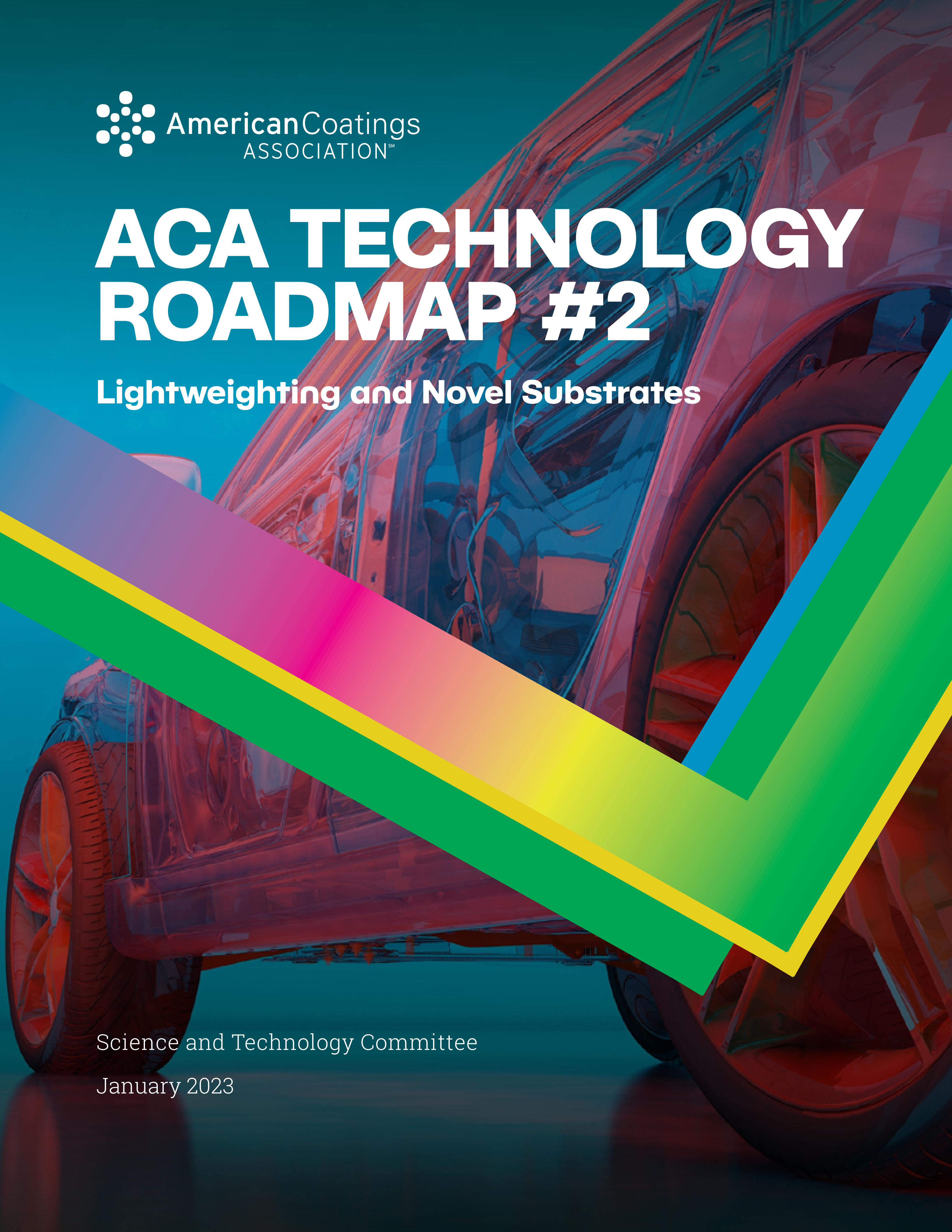
American Coatings ASSOCIATION℠

ACA TECHNOLOGY ROADMAP #2

Lightweighting and Novel Substrates



Science and Technology Committee

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EXECUTIVE SUMMARY

The American Coatings Association (ACA)[1] is developing a series of future-looking ACA Technology Roadmaps. Through a rigorous process, potential topics were identified (see Appendix A). This roadmap addresses the topic of lightweighting, which primarily involves the coating of novel substrates.

