# Future Lower Cost Carbon Fiber for Autos: International Scale-up & What is Needed

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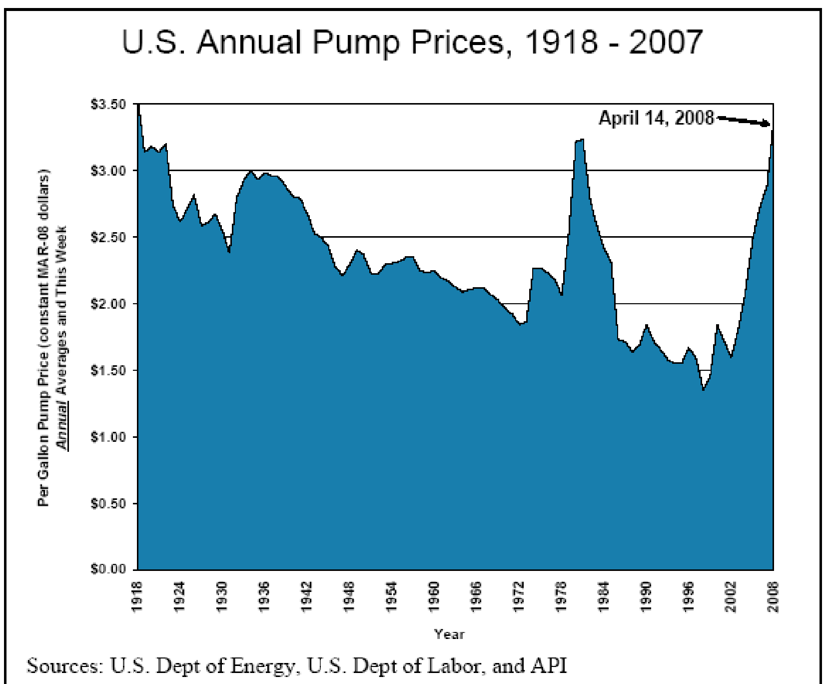
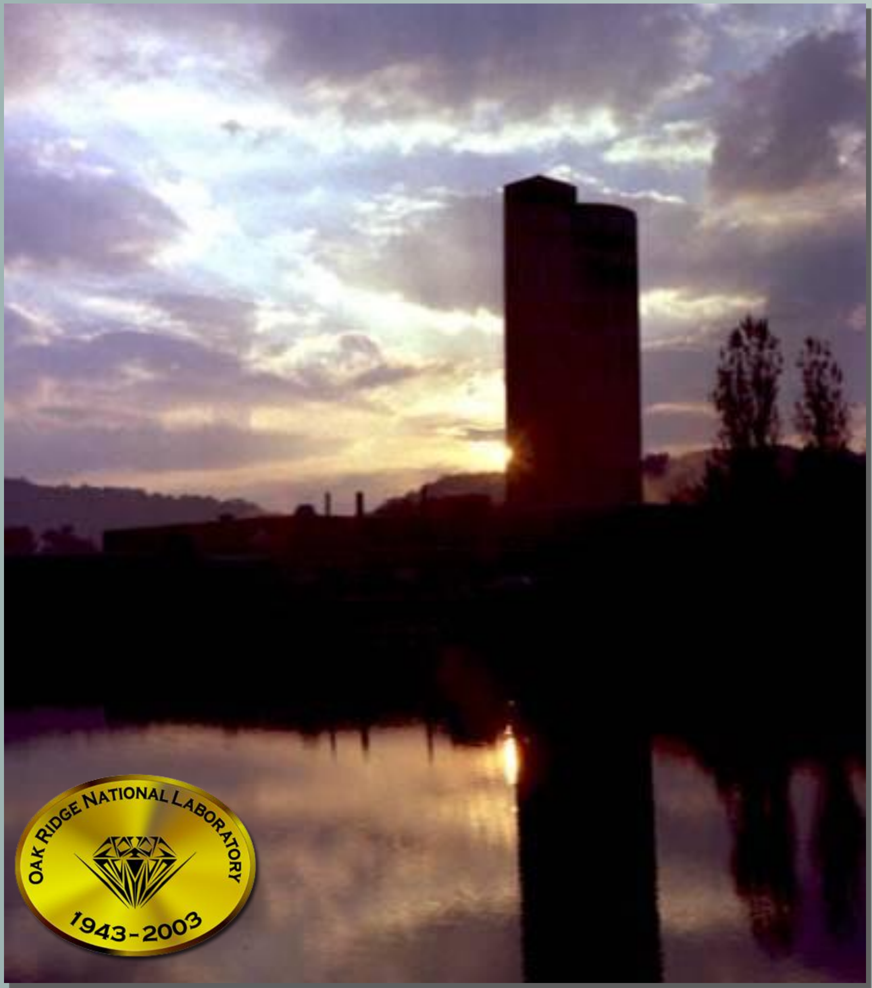
PLEASE INSERT YOUR CREDIT CARD.
PLEASE WAIT.
PLEASE ENTER THE MAKE & MODEL OF YOUR CAR, FOLLOWED BY YOUR ANNUAL SALARY.
PLEASE WAIT.
YOUR LOAN HAS BEEN APPROVED.
YOU MAY FILL UP.


