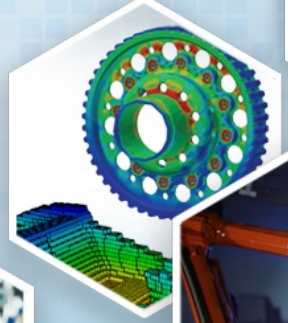
Opportunity Brings New Challenges: The Future of Thermosets

Dale Brosius, Chief Commercialization Officer, IACMI

SPE Thermoset TOPCON

May 2023



THE COMPOSITES iacmi INSTITUTE

Convene. Connect. Catalyze.

My SPE History

- Thermoset Division
  - Joined SPE 1992
  - Thermoset Division BOD 1999-2009
  - Division Chair 2004-2006
  - Various conference chair positions
- Composites Division
  - Composites Division BOD 2006-Present
  - Division Chair 2011-2013
  - ACCE Chair four times
  - Councilor 2018-Present
- Honored Service Member 2009

1985 – Early days of the wind turbine market

1986 – Automotive Composites Development

Early Trek composite tubes

Circa 1989

Castor 120 Firing – T1000G towpreg - 1990

Race car parts fabrication

Circa 1990

1991 – First all carbon chassis in IndyCar

First Class A carbon part on GM vehicle -2003

Wind turbine build - 2016

“Within ten years, all thermosets on airplanes will be replaced by thermoplastics.”

