Autocomposites
Workshop Report

KICKSTARTING THE WIDESPREAD ADOPTION OF AUTOMOTIVE CARBON FIBER COMPOSITES

KEY FINDINGS & NEXT STEPS

Acknowledgements

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EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Passenger vehicles dominate oil consumption in the United States, accounting for 49 percent of nationwide use, or some 8.8 million barrels per day. They therefore contribute—sometimes in significant ways—to many problems associated with this commodity, including: exporting ~$1 billion petrodollars per day, climate change, geopolitical instability, smog, respiratory problems, and the widespread environmental impact arising from oil spills.

Those issues can be addressed, in part, by weaning passenger vehicles from oil by making them more efficient. The most direct design lever for reducing consumption and improving efficiency (while preserving or even enhancing safety and performance) is to make vehicles lighter. In the near term, lightweighting improves fuel economy; in the longer term, it enables more cost-effective electrification of the powertrain.

While it is certain that nimble, lightweight, and safe vehicles of the (near) future will utilize mixed material solutions, carbon fiber—with its unparalleled stiffness, strength, and ability to absorb large amounts of energy—is an ideal candidate to allow transformative reductions (e.g. >50%) in vehicle weight. Catalyzing effective use of carbon fiber composite today can unlock a future of completely redesigned carbon-fiber-intensive vehicles, in turn enabling several future pathways for breakthrough efficiency. Given carbon fiber's current low penetration levels in vehicles, there are many opportunities to increase its use and adoption in mainstream, high-volume vehicles to make them lighter, stronger, and safer.

Historically, several barriers have prevented the widespread adoption of carbon fiber composites in passenger vehicles: high material costs, slow and immature manufacturing processes, rudimentary design and analysis tools, lack of experience, and inertia arising from a mature and entrenched supply chain. Yet much has changed in the past decade through enhanced processes, the increasing value of weight savings, improved knowledge and experience, and supply chain evolution.

During the course of a three-day workshop held in the Detroit area in November 2012, ~40 leading experts from across the automotive carbon fiber composite value chain, industry experts, and government representatives convened to develop approaches to break down the barriers that have stifled advancements in vehicle weight reduction made possible by widespread penetration of carbon fiber composite into mainstream vehicles.

EXECUTIVE SUMMARY

KEY INSIGHTS:

A PARTS- AND SUBASSEMBLY-FOCUSED PROGRAM OFFERS A VIABLE APPROACH.

A parts- and subassembly-focused program for carbon fiber composite material substitution offers a viable approach for catalyzing high levels of automotive carbon fiber adoption, especially in areas of the vehicle requiring stiffness and strength and that place a high value on weight reduction. This approach:

1. Avoids the risks of a whole-vehicle redesign, but can help catalyze a total transformation over time
2. Is applicable to a wide variety of vehicle types and classes
3. Is compatible and complementary to the use of other lightweight materials

COMPELLING OPPORTUNITIES EXIST IN THE NEAR TERM.

There appear to be a number of compelling opportunities than can be pursued now for adoption in vehicles in the next 4–6 years that will address existing challenges while catalyzing innovation, production scale-up, and adoption of carbon fiber. Design, manufacturing processes, costs, and value were evaluated for several part families and early analysis strongly suggests that they offer a viable business case. Key parts families include—but are not limited to—doors, rear hatches, seats, and engine cradles.

- For the three parts, the extra cost per pound saved ranged from $2.78 to $4.76.
  - ***However, in most cases, value completely offset cost, rendering the carbon fiber composite total part cost equal to or better than its steel counterpart.***
- Weight savings ranged from 60 to 70%.
- Additional parts proved promising. They included:
  - Wheels
  - Rear cradle
  - Battery carrier/shield (for EVs, hybrids, and possibly heavy trucks)
  - Bumper beam
  - Suspension springs
  - Cross-car beam (possibly integrated with HVAC duct)

EXECUTIVE SUMMARY

KEY INSIGHTS: (CONT'D)

SELECTION CRITERIA CAN HELP SCREEN FOR THE MOST PROMISING PARTS/SUBASSEMBLIES.

A clear and finite set of selection criteria can be used to focus efforts for carbon fiber substitution in parts/subassemblies. Primary criteria include:

1. Weight reduction potential
2. High stiffness and strength requirements
3. Producible at scale with current or imminent processes
4. Avoids near-term safety qualification and/or assembly line modifications
5. High potential for part consolidation
6. Additional value beyond direct weight savings and fuel economy (e.g. parts consolidation, compounding cost and weight savings for attached parts, improved acceleration or handling)
7. Scalable to other models and platforms

PARTS WITH A STRONG SAFETY FUNCTION FIGURE CENTRALLY IN THE LONGER TERM.

Parts with a strong safety function will be good candidates in the longer term as design tools and capabilities are increasingly able to predict—and customers come to understand—the crash energy absorption potential of carbon fiber composite. However, extremely crash-critical parts may face prohibitive qualification risk in the near term.

WINNING STRATEGIES MUST OPTIMIZE CARBON-FIBER-BASED DESIGNS TO CAPTURE FULL VALUE.

Because fiber is expensive—and is expected to remain so in the next five years—winning strategies will optimize designs that fully harness the intrinsic properties of carbon fiber by maximizing weight savings while making optimal use of material. Consequently:

1. It is essential to enhance material characterization and design tools, material databases, and manufacturing processes to minimize scrap and optimally place carbon fiber.
2. There is a clear need for enhanced collaboration, research, and coordination in the areas of improved material characterization, predictive modeling, low-cost precursors, and tool development for advanced manufacturing processes.
   a. These efforts are underway, but are insufficiently organized and funded, with limited learning across disparate efforts.
   b. Substantial CF experience and innovation is occurring outside the United States, so a global view is imperative.
3. Hybrid material approaches where cheaper, lighter material can be used in areas outside direct load paths will play an important role.

EXECUTIVE SUMMARY

KEY INSIGHTS: (CONT'D)

REDUCING FIBER COSTS OFFERS A POTENTIAL FULCRUM FOR EXPLOSIVE ADOPTION OF CARBON FIBER.

Fiber cost is by far the primary contributor to the cost of a carbon fiber composite part. Step-change reductions in carbon fiber precursor and carbon fiber manufacturing costs would help create an explosion in carbon fiber adoption rates beyond those available by addressing the aforementioned points. Key levers include:

1. Precursor accounts for half the cost of producing carbon fiber—finding low cost alternatives to today's precursor is very challenging but offers a big payoff. Focus on a select number of high-potential precursors (e.g. polyolefin) for further investigation and optimization for large-scale carbon fiber production.
2. Enhanced competition and optimization of carbon fiber production in the automotive sector to drive cost reductions of carbon fiber resin systems.
3. Consolidation and better characterization of carbon fiber-resin systems to simplify the design process, create consistent performance standards, and drive scale. Although the industry has historically resisted standard grades of fiber and resin, the lack of such specifications will limit the ability to reach scale and compete with more mature materials such as steel, aluminum, and magnesium.

OEM ASSEMBLY REQUIREMENTS AND TIMING NO LONGER POSE INSURMOUNTABLE HURDLES.

Manufacturing processes and cycle time have matured significantly in the past decade, to the point that meeting OEM assembly requirements and timing have become tractable problems.

THERE IS CLEAR NEED FOR A TEAM OF PLAYERS FROM ACROSS THE SUPPLY CHAIN TO FOCUS EFFORTS ON BRINGING PARTS/SUBASSEMBLIES TO MARKET.

There is a clear need for focused efforts by teams composed of players from across the supply chain to drive competitive efforts to bring parts and/or subassemblies to market in the next 4–6 years. This approach will require:

1. Both competition and some collaboration (i.e. "coopetition")
2. Teams of participants from across the supply chain to contribute capital and skills, leveraged by seed funding from government or external sources
3. Strong leadership from either the Tier 1 or OEM level with an intimate knowledge of—and ability to tap into—the OEM production part development process
4. Organization and structure to support a multi-year outlook with an emphasis on vehicle performance outcomes and supply-chain optimization arising from actual carbon fiber adoption into existing assembly processes

EXECUTIVE SUMMARY

KEY INSIGHTS: (CONT'D)

THERE IS A CLEAR NEED TO STIMULATE CROSS-DISCIPLINARY, CROSS-INSTITUTION COLLABORATION.

A clear need exists for cross-industry collaboration with government and academia to enhance innovation and spur further adoption of automotive carbon fiber composites. An innovation hub that brings together industry, academia, and government would:

1. Better connect academic and government research to industry needs
2. Centralize, strategize, and coordinate research efforts
3. Centralize material data and better characterize the array of carbon fiber composite material combinations and specifications
4. Provide shared access to manufacturing equipment and material data test rigs
5. Provide space to demonstrate new processes and cross-pollinate ideas

EXECUTIVE SUMMARY

A PATH FORWARD:

The workshop and the insights it generated helped galvanize an eager willingness to carry forward momentum and coordinate action to catalyze solutions for this industry.
Promising next steps include:

1. A parts campaign to bring specific parts to market
2. An innovation hub to centralize and coordinate learning, demonstrate new processes, and catalyze continued collaborative progress in this nascent industry
3. A noncompetitive effort focused on material characterization (which may be part of the hub as well)
4. A coordinated industry effort focused on cheaper precursor

WORKSTREAM 4:
A coordinated industry effort focused on cheaper precursor

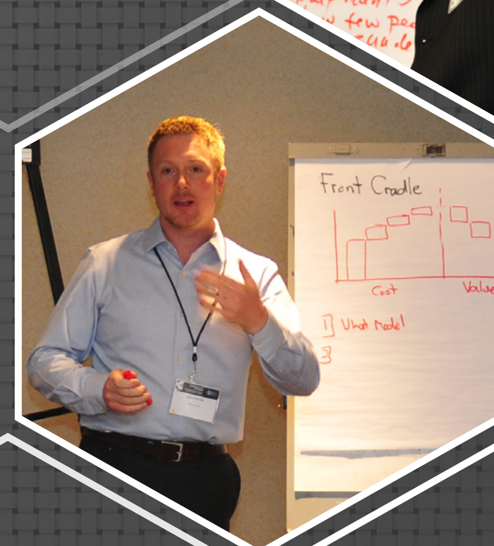
WORKSTREAM 3:
A noncompetitive effort focused on material characterization (which may be part of the hub as well)

WORKSTREAM 2:
An innovation hub to centralize and coordinate learning, demonstrate new processes, and catalyze continued collaborative progress in this nascent industry

WORKSTREAM 1:
A parts campaign to bring specific parts to market

INTRODUCTION

01



INTRODUCTION

The United States burns over 13 million barrels of oil per day keeping our vast transportation system running. The cost of this use—to our health, geopolitical stability, climate, and pocket books—is huge and often hidden.

Cars are by far the biggest user of oil (~8.8 million barrels per day), accounting for about half of all U.S. oil use. The most effective means of reducing U.S. oil dependence (other than simply driving fewer miles) is to dramatically increase vehicle fuel efficiency.

Lighter autobodies improve fuel efficiency and allow powertrains—regardless of their fuel type or technology—to be smaller, lighter, and more efficient. The value of weight reduction for electric vehicles is even more pronounced, reducing the cost and bulk of batteries, extending range, or both.

The most likely long-term scenario for achieving breakthrough weight reduction (50% or greater) for mainstream vehicles is a mixed material solution. Part for part, autobody for autobody, carbon fiber composite enables the most dramatic weight reduction of any advanced material currently in use due to its unparalleled structural characteristics. It is very likely to play a critical enabling role in this mix.

Automotive carbon fiber composite adoption nevertheless faces many barriers. Material cost must be reduced to move beyond niche markets and ultimately enable cost-effective carbon-fiber-intensive mainstream vehicles. Other challenges include enhancing design tools, improving material characterization, improving and integrating existing manufacturing and assembly processes, and addressing lifecycle challenges related to repair and recycling (see Figure 1).

CARBON FIBER COMPOSITE—WITH ITS UNPARALLELED STIFFNESS, STRENGTH, AND ABILITY TO ABSORB CRASH ENERGY—IS AN IDEAL CANDIDATE TO ALLOW TRANSFORMATIVE REDUCTIONS IN VEHICLE WEIGHT, INCREASES IN FUEL ECONOMY, AND IMPROVEMENTS IN VEHICLE PERFORMANCE AND SAFETY.

Fortunately, it is becoming increasingly clear that tractable solutions that overcome these barriers are available and progress is being made on numerous fronts. European players have recently invested in a long-term strategy around this material for scale production and are building out and integrating supply chains. New processes have recently come online that can quickly, consistently, and cost-effectively produce carbon fiber composite parts at scale. Despite persistently high material cost, customers are valuing fuel efficiency and other weight-related benefits more than ever, and heightened CAFE standards are increasing automakers' incentive to pursue lightweight design.

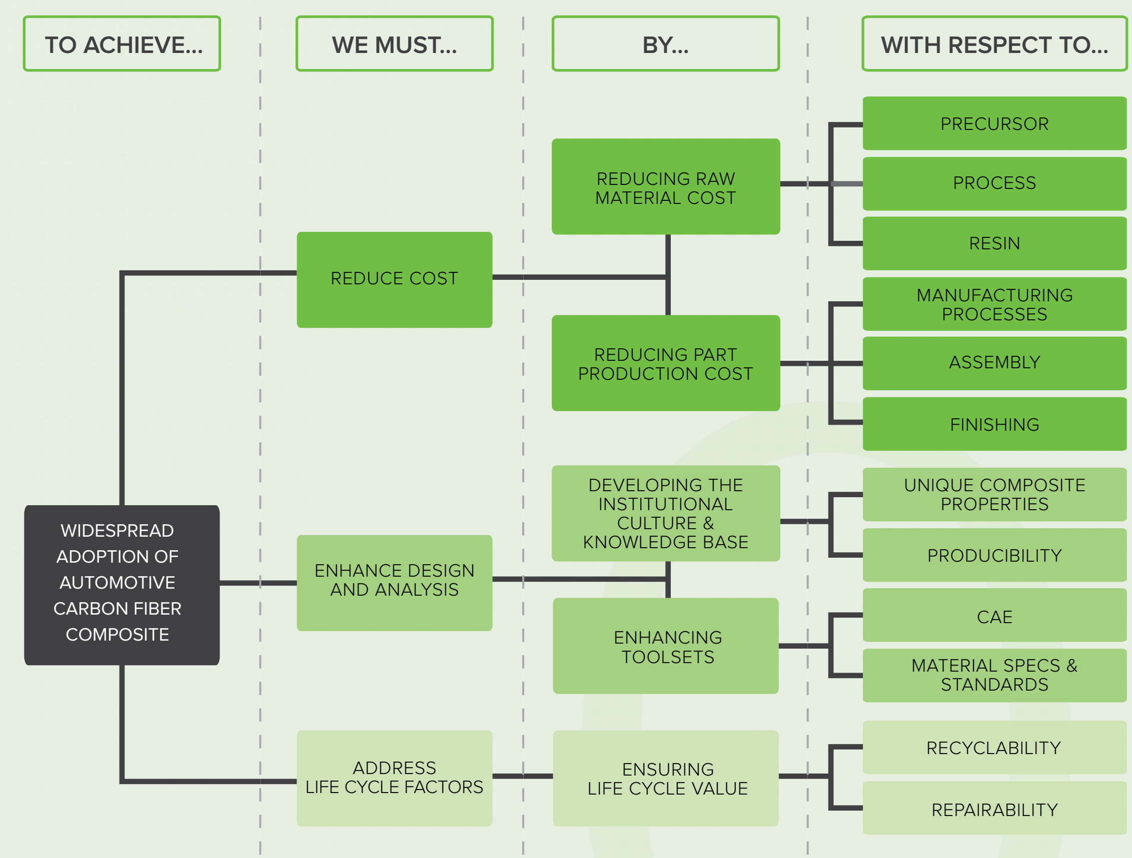
INTRODUCTION (CONT'D)

Granted, materials such as high-strength steel, aluminum, and magnesium can be used to achieve substantial near-term weight reduction, and they'll likely play an important role in tomorrow's lightweight, mixed material vehicle. Carbon fiber composite offers a better long-term solution with an all-new and potentially more cost-effective manufacturing model relative to any of these other materials, more dramatic weight reduction, and increasingly (as simulation tools mature), even more customer value in the form of unparalleled safety performance.

The full benefits of carbon fiber composite are best harnessed with a "clean sheet" approach in which vehicles are redesigned around the unique characteristics of this material. Automakers have developed concept and niche vehicles that do so. But bringing these technologies to mainstream vehicles by jumping to an all-new scale design and manufacturing paradigm (including new plants,

THE LOGIC TREE FOR STIMULATING AUTO INDUSTRY ADOPTION OF CARBON FIBER

FIGURE 1:



INTRODUCTION (CONT'D)

processes, people, and products) has proven too risky and difficult to pursue for mainstream, high-volume vehicles.

