develop integrated analysis techniques, test methods, and data to accelerate design of automotive plastics and polymer composites | | ● | |
| | Pursue innovative methods to optimize performance of plastics and polymer composites and procedures for replacing heavier parts | | ● | |
| | Coordinate with OEMs to define automotive specifications and materials properties; establish and maintain a database to support materials selection and design efforts | | ● | ● |
| | Demonstrate plastics and polymer composite intensive body in white (BIW) concepts that meet requirements for high-volume vehicle builds | | ● | ● |
| MIXED MATERIAL DESIGN | Conduct a demonstration project for automotive plastics or resin systems with high dimensional stability | ● | | |
| | Identify key automotive subsystem(s) with the greatest opportunities to replace structural components with new high-performance polymer composites (e.g., B-pillar structural components) | ● | | |
| | Conduct a demonstration project for plastics-intensive automotive interiors with focus on personalization and maximum cabin space | | ● | |

# Multimaterial Joining



Thermoplastic-based reversible bonding

## DESIGN IMPACTS

Satisfying automotive lightweight goals via mixed-material design approaches requires **consistent and reliable joining techniques** to bond or bolt together dissimilar automotive components.

To meet end-of-life recyclability goals, automakers will manufacture vehicles that are designed for **easy and economic disassembly** for life-extending refurbishment as well as recovery and reuse at the end of their usable life. Consolidating plastic parts and using recyclable polymer grades will help automakers achieve end-of-life recyclability goals.

Sensors, radar, LIDAR, cameras, and other electronics will add complexity to general assembly and testing of future automotive designs. **Replaceable or removable components could improve the maintenance-friendliness, repairability, and recalibration** of automotive sensors and safety system.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**Thermoplastic-based reversible bonding techniques** can permit the rapid assembly, disassembly, and repair of automotive components for meeting end-of-life recyclability goals.

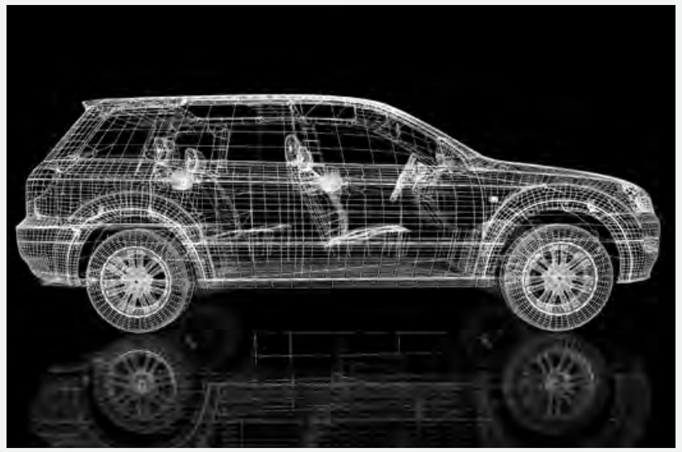
**Form-fitting advanced polymers** can be molded into complex shapes to fully encase automotive sensors and safety systems and can reduce assembly steps and cost compared to other materials.[45]

Materials innovations such as **novel curing systems** can permit the economic recovery of fibers from thermoset-based composites into remanufactured automotive components, thereby reducing landfill waste.

Materials like **resin-transfer-molded carbon non-crimp fabrics** can increase part consolidation, resulting in significantly fewer parts and less production floor space compare with conventional metal-based designs.[46]

| | | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|---|
| JOINING TECHNOLOGIES | Continue sponsorship of critical R&D demonstration programs for multimaterial joining processes | ● | | |
| | Identify industry-wide R&D demonstration opportunities to advance novel thermoplastic-based reversible bonding techniques to permit rapid assembly, disassembly, and repair | ● | | |
| | Determine infrastructure requirements for industry-wide automotive repair and replacement of in-service automotive plastics and polymer composites | ● | | |
| | Sponsor pre-competitive efforts to demonstrate the effectiveness of structural adhesives for multimaterial joining, disassembly, and repair | ● | ● | |
| | Demonstrate effective joining techniques for metal-composite hybrid structures | ● | ● | |
| | Coordinate an industry-wide design competition to create maintenance- and repair-friendly components for encapsulating sensor, LIDAR, and other machine vision components | | ● | |
| REFURBISHMENT AND RECOVERY | 9 **Demonstrate the performance benefits of structural adhesive joining techniques or plastics-based fasteners as a means for ease of maintenance, repair, and disassembly** | ● | ● | |
| | Identify an automotive subsystem that would benefit from re-design for ease of disassembly; sponsor a design pilot to demonstrate the concept through existing technology demonstration programs | ● | | |
| | Establish automotive industry standards and test methods (including tools and approaches for disassembly) for new interior composites applications | | ● | |
| | Coordinate an industry-wide initiative to encourage end-of-life disassembly procedures for improved recovery of automotive components (e.g., electronic components) | | ● | ● |
| SENSORS | Define application specifications to inform material suppliers of specific sensor placement/location for optimum multimodal sensor detection | ● | | |
| | Identify areas of vehicles with the greatest opportunities for consolidation of electrical parts using high-performance plastics and polymer composites | | ● | |

