Low Cost Carbon Fiber Overview

9 May 2011

C. David (Dave) Warren
Field Technical Manager
Transportation Materials Research

Oak Ridge National Laboratory
P.O. Box 2009, M/S 8050
Oak Ridge, Tennessee 37831-8050
Phone: 865-574-9693
Fax: 865-574-0740
Email: WarrenCD@ORNL.GOV

This presentation does not contain any proprietary, confidential or otherwise restricted information.

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Vehicle Technologies Budget

Task	FY 2010 Budget	Industry Cost Share	FY 2011 Budget	Industry Cost Share
Precursors	$1,725,000	$688,000	$1,850,000	$1,136,000
Commercialization of Textile Precursors				
Precursor & Fiber Evaluation				
Polyolefin Precursors				
Lignin Based Precursors				
PAN-MA Precursors *				
Conversion	$1,815,000	$61,500	$2,929,000	$115,000
Advanced Oxidation				
Conventional Interfacial Adhesion				
Pilot Line Upgrade				

* - $150K of which from H_2 Storage

Barriers

- Carbon Fiber Cost is Too High for Automotive Applications
- Carbon Fiber Supply to Too Limited for the Automotive Industry
- Property Translation is Immature for CF in Automotive Resins

Other Coordinated Activities

Other Related Projects	Funding Agency	Total Budget	Industry Partner	Industry Cost Share
Precursors				
Polyolefin Constituent Precursors	DOE/IT	$2,000,000	CRADA	$6,000,000
Graphite electrodes for Arc Furnaces	DOE/IT		CRADA	
Nanoporous CF for Supercapacitors - Lignin	DOE/IT	$2,300,000	CRADA	$380,000
Composite Filters for HVAC Systems - Lignin	DOE/IT		CRADA	
Filters for HVAC – CO2 & VOC Capture - Lignin	DOE/EERE T2	$450,000	CRADA	$450,000
Advanced Structural Fibers	DARPA	$8,000,000	NO	$0
Melt Spinnable PAN for H2 Storage	DOE/FCT	$1,300,000	NO	$0
Conversion				
Carbon Fiber Technology Center	ARRA	$34,700,000	NO*	N/A
Microwave Assisted Plasma Carbonization	DOE/IT	$3,000,000	CRADA	**
Carbon Fiber Test Standards	IEA	TBD	Agreement	TBD

IT – DOE Industrial Technologies Program
IEA – International Energy Agency

* - Enables multiple partnerships
** - Cost Share Part of Polyolefin Project
Agreement – 26 Country collaborative agreement

Partnerships

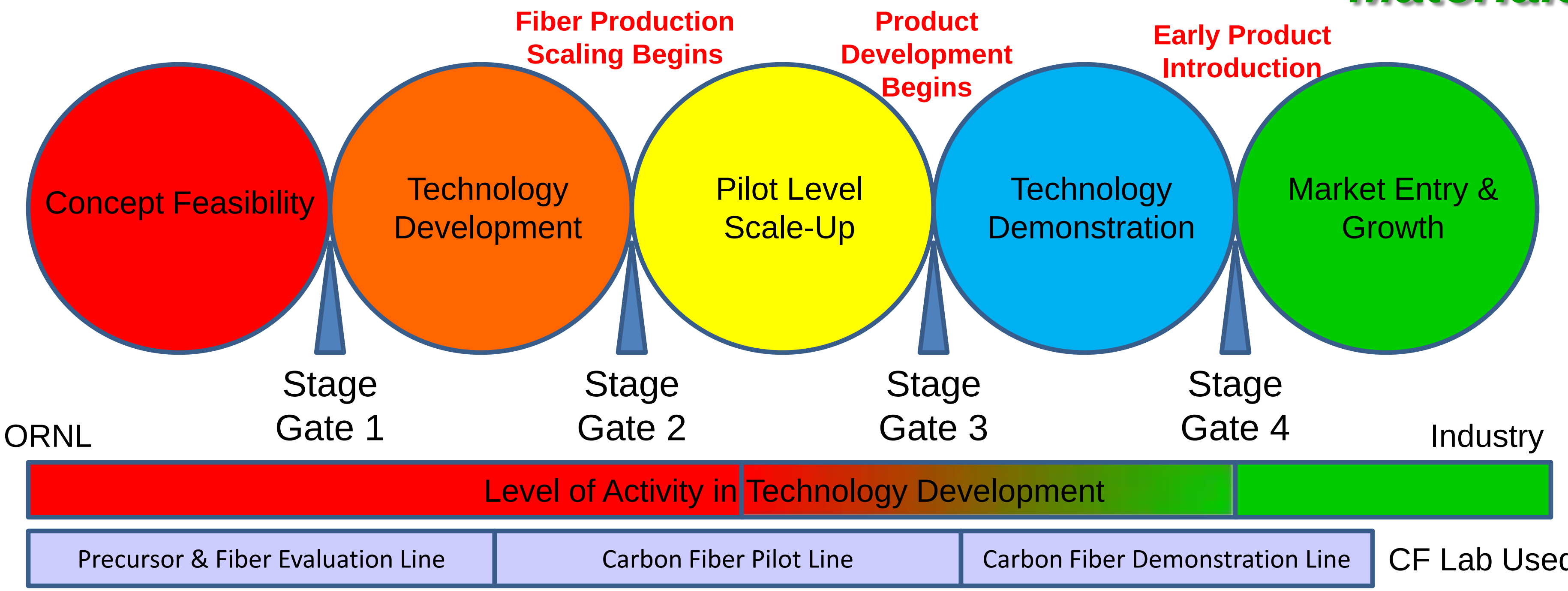
Task	Task Lead	Partners
Precursors		
Commercialization of Textile Precursors	Dave Warren	FISIPE, S.A., SGL Carbon Fibers?
Precursor & Fiber Evaluation	Robert Norris	IZUMI International
Polyolefin Precursors	Amit Naskar	Proprietary
Lignin Based Precursors	Fred Baker	Lignol Innovations, Kruger-Wayagamack, Innventia, Georgia Tech
PAN-MA Precursors	Felix Paulauskas/ Pol Grappe	FISIPE, S.A.
Conversion		
Advanced Oxidation	Felix Paulauskas	SENTECH
Conventional Interfacial Adhesion	Soydan Ozcan	Magna, FISIPE, Zoltek, Continental Structural Composite, Michelman®, SENTECH, AOC, Plasticom
Pilot Line Upgrade	Robert Norris	N/A

Future Research Efforts

Task	Target Start	Goals
Precursors		
Rayon Replacement – Ablative Materials	FY 2012-2013	Substitute for Rayon
Conversion		
Advanced Surface Treatment & Sizing	FY 2013	Non-Standard Surface Treatment
Development of Feedback Process Control	FY 2013	Improved Economics via Monitoring and Correcting Conversion Parameters
Plasma Modification of Surface Topography	FY 2014	Mechanical Interlocking of Fiber to Resin
Model for the Conversion of Carbon Fiber	FY 2011-2012	Understand and thus improve Oxidation Kinetics
Non-Conversion Processing		
Tow Splitting	FY 2012	Cost Savings – Process Large Tows, Use as Small Tows
Development of Alternative Product Forms	FY 2013	Product Forms Amenable to High Volume Industries – Not Spooling
Applications for Recovered Carbon Fiber	FY 2013-2014	Carbon Fiber Recycling that makes sense

