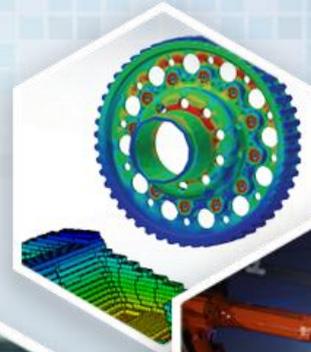


IACMI Roadmapping Phase 2 Release

Uday Vaidya, PhD

Chief Technology Officer

February 01, 2017



Roadmapping Goals



- ◆ Integrate the views and establish consensus of stakeholders from value chains in vehicles, wind & CGS
- ◆ Identify other markets in which IACMI capabilities and expertise may be reasonably extended
- ◆ Identify & assess pathways for sustainability – past Year 5
- ◆ Develop & periodically revise the targeted technology roadmap
- ◆ Mission-critical, market-specific, and cross-market challenges, opportunities and technology solutions

IACMI Phase 2: Roadmap Development



Workshop Inputs

- **Phase 1 Roadmap**
- Literature review
- Online stakeholder survey #1
- Expert interviews
- **Initial set of cross-cutting subtopics**
- Existing IACMI strategy information
- Meeting Info Package
 - Agenda
 - Expected Outputs
 - Focus Questions

IACMI Roadmapping Workshop 1

MARCH 2016

Workshop Outputs

- Technical gaps, R&D topics, R&D priorities of initial cross-cutting subtopics
- Updated stakeholder engagement plan

Workshop Inputs

- **Final set of cross-cutting subtopics**
- Online stakeholder survey #2
- Additional expert interviews
- Meeting Info Package
 - Agenda
 - Expected Outputs
 - Focus Questions

IACMI Roadmapping Workshop 2

MAY 2016

Workshop Outputs

- **Phase 2 Roadmapping Strategy**
- R&D priorities
- R&D technical timelines

Roadmap Timeline



- ◆ **Fall 2015 - Preliminary Phase 1 roadmap complete**
- ◆ **February 2016 - Public version of Phase 1 roadmap**
- ◆ **March 2016 - Workshop 1: Knoxville, TN**
- ◆ **May 2016 - Workshop 2: Detroit, MI**
- ◆ **October 2016 - Phase 2 roadmap drafted**
- ◆ **November 2016 - BOD approval**
- ◆ **January 2017 – IACMI/DOE concurrence**
- ◆ **January 23, 2017 - Final Phase 2 roadmap**

Development Approach

- ✓ Phase 1: Accelerated roadmap priority identification
- Phase 2: Full roadmap process development, stakeholder engagement, and roadmap development
- Phase 3: Roadmap monitoring and updating

IACMI Five-Year Objectives

- ◆ ↓25% CFRP cost
- ◆ ↓50% CFRP embodied energy
- ◆ ↑80% recyclability of fiber-reinforced composites

Technology Areas of Focus for the Roadmap



- ◆ **Vehicles**
- ◆ **Wind**
- ◆ **Compressed Gas Storage**
- ◆ **Materials and Processing**
- ◆ **Modeling and Simulation**

Input to the Roadmap from Several Sources



Inputs/Sources	
Telephone interviews	40
Online surveys	1000
Literature sources	70
Workshops	4

Impact Ratings of Activities on IACMI Goals: Vehicles



Vehicles	Average Rating	Total Responses
Demonstrate low cost carbon fibers in automotive part applications	4.49	70
Advance high speed, high strength joining techniques for dissimilar materials (e.g., metal and composite vehicle parts)	4.10	73
Develop low scrap, automated composite preforming fabrication techniques to match molding times	4.04	70
Reduce part-molding cycles of RTM fabrication methods from 8 minutes to 3 minutes	3.91	64
Reduce processing cycles of thermoplastic prepreg stamping fabrication techniques from 7 minutes to 3 minutes	3.88	66
Develop discontinuous carbon fiber reinforced thermoset/thermoplastic processing	3.84	68
Generate fast-processing resins with internal mold release for RTM and stamping	3.83	66
Reduce processing cycles of thermoset prepreg stamping fabrication techniques from 10 minutes to 3 minutes	3.78	65
Reduce processing cycles of injection overmolding fabrication techniques for engineered thermoplastics from 3 minutes to 90 seconds	3.76	66
Increase the in-plant reuse rate of carbon fiber process scrap in high quality parts	3.64	69
Develop low scrap, automated tape layup prepreg fabrication techniques to match molding times	3.62	71
Develop NDE validation techniques for fiber-based architectures	3.52	67
Enhance NDE validation techniques for bonded joints	3.51	68
Increase recovery and reuse rates of end-of-life carbon fiber parts	3.47	73
Enable rapid detection of void levels in molded parts	3.42	69
Enhance robotics capabilities to enable high speed handling of materials, preforms and molded parts	3.41	70
Implement low cost tooling (e.g., via additive manufacturing) for molding of automotive vehicle parts	3.37	71
Implement in-situ process controls to monitor the degree of curing in composite parts	3.21	67

BP2

BP3

BP4

BP5



Reduce processing cycles of thermoset (TP) prepreg stamping from 10 to 3 min

Reduce part molding cycles of HP RTM fabrication methods from 8 to 3 min

Develop low scrap automated composite preforms and tape fabrication technologies to match molding times

Demonstrate low cost carbon fibers in auto parts (eg via injection molding)

Implement low cost tooling (e.g. via additive manufacturing) for molding of automotive parts

Advance high speed, high strength joining and repair for dissimilar materials

Milestone

TP/Prepreg stamping and HP RTM 5 min cycle time

Milestone

Low waste tape layup & composite preforming

Milestone

IOM: 2 minute process cycle times

Milestone

Demonstrate low cost AM tooling for low pressure molding of automotive parts

Milestone

Demonstrate dissimilar joining and repair techniques at lab scale



Milestone

TS Prepreg stamping & HP-RTM 3 min process cycle time

Milestone

Standardized recycling strategies

Milestone

IOM: 90 second process cycle times

Milestone

Demonstrate low cost AM tooling for high pressure molding of auto parts

Milestone

Demonstrate dissimilar joining and repair techniques at industrially relevant scale and size

