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R4-I: The Institute for Recovery, Reuse, Remanufacturing, and Recycling

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R4-I: The Institute for Recovery, Reuse, Remanufacturing, and Recycling

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ACRONYMS

R4	recovery, reuse, remanufacturing, and recycling
NSF	National Science Foundation?
CR^3	Center for Reuse, Recovery, and Recycling
MEP	Manufacturing Extension Partnership
R4-I	Institute for R4
CRT	Cathode-Ray Tube
LCD	liquid crystal display

R4-I: The Institute for Recovery, Reuse, Remanufacturing, and Recycling

1. BACKGROUND

1.1 Seeking Sustainable Advanced Manufacturing

Since 1982, U.S. manufacturing activities and jobs have been on the decline. During the recent economic downturn, a significant number of manufacturing jobs were lost to foreign firms. There have been a number of factors responsible for the decline of U.S. manufacturing. Low labor costs in developing nations is usually cited as a major driving factor.[1]Reduced environmental costs are also common for these developing countries since they have no regulatory structure.[2] However, other factors, such as availability of raw materials, cheap water, and low cost energy, also share responsibility for the decline in U.S. manufacturing.[3]

The increased availability of natural gas and the elevated cost of transporting goods has caused some firms to consider moving manufacturing operations back to the U.S.[4] Furthermore, existing manufacturing activities need to be underpinned by advanced technologies, raw material, and water availability so that they may remain cost competitive relative to foreign produced products. The actions taken to foster these returning activities and bolster existing manufacturing will create new jobs and enhance U.S. economic growth.

Recovery, reuse, remanufacturing, and recycling (R^4) of materials and goods are currently practiced to various extents in the U.S.[5] The appropriate advancement of R^4 concepts has the potential to act as one way to reduce manufacturing costs. Heavy equipment manufacturing is one of the U.S.'s major manufacturing sectors. Remanufactured engines and parts significantly reduce the life cycle cost of these items. Availability of remanufactured components is directly responsible for U.S. produced equipment holding its economic viability relative to cheaper foreign produced equipment.[6] Automobile manufacturing has transitioned from bodies made of steel to light weight alloys, such as aluminum. This transition is economically feasible because of the fact that greater than 70% of aluminum is recycled.[7] Given the fact that recycled aluminum requires 95% less energy than virgin material, recycled material keeps the cost of aluminum reasonable.

R^4 has the potential to positively impact other manufacturing sectors. The U.S. is a major supplier of personal hygiene products.[8] Most of these products are supplied in plastic containers. If appropriate recycled plastic materials were readily available, the cost of producing containers for these hygiene products could be reduced by as much as two-thirds.[9] Although this cost reduction is small compared to the cost of the hygiene material, it provides some flexibility in pricing strategy. Manufacture of prepared and processed foods represents another major sector of U.S. manufacturing.[10] In many areas where food processing occurs, the cost of water and waste water treatment has risen significantly due to limited or declining water availability. Water disposal costs have dramatically increased in the last 10 years due to increased demand and constrained water treatment resources. Efficient and cost effective water recycling technologies can substantially reduce process water demand and post-processing water discharge.

Not only does R^4 reduce manufacturing costs, it creates jobs. In 2008, the number of jobs related to R^4 activities was estimated to be greater than 861,000.[11] One recent study showed that job creation depended on material type.[12] The job estimates varied from less than three jobs per 1,000 tons for wood and textiles; to about four jobs per 1,000 tons for paper, iron, and steel manufacturing; to about 10 jobs per 1,000 tons of plastics; and more than 17 jobs per 1,000 tons for nonferrous metals. Remanufacturing and reuse created an estimated seven jobs per 1,000 tons of several materials/products and around 20 jobs per 1,000 tons for metal products.

Another advantage of performing R^4 is the significant reduction of greenhouse gases, such as carbon dioxide from power production and methane from landfill decomposition. Recycling of electronic waste can greatly reduce heavy metal pollution.[12]

2. VISION

2.1 The Institute for Recovery, Reuse, Remanufacturing, and Recycling (R^4-I)

The vision outlined in this White Paper describes the creation of an institute that strives to achieve greater amounts of R^4, working with manufactures to enhance product designs to better facilitate R^4, creating a skilled and semi-skilled workforce to improve product designs and to operate advanced R^4 processes, and creating a substantial number of new manufacturing and R^4 jobs. The institute's goal is to be the premiere industry-national, laboratory-university collaborative dedicated to sustainable manufacturing and sustainable stewardship of natural resources. The institute will be a regionally focused national network. Regional centers will have specific foci that seek to take advantage of regional needs and skill sets. A regional-national network concept better serves collaborating member's needs by establishing the needed regional knowledge base and educating future industrial leaders. Technologies will be developed and demonstrated in an integrated manufacturing-demonstration facility setting(s). Technologies will be transferred to industry with the goal of achieving materials sustainability from initial product design through manufacture to end-of-life disposition in a manner that yields both energy and product cost savings. Integration will be accomplished by participation of manufacturing and equipment-producing industries in establishing academic and vocational training programs resulting in a skilled workforce able to operate and lead this new manufacturing paradigm.

