

## Technology Roadmap

### Center Philosophy and Roadmap for R&D Project Planning

The Center for Resource Recovery and Recycling (CR<sup>3</sup>) is committed to working on research projects that offer its membership opportunities to move themselves and society toward a sustainable future. It works to establish a future in which residues and wastes are minimized and the by-products that result from manufacturing and use are reused or recycled to the maximum extent while striving to do so in economically favorable and more sustainable ways. The Center works collaboratively to improve, invent, and/or innovate processes, materials, products, and/or devices through precompetitive R&D within the realm of the Center's core competencies.

The Center does not operate with a plan to achieve a pre-defined future state for various materials, products, processes, or technology. In fact, the Industry Advisory Board recommended that the membership not be organized into pre-defined groups with various foci and desired future states. The R&D selected by the Center is based on satisfying near-term member needs that directionally move them toward a more sustainable future. The Center functions as client-oriented and its active R&D projects change as the membership changes. As a result, gaps between the current state and the desired future state are project specific and are not identified as a gap or void in an overall Center roadmap. The Center considers this agility a strength.

CR<sup>3</sup> R&D project creation and selection is guided by the interests of its diverse group of members and academic partners and allows for multi-member collaboration. The strong focus on satisfying the needs of Center members helps ensure our student, postdoc, and faculty academic partners are engaged in relevant and real-world challenges. The focus on member needs also increases the likelihood that technological developments will be adopted. Industrial, organizational, governmental, and societal needs that are considered when forming new project proposals include, but are not limited to:

- recovery and reuse or recycling of scarce and critical materials, including urban mining;
- controlling the cost of material resources used in manufacturing, for example by developing alternative materials or alternative sources of materials;
- reducing waste and by-product creation, especially from manufacturing operations and end-of-life products;
- energy efficiency;
- sustainable process and product development that satisfies environmental regulation and policies;
- minimizing carbon and water footprints;
- decreasing the depletion rate of natural resources;
- ensuring materials and products with recycled content are competitive with regard to physical and chemical properties and environmental risk;
- and safety during product creation and throughout a product's life cycle.

## Technological and Core Competencies

CR<sup>3</sup> benefits from working collaboratively allowing the technical and core competencies of both members and academic partners to be utilized. Members and academic partners have access to the Center's collective pool of external expertise and scientific networks that can help assess feasible scientific and technological solutions to proposed research. The global perspective that comes from its diverse international membership and academic partner affiliations is considered a Center strength. Confidentiality is critical to the success of this type of multi-member R&D partnership and the Center has policies and provisions in place to protect its collective and individual members' interests.

CR<sup>3</sup> functions in a way that enables all participants to help steer the development and direction of research projects. The best candidates for Center R&D projects are those that would utilize both core and supporting technical competencies. CR<sup>3</sup>'s project selection and development process gives our academic partners the opportunity to identify gaps between proposed R&D and existing technological and core competencies and allows time to acquire necessary resources prior to beginning new projects. Changes in market conditions could result in rapid Center membership changes which could create resource and competency gaps for active projects and such instances would be dealt with individually.

Center competencies include the following.

### Core Competencies

- mineral processing
- thermodynamics and kinetics
- pyrometallurgy
- hydrometallurgy
- electrometallurgy
- physical metallurgy
- inorganic chemistry
- organic chemistry

### Supporting Technical Competencies

- physical, chemical, and mechanical property testing
- material characterization
- additive manufacturing
- sensor and measurement device application development
- life-cycle assessment (LCA) and environmental impact assessments
- commercial feasibility assessments, including economics
- modeling and simulation including thermodynamics, kinetics, and fluid dynamics
- robotics
- sorting technology
- industry 4.0 concepts

When necessary, members and academic partners can work to provide additional supporting competencies directly or through leveraged relationships.

## R&D Project Categories

The projects can be categorized as focused on material type (paper/wood, ores, metals, ceramics, glass, organic substances, polymers, composites, nanomaterials, residues, etc.), product (minerals, non-ferrous alloys, ferrous alloys, electronics, energy-storage, automotive, magnets, cement and adhesives, aggregates, building materials, etc.), and/or process and technology projects (mineral and material processing, pyrometallurgy, hydrometallurgy, electrometallurgy, production equipment, sensors and measurement systems, modeling and simulation, etc.). How a project may be categorized is not a driver for project creation. CR<sup>3</sup>'s project creation and selection process is designed to fund R&D that promotes sustainability and satisfies the needs of Center members and/or society within a collaborative framework. Categorized lists of projects can be useful in identifying areas where member recruitment activities should be focused.

## Satisfying Member Needs

CR<sup>3</sup> serves its membership by allowing both members and academic partners to propose R&D projects. The Center's membership is constantly changing, reflecting the topical, economic, and market dynamics within businesses, organizations, governments, and society. It has therefore proved difficult to establish narrow, pre-defined areas as foci for future research efforts, for example: rare earth magnet recovery and recycling, sortation technology for scrap metal, automotive Li-ion battery recycling, recycling of bauxite residue, methods to refine copper out during steelmaking, or conditioning of lead smelting slags. Instead the Center has adopted the philosophy that as long as projects address the types of needs listed in the "Center Philosophy" section and are selected based on the input of all Center members, then they are worthwhile, within the Center's scope, and best meet the identified needs of the current membership.

## R&D Project Selection

The project selection process used by CR<sup>3</sup> gives members and faculty the opportunity to review all new R&D proposals, provide feedback on them, and then send them back to the proposer for refinement. Members are then given the chance to collaborate on project proposals, refine them further, and define resources necessary for the R&D, perhaps in the process altering the original project scope and/or consolidating projects. Affiliated research universities are then assigned to project proposals and develop statements of work for all proposals, including the identification of competencies and/or resources that will need further development or that need to be acquired. There are provisions in the process to create proposals to extend currently active projects, even if the need is recognized late in the project selection cycle. Project proposers are then given a final opportunity to present their ideas to the Industry Advisory Board just before a project selection ranking ballot is sent out. The following year, as many projects as

possible are funded based on the priority assigned to them in the project ranking step. Projects that don't get funded may be resubmitted in future years.

## R&D Project Guidance

Focus Groups are formed for each active project to engage members in the management and guidance of Center R&D. While each member company only gets one vote to set direction, member companies may bring as many representatives as they wish to Focus Group meetings in order to help ensure the project's success. Project reviews with the entire membership followed by Focus Group meetings occur face-to-face twice per year, which allows all members to provide each project's Focus Group with questions, comments, and other feedback to help direct future R&D activity. CR<sup>3</sup> uses National Science Foundation (NSF) Level of Interest and Feedback Evaluation (LIFE) Forms to help in project development and for ongoing project guidance. In-person meetings are complemented with interim Focus Group teleconferences as needed.

## Talent Development

The Center helps develop talented graduate students and postdocs that have a predisposition to consider sustainability as they work and live. Through interaction with Center members during Industry Advisory Board and Focus Group meetings, researchers develop their non-technical skills, such as presenting, reporting, and personal interaction and also develop an understanding of how member companies and organizations think and work. Further, the project proposals submitted by members help develop talent of specific interest to those member companies and organizations while engaging researchers in relevant and real-world challenges. And, members grow their own knowledge and develop their personnel through Center events, R&D projects, and networking.



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