Example – Vehicles

Workshop Structure



IACMI Goals

- ↓ 25% cost
- ↓ 50% energy
- ↑ 80% Recyclability

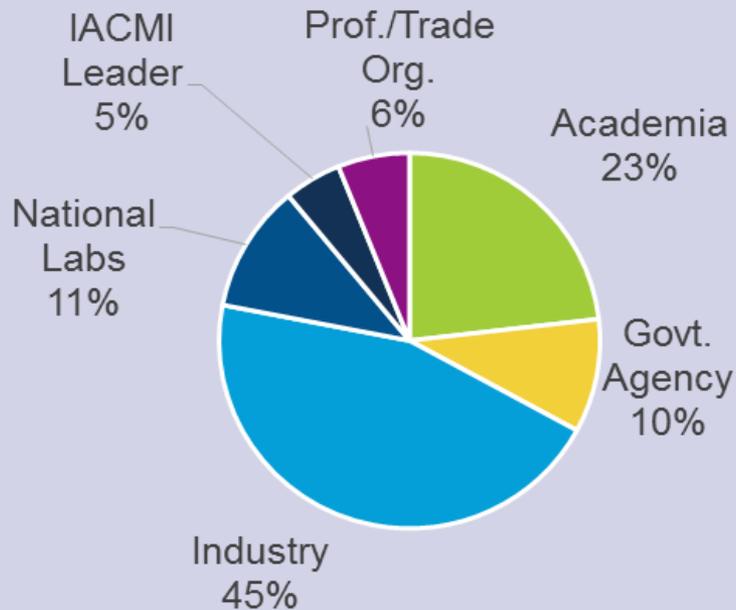
Identify
Technical Gaps
and Barriers

Identify
Research and
Development
Needs

Define
Timelines for
R&D Needs



Total Participants: 82



Workshop Outputs

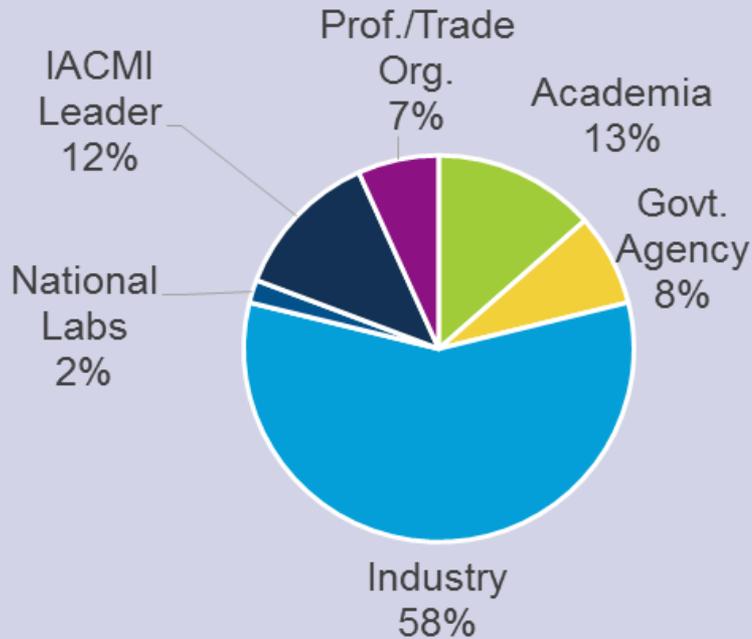
- Challenges/Limitations
- R&D Activities and Timelines (BP2-BP5)

Focus Areas (Breakout Sessions)

- Modeling & Simulation
- Recycling
- Nondestructive Evaluation
- Reinforcements, Resins, Additives, and Intermediates
- Design, Prototyping & Validation
- Additive Technologies

Phase 2 - Workshop #2: May 10–11, 2016

Total Participants: 104



Workshop Outputs

- Challenges/Limitations
- R&D Activities & Timelines (BP2-BP5)

Focus Areas (Breakout Sessions)

- **Multimaterial Joining**
- **Crashworthiness & Repair**
- **Standardization & Qualification**
- **Large-Scale Composites Manufacturing:**
 - **Wind Turbines**
 - **Compressed Gas Storage**
 - **Vehicles**

Major Challenges

Data	<ul style="list-style-type: none">➤ Poor prediction accuracy due to insufficient materials data➤ Lack of data transfer standards (e.g., materials properties, tool interfaces, data structure)
Workforce	<ul style="list-style-type: none">➤ Inability to ascertain confidence in models
Specific Applications	<ul style="list-style-type: none">➤ Insufficient accuracy in composite part cost predictions➤ Limited ability to predict crash performance
Characterization	<ul style="list-style-type: none">➤ No material characterization protocols for constructing accurate materials models
Complexity	<ul style="list-style-type: none">➤ Lack of user-friendly modeling & simulation tools
Validation	<ul style="list-style-type: none">➤ No consensus on protocols for using experimental data to validate simulation results

High-Priority R&D Activity Pathways*

- Simulating Manufacturing Processes
- Standardization of Data Transfer
- Linking Data and Validated Models to Increase Confidence
- Accurate Prediction of Part Cost and Embodied Energy
- Enhanced Crash Performance Prediction
- Materials Characterization Standards & Minimum Data Requirements
- User-Friendly Modeling and Simulation Tools

**Each bullet contains a sequence of multiple R&D activities over Budget Periods 2–5.*

Recycling



Major Challenges

Infrastructure/ Regulatory	<ul style="list-style-type: none">➤ Inability to effectively collect/consolidate post-consumer/industrial components prevents economy of scale➤ No business/regulatory framework to recycle composites (e.g., consumer-led, producer-led, value-driven)
Reclamation & Reuse	<ul style="list-style-type: none">➤ Need for integration of reclaimed materials in new, high-value products➤ Low value proposition to use reclaim fibers due to potential loss of fiber properties➤ Difficult to preserve fiber length (i.e., strength properties from length-to-diameter ratio)
Recycling Processes	<ul style="list-style-type: none">➤ Challenging to recycle thermosets (i.e., non-reversible chemistry)➤ Unable to cost-effectively remove resins from CFRPs
Waste Streams	<ul style="list-style-type: none">➤ Need for waste stream segregation to enable products with “certified” properties

Recycling



High-Priority R&D Activities

End-Use Applications	➤ Work with OEM to demonstrate prototypical production of recycle-based components
Materials Development	➤ Optimize surface treatment/sizing technology to maximize fiber recovery and mechanical properties
Modeling/ LCA	➤ Full-scale turbine blade recycling project: Document costs, methods, and challenges ➤ Demonstration program on design-for-manufacturability and design-for-recyclability
Reduction/ Reuse	➤ Incorporate offal/CF scrap into turbine blades and other high-quality parts
Supply Chain	➤ Develop technical marketing materials for recycled carbon fibers
Education	➤ Create “design for sustainably” data for end-of-life product design for academic programs

Multimaterial Joining

Major Challenges

Design Methodologies	<ul style="list-style-type: none">➤ Limited selection of non-adhesive joining processes & methodologies➤ Lack of robust, experimentally validated design tools for multimaterial joining
Automation	<ul style="list-style-type: none">➤ Need for automation techniques focus on consistency rather than production volume
Inspection/ Data Acquisition	<ul style="list-style-type: none">➤ Insufficiently validated in-situ inspection techniques for detection of kissing bond defects
Joining Techniques	<ul style="list-style-type: none">➤ Lack of robust, repeatable surface treatment preparation techniques with 60-second cycle times
Modeling/LCA	<ul style="list-style-type: none">➤ Difficult to account for material and process parameter sensitivities (e.g., process/cure times, cure temperatures, heating/cooling rates)
Performance Limitations	<ul style="list-style-type: none">➤ Need high-strength adhesives with reliable substrate interfacial bonding characteristics➤ Adhesive bonds prone to long-term performance degradation from operating environments