To accomplish this goal, several approaches will be utilized in parallel, including:

- Government policy development that drives enhanced R^4 public participation
- Recovery approaches that are both energy efficient and practical
- Reuse, Repair, and Reconditioning improved societal acceptance
- Remanufacturing obtaining better product designs and performance that encourage greater utilization
- Recycling enhancements that improve material refinement and provide drivers to implement
- Waste recovery from landfills and improved use of construction materials.

The value of the institute is that it not only enhances materials utilization but creates a substantial number of jobs. Based on projected 2030 levels of waste generation[11], a change in waste recycling growing from the present 33% to 41%[12] creates 280,000 jobs. Further, a significant number of these created jobs have wages substantially above the minimum wage. This further supports middle class growth.

2.2 Institute Mission

The mission of the institute is to collaborate with manufacturers, equipment suppliers, R^4 performers, academics, and national laboratories to:

- Establish generic basic recovery, recycling, and remanufacturing science
- Develop technologies to identify and efficiently separate valuable materials for a range of waste streams

- Build strategies and technologies to enable greater recovery of materials used within material requiring manufacturing processes
- Create new design tools and principles that facilitate material recovery and remanufacturing of goods
- Extend and demonstrate the research and development (R&D) already underway at other federal agencies, such as National Science Foundation's Center for Recovery Reuse and Recycling and National Institute of Standards and Technology Manufacturing Extension Partnerships, and other advanced manufacturing institutes
- Create manufacturing and recycling jobs
- Train the current and future workforce.

2.3 Institute Description

The Institute for R^4 (R^4-I) is an ideal application for, and realization of, the concept of the U.S. Department of Energy's Manufacturing Demonstration Facilities. It is driven by, and responds to, the needs of industry. The institute brings together the world's leading experts in all relevant areas across the entire materials lifecycle to tackle manufacturing and recycling problems from a systems view that assures the availability of materials with essential properties in applications that impact a variety of manufacturing sectors including energy production, transportation, food processing, consumer goods, and others. It has the combined skill of industry, academia, and government laboratories to identify the most pressing problems and opportunities and promises technological approaches based on sound science and rigorous economic and risk analysis. The institute will focus its substantial resource base to provide innovative solutions that have the impact and sufficient flexibility to be applicable across a range of industries. R^4-I will provide extensive real and virtual facilities for information dialog, idea exchange, and concept testing. The institute's national laboratory-based, strong basic science underpinnings will shorten commercialization and deployment times while substantially reducing risks of failure. R^4-I will have the capacity to develop new theoretical and experimental approaches that will foster novel discoveries, new patented technologies, and revolutionize existing methods and approaches. More importantly, the institute will provide an environment that reduces the technology risk to these new discoveries and rapidly deploys them into the market place. R^4-I brings together a diverse, broad-ranging team that is comprehensive, agile, strategic, and bold in its thinking. It is unique in the recognized expertise of its members and comprehensiveness of its approach.

2.4 Waste Streams of Interest

2.4.1 Cathode-Ray Tube (CRT) Glass and Other Electronics Glass

R^4-I will not concentrate on food and beverage container recycling, since greater than 40% of these materials are currently recycled.[13] Instead, the institute will focus on the near-term problem of accumulating CRT glass. Due to recent disposal restrictions, CRT glass cannot be disposed in conventional landfills. Given the high lead content of this glass, the waste can now only be disposed in hazardous waste certified sites. Due to the introduction of flat screen monitors and televisions, a substantial amount of CRT glass is accumulating and, due to the cost of disposal, is being stored in large warehouses. To address this problem, effective and efficient new technology is required to process the material and remove the lead.

Although CRT glass represents a near-term problem, production of new CRTs will disappear in the near future (15 to 20 years) and the waste stream will dry up. Industry representatives are more concerned with processing of the substantial influx of liquid crystal display monitors, liquid crystal display and plasma televisions, hand held devices, and laptop computers. New tools and processing methods are needed to process these devices.

2.4.2 General Electronics (e-waste)

The high cost of e-waste recycling in the U.S. and Europe poses a significant challenge in managing this high-tech waste. Electronic equipment and gadgets are the fastest growing waste stream in many countries. In 2012, global sales of new equipment included 238.5 million televisions, 444.4 million computers and tablets, and 1.75 billion mobile phones.[14] All of these electronics become obsolete or unwanted within one to three years of purchase. There are significant challenges in finding efficient and effective methods to reuse or recycle materials used in this e-waste. In addition, there are substantial environmental issues associated with the waste, since it contains a number of heavy metals and toxic compounds. New disassembly methods, tools, and processing methods are required to effectively process this material.