Process for Carbon Fiber Technology Commercialization

LM002
Materials



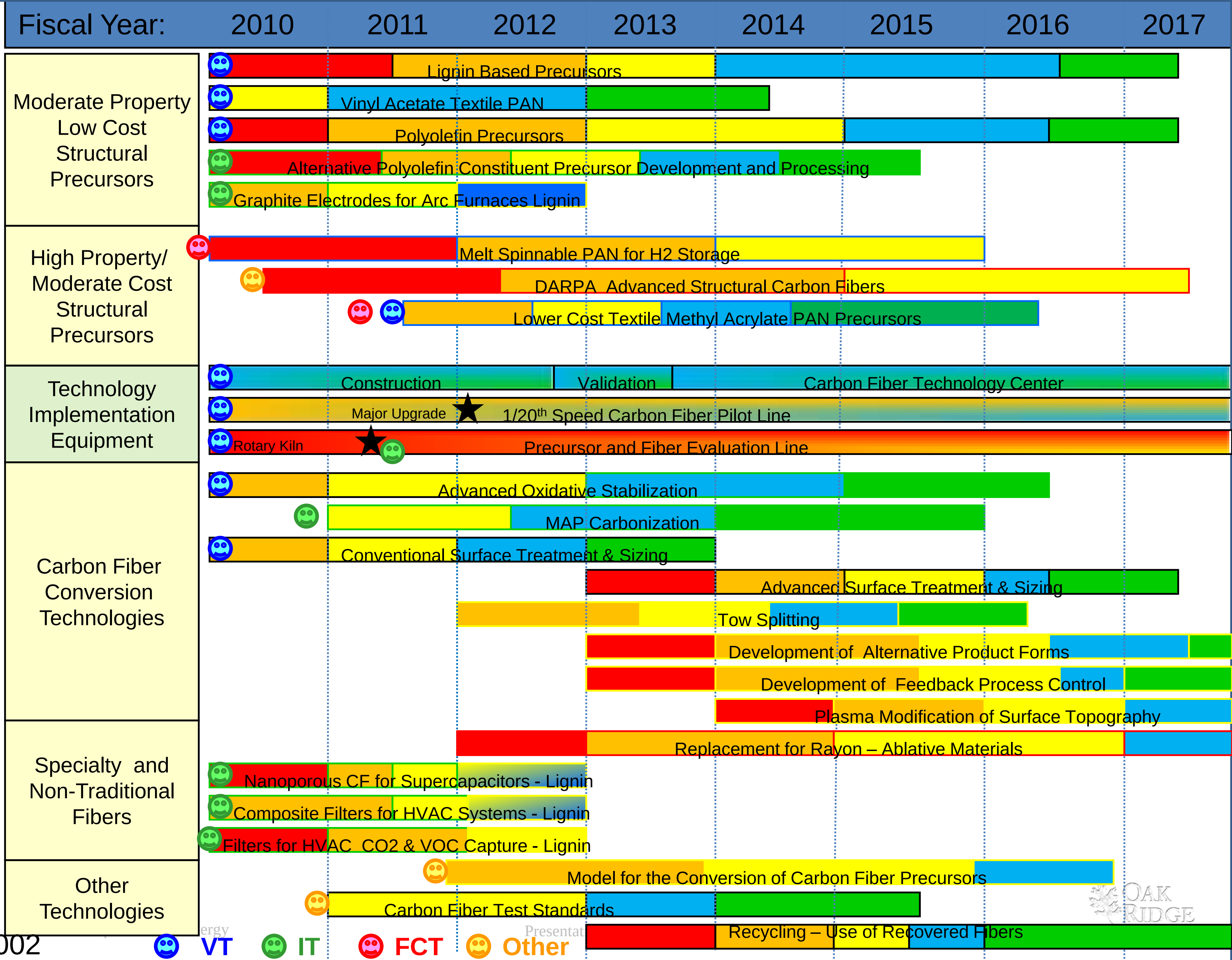
- Demonstrate technical feasibility
- Demonstrate likely cost effectiveness
- Bench scale
- Small material volume
- Batch processes
- Concludes with design of issue resolution plan

- Demonstrate technology works
- Demonstrate cost effectiveness if scaled
- Bench scale
- Small material volume
- Batch processes transitioning to continuous
- Concludes with design of prototype unit or materials

- Resolve continuous operation issues
- Develop continuous operation capability for short time periods
- Moderate material volume increasing as issues are resolved
- Concludes with design of continuous unit or final material selection

- Work to resolve scale –up equipment issues
- Develop multi-tow continuous operation capability for long periods of time
- Material volumes for product design and development
- Concludes with industrial adoption

- Industry adoption
- Product development
- Customer base development


Fiscal Year: 2010 2011 2012 2013 2014 2015 2016 2017
Moderate Property Low Cost Structural Precursors
Lignin Based Precursors
Vinyl Acetate Textile PAN
Polyolefin Precursors
Alternative Polyolefin Constituent Precursor Development and Processing
Graphite Electrodes for Arc Furnaces Lignin
High Property/ Moderate Cost Structural Precursors
Melt Spinnable PAN for H2 Storage
DARPA Advanced Structural Carbon Fibers
Lower Cost Textile Methyl Acrylate PAN Precursors
Technology Implementation Equipment
Construction
Validation
Carbon Fiber Technology Center
Major Upgrade
1/20th Speed Carbon Fiber Pilot Line
Rotary Kiln
Precursor and Fiber Evaluation Line
Carbon Fiber Conversion Technologies
Advanced Oxidative Stabilization
MAP Carbonization
Conventional Surface Treatment & Sizing
Advanced Surface Treatment & Sizing
Tow Splitting
Development of Alternative Product Forms
Development of Feedback Process Control
Plasma Modification of Surface Topography
Replacement for Rayon – Ablative Materials
Specialty and Non-Traditional Fibers
Nanoporous CF for Supercapacitors - Lignin
Composite Filters for HVAC Systems - Lignin
Filters for HVAC CO2 & VOC Capture - Lignin
Other Technologies
Model for the Conversion of Carbon Fiber Precursors
Carbon Fiber Test Standards
Recycling – Use of Recovered Fibers
VT IT FCT Other
OAK RIDGE

LM002

Process for Carbon Fiber Technology Commercialization

LM002

Materials

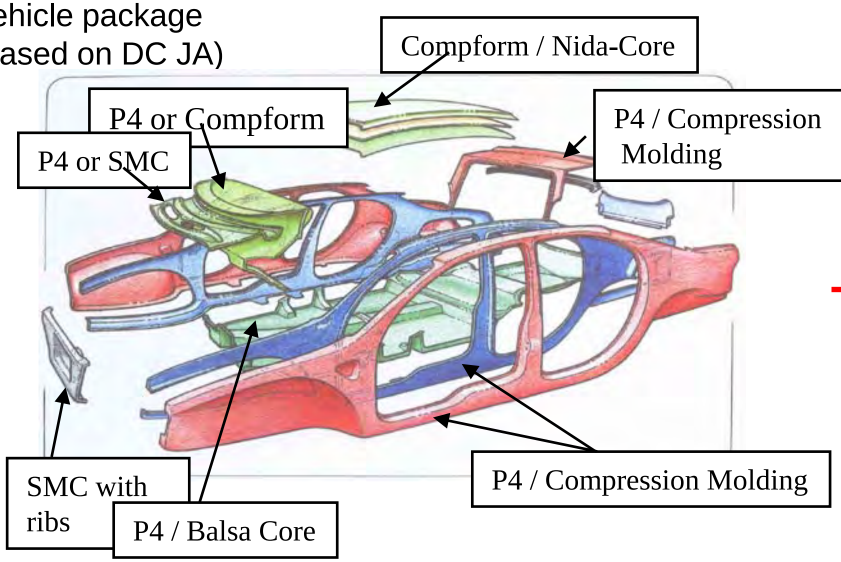
Technology Task	Transition from Concept Proof to Technology Development	Transition from Technology Development to Pilot Scale-up	Transition from Pilot Level Scale-up to Technology Demonstration	Transition from Technology Demonstration to Commercialization
Lignin Based Precursors	Demonstrate 150KSI/15MSI (9/2010)	Demonstrate 250KSI/25MSI (9/2012)	Demonstrate Continuous Processing (9/2013)	Demonstrate Reliable Continous Conversion (3/2016)
Textile PAN	Demonstrate 150KSI/15MSI (8/2007)	Demonstrate 250KSI/25MSI (8/2008)	Demonstrate Continuous Processing (9/2010)	Demonstrate Reliable Continous Conversion (9/2012)
Polyolefin Precursors	Demonstrate 150KSI/15MSI (9/2010)	Demonstrate 250KSI/25MSI (9/2012)	Demonstrate Continuous Processing (9/2014)	Demonstrate Reliable Continous Conversion (3/2016)
Melt Spun PAN of Gaseous Storage	Demonstrate Convertible Precursors (9/2011)			
Lower Cost PAN-MA for Gaseous Storage	Demonstrate 300KSI/25MSI (6/2012)	Demonstrate 650KSI/35MSI (9/2013)	Demonstrate Continous Processing (9/2014)	Demonstrate Reliable Continous Conversion (3/2016)
Advanced Oxidation	Demonstrate Sufficient Oxidation and Stabilization (9/2009)	Demonstrate Conversion meeting 250KSI/25MSI (9/2010)	Demonstrate Continuous Operation - Build Pilot Unit (9/2012)	Demonstrate RealiabilitY - Build Pre-Production Unit (9/2014)
MAP Carbonization	Demonstrate Sufficient Carbonization (3/2005)	Demonstrat Conversion meeting 250KSI/25MSI (9/2007)	Demonstrate Continous Operation - Build Pilot Unit (9/2012)	Demonstrate Realiability - Build Pre-Production Unit (9/2014)
Surface Treatment	Not Applicable	Demonstrate 11KSI SBSS (9/2010)	Demonstrate 14 KSI SBSS (9/2011)	Incorporate in Demonstration Projects with Industry (3/2013)
Carbon Fiber Test Standards	Not Applicable	Not Applicable	Develop Test Methods and Preliminary Standards (9/2013)	Validate Standards (3/2014)
Recycling of Carbon Fiber	Prove quality fibers can be recovered (9/2013)	Prove recycling process is scalable (9/2014)	Develop pilot level recycling unit(s) (3/2015)	Design and develop a Pre-production scale recycling unit (9/2015)

Why?