The aim of each ACA Technology Roadmap is to identify "open-innovation" research that supports both near- and long-term needs of the coatings industry. ACA Technology Roadmaps are not intended to promote or advance any product, practice, solution, or technology. Contributors were cautioned not to disclose any confidential business information. Where future collaboration is recommended, it is intended to comport with antitrust rules and be guided by legal counsel.

While the "lightweighting" topic arose from the ongoing efforts by the transportation industry to use lighter materials to increase fuel efficiency, discussions with experts also covered the trends toward vehicle electrification, autonomous driving, and even lightweight building materials. Accordingly, the scope of this ACA Technology Roadmap considered research and development needs for paint and coatings products supporting end-user moves toward lightweight and novel substrates that address energy efficiency, electrification, infrastructure construction, and 3D-additive manufacturing.

Through a series of expert interviews and subsequent consensus-building discussions, the following **recommendations emerged** to guide forward-looking research efforts by the coatings industry to address industry-wide challenges presented by lightweighting and novel substrates.

1. Establish well-defined grades for aluminum, its alloys, and other novel substrates. Consider encouraging these industries to create substrate certification systems.
2. Determine the degree to which recycled content affects surface energy and coating adhesion (e.g., polyolefin car bumpers), including in the refinish market.
3. Establish criteria on which types of paint can and cannot be detected ("seen") by autonomous vehicles.
4. Better define the challenges of painting 3D-printed surfaces, such as release agent residues and surface roughness.
5. Expand the current set of additives that modify rheology so that coatings better cover rough surfaces and around edges of substrates.
6. Expand the current set of other additives to improve adhesion to substrates with complex surface energies.
7. Encourage further collaboration between coatings suppliers and equipment manufacturers to address rheology challenges, for example, by the use of digital ink heads to spray automotive coatings to achieve a flawless appearance.

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[1] The American Coatings Association (ACA) is a voluntary, nonprofit trade association working to advance the needs of the paint and coatings industry and the professionals who work in it. The organization represents paint and coatings manufacturers, raw materials suppliers, distributors, and technical professionals. ACA serves as an advocate and ally for members on legislative, regulatory, and judicial issues, and provides forums for the advancement and promotion of the industry through educational and professional development services.

8. Develop new tools and modeling capabilities for *in situ* monitoring and predictive modeling to study the complex interactions between new substrates and paint formulations.
9. Better equip raw material suppliers and applicators with the tools and methods to evaluate the environmental impact and sustainability of coatings, especially those with lower cure temperatures.
10. Consider encouraging the building materials industry to establish specifications for "lightweight" concrete to aid the development of moisture-barrier coatings.

Ideally, one could envision a scenario where substrates are well-defined, and the resins used in paint formulations could be applied over multiple substrates enabled by new additives that would provide the application-relevant rheology, adhesion, and cure. Additionally, new application methods could reduce waste and enable lower coat weights.

Background on the ACA Technology Roadmap Project

ACA, through its Science and Technology Committee, is developing a series of ACA Technology Roadmaps that aim to establish broad technical consensus on industry-wide "open-innovation" research that supports both near- and long-term needs of the coatings industry. A rigorous, multi-step analysis was undertaken to identify potential ACA Technology Roadmap topics, the result of which is included in Appendix A. Once a topic is selected for development from the list, ACA staff and a diverse set of industry leaders – through a consensus-based process – identify research that has the potential to advance industry sustainability and growth by informing manufacturers, raw materials suppliers, academic institutions, government research laboratories, and other research organizations.

This second ACA Technology Roadmap examines the trend toward lightweighting, which involves the coating of novel substrates. The first topic addressed the industry's challenges in sustained use of critical materials for formulating both existing and emerging products. Refer to the first ACA Technology Roadmap for a more detailed discussion of the project's aims, benefits, and execution.[2]

First and foremost, the **ACA Technology Roadmaps are not intended to promote or advance any product, practice, solution, or technology over or to the exclusion of others, nor restrain in any fashion the individual competitive effort of any company. Rather, the ACA Technology Roadmaps are intended to drive innovation and competition by broadly sharing identified technological needs of the industry.** Further, the process used to develop content was carefully established to ensure contributors were cautioned not to disclose any confidential business information, research plans, or competitively sensitive information. Where further collaborative action among companies is recommended, it is intended to be with the consultation of legal counsel to ensure compliance with antitrust rules and other applicable laws.

