American Coatings Association℠

ACA TECHNOLOGY ROADMAP #1

Sustained Use of Critical Materials

ACA Science and Technology Committee

August 2022

EXECUTIVE SUMMARY

The American Coatings Association (ACA)[1], through its Science and Technology (S&T) Committee, is developing a series of Technology Roadmaps that aim to establish broad technical consensus on actionable research that is organized according to "themes."

Through an open, collaborative, and consensus-based process, ACA staff and industry leaders seek to identify research needs that have the potential to advance industry sustainability and growth by informing manufacturers, raw materials suppliers, academic institutions, government research laboratories and other research organizations.

The first of these themes looks at the industry's challenges in sustained use of critical materials for formulating both existing and emerging products.

The rigorous, multi-step analysis undertaken for this Technology Roadmap collected consensus-based input from a diverse set of industry experts using anonymous initial surveys followed by personal interviews to explore identified concepts for consideration. The resultant synthesis of potential consensus points was further refined by broader industry peer review. Key considerations included exploring the relevance and value of materials for coatings, the definition and communication of "safety," the challenges of formulation and application, the importance of customer relationships, and the overall industry posture on emerging public policy with respect to product stewardship.

The **key considerations** offered in the findings of this Technology Roadmap include:

- The broad formulary required by an industry producing a diverse product line for an expanding group of end users (for both industrial and consumer products);
- The complicated "substitution process" for many unique raw materials;
- The role of the supply chain in supporting procurement and manufacturing use of new materials;
- End-user capacity for safe use and its relationship to product performance;
- Coatings industry collaboration and transparency on advancing policies and science requirements for safe materials; and
- Industry capacity for "proactive change," and its acceptance by a diverse customer base.

A **consensus vision statement** was developed for the industry's current and ongoing management of critical materials from consideration within this Technology Roadmap:

The coatings industry is recognized as a leader in supporting the underlying science and public policy for safe use of raw materials, accessing the most up-to-date information on product stewardship, and supporting established programs that both recognize and advance improvements in safe practices.

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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.

With this and future ACA Technology Roadmaps, the paint and coatings industry aims to build on its continued focus of offering paints and coatings that meet the needs of its customers without compromising their safety or endangering the environment.

Background on the ACA Technology Roadmap Project

For over two years, the ACA S&T Committee developed a plan for producing a series of ACA Technology Roadmaps intended to spur research and development needed by the industry. The goal of the project is to support both near- and long-term needs of the coatings industry in an "open innovation" setting by identifying and communicating basic and applied research needs to manufacturers, raw materials suppliers, academic institutions, government research laboratories and other research organizations.

First and foremost, the 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 Technology Roadmaps are intended to drive innovation and competition by broadly sharing identified technological needs of the industry. Further, the process used to develop report 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 herein, it is intended to be with the consultation of legal counsel to ensure compliance with antitrust rules and other applicable laws.

As one of the initial steps in project development, other similar efforts were consulted. The administrative processes used to achieve consensus (e.g., for water treatment industry see https://www.nrel.gov/docs/fy21osti/79886.pdf) were reviewed along with the technology roadmaps for the allied chemical industry (see https://onlinelibrary.wiley.com/doi/10.1002/anie.202014779), most notably in regard to sustainability efforts.

With this background, the ACA S&T Committee established a Steering Committee to hold initial, exploratory discussions on the development of ACA Technology Roadmaps for the industry and the formal process that would be used to solicit input and establish consensus. The following key guiding principles served to maintain focus during the development efforts.

VALUE OF COATINGS

The paint and coatings industry is an important and dynamic part of our nation's economy and plays a key role in creating products that help preserve and protect everything, from everyday objects to our most important infrastructure. Aside from providing aesthetic appeal, paints and coatings act as a protective barrier to extend the useful life of the surfaces and substrates to which they are applied. While often overlooked or invisible, coatings are indispensable products. Coatings not only preserve our cars and homes but also preserve the bridges we drive across and the tunnels through which we travel. They even save energy by keeping buildings cooler and provide many other benefits.