- Chemical Company Executive, 1987

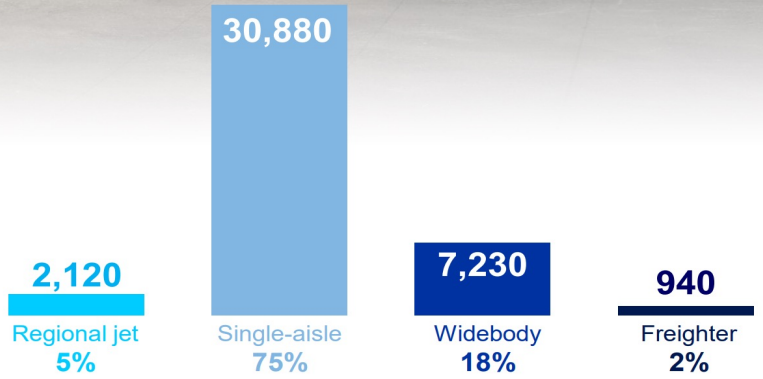
35 years later

>50% of structural mass in composites

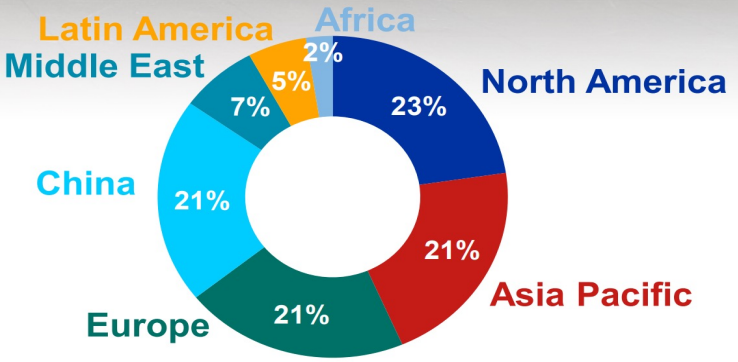
of which >95% is thermoset

Airlines will need 41,170 new airplanes over 20 years

By type

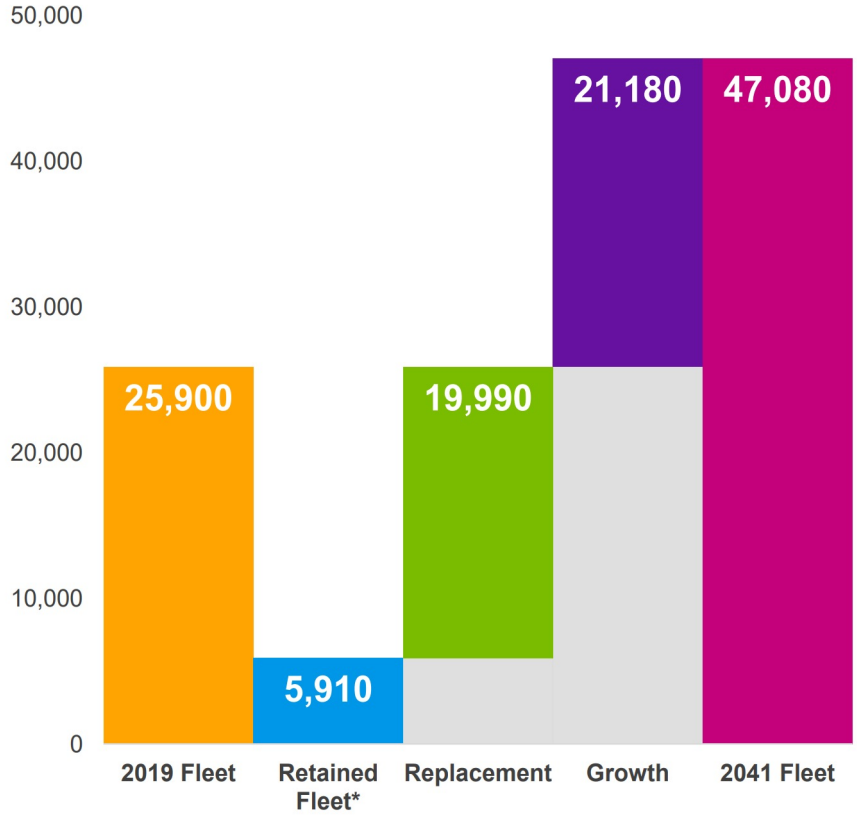


By region

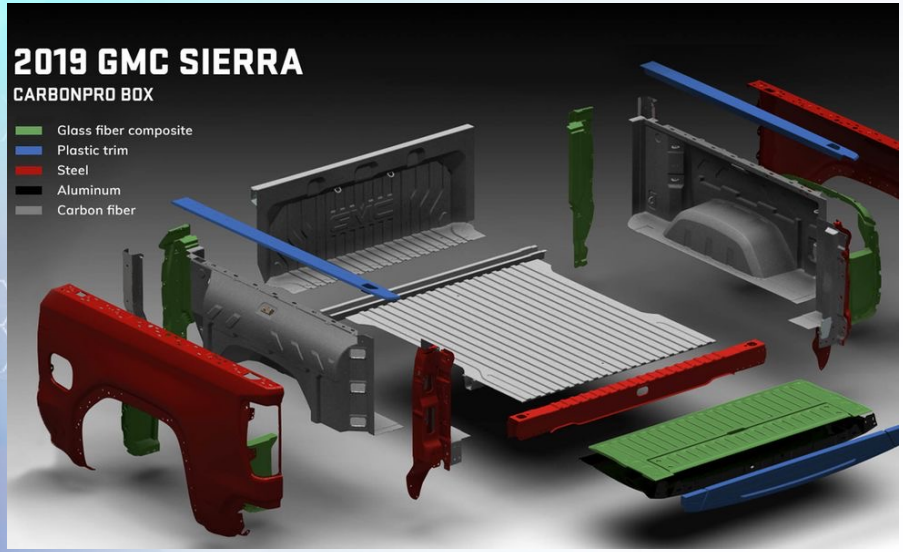


Forecast period 2022-2041, Asia Pacific does not include China

Global fleet will nearly double; half of deliveries for replacement



*Retained fleet includes 2020-21 deliveries



Thermoplastic pickup box

Limited availability

Sold only on highest model

SMC pickup boxes

Toyota Tundra & Tacoma

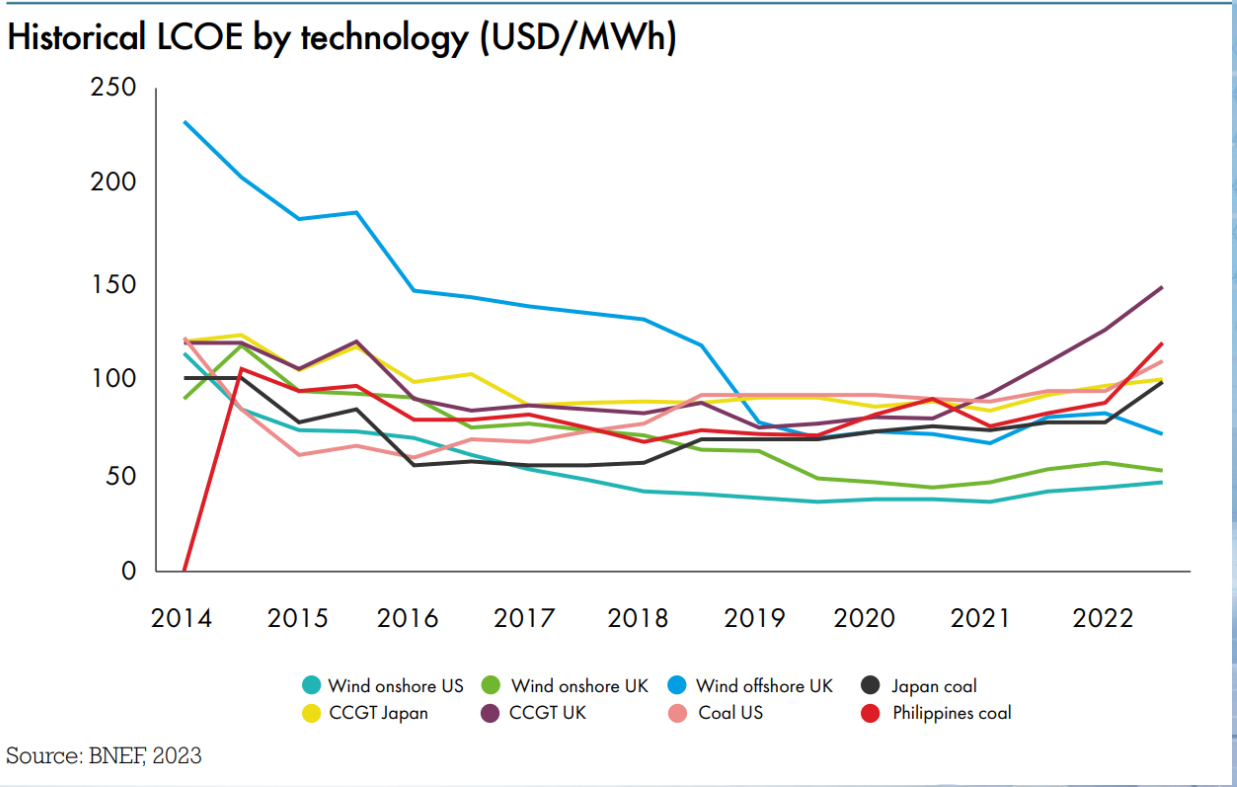
Hyundai Santa Cruz

Only option available – all thermoset. Total volume over 400,000 annually

Honda Ridgeline

The Clean Energy Economy will be a boon for thermosets

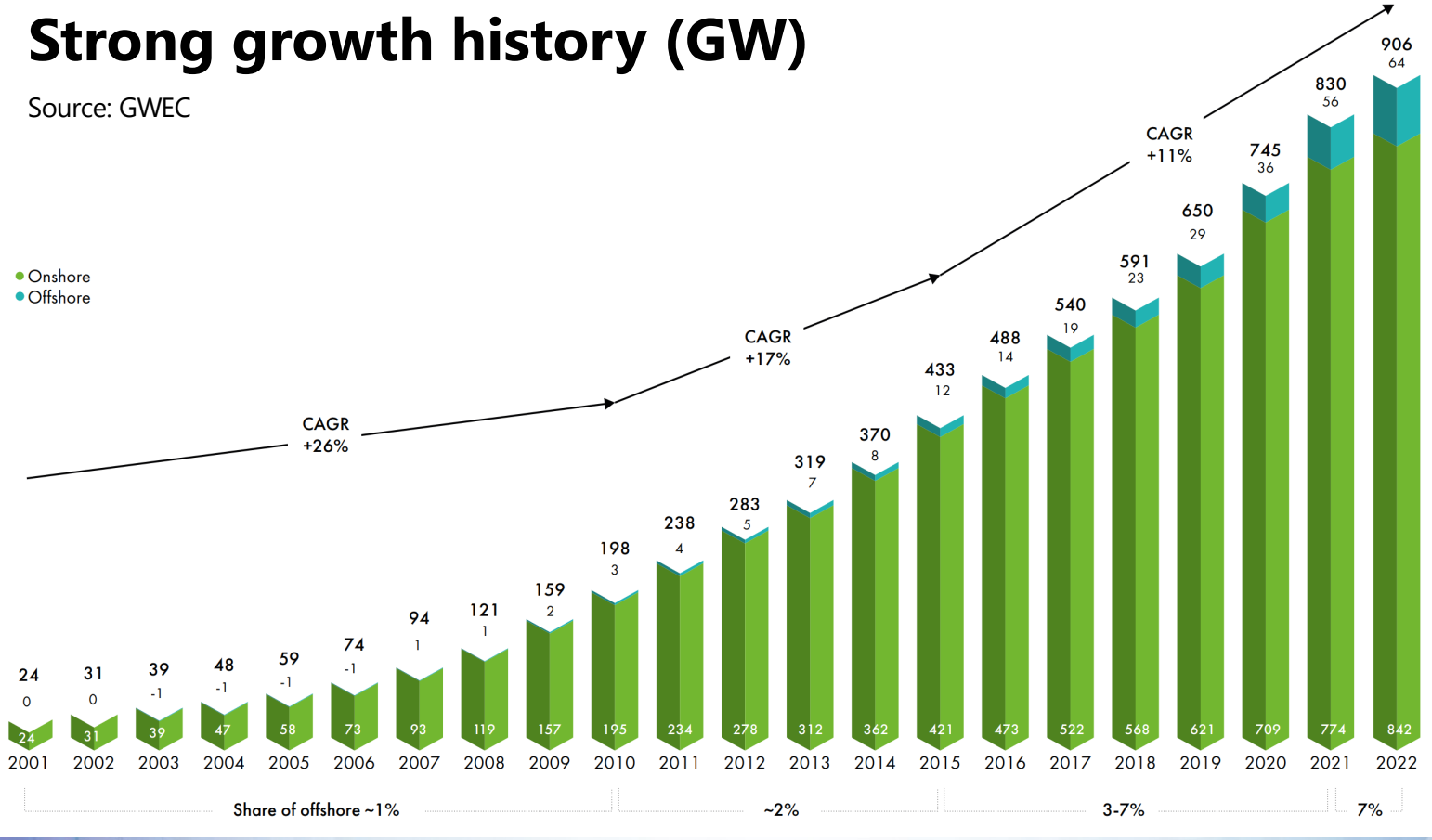
Renewables, especially onshore wind, is cheaper than coal or natural gas