Multimaterial Joining



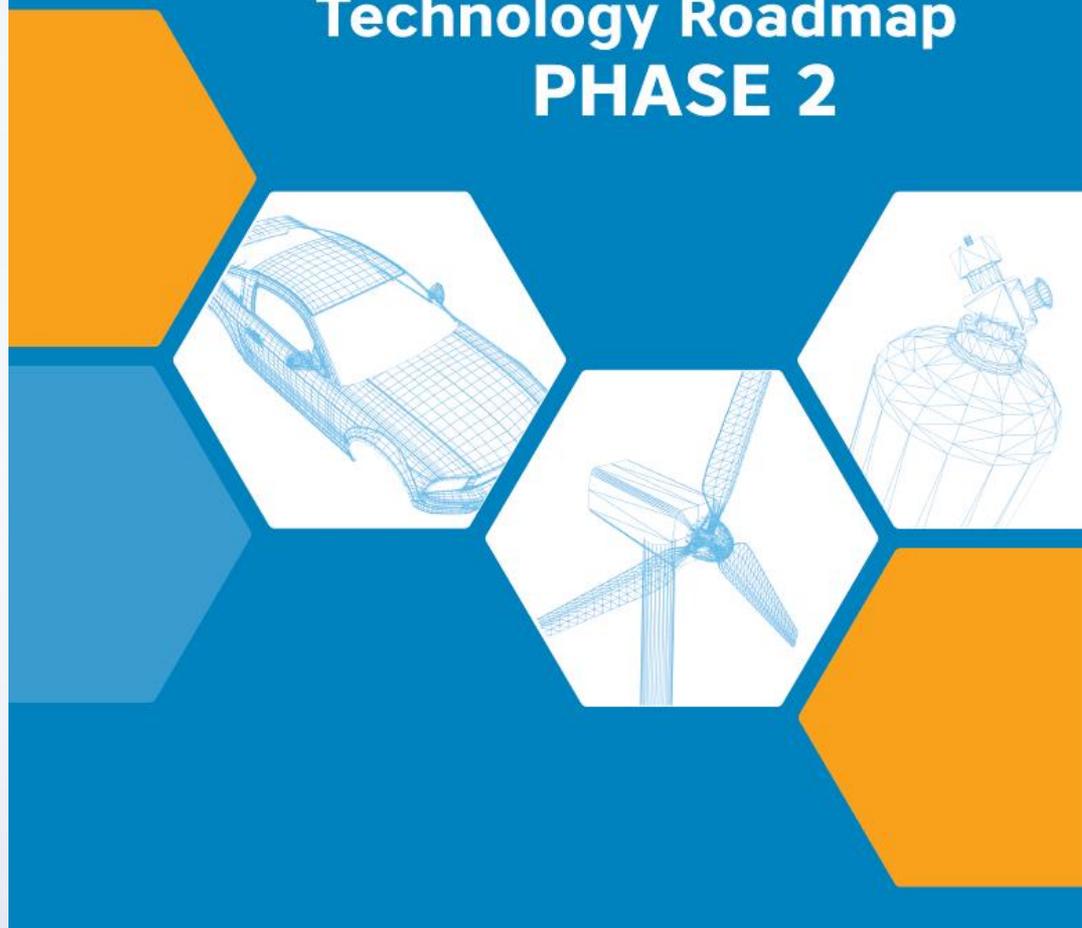
High-Priority R&D Activities

Benchmarking	<ul style="list-style-type: none">➤ Round-robin matrix study on joint design (adhesive bonding, mechanical fastening)➤ Educational seminars on multimaterial joining for IACMI members➤ Compile existing programs/databases on adhesive bonding property/failure data
Joining Techniques	<ul style="list-style-type: none">➤ Develop novel non-adhesive joining methods (e.g., brazing, soldering, fasteners)➤ Design multimaterial joining adhesives reinforced with additives (e.g., nanoparticles)
Modeling/LCA	<ul style="list-style-type: none">➤ Develop accelerated ageing tests for joints applications to generate experimental data
Inspection/ Data Acquisition	<ul style="list-style-type: none">➤ Develop interfacial inspection/quantification methods for adhesive quality, integrity, uniformity➤ Incorporate embedded NDE sensors in joining & assembly approaches that fit manufacturing line speed and size limitations
Techology Demonstration	<ul style="list-style-type: none">➤ Leverage LIFT/IACMI assets to provide cross-technology MM joining programs

Release of Phase 2 IACMI Roadmap



Institute for Advanced
Composites Manufacturing Innovation
Technology Roadmap
PHASE 2



Roadmapping Strategy



This roadmap presents an integrated strategy to achieving widespread adoption of fiber-reinforced polymer composites by 2020 and beyond. The strategy highlights the need to coordinate research and development among the five IACMI Technology Areas toward the five- and ten-year technical targets of lower cost, reduced embodied energy, and increased recyclability of fiber-reinforced polymer composites.

Technology Areas



Figure 2. IACMI Technology Areas and Key Technical Objectives



Composite Materials and Processes

Focuses on reclaimed carbon fiber composite designs, NDE-based process controls, materials characterization approaches, novel additive manufacturing methods, and more efficient precursors and conversion processes.

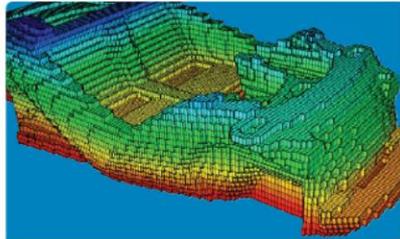
Advance carbon fiber technologies via alternative precursors, efficient processes, and interface engineering

Demonstrate production of high value intermediates and composites from reclaimed carbon fiber

Apply NDE data to process design and control

Apply materials characterization capabilities to technology advancement and benchmarking

Apply additive manufacturing to reclaimed structural fiber fabrication and rapid prototyping



Modeling and Simulation

Focuses on educating and training the next-generation workforce to embrace composite design tools and methodologies, and successfully incorporating the multiphysics phenomena of manufacturing polymer composite materials and structures into simulation tools.

Provide access to advanced composites simulation tools across the supply chain

Demonstrate crash simulation tools and methods

Deploy phenomena-based composite simulation tools



Compressed Gas Storage

Focuses on factory automation techniques, predictive integrated computational materials engineering (ICME) approaches, conformal tank designs, braided composite preform designs, and methods that enable reductions in safety factors to reduce the amount of carbon fiber required in tank designs.

Focus on factory automation and lean manufacturing techniques

Demonstrate novel braided composite preform tank designs

Enable high-volume manufacture of conformal composite CGS tanks

Employ predictive ICME approaches for tank design, manufacture, and certification



Vehicles

Focuses on reducing composite manufacturing costs and improving recyclability through innovative design concepts, scalable fabrication processes, robust modeling and simulation tools, effective joining technologies, and reliable defect detection methods.

Explore innovative design concepts for automotive composites

Demonstrate high-rate, robust, and scalable fabrication processes

Develop robust modeling and simulation tools for reliable cost and performance predictions

Foster development of effective multimaterial joining technologies

Enable rapid and reliable detection of composite defects



Wind Turbines

Focuses on demonstrating recyclable thermoplastic resins, exploring segmented wind turbine designs, employing automation to reduce cost and labor content, and designing joinable pultruded wind turbine components.

Integrate advanced thermoplastic resins into current production processes

Increase automation of fiber placement and inspection technologies

Design modular wind turbine components for affordable transport and installation

Demonstrate pultruded composite wind turbine components



Composite Materials and Processes

Focuses on reclaimed carbon fiber composite designs, NDE-based process controls, materials characterization approaches, novel additive manufacturing methods, and more efficient precursors and conversion processes.