# Nondestructive Evaluation



## DESIGN IMPACTS

Manufacturers use NDE technologies to **evaluate part performance without causing damage to parts, reduce costly experimental testing, and validate predictive materials and manufacturing models**. As average vehicle usage rates increase and lifespans decrease, NDE techniques will become more useful for rapidly assessing the structural health and integrity of automotive components to ensure safety and reliable vehicle operation.

## OPPORTUNITIES FOR ADVANCED PLASTICS AND POLYMER COMPOSITES

**NDE technologies** are used for measuring resin concentration, fiber concentration, fiber loading, fiber size, fiber orientation, fatigue, disbands (interfaces), and delaminations (inter-layers) of fiber-reinforced polymer composites (FRPCs).

**Embedded structural health monitoring (SHM) technologies** could enable the detection of invisible damage in automotive FRPCs.

## SCREENING AND DEFECT DETECTION

| | NEAR (2020–2022) | MID (2023–2025) | LONG (2026–2030) |
|---|---|---|---|
| (10) **Develop embedded non-destructive failure and damage detection systems (e.g., SHM monitoring) suitable for all polymeric materials systems** | | ● | ● |
| Develop rapid scanning techniques for inspection of large area composite components | ● | | |
| Continue sponsorship of critical R&D demonstration programs that offer support for NDE techniques used in manufacturing processes and service/repair issues | ● | | |
| Establish consensus on test methods for evaluating long-term degradation and durability of advanced polymers and carbon fiber composites (e.g., NDE/SHM) | ● | ● | |
| Conduct a study to distinguish different types of defects (i.e., service versus manufacturing defects) and their impacts on lifetime performance and structural integrity | ● | ● | |
| Establish best practices to certify repair and replacement techniques for automotive plastics and polymer composites | | ● | |
| Enhance computer-aided engingeering (CAE) predictive capabilities (e.g., AI or machine learning based methods) to accelerate materials discovery for advanced plastics and polymer composites for safety applications | | ● | |
| Partner with academia to develop NDT/NDE methods for automotive plastics and polymer composites | | ● | |
| Create a technoeconomic model to evaluate the repairability of automotive polymer and composites | | ● | ● |
| Develop robust data analytics algorithms to support accurate interpretation of NDE sensor data | | ● | ● |
| Develop novel handheld technologies for inspecting large parts | | ● | ● |
| Develop multimodal sensor techniques capable of detecting a range of defects for various types of materials and structural components | | | ● |