Practically every manufactured item has a coating, and the "value added" by the coating to enhance its performance or lifespan is extraordinary. References to paint and coatings go beyond paint used to cover walls in the home; enamels, primers, undercoats, stains, varnishes, aerosol paint, caulks, sealants, and adhesives are all coatings. And, more and more often, a thin film

of coating is being used to replace traditionally used materials — like plastic laminate —because of the ease, economy, and the technologically engineered advantages that coatings offer.

The paint and coatings industry is not only integral to providing products that sustain day-to-day living, but also provides jobs for its thousands of employees and end-use customers. The manufacture of paints and coatings is a small industry in the United States as compared with other industries, with some 41,300 workers.[2] Industry facilities are in urban areas like Chicago, Cleveland, and Louisville, as well as in Northern New Jersey, throughout California, Florida, and Washington State. However, it is important to note that the manufacture of paints and coatings feeds not only the health of jobs related to the sale of paints and coatings — paint and wall covering contractors, as well as retail establishments — but also those in manufacturing end-use markets that use those paints and coatings: auto, aerospace, paper, machinery, home appliances, electronics, wood furniture, and metal containers, among the universe of other applications.

Overall, the U.S. paint and coatings industry employs some 299,500 workers.[3] The U.S. paint and coatings industry includes manufacturers, raw materials suppliers, and distributors. Raw materials for paints and coatings are derived not only from petroleum and minerals, but also from natural products, such as clays, tree saps, and vegetable oils. Petrochemicals are still among the most critical raw materials, and the industry is seriously affected by petrochemical shortages and price fluctuations.

IMPORTANCE OF RESEARCH TO COATINGS

The coatings industry makes use of an extremely broad array of materials, knowledge, equipment, and sciences to make effective and durable products.

Coatings contain polymers, solvents, minerals, biocides, pigments and more, and the potential for interactions within this complex product formulation requires its own knowledge and science. Additionally, as they are used to coat vastly different surfaces ranging from medical devices to concrete, the industry must command a detailed knowledge of a coating's behavior as it is formulated, manufactured, packaged, applied, cured, used, repaired, and recycled. Application of chemistry, microbiology, physics, and mathematics are all essential components of the required expertise to produce a viable coating product.

The coatings industry and its supply partner industries are one of the most intense generators of intellectual property. In 2020 alone, more than 40,000 patent applications were made in the fields relatable to coatings. Most of these were application patents with a myriad of uses. To sustain and expand this growth, however, advances are needed in several areas of basic research. According to the National Science Foundation (NSF), data support the conclusion that basic science research assists the production of innovation peaks.[4]

Surveys of coatings scientists reflect the need for progress in underlying knowledge if the industry is to continue its global leadership in innovation, particularly those innovations leading to a whole new class of coatings and coatings performance. The competitive position of coatings as a technology and their advancement depends on new developments in chemistry, microbiology, physics, and mathematics that can then be applied to provide innovative products that will serve to meet the demands of our world in the decades to come.

NOTE: Appendix A provides a more detailed description of the development topics contemplated for future ACA Technology Roadmap efforts.

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2 Statistics are from the U.S. Bureau of Labor Statistics' Quarterly Census of Employment and Wages. Labor statistics were derived using the following NAICS Code 325510 Paint and Coating Manufacturing (see https://www.paint.org/about/industry/economic-contributions/

3 U.S. Bureau of Labor Statistics' Quarterly Census of Employment and Wages

4 https://www.nsf.gov/eng/iip/innovation.pdf and https://nsf.gov/nsb/publications/2012/nsb1203.pdf

ACA TECHNOLOGY ROADMAP #1: SUSTAINED USE OF CRITICAL MATERIALS

Relevance and Value

It is possible that no other industry uses and depends on such a wide variety of raw materials as does the coatings industry. ACA has often advocated that more than 20,000 discrete chemicals are used in paints and coatings, which does not include myriad proprietary materials or base stock materials from which they are produced. The average coatings firm uses as many as 1,500 to 2,000 materials to produce its product line at any time. These materials include polymers, pigments, solvents, biologicals, and minerals. Substitution of any one of these materials is an arduous and rigorous process to ensure that established product safety and multifaceted performance are not compromised. Thus, a critical need for long-term coatings industry growth and relevance is a continual supply of new, functional, and safe raw materials.