U.S. Annual Pump Prices, 1918 - 2007
April 14, 2008
Per Gallon Pump Price (constant MAR-08 dollars)
Annual Averages and This Week
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00
1918
1924
1930
1936
1942
1948
1954
1960
1966
1972
1978
1984
1990
1996
2002
2008
Year
Sources: U.S. Dept of Energy, U.S. Dept of Labor, and API


MARLETTE
LOAN OFFICER
"SO YOU WANT TO BUY A TANK OF GAS?!"

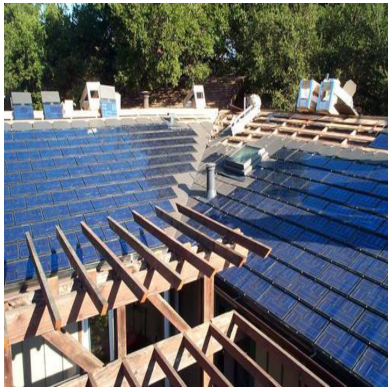
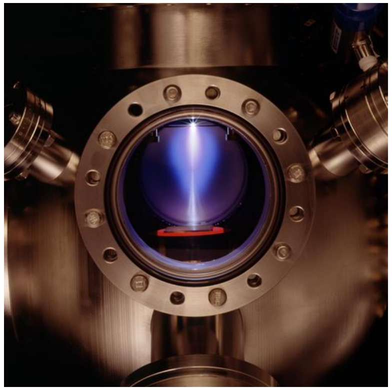
# Oak Ridge National Laboratory




- DOE's largest multiprogram science laboratory
- Nation's largest energy R&D laboratory
- Nation's largest concentration of open source materials research
- World-class computing facilities
- Built the $1.2 billion Spallation Neutron Source
- $300 million modernization program in progress
- $1 billion budget
- 4200 employees
- 3000 research guests annually