Advance carbon fiber technologies via alternative precursors, efficient processes, and interface engineering

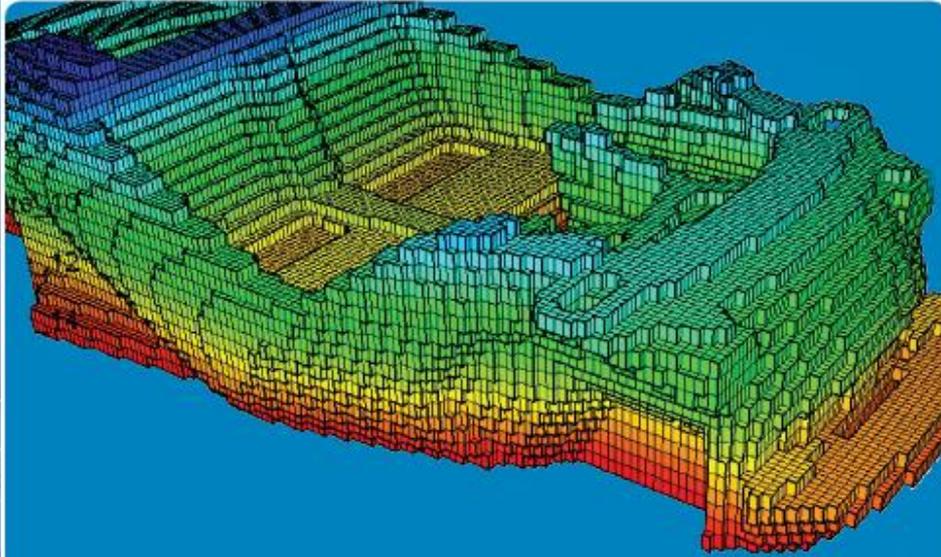
Demonstrate production of high value intermediates and composites from reclaimed carbon fiber

Apply NDE data to process design and control

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Modeling and Simulation

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Provide access to advanced composites simulation tools across the supply chain

Demonstrate crash simulation tools and methods

Deploy phenomena-based composite simulation tools

Compressed Gas Storage



Focuses on factory automation techniques, predictive integrated computational materials engineering (ICME) approaches, conformal tank designs, toughened and recyclable thermoplastic tank designs, and methods that enable reductions in safety factors to reduce the amount of carbon fiber required in tank designs.

Focus on factory automation and lean manufacturing techniques

Demonstrate tough, recyclable thermoplastic tank designs using high-speed tow placement

Enable high-volume manufacture of conformal composite CGS tanks

Employ predictive ICME approaches for tank design, manufacture, and certification



Vehicles

Focuses on reducing composite manufacturing costs and improving recyclability through innovative design concepts, scalable fabrication processes, robust modeling and simulation tools, effective joining technologies, and reliable defect detection methods.

Explore innovative design concepts for automotive composites

Demonstrate high-rate, robust, and scalable fabrication processes

Develop robust modeling and simulation tools for reliable cost and performance predictions

Foster development of effective multimaterial joining technologies

Enable rapid and reliable detection of composite defects



Wind Turbines

Focuses on demonstrating recyclable thermoplastic resins, exploring segmented wind turbine designs, employing automation to reduce cost and labor content, and designing joinable pultruded wind turbine components.

Integrate advanced thermoplastic resins into current production processes

Increase automation of fiber placement and inspection technologies

Design modular wind turbine components for affordable transport and installation

Demonstrate pultruded composite wind turbine components

Roadmapping Strategy



Crosscutting Areas



Additive Technologies



Crashworthiness & Repair



Design, Prototyping & Evaluation



Multimaterial Joining



Nondestructive Evaluation



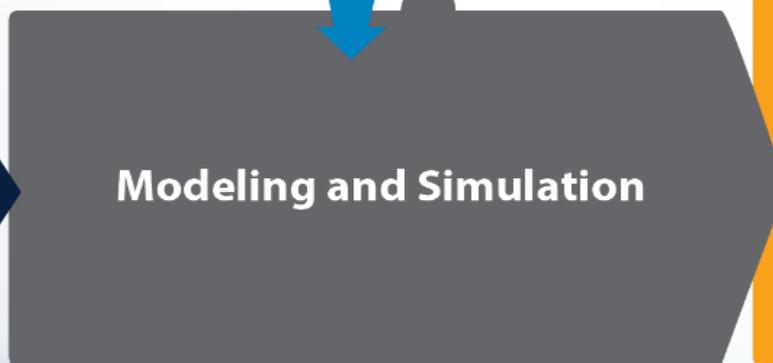
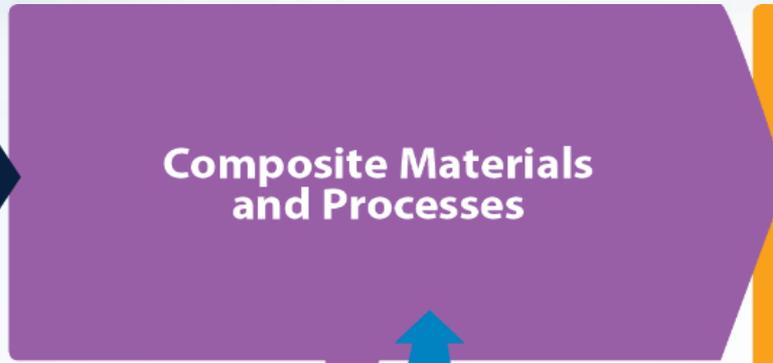
Recycling