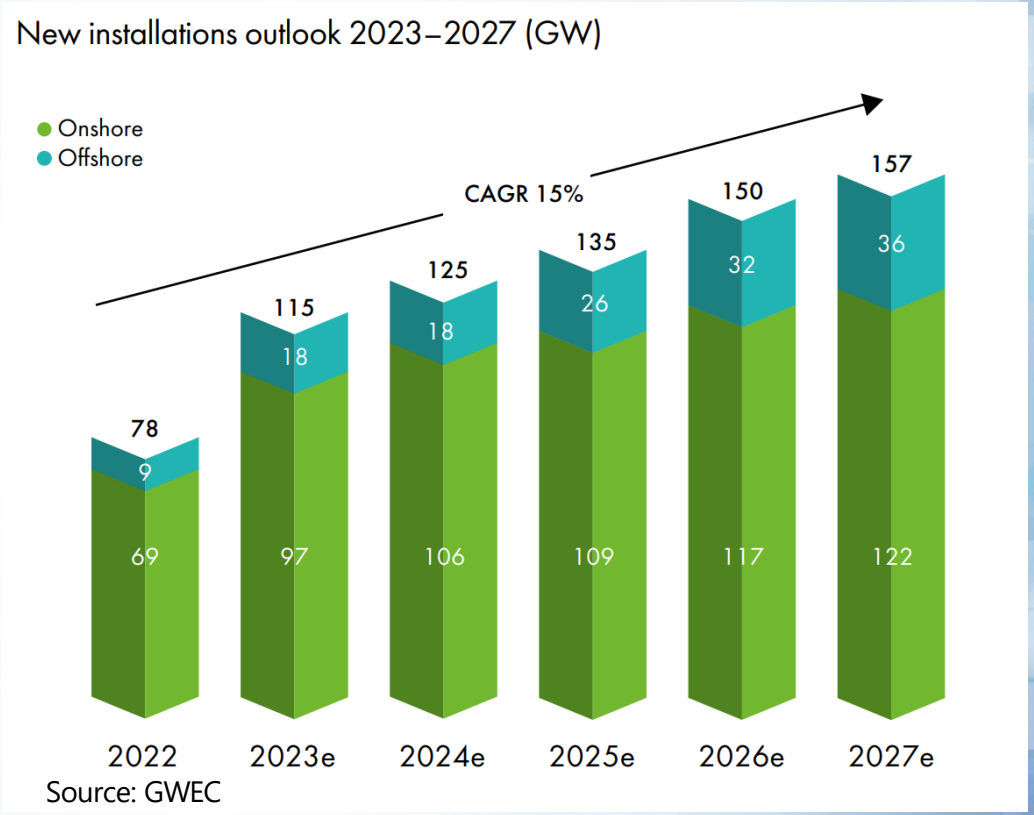
Source: BNEF, 2023

Strong growth history (GW)

Source: GWEC



Strong market forecast for wind turbines



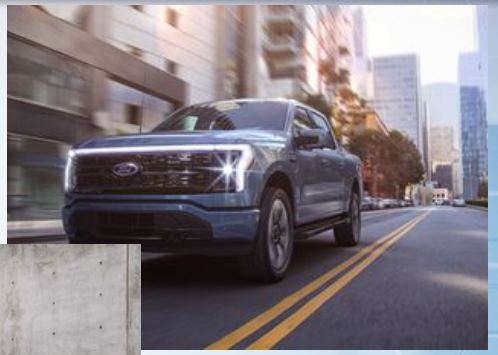
Wind market is already one of the largest users of thermosets