Materials

A 10% mass reduction translates to a 6-7% increase in fuel economy or may be used to offset the increased weight and cost per unit of power of alternative powertrains

Vehicle package
(based on DC JA)



Program Minimum:
Strength: ≥ 250 Ksi
Modulus: ≥ 25 Msi
Strain: ≥ 1%

Phase 1 Results:
67% mass savings over baseline
Bending stiffness exceeded 20%
Torsional stiffness exceeded 140%
Durability and abuse load cases satisfied
Manufacturing strategy developed

Vehicle Materials GOALS

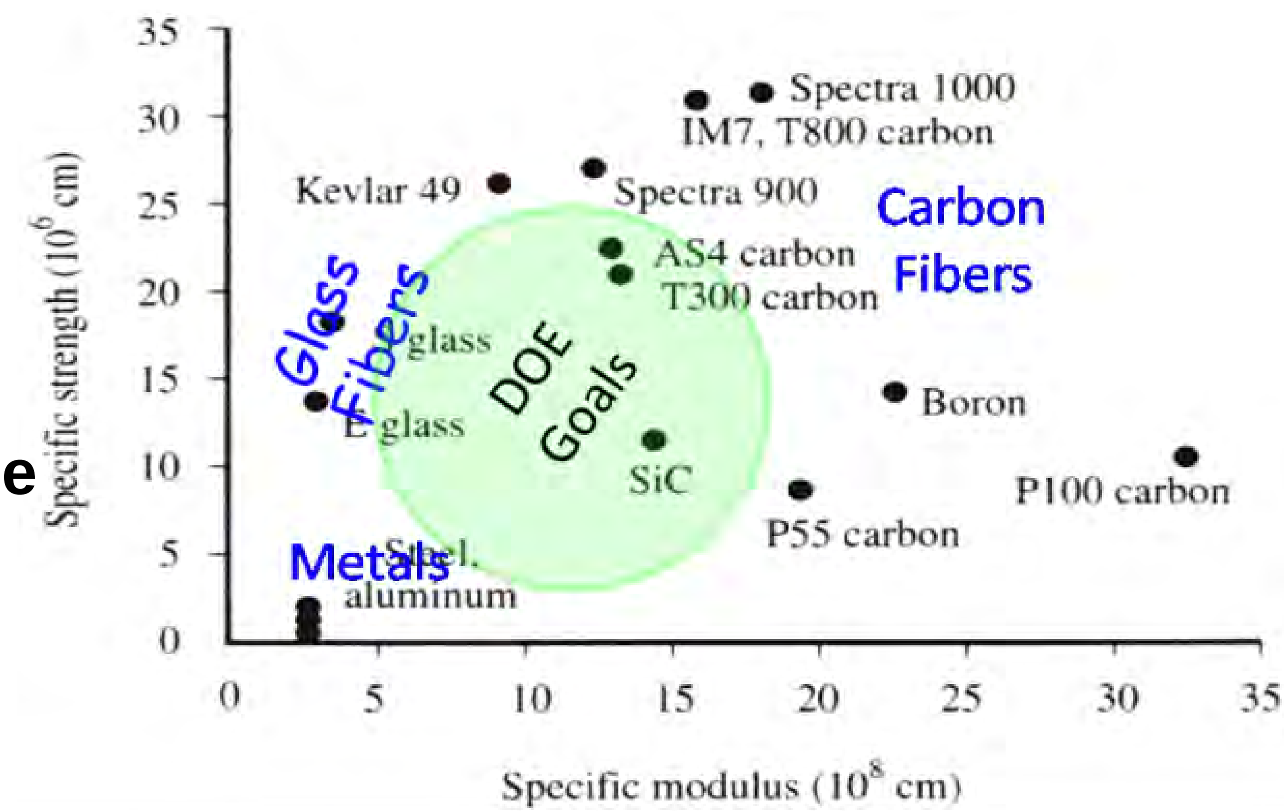
$5 - $7 Per Pound
(FY2009 Dollars)

Cost Performance Categories

High Performance	>750 KSI (>35 MSI)	Cost is not Limiting, Performance Driven
Moderate Grade	500 – 750 KSI (30-35 MSI)	Cost and Performance Balance
High Volume Grade	250 – 500 KSI (< 30 MSI)	Cost Sensitive, Performance Enabling
Non Structural	Chemical & Physical Prop.	Usually Low Cost and Unique Needs

Most High Volume Industries would require the last 2 Categories

4 Broad Cost/Performance Categories for Carbon Fiber



Graph provided courtesy of Jose Zayas, Wind Energy Program Manager, SNL

Potential Markets and Needs

Materials

250-500 KSI, 25 MSI Fiber | 500 - 750 KSI, 35 - 40 MSI Fiber

Industry	Benefit	Applications	Drivers	Obstacles	Current Market	Potential Market
Automotive	Mass Reduction: 10% Mass Savings translates to 6-7% Fuel Reduction	Throughout Body and Chassis	Tensile Modulus; Tensile Strength	Cost: Need $5-7/lb; Fiber Format; Compatibility with automotive resins, Processing Technologies	< 1M lbs/yr	> 1B lbs/year
Wind Energy	Enables Longer Blade Designs and More Efficient Blade Designs	Blades and Turbine Components that must be mounted on top of the towers	Tensile Modulus; Tensile Strength to reduce blade deflection	Cost and Fiber Availability; Compression Strength; Fiber Format & Manufacturing Methods	1-10 M lbs/yr	100M - 1B lbs/yr
Oil & Gas	Deep Water Production Enabler	Pipes, Drill Shafts, Off-Shore Structures	Low Mass, High Strength, High Stiffness, Corrosion Resistant	Cost and Fiber Availability; Manufacturing Methods	< 1M lbs/yr	10 - 100M lbs/yr
Electrical Storage and Transmission	Reliability & Energy Storage	Low Mass, Zero CTE transmission cables; Flywheels for Energy Storage	Zero Coeficient of Thermal Expansion; Low Mass; High Strength	Cost; Cable Designs; High Volume Manufacturing Processes; Resin Compatibility	< 1M lbs/yr	10-100M lbs/yr
Pressure Vessels	Affordable Storage Vessels	Hydrogen Storage, Natural Gas Storage	High Strength; Light Weight	Cost; Consistent Mechanical Properties	< 1M lbs/yr	1-10B lbs/yr

Potential Markets and Needs (Continued)

Materials

250 - 500 KSI, 25 MSI Fiber

500 - 750 KSI, 35 - 40 MSI Fiber

Industry	Benefit	Applications	Drivers	Obstacles	Current Market	Potential Market
Infrastructure	Bridge Design, Bridge Retrofit, Seismic Retrofit, Rapid Build, Hardening against Terrorist Threats	Retrofit and Repair of Aging Bridges and Columns; Pretensioning Cables; Pre-Manufactured Sections; Non-Corrosive Rebar	Tensile Strength & Stiffness; Non-Corrosive; Lightweight; Can be "Pre-Manufactured"	Cost; Fiber Availability; Design Methods; Design Standards; Product Form; Non-Epoxy Resin Compatibility	1-10M lbs/yr	1-100B lbs/yr
Non-Aerospace Defense	Lightweight Ground and Sea Systems; Improved Mobility and Deployability	Ship Structures; Support Equipment; Tanks; Helicopters	Low Mass; High Strength; High Stiffness	Cost; Fiber Availability; Fire Resistance; Design into Armor	1-10M lbs/yr	10-100M lbs/yr
Electronics	EMI Shielding	Consumer Electronics	Low Mass; Electical Conductivity	Cost; Availability	1-10M lbs/yr	10-100M lbs/yr
Aerospace	Secondary Structures	Fairings; seat structures; luggage racks; galley equipment	High Modulus; Low Mass	Cost of lower performance grades; Non-Epoxy Resin Compatibility	1-10M lbs/yr	10-100M lbs/yr
Non-Traditional Energy Applications	Enabler for Geothermal and Ocean Thermal Energy Conversion	Structural Design Members; Thermal Management, Energy Storage	Tensile Strength & Stiffness; Non-Corrosive; Lightweight	Design Concepts; Manufacturing Methods; Fiber Cost; Fiber Availability	1-10M lbs/yr	10M-1B lbs/yr
Electrical Energy Storage	Key Storage Media	Li-Ion Batteries; Super-capacitors	Electrical and Chemical Properties	Design Concepts; Fiber Cost and Availability	1-5M lbs/yr	10-50M lbs/yr
Total					**11-70M lbs/yr**	**3-114B lbs/yr**