Resins, Reinforcements, Additives & Intermediates



Standardization & Qualification



2020 Targets

Cost
↓ 25%

Energy
↓ 50%

Recyclability
↑ 80%

2025 Targets

Cost
↓ 50%

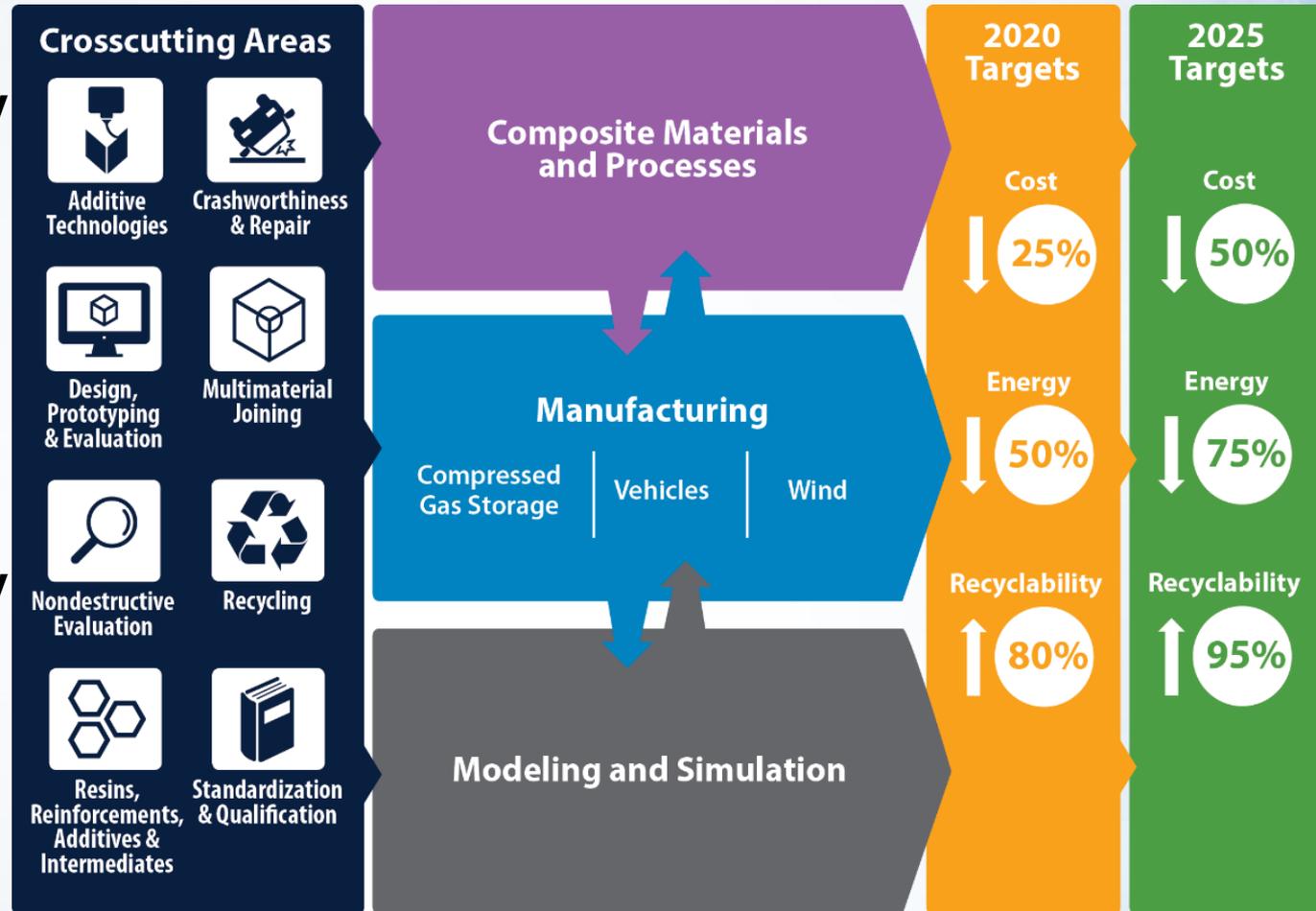
Energy
↓ 75%

Recyclability
↑ 95%

Roadmapping Strategy



- Integrated R&D efforts across IACMI Technology Areas toward 5-/10-year targets
- Industry-led projects draw upon resources from one or more IACMI Technology Areas
- Eight cross-cutting subtopics help address full range of enabling technologies



Roadmap Chapters: Five IACMI Technology Areas (TA)



- Each IACMI TA chapter comprises:
 - 1. Key Technical Objectives:**
 - High-level TA-specific objectives that comprise several R&D activities
 - 2. Priority R&D Activities through 2020:**
 - TRL 4–7
 - Activities connect to five-year targets: Cost, Energy, Recyclability
 - Arrows depict sequences/logical pathways
 - Roadmap focuses only on priority activities within IACMI's scope

1. Key Technical Objectives / High-level TA-specific objectives that comprise several R&D activities



IACMI TA	Key Technical Objectives
Composite Materials & Processes	<ul style="list-style-type: none">• Advance carbon fiber technologies via alternative precursors, efficient processes, and interface engineering• Demonstrate production of high value intermediates and composites from reclaimed carbon fiber• Apply NDE data to process design and control• Apply materials characterization capabilities to technology advancement and benchmarking• Apply additive manufacturing to reclaimed structural fiber fabrication and rapid prototyping
Modeling & Simulation	<ul style="list-style-type: none">• Provide access to advanced composites simulation tools across the supply chain• Demonstrate crash simulation tools and methods• Deploy phenomena-based composite simulation tools
Compressed Gas Storage	<ul style="list-style-type: none">• Focus on factory automation and lean manufacturing techniques• Demonstrate tough, recyclable thermoplastic tank designs using high speed tow placement• Enable high-volume manufacture of conformal composite CGS tanks• Employ predictive ICME approaches for tank design, manufacture, and certification
Wind Turbines	<ul style="list-style-type: none">• Integrate advanced thermoplastic resins into current production processes• Increase automation of fiber placement and inspection technologies• Design modular wind turbine components for affordable transport and installation• Demonstrate pultruded composite wind turbine components
Vehicles	<ul style="list-style-type: none">• Explore innovative design concepts for automotive composites• Demonstrate high-rate, robust, and scalable fabrication processes• Develop robust modeling and simulation tools for reliable cost and performance predictions• Foster development of effective multimaterial joining technologies• Enable rapid and reliable detection of composite defects

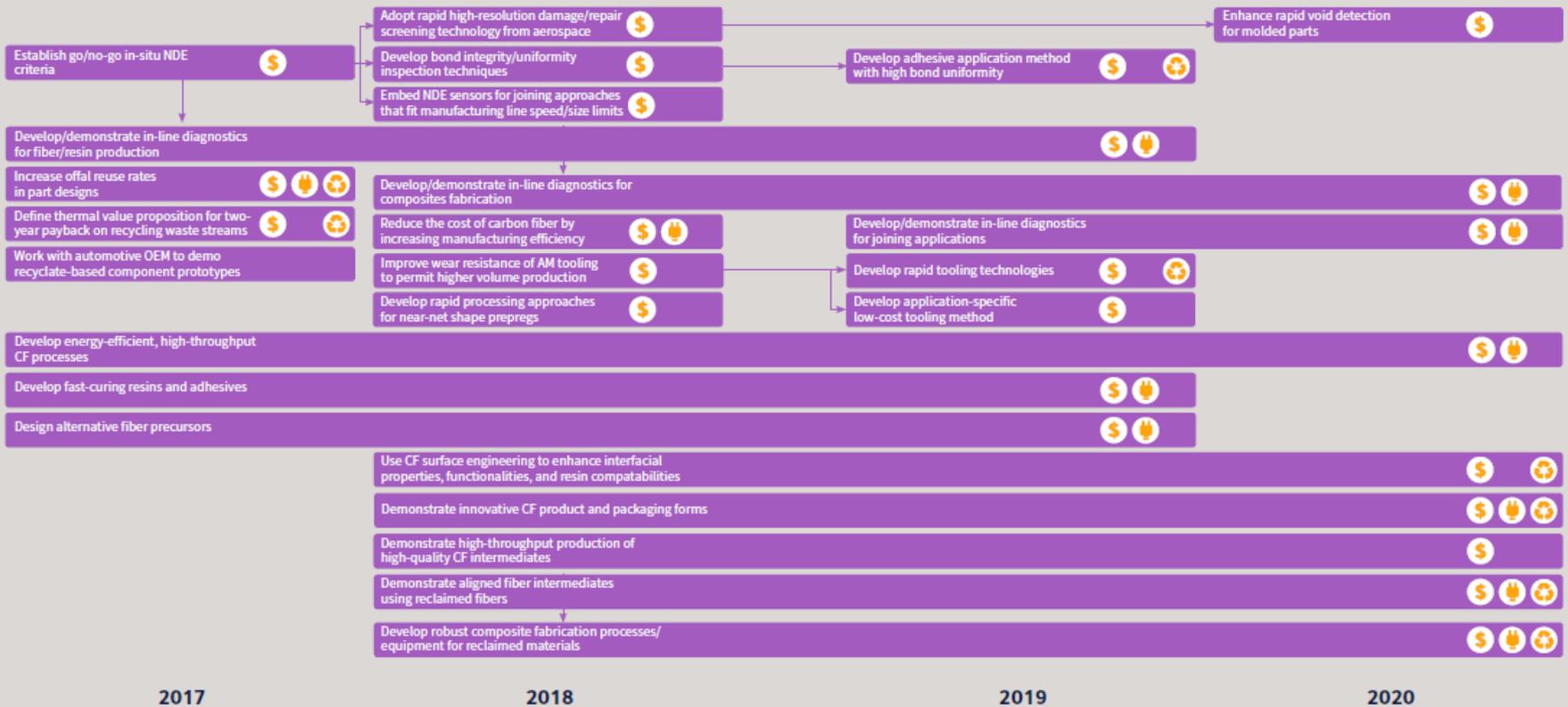
Example Timeline of Priority Activities - Spreads