To meet this need, coatings manufacturers and raw material suppliers must work diligently and rely on current science and sustainable practices to ensure that all raw materials (those used currently and potential substitutes), as acknowledged by procurement, manufacturing, applications, and end users, are reliably safe, functional, and lasting. Consensus definitions of safety based on current science and regulatory policy are essential to guide product development and ensure a continued and viable product line. Raw materials that allow coatings to meet ever-more-stringent regulations are of particular interest today and for the foreseeable future.

Materials used and developed for the coatings industry provide a major contribution to the U.S. economy. Finished coatings by U.S. manufacturers are valued at $26.1 billion[5] dollars, and the industry and its efforts to support new product development provide employment for thousands of researchers in industry, academia, and government.

The remaining sections of the Technology Roadmap outline the key considerations raised by the interviewees. Under each heading, the bulleted list captures the insights provided by the various experts consulted during the interview process. General considerations are presented first, followed by four specific categories of critical materials.

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[5] U.S. Census Bureau's Annual Survey of Manufactures. Data for 2020 are the most recent available from the U.S. Census Bureau

Considerations of "Safer" Materials

- While terms like volatile organic compounds (VOCs), green chemicals, and sustainable development have gained some familiarity with the public, the concept of what is a "safer material" is complex and may not be widely understood by occupational and consumer end users of chemicals and formulated products.
- The definition of these terms varies widely across industries, consumer groups, and regions.
- Some may classify safety based on "low odor," while for others, long-term health risks associated with exposure are the major concern, and still others focus on environmental safety.
- Priorities for seeking chemical and formulated product safety are often different among groups, especially parents, other care givers, and sensitive populations.

Consideration of Safety Communication

- As there is agreement around the lack of knowledge associated with the definition of "safer" materials, it is essential for industry communications to offer education and insight around the terms used in this report, to ensure they are clear, concise, and easily understood.
- There are multiple safety and sustainability terms that are used in communications (e.g., carbon footprint, life-cycle assessment, eco-label programs). Each of these terms has benefits, but each was designed to meet the needs of a specific audience and most people do not understand the terminology or know how to interpret their underlying reference. Use of such terms may not be the most effective/accessible way to present safer materials.
- Social media and other outlets of public perception are powerful forces in today's world and should be considered and utilized for effective communication.
- To be successful in advancing safe formulation, use, and disposal of paint and coatings products, everyone (companies, raw material suppliers, formulators, industry consortia, advertisers, customers, etc.) must be involved in education and awareness raising, as no group can do it alone.
- All materials, both existing and new, have benefits and risks associated with their use. It is important to educate the public about the industry's decision to provide safe manufacturing and use of products. This commitment to open and candid communication can help advance innovation and promote the use of safer alternatives.
- In many cases, the technology-forcing regulations compelling the move to "safer" materials can mean more expensive inputs and higher manufacturing costs. In some cases, business opportunities may lag in regions where regulations do not mandate the use of safer alternatives. Despite this, companies should consider embracing the practice of advancing safe use of materials everywhere, not only in regions that require it.
- Consumers say they want safer materials but may buy what is cheaper and "safe enough." This paradox must be confronted by coatings manufacturers, and education is key.