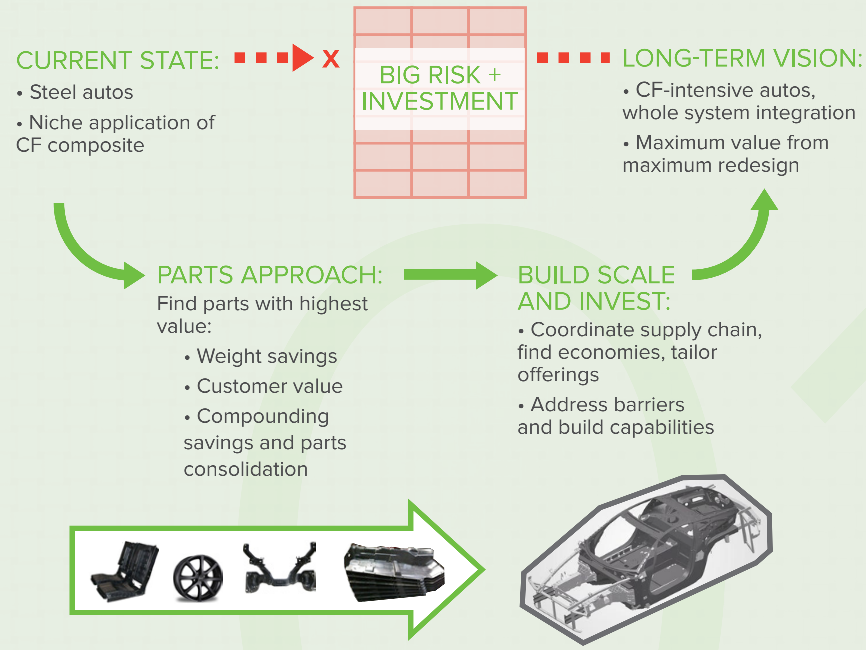
An alternative approach to achieve a full transition can start with individual parts, allowing automakers and their supply chains to scale up and systematically invest while navigating barriers. Those who embark on the path now will be best positioned to reap not only near-term value associated with carefully selected applications, but also positioned to reap the longer-term competitive benefits of a transformed industry built around lighter, stronger, safer, and higher-performing vehicles. The parts-based approach is summarized in Figure 2A.

Switching a few parts may seem irrelevant to total vehicle weight and the scale of the carbon fiber industry, but quite the opposite is true. As shown in Figure 2B, *just one part on four mainstream models would double total automotive demand for carbon fiber. Four parts on eight mainstream models would double total worldwide demand for carbon fiber, resulting in enormous driving forces to streamline processes, increase innovation, spur competition, and optimize supply chains.* From a weight perspective, switching the rear hatch door on a van or crossover vehicle could save 30–50 lb and offset up to half of a $200–300 material and manufacturing cost premium (before accounting for any additional customer value beyond fuel savings, which can make an even larger contribution to the cost-benefit picture—see the section "Business Case Evaluation," p27).

SUMMARY OF THE PARTS-BASED APPROACH

FIGURE 2A:

STARTING AT THE PART LEVEL, AUTOMAKERS CAN AVOID THE RISK OF A "WHOLE VEHICLE REDESIGN" APPROACH, BUT CATALYZE A TOTAL TRANSFORMATION OVER TIME.



INTRODUCTION (CONT'D)

Coordinating the many pieces of the automotive carbon fiber composite supply chain on the most promising parts requires input and action from each major player within that chain. A combination of collaboration and competition, or "coopetition," can unleash collective opportunity and overcome structural and economic barriers that individual players would find difficult to surmount. Specifically, building a noncompetitive, collaborative, industry-wide foundation on which businesses can more effectively execute competitive strategies can play a role in not only further enabling part-specific opportunities but also spurring industry growth and longer-term adoption.

Government and academia, through their respective relationships with industry, are at the heart of building this foundation, whether as brokers of cooperative technology advancement, direct funders of critical research, or navigators of a broader strategic pathway for a transformed industry.

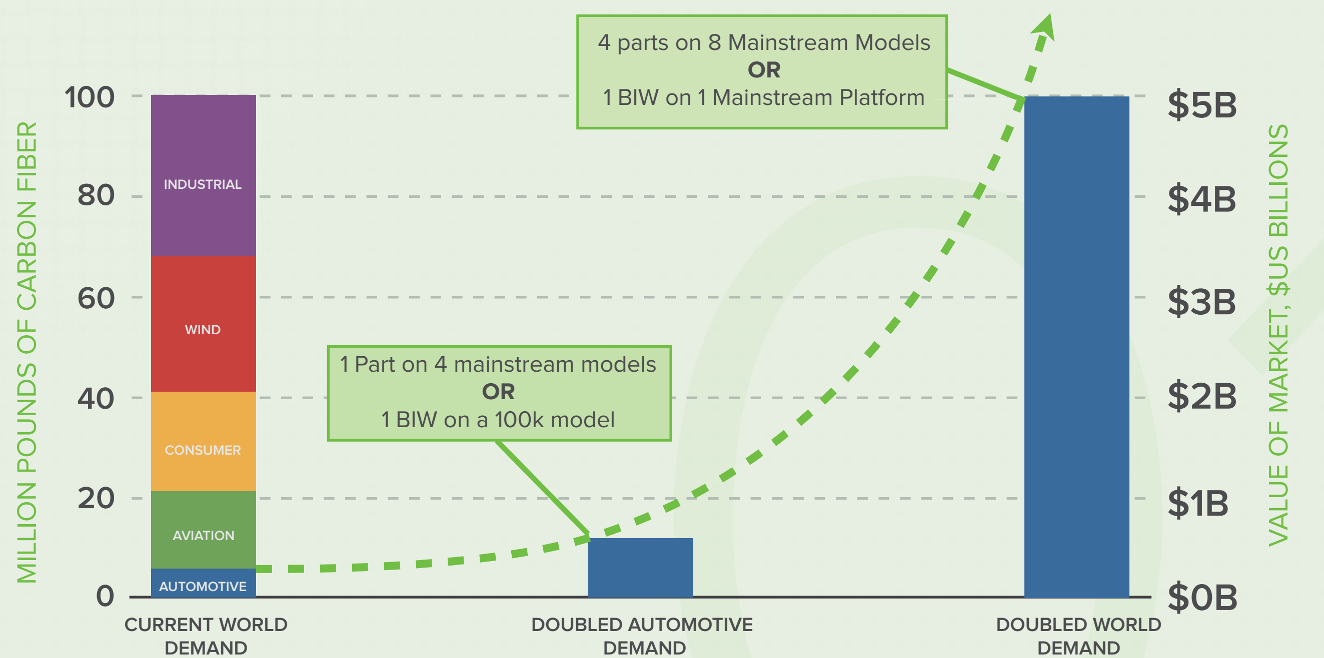
Using a facilitated gathering of diverse stakeholders—the material supply chain, automakers, Tier 1s, investors, scientists, and government decision makers—this workshop sought to identify, evaluate, and enable pathways to market that could kickstart high-volume adoption of automotive carbon fiber composites.

INDUSTRY IMPACT OF THE PARTS-BASED APPROACH

FIGURE 2B:

[A FEW PARTS, IMPLEMENTED AT MAINSTREAM VOLUME, CAN DRIVE SIGNIFICANT SCALE AND INVESTMENT.]

*BIW = body in white



WORKSHOP PROCESS & FLOW

02

WORKSHOP PROCESS AND FLOW

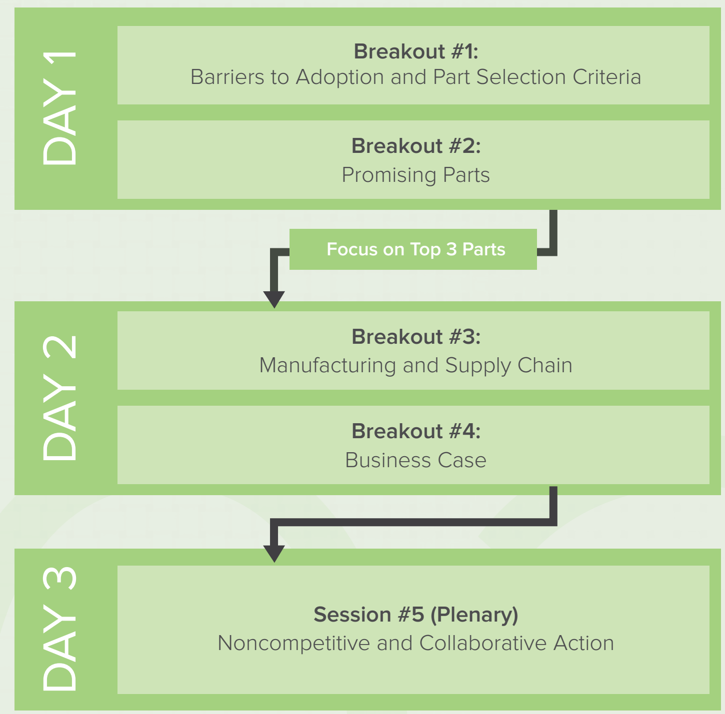
The three-day workshop included five main sessions. Sessions 1–4 (held on the first two days) focused on individual parts and followed a “breakout group” approach in which three smaller groups focused on a specific objective. A plenary session in which the groups reconvened to synthesize their outputs followed each breakout session. Figure 3 summarizes the workshop process.

Session 5 focused on opportunities for noncompetitive action and collaboration across the industry as a whole and was conducted in a plenary session. The objective(s) of each session were:[1]

- **SESSION 1:** Identify and prioritize 1) barriers to adoption, and 2) part downselection criteria that, if met, could address those barriers
- **SESSION 2:** Apply downselection criteria to identify promising parts
- **SESSION 3:** For the top three parts, identify manufacturing processes by which parts can be made and the supply chain composition around that process
- **SESSION 4:** Develop a business case (cost to manufacture based on a detailed cost model developed by Munro & Associates vs. value provided) for the top three parts and manufacturing processes
- **SESSION 5:** Identify noncompetitive and collaborative action for advancing the industry as a whole

WORKSHOP PROCESS FLOW

FIGURE 3:



[1] See the “Autocomposites Workshop Pre-Read Document”

DISCUSSION:

THE PARTS-BASED APPROACH

03

SESSION 1

PART SELECTION CRITERIA AND PRIORITIZATION

A high-value, cost-effective, and scalable part:

- Offers substantial weight reduction potential
- Is primarily stiffness-driven, but can also be strength-driven
- Is manufacturable at scale with current or immediately foreseeable processes
- Avoids near-term safety and assembly challenges
- Offers the potential for integrative design (part consolidation)
- Offers tangible customer value
- Is readily adapted and scaled to additional models and platforms (scaling logic)

WEIGHT REDUCTION POTENTIAL

Weight reduction potential that leads to fuel savings is the primary motivation for lightweight material substitution and is therefore a fundamental criterion for part selection. As discussed in the Introduction, carbon fiber offers a very high specific strength, but is even better relative to other materials from a specific stiffness standpoint. In order to use carbon fiber most effectively, and achieve the highest weight savings, participants looked for large, heavy structural parts with high stiffness requirements.

MANUFACTURABILITY AND PRODUCTION VOLUME

Candidate parts were also selected with an eye to manufacturability at scale. For the workshop's purposes, scale production was targeted with an initial range of 50–100k per year.[2] Achieving a production volume within this range would be a significant step beyond current automotive application of CF composites—challenging enough to drive innovation, automation, higher cycle times, and repeatability/consistency, but within reach with existing processes. Just three to four parts at this volume would roughly double automotive demand for carbon fiber (see Figure 2B, p14), helping strengthen the case for investing in automotive-specific material research and development, including reducing fiber cost.

AVOIDED CHALLENGES

A few challenges may pose a near-term qualification risk or may currently prevent high-volume applications.

While Class A finish on carbon fiber composite parts has been achieved on several low-volume vehicles, it may make sense to select a part that does not require Class A finish due to challenges associated with integrating with the main line paint process (E-coat, powder coating) or a need to paint it independent of the main-line process, which can lead to color matching challenges and higher costs.

[2] See the discussion of "Manufacturing Process and Supply Chain Composition" [Session 3] for a full discussion of the high-volume manufacturing processes considered at the workshop.

SESSION 1

PART SELECTION CRITERIA AND PRIORITIZATION (CONT'D)

In the longer term, carbon fiber composite offers tremendous potential to improve safety due to its ability to absorb more crash energy per pound than metals. Due to the immaturity of predictive tools and testing data at this stage, however, safety may nonetheless present a near-term challenge that can be navigated by selecting parts that, while not completely devoid of safety considerations and thus long-term safety value, are not in a critical crash load path.

PART CONSOLIDATION

Composite manufacturing processes can often enable reduced part count by integrating and combining multiple features, thus avoiding the need to piece together complex parts from various extrusions, stampings, etc.

ADDITIONAL CUSTOMER VALUE

Finding additional elements of customer value that customers would be willing to pay for, such as greater visibility, more space, greater ease of use, and improved durability, proved to be especially valuable to building a feasible business case for the three parts considered.

COMPOUNDING BENEFITS

In many cases, a composite part can lead to integrative or snowballing benefits on related parts or elsewhere on the vehicle. Lightening a sliding van door, for example, would lead to secondary weight reduction because it would allow a downsized door motor, rolling mechanism, pivot arms, and surrounding support structure.

ADD-ON PART

Participants generally agreed that minimizing disruption to the assembly process is essential when selecting first-generation parts for carbon fiber composite substitution. As a result there was a focus on bolt-on (or adhere-on) parts that could be incorporated with minimal disruption to existing trim, body, and paint processes. Such parts can also be more readily replaced in the event of damage or quality issues.

SESSION 1

PART SELECTION CRITERIA AND PRIORITIZATION (CONT'D)

MARKET SEGMENT

Different segments can require unique parts. Perhaps more importantly, vehicle design goals and customer needs and preferences vary by segment. For weight reduction in particular, platform and even part location may also drive value; some applications can now justify paying significantly more than the $1–3/lb historically viewed as typical of the mainstream segment.

- The sports/performance and luxury segments, for example, enjoy a customer base willing to pay a premium for improved acceleration and handling. Tactile and visible lightweight features, particularly if they help provide a high-end appearance, can also justify a price premium in these segments.
- Fleet segments, particularly if characterized by high annual mileage in excess of 15,000 miles per year (and up to 4–5 times that), are particularly focused on fuel savings and thus are often willing to pay more for weight reduction.
- The electric vehicle segment is willing to pay for range and thus willing to pay a premium for weight reduction that leads to increased range. Manufacturers can also benefit from weight-reduction-related battery cost savings.

Heightened CAFE standards will also create an imperative to achieve incrementally increased average MPG across segments, justifying more expensive weight reduction.

CAREFULLY CHOOSING THE APPLICATION AND MARKET SEGMENT SUCH THAT MAXIMUM VALUE CAN BE DELIVERED TO CONSUMERS IS A CRITICAL ENABLER OF VIABLE NEAR-TERM BUSINESS CASES FOR CARBON FIBER COMPOSITE PART ADOPTION.

SESSION 1

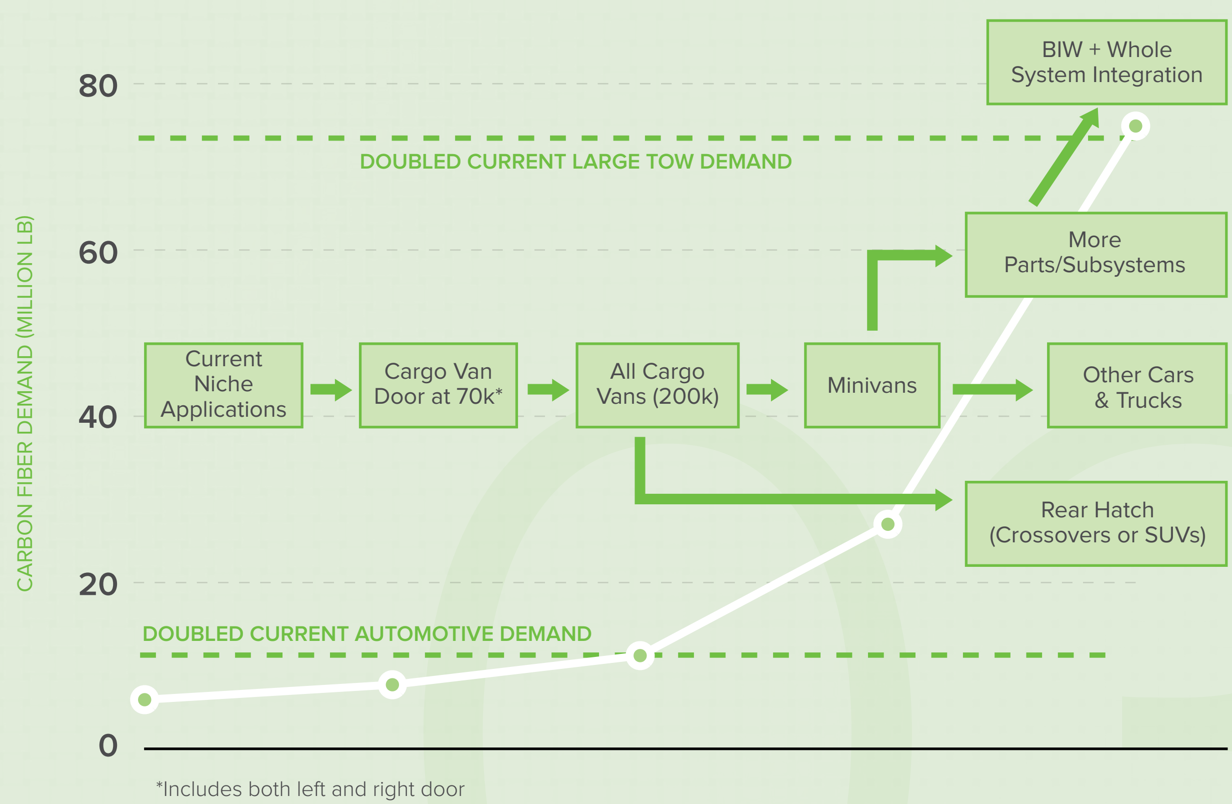
PART SELECTION CRITERIA AND PRIORITIZATION (CONT'D)

SCALING LOGIC

Participants gave preference to parts that provide a logical and feasible market entry point, but which can also lead to more widespread implementation. For example, the door inner market entry point might be fleet cargo vans to take advantage of the higher value of weight savings in the fleet market (~200,000 vehicles/year) and to deliver value associated with higher reliability and durability. As the manufacturing process and supply chain capability continued to drive cost reduction, this could then lead to implementation on passenger vans (~600,000/year) and eventually to all vehicles. See Figure 4.