Figure 4. Priority R&D Activities

Composite Materials and Processes

Targets addressed: Recyclability Cost Energy



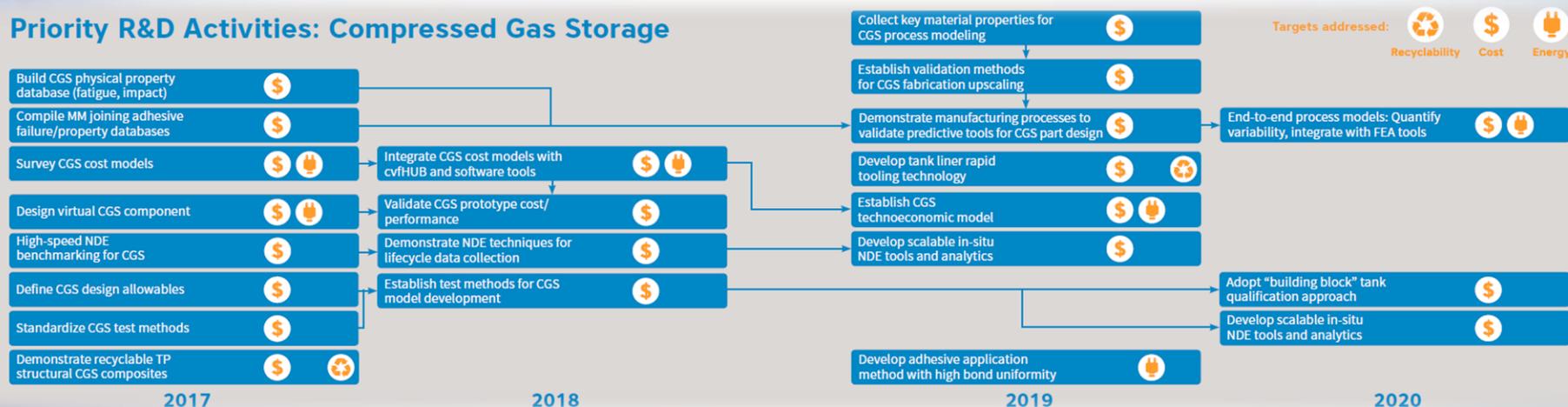
Roadmap Chapters: Five IACMI Technology Areas (TA)



2. R&D Activities through 2020

- TRL 4–7
- Activities connect to five-year targets: Cost, Energy, Recyclability
- Arrows depict sequences/logical pathways
- Roadmap focuses only on priority activities within IACMI’s scope

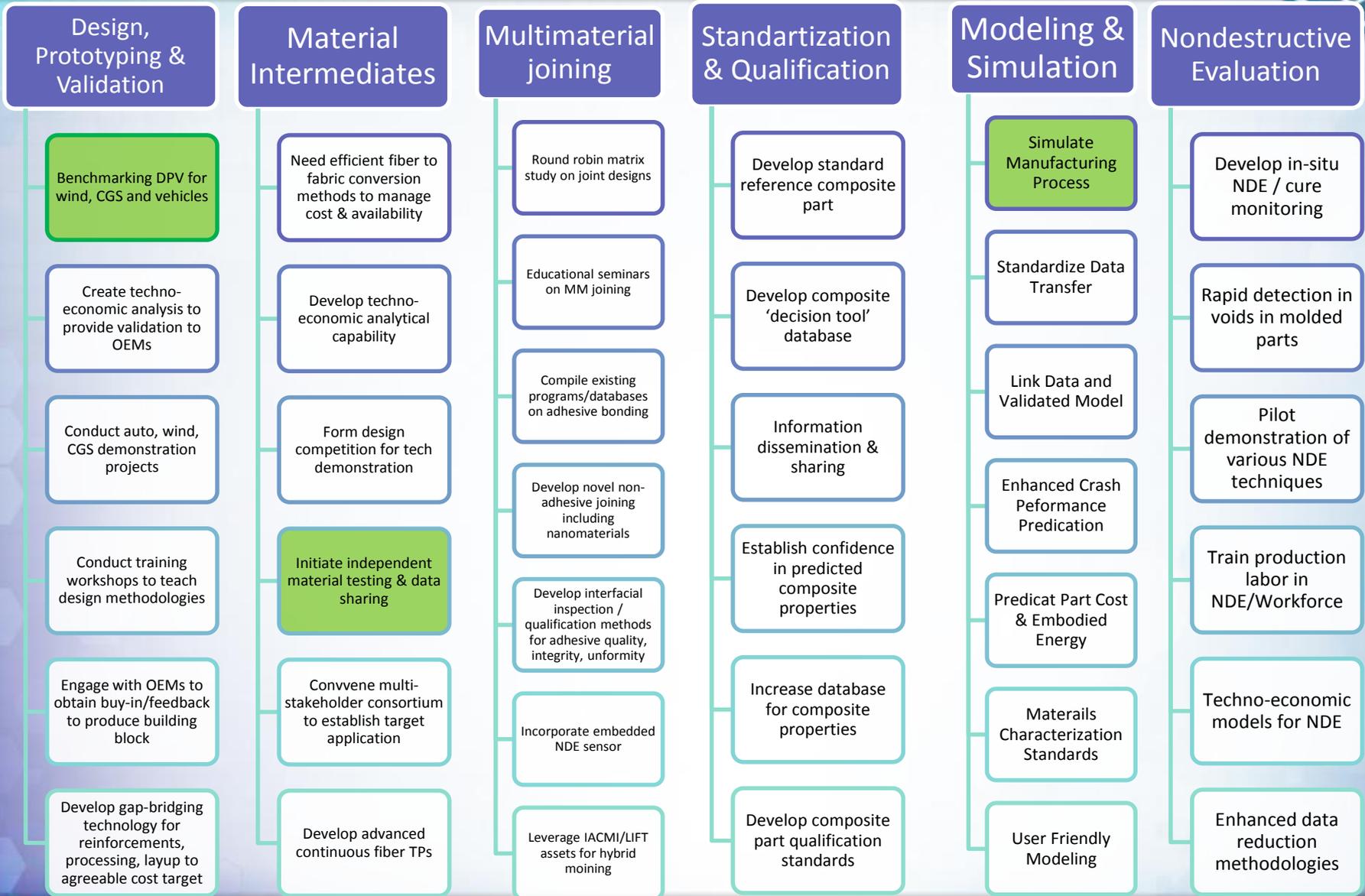
Priority R&D Activities: Compressed Gas Storage