# Office of Energy Efficiency and Renewable Energy

## http://www.eere.energy.gov

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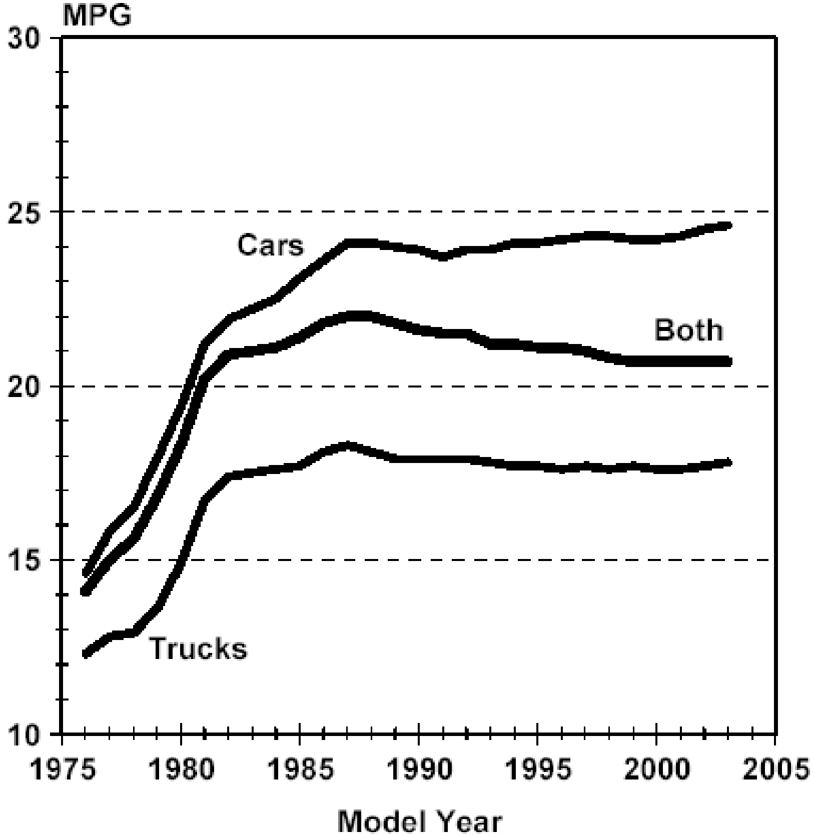
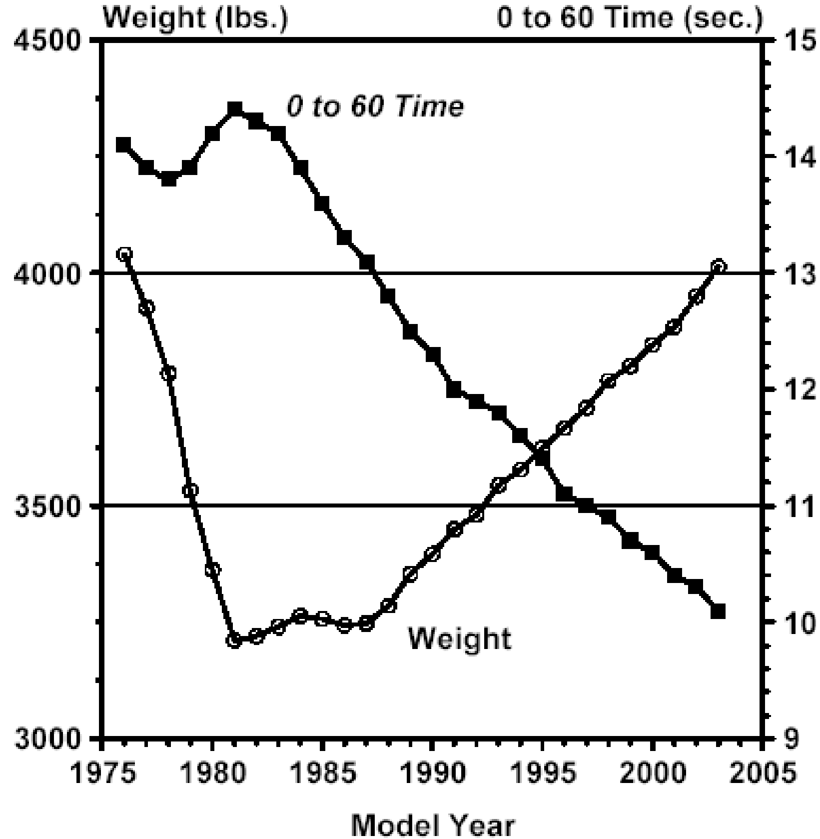
# Light-Duty Vehicle Trends

Adjusted Fuel Economy by Model Year
(Three-Year Moving Average)