Challenges to the Sustained Use of Critical Materials

- For all products (both existing and safer alternatives), the industry needs to rely on proper application and other end-user constraints to get a high-quality finished substrate. New, safer materials that disrupt the ability to achieve this face obstacles to acceptance.
- Confirmation bias[6] may play a role in assessing market acceptance for new, safer materials and products.
- Where cost is a barrier to acceptance of new, safer materials, advancing acceptance will require different strategies for "Business to Business" (B2B) versus "Business to Consumer" (B2C). Claims (and supportive data) with equivalent (or better) performance than existing materials can make a difference, but acceptance of increased costs only comes with the confirmed performance improvements for critical innovations (e.g., aerospace, where critical life-safety performance requirements are paramount). In addition to achieving equivalent (or better) product performance, creative marketing/consumer education efforts are important to explain why the benefits of the use of safer materials justify a higher cost.
- Innovation for safer materials is often stymied when developers and potential end users do not have a "voice" in the process of regulatory approval. At the same time, timely industry efforts to advance risk management and use benefits strategies often are deemed insufficient when policymakers want risk elimination.
- While alternatives to known hazardous materials can be offered as a safety benefit, the fact that they may not have as much data supporting their inherent safety may be a barrier to acceptance. In addition, the cost of acquiring additional safety data (i.e., toxicity testing) may preclude substitution.
- Policies that support transparency of information on the safety of materials can help drive awareness and educate all customers, advancing acceptance. This can also provide for a level playing field for product manufacturers. These policies center around hazard communication (e.g., product labeling) and green product standards (with objective criteria).
- Proactive efforts by manufacturers to adopt safer technologies can have short-term business impacts, but may also offer prospects for continued or expanded long-term business. As a result, institutionalizing proactive substitution, given the varied outcomes, is a challenging goal to achieve in the broader coatings marketplace.
- Safer materials with unproven supply chains are not likely to be embraced by coatings companies. Likewise, safer materials that have not been through required regulatory hurdles (e.g., TSCA evaluation, REACH registration, biocide approval in all markets) will not be accepted.
- Collective efforts to advance proper risk assessment on safer materials (i.e., life-cycle assessment vs. conventional risk assessment) and common-sense advocacy on what constitutes "safer" materials and products is required to create a pathway to acceptance. This effort must be undertaken by and for coatings companies, as reliance on raw material supplier approaches may be insufficient to affect change.

Opportunities for Consideration and Advancement

- It is a widely shared sentiment that advance action in support of critical materials would benefit the industry, especially if undertaken before public concerns and regulatory interests require a retrospective industry response.

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6 https://www.britannica.com/science/confirmation-bias

- The industry should acknowledge published data and case studies that advance the positive impacts it is having on concerns such as global warming through cool roofing coatings, use of recycled plastics, and other innovations.
- The industry should do more to develop collaborative relations and projects with third parties, micro influencers, regulators, insurance companies, NGOs, and other stakeholders with good standing and responsible positions to help educate consumers and standardize necessary definitions like "green," "sustainable," etc.
- The industry should work aggressively and collaboratively, using an appropriate mechanism for research, and invest in the development of data sharing and technical approaches for testing, analytical equipment/methods, and toxicity models that support innovations in safety.
- Links should be established to published databases that provide both available and developing information on the safety and environmental impacts of existing and new materials. The referenced databases should help identify alternative feedstocks for production and the potential impacts of their widespread and diverse end uses (e.g., biobased materials in competition with food uses). Linkages to regional use approvals for such materials (e.g., government green purchasing requirements) can help in decision-making and fact-checking for broader markets.
- Available data on both new/developing materials and existing feedstocks should be revisited to expand the underlying basis for continued safe use to identify potential forward-looking safety testing needs.
- A major opportunity for broad industry collaboration lies in devising specifications for enhanced, readable, modern, and simple label/scannable information for all end users that supports outreach and education on product safety and function.
- In general, there are considerable advantages for expanding programs to educate consumers/industrial end users, policy makers, and other influencers on the requirements for the composition of coatings, the formulation impacts on their broad utility, and, where appropriate, the continued need to require use of personal protective equipment (PPE), including respiratory, skin, and eye protection. This could be accomplished through webinars, case studies, and other new media formats based on good science. Awareness and interest, especially among younger end users, will continue to grow, albeit slowly.
- There are technical challenges that could benefit from collaborative efforts, including securing government funding (i.e., through the NSF, Department of Energy, or Department of Defense), and addressing scale-up barriers for producing commerce-ready materials.