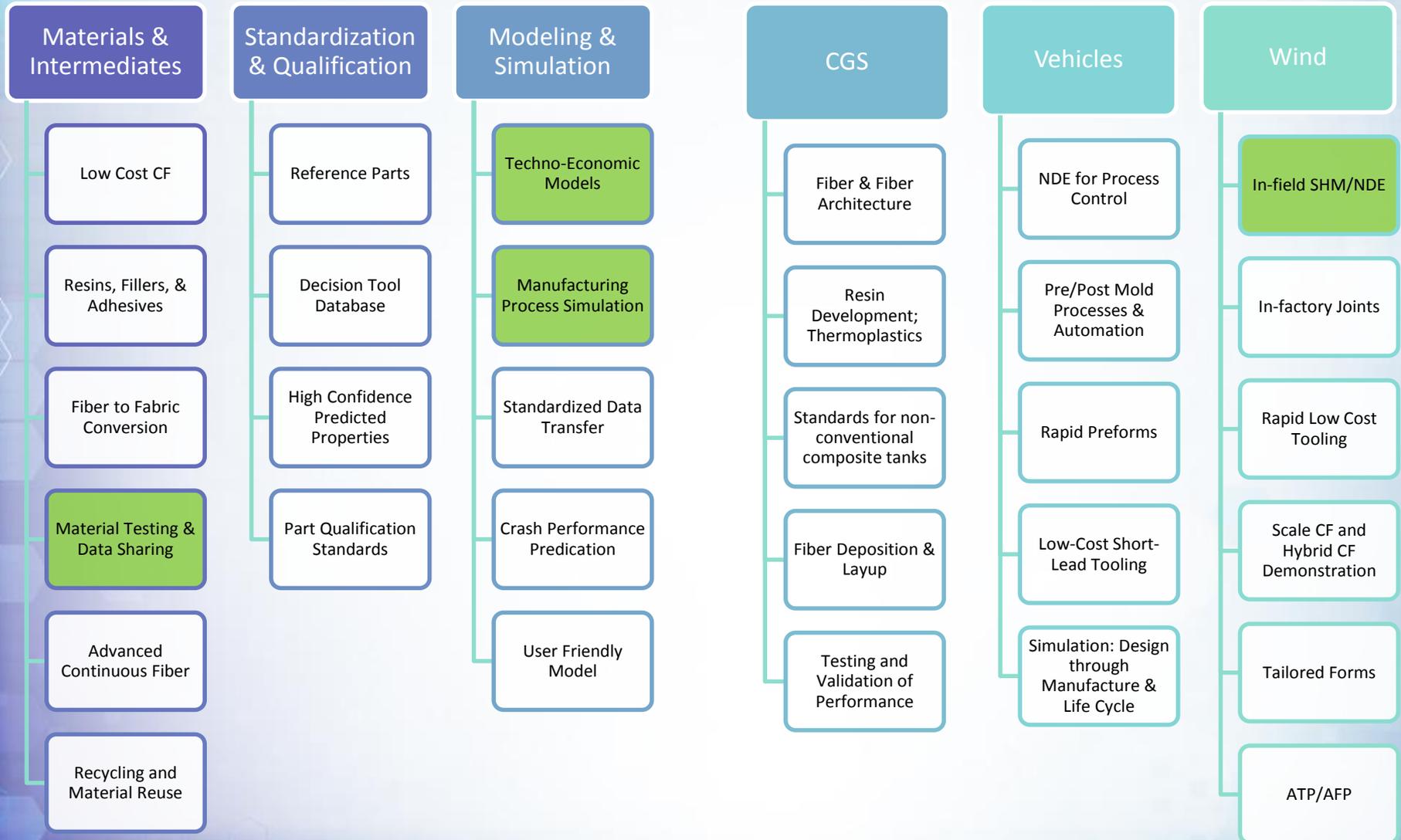
Example timeline of R&D activities for Compressed Gas Storage Technology Area.

Roadmap topics (Master)

Alignment to Projects



Roadmap Alignment – (Example)

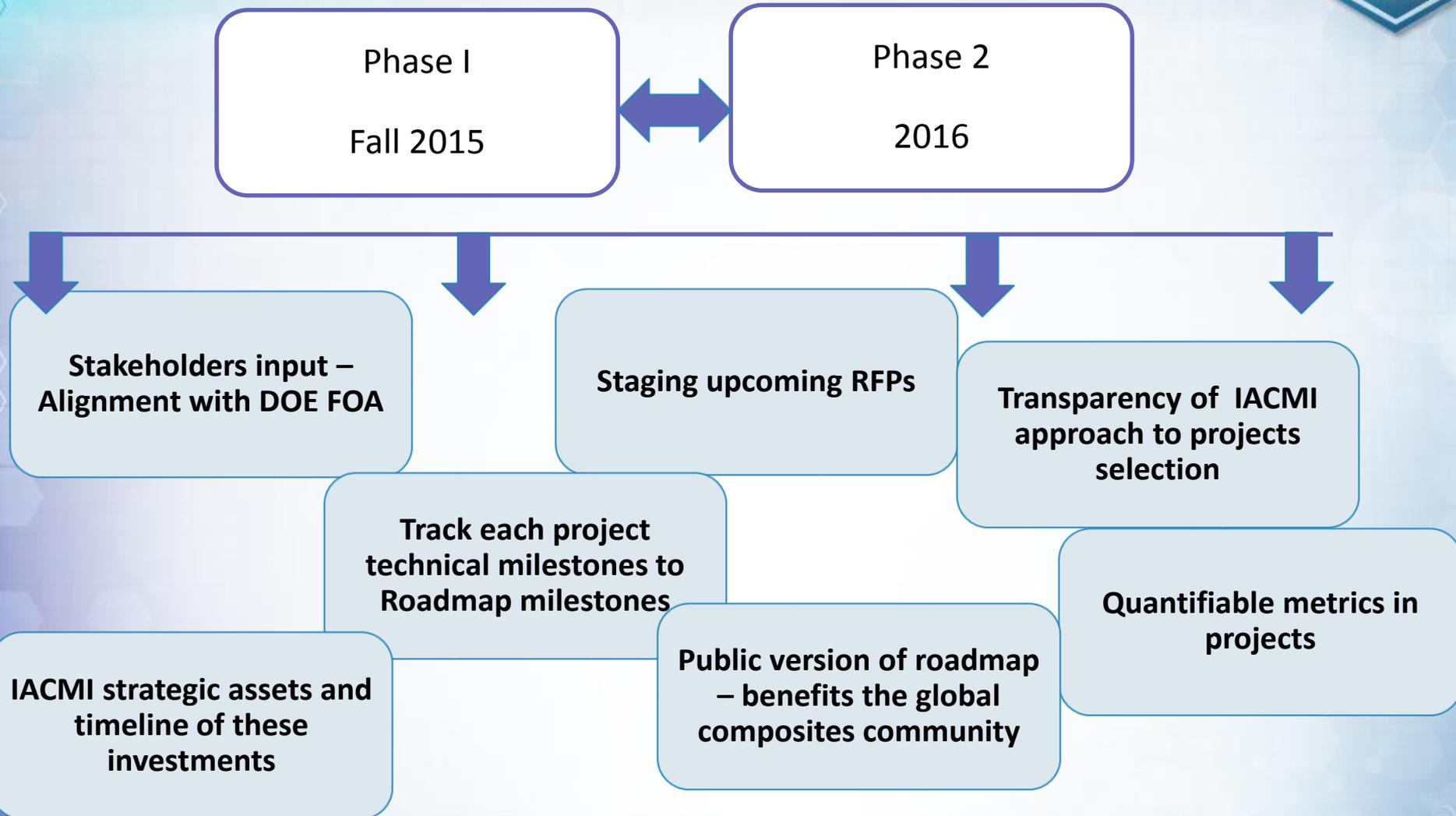


Reflection...



- ◆ ROADMAP is a living document
- ◆ GUIDE and not necessarily a lock-down long-term plan for IACMI.
- ◆ ‘Snapshot’ of the current thinking ‘at this time’ of those members and the composites community that responded.
- ◆ Background, experience and knowledge of the subject areas of the respondents varies greatly.
- ◆ Inherent interests of the responders will depend on their position in the supply chain. Hence, their responses will reflect this.
- ◆ Continuing efforts made to increase the knowledge level of the participants through seminars and educational programs.
- ◆ Input from ‘experts’ and the TADs will be utilized to verify, modify and alter the roadmap as/if needed to insure that only the most important technical areas are identified and prioritized consistent with the goals of IACMI and DOE.

Summary and Roadmap Utilization



Are Technical Barriers & Gaps identified in the Roadmap being addressed in the projects?

Summary

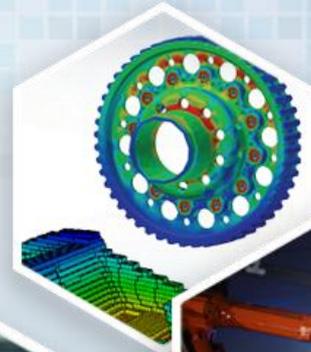


- ◆ Each IACMI project tied to the roadmap elements
- ◆ Represents alignment within the 8 sub-topics and 5 cross-cutting areas
- ◆ Each project will meet a subset of identified technologies
- ◆ A roadmap alignment template will accompany reporting for each project
- ◆ Collectively the goal is to address 'most' critical metrics

Thank You!