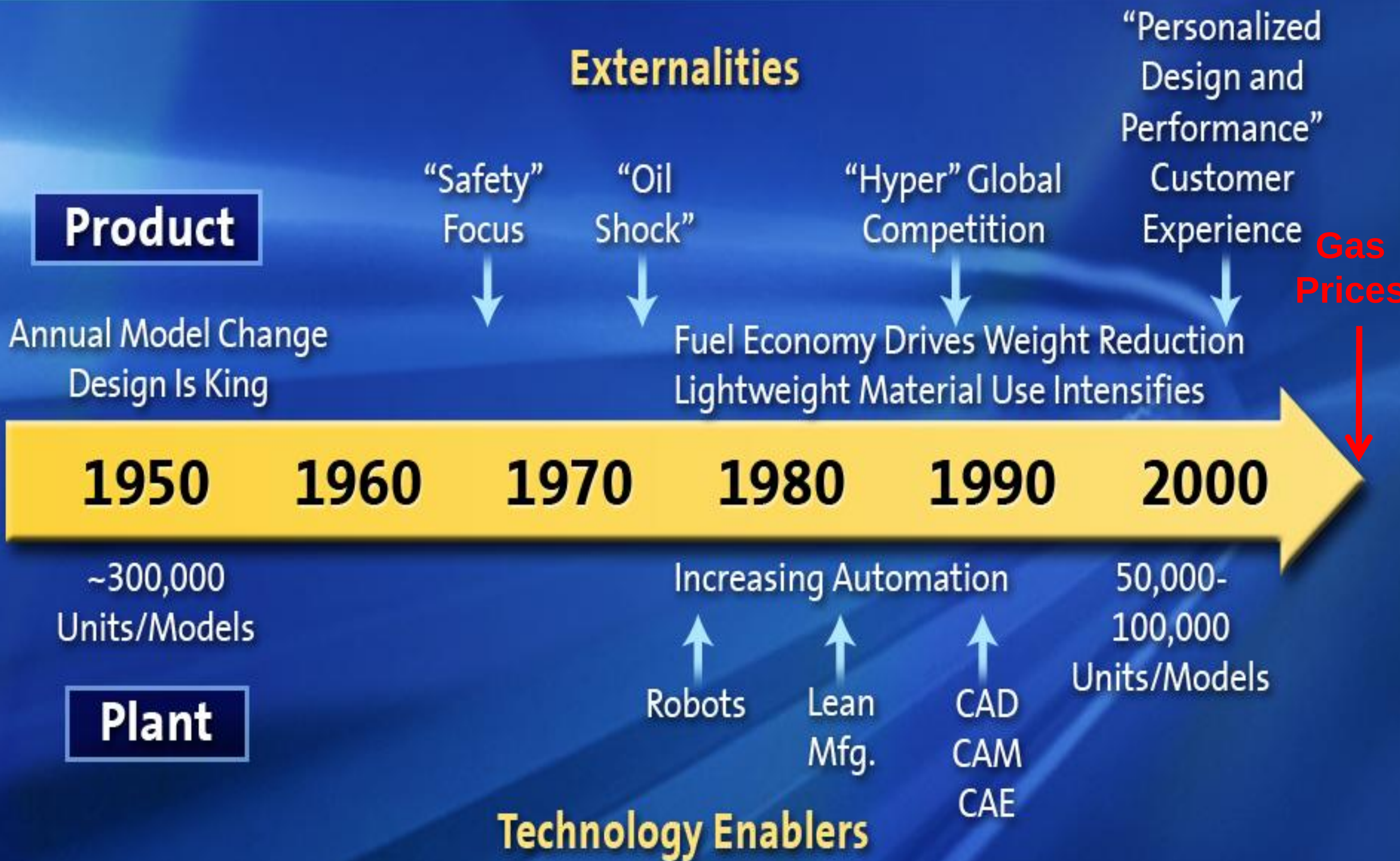



Weight and Performance by Model Year
(Three Year Moving Average)




Source: *Light Duty Automotive Technology and Fuel Economy Trends: 1975 through 2004*, U.S. Environmental Protection Agency, April 2004.