SCALING LOGIC FOR A VAN DOOR INNER + INTRUSION BEAM

FIGURE 4:



*Includes both left and right door

SESSION 2

PART SELECTION APPLICATION OF CRITERIA

Using these criteria, the workshop's three breakout groups worked to identify prospective parts. The top three choices, along with their advantages and disadvantages, are summarized in Figure 5.

Participants also identified the following parts as interesting candidates:

- wheels
- rear cradle
- bumper beam
- suspension springs
- EV battery carrier/shield
- cross-car beam (possibly integrated with HVAC duct)
- a "top hat" concept for integrated above-the-floor body-in-white.

ADVANTAGES AND DISADVANTAGES FOR TOP 3 PROSPECTIVE PARTS

Figure 5:

PART	ADVANTAGES	CHALLENGES	CUSTOMER VALUE
ENGINE CRADLE	Highly stiffness-driven, high customer value for performance applications, bolt-on chassis component (avoiding e-coat)	Extremely challenging safety (lies within frontal crash load path, requiring very high and rapid energy dissipation), limited potential for compounding savings or parts consolidation. Subject to heat from engine.	Chassis stiffness and improved weight distribution—improved handling and more responsive acceleration. Composite construction would be highly tunable for attenuating engine noise and vibration.
SEATS	Large potential for parts consolidation and compounding weight savings. Can start with rear seat, move to front, etc. (ramp-up logic), add-on assembly, affects relatively few adjacent design groups	Glass fiber composite is a strong competitor—harder to make the case for using carbon fiber	Lighter seat for easier operation, especially nice for stowaway
DOOR INNER + INTRUSION BEAM	Tactile and tangible customer value, large potential for parts consolidation and compounding weight savings (e.g. rollers, mounting and motors, especially in van door case), can evolve from cargo vans to passenger vans to cars (ramp-up logic), add-on assembly, affects relatively few adjacent design groups, avoids class A finish initially (inner skin first)	Intrusion beam is safety critical, although a much more tractable challenge than the engine cradle (lower and more static load cases)	Lighter door is easier to handle and operate, fewer parts enables fast & dimensionally stable assembly, higher fatigue resistance improves durability, potential for improved safety, potential for improved visibility (larger windows, thinner frames).

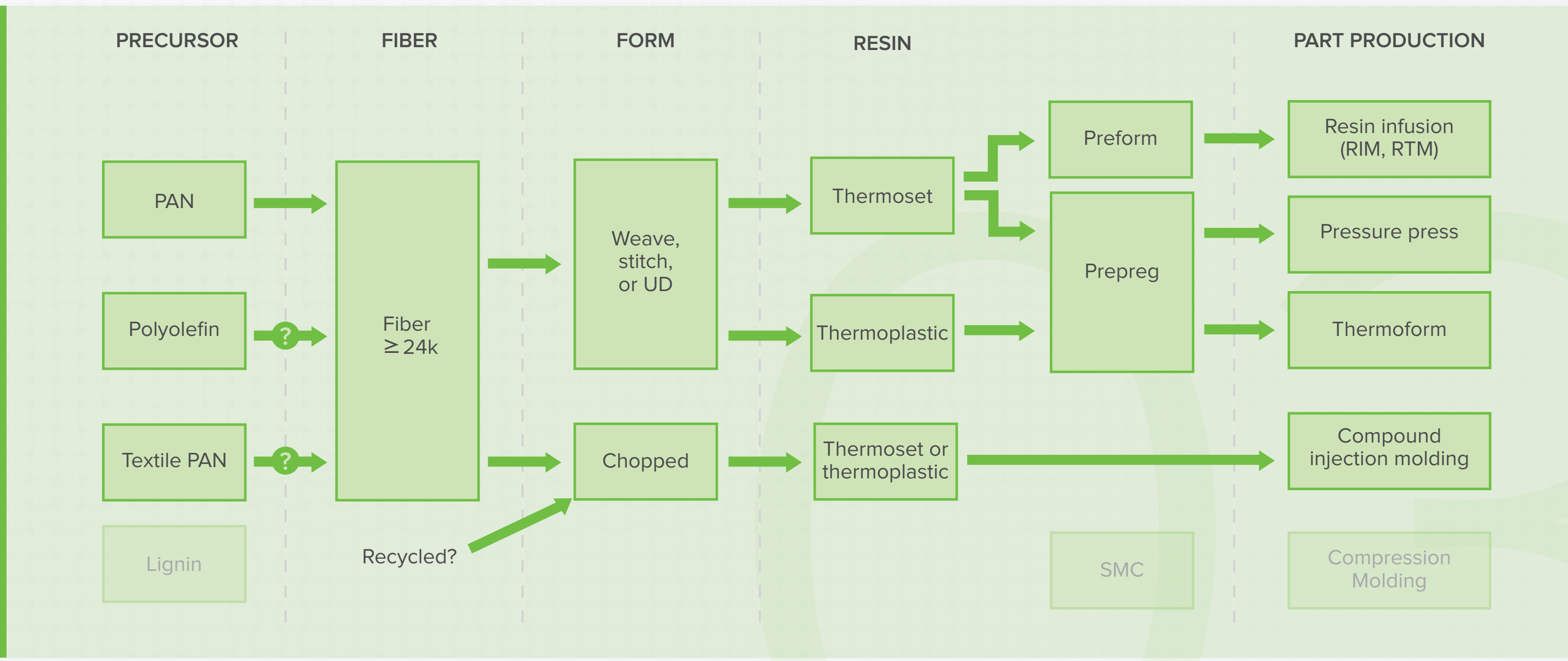
SESSION 3

MANUFACTURING PROCESS AND SUPPLY CHAIN COMPOSITION

The supply chain is interdependent and interlinked. Precursor type is linked to fiber sizing and surface treatment, which must be matched to a compatible resin system, which then dictates applicable part manufacturing processes. In developing a path forward, it is critical to navigate these links by connecting promising and compatible technologies, not only for near-term adoption of parts but also to ensure that future R&D efforts are coordinated with these interdependencies in mind.

For each of the top three prospective parts, several manufacturing pathways (Figure 6) were identified as well suited to auto industry needs and capable of meeting required volumes of 50–100k.

FIGURE 6:
PROMISING SUPPLY CHAIN PATHWAYS FOR AUTOMOTIVE CARBON FIBER COMPOSITES



SESSION 3

MANUFACTURING PROCESS AND SUPPLY CHAIN COMPOSITION (CONT'D)

MANUFACTURING PATHWAYS FOR THE DOOR INNER ASSEMBLY

Consider, for example, the door inner assembly (which includes the intrusion beam and window frame, if applicable). The group identified two main manufacturing processes: a pressure press process (as used by Globe Machine and Plasan, for example) and High Pressure Resin Transfer Molding (HPRTM, as used by Momentive). The pressure press process would utilize an epoxy unidirectional prepreg material that is placed and oriented along structural load paths. Door hinges could be integrated into the assembly through overmolding.

The fiber would be commercial-grade PAN-based carbon fiber with properties around 25–32 Msi modulus and 400–500 ksi strength. Tow size would be around 24K and could result from tow-splitting larger tows in order to save cost; however, this would only be a near-term approach since carbon fiber production lines optimized for 24K should be cheaper than lines optimized for larger tow sizes that have to then be split.

The group also discussed accepting lower properties (aka “downspecing”; see “Cost Reduction Levers” below) in order to enable alternative precursors such as polyolefin and could be an opportunity for the door inner assembly once specific structural requirements are worked out.

For the HPRTM process, the preform could be made of a stitched fabric or multiaxial weave that would ideally be part of an in-house direct weave process by which continuous fiber is woven directly into a net shape preform. Another means of creating the preform would be to randomly orient chopped (or even recycled) fiber using a deposition process. Epoxy-based prepreg would then be infused into the mold.

Other processes identified by the group (but not discussed in detail) to manufacture a carbon fiber composite door inner assembly were direct long fiber thermoplastic compound injection molding, or DLFT, and compression-molded sheet molding compound (SMC).

SESSION 3

MANUFACTURING PROCESS AND SUPPLY CHAIN COMPOSITION (CONT'D)

MANUFACTURING PATHWAYS FOR THE ENGINE CRADLE

The engine cradle group identified a thermoplastic thermoforming process to create a two-piece assembly using commercial-grade fibers. The process would use uni-directional prepreg tape (with either PET or nylon resin), placed rapidly through an automated process into a predetermined and structurally optimized pattern, or layup. The layup would be temporarily bonded before moving to the thermoforming process. The two parts (upper and lower) of the assembly would then be fusion bonded together, followed by a brief trimming/machining process and addition of any inserts. Alternatively, an overmolding process might also be used.

The group also agreed the part could be made using RTM.

Participants also discussed a hybrid approach using glass fiber as a means of possibly saving cost, but later discussion in the larger group indicated glass might not provide the required stiffness for an engine cradle, at least not without giving up a lot of weight savings.

MANUFACTURING PATHWAYS FOR SEATS

The seats group identified several ways existing seats could be redesigned to take advantage of carbon fiber's unique properties, including—for the base—combining the seat track, seat suspension, seat bottom frame, restraint, and cross tubes all into a one-piece seat base. Similarly, the group developed a seat back design that integrates headrest guide, seat suspension, restraint, and heating into a one-piece assembly.

Participants identified two manufacturing processes for the seat base and back: 1) injection molding using a PA66 thermoplastic resin and 2) resin transfer molding (RTM) using an epoxy-based resin, with the potential to use UV catalysis to speed cure time. For RTM, the preform would ideally be a unidirectional weave in order to maximize strength-to-weight ratio through anisotropic design (i.e. matching fiber directionality to load paths).

The seats group also discussed making frugal use of carbon fiber to reduce material cost, mainly through localized reinforcement, possibly as part of a hybrid material approach in which cheaper (but heavier) glass fiber is applied where strength (but not stiffness) is needed.

As with the door inner group, the seats group also discussed accepting lower strength and stiffness in order to save material cost, but did not see this as a near-term opportunity since downgraded fiber does not offer substantial cost reduction relative to higher grade carbon fiber at this time.

SESSION 3

MANUFACTURING PROCESS AND SUPPLY CHAIN COMPOSITION (CONT'D)

SESSION 3 TAKEAWAYS

Due to recent advances with several manufacturing processes, including injection molding (e.g. D-LFT) and RTM (both of which independently arose in more than one breakout session in the workshop), cycle time does not appear to pose a significant barrier in moving forward with initial volume implementation of a part. Of course there is still plenty of room for tooling development and process innovation for volume production of composites, particularly as producers tackle more complex and larger subassemblies and strive to ensure the required high throughput.

Recycled fiber (in chopped form) came up in one of the groups but still has a long way to go to gain widespread commercial acceptance. Among the largest barriers is material characterization, which also plagues virgin fiber but represents perhaps an even larger challenge for recycled fibers.

Polyolefin precursor was identified as the most promising alternative to PAN in both the near and long term (as opposed to lignin), but this may not be indicative of an industry-wide consensus since no commercial producers who had worked with lignin attended the workshop.

Anisotropic design was identified in all of the groups as an ideal approach that would maximize both strength- and stiffness-per-pound (and therefore minimize carbon fiber usage and cost) vs. quasi-isotropic forms such as multiaxial weave.

SESSION 4

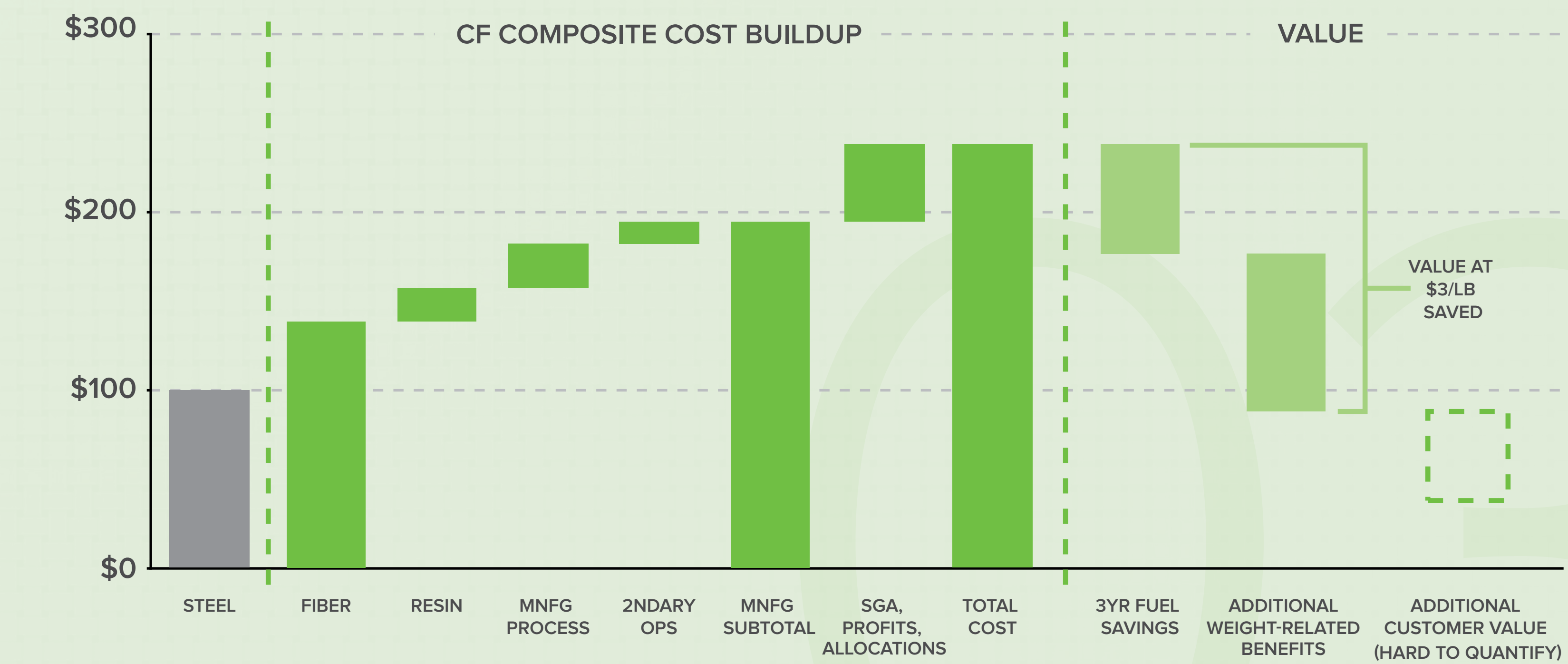
BUSINESS CASE EVALUATION

Business cases for the top three parts were examined in greater detail, including running a cost model developed by Munro & Associates to determine a detailed cost buildup (material; manufacturing; and selling, general, and administrative [SG&A]) for each of the parts. Figure 7 shows the overall cost-benefit summary chart for the door inner business case; Figure 8 shows the cost buildups for each of the parts.

COST

The total cost premium for the parts was estimated to be $2.78–4.76 per pound saved relative to the steel part, or about three times the cost of the steel part. This is a significant premium, but is offset by benefits outlined in the next section.

FIGURE 7: COST/BENEFIT FOR THE CARGO VAN DOOR + INTRUSION BEAM



SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

Part costs are driven primarily by fiber material cost, which is in turn driven primarily by precursor cost.

Nonmaterial manufacturing costs (equipment, tooling, labor, etc.) make a relatively minor contribution. According to the three cost analyses (one for each part) using the cost model developed by Munro & Associates and existing literature on the topic,[3] ***nonmaterial per-part carbon fiber composite manufacturing costs can be significantly lower than for conventional steel-based production,*** even when comparing a 50–100k target volume for composite manufacturing against a 250k volume for steel-based manufacturing. This lower capital cost may be an advantage in situations where volume predictions have high uncertainty, a common circumstance. But as with any new product, despite these advantages, there is still an upfront investment risk associated with adopting a new part-manufacturing paradigm. Also, due to the immaturity of today's analysis techniques, material characterization, and testing protocols, each new composite part will require its own testing and safety qualification program, adding significant development costs.