Low Cost Carbon Fiber: Common Issues and Needs

Materials

Civil Infrastructure
Rapid Repair and Installation, Time and Cost Savings

Bio-Mass Materials
Alternative Revenue
Waste Minimization

FUELING OUR FUTURE
BIOMASS 2008

Non-Traditional Energy
Geothermal, Solar & Ocean Energy

Courtesy Umeco

Non-Aerospace Defense
Light Weight, Higher Mobility

Aerospace
Secondary Structures

Courtesy Fairings-Etc.

Common Issues:
Fiber Cost
Fiber Availability
Design Methods
Manufacturing Methods
Product Forms

Energy Storage
Flywheels,
Li-Ion Batteries,
Supercapacitors

Courtesy Beacon Power

Electronics
Light Weight,
EMI Shielding

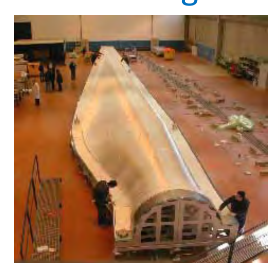
Pressurized Gas Storage
Only Material With Sufficient Strength/Weight

Power Transmission
Less Bulky Structures
Zero CLTE

Oil and Gas
Offshore Structual Components

Vehicle Technologies
Necessary for 50+% Mass Reduction

Wind Energy
Needed for Longer Blade Designs



Courtesy Umeco

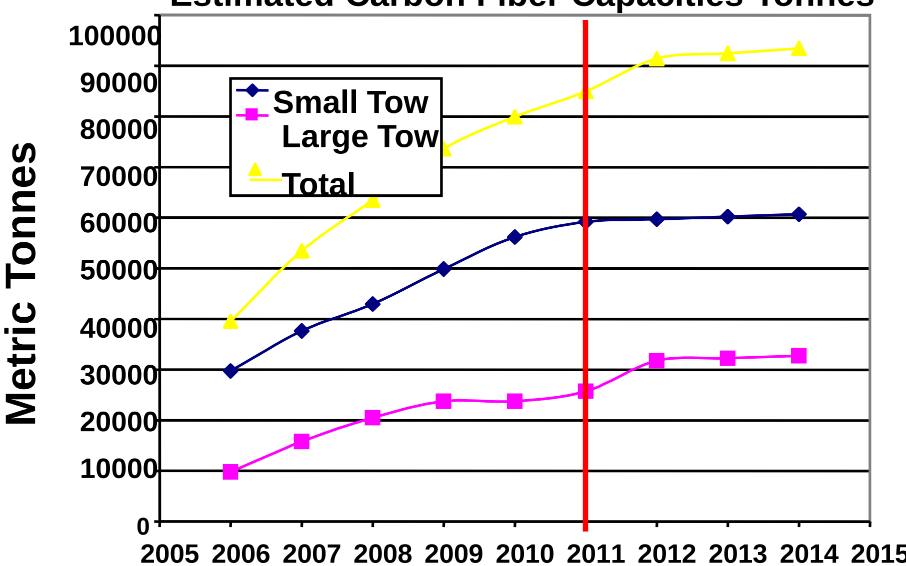
Domestic Carbon Fiber Production & Comparison

Materials

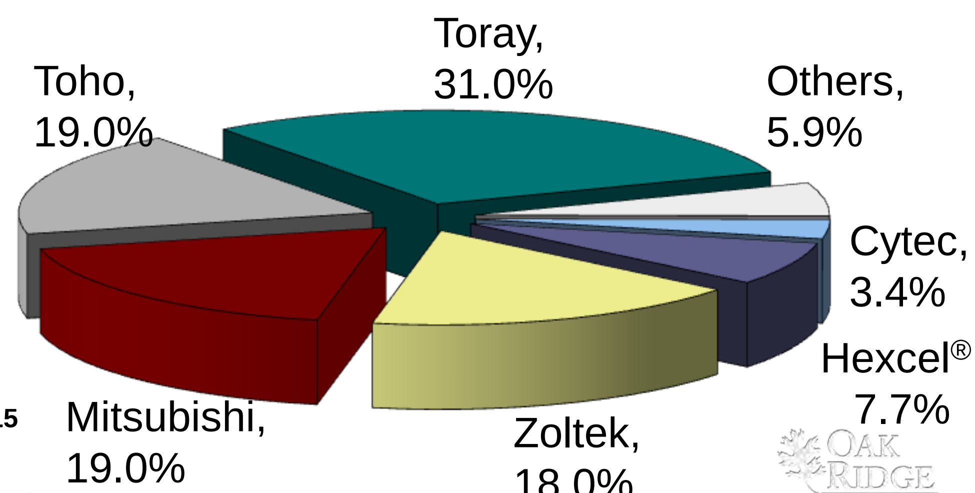
Recently Announced: SGL & BMW
Joint Venture in Washington State

North American Carbon Fiber Manufacturers

Estimated Carbon Fiber Capacities Tonnes



Global Market Share by Company



Source: McConnell, V. "*The Making of Carbon Fiber*", CompositesWorld, 19 December 2008.

Global Carbon Fiber Production

Global Carbon Fiber Production

Estimated Capacity 2010 by manufacturer and type of fiber

Not included is a 40,000,000 lb/year Chinese plant to come on-line after 2010 and a major Russian Plant being built.

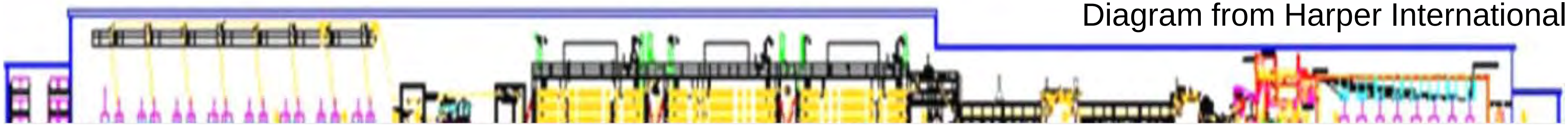
*Small Tow is ≤ 24,000 filaments. Large Tow is > 24,000 filaments.

Company	Headquarters	Manufacturing Sites	Small Tow* Production, lbs/year	Large Tow* Production, lbs/year	Total Production, lbs/year
AKSA	Turkey	Turkey	4,000,000		4,000,000
Cytec	US – SC	US-SC	5,000,000		5,000,000
Dalian Xingke	China	China	1,320,000		1,320,000
Grafil - Mitsubishi	US – CA	US - CA	4,400,000		4,400,000
Hexcel®	US – UT	US - UT, AL	16,000,000		16,000,000
Kemrock®	India	INDIA	1,430,000		1,430,000
Mitsubishi - Rayon	Japan	Japan, US-CA	13,530,000	6,000,000	19,530,000
SGL	Germany	Germany, UK, US-WY		14,300,000	14,300,000
SGL Automotive CF	US – WA	US-WA		3,307,000	3,307,000
Toho	Japan	Japan, US-TN	29,620,000		29,620,000
Toray	Japan	Japan, US-AL	39,440,000	660,000	40,100,000
Yingyou	China	China	484,000		484,000
Zoltek	US-Mo	US -UT, TX, MO, Mexico		19,300,000	19,300,000
Total			**115,224,000**	**43,567,000**	**158,791,000**

Source: McConnell, V. "*The Making of Carbon Fiber*", CompositesWorld, 19 December 2008. & BMW Press Release July 2010.