2.4.3 Automobiles

A significant amount of the automobile is already recycled, reused, or remanufactured, so much so that approximately 80% of the vehicle is recovered. The remaining 20% represents an opportunity and challenge. This material is primarily plastics and foams used in the interiors of modern vehicles. A significant amount of work has been performed related to physical separation of these materials with some success. However, the diversity of plastic materials used by the automotive industry is significant. Often, two different plastic materials will have very similar separation properties but will not perform well being formed or melted. New processing methods that support existing physical separation methods are required to greatly refine and enhance the quality of the separation streams. Further, extensive reuse of this material is hampered by accurate chemical and physical data related to the molding and forming properties of this recycled material. These data need to be collected and shared with the molding and forming industries and their associated trade groups.

2.4.4 Water

Industrial water withdrawals were about 4%, or 18 Bgal/day.[15] Nearly all of this was fresh water. In addition, another 195 Bgal/day, corresponding to 43% of water withdrawals were used for thermoelectric power production. Most of this water is consumed by once-through cooling. These two uses represent almost one-half of all water usage. Recovery, recycle, and reuse of this water represent a significant opportunity both from a resource availability and cost perspective. The major opportunity that exists is to find different, efficient methods to treat and reuse cooling water that does not require evaporation. Technology currently exists to treat and recover industrial water. The primary issues associated with these technologies are the expenses associated with implementation, maintenance, and significant energy usage. Technologies are needed that are cost effective, resilient, and decouple the need for high quality energy input.

2.4.5 General Metals

Recycling of ferrous and non-ferrous metal is being performed; however, a significant amount of material still finds its way into landfills. This happens because the value of the metal is low and is not effectively recovered due to processing and recovery costs. A new effort is needed to evaluate a range of technologies and automation to discover more effective methods to recover these metallic materials.

2.5 Goals of the Institute

Near-term Goals:

The R^4-I will concentrate its attention initially on the critical areas of recycling and remanufacturing. The focus of recycling activities will be on electronic materials, aluminum, plastics, water, and metals, with emphasis on the transition metals. The remanufacturing activities will concentrate on development of design tools and research to support establishment of industry standards.

One of the most urgent goals of this Institute is to assure that recovery and recycling of electronic components (e-recycling) is performed in an energy and environmentally conservative manner. The future viability of e-recycling hinges upon efficient and environmentally-responsible separations and extraction processes. The research performed by the R^4-I will be on those topics. Economic models are required to aid these ventures to anticipate vulnerabilities associated with price fluctuations and manipulation during implementation phases. The Institute will devote significant resources to enhance the robustness of the primary extraction economics. It will introduce novel new technologies that improve extraction efficiency and find new uses for co-products.

A major challenge for remanufacturing is how units are originally fabricated. Original manufacturing desires that the units have long functional life. Remanufacturers want the unit to be easily dissembled. The Institute will approach this challenge through two approaches: design for remanufacture and development of advanced joining and assembly methods. The ultimate goal of these efforts will be to provide to industry the engineering design tools, methodologies, and specifications that support rapid deployment of manufacturing and remanufacturing technologies.

A serious problem associated with recycling of plastic materials is effective and efficient sorting of a widely varying mixture of different plastic compounds. Although a considerable amount of R&D was expended on physical sorting of plastic materials, there still remains significant technical challenges. Industry standards are needed to define the purity, properties, and forms of recycled plastic material. R^4-I will focus on development of efficient separation processes that use state-of-the-art sensors and automation to overcome this problem. Further, the institute will work with plastic material producers and molding and forming industrial representatives to identify critical physical and chemical property specifications. R^4-I will then perform the physical and chemical property measurements needed to define these specifications.

Ensuring future availability of clean water for various manufacturing sectors is another goal of the institute. There are a variety of existing technologies available for process water recycle and reclamation. These technologies are characterized as being energy intensive and expensive to implement and maintain. The institute will pursue novel water recovery methods and technologies that greatly reduce implementation and operational cost. Further, the R^4-I will seek to find technical solutions that decouple energy costs from water recovery costs. This will be achieved by pursuit of technologies that use low grade manufacturing heat. This approach has the potential to effectively utilize a wasted heat resource and eliminate cooling towers and other forms of evaporative cooling, which lose a considerable amount of water to evaporation.

Mid to Long-term Goals:

Lithium waste streams are addressed as a medium-term priority by developing new chemical processes for lithium recovery. It is projected and expected that used/depleted, lithium-based batteries will become a major waste stream in the future due to these batteries being used in consumer electronics, vehicles, energy storage, and grid applications. The institute will seek to develop new materials for extraction of the lithium that will result in significantly shortened production timescales for extraction, as well as make the supply-chain more flexible and responsive and, therefore, strategically positioned to respond to this growing new waste stream.