The larger challenge from the OEM perspective—beyond high material cost and assurance that the part will work—is minimizing disruption and switching costs associated with rearranging existing body shop, trim, and paint line processes, at least in the near term.[4]

SUMMARY OF COST/BENEFIT RESULTS FOR THE 3 PARTS

Figure 8:

	DOOR INNER	ENGINE CRADLE	SEAT BACK	RANGE
STEEL PART				
WEIGHT (LB)	72	70	10.5	
COST	$100	$105	$13	$1.25-$1.50/lb
CF COMPOSITE PART				
WEIGHT (LB)	22	28	4.2	
% WEIGHT SAVED	70%	60%	60%	60-70%
COST				
Fiber	$140	$176	$22	$5.25-$6.35/lb
Resin	$19	$22	$4	$0.80-$0.90/lb
Process	$25	$23	$7	$0.80-$1.70/lb
Secondary Ops	$12	$11	$3	$0.39-$0.70/lb
SGA, Profits, Alloc.	$43	$51	$7	$1.70-$1.90/lb
TOTAL COST	$239	$283	$43	$10.10-$10.90/lb
COST/LB SAVED	$2.78	$4.23	$4.76	$2.78-$4.76/lb saved
PV OF 3YR FUEL SAVINGS	$60	$52+	$8	$1.20-$1.30/lb saved

[3] Fuchs et al. "Strategic materials selection in the automobile body: Economic opportunities for polymer composite design." Massachusetts Institute of Technology 2007

[4] In the near term, minimizing disruption to existing processes will make the implementation of first-generation carbon fiber composite parts more likely. In the longer term, to optimize the assembly process and fully unleash the advantages of this material, it will be essential to redesign the whole assembly line around its unique manufacturing and assembly characteristics, particularly as more and larger parts are adopted.

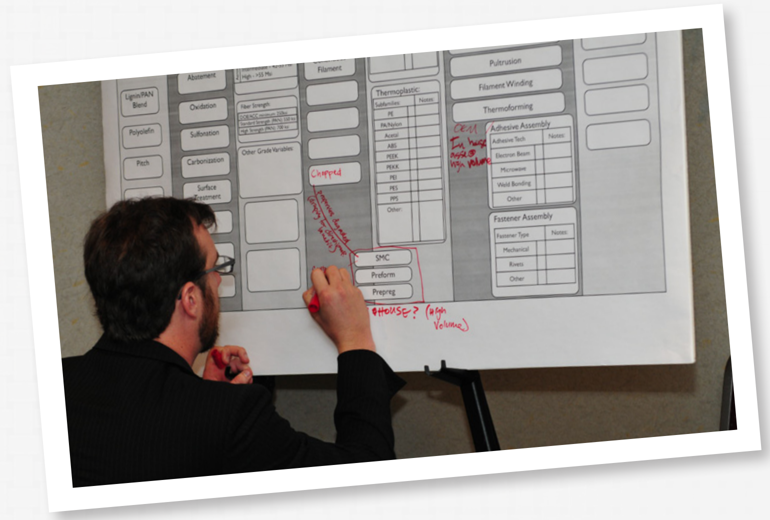
SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

COST REDUCTION LEVERS

Key cost reduction levers are:

- Design optimization for maximum weight savings
- Optimal material use
    - Minimizing scrap during manufacturing
    - Hybrid material approach
    - Use of recycled fiber
    - Use of cheaper grades



Fiber price is deservedly a key focus for manufacturers. Yet, also consider that the resin portion of a carbon fiber composite part cost is alone greater than the steel cost in the baseline part. It is therefore critical, as noted previously, to identify parts that offer sufficient value to offset the enduring carbon fiber composite material cost premium. On the cost side, perhaps the most effective way to mitigate the impact of high fiber cost is to use as little of it as possible. Three means of doing so are 1) design optimization, which maximizes weight savings and minimizes material usage (this is tied to CAE improvement which is discussed below), 2) manufacturing optimization to optimally place material and minimize scrap, and 3) a hybrid material approach in which carbon fiber is used only where its extraordinary properties are needed (directly along load paths) while incorporating glass, recycled carbon fiber, or another, cheaper (but also lightweight) material in other areas.

Recycled fiber can also be used as a primary material. Because some scrap is inevitable, recycling unused carbon fiber can make a significant contribution to improving manufacturers' cost basis.

Downgrading (or "downspecing") of carbon fiber was also discussed since fiber grades with lower strength and modulus can be much cheaper than higher performing fibers. Finding applications for downgraded fiber would also potentially enable alternative precursors since (thus far, at least) they entail lesser properties as compared to PAN- or pitch-based fibers. However, if particular properties are degraded too far the purpose of using carbon fiber as opposed to another, cheaper fiber, such as glass, is defeated. This is a particularly important consideration in strength-driven applications since carbon fiber lower than about 500 ksi no longer rivals the best grades of glass fiber (S-glass) in strength per pound.

SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

For stiffness-driven applications, on the other hand, one can afford to give up some strength, but not so much as to make strength a design driver. As for modulus, ***since carbon fiber tends to be about three to four times stiffer per lb than glass, modulus can be significantly downspec'd and carbon fiber will still exhibit superior weight savings potential*** relative to not only glass, but steel and aluminum as well. For example, the very lowest grades of carbon fiber, developed in some cases at pilot scale from alternative precursor, exhibit ~20 Msi modulus. This fiber's specific stiffness would be over twice that of glass fiber, and would still be about two times stiffer per lb in composite form than steel or aluminum.

Yet another consideration when it comes to downspecing is manufacturability. The Automotive Composites Consortium has recommended limits of 250 ksi and 25 Msi modulus for carbon fiber with the reasoning that manufacturers can't produce parts thin enough to take advantage of limits in excess of these values. Given recent advances in manufacturing processes and the nuances of stiffness- vs. strength-driven applications, these limits may merit reinvestigation.[5]

DESIGN APPROACHES THAT MAXIMIZE A CARBON FIBER PART'S STRENGTH- AND STIFFNESS-PER-POUND, IN COMBINATION WITH MANUFACTURING APPROACHES THAT MINIMIZE USE OF CARBON FIBER, WILL ACHIEVE THE GREATEST WEIGHT REDUCTION—A CRITICAL VALUE LEVER—FOR THE LOWEST MANUFACTURING COST.

[5] Participants also discussed additional requirements beyond strength and stiffness such as temperature, impact resistance, and corrosion resistance, all of which play into decisions about downgraded fiber and alternative precursors.

SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

COST SENSITIVITY

Because fiber cost is the primary driver of part cost, *any variable that affects fiber quantity will significantly affect cost: weight savings achieved, fiber volume fraction, and frugal use of material.* Estimates of some of these variables can vary quite a bit in a workshop setting (weight savings ranged 60–70% and volume fraction 50–65%, partly due to differences in application) and so it is important to consider them more carefully for implementation. Fiber price itself plays an important role too, but optimizing fiber use to begin with is the highest-leverage means of reducing cost. Part cost is relatively insensitive to manufacturing cell cost (which includes fixed tooling, equipment, and labor costs) and resin price, but obviously a best-case approach drives all costs down.

COST SENSITIVITY

FIGURE 9:

- High sensitivity to design optimization and fiber price
- Relatively low sensitivity to manufacturing cell/process cost and resin price
- Suggests need to work on material characterization and predictive design tools as well as reducing fiber cost

ASSUMPTIONS:

LOW	HIGH
70%	60%
$7.50/LB	$12.50/LB
-25%	+25%
$1.60/LB	$2.60/LB

Sensitivities are based off of van door case.

SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

VALUE

Key value drivers are:

- Weight reduction
  - Fuel savings
  - Acceleration (in certain segments)
  - Easier to operate (e.g. lighter door and stowaway seats)
- Compounding benefits
  - Secondary weight reduction (e.g. downsized support structure)
- Tangible values the customer is willing to pay for
  - Safety (especially as predictive tools mature)
  - Noise, Vibration, and Handling (NVH) due to higher stiffness
  - Better visibility (due to reduced structural sections and expanded openings)
  - More space (due to reduced structural sections)
  - Lower maintenance (improved corrosion and fatigue resistance)

Workshop findings around value, if summarized in one sentence, would be: ***"Carefully choosing the application and market segment such that maximum value can be delivered to customers is critical to the overall business case for carbon fiber composite part adoption."*** Customer value includes aspects offered by a carbon fiber composite part that customers might be willing to pay for, both weight-related and otherwise. This is a very difficult number to put a value on, and heavily depends on market segment, but is likely the largest single value lever, particularly at early stages of adoption.

Much of the value derived from implementing carbon fiber composite parts is related to weight reduction. Dollars spent per pound saved ($/lb) has long been a useful if basic metric in assessing costs and value levers. Automakers have used an upper limit on this metric to make design implementation decisions. The rule of thumb used to hover around $1/lb, but has recently approached $3/lb or so, and in some market segments—including EVs, fleets, performance, and luxury—can be much higher than $3/lb. CAFE standards, particularly those on the way for 2015 and 2025, are also driving the allowable cost for weight savings higher in some cases.

SESSION 4

BUSINESS CASE EVALUATION (CONT'D)

In any case, the rule of thumb comes with several caveats: 1) automakers have adopted more sophisticated means of determining a cost allowable whereby weight savings is valued differently depending on not only the intended market segment, but also where in the vehicle the weight is being removed, and 2) many of the value levers associated with carbon fiber composite parts have nothing to do with weight savings, so the metric provides a basis of common comparison rather than a literal indication of dollars spent per value derived.

Assuming most consumers value fuel savings within a three-year time horizon and drive an average of about 12,000 miles per year, weight savings delivers $1–2/lb of value in fuel savings alone. Although harder to quantify, other weight-related benefits include better acceleration, as well as compounding benefits such as downsized brakes, support structure and, in the case of a sliding van door, motors and roller mechanisms. Customers may also value the saved weight if it is in a part of the vehicle that offers tactile and visible interaction. A lighter stowaway seat would be easier to operate, for example.

There are several non-weight-related elements of value as well, the main one of which is safety (which is likely to impart greater value as analysis tools improve and customers come to understand carbon fiber composite's safety characteristics), but also stiffness that can impart better noise, vibration, and handling (NVH) characteristics.

THOUGH A CARBON FIBER PART CURRENTLY COSTS ABOUT THREE TIMES THAT OF A STEEL COUNTERPART, THREE-YEAR FUEL SAVINGS AND OTHER COMPOUNDING BENEFITS CAN MAKE WELL-CHOSEN CARBON FIBER PARTS COST COMPETITIVE.

SESSION 4

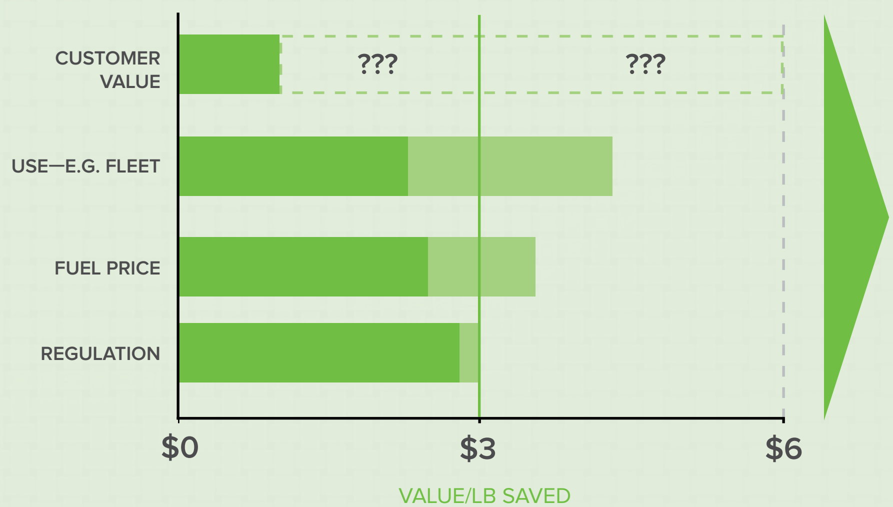
BUSINESS CASE EVALUATION (CONT'D)

VALUE SENSITIVITY

Part of the implementation logic is to ***seek out parts that offer extraordinary customer value,*** and this proved to be a critical element to identifying parts that participants felt would offer a feasible adoption pathway. Fuel price plays a noticeable role but much less than utilization or customer value. Regulation appears to play a minor role but it is key to note that the $0.22 increase in the amount automakers are willing to pay for weight savings would be more or less across the board, regardless of market segment, extraordinary customer value, or utilization, so in fact it is a fairly influential variable.

VALUE SENSITIVITY

FIGURE 10:



- Hard to quantify customer value sensitivity, but could be equally or more important than fuel savings
- Suggests need to focus on customer value when choosing and designing parts for carbon fiber composite adoption
- Fuel price and vehicle utilization also contribute a significant effect on value
- Current CAFE fines translate to $0.22/lb saved

ASSUMPTIONS:

LOW	HIGH
?	?
6K	30K
$2/GAL	$5/GAL
SUBTRACT CAFE $55/MPG	

Sensitivities are based off of van door case. To provide a common basis of comparison, sensitivities for both cost and value are expressed in terms of $/lb even though several value variables have nothing to do with weight savings.

DISCUSSION:

NONCOMPETITIVE, INDUSTRY-WIDE FINDINGS

(SESSION 5)

04

SESSION 5

NONCOMPETITIVE, INDUSTRY-WIDE FINDINGS

Participants unanimously agreed that industry collaboration and noncompetitive action would play a major role in achieving a manufacturing transformation built around automotive carbon fiber composites and other lightweight materials.

While several industry needs were identified, three key technical gaps emerged as particularly pressing that could be addressed noncompetitively:

- Material characterization
- Computational predictive modeling
- Fiber cost reduction (mainly through alternative precursors)

In general and as discussed in the subsequent Next Steps section, there is also a need for more effective collaboration and coordination between industry, academia, and government.

Addressing these challenges would enhance the business case for individual parts made from carbon fiber composite and open the door to implementation of larger parts on the path to composites-intensive vehicles.

COORDINATING INDUSTRY, ACADEMIC, GOVERNMENT, AND NATIONAL LAB ACTIONS—ESPECIALLY THROUGH NONCOMPETITIVE R&D—WILL BE CRUCIAL TO DRIVING INNOVATION; ADDRESSING KEY COLLECTIVE NEEDS, SUCH AS BETTER MATERIAL CHARACTERIZATION, IMPROVED PREDICTIVE MODELING, AND FIBER COST REDUCTION; AND FOCUSING RESEARCH EFFORTS WITHIN THE CONTEXT OF A LARGER U.S. AUTOMOTIVE STRATEGY.

SESSION 5

TECHNICAL GAP: MATERIAL CHARACTERIZATION

Reliable material specifications allow designers to take full advantage of carbon fiber composites' unparalleled material properties. Uncertain performance leads to individual testing of parts to prove they can perform. This increases costs and can also lead to overdesign (designing to the worst case or to uncertainty margins) that erodes weight savings. Better understanding of material properties, in conjunction with predictive modeling (p39), will also allow designers to take advantage of better crash energy absorption properties—a significant opportunity in the long run.

The technical gap associated with material characterization boils down to three main data challenges: generation, access, and consistency.

GENERATING DATA

Composite material requires several additional dimensions of characterization relative to metals. Composites must be characterized not only with respect to their two (or more) constituent materials but also with respect to the interaction between those materials. The plethora of resins and fiber types, along with the typically wide statistical variance of their interaction, also significantly increases the quantity of data required to accurately characterize the material.

ACCESS TO DATA

A large amount of the existing data has been generated in a competitive setting and is held as proprietary. Even when the data is shareable, there is no centralized and widely available source or database for it.

CONSISTENCY OF DATA

Because of this proprietary approach, data is not presented or collected in a consistent format that would be useful to designers or manufacturers.

SESSION 5

TECHNICAL GAP: MATERIAL CHARACTERIZATION (CONT'D)

Due to the many variables involved with composite material systems, the standard (mostly metals-based) approach to material specification may be largely inapplicable to composites. ***Producers also tend to resist the notion of "standardization" since it might stifle innovation around developing unique material systems.*** They are focused on differentiating themselves with unique material offerings. Standardization might also be accompanied by commoditization as fierce competition ensues to provide a given material specification as cheaply as possible.

Testing is the primary means of developing consistent material data. ***Standardizing test equipment and test methods would help ensure cost-effective generation of consistent material data.*** There is currently no standard means of determining bond strength at the fiber-resin interface, for example. More generally, developing a set of coupon tests to characterize different standard structural members and cross sections under standard load cases could provide the noncompetitive building blocks for manufacturer-specific characterization of particular parts.

Specifying the desired performance ranges (those that would be most applicable to the most promising near-term part candidates) would also help producers prioritize the most lucrative near-term opportunities. Pre-selecting and prioritizing the most promising material systems (see the previous discussion of Manufacturing Process, p23) can help to reduce the amount of data that must be generated and thus the cost of generating it. See the Next Steps section (p43) for more detail behind how an industry-wide approach to material characterization could work.