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[2] Available at https://www.paint.org/wp-content/uploads/2022/08/ACA-Technology-Roadmap-1.pdf

ACA TECHNOLOGY ROADMAP #2: LIGHTWEIGHTING AND NOVEL SUBSTRATES

Introduction and Scope

The topic "lightweighting" arose from the ongoing efforts by the transportation industry (which includes aerospace, marine, and automotive) to reduce the weight of its vehicles to increase fuel efficiency. The transportation industry is achieving weight reduction by moving from traditional heavy structural materials (e.g., steel, other ferrous alloys) to lighter materials (e.g., aluminum and related alloys, plastics, composites). Knowledge gained with these new, lighter materials has allowed for their wider use in a variety of manufacturing settings (including additive manufacturing and 3D printing parts). This, in turn, reduces transportation costs for finished goods and facilitates, simplifies product design and production, and enables easier materials handling and more widespread product delivery. Coatings used on the novel "lightweight" materials often require formulation and application changes. Some transportation sectors desire thinner layers of coatings to lightweight the vehicles.

It is important to note that, along with lightweighting-related product design efforts, the automotive industry is also advancing electrification and moving away from traditional fossil fuels. Electric vehicles, with their required batteries, are inherently heavy and have their own unique material/substrate requirements emanating from challenges in heat control, insulation, and fire protection. Coatings required for new materials used in electric vehicles require formulation and application changes as well. Also, while not related to lightweighting per se, the emerging area of autonomous driving technology has its own unique set of formulation issues for coatings applied to new substrates to promote surface reflection ("visibility") of vehicles, and for roadway lane markings and signage to be detected ("seen"), as well as the objects along the route (i.e., support the use of light-detection and ranging radar).

Also arising out of the discussions for this Technology Roadmap were coatings formulation considerations associated with changes in substrates for infrastructure and building products.

Based on the above, the list of industrial sectors considered in this Technology Roadmap were:

- Aerospace (i.e., aluminum, alloys, composite carbon-fiber plastics)
- Road vehicles (i.e., aluminum, composite carbon-fiber plastics)
- Infrastructure (i.e., lightweight concrete and structural composites)
- Additive manufacturing (i.e., 3D printing)

This Technology Roadmap, through expert interviews, identified research and development needs for paint and coatings products supporting end-user movement toward lightweight and novel substrates that address energy efficiency, electrification, infrastructure construction, and 3D-additive manufacturing.

Performance Challenges Related to Lightweighting

Historically, coatings used in industrial coating applications have provided benefits beyond a beautiful, weatherable finish: they have increased the lifetime of assets by reducing the detrimental effects of wear and corrosion. One of the most coated substrates in these applications is steel, which comes in a multitude of well-defined grades. However, as steel shortages continue and the industry moves toward lightweighted substrates for improved fuel economy, among other benefits, the value a coating provides has shifted from protecting the steel from corrosion to protecting the lightweight substrate from UV damage, providing a defect-free finishes over rough surfaces, and reducing the environmental impact of the coating.

A significant challenge for coatings on lightweight substrates is caused by new/different surface profiles and surface energies compared to standard-grade steel. Many of the lightweight materials lack the substrate specifications and the consistent material content that steel has provided, thereby creating a "guessing game" when selecting a paint formulation. Many of the lightweight materials also contain a percentage of recycled content, which may not be noted in the substrate's certificate of analysis and can dramatically change the surface energy. Thus, two shipments of the "same" material can have vastly different surface characteristics, providing good paint adhesion to one but not to the other. An example of this problem has been highlighted in developing refinish coatings for polyolefin bumpers where the level of recycled content determines the surface energy. In some cases, a paint is chosen based on a previous recoat job yet fails to adhere to the new job. This requires paint removal and a complete repaint job. Lack of substrate definition and consistency has created a challenge for formulators who seek to develop coatings that will adhere to multiple grades of lightweight materials, thereby simplifying inventory and improving waste management.

3D printing is another exciting advancement in lightweighting as it creates more design freedom and provides companies the ability to prototype and test ideas through small-batch runs. It also allows custom-made parts, often faster and more accurately than by traditional machine shops. 3D printing typically uses a combination of materials, including carbon fiber, plastic, and metals. 3D printing, however, leads to many of the previously described challenges regarding surface wetting and adhesion. Release agents are often added to the 3D printing formulations to help release the generated part from the mold. Unfortunately, many of the release agents stay with the part and dramatically change the surface energy based on the location of the additive. In addition, these substrates often have more surface roughness and a much higher profile than standard grades of steel, creating unique surface physics that can adversely affect adhesion of the applied coating.