Carbon Fiber Costs (Baseline)

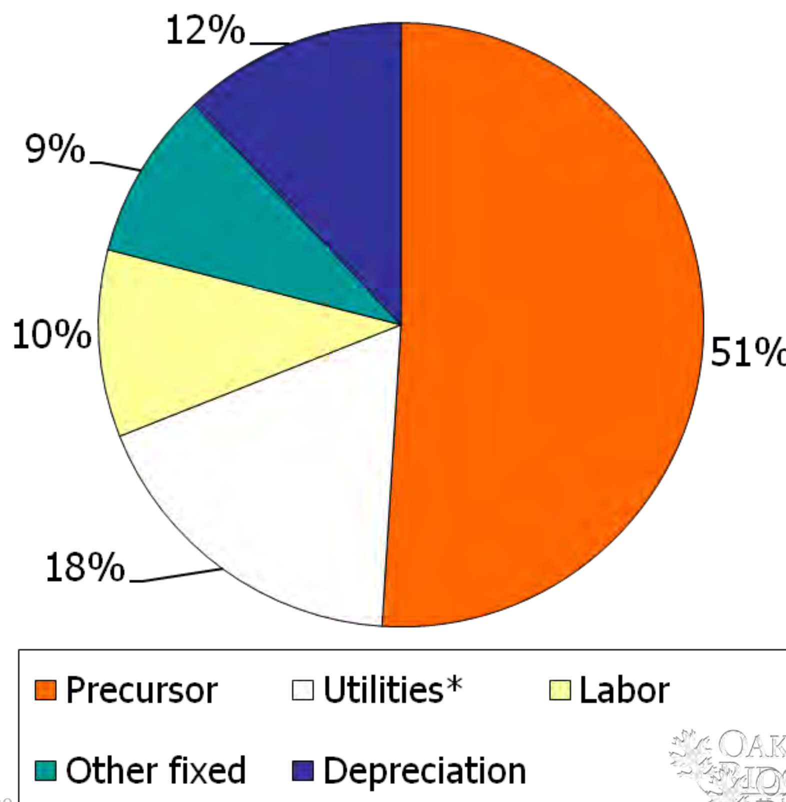
Diagram from Harper International



Precursors	Stabilization & Oxidation	Carbonization/ Graphitization	Surface Treatment	Spooling & Packaging
$5.04 (51%) Includes Pretreatment and Handling	$1.54 (16%)	$2.32 (23%)	$0.37 (4%)	$0.61 (6%)

Baseline - $9.88

With conventional processing using a carbon fiber-grade (CF) PAN, precursor is over **50%** of the carbon fiber cost

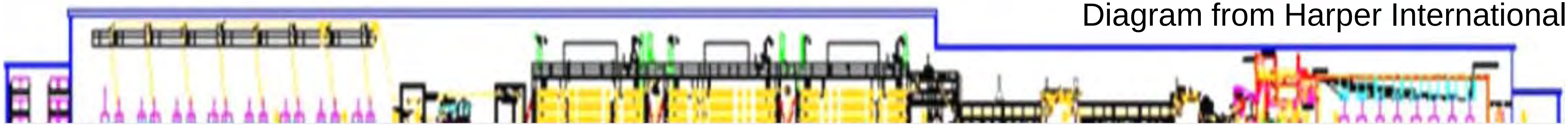


4 Elements of Cost Reduction
1. Scale of Operations
2. Precursors
3. Conversion
4. Manufacturing of Composite

* Data From Kline & Company

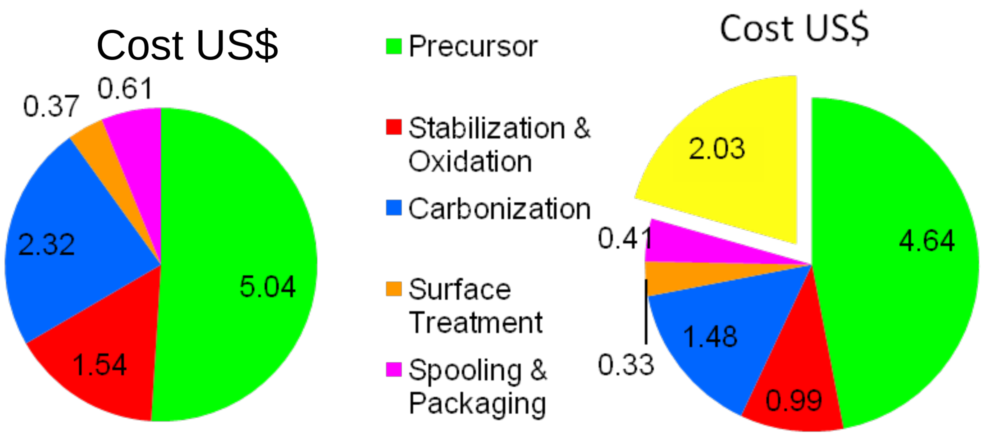
Carbon Fiber Costs (1. Scale of Operations)

Diagram from Harper International



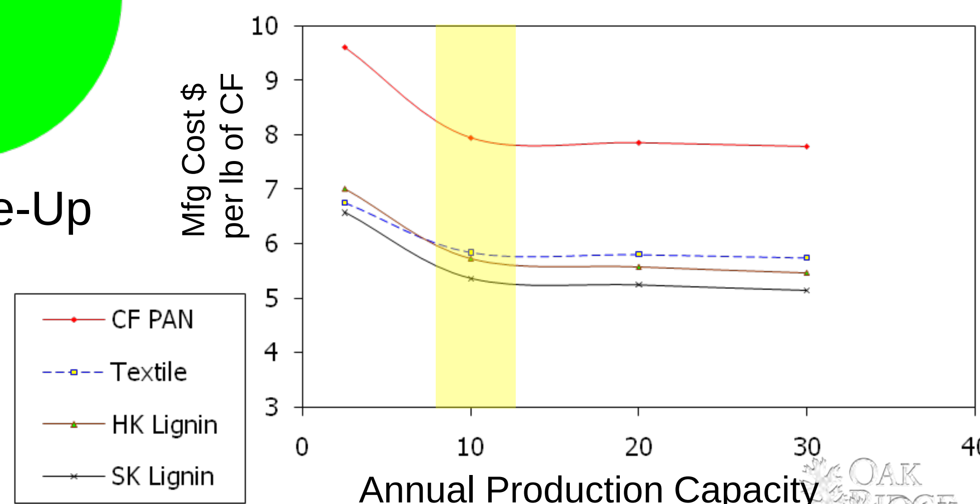
Precursors	Stabilization & Oxidation	Carbonization/ Graphitization	Surface Treatment	Spooling & Packaging

	Precursors	Stabilization & Oxidation	Carbonization/ Graphitization	Surface Treatment	Spooling & Packaging
Baseline Today - $9.88	$5.04	$1.54	$2.32	$0.37	$0.61
High Volume - $7.85	$4.64	$0.99	$1.48	$0.33	$0.41



Baseline   Scale-Up

Significant Cost Reduction can be achieved by increased Scale-up of Plant and Line Size



* Baseline Data From Kline & Company

But

Not All the Needed Cost Reduction

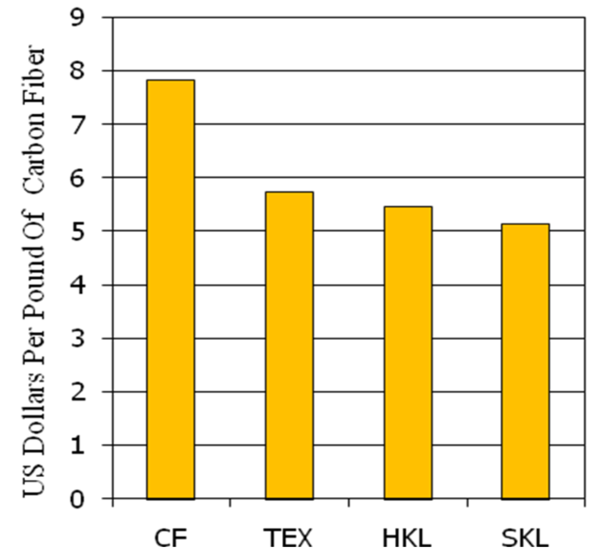
Carbon Fiber Costs (2. Precursors)