SESSION 5

TECHNICAL GAP: COMPUTATIONAL PREDICTIVE MODELING TOOLS

Improving the predictive power of modeling tools, particularly with respect to fatigue, failure modes, and high-strain-rate crash behavior, is also needed. Current capabilities lag behind those for steel and other commonly used materials and would also help designers fully harness carbon fiber composites' unparalleled structural properties (crash energy absorption and fatigue resistance, in this case[6]) while avoiding overdesign and relying less on expensive testing. ***Improved safety is a potentially tremendous component of the value proposition offered by composite automotive parts, but is too poorly understood in most cases for automakers to build it into their business cases.***

Both material characterization and predictive modeling rely on testing, so it may make sense to approach them in parallel. Each testing cycle, whether coupon or actual production part, can help to improve a model by comparing actual vs. predicted behavior and tweaking the model accordingly. Competing computer aided engineering (CAE) tool providers could collectively benefit from such testing cycles (assuming they were carried out in a centralized location and made widely available) even though their models would differ based on their respective proprietary finite element analysis (FEA) and optimization codes.

Even with drastic improvements in predictive modeling, however, testing will likely continue to play an important role in composite part qualification, just as it still does for metals. In addressing the twin challenges of material characterization and predictive modeling, therefore, reducing the cost of testing (e.g. by using shared and standardized testing facilities and procedures) will help to address both challenges to the benefit of the industry as a whole.

Advances in FEA codes and approaches are often developed noncompetitively at the academic level since CAE providers are often unable to devote resources and capital to exploring next-generation modeling techniques. At the same time, these academic advances are often difficult for CAE providers to capture because efforts amongst various universities are fragmented, often lack strategic direction or consistency, and are not always based on industry needs. A link between CAE providers and university researchers is therefore needed to help theoretical research reach commercial application.

[6] See the "Autocomposites Workshop Pre-Read Document", p.34

SESSION 5

TECHNICAL GAP: FIBER COST

Just one carbon fiber composite autobody on one mainstream vehicle would double world demand for carbon fiber (Figure 2B), and cheaper precursor is among the top potential enablers of greater adoption of automotive carbon fiber. ***PAN cost is largely insensitive to the economies of scale that even widespread automotive adoption would offer, so the primary means of fiber cost reduction would be a paradigm shift to a precursor alternative such as polyolefin*** (along with advanced processing techniques). Alternative precursors may also offer some price volatility relief if not derived from a volatile market commodity. So why haven't producers jumped at this multi-billion dollar market growth opportunity?

The shift to alternative precursors faces three key challenges.

First, alternative precursors and advanced processing techniques face technical challenges, mainly associated with meeting or exceeding material properties of PAN-based fibers. Technologies have been on the table in the research realm (primarily ORNL in conjunction with fiber producers[7]) for nearly a decade, yet have not achieved commercial adoption. This has led many in the industry to conclude that near-term (4–6 years) fiber cost reduction is unlikely and underscores the importance of pursuing near-term parts that can present a viable business case even with today's high fiber prices. Those having established a position with near-term parts would then be best positioned to take advantage of fiber cost reductions as they materialize in the longer term.

SUMMARY OF FIBER OPTIONS

Figure 11:

PRECURSOR	GRADE	CHALLENGE	TIMELINE	MIN. PROPERTIES
PAN	Aerospace	Very Expensive	NOW	MET
PAN	Commercial	Expensive	NOW	MET
Textile PAN	Commercial	Fiber Properties	NEAR	MET
Lignin	Commercial	Fiber Properties, Blending, Stretching	MED	NEARLY MET
Polyolefin	Commercial	Material Properties	FAR	NOT MET

Second, scale production of carbon fiber made from alternative precursors would be a disruptive move for incumbent fiber producers whose business models (and sunk costs in PAN-based technology) are comfortably focused on the growing aerospace and wind industries.

Third, new entrants who might start from scratch with a disruptive business model based on alternative precursor face daunting barriers to entry, chiefly high capital costs and unsolved technical challenges with the material.

[7] See the "Autocomposites Workshop Pre-Read Document", p.16–22

SESSION 5

OTHER NEEDS

The following additional needs were also identified as potential areas for noncompetitive action, and are described in greater detail in the appendices:

- Joining/Bonding R&D
- Tool Development
- Preform Development
- Surface Treatment R&D
- Fatigue Behavior R&D
- Recycled Fiber Use and Recovery
- Consumer Marketing and Education
- Energy-Efficient Carbon Fiber Production

SESSION 5

COORDINATING INDUSTRY, ACADEMIC, AND NATIONAL LAB ACTION

Efforts on most of the above needs will require strategic coordination between industry, government, and academia.

While several cutting-edge manufacturing and materials science research projects are underway at the university level, the effort as a whole is fragmented. There is currently no coherent mechanism for communicating overarching industry needs to academia. As a result, many institutions end up wastefully spending money and buying equipment for similar projects (when one or the other could focus on it) or on projects that focus on very specialized work that may have little relevance to industry.

Several promising government-based funding mechanisms are currently in place, including the Vehicle Technologies Program at the Department of Energy's Office of Energy Efficiency and Renewable Energy, the Advanced Manufacturing Partnership, and the National Network for Manufacturing Innovation (NNMI) under the Advanced Manufacturing National Program Office (AMNPO). There is an opportunity to prioritize funding around near-term vs. long-term industry needs and the areas that are most effectively dealt with noncompetitively.

The national laboratories, particularly Oak Ridge National Laboratory, are also pursuing several noncompetitive and competitive research projects, but it's hard to work at the advanced research level and simultaneously be effective at commercialization. There is thus an ***opportunity to prioritize national lab R&D projects within the context of a larger U.S. automotive strategy,*** for example with particular focus on near-term pathways to market for carbon fiber composite parts.

NEXT STEPS

05

NEXT STEPS

The workshop identified the opportunity to drive significant carbon fiber composite adoption, learning, and investment by focusing on those high-value parts that can offer a compelling business case today.

Many of the needs identified in the Discussion section above can be addressed through two overarching approaches that could be run in parallel: 1) a Parts Campaign and 2) an Innovation Hub. A third, more specialized effort could address the specific challenge of high fiber cost.

SUMMARY NEEDS & POTENTIAL INITIATIVES

Figure 12:

NEEDS	KEY CHALLENGES	POTENTIAL INITIATIVE
PARTS LEVEL CF ADOPTION FOR HIGH VALUE APPLICATIONS	• Choosing the right parts • Part design • Coordination across/configuring the supply chain • Tying into OEM production part development process • Building Tier 1 capacity	1 **PARTS CAMPAIGN**
ENHANCED R&D COORDINATION	• Better coordination between industry, government, and academia on applied R&D + technology transfer • Access to (shared) manufacturing equipment and test rigs	2 **INNOVATION HUB** (INCLUDING MATERIAL CHARACTERIZATION, PREDICTIVE TOOLS, ETC.)
MATERIAL CHARACTERIZATION + PREDICTIVE DESIGN TOOLS	• Need to generate material property data for lots of fiber + resin combinations • Limited access to existing data • Inconsistency of test standards/procedures • Developing predictive tool fundamentals + x-fer to industry	
OTHER R&D NEEDS	• Joining/Bonding • Tool development • Surface treatment • Fatigue behavior • Etc. (see main body text for more)	
CARBON FIBER COST REDUCTION	• Precursor contributes half of cost, but scale helps little • High barriers to new entrants (capital + technical challenges) • Difficulty of commercializing national lab technology	3 **LOW COST, ALTERNATIVE PRECURSORS**

PARTS CAMPAIGN

As discussed in the section “Business Case Evaluation,” ***there is a viable business case today for making some well-chosen parts from carbon fiber composite.*** Getting started will take a highly cooperative team(s) with expertise and production capability at each link of the supply chain (Figure 13).

A Parts Campaign could include a number of discrete steps:

1. HOLD A FOLLOW-UP MEETING

The first step will be to bring together interested parties from across the supply chain to solicit interest in pursuing specific parts. The teams will ultimately develop proprietary solutions for a competitive and profitable product. RMI is well positioned to host this initial meeting.

2. IDENTIFY A LEADER

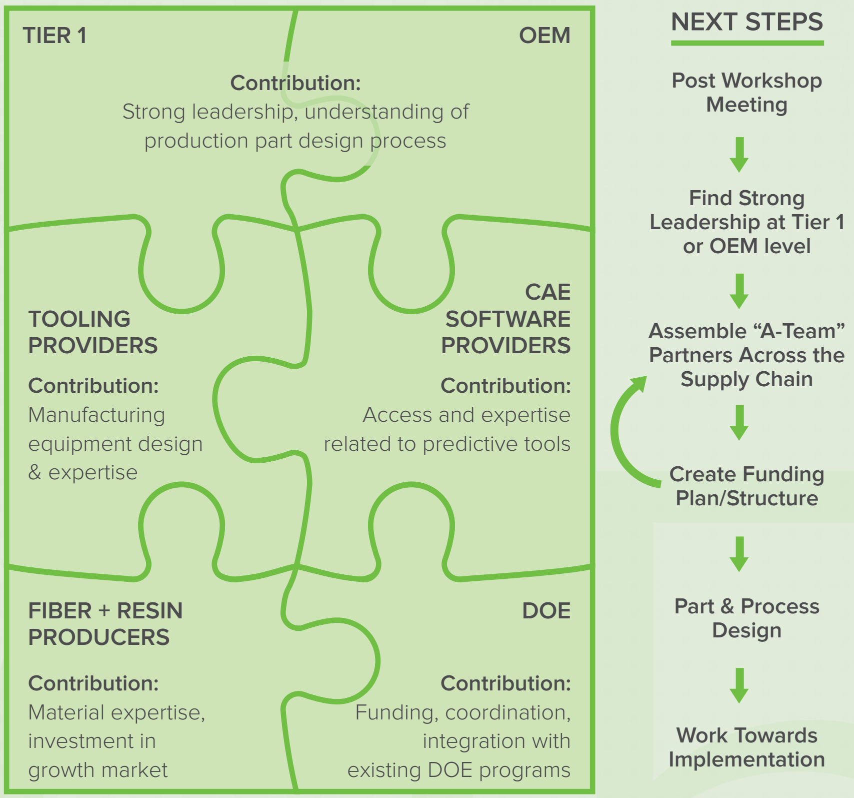
Finding the right leadership is likely the most important ingredient. The effort should be led from either the OEM or the Tier 1 level in order to ensure a practical understanding of the production part development and incorporation process. The leader should be dedicated to the project and held accountable for the project results and schedule.

3. BUILD THE TEAM

The team should be built on the unwavering premise of production intent of a carbon fiber composite part on a particular vehicle, for profit. It should be lean and limber and consist of 6–8 top experts, covering each link in the supply chain: fiber producer, resin provider, intermediate form supplier (if different from resin provider, e.g. prepreg), tooling/equipment maker, Tier 1 manufacturer, and OEM.

PARTS CAMPAIGN: KEY INGREDIENTS

FIGURE 13:



PARTS CAMPAIGN (CONT'D)

4. FINALIZE THE PART, PROCESS, AND IMPLEMENTATION PLAN

While the workshop took several important steps toward identifying and evaluating promising parts and manufacturing processes, the assembled team should work out the details of which part will be selected for production (e.g. van door inner vs. rear hatch), including selecting a specific vehicle/platform on which it will be incorporated.

5. DEVELOP A FUNDING MODEL

Another element that will need to come together very early in the effort is the development of a workable funding model. Contributions from participants can be either direct or in-kind—e.g. presses and equipment from toolmakers. Matching funds from DOE, DoD, or other public funding sources will help lighten the financial burden of participants and ensure the effort enjoys broad strategic support. Funding could be arranged in project phases, which would be available to well defined and promising part/team(s) at various stages of the project.

6. PART AND PROCESS DESIGN

Expert part leaders or release engineers at the OEM should be directly involved (if they are not themselves responsible for the design) to ensure functional requirements for the part and the specific requirements for the production part design process are met, including design/process failure mode effects and analysis (D/PFMEA), and design validation plan and report (DVP&R).

Very early in the process, structural analysis and optimization (ideally including topology to enable optimal placement of material) should begin. This could be an effort run within the OEM or Tier 1, or jointly run in conjunction with a CAE provider. This early analysis will enable a more detailed estimate of weight for the cost-benefit picture, and also guide decisions regarding tool design and development.

7. IMPLEMENTATION

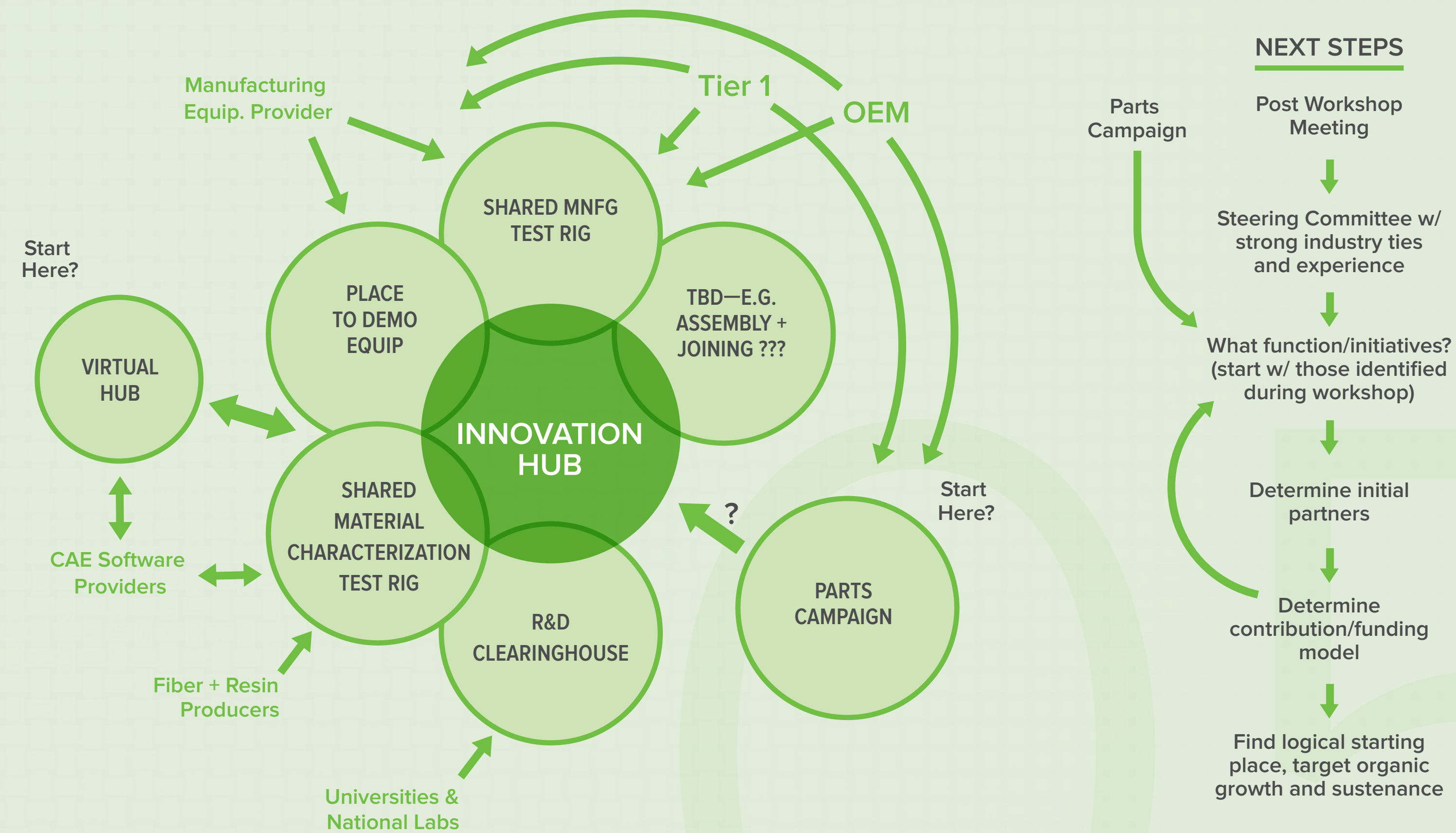
The part will need to be approved by the appropriate leaders at the OEM, pass critical design reviews, testing programs, and final qualification. For the Parts Campaign, it is important that funding, time, and resources be built into the project to ensure all these critical gates are met. If any roadblocks occur in the process, the team should be prepared to revise the design or process to meet appropriate requirements and ensure final implementation.

CARBON FIBER TECHNOLOGIES CAN BENEFIT MAINSTREAM VEHICLES THROUGH A PARTS-BASED APPROACH, ALLOWING AUTOMAKERS TO REAP NEAR-TERM VALUE WHILE ENABLING THEIR SUPPLY CHAINS TO SCALE UP AND SYSTEMATICALLY INVEST AND NAVIGATE INDUSTRY HURDLES.

INNOVATION HUB

Beyond a Parts Campaign, *the broader need for greater collaboration and coordination between industry, government, and academia led to a pervasive idea to create a U.S. Carbon Fiber Composites Innovation Hub.*

FIGURE 14:
KEY INGREDIENTS TO THE INNOVATION HUB



INNOVATION HUB (CONT'D)

The Hub is an overarching concept whose ***main purposes would be to centralize and harmonize academic and industry research, communicate industry needs to academia and government, and enable industry to demonstrate, test, and innovate technology advances critical to greater adoption of automotive composites.*** Specific thrusts could include material characterization, including standard coupon testing to co-develop design allowables for promising resin-fiber families, crash simulation and testing (the data from which would feed into advanced simulation tools to improve their predictive power), shared test rigs to prove out joining technology, and manufacturing tool development and demonstration to advance and exhibit advanced manufacturing processes.