# Key Drivers and Technology Enablers



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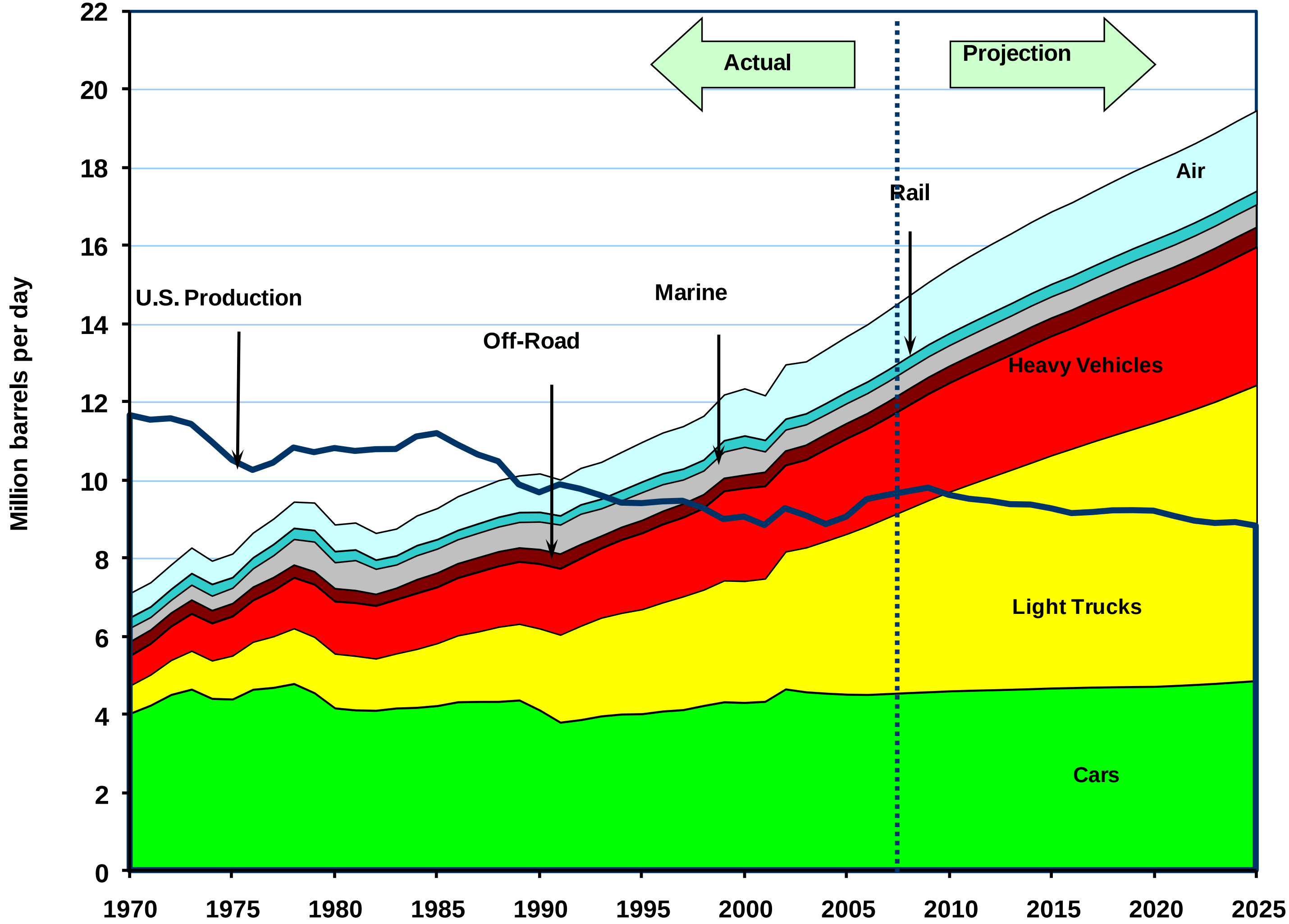