General Considerations for Industry to Explore

- Consider establishing an industry working group to discuss "Sustained Use of Critical Materials for Coatings." This group should include scientists, product stewards, marketing/communications staff, and other stakeholders. The exercise itself is the benefit, generating better understanding, positive image possibilities, customer education programs, and labeling improvements.
- Consider forming a coatings consortium to investigate, support, and fund research that could spur innovations in product safety. Such research could include advances in risk assessment models and analytical tools.

CRITICAL MATERIALS – FOUR FOCUS AREAS

In developing this Technology Roadmap, four categories and/or characteristics of critical materials were discussed to identify areas for further focus. The four categories were:

- Biocides
- Human sensitizers
- Alkylphenol ethoxylate (APEO) surfactants
- VOC/Maximum Incremental Reactivity (MIR)-compliant materials

In exploring these four categories, the participants applied the general principles identified previously but were requested to offer integrated content, based on their awareness of current practice and efforts in support of safer materials in each category. The following specific, consensus takeaways emerged from the project's extensive and open review process.

The Biocides Roadmap

CHALLENGES

- Replacing current biocides with new ones is extremely difficult from a cost and regulatory standpoint. The lack of reliable toxicity models and experimental data increases registration timelines.
- Currently, there are few materials with the right performance (biocidal activity) that are also considered safe in conservative risk assessments conducted by regulators.
- In many instances, the consequences of biocide failure in coatings are real and expensive.
- Better education among formulators regarding the function and risks associated with biocides may help to better target their use.
- Biocides are required to enable waterborne technology, yet there is a lack of understanding whether waterborne solutions are inherently more ecofriendly (e.g., from an LCA perspective) at the outset.
- New materials require new supply chains. It is challenging to bring new materials to the market with uncertainty in demand and/or required supply.

TECHNOLOGY GAPS/RESEARCH NEEDS

- Currently, there are no materials that are recognized as matching the cost and performance of today's biocides. To bring alternative materials into this space, better toxicity models and long-term exposure data need to be generated. Industry collaboration can help all companies to get through the registration process and supply-chain challenges.

OPPORTUNITIES

- Developing toxicity data and other critical information is costly and time-consuming; by working together, companies and industry consortia can develop new models and experimental data to quickly screen for toxicity and potential insights on efficacy.
- New materials require reformulation; formulators must be offered support or incentives to convert to safer alternatives.
- It is important to provide education on the safe use of current biocides (including proper PPE) and new alternatives.

RECOMMENDATIONS

- With government and industry funding, initiate and support a center to advance the availability and use of biocides including jointly funded research on materials and methods of evaluation/safe-use prediction.

VISION STATEMENT

- Enable the development of safe biocides that become widely available to support innovation of new coatings products and are not an impediment to achieving other safety goals, both human and environmental.

The Human Sensitizers Roadmap

CHALLENGES

- The topic of sensitization is not well understood, and it is widely acknowledged as something that triggers a response in some people yet does not affect others. Without a thorough understanding of the problem, newer alternatives may have similar problems as incumbent materials.
- Proper PPE has been the most effective method for handling sensitizers. Focus should be on education and use of proper PPE, especially in spaces such as do-it-yourself (DIY).

TECHNOLOGY GAPS/RESEARCH NEEDS

- New materials require new formulations, so businesses should be offered support or incentives to convert to advance product safety-related changes.
- Research should be conducted to identify new, non-sensitizing materials and document their performance in real-use scenarios.

OPPORTUNITIES

- Customers can be better educated on the hazards/risks of specific ingredients in paint and best handling practices. Proper PPE has been the most effective method for handling sensitizers. Focus should be on education and use of proper PPE, especially in spaces such as DIY.
- Apply for available funding from agencies, such as NSF, to support non-sensitizing options.
- Engage with U.S. EPA and toxicology experts to develop new and reliable toxicity sensitization models to expedite the development of new materials.