The Hub could be modeled to some extent after partnerships in other countries such as those undertaken by Fraunhofer ICT focusing on applied research and technology transfer.

Specific next steps associated with the Innovation Hub include:

1. HOLD A FOLLOW-UP MEETING

The first step will be to bring together interested parties from across industry, government, and academia to solicit interest and determine broadly what needs and challenges the Hub could tackle. Findings from the workshop would provide a starting point. RMI is well positioned to host this initial meeting.

2. ASSEMBLE STEERING COMMITTEE

The next step will be to recruit a steering committee that can bring the right expertise to the table from industry, academia, and government; represent the critical moving parts of the industry; and lead the coordination and implementation effort to put the Hub into place. As with the Parts Campaign effort, the Hub will require a single, dedicated leader who can oversee and drive the effort, including building all the right interfaces with government and academia at early stages.

3. SELECT INITIATIVES

There are many important needs the Hub could address, and it is not clear which should be targeted for near-term focus. This may be a logical step to incorporate learnings from the Parts Campaign or to select initiatives that would further enhance the viability of the part(s) in question.

Example Hub initiatives are described toward the end of this section.

4. DETERMINE PARTNERS

Once focus areas are selected, the steering committee will have to pull together the right industry, academic, and government partners who would work together at the Hub to pursue them.

INNOVATION HUB (CONT'D)

The committee would also have to harmonize the vision and plan for the Hub with what is already planned in conjunction with President Obama's NNMI (http://www.manufacturing.gov/event_011613.html). Given the very broad mission of that initiative (all manufacturing, not just automotive, and all materials, not just composites) vs. the fairly specific focus from this workshop of automotive carbon fiber composites, the Hub may turn out to be a specific offshoot of that program or may exist as a standalone facility. In any case, roles and responsibilities should be clarified to avoid overlapping scope with existing efforts not only in government but in academia and industry as well.

5. DEVELOP A FUNDING MODEL

The steering committee will develop a funding model. It could be based to some extent on certain Fraunhofer arrangements in which 1/3 of funding is provided by users of the Hub (e.g. leasing fees and industry contributions, whether cash or in-kind, such as equipment), 1/3 is provided by government (NIST, DOE, EERE, DoD, and the Advanced Manufacturing National Program Office (AMNPO)) through one of its advanced manufacturing funding mechanisms, and 1/3 is provided by external sources such as investors. Another model is to have a 70–30 split between public funds (both federal and local) and industry.

The Hub may start out virtually, as some of its functions may not require an actual building, at least initially. Initiatives such as selecting promising material systems for automotive application and creating a centralized material database may provide a near-term starting point as we undertake to plan, design, and build a physical hub in Detroit.

6. PLAN, DESIGN, AND BUILD THE HUB

Once funding details and focus areas are worked out, the design of the building will have to be determined, possibly with space available for testing and demonstration equipment, archives, and office space.

7. CREATE A HUB OVERSIGHT AND MAINTENANCE PLAN

The steering committee (or a group assigned by them) should hold regular technical and financial reviews to develop near-term plans and goals and ensure healthy operation of the hub.

INNOVATION HUB (CONT'D)

EXAMPLE HUB FOCUS AREAS TO START THE CONVERSATION

POSSIBLE HUB FOCUS #1: MATERIAL CHARACTERIZATION

The Hub would:

- Identify promising resin-fiber systems
- Gather existing material data
- Determine additional needed data
- Design a "top-down" material specification program
- Ensure coordination with existing material data systems

The Hub would first identify the most promising resin-fiber systems for automotive application (that is, the resin-fiber systems with the highest applicability to scale production of automotive composite parts), with workshop findings as a starting point. Next, it would gather relevant test data that has already been performed for that material system, then prioritize the data that is needed to address gaps in understanding.

Rather than the bottom-up specification approach typical of metals or of aerospace composites specs,[8] in which the composition of each constituent material is defined, a top-down approach may be more appropriate in which a set of performance requirements are established and producers are free to meet them with whatever material system they choose. If and when they do, their material system could then be added to the list of possible materials for the specified performance range and added to a shared Hub database for the benefit of end users.

Any new effort would have to be coordinated and possibly built upon existing databases and approaches, including those in aerospace, such as Composite Materials Handbook 17 (CMH-17), National Institute for Aviation Research (NIAR), the National Center for Advanced Materials Performance (NCAMP), existing Aerospace Material Standards (AMS), and government efforts such as the Materials Genome Initiative (MGI).

[8] The aerospace industry has developed an extensive set of material specifications and standards that help them certify structures and ensure predictable quality control and optimal processing allowables. However, only a few specific resin-fiber combinations, almost all of them based on epoxy prepreg, have been developed.

INNOVATION HUB (CONT'D)

EXAMPLE HUB FOCUS AREAS TO START THE CONVERSATION

POSSIBLE HUB FOCUS #2: TESTING (RELATED TO MATERIAL CHARACTERIZATION)

The Hub would:

- Develop standard coupon testing methods to develop material allowables
- Develop standard part testing methods to prove out specific parts
- Provide standard testing equipment
- Provide body-in-white level testing rigs to prove out joining technology

As previously described, testing is central to developing robust material allowables for particular resin-fiber material systems. The Hub could develop and deploy standard tests (for coupons, initially, and also for parts) and equipment for use by the industry to harmonize what is today a very fragmented and inconsistent approach to developing material data. Larger, shared test rigs at the whole-vehicle level could help prove out and advance new joining technologies.

POSSIBLE HUB FOCUS #3: SIMULATION TOOLS

The Hub would:

- Provide a forum for CAE simulation improvement
- Enable competing providers to benefit without disclosing proprietary codes
- Offer CAE providers the opportunity to exhibit advances to their OEM and Tier 1 customers

The test data resulting from standard coupon and part testing could be fed back into CAE codes to improve their predictive power. Despite each CAE provider having its own proprietary code, the data from each test would be made available, perhaps in a standard format, to fine-tune models and raise the level of their products. They could visit the Hub periodically or in conjunction with ongoing demonstration projects by manufacturers at the Hub to put their models to the test while demonstrating and marketing the resulting improvements.

INNOVATION HUB (CONT'D)

EXAMPLE HUB FOCUS AREAS TO START THE CONVERSATION

POSSIBLE HUB FOCUS #4: CENTRALIZING AND COORDINATING RESEARCH EFFORTS

The Hub would:

- Gather existing research
- Serve as a clearing house for existing knowledge
- Provide industry ties and communicate industry needs
- Prioritize research efforts according to industry needs and broad strategic goals

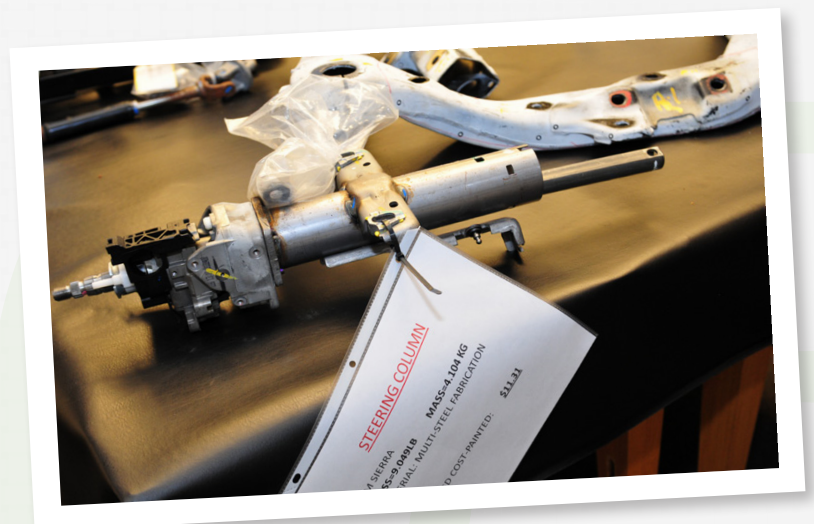
The Hub would serve as a clearing house for advanced research at the industry, academic, and national lab levels. Any member of those three stakeholder groups could come to the Hub to determine what research has already been done or is already planned and what research is deemed the greatest need from the industry's standpoint. This is likely to result in a mutual benefit to the universities and industry since industry would get research they can use and universities would embark on research that has a direct strategic relation to advancing U.S. industry. The work would thus be highly fundable, tangible, and rewarding for those undertaking it.

POSSIBLE HUB FOCUS #5: TOOL DEVELOPMENT AND MANUFACTURING PROCESS DEMONSTRATION

The Hub would:

- Provide access to shared manufacturing equipment
- Provide space for testing new tooling

The Hub would provide shared access to large manufacturing equipment, such as presses, and a place to prove out new processes.



LOWER COST ALTERNATIVE PRECURSOR

As outlined in the Discussion Section (p.40), despite the tremendous market growth opportunity associated with low-cost precursors that could dramatically reduce automotive carbon fiber cost, three main challenges associated with precursor adoption are:

1. Technical challenges: commercializing advanced processing, achieving PAN-caliber material properties
2. Incumbent business models and sunk costs: Existing players have little incentive to disrupt their perfectly viable current business model focused primarily on aerospace and wind
3. Barriers to entry for new entrants: high capital costs and technical risk

NEXT STEP: ENGAGE ACADEMIA, GOVERNMENT, AND INDUSTRY

The next step in an effort focused on catalyzing commercial adoption of alternative precursor would be to convene, in a meeting or series of meetings, fiber producers; select individuals from the textile, lignin, and chemical industries (including resin providers); government and national lab scientists, and especially those from Oak Ridge National Laboratory; industry experts; and cost estimators. The objectives of the meeting(s) would be to:

1. Downselect and prioritize the several alternative precursor options (polyolefin was the preferred choice among the majority of participants of the Autocomposites Workshop, but a more diverse group may select others), including sizing the market for potential applications building from the findings in this report.
2. Design a program for developing a scale plant for the precursor of choice, including, if applicable, a technology roadmap for implementing R&D improvements at appropriate gates.
3. Develop a funding model that explores the possible options of government matching funds and co-funding among several manufacturers in the material supply chain.

CONCLUDING REMARKS

CONCLUDING REMARKS

It is rare to have the opportunity to participate in a three-day working session with attendees whose deep expertise spans virtually all relevant facets of one of the world's largest and most important industries—the automotive sector. It is rarer still to have those participants laser-focused on driving towards insights on what can be done to truly transform the industry to help it tackle one of the world's most pressing challenges—our large and singular dependence on oil.

When such an event does take place one does well to heed the messages that are created and to understand that the collective insights of that group exceeds any single proprietary and competitive knowledge. More important, those insights will likely point to large and largely untapped business opportunities that entrepreneurial companies can grasp to build real and lasting value and competitive advantage.

Such is the case with the Carbon Fiber Autocomposites Workshop. The messages are clear:

- A parts-focused approach can create real value now for stakeholders across the value chain, lead to meaningful improvements in vehicle efficiency, and stimulate innovation to unlock the widespread adoption of carbon fiber composites.
- Unleashing this opportunity will take small teams of experts with mandates to make it happen, as well as an appropriate mix of private and government capital to stimulate efforts.
- Cooperation and collaboration in select areas that will benefit all players is essential and effective mechanisms to do so should be developed forthwith.
- The stakes are large since early innovators are likely to set the stage for global competition and hence global competitiveness.
- Winning strategies need to be developed and executed now given the long lead times for adoption, the pace of global innovation, and the pressing need to reduce oil dependence.

While there are many challenges to be addressed, it is clear from the discussions during the workshop that there are tractable solutions to pursue. We hope that the insights, guiding principles, and approaches contained in this report will act as a useful guide to all those wishing to participate in and reap the rewards of the transformation of the automotive industry.

APPENDIX 1: WORKSHOP NOTES

A1

APPENDIX 1 : WORKSHOP NOTES

RED TEAM

BREAKOUT #1: CRITERIA FOR PART SELECTION

Non-negotiables

- Weight reduction potential
- Takes advantage of structural properties of carbon fiber
- Pathway to volume

Very important

- Potential for interchangeable subsystems
- Potential for functional integration/replaces a part with high cost and complexity

Important

- Has directional loading
- Safety critical
- Below the skin/avoids e-coat

BREAKOUT #2: PART SELECTION

First, we brainstormed a list of 15 potential parts:

1. Front cradle
2. Rear cradle
3. Seat structure
4. IP beam
5. Door inner
6. Transmission case
7. Roof bows
8. Hood inners
9. Sliding doors
10. Wheels
11. Bench seat
12. Prop shaft
13. Front end module
14. Battery box for EVs
15. Stow and go seat system

Next, we ranked each potential part against the 8 criteria on a scale of High (H), Medium (M), and Low (L), and noted other benefits and challenges (see table below). From this ranking we arrived at our four highest priority parts:

1. Front cradle
2. Rear cradle
3. Seats
4. Wheels

We also saw greatest potential in the battery box for EVs, but eliminated this due to low volume.

APPENDIX 1 : WORKSHOP NOTES

RED TEAM (CONT'D)

	CRITERIA								BENEFITS	CHALLENGES
	WEIGHT REDUCTION	STRUCTURAL	VOLUME PATHWAY	INTERCHANG SUBSYSTEMS	FUNCTIONAL INTEGRATION	DIRECTIONAL LOADING	SAFETY CRITICAL	BELOW SKIN		
FRONT CRADLE	H	H	H	H	H	H	H	H	Front weight reduction, sway bar, impact structure, NVH	Need longer floors
REAR CRADLE	M	H	H	H	H	M	M	H	Lateral stiffness, redesign is need anyway	
SEAT STRUCTURE	H	H	H	H	H	H	H	H	Consumer functionality	Needs validation
IP BEAM	M	M	H	H	H	H	H	H	HVAC integration, NVH	Can't compete with glass
DOOR INNER	H	H	H	H	H	H	H	L	Consolidation of door module	
TRANSMISSION CASE	H	M	H	H	H	M	M	H		Trans. fluid, coolant, heat
ROOF BOWS	L	H	H	L	L	H	M	H		
HOOD INNERS	M	H	H	H	L	H	M	L		
SLIDING DOORS	H	H	L	H	H	H	H	L		
WHEELS	H	H	H	H	L	H	H	L	After market potential, rotational weight, unsprung, spare tires	Serviceability
BENCH SEAT	M	M	L	NA (we eliminated this part mid-ranking)						
PROP SHAFT	H	M	M	H	L	H	L	H	Stiffness to mass ratio	
FRONT END MODULE	M	H	H	H	H	H	H	H		
BATTERY BOX FOR EVS	H	H	L	H	H	H	H	H		
STOW AND GO SEAT SYSTEM	H	M	M	H	H	H	M	H		

APPENDIX 1 : WORKSHOP NOTES

RED TEAM (CONT'D)

BREAKOUT #3: MANUFACTURING AND SUPPLY CHAIN – SEATS

First, we discussed the potential market and chose the front seats of cross-overs and vans.

Potential Market:

- Cross-overs/vans front seat***
- Stow and go
- Back seat

Next, we discussed re-designing the seat and came up with the following ideas:

Base

- Built-in suspension
- Integrated track and frame seat bottom
- Integrated restraint
- Frictionless slide (eliminates ball bearing and grease)
- Carbon fiber cross tubes
- Integrated heat
- Clock and lock functionality

Seat Back

- Integrated guide for headrest
- Integrated suspension
- Integrated restraint
- Integrated heat

Precursor: Polyolefin

- Lower-cost raw material
- High carbon content
- Potential processing issues

Fiber Processing

- Oxidations, carbonization, surface treatment, PA (if injection molding) or epoxy (if RTM) specific sizing

Grade Requirements

- Tow size > 25k
- Modulus > 30 Msi
- Strength > 550 ksi
- Other grade variables: virgin materials

APPENDIX 1 : WORKSHOP NOTES

RED TEAM (CONT'D)

Fiber form

- Continuous filament or chopped
- Preform (if RTM)

Thermoset

- PA (6 or 66) if injection molding
- Epoxy or UV catalyzed (if RTM)

Manufacturing Process

- Injection modeling
- RTM (only for seat back)

Other notes

- May need UD weave to get strength to weight ratio required
- Some localized reinforcement likely needed
- Doesn't save much cost to make a lower spec carbon fiber material
- There is some market for recycled carbon fibers...but not for these applications

APPENDIX 1 : WORKSHOP NOTES

RED TEAM (CONT'D)

BREAKOUT #4: BUSINESS CASE – SEATS

Seat choice: Chevy Traverse

** We only got through the seat back for this exercise; we never made it to the seat bottom.

Materials competition
Current: steel (10.5 lb)
Future: Mg, glass composite

Fiber/resin/process assumptions

- 50% PA 66, injection molding
- Thickness = 0.11"
- Pivot points included
- Retraction included
- 450–500 ton press

Cost assumptions

- Compound 6 or 66: $10–15/lb
- Long glass $2.50/lb
- Short glass $1.50/lb

We think the business case could be a lot better if we had the time and tools to redesign:

- We estimate that we could reduce the amount of carbon fiber needed by 20–30% by redesign and varying the thickness throughout the part, but the tools and database of material characteristics don't exist to model this and do crash tests.
- We estimated a 60% weight savings and only considered injection molding, but we could probably get 70% with a redesign and a mix of manufacturing processes.