More Affordable Precursors are Needed

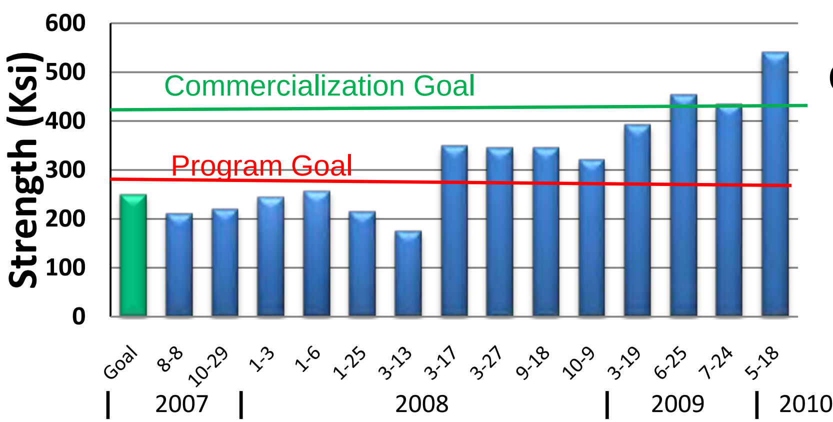
3 Current Precursor Options

1. Textile Grade PAN (MA or VA formulations)
2. Lignin Based Precursor (Hardwood or Softwood)
3. Polyolefins (not shown on chart)

Alternative Precursors and Conventional Processing



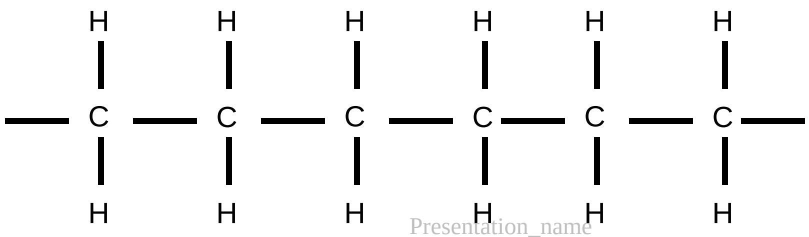
Carbonized Textile Precursor

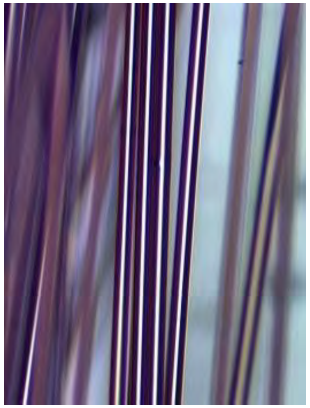


Current Carbonized Textile Properties:
Strength: 540 KSI
Modulus: 38 MSI

POLYOLEFINS

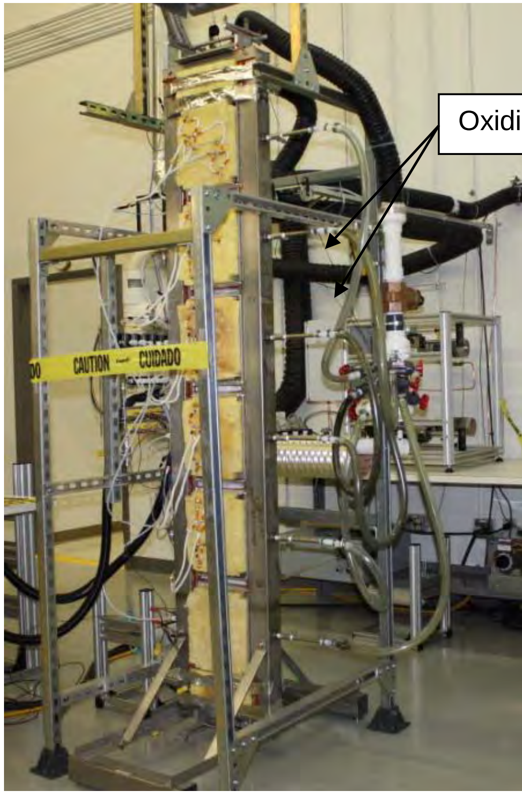
86% C Content; 65-75% Yield
$0.50-$0.75/lb; Melt Spun





Processed Precursor Fibers from a Hardwood/Softwood Lignin Blend.

Current Research (3. Conversion)



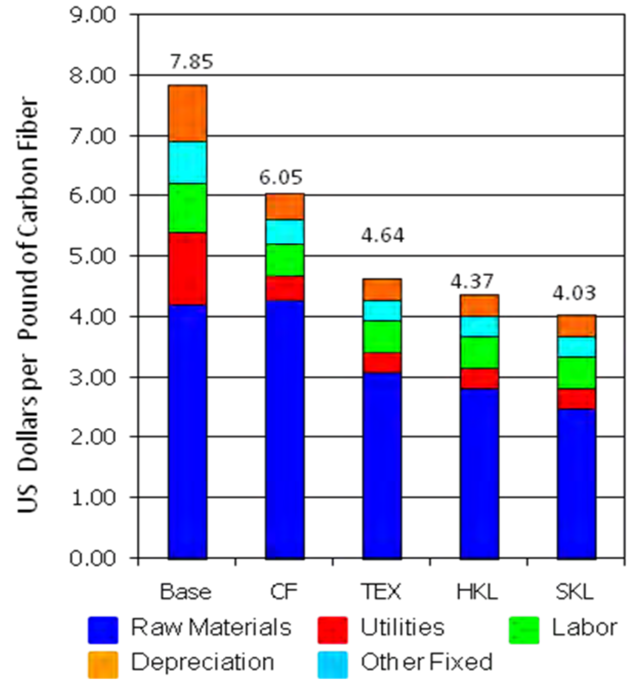
Advanced Oxidation Module

Alternative Processing Methods Under Development

1. Oxidative Stabilization
2. MAP Carbonization
3. Surface Treatment

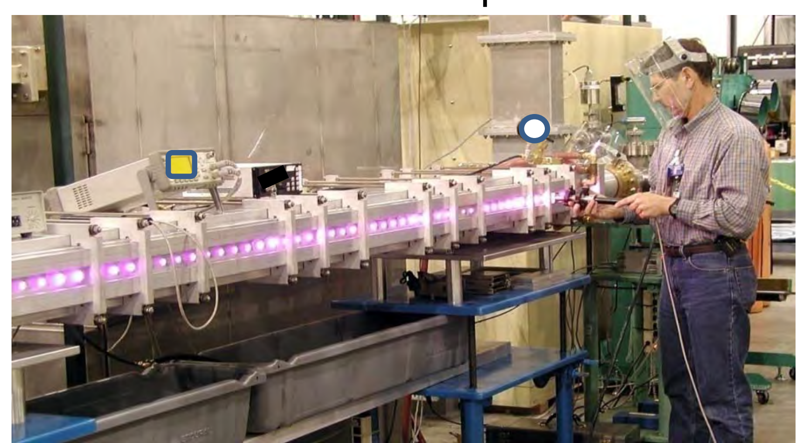
(Not on graph)