Throughout the life of the institute, efforts will focus on qualifying new materials for use in existing products and redesigning products to accommodate greater amounts of recycled materials. R^4-I has correspondingly longer-term goals to develop a range of materials that incorporate significantly smaller amounts of strategic metals in electronic components and include an emphasis on deployment of new products into the marketplace.

Crosscutting all short, medium, and long-term goals are the basic scientific tools that R^4-I will develop to enhance the understanding of a wide variety of materials to enable enhanced approaches to

separation, reduction, re-use, recycling, and substitution. Such tools include advanced theoretical skills and world-class computational and experimental resources that will be used to establish and continually improve the nation's ability to create innovations that assure the value chain across the entire materials and product lifecycle.

2.6 Nodes and Elements of the Institute

R^4-I will be composed of four Nodes (Areas of Institute Emphasis) with six or more regionally located elements that are focused on specific manufacturing needs (Figure 1). The Idaho National Laboratory's Center for Advanced Energy Studies, a collaborative Center of Excellence between the three major Idaho universities, will serve coordination and administration roles for the Institute. Examples of envisioned Elements include:

- West coast - e-waste
- Northwest - batteries
- Midwest - automotive plastics
- West - water
- Southeast - aluminum
- Northeast - product design for remanufacturing

Each of these elements will focus on technologies that advance some or all of the topics associated with R^4 relative to their specific Node. In addition, each node will perform educational outreach, technology transfer, economic analysis, and other crosscutting activities. While the Nodes are regional in nature, each will be able to draw technology and knowledge from across the entire Institute and are not geographically limited.

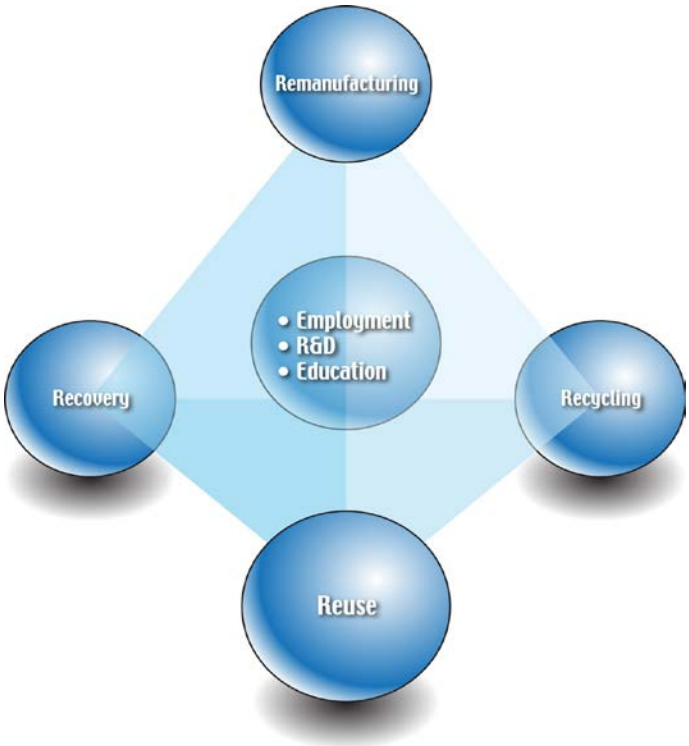

Figure 1. R4-I's Node Concept.

2.7 Tool Development

Some of the challenges associated with component reuse and remanufacturing and materials recovery are existing manufacturing methods and component designs that are intended to ensure product performance for a single product lifecycle. Parts are secured so that they will not break or fail during use. The need for extremely dependable components makes remanufacturing and recovery of materials impractical or expensive. The R^4-I will attack these challenges by pursuing new design philosophies and tool sets that facilitate reuse, remanufacturing, and recovery while maintaining product performance and durability. In addition, the institute will develop new methods for efficient joining of similar and dissimilar materials. Advanced materials' properties will be designed and developed so that joined materials can be separated under specific conditions that release the part but eliminate physical part damage. Once these tools and methods have been developed, the institute will perform the needed work to validate the effectiveness of the methods and tools and certify their use. The educational outreach activities will be used to deploy these new methods. Licensing and technology transfer will be used to deploy the new design methods and tools.

2.8 Educational Outreach

Training the future workforce to perform the jobs that will be created by the institute's technically advanced systems is an integral element of a successful institute. There are three separate components of this outreach activity: 1) development of the next generation of professionals knowledgeable of the technology issues and capable of developing the next generation of technical solutions, 2) education of a semi-skilled workforce to operate the new equipment and processes, and 3) providing of on-the-job training opportunities for the existing workforce to enhance and upgrade their skills.