Value add:

- Could downsize batteries in hybrids/EVs
- Get rid of ball bearings and grease in tracks
- Has static dissipative properties (glass does not)

DATA FOR WATERFALL CHART

Steel Cost (per lb) = $13	Carbon cost (per lb) = $43	50% Glass cost (per lb) = $24.5
	-$18 Weight savings *assumed a 6 lb savings @ $3/lb	-$10 Weight savings
	-$5 foam weight savings	-$3 foam weight savings
	-$7-7.5 integration savings	-$7-7.5 integration savings
	~ $13/lb	~ $5/lb

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM

BREAKOUT #1: CRITERIA FOR PART SELECTION

Part Selection Criteria:

- Able to differentiate w/CF advantages—e.g. stiffness—over using glass composite material
- Availability and consistency of material properties/database
- Predictive/simulation challenges
- Skilled workforce with real composite experience—design + manufacturing expertise
- Joining and fastening—e.g. bond read out (where the fastener/bond shows through the other side of the part)
- Need to redesign/rethink distribution of function in parts to get value
- Mental model is from aerospace—baggage from aerospace history—need to adapt to automotive needs
- Stability of price + supply + robustness of supply chain = supply chain risk
- Driving automation with composites is difficult
- Reducing downstream costs
- Lack of customer and consumer confidence
- Perceived risk leads to higher factors of safety
- Finishing processes
- Getting the full value out of composites is tough—such a big design space with so many parameters

Part Selection Criteria:

- Part consolidation potential
- Stiffness driven application
- Target 50–70k per year
- No straight lines—composite could enable new forms: composites could enable more manufacturing freedom to design more optimized shapes. Parts would likely take on biomimicry/treelike forms. Shapes would have more trusses and struts, curves, x shapes, no constant cross sections, etc. Composite could allow this where steel is challenged/limited.
- Automatable
- Position high + front on vehicle: this is the best place to save weight for improved performance and also for allowing cascading/snowballing savings
- Simple, but 3D geometry: don't want the geometry to be too crazy otherwise current composite processes won't be able to handle. On the other hand, can't be too simple/straight or it would be made very easily from steel.

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM (CONT'D)

Risk/reward tradeoff
Additional criteria were identified that would need to be evaluated on a risk/reward tradeoff basis for each situation—e.g. going after a safety critical part would be very challenging but could also have a huge reward.

These included:

- Safety critical: high risk, high reward
- Fatigue (e.g. chassis + suspension) in contrast to stiffness critical: CF composite could have advantages at both, but probably take on just one at a time, currently some design/material characterization limitations with both.
- Part of the BIW: challenges around e-coat plus integrating into such a large and critical system
- Exposed weave: can add value to customer in some cases, but also adds difficulty as surface finish becomes important

Additional thoughts:

- At 250k, no longer need to seamlessly integrate into the existing plants. At 250k, you can be a part of the primary manufacturing process that the plant was designed for. At 50k you will need a drop-in solution.
- Suggestion to strongly avoid the B-pillar. Need to be able to tune the crash behavior here, which requires simulation. In general, expectation is that for meeting safety requirements, need to design (through CAE), then test one part in house (with success), then test one part for certification—anything beyond this is unacceptable.
- CAE tools for steel are sometimes overrated—e.g. less accurate then people assume—but are however commonly accepted and defensible (due process)

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM (CONT'D)

BREAKOUT #2: PART SELECTION

Brainstormed potential parts:

- Part Selection Deck lid or hood, however it was noted that you might be better off with something of higher value, lower scrutiny and safety requirement
- Roof rail (goes from A pillar to C pillar at the side of the roof): difficult to substitute out and could eliminate mnfg process steps + lower part count
- Roof Bow
- Roof system: A-C rail + cross
- Roof panel
- Hood
- Transmission cross member
- F/R suspension cradle
- Seat structure
- Top hat: roof + rails + pillars from the belt up
- Cross car beam
- Seat Frame

Top 3:

- Front Cradle
- Top Hat
- Cross car beam

Additional thoughts:

- Big challenge around e-coat process. Sending a composite part through e-coat is a challenge because of high temp sensitivity of resin and thermal expansion differences between steel and composite

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM (CONT'D)

BREAKOUT #3: ENGINE CRADLE MANUFACTURING AND SUPPLY CHAIN

How would we make it?
A little challenging since the composite optimized shape probably wouldn't look anything like the steel version. Optimized design would probably take on a biological or more organic form. Regardless would probably need to be closed section with top and bottom molded separate and then joined—likely through fusion bonding.

Engine cradle functions:

- Support engine
- Load path in crash
- Suspension mount
- Crash load management for engine
- AWD trans components
- Vibration damping. Idea: perhaps composite cradle could be more easily tunable for noise damping because its easier to add features/holes to handle various frequencies

Exploring the supply chain:

- Precursor: likely PAN, but perhaps also textile PAN or even Lignin
- Grade Requirements: jumped immediately to 50k with no discussion of lower tow
- Fiber form: focused on oriented continuous fibers due to the high strength requirement of the part
- Resin: at this point, interest in both thermosetting and thermoplasting (PET and perhaps Nylon in particular)
- Manufacturing Process: SMC compression molding, resin infusion, but mostly interested in thermoforming
- Further discussion of the supply chain, but now considering high volumes up to 1mn: identified thermoplastics as the process with the most potential for the required very fast cycle times at high volume.

Market Segment

- Lincoln MKS (~60k volume), Corvette (35k), Chrysler 300C (50k), or Charger (50k)

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM (CONT'D)

Additional thoughts:

- No concession from fiber suppliers that scaling up or potential size of market would in itself bring cost reductions
- Next we did a quick estimate of cost. The comment was made that even if fiber were free the manufacturing cost would still be too expensive. However, as we determined through the rough estimate, that is likely not the case—mnfg cost makes up only a small portion of the overall part cost and is likely at least competitive with steel processes
- Also part of the rough cost estimate, we looked at glass fiber composite. Glass looked like a better value than carbon composite in terms of $/lb saved (although not total weight saved). There is also some question of whether a glass fiber cradle might reduce strength/stiffness performance.
- Rapid wetting of high tow (50k) fibers is a problem that needs attention
- Temperature sensitivity of thermoplastic could be an issue for the engine cradle because it is exposed to the engine heat. Performance could be degraded at high temp

APPENDIX 1 : WORKSHOP NOTES

YELLOW TEAM (CONT'D)

BREAKOUT #4: ENGINE CRADLE BUSINESS CASE

Why front cradle?
(note that the cradle was prescribed to the group at the beginning of day #2—top hat was thought to be a bridge too far in the five-year implementation horizon, and the cross car beam was noted to have been studied for potential material substitution many times over)

- Large potential for weight savings with a stiffness critical part—42 lb saved from 70 lb part = 28 lb engine cradle
- Crash performance (although could also be a showstopper)
- Could be easily attached after the e-coat
- Bolt on component: easier to integrate into current assembly line, could be produced by Tier 1
- Potential to free up space and free up some packaging constraints in a very space constrained environment (although this is uncertain)
- Reduce assembly steps: although the steel cradle was relatively cheap, it was made from a lot of parts

Materials competition

- Current: steel (70 lb)

Fiber/resin/process assumptions

- Two-part (upper and lower) assembly to create close channel
- 60%+ commercial grade carbon fiber
- Thermoplastic resin—likely PET or perhaps nylon
- Oriented continuous fiber (UD) tape
- Auto layup + thermoform process
- Fusion mold joining
- Final trim, machine, inserts (although perhaps overmold)

Composite part assumptions:

- 60% weight reduction – 28 lb composite part
- 60% fiber content by weight

Cost assumptions

- Fiber: $10/lb
- Resin: $2/lb

See report for summary of part production cost + benefit

Additional thoughts:

- OEM pushback: $/lb was the wrong way to judge benefit. Need to evaluate value in the specific application—e.g. torsional stiffness worth a lot in a sports/performance application.

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM

BREAKOUT #1: CRITERIA FOR PART SELECTION

Very Important

- Takes full advantage of CF properties (primarily stiffness but also strength)
- Leverageable (adaptable to additional models/platforms)
- Offers consolidation opportunity
- Qualifiable (minimize costly testing and/or qual risk)
- Ease of integration with rest of vehicle
- Offers additional value to the customer (identified in Breakout #2)
- Disturbs adjacent design groups minimally (identified in Breakout #2, i.e. fewer people must be convinced)

Important

- Easily replacable
- Offers weight savings in area of vehicle where weight reduction has higher value
- Offers opportunity to address CAE challenges
- Not a “litigious” part
- Under the skin
- Manufacturable with high repeatability

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

BREAKOUT #2: PART SELECTION

We first came up with ~10 parts, then ranked each based on the extent to which it fulfilled the above criteria, including specific elements of customer value that the part may offer, along with some of the challenges associated with making the part from carbon fiber composite (in the case of less desirable candidates).

Seats

- Offers feasible market entry points (ramp-up logic")
  - Rear to front evolution (easier to start with rear seats to avoid safety and qual challenges, then evolve to front)
  - Alternatively start w/Stow N' Go Seats, whose customers will value lightness above other markets
- Leverageable to other models and platforms and also because seat suppliers touch many OEMs
- High part consolidation potential
- Offers additional passenger space since cross section can be minimized to take advantage of higher CF stiffness
- Below the skin
- Qualifiable: testing protocols are well-established
- Add on part (bolt on) to minimize disruption to existing assembly/paint/trim processes
- Manufacturable with existing processes

Door

- Offers lucrative market entry points (ramp-up logic)
  - Start with inner and frame, evolve to outer as Class A gets worked out, then to other models and platforms
- High consolidation potential (integrated inner+frame+intrusion beam+outer (eventually))
- Customer will value:
  - tactile aspects of a lighter door (easier to operate)
  - thinner door (thinner frame will increase visibility)
  - larger window due to higher CF composite stiffness for a given frame design vs. steel (more glass, more visibility)
- Leverageable

Shielding support structure for EV battery

- Despite low volume initially, would be leverageable to hybrids, trucks w large batteries
- Might also be spun off or combined with the function of an underbody aero shield, which, if made from carbon fiber composite would offer:
  - Corrosion resistance
  - Impact resistance
  - Vehicle stiffness that could lead to BIW weight savings

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

- Offers a feasible market entry point in the sense that current value chain is not overly capitalized (few sunk costs amongst current providers)

Bumper Beam

- CF would lend safety benefit (low-speed impact resistance/ toughness combined with high-speed crash energy absorption)
- Reduced section would create more space/envelope (including a reduced overhang)
- Would be under the skin, after paint
- Could be integrated with crush cones to save even more weight (compounding benefit)

Suspension Springs

- Offer feasible market entry point: trucks
- Add on (bolt on)
- Easy to manufacture (already done with glass composite)
- Would create leverageable data: spring data would be applicable to future energy recovery applications

Front-end Module

- Compounding benefit: can impart structural benefit to body
- Offers longer term safety benefit: low speed toughness plus high speed crash energy absorption

Roof Panel Module

- Consolidation potential: sunroof, rack, moon roof
- Non-structural but may become structural with greater integration with the vehicle, eventually offering compounding weight savings
- Offers "below the skin" approach since roof may not need full Class A

Hood

- First candidate for external application
- Thermal challenges (engine heat) particularly for thermoplastic

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

BREAKOUT #3: MANUFACTURING AND SUPPLY CHAIN – DOOR INNER ASSEMBLY

Door Strategy

1. Target market
   - Cargo van sliding side door and/or rear hatch, evolving into passenger mini vans, SUVs, trucks, and ultimately LDVs
2. Design approach
   - Integrated inner and frame, evolving into outer as Class A progresses
   - Integrated (and perhaps eliminated) intrusion beam
   - Integrated (overmolded) door hinges
   - Foam core (filament wound, possibly braided) frame sections
3. Priorities
   - Smart, frugal use of fiber
   - Better-than-today dimensional stability
   - Match resin to surface treatment of fiber

Next, we discussed re-designing the seat and came up with the following ideas:

Precursor: Polyolfein (longer term) or Textile Grade PAN

- PO best bet to meet PAN-caliber material properties
- High carbon content
- Melt spinnable

Fiber Processing

- Surface treatment and sizing must be matched to resin type
- Sulfonation a key step

Grade Requirements

- Tow size > 25 k

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

Fiber form

- Weave
- Preform (net shape preformed (direct weave) in house (preferable) or from pre-bought weave from outside supplier)
- Nonwoven
- Chopped, and possibly recycled if DLFT or RTM with deposition preform
- Stitch, with resin
- Braid (for filament wound frame sections)
- SMC (possibly with chopped/recycled fiber) if compression molded

Resin

- Thermoset prepreg if pressure pressed
- Injected epoxy if RTM
- Thermoplastic if DLFT

Manufacturing Process

- Pressure Press (e.g. Globe Machine/Plasan)
- RTM
- Filament winding, possibly w braid (for frame sections)
- Injection Molding (DLFT)
- SMC + Compression molding

Other notes

- Door may be amenable to sandwich panel construction to minimize CF use and save cost
- Single supplier a risk when selecting less common grades such as 50k
- Tow splitting from industrial grade very high tow (>50k) a possibility for near-term cost reduction

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

BREAKOUT #4: BUSINESS CASE – SEATS

Market Entry

- Cargo van side door (no glass)
- Dodge Sprinter or Econoline

Materials composition

- Current: steel (72 lb)
- Future: CF composite

Fiber/resin/process assumptions

- 50% epoxy RTM

Cost assumptions

- Resin: $2/lb
- CF: $10/lb

Weight Savings

- Rather than assume a % weight reduction, final weight was based on participant experience (Gary Lownsdale) to be around 22 lb.

DATA FOR WATERFALL CHART

DOOR INNER

STEEL PART	
Weight	72
Cost	$100
CF COMPOSITE PART	
Weight	22
% Weight Saved	70%
Cost	
Fiber	$140
Resin	$19
Process	$25
Secondary Ops	$29
SGA, Profits, Alloc.	$43
Total Cost	$256
Cost/LB Saved	$3.12
PV of 3yr fuel savings	$60

APPENDIX 1 : WORKSHOP NOTES

GREEN TEAM (CONT'D)

Value add

- Compounding benefits: downsized hardwear, rollers, pivor arms (-4 lb, -$4 cost [accounted separately as "additional customer value", rather than weight savings, in business case)
- No paint ($0.50 cost savings [steel coat costs $0.50])
- Customer value
  - Lighter door easier to open/close
  - More fatigue resistant: more reliable / durable (less maintenance)
- Better dimensional stability
- Fewer weldments (less splatter)
- Saved assembly time and simplified assembly with adhesive
  - Press hemming for assembly
- Cheaper fixtures and tooling
- Higher corrosion resistance
- Brake wear (currently an issue for vans)
- Door is safety critical: will lend additional value in subsequent stages of implementation, particularly for LDVs

Scale-up Approach (ramp-up logic)

1. Enter with cargo vans ~200kpy, 2M lb of carbon fiber, 4M assuming 2 doors per van
2. Expand to minivans (600k total volume), 12M lb carbon fiber
   - oFully adaptable process: similar tooling, # of tools and presses
3. Expand to LDVs (~10Mpy, ~500M lb of carbon fiber)
   - Challenges: packaging is more complex (moveable glass)
   - NVH could be a concern (would have to tune resonant frequency

APPENDIX 1 : WORKSHOP NOTES

SESSION 5 NOTES NONCOMPETITIVE LEVERS

There are parts of a car, and certain types of cars, where OEMs are willing to pay $1–10/lb. People will pay the premiums for performance on luxury, high-performance vehicles. Might not be a good idea to pursue the “special cases” because it likely wouldn’t be a long-term commitment.

If you build the business case around adding value vs. reducing costs, the solution will be more long term.

There is no way to achieve the 54.5 mpg without composite materials (glass or carbon).

We are way behind the curve compared to other countries.

We should be open to mixed material solutions—working with glass can build skills need for carbon fiber.

Weight savings from carbon fiber composite = 40–80%

- Heavy trucking: used to be no one would pay for weight savings, now you’re seeing about a $1/lb saved
- 60–80% weight reduction could be possible in some cases with good design
- Vehicles/customers who are willing to pay are those who’ve already tried everything else
- Maybe learning from aero doesn’t transfer very well to automotive
- Proper joint design is still a big challenge. Not seeing the expected performance of parts because of lack of understanding around joints
- Corrosion when used with steel is also a remaining challenge, especially because mixed material solutions will probably be important
- Design parts to take full advantage—even in aero we have quasi isotropic parts that don’t need to be
- Continuous high fiber volume, aligned composites is the right skillset
- Already existing Stanford + MSC – test + validation partnership
- Reach out beyond the U.S.—don’t be limited by U.S. institutions + network. Start with those in other countries who are already leading
- Already existing: Dave Cramer mentioned the NCAMP collective
- Co-locating research has big benefits
- Need for an integration/collaboration facility. Center of excellence. Fraunhofer as a very important starting point.
- Christophe gave description of the Fraunhofer approach: tiered with participants paying different entry fees but also getting commensurate benefits—e.g. voting rights. OEM involvement. Very open environment.