Alternative Processing



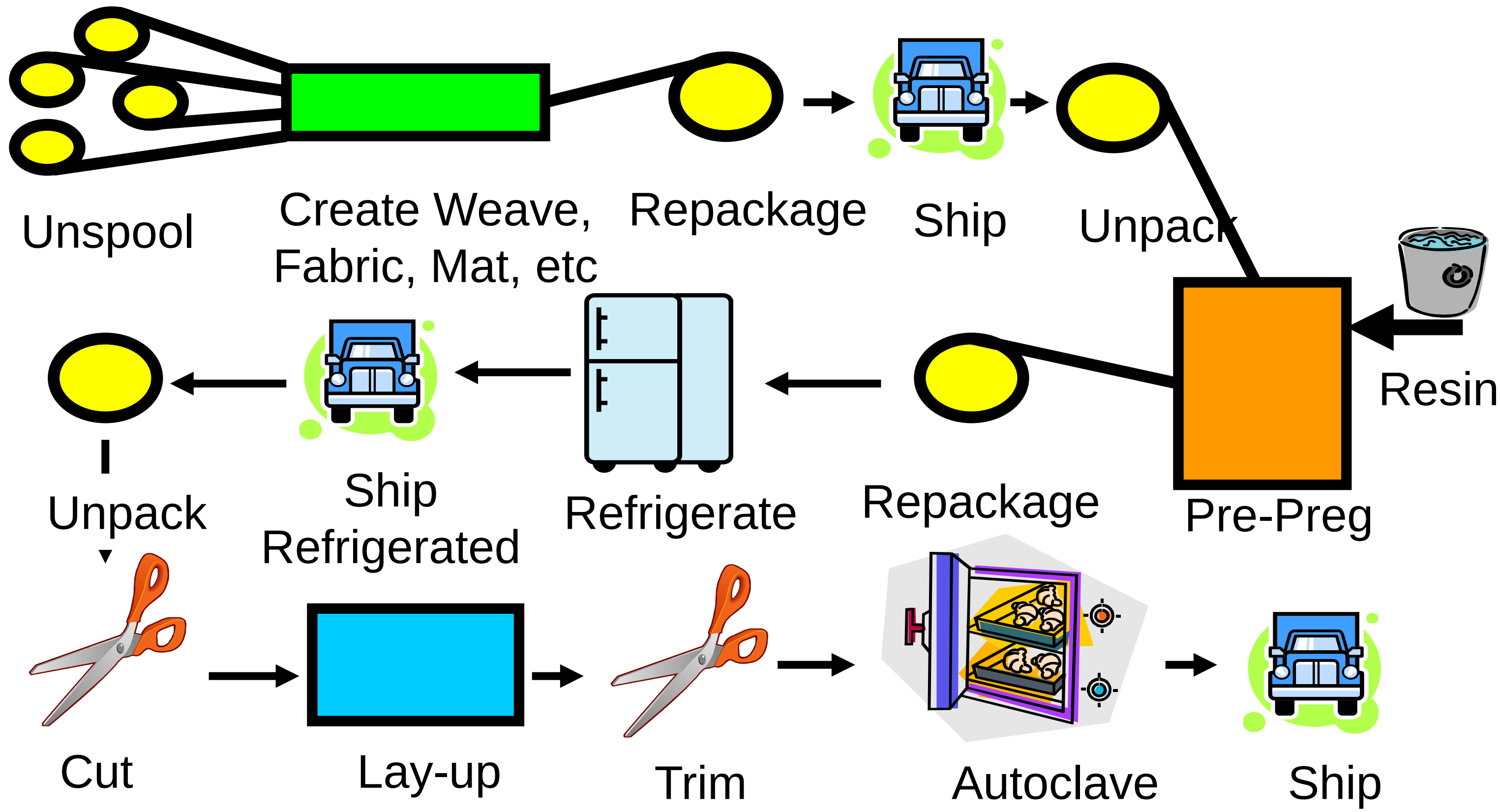
Advanced Surface Treatment

MAP Carbonization/Graphitization Unit



Cost Reduction (4. Processing)

Composite Down Stream Processing



System designed for Epoxy based, Aerospace parts

Japanese and German automakers and carbon fiber companies are vertically integrating this process.

20 Managed by UT-Battelle for the U.S. Department of Energy

Carbon Fiber Portfolio (Current)

Production Costs for Current Technology in High Volume

Surface Treatment

59%	13%	19%	4	5

Precursors | Stabilization & Oxidation | Carbonization/ Graphitization | Spooling & Packaging

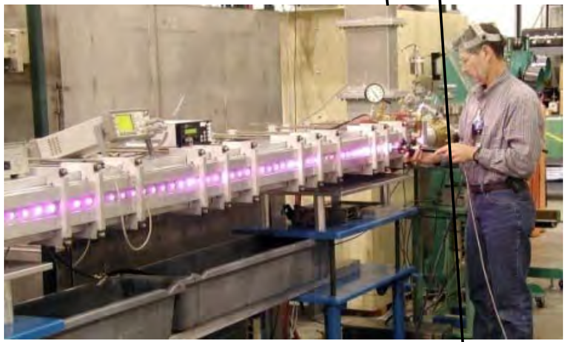
Textile Precursor

Lignin Precursors

Polyolefin Precursors

Advanced Oxidative Stabilization

Microwave Assisted Plasma



Commercialization (All Projects)

Precursor and Fiber Evaluation (All Projects)

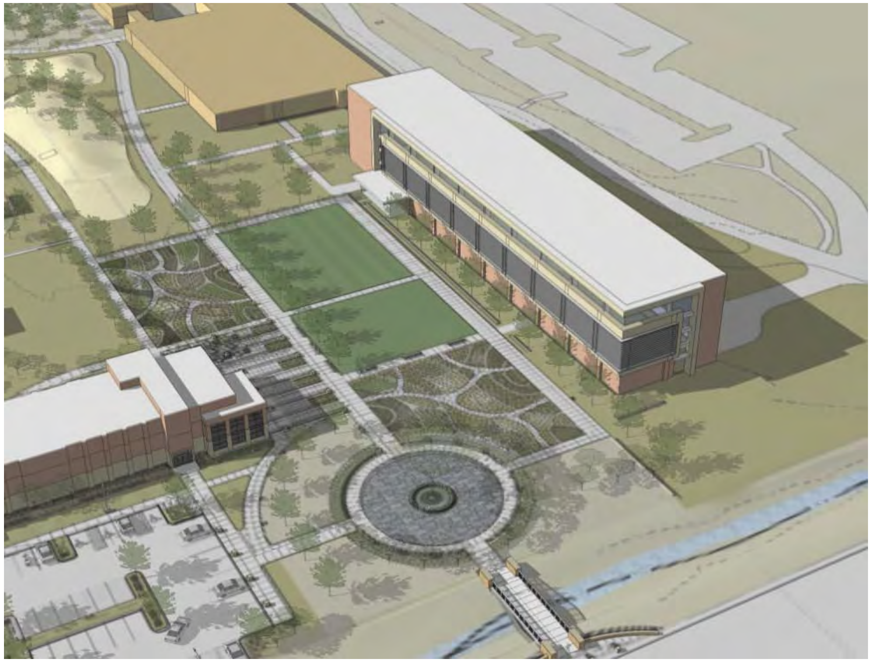
Surface Treatment & Sizing

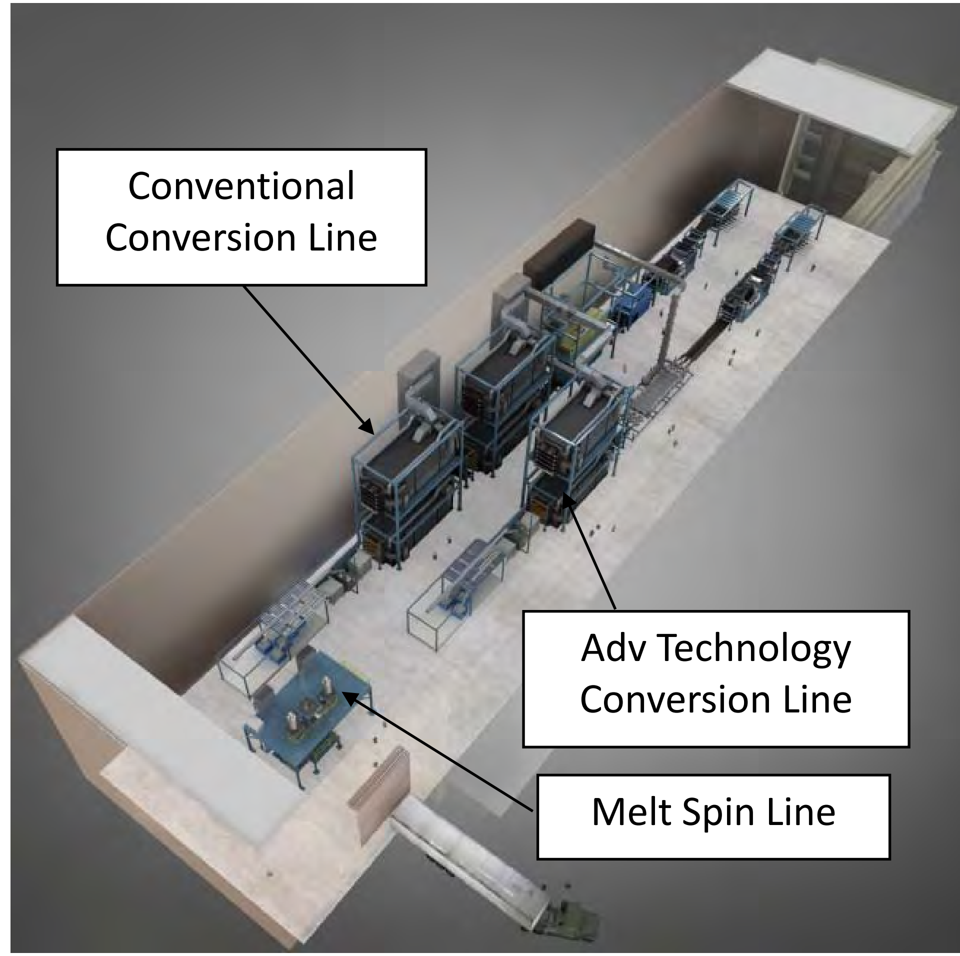
Comparison of Impact – Moderate Performance Fibers