107m blade for 12MW offshore turbine

Thermoset resins with glass and carbon fiber

Electric Vehicles will replace ICEs

Over 35 models not from Tesla available in US now

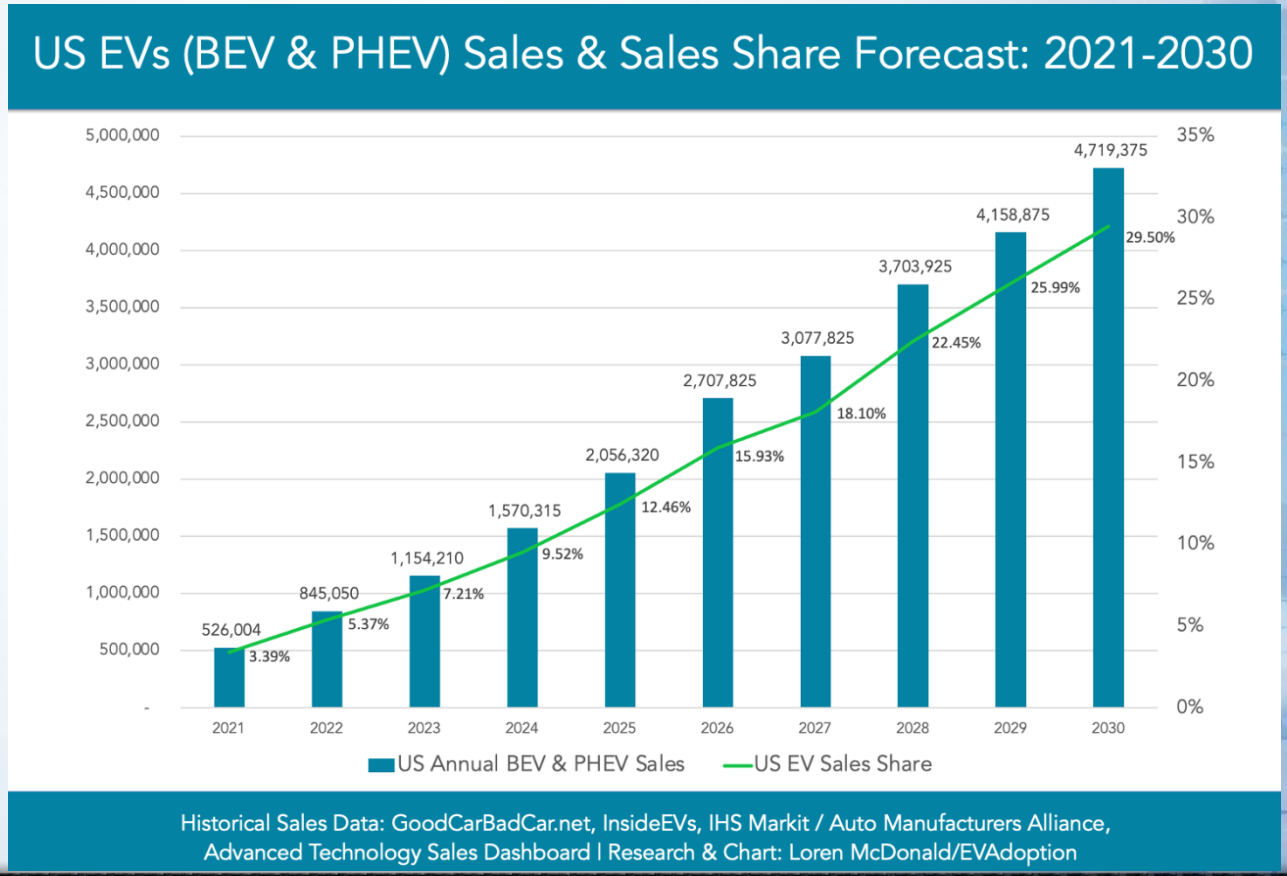


Market poised for double digit growth through 2030

Mass Savings is more important in EVs

ICE vehicles: 10% mass reduction = 6-8% improved fuel economy

Electric vehicles: 10% mass reduction = 10% further range (or smaller battery pack)

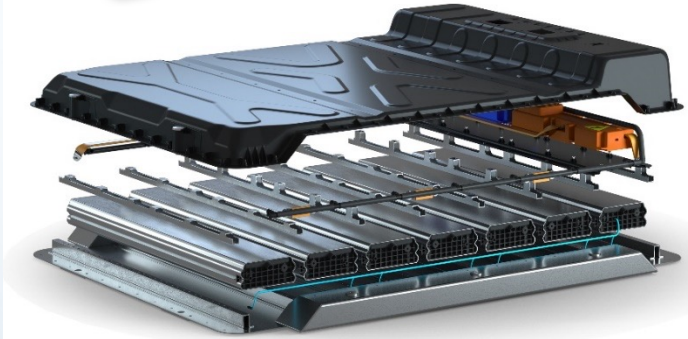


Battery enclosures are the obvious target for thermoset composites

Stiffness, impact, fire resistance, EMI shielding important

Opportunity for multifunctional solutions not offered by metals, combined with mass savings

Don’t overlook traditional applications, like body panels and structure for weight savings



Electrification of the US economy is good for thermosets

Drive to renewables: wind, solar, water

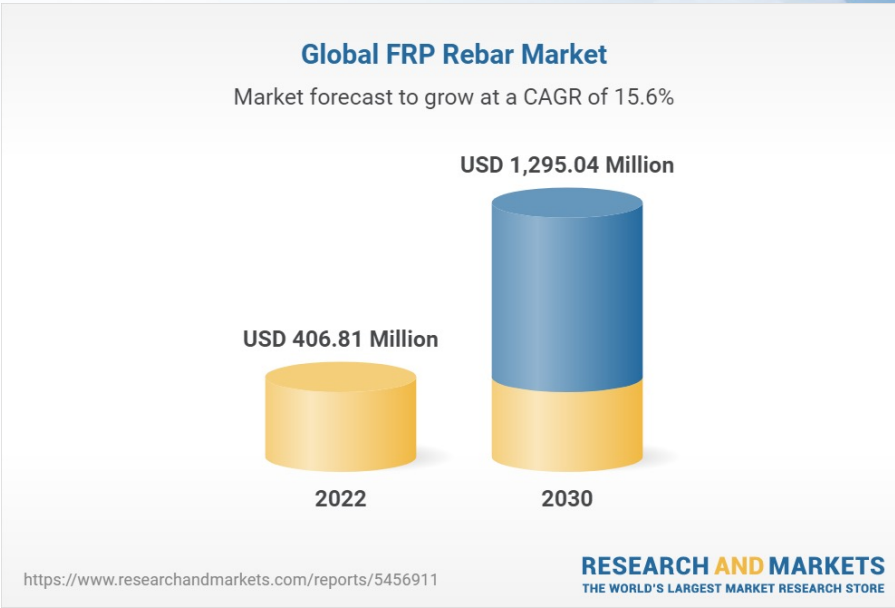
Vehicle electrification (cars, trucks, mass transit)

Electrification of heavy manufacturing

Green hydrogen (requires green electricity) replacing natural gas and coal in metals production