APPENDIX 1 : WORKSHOP NOTES

SESSION 5 NOTES
NONCOMPETITIVE LEVERS (CONT'D)

- You need a collaboration center because of the breadth of knowledge that's involved with the problem
- Committee of industry players
- OEMs are needed both to say what's needed but also to signal importance
- Dave Cramer: Industrial scale demo facilities are a big deal
- Fraunhofer goes to companies and pulls them in
- In Germany, industry and universities building a very strong network
- "put the honey on the table and the bees will come"
- Anand mentioned a presidential initiative called the Materials Genome Initiative that could also be a model
- Jon Myers wants locally and auto-focused collaboration facility
- Maybe a more structure approach/understanding of what the private sector should take on—e.g. structural + non-class A
- Who would broker? Maybe RMI is a good candidate
- Canada has made some progress here—Dube: carving a future. What drives such collaboration? You need to have somebody who it's their day job and they're very motivated. Canada has been working with Fraunhofer on a center (Dieffenbacher, U of Western Ontario also involved). But the Fraunhofer model is a little foreign here—e.g. funding is 2/3 government (half federal and half local). Red tape is greatly reduced for Fraunhofer. Lower inhibitions for those involved to work better together. You can rent the facility and bring your own people or you can contract Fraunhofer to do the research.
- One participant noted that he is struck by how regional things have been in the workshop thus far—i.e. regional vs. a global platform
- Safety is a huge value driver, maybe a big non-competitive lever
- Advanced steel ("safety steel") as an example of how to work from spending money on engineers, prototypes, etc.
- AISI
- These efforts are very profit motivated as opposed to American Chemistry Council
- Aluminum Association is another example

Regarding the van door business case:

- Maybe rear hatch might be an even better candidate. Large + expensive motor plus savings on expensive gas shocks
- $3/lb saved metric likely incorporates fuel savings benefit
- GM has published a study on snowballing weight savings—100 lb savings leads to 30–40 lb secondary weight reduction
- Be careful not to double count weight savings and increased stiffness as the weight savings might not be as high if you go to a much stiffer part

APPENDIX 1 : WORKSHOP NOTES

SESSION 5 NOTES NONCOMPETITIVE LEVERS (CONT'D)

Next steps for specific part business case:

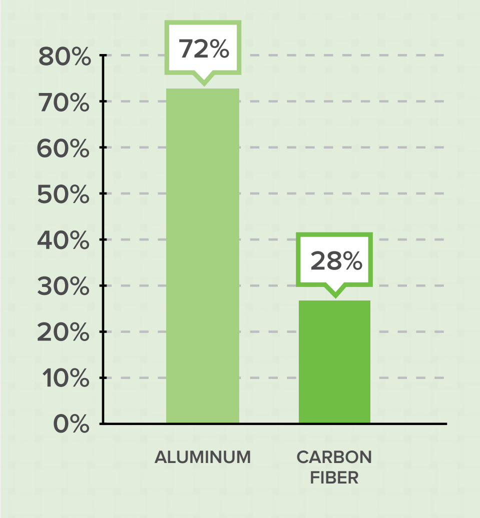
- What should we do to see if this has legs to go to market
- Haven't seen any studies that have gone all the way to the part
- Sandy recommends a study by AGIT Dr. Hajest: how do you do composite aircraft at 60k? Sandy recommends getting in touch with him
- Sandy also thinks mold flow and CAE analysis would be in the near future
- Need to engage OEM to know exactly what tests and requirements will be for the part
- Chrysler is interested but can't bring funding at the moment, but recommends try for government funding
- Engage Magna, they do lots of doors
- GR question: how would collaboration center be different from the ACC?
    - Too much bureaucracy in ACC
    - Setup + plan, get partners, get funding vs. meet once a month to talk, then talk more, then talk more, etc.
    - Dave Warren comment on how this will be different from ACC: precompetitive to prove feasibility, but with ACC you can't really take through to implementation
- We need a commando team vs. an army
- Stiffness at the bottom hinge of window is critical and was a challenge with composite doors tried in the past (Astrovan). Thermoplastic might be good considering this fact
- Cedric Ball: On this team you should have marketing people and also lawyers to work with the IP
- Run a parallel path w/steel part and another release engineer for a backup plan

Needs

- Polyolefin R&D as an alternative precursor
- Joint redesign R&D
- Better simulation tools (Stanford is working on this)
- Robust database of material characterizations and standards specific to automotive (Stanford is working on this)
- Collaboration (globally and across market segments/supply chain in U.S.)
- Corrosion R&D
- Consumer marketing and education to create demand

APPENDIX 1 : WORKSHOP NOTES

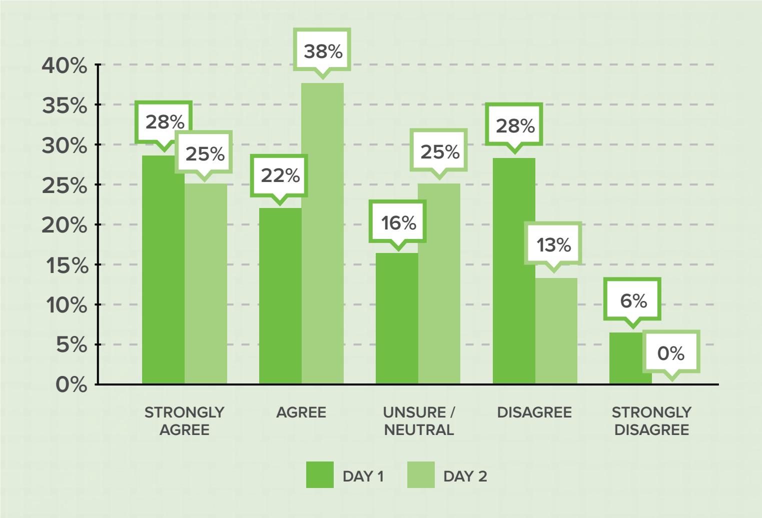
CLICKER QUESTION RESPONSES



Will the average U.S. vehicle in 2025 contain a higher content (by mass) of aluminum or carbon fiber composite?

A. Aluminum

B. Carbon Fiber



Agree or Disagree? North America can lead the manufacturing transition to automotive carbon fiber composites

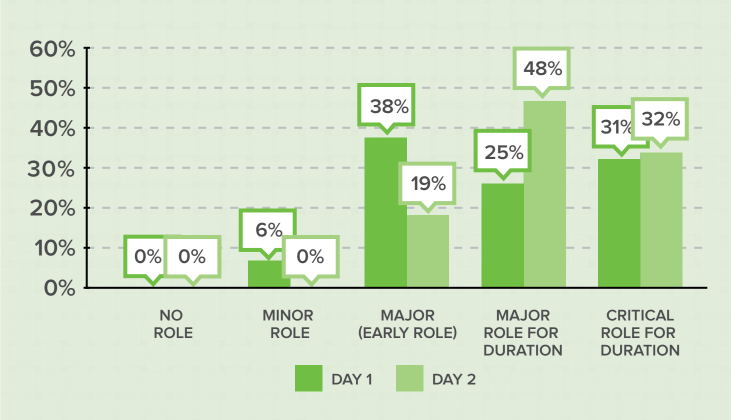
A. Strongly agree

B. Agree

C. Unsure/Neutral

D. Disagree

E. Strongly disagree



What is the role of industry collaboration and noncompetitive action in achieving this manufacturing transition for the U.S.?

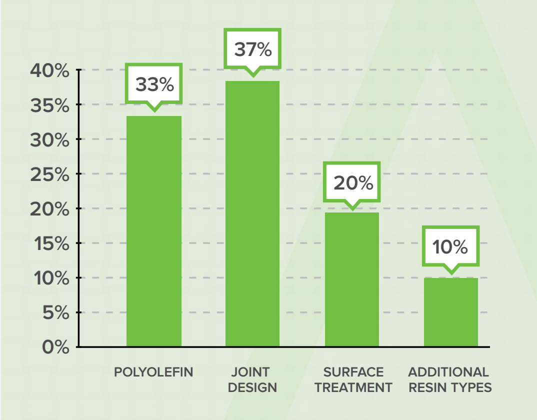
A. No role

B. Minor role

C. Major (early) role

D. Major role for duration

E. Critical role for duration



What are the 2 most important near-term R&D needs for the industry?

A. Polyolefin

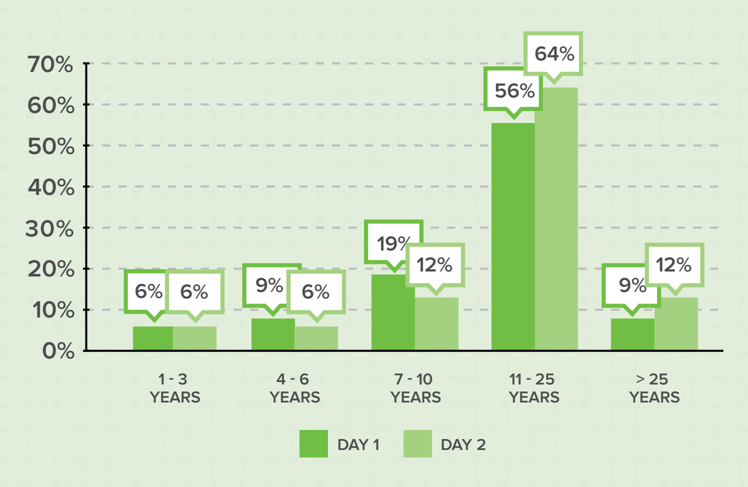
B. Joint design

C. Surface treatment

D. Additional resin types

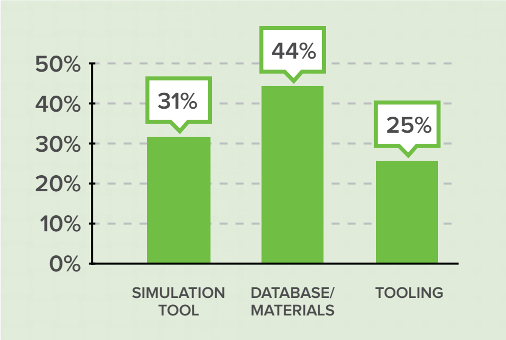
APPENDIX 1 : WORKSHOP NOTES

CLICKER QUESTION RESPONSES (CONT'D)



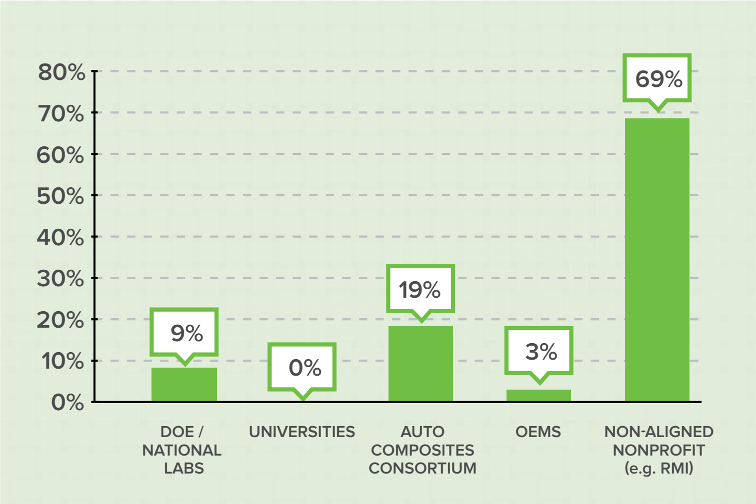
How quickly do you think a U.S. OEM could achieve a 50% weight reduction (From ~3400 to 1700 lb) on today's average midsize sedan and produce it at scale?

A. 1–3 yrs
B. 4–6 yrs
C. 7–10 yrs
D. 11–25 yrs
E. > 25 yrs



If we create a U.S. Collaboration and R&D Center, what is the most important thing for them to take on?

A. Simulation tool improvement
B. Database/material characterization
C. Tooling advancements



Who should lead the effort to develop the framework for a U.S. collaboration?

A. DOE/National Labs
B. Universities
C. Auto Composites Consortium
D. OEMs
E. Non-aligned nonprofit (e.g. RMI)

APPENDIX 2: ADDITIONAL INDUSTRY NEEDS & NONCOMPETITIVE OPPORTUNITIES

A2

ADDITIONAL INDUSTRY NEEDS & NONCOMPETITIVE OPPORTUNITIES

Joining/Bonding R&D

Joining composite parts to the rest of the vehicle must be done in a way that retains a strong and durable joint, does not induce challenges associated with dissimilar material interfaces (such as galvanic corrosion and coefficients of thermal expansion), and fits within the OEM assembly process without undermining the vehicle production rate. Joining composites to other materials such as steel, aluminum, and plastic (each with its own interfacial properties) as part of a mixed material solution must improve to enable high-volume production. In particular, the effects of thermal cycling, fatigue cycling, creep, and environmental effects on the durability of mechanical and adhesive joints[10] are currently poorly understood. As a result, expensive qualification is often required for each application. In an official post-workshop survey administered with electronic voting clickers (see Appendix for full results), joint design was selected as the greatest near-term R&D need.

Tool Development

Innovation to develop better tools and equipment for composites manufacturing will enable improvements to existing manufacturing processes and lead to development of new ones. As carbon fiber composite part production volumes grow and cycle times drop while parts become larger and more complex, addressing particular challenges such as wetting, class A finish, repeatability, non-destructive evaluation, and dimensional stability will increasingly determine whether composite parts can be cost effectively adopted. Beyond part production, improved tools capable of producing complex knits, multiaxials, and weaves will help to minimize waste in cases where such textile forms are used. As compared to other efforts in the industry—notably Japan, Germany, and Canada—there is room for more effective U.S. industry-academia-government co-development of manufacturing process advancement and innovation around tooling development.

Preform Development

Although specific to particular manufacturing processes, effective draping and placement of fiber in a preform can affect part performance and scrap rate, thus strongly influencing part cost (see Cost Sensitivities). Preform development, perhaps as part of a broader effort around tool development, could help enable cost-effective adoption of carbon fiber composite parts.

Surface Treatment R&D

Fiber surface morphology is largely determined by the surface treatment step of fiber processing, underscoring the importance of matching downstream resin types with upstream fiber surface treatment methods. "Coupling," or the bond between resin and fiber, can be the limiting factor in terms of a part's ultimate strength capability. There is opportunity to noncompetitively identify additional surface treatment approaches and improve those already in use, matching them to the most promising resin systems.

[10] See the "Autocomposites Workshop Pre-Read Document", p. 30

ADDITIONAL INDUSTRY NEEDS & NONCOMPETITIVE OPPORTUNITIES (CONT'D)

Fatigue Behavior R&D

While it is often said that carbon fiber is fatigue resistant, microcracks can nevertheless emerge and propagate within the resin matrix of the composite, thus creating stress concentrations that over time can lead to substantial damage. The fiber can also fail, as can the interfacial resin-fiber bond. The many failure modes of carbon fiber composite in combination with its many variations of resin and fiber can quickly lead to prohibitively costly and complex testing regimes. Industry collaboration to advance understanding of fatigue behavior, perhaps as part of a broader material characterization effort, could help lower the risk associated with more widespread adoption.

Recycled Fiber Usage and Recovery

Given the very high cost of virgin carbon fiber, the very high part cost sensitivity to scrap rate, and the opportunity around usage of downspec'd fiber in particular applications, recycled fiber[11] presents a promising opportunity to reduce carbon fiber composite part costs. Noncompetitively addressing the technical challenges and implementation risks associated with recycled carbon fiber could further unlock this opportunity while avoiding a waste management problem in the longer term.

Consumer Marketing and Education

Given the prime contribution of consumer value to the business case for adoption of carbon fiber composite parts, consumer education around the tactile, visible, performance-, and safety-related benefits of carbon fiber composites may help to spur customer demand. Noncompetitive consumer research and/or collaborative marketing, starting most likely with safety, may help to ensure consumers are willing to pay for the benefits imparted by carbon fiber composite.

Energy-Efficient Carbon Fiber Production

Electricity cost is the second largest contributor to the cost of carbon fiber after precursor.[12] Twelve percent of the cost of precursor is also driven by energy costs. This has led carbon fiber producers to seek out states with low electricity costs (WA, WY, SC, AL, TX, and TN) and in some cases—most notably in the case of SGL setting up in Moses Lake, WA—to seek out clean, emissions-free electricity as a nod to environmental stewardship. Whatever the motivating factor, pursuing more energy-efficient production of fiber through improved oxidation, carbonization, and effluent gas treatment and handling, perhaps through noncompetitive channels already available such as ORNL's Carbon Fiber Technology Facility, would enable fiber cost reduction and open the door to a more sustainable and competitive long-term market.

[11] See the "Autocomposites Workshop Pre-Read Document", p.37 for a discussion of different recovery technologies and recycled carbon fiber implementation approaches

[12] See the "Autocomposites Workshop Pre-Read Document", p.18

APPENDIX 3: PARTICIPANT LIST & CONTACT INFORMATION

A3

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