Comparison of Technologies	Energy kBTU/lb	CO_2 Emitted /lb of CF	Plant Cost $/lb CF	Operating Cost $/lb CF	Precursor Cost $/lb CF	Total Mfg Cost $/lb CF	Best Properties Achieved
Conventional Precursors (CC)	389	49.2	8.72	2.71	4.02	7.85	Baseline
Conventional Precursors (AC)	272	34.4	4.28	1.34	4.02	6.05	Baseline
Textile PAN – VA (CC)	389	49.2	5.56	2.06	2.90	5.74	Exceeds 450 KSI
Textile PAN-VA (AC)	272	34.4	3.57	1.20	2.90	4.64	Exceeds 450 KSI
Melt-Spun PAN (CC)			18.04	3.36	1.62	7.91	400-600 KSI
Melt-Spun PAN (AC)	138	19.4			1.62	6.11	Should match Conventional
Polyolefins (CC)	167	22.6			~1.00	< 4.00	200-400 KSI
Polyolefins (AC)	96	13.4			~1.00	< 3.00	Should be Comparable

CC – Conventional Conversion AC – Advanced Conversion

Carbon Fiber Technology Center





Facility and equipment perspective.

- North America's most comprehensive carbon fiber material and process development capabilities
- Development of carbon fiber technology for energy and national security applications
- Low-cost and high-performance fibers
- Fast, energy efficient processing
- Capability to evaluate micrograms and produce up to 25 tonnes/year
- Produce fibers for material and process evaluations by composite manufacturers
- Train and educate workers
- Grow partnerships with US industry

Significant Awards and Presentations

Significant Recognitions:

- Gordon Battelle award for the Carbon Fiber Team
- AMTEC Award from DOT for Roane State Community College
- Baker named fellow of the Royal Society of Chemistry (FRSC)

Conference Keynote and Plenary Presentations:

- Warren: Keynote - 2010 Structural Composites Conference in Birmingham, AL.
- Warren: Keynote – 2010 Global Outlook for Carbon Fiber in Valencia, Spain.
- Warren: Workshop Seminar - 10th Lightweight Materials for Defense, Washington, DC.
- Warren: Keynote – 2011 Carbon Fiber Future Directions in Geelong, Australia
- Naskar: Keynote – Exclusive Case Study: Developing Low Cost Carbon Fiber, Detroit, MI.
- Norris: Invited – Carbon Fibers – Contributing to a More Energy Conscious and Energy Efficient Future, Denver, CO.
- Baker: Keynote - Utilization of Sustainable Resource Materials for Production of Carbon Fiber Materials for Structural and Energy Efficiency Applications, Windsor, Ontario, Canada.
- Baker: Keynote - Utilization of Lignin for Production of Carbon Fiber Materials for Structural and Energy Efficiency Applications, Toronto, Ontario, Canada.

Published Papers

- "Advancement in the Manufacturing of Textile Grade PAN-Precursors for Low-Cost Carbon Fiber: Morphological Evaluations" Presented at and published in the proceedings of the SAMPE 2010, Seattle, WA, 17-20 May, 2010.
- "Review of ORNL's Latest Work on Low-Cost Carbon Fiber Manufacturing Technologies", Presented at and published in the proceedings of 13th Annual Global Outlook for Carbon Fibre, Valencia, Spain, 29-30 September 2010.
- "The Need for a Global Standards System in Production of Carbon Fibres" Presented at and published in the proceedings of the 2010 SAMPE Fall Technical Conference; Salt Lake City, UT, 11-14 October 2010.
- "Surface Treatment of Carbon Fibers by Continuous Gaseous System", Presented at and published in the proceedings of the 2011 SAMPE Conference, Long Beach, CA, 23-26 May 2011.
- "Stress Relaxation Behavior and Mechanical Properties of Functionalized Polymers", ACS National Meeting, Boston, MA.
- "Atypical Hydrogen Uptake on Chemically Activated, Ultramicroporous Carbon," CARBON, **48**, pp. 1331-1340, (2010).
- "On the characterization and spinning of an organic-purified lignin towards the manufacture of low-cost carbon fiber," J. Appl. Polymer Sci.; Accepted for publication, 2010.

Chairing Paper Sessions at Conferences:

- Warren: Chaired 2010 Carbon Fibre Conference *Applications* Section, Valencia, Spain
- Eberle: Chaired a session at the SAMPE 2010 Composites Conference.
- Baker: Chaired Oral Session on *Fibers and Composites* at CARBON 2010.

Significant Awards and Presentations

ID / Patent #	Inventor	Last 18 months Title
7,727,932	Baker	Activated Carbon Fibers and Engineered Forms from Renewable Resources
2462	Naskar et. al.	Precursor Compositions and Stabilization Methods for Polyolefin-Based Carbon Fiber Manufacturing
2187	Baker et al.	Genetically-Modified Lignin-Derived Bio-Thermoplastics for Polymer Matrix Composites
2051	Baker et al.	Carbon Nanotube (CNT)-Enhanced Precursor for Carbon Fiber Production and Method for Making a CNT-Enhanced Continuous Lignin Fiber
7,649,078	Paulauskas & Sherman	Apparatus and method for stabilization or oxidation of polymeric materials
7,786,253 B2	Paulauskas et. al.	Apparatus and method for oxidation and stabilization of polymeric materials
7,824,495 B1	Paulauskas et. al.	System to Continuously Produce Carbon Fiber via Microwave Assisted Plasma Processing
7,534,854 B1	Paulauskas, White, & Sherman	Apparatus and method for oxidation and stabilization of polymeric materials
1973	Naskar, Paulauskas, Janke, & Eberle	Novel compositions for PAN based carbon fiber precursors
2322	Several	Precursor Materials and Fiber Formation for Ultra High Strength Carbon Fibers
2323	Several	Conversion of Ultra High Performance Carbon Fibers
2477	Naskar, Paulauskas	Microwave Processing of Functionalized Polyolefin Fibers
2476	McCarvill, et al	Method of Improving Adhesion of Vinyl Esters and Polyesters to Carbon Fibers
2462	Naskar, Janke, Eberle, Paulauskas	Precursor Compositions and Stabilization Methods for Polyolefin-Based Carbon Fiber Manufacturing
2557	Paulauskas, et al	Apparatus and process for Surface Treatment of Carbon Fibers
2541	Vautard, Ozcan, Paulauskas	Reactive Sizing Agent for Improving Adhesion Between Carbon Fibers and Vinyl Ester Resins
2558	Vautard, Ozcan, Paulauskas	Improvement of the Interfacial Adhesion in Carbon Fiber – vinly Ester Composites by the use of Coupling Agent

The Carbon Fiber Team

Materials


Felix Paulauskas


Amit Naskar


Frederick Baker


Soydan Ozcan


Nidia Gallego


Mohamed Abdallah


Cliff Eberle


Dave Warren


Robert Norris


Ken Yarborough


Ronny Lomax


Fue Xiong

The Carbon Fiber Team


Brian Eckhart


Daniel Webb

The entire team contributed to this presentation!!!!


Pol Grappe


Tomonori Saito


Marcus Hunt


Kelby Cassity


Future Staff

COMPARISON OF CASES - High Volume

Program Goals are to Combine Precursor Savings with Advanced Conversion Savings

Factor	CF-GRADE PAN				TEXTILE-GRADE PAN			
	Con. Tech	PO	MAP	PO and MAP	Con. Tech.	PO	MAP	PO and MAP
Capacity, MM lb/yr	24.0	31.0	24.0	31	27.5	31.0	27.5	31.0
Number of lines	14	6	14	6	8	6	8	6
Line speed, Ft/hr	1,064	3,192	1,064	3,192	2.128	3,192	2,128	3,192
Investment, $ Million	209.4	166.0	174.1	132.5	152.9	144.1	126.0	110.5
Investment, $ per lb of CF	8.72	5.36	7.23	4.28	5.56	4.66	4.58	3.57
Total Head count	372	320	372	320	300	320	300	320

Con Tech – Conventional Technology PO – Plasma Oxidation MAP – Microwave Assisted Plasma

However

Incorporating too many new technologies at once in a new plant design may be too high of a risk.