Thermosets excel in high voltage/high current applications

Infrastructure will be a significant market for thermosets, led by rebar



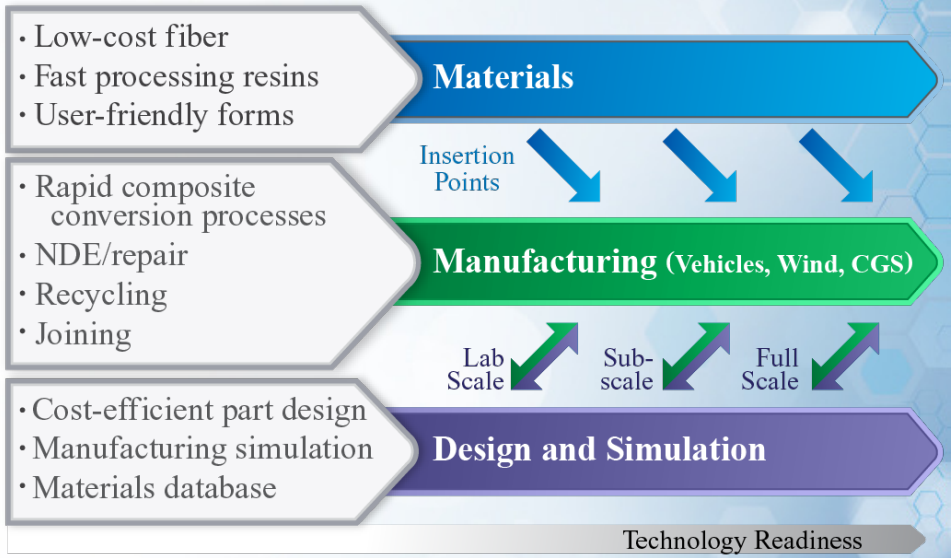
More than rebar

It’s all sunshine so far. Where are the clouds?


“The only technical parameter that matters is cost.”
- BMW Executive

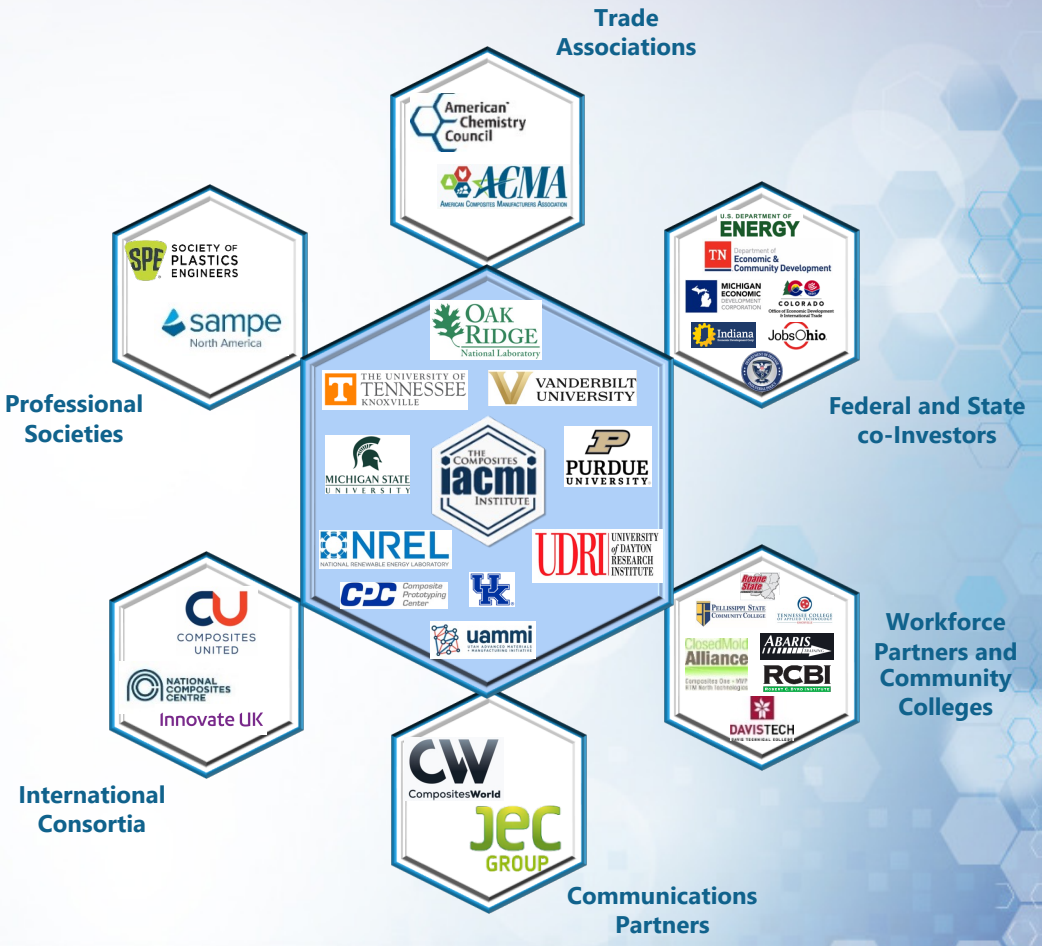
IACMI – The Composites Institute

- Initial vision for IACMI driven by "How do we catch and surpass Germany and the UK?"
  - Fraunhofer Institutes –Pioneer in high volume composites processing for 20+ years
  - National Composites Centre UK created 2009, facility operations 2011 – early focus aerospace, then automotive
- Barriers to Composites Growth
  - High price of carbon fiber and intermediates
  - Slow manufacturing processes
  - How to design to true minimum mass
  - Confidence in manufacturing processes and performance
  - Carbon fiber manufacture is energy intensive
  - Traditional processes are high scrap
  - Inefficient recycling technologies and infrastructure



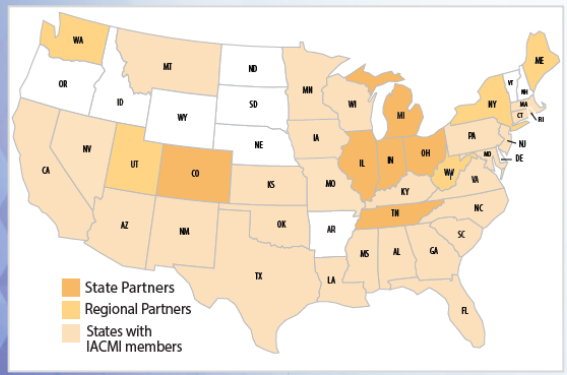
Ecosystem of Innovation

- **Core Partnerships** with leading universities, national laboratories, gov't agencies
- Leveraging existing networks across technical, professional, and economic development organizations
- **IACMI addresses the technoeconomic challenges facing the composites industry**



Extensive Industry Network

- **125+ Active members in 39 states**
- **100 Industry members** (68% SMEs)



Operating Model – Industrial Collaboration Spaces

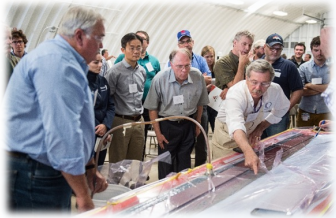
Michigan


Colorado


Tennessee

Indiana


Ohio



Shared Spaces for Catalyzing **Innovation**, Expediting **RD&D**, Supporting **Workforce Development**

Wind blade fabrication

Purpose: Scale Technology to 13m and validate against baseline 13m epoxy blade

Outcome: 13m blade successfully fabricated and structural test completed (bending and fatigue), with results comparable to epoxy baseline. Technoeconomic modeling shows advantages for TP blade.