Backup Slides



Roadmap topics (Master, contd.): Alignment to Projects



Additive Technologies

Conduct techno-economic study comparing metal with composite AM tooling

Explore science-chemistry or processes for improved Z-properties

Conduct study on material characteristics for high temp tooling

Develop in-situ process monitoring & control for FDM processes

Develop low and high pressure compression molding AM tooling

Investigate AM tooling for wind, auto and CGS

Crashworthiness & Repair

Conduct sensitivity analysis to determine process window effects

Identify top 5 auto component focuses for adoption of composite solutions

Develop database of physical properties based on currently available composite materials

Fund internships for new engineers to teach supply chain aspects

Demonstrate manufacturing processes to validate predictive tools

Develop composite repair certification program accepted by OEM/Tier 1

Large scale manufacturing : CGS

Toughened resins

High strength low cost fiber for CGS tanks

Develop standards for non-conventional composite tanks

Need fiber deposition methods compared to current methods

Benefits of alternate fiber architectures

Alternate TP materials, screening and testing methods, validate tank performance

Energy saving pathways – thermoset versus thermoplastics

Large scale manufacturing: Vehicles

Development-reimagine car with composites

Serve as change agent - techno-economic

pre-competitive optimization study on large modules integrating manufacturing process to part

Develop a study that conceptualizes usage scenarios that drive decision-making on equipment placement and workspace flexibility for ideal conditions at Corktown demonstration facility

Compare additive and subtractive solutions for large-scale manufacturing

Develop simulations to predict quasi-static and lifetime performance of composites

Large scale manufacturing: Wind

Develop low cost in field SHM / NDE

Develop in-factory joints for wind blades

Develop rapid low cost tooling for wind blades

Develop large scale carbon fiber blade demonstrator

Develop hybrid CFRF high performance blades

Assess tailored forms such as pultruded bars, rods

Learn from aerospace – automated tape placement

Recycling

Work with OEM to demo production of recycle components

Optimize surface treatment / sizing technology to maximize fiber recover & mech propr

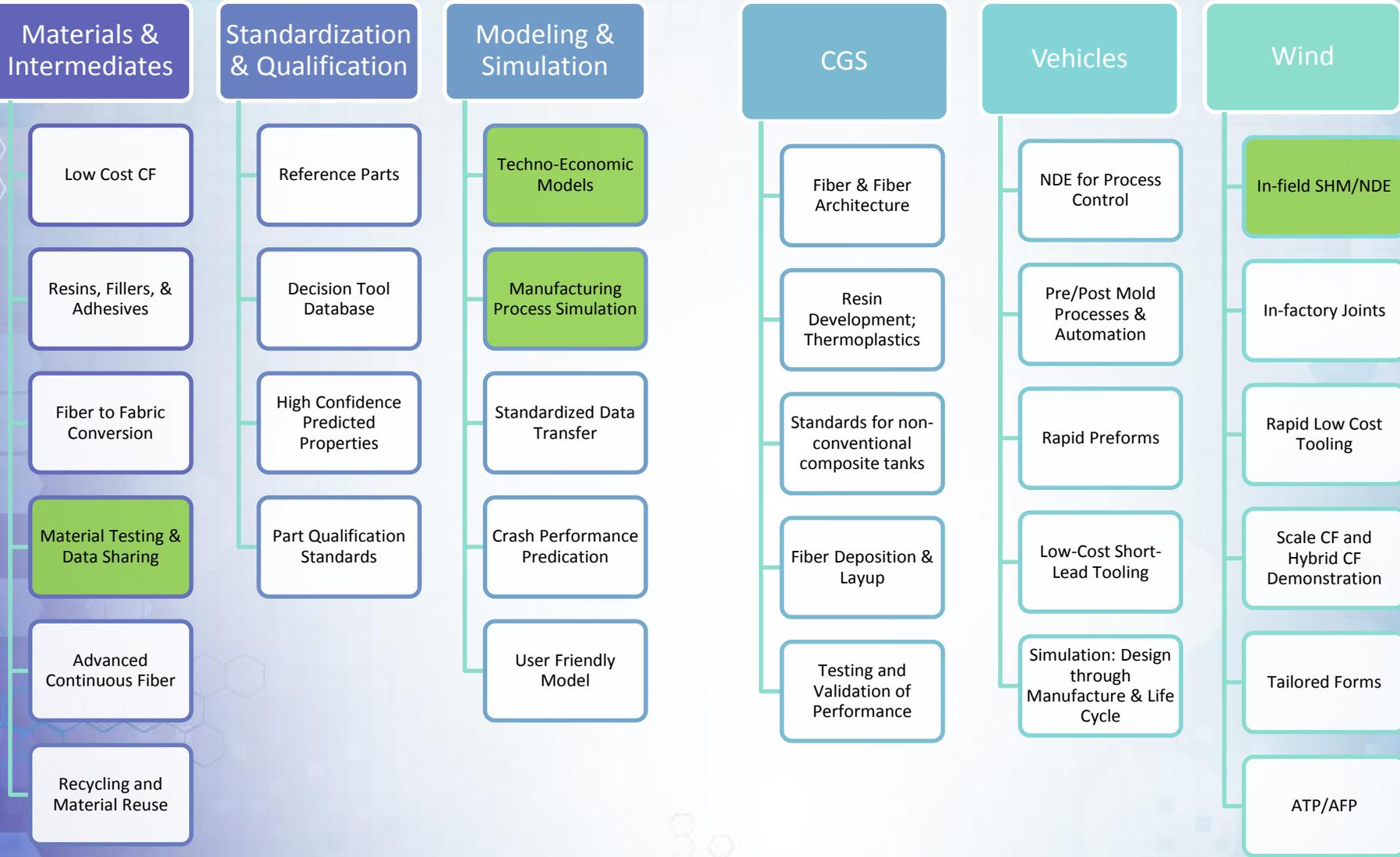
Full scale turbine blade recycling project; document costs, methods and challenges

Demo program on design for DFM and DFR and DFS

Incorporate offal / CF scrap into turbine blades & high quality parts

Develop technical marketing materials for recycled carbon fibers

Roadmap Alignment (Subset / Derived from Master)



Phase II Roadmapping Workshops



- ◆ March 23-24 (Knoxville), and May 10-11 (Detroit)
- ◆ Attended by 90 (March) and 110 (May) stakeholders
- ◆ Topics: Wind, CGS, Automotive, M&P, M&S
- ◆ Professional facilitators – Nexight Group
- ◆ Technical Leads for each session
- ◆ Raw data gathered through the detailed sessions
- ◆ Findings used in Generating the Phase 2 Roadmap

Example Timeline of Priority R&D Activities



 = IACMI-funded

2017

2018

2019

2020



Design,
Prototyping
& Evaluation
(cont.)

Conduct training workshops on composite design methodologies and contemporary production and assembly methods

Use cvfHUB to develop formal “composite decision tool” database linking material properties to end-use performance



Multimaterial
Joining

Gather/compile existing databases and programs on material properties and failure characteristics of multimaterial joining adhesives

Host IACMI member seminars on major multimaterial joining topics (e.g., quality control, NDI, qualification protocols, cleanliness and surface preparation)

Develop novel non-adhesive multimaterial joining methods

Develop accelerated aging tests for composite

Launch joint LIFT/IACMI programs on cross-sector multimaterial joining issues

Explore hybrid, multimaterial CFRP systems (thermoplastics/thermosets) for large, high-performance blades

Develop new fabrication method for applying adhesives to substrates (e.g., pre-treatment step for high bonding uniformity)

Demonstrate large-scale CFRP jointed blade design with integrated multimaterial thermoplastic/thermoset component