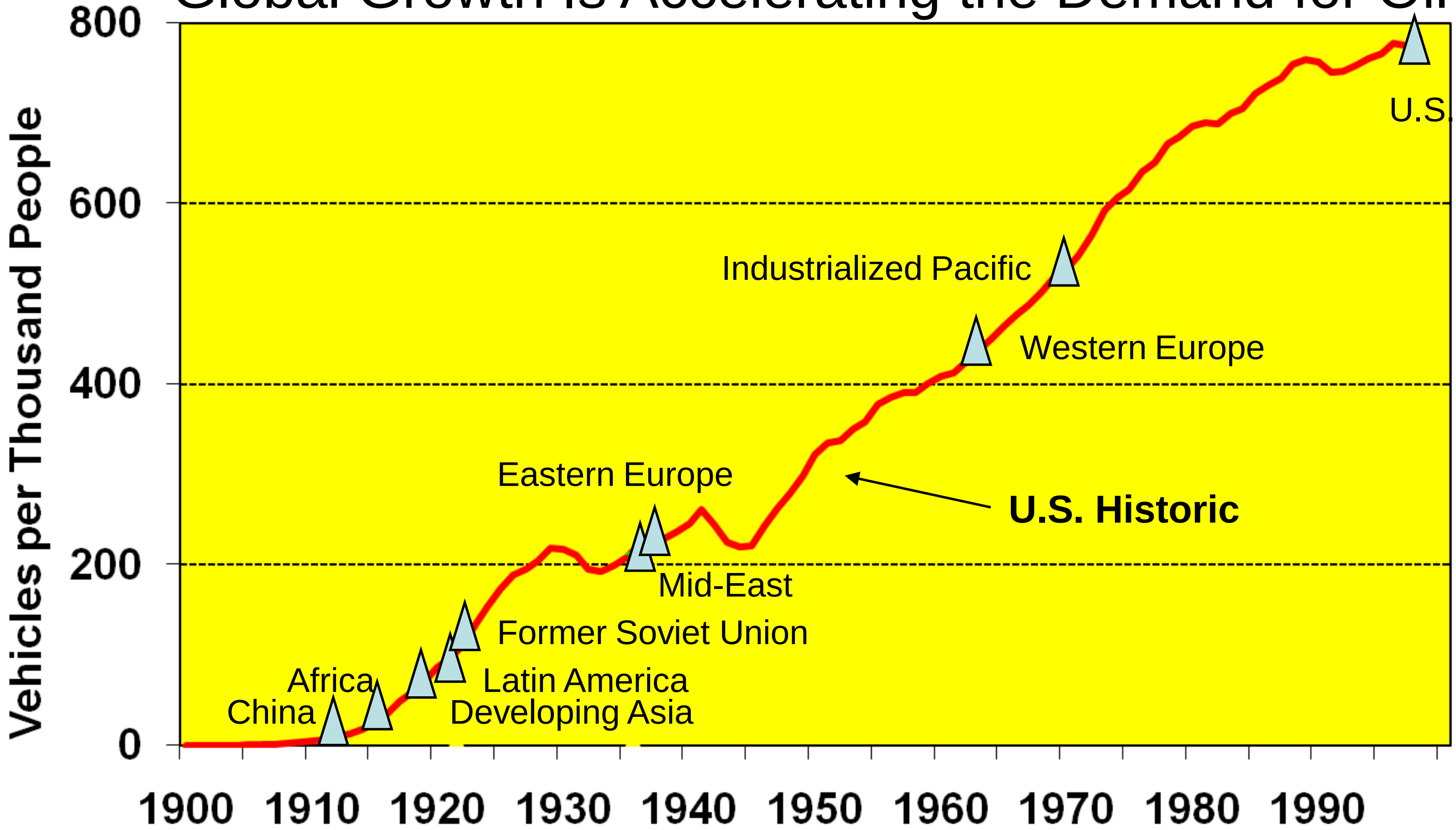
# USA Transportation Petroleum Use by Mode (1970-2025)