R^4-I activities directed at creating new technology and processing solutions for industry challenges are ideally suited to develop the next generation of technologists. The institute will sponsor research at national laboratories and a range of universities. This funding will have requirements for support of graduate students and postdoctoral fellows. In addition, the institute will sponsor undergraduate internships at national laboratories and with industrial partners. The institute will also support staff exchange between institute partners designed to provide firsthand knowledge of the problems and deployment hurdles that new technology encounters. As a consequence, the R^4-I will facilitate development of professionals that understand industry issues and are capable of advancing the state-of-the-art.

Having a workforce capable of operating the equipment and processes is vital for success of U.S. manufacturing and industry as a whole. The institute will work with colleges and vocational training centers to develop a training curriculum that provides the needed skills and knowledge. R^4-I will work with representatives associated with vocational program certification at Texas Tech University to have a program that can be implemented anywhere in the U.S. The institute will seek to deploy these training programs using regional relationships at each institute node. R^4-I will work with its industrial partners to provide equipment and resources to these regional training programs. A network of training nodes will be created. This network will facilitate access to these resources independent of the student's location. Not only will the student be able to access training opportunities offered by the institute, he or she will have access to training programs offered by other advanced manufacturing institutes.

Training the existing workforce will also be a goal of the education outreach. R^4-I will coordinate with industry partners and various colleges and vocational training programs to facilitate industrial, on-the-job training opportunities. Opportunities will include development of night courses, online training, and one to two day short courses. The primary intent of this on-the-job training is to enhance worker skills on a particular piece of equipment or element within a process.

2.9 Industrial Connectivity

R^4-I is completely focused on sustainable manufacturing job creation. This goal does not happen without substantial industry involvement, participation, and commitment to technology deployment. Industrial involvement will be interwoven within the Institute and will comprise a significant component of the executive and operational board of directors that provide overall direction to the institute. The individual institute nodes will be where major industrial involvement occurs. Industry will participate in project selection and technology deployment and support educational outreach.

The institute will have a tiered arrangement of industrial involvement comprised of supporting, participating, and adjunct members. All industrial participants will have access to institute publications, bi-annual meetings, special topic workshops, and educational programs and training.

The highest level of industrial participation is the "Institute Sponsor." To be a Ssponsor, the industrial concern will need to commit significant funds ($200,000 – $500,000/year)as funds-in, in-kind, or equipment contributions. Industrial Sponsors will enjoy the first right of refusal on available intellectual property for an exclusive field of use. Sponsors will have preferred rights to sponsor proprietary R&D capabilities within the institute. Sponsor members will be reserved positions on the various institute boards and committees.

The intermediate level of industrial involvement is the "Institute Participant." To be a Participant, the industrial concern will need to commit funds $80,000 to $100,000/year) as either funds-in, in-kind, or equipment donation. Participants will enjoy access to non-exclusive fields of use for institute intellectual property. Participants will have access to institute R&D capabilities to perform proprietary R&D.

The lowest level of industrial involvement is the "Adjunct" membership. To be an Adjunct member, the industrial concern will pay an annual fee of $10,000. This basic membership does not provide any special access to institute capabilities other than that provided to all industrial members detailed above.

Figure 2. Commercialization concept.

2.10 Proposed Business Model

R^4-I is an umbrella institute that will be administered by the Idaho National Laboratory's Center for Advanced Energy Studies, with programmatic direction and execution evaluation provided by an executive and operation board, respectively (Figure 4. R4-I's streamlined management structure capitalizes on the colocation of major resources and the use of integrated technology platforms to ensure cross-discipline collaboration, video conferencing for meetings when required, and integration of both the latest and emerging technologies to build an extended "virtual single roof." Board participation will be based on a set of clearly defined criteria, and board members will have terms limited to three years. The institute will be composed of physical nodes regionally located at national laboratories, universities, or selected industrial sites (Figure 3). Each node will have a unique technical focus (e.g., aluminum recycling) based on specific regional manufacturing needs. Work performed at partner/node sites will be seamlessly integrated across the institute on a real-time basis via community and computing capabilities that integrate a range of technologies to build an extended "virtual single roof," allowing multidisciplinary collaboration among R4-I staff at all sites. R4-I will operate programs at Idaho National Laboratory and other major research centers for extended stays in residence by individual visiting researchers and for short intensive programs for larger teams. Many of the facilities and much of the expertise and equipment necessary to execute R4-I's proposed research program are in place and capable of performing substantive research almost immediately.