Infusion and Cure ➡

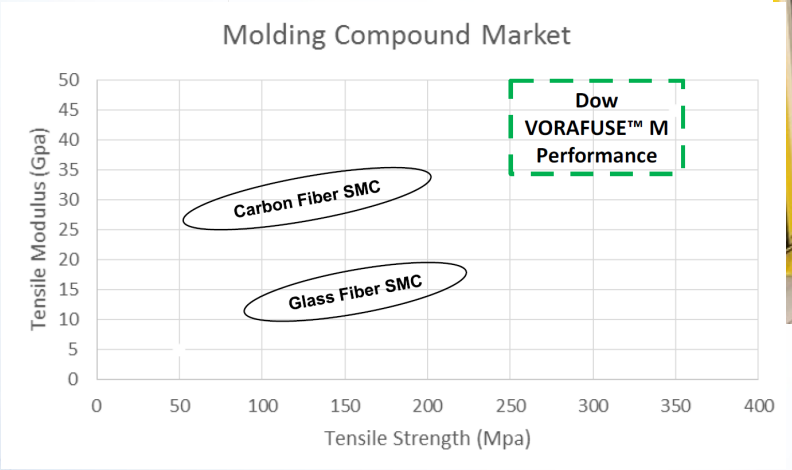
Demolding ➡

Bonding ➡

Blade Prep for Testing

Large-scale prototype & run-at-rate capabilities

Ford carbon fiber liftgate inner panel

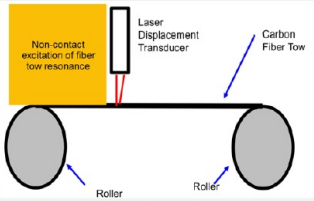


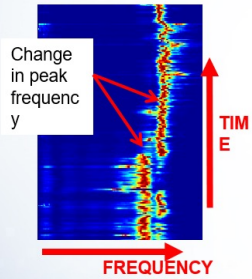
Ford liftgate project

$$w(x,t) = \sum_{n=1}^{\infty} \underbrace{\sin\left(\frac{n\pi x}{L}\right)}_{\text{Space-varying part}} \underbrace{\psi_n(t)}_{\text{Time-varying part}}$$

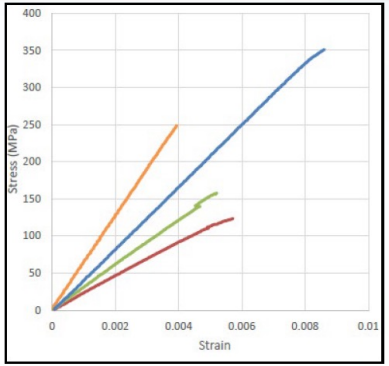
$$\omega_n = \frac{n}{2L}\sqrt{\frac{T}{\rho}}$$

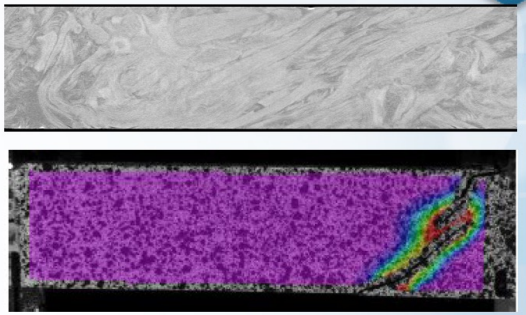
1% ρ --> .5-1.25Hz
0-0.75Hz resolution



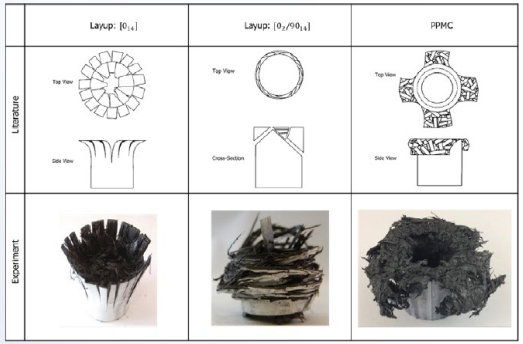


In line non-contact measurement of carbon fiber properties





Mechanical strength testing and morphology



Flow simulation and crash performance correlation

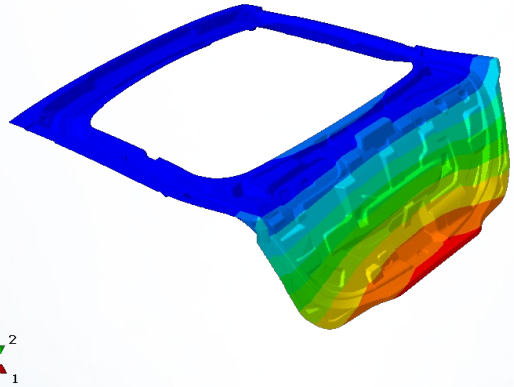
Digital Image Correlation (DIC) for fiber orientation

Ford/Dow Liftgate

Enabling Manufacturing-Informed Design with Novel High-Rate Materials and Processes