RECOMMENDATIONS

- Investigate the development of new and reliable toxicity sensitization models to expedite the development of new materials. In the event such a group exists, offer to join that group if coatings interest can be achieved.
- PPE, its current status, development activities, and educational opportunities should be the focus of an annual ACA conference, as it relates to coatings. This could be the basis of a joint research investment, if warranted, and even organized outside of ACA.

VISION STATEMENT

- Available PPE, sensitization test methods, and knowledge for coatings applications is considered the foundation for advancing new technology.

The APEO Surfactants Roadmap

CHALLENGES

- A number of APEO surfactants and metabolites have shown some evidence of being endocrine disruptors, which has led to efforts to phase out use in paints and coatings.
- Regulatory flexibility does not seem likely.
- There are numerous APEO-free alternatives which, while somewhat more expensive, are economically feasible.
- Achieving equal or better performance without considerably higher cost in some applications.
- Reformulation has not been without difficulty and requires considerable resources.
- While the current evidence indicates, based on predictive toxicology, that many alternatives to APEO are safer, the body of knowledge could be improved, and uncertainty reduced.
- There may still be unintended, unforeseen consequences from their substitution.

TECHNOLOGY GAPS/RESEARCH NEEDS

- Current tools for predicting better safety can be improved.
- Technology improvements in systems and methodology for formulation and reformulation are needed.

OPPORTUNITIES

- Collectively fund needed research on APEO alternatives and their cost structure.
- Fund research/development of new tools and systems to facilitate and reduce cost of formulation and re-formulation.

RECOMMENDATIONS

- Hold a session or specialized conference on the status of APEO and alternatives. Topics should include current safety evaluations and prospects for reduced cost alternatives.

VISION STATEMENT

- Industry use of APEO alternatives is well understood.

The VOC/MIR-Compliant Materials Roadmap

CHALLENGES

- The various definitions of these components (VOC and MIR) for air quality considerations are not uniform regionally (nor around the globe), which leads to confusion.
- "Exempt" solvents defined by regional regulations offer some benefit over other solvents, but they too are subject to changing status as "safer" alternatives. Also, they are not globally accepted as VOC-exempt, thus requiring different formulations for different regions.
- While some regions allow VOC-exempt solvents based on the regional definition of VOC, whether the actual goals of environmental improvement are being achieved seems lost and some other health risks may be involved in their use.
- In comparison to outdoor air quality control, there is much less focus on indoor quality, though this may change in the future.
- Where solvent capture is feasible, it may be better overall to operate a solvent-borne (SB) system when the entire system footprint is considered (i.e., through an LCA).
- Communicating why a particular approach (i.e., water-borne, solvent-borne, or high-solids) has been selected is a challenge and industry efforts in this regard can be improved.

TECHNOLOGY GAPS/RESEARCH NEEDS

- More research is necessary on safer solvents, selection and use of PPE, and other exposure- and release-mitigation methods.
- Structure-activity relationship models should guide research and meaningful regulation.
- Technical advances in water-borne and high-solids coatings may still be needed to drive these to sustainability.

OPPORTUNITIES

- Revisit with other stakeholders and collectively push for a holistic redefinition of this issue based on science and a clear understanding of what human/environmental goal is to be achieved.
- Accept that there is, for the near future, no single, clear, universally applicable, advantageous system. Cooperative research would be beneficial in several areas, including solvent-borne, water-borne, and high-solids materials and mitigation/PPE engineering.
- The uncertainty of definitions and regulations increases risk of funding research on an individual basis, which suggests that collaboration may be the optimal approach to reduce risk. Collaborative research initiatives may also take advantage of government and university funding.

RECOMMENDATIONS

- Host a focused conference/roundtable discussion with other stakeholders to collectively push for a holistic redefinition of this issue based on science and a clear understanding of what human/environmental goal is to be achieved, and gauge this against current regulations. Form next steps based on this revisitation.

VISION STATEMENT

- ACA is a leader in air quality policy formulation based upon sound science.

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 Technology Roadmaps. Discussions 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 later.

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")*