# CALL TO ACTION

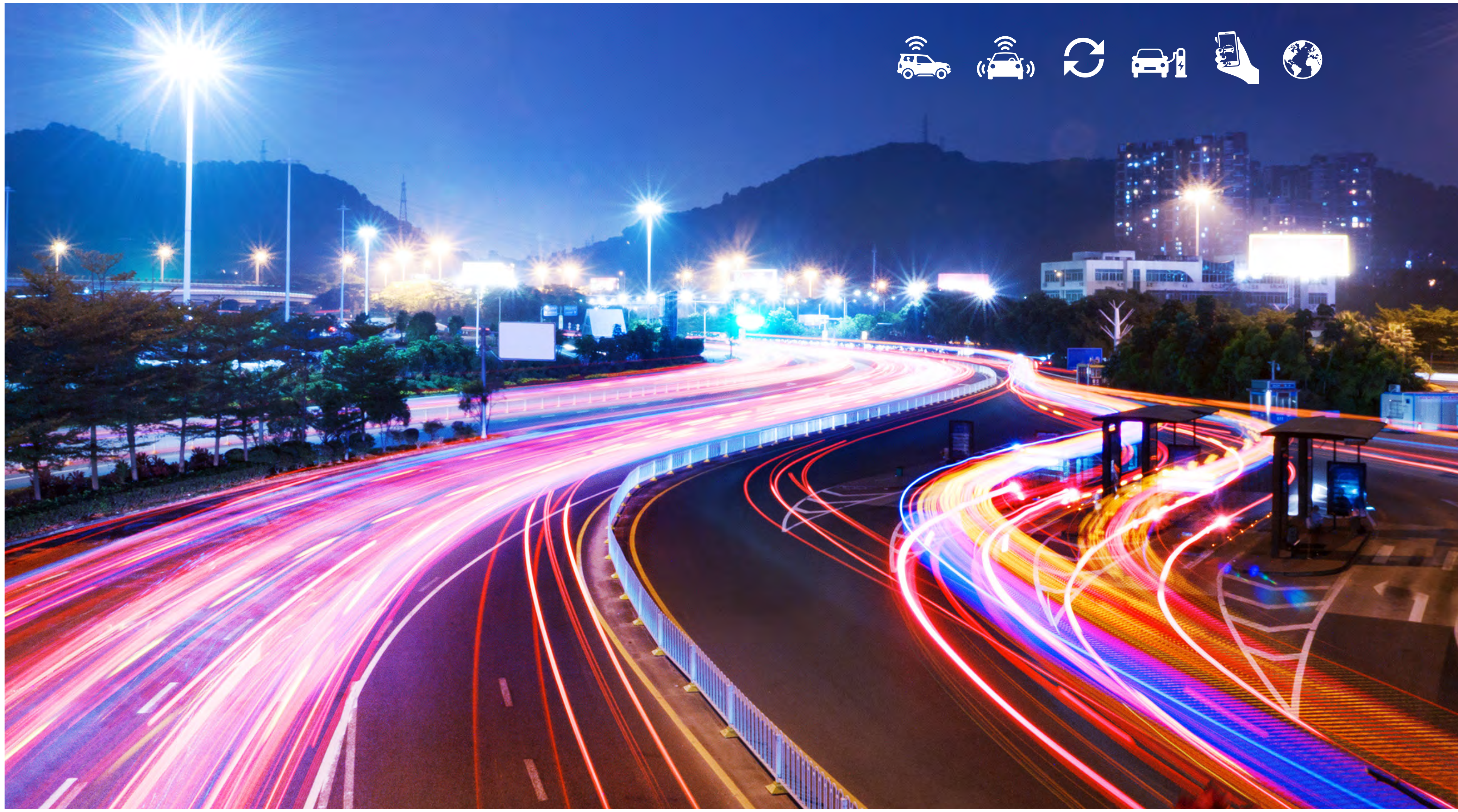
## >> Both independent and coordinated action is critical to accelerating progress toward safe, modern mobility solutions

As the personal mobility revolution continues to evolve, the potential for delivering and capturing business value in the automotive sector through materials innovation has never been higher. The advanced plastics and polymer composites industry is ready to work with automakers to reach new levels of automotive performance and provide consumers with the mobility experiences of the future.

The scope of the R&D activities outlined in this roadmap and level of investment required is beyond the means of any single organization. ACC will steward the roadmap's implementation but does not have the resources necessary to implement it in its entirety. **Both independent and coordinated action among stakeholders is critical**: industry partners—automotive advanced plastics and polymer composites providers, automotive OEMs, and suppliers—as well as academic and national laboratory researchers and government agencies must all work together to conduct the R&D activities and lead the initiatives outlined in this roadmap and accelerate progress toward safe, modern mobility solutions.

Leveraging the collective, cross-sector expertise and resources of these mobility stakeholders is the best way to unleash the full potential of advanced plastics and polymer composites. Together, we can create the breakthrough innovations needed to realize more affordable, accessible, sustainable, and environmentally responsible mobility solutions for all.

We need **your help** to realize the future of personal mobility. To get involved in this roadmap's activities, contact Gina Oliver at Gina-Marie_Oliver@americanchemistry.com



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# Appendix B. Acronyms

| | |
|---|---|
| **ACC** | American Chemistry Council |
| **ACCESS** | autonomy, connectivity, circularity, electrification, shared mobility, sustainability |
| **ADAS** | advanced driver-assist systems |
| **AI** | artificial intelligence |
| **APRR** | advanced plastic recycling and recovery |
| **BIW** | body in white |
| **CAE** | computer-aided engineering |
| **EMI** | electromagnetic interference |
| **EOL** | end of life |
| **EV** | electric vehicles |
| **FE** | finite element |
| **FRPC** | fiber-reinforced polymer composite |
| **IACMI** | Institute for Advanced Composites Manufacturing Innovation |
| **IoT** | internet of things |
| **IR** | infrared |
| **LCA** | lifecycle assessment |
| **LIDAR** | Light Detection and Ranging |
| **NHTSA** | National Highway Traffic Safety Administration |
| **NDE/NDT** | nondestructive evaluation/testing |
| **NVH** | noise, vibration, and harshness |
| **OEM** | original equipment manufacturer |
| **PHEV** | plug-in hybrid electric vehicle |
| **R&D** | research and development |
| **SAE** | Society of Automotive Engineers |
| **SHM** | structural health monitoring |
| **UV** | ultraviolet |
| **VOC** | volatile organic compound |
| **V2I** | vehicle to infrastructure |
| **V2X** | vehicle to everything |
| **V2V** | vehicle to vehicle |



# Appendix C. Notes


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