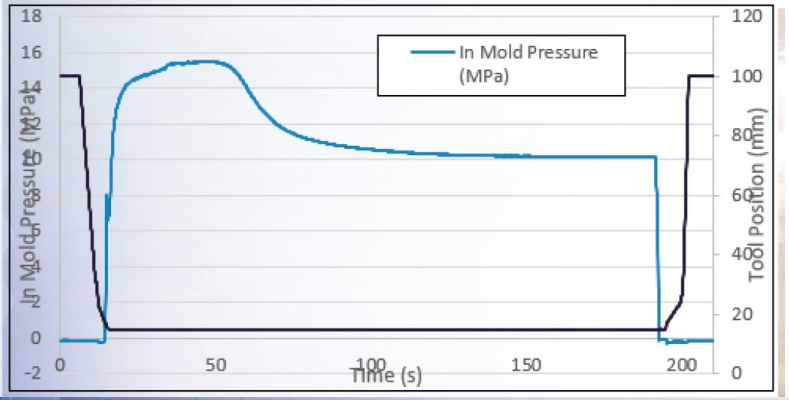
Flow Orientation

Static Stiffness



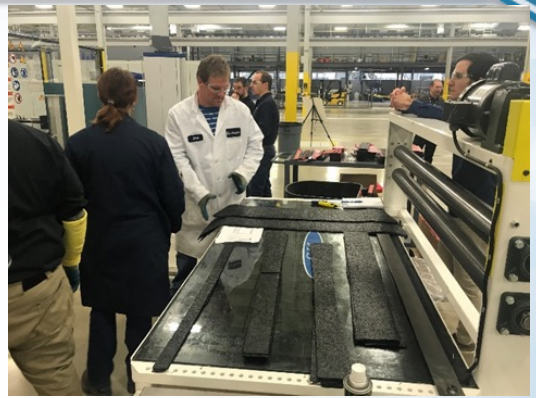
Crash Performance

Ford carbon fiber liftgate inner panel



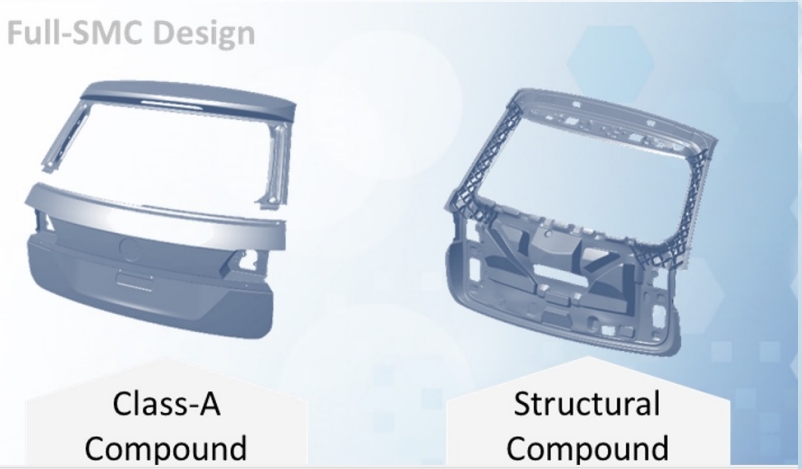
Ford/Dow Liftgate

- Modeled 35% cost reduction vs. baseline
  - 17% reduction in base material cost
  - 83% reduction in material scrap/offal
  - 33% decrease in molding cost due to cycle time
  - Additional savings in manual labor expected but not included



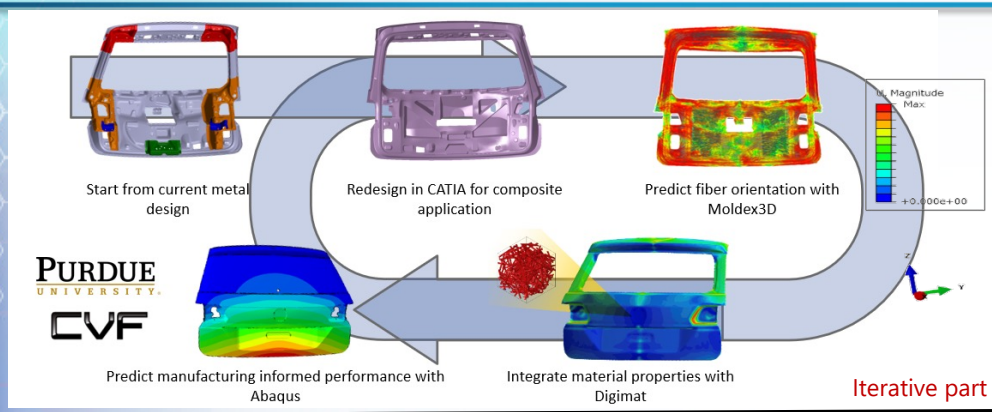
	Baseline	Improved
Part weight	5.9 kg (13 lb)	5.9 kg (13 lb)
Annual volume	100,000	100,000
Molding time	10 minutes	3 minutes
Material Cost	$26.40/kg	$22.00/kg
Material Scrap/Offal	30%	5%

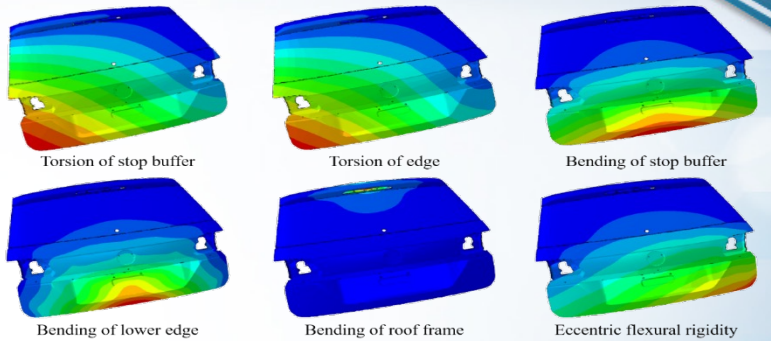
VW Atlas SMC liftgate project



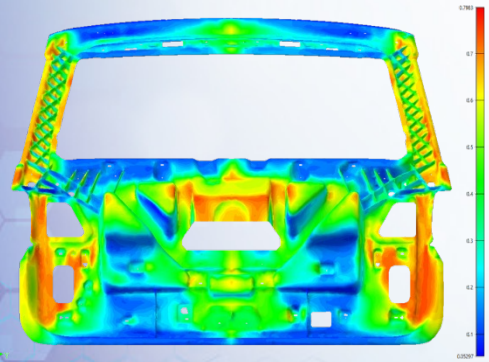
	Steel		Composite	
Part Count	10	→	3	-7
Weight	21.1 kg	→	13.6 kg	- 36%

VW liftgate project



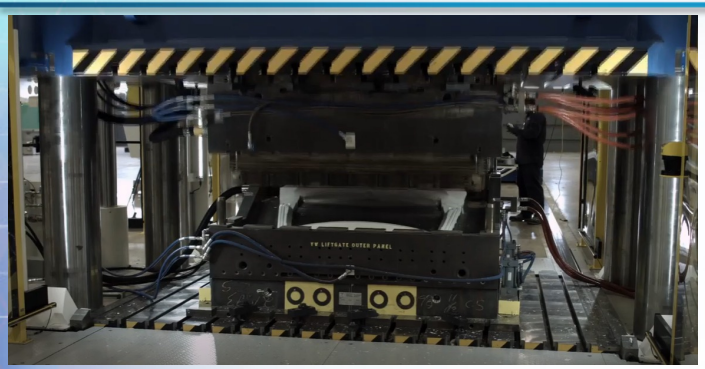


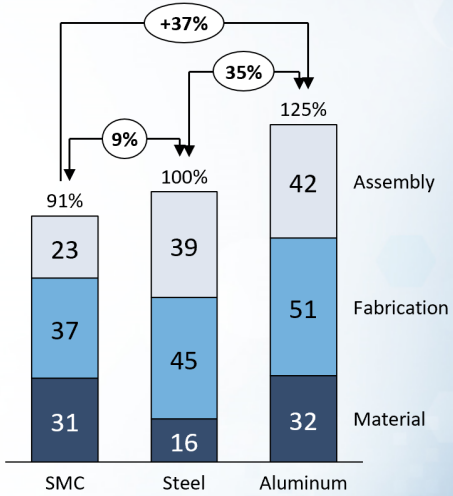
Iterative part design and load case structural modeling