Needed Innovation

DEFINITIONS

Although seemingly trivial, a major need in lightweighting is improved definitions and standards around lightweighted materials (composition, recycled vs. virgin content, environmental profile, etc.). Just as steel has many different grades and different properties related to each grade, the new materials are equally diverse. Industry groups should define and characterize the new materials to provide greater clarity to coating manufacturers and additive suppliers. Certifications could be developed that would ensure a material meets a set of specifications. Such certifications would provide better predictability on surface physics that can help to inform coating design and selection.

ADDITIVES

A growing challenge in lightweighting is the development of formulations that have the right flow and leveling properties over rough substrates using the current set of rheology additives. Rheology and flow properties are particularly important around edges and over rough surfaces where it can be difficult to maintain consistent film thickness. Thinning or balling of the coating in these areas can cause poor coating appearance or reduction in corrosion protection. New rheology modifiers are needed to provide improved coverage over rough materials. For example, new research has shown that digital ink heads can be used to spray automotive coatings, thereby overcoming some of the biggest challenges, such as maintaining a flawless automotive appearance. In that case, collaboration between coatings suppliers and equipment manufacturers was essential to identify digital ink heads as a way to address rheology challenges. Such collaboration may successfully address other rheology challenges.

Rheology modifiers and other additives also play an important role in reducing the amount of paint required to coat a part. This can be accomplished by achieving maximum transfer efficiency (zero overspray) or enabling lightweighting through reduced coating weight on the part (e.g., by reducing layers from a multilayer paint system or by reducing the coating thickness of a single layer).

Lastly, new additives are needed to improve adhesion to substrates with complex surface energies. Many of the adhesion promotors used today have been designed specifically to improve adhesion to traditional substrates, such as steel. As surfaces change with new substrates and recycled content, or require different refinish considerations after damage, the traditional additives may no longer provide adequate adhesion.

TOOLS

New tools and modeling capabilities are needed for *in situ* monitoring and predictive modeling to study the complex interactions between new substrates and paint formulations. It is difficult to *a priori* determine the flow, leveling, and adhesion of a coating to a mixed or poorly defined substrate, and there are few tools to stimulate complex interactions to help formulators understand real-world conditions for applied films, underscoring the realities of multi-layer coatings that are used under changing temperature and humidity levels in different regions of the world. Today, many problems can only be analyzed after the damage has occurred, which does not always provide insight into mitigation strategies.

SUSTAINABILITY METRICS

Lightweighting is linked to sustainability goals. Companies are developing strategies driving towards efficiency, durability, a circular economy, carbon neutrality, solar reflectivity, and/or considering strategies for increased repurposing, reuse, recycling, and biodegradability.

As customers demand more sustainable solutions, companies are looking beyond their own manufacturing processes to achieve sustainability targets. Determining the full environmental profile, however, can be challenging because many raw material suppliers do not have their products characterized in a meaningful way (e.g., life-cycle analysis, paint shop modeling). Equipping raw material suppliers and applicators with the tools and methods to evaluate the environmental impact of variables such as coating thickness, resin cure time and temperature, materials consumption, waste streams, refinish, and end-of-life disposal is needed to assess the full environmental impact of their products and services.

As an example, lightweighting substrates often require lower cure temperatures. The drying ovens used to cure paint are often the largest consumer of energy throughout the life cycle of the part. Painted steel is often cured at 150 °C, while plastic or carbon-fiber composite parts have a maximum cure temperature of 100-120 °C (or even down to 80 °C in some instances). Ideally, new coatings that can be cured over a broad temperature range (80-150 °C) would allow them to be used in any factory setting regardless of the oven temperature.

BUILDING MATERIALS

The changes in concrete mixing systems to support pumping during construction has resulted in what is considered a "lightweight" product. Of particular concern to coatings manufacturers providing moisture-barrier products for structures made with "lightweight" concrete is the variability in the substrate and the lack of consistent specifications. While considerable variability in the surface energy of concrete substrates is unlikely, the underlying performance requirements for applied moisture barriers must be met.