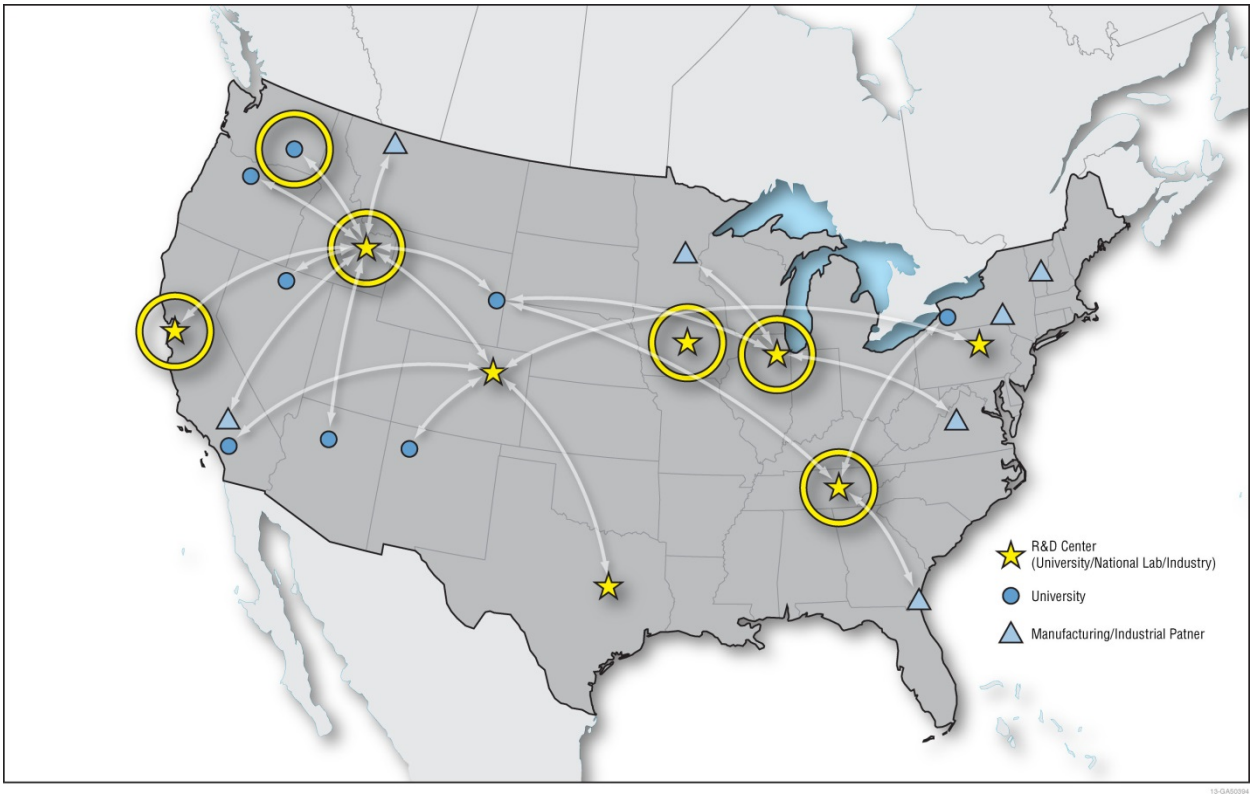

Figure 3. Map of the institute's participants and their potential interactions.

The institute will initially be supported by federal funding provided by one or more federal sponsors. Over a period of five to seven years, the R^4-I will transition to private sector funding and competitively won projects supported by collaborations and industrial partners. The institute creates jobs by enhancing recycling of particular materials. It will work with various manufacturing firms to facilitate use of R^4 materials. By using these materials, manufacturers will be able to reduce production costs, expand sales, and increase job creation. The institute will develop formal relationships with various financial firms to

provide funding for new business startups and spinouts. It will annually hold a "technology event" to showcase new ideas and inventions produced by the institute members. The institute will provide skilled workers to fill these newly created jobs. R^4-I will leverage technology development opportunities and lessons learned across the institute's nodes and with other advanced manufacturing institutes. The institute will foster communications between technology providers, technology users, and equipment suppliers. R^4-I will supply support to both industrial partners' and non-partners' industry concerns based on a clearly defined process that appropriately handles intellectual property issues.

Under the single roof, R4-I will have four research nodes, each of which is a specific area of focus for the program with a regional flavor. The program will build business for the program through outreach to the industrial partners who will identify specific areas of pre-competitive research that are needed to make commercial progress and enhance R4-I's goals (Figure 5). As a result of this approach to building business, R4-I will create jobs through education and specific R&D as desired by the industrial partners using private support. These efforts will provide increased semi-skilled and skilled jobs in the market place.