Fiber orientation prediction and measurement using Digital Image Correlation (DIC)

VW SMC liftgate project





Recurring cost comparison (performed by VW)

Transition to Series Production

Project Partners

The University of Tennessee Knoxville

Oak Ridge National Laboratory

The Institute for iacmi Advanced Composites Manufacturing Innovation — The Composites Institute

Purdue University

Owens Corning

INEOS Automotive

Partnering along the supply chain allowed for a batch of SMC Liftgate to be produced, painted and tested

Volkswagen Group Transfers/Influence

Volkswagen ID.Buzz Liftgate

Lamborghini Aventador Rear Fender

Bentley Continental GT Deck Lid

MAN TGX Roof Deflector


“Thermosets aren’t sustainable
and can’t be recycled.”

Achieving sustainability in thermosets

Thermosets reduce energy use during use (mass reduction), produce clean energy (wind), and last far longer than traditional materials (infrastructure and corrosion), all of which contribute to a sustainable economy.

Some material options to further improve sustainability:

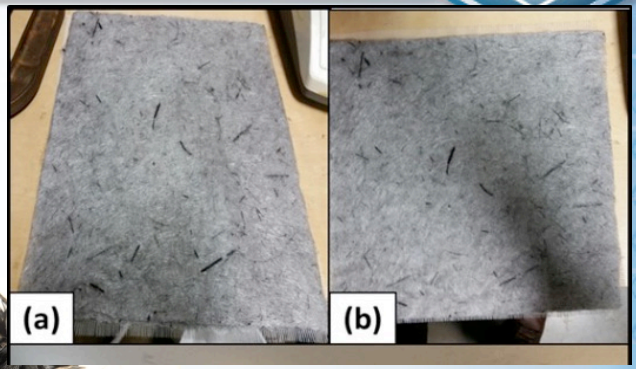
- Recycling of process scrap and end of life thermosets
- Using bio-based thermoset resins and/or natural fibers
- Using reversible thermosets, including:
  - Vitrimers, e.g. VITRIMAX
  - “Unzippable” thermoset resins, e.g. Recyclamine

Recycling Levels – easiest to hardest

Level	Description	IACMI Member (Project Number)
Level 0	Waste minimization, avoid landfill, feed back into process	Many companies/projects
Level 1	Repurposing of uncured scrap (prepreg, dry fiber)	CRTC (6.7)
Level 2	Grinding and remolding of cured scrap and end of life with new resin for alternate applications	Greentex (6.27)
Level 3	Recover fibers from thermoset/thermoplastic prepregs or compounds via pyrolysis or solvolysis	Vartega (6.20) ELG Carbon Fiber Carbon Conversions (6.5)
Level 4 Level 5	Recover fibers and/or other products from cured scrap Recover fibers and/or other products from EOL parts (Typically, pyrolysis or depolymerization)	CHZ Technologies (6.4, 6.29) ELG Carbon Fiber (6.7) Carbon Conversions (6.5)

IACMI portfolio contains projects at all recycling levels

Seven Years of IACMI Recycling Innovation



April 27, 2021

Braskem Launches Carbon Fiber Reinforced Polypropylene Filament for Additive Manufacturing

Reducing Embodied Energy via Recycling

	Baseline	Recycled fiber	
Carbon fiber @10%	115 MJ/kg	5 MJ/kg	← 96% reduction
PA 6/6 @90%	52 MJ/kg	52 MJ/kg	
Compounding	8 MJ/kg	8 MJ/kg	
Injection Molding	11 MJ.kg	11 MJ/kg	
Total energy	186 MJ/kg	76 MJ/kg	← 60% reduction

Published 4/11/2023

IACMI receives funding renewal from U.S. DOE to continue composites R&D

Over the next five years, IACMI aims to further composites R&D efforts to support U.S. decarbonization and its pillars: technology, economy and workforce development.

The U.S. Department of Energy (DOE)'s Office of Energy Efficiency and Renewable Energy publicly announced its decision to renew funding for its **Institute for Advanced Composites Manufacturing Innovation (IACMI).** IACMI becomes the first Clean Energy Manufacturing Innovation Institute to be renewed by DOE.

IACMI will receive federal funding across five fiscal years, with a first-year investment of $6 million to further technological R&D and accelerate commercialization in the domestic composites manufacturing sector. This federal funding builds upon initial institute funding of $70 million from DOE and $130 million from IACMI's member partners.

iacmi THE COMPOSITES INSTITUTE

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES OFFICE

Advanced Materials & Manufacturing Technologies Office

DOE Furthers Commitment to Advancing Composites Manufacturing Through Innovation Institute Renewal

APRIL 11, 2023

"Today, I am thrilled to announce DOE is extending our partnership with IACMI with a continued investment over another five years."

- **U.S. Department of Energy Secretary Jennifer Granholm**

DOE and IACMI cut a ribbon on a new IACMI Collaboration Facility in Knoxville, TN

Summary

- **The market for thermosets is strong and offers continued growth opportunities**
  - Driven by clean energy and need to reduce carbon footprint
  - Low mass = lower energy usage
  - Thermosets meet the most demanding applications for polymer materials
  - Durability a major asset in resilient and sustainable infrastructure
- **Industry must continue to address key challenges to remain the preferred material**
  - Focus on cost reduction via cycle time and scrap reduction, improved design
  - Implement thermoset recycling strategies to reduce landfill at all stages of life
  - Demonstrate sustainability by incorporating recycled materials, reversible resins, and bio-based materials

Thank you!

Contact info:

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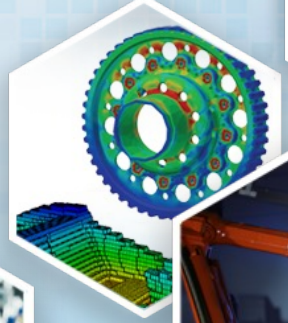
Website: www.iacmi.org



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