Summary of Required Key Advances

The following takeaways have been extracted from the discussion presented above to guide forward-looking research efforts by the coatings industry to address the challenges faced industry-wide by lightweighting and novel substrates.

1. Establish well-defined grades for aluminum, its alloys, and other novel substrates. Consider encouraging these industries to create substrate certification systems.
2. Determine the degree to which recycled content affects surface energy and coating adhesion (e.g., polyolefin car bumpers), including in the refinish market.
3. Establish criteria on which types of paint can and cannot be detected ("seen") by autonomous vehicles.
4. Better define the challenges of painting 3D-printed surfaces, such as release agent residues and surface roughness.
5. Expand the current set of additives that modify rheology so that coatings better cover rough surfaces and around edges of substrates.
6. Expand the current set of other additives to improve adhesion to substrates with complex surface energies.
7. Encourage further collaboration between coatings suppliers and equipment manufacturers to address rheology challenges, for example, by the use of digital ink heads to spray automotive coatings to achieve a flawless appearance.
8. Develop new tools and modeling capabilities for *in situ* monitoring and predictive modeling to study the complex interactions between new substrates and paint formulations.
9. Better equip raw material suppliers and applicators with the tools and methods to evaluate the environmental impact and sustainability of coatings, especially those with lower cure temperatures.
10. Consider encouraging the building materials industry to establish specifications for "lightweight" concrete to aid the development of moisture-barrier coatings.

Lightweighting challenges cannot be solved by individual players alone. Successful solutions require all players in the value chain to collaborate: resin suppliers, additive manufactures, industrial groups, equipment manufacturers, applicators, and owners. Ideally one could envision a scenario where substrates are well-defined, and the resins used in paint formulations could be applied over multiple substrates enabled by new additives that would provide the appropriate rheology, adhesion, and cure. Additionally, new application methods could reduce waste and enable lower coat weights.

APPENDIX A

ACA Technology Roadmap Project – Development of Topics

ACA's Science and Technology Committee initially considered a wide assortment of "research themes" to elaborate upon in subsequent, targeted discussion aimed at creating ACA Technology Roadmaps. Discussions eventually identified several broad categories and related subcategories, which allowed for organizing and prioritizing the effort. These are highlighted below, and those marked in bold text are the consensus areas for initial focus. Content in italicized text will be considered in the future.

1. Materials (i.e., availability, safety, performance)
    - **a. Sustained use of critical materials**
    - *b. Renewable, reduced carbon footprint (bio-based materials, substantiation of life cycle)*
    - **c. Reducing regulatory uncertainties – technical/testing methods**
2. Formulation (i.e., dispersion/use/performance in coatings)
    - **a. Dispersibility (understanding colloidal stability, nanomaterials, pigments, etc.)**
    - *b. Speeding up development process (predictive modeling/artificial intelligence/machine learning, automation/high throughput/accelerated testing)*
    - **c. Initial visual appearance and performance impacted by film formation, dampening, flow and maintenance of appearance**
    - *d. Wet-state preservation and supply-chain impacts (ties into sustained use of critical materials)*
3. Application (i.e., substrate/flow/cure)
    - **a. Coatings challenges presented by lightweighting and new/mixed substrates (i.e., substrate change over time and substrate-surface interaction)**
    - *b. Waterborne systems (broader application robustness)*
    - **c. Kinetics control (curing, drying for technologies)**
    - *d. Improved transfer efficiency (application-related equipment)*
    - *e. Predicting end-use performance with lab testing (i.e., modeling)*
4. End use and product
    - *a. Predicting lifetime performance (i.e., accelerated testing, predictive modeling, sensors)*
    - **b. Durability and water resistance of waterborne systems**
    - *c. Enhanced physical properties (including durability, scratch, mar, flexibility, toughness, mechanical, etching, chemical resistance)*
    - *d. Improved adhesion on all substrates and under all conditions*
    - *e. Improved environmental durability (i.e., weathering, color stability, UV and other natural exposures) and maintenance of appearance (aesthetics of color, sheen, etc.)*
    - **f. Improved corrosion and infrastructure protection**
    - **g. Enhancing value of coatings through non-traditional attributes (functional coatings)**
5. End of life
    - **a. Improved recyclability of unused product, applied film, and the package**
    - *b. Better evaluation tools for assessing full-system impacts (i.e., "cradle-to-cradle" and "eco-footprint" methodology and other predictive models for "end of life")*