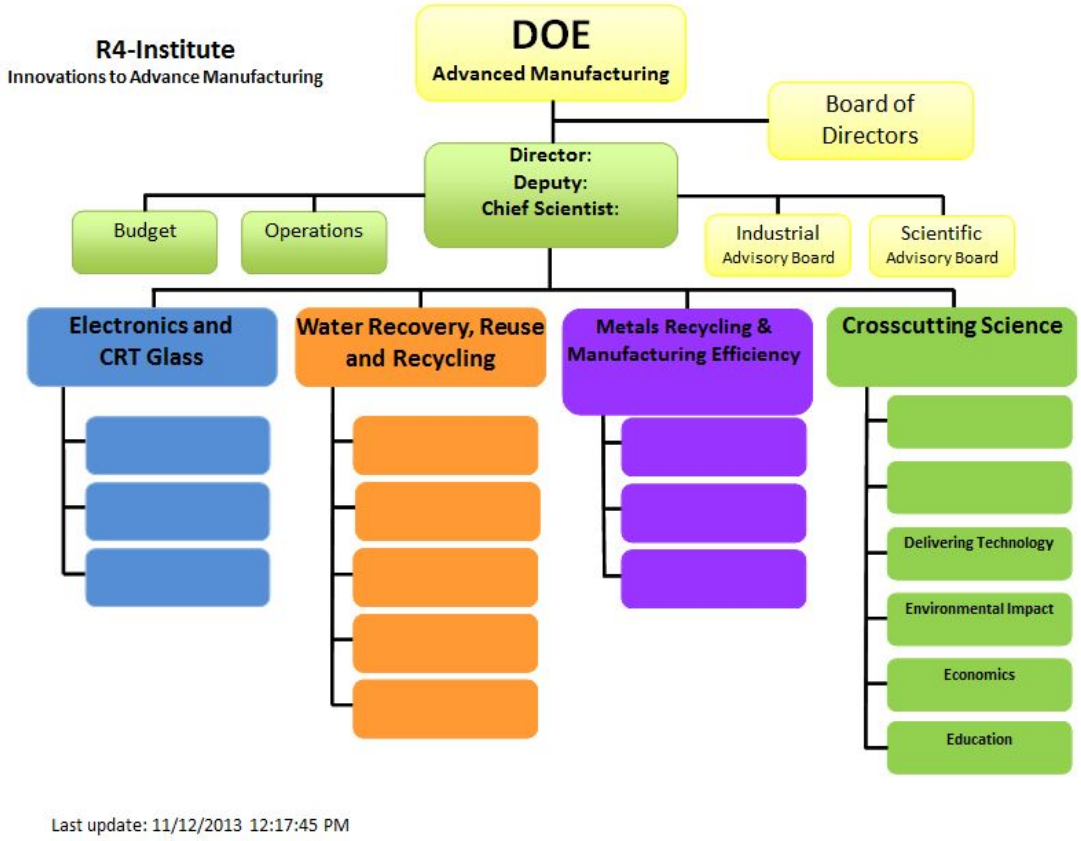

Figure 4. R4-I's Proposed Organizational Chart.

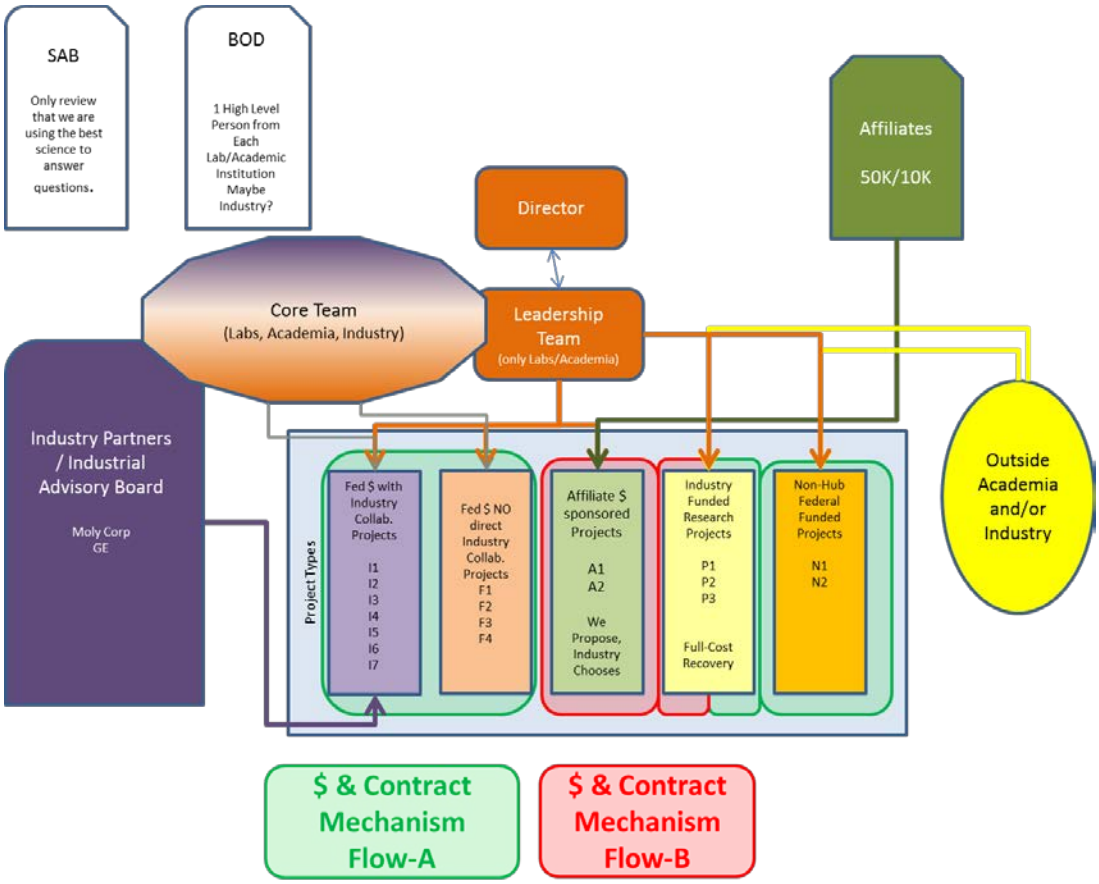

Figure 5. Commercialization/Project flow.

3. SUMMARY

As a consequence of the growing importance of sustainable manufacturing as an approach for industrial competitiveness, the substantial lost value of materials that are disposed in landfills, and the need to create middle class jobs, an industry-national, laboratory-university collaborative institute (R^4-I) is proposed. The institute is to be a regionally focused national network of R&D centers (Figure z). These regional centers will perform R&D, technical deployment, business creation, and educational outreach. The theme of these nodes will be to advance R^4 concepts for a waste stream(s) that has regionally located industrial emphasis. The near-term goal of the institute is to advance the critical area of recycling of electronic materials, aluminum, water, display glass, and transition metals. New technology for lithium recovery and reuse will be one mid-term goal. Qualified new materials for use in existing products and redesigned products to accommodate new materials and remanufacturing are the long term goal of the institute. R^4-I will focus on a number of important waste streams including electronics, automotive, water, and metals. The institute will use various engineering approaches to develop the next generation of product design tools and fabrication methods. These tools and methods will guarantee product performance over the useful life of the product and facilitate reuse, remanufacturing, and recovery. The institute will not only create jobs but will also provide the educational programs and training needed to have a skilled and knowledgeable workforce to perform these jobs. Industrial involvement is critical to the success of the institute to deploy

technology, create new business, and enhance recycling. Overtime, industrial financial support for the institute will grow and displace federal funds. A tiered approach to industrial participation is proposed that offers selected privileges based on the amount of support to the institute. A business model is proposed where an umbrella institute is formed. The Idaho National Laboratory's Center for Advanced Energy Studies will oversee administration of the institute. Regionally located nodes will perform R&D, technology development, deployment, and educational outreach on a regionally significant topic. These nodes will create jobs through technology transfer approaches and educational outreach. Information will be shared across the institute via newsletters, video conferencing, biannual meetings, topical workshops, etc. The ultimate success of the institute will be the creation of regionally specific sustainable manufacturing businesses and jobs.

4. REFERENCES

1. Byrne, J.A., "Out-source of Pain," *New York Post*, August 1, 2010.
2. Sinn, W., 'Offshore Manufacturing: the Pros and Cons,' *Design World*, December 18, 2013.
3. The Offshore Group, "Mexico Manufacturing Information," July 23, 2013.
4. Sievers, D. (Hackett Group), "US Manufacturing Focusing on Productivity, not Offshoring to Drive Cost Reduction," *New Equipment Digest*, March 14, 2013.
5. Resourceful Schools Web Site, www.resourcefulschools.org/facts/
6. Auto Alliance, "Automotive Recycling: A Look at the Automotive Recycling Industry," www.autoalliance.org.
7. U.S. EPA, Mid-Atlantic Municipal Solid Waste, "10 Fast Facts on Recycling," www.epa.gov/reg3wcmd/solidwasterecyclingfacts.htm.
8. Euromonitor International, "Beauty and Personal Care in the US," *Country Report*, July 2013, 177.
9. Recycling Coalition of Utah, "Plastic Recycling," www.utahrecycles.org/get-the-facts/the-facts-plastics/?UTAHRECYCLES=fhfvunoizt.
10. The Manufacturing Institute, "The Facts About Modern Manufacturing," 8th Ed.
11. U.S. EPA, Office of Solid Waste and Emergency Response, "Recycling is Working in the United States," Recycling Economic Information Study.
12. Tellus Institute with Sound Resource Management, "More Jobs, Less Pollution: Growing the Recycling Economy in the US."
13. Glass Packaging Institute, "Recycling Facts," www.gpi.org/recycling/glass-recycling-facts/.
14. Gartner, Announcements, Eghan, UK, February 9, 2011, www.gartner.com/newsroom/id/1543014/.
15. Blackhurst, M, C. Hendrickson, J.S. I. Vidal, "Direct and Indirect Water Withdrawals for U.S. Industrial Sectors," *Environ. Sci. Technol* (2010), **44**, 2126.