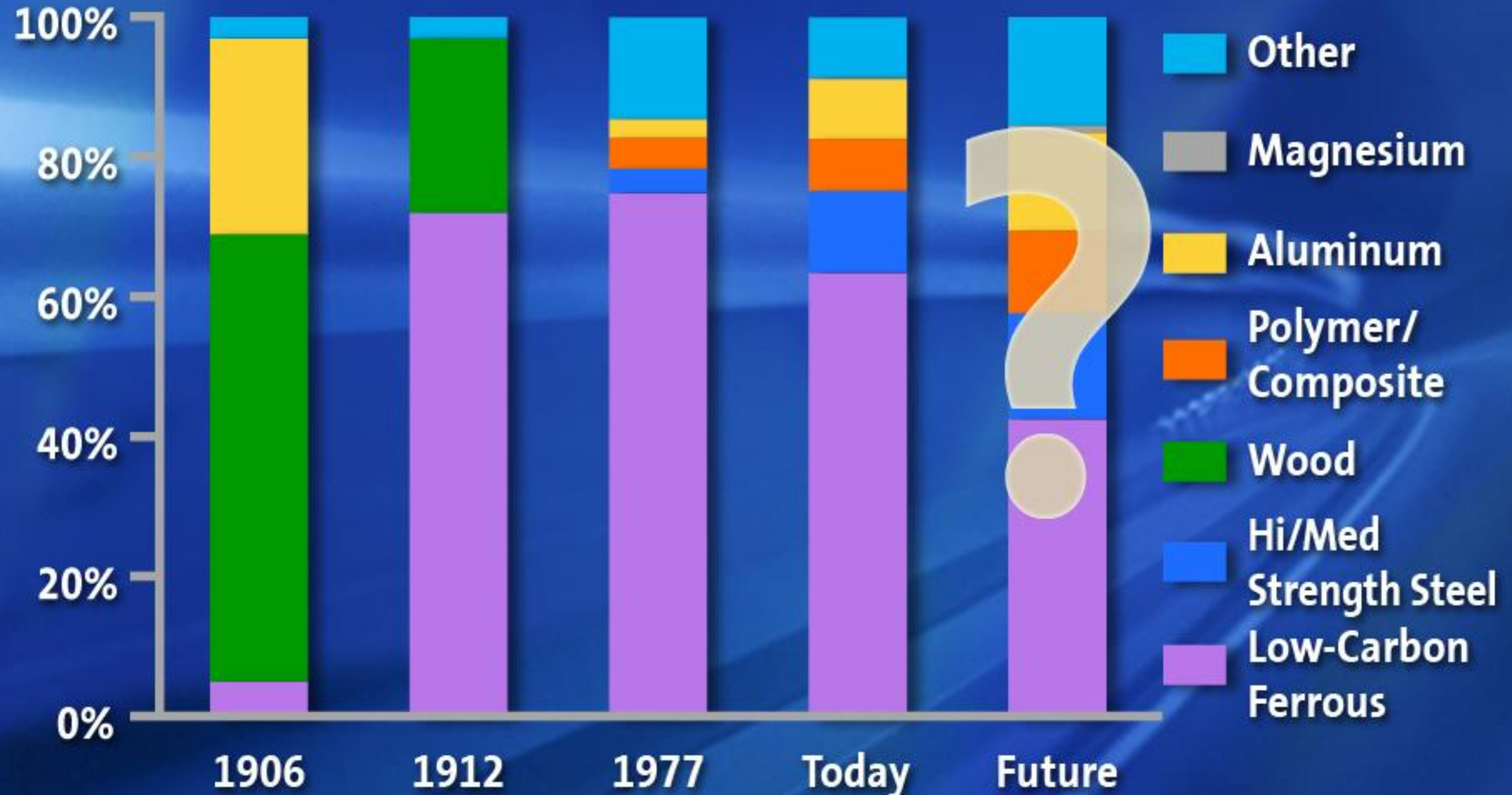

Note: Domestic production includes crude oil, natural gas plant liquids, refinery gain, and other inputs. This is consistent with EIA, MER, Table 3.2. Previous versions of this chart included crude oil and natural gas plant liquids only.
Source: Transportation Energy Data Book: Edition 24, ORNL-6973, and EIA Annual Energy Outlook 2005, Preliminary release, December 2004.

# Global Growth Is Accelerating the Demand for Oil




**China, with 13 vehicles per 1000 people, is where the U.S. was in 1913**

# Materials in a Typical NA Vehicle



# 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

## Increasing Severity of Challenge

Increasing Impact on Mission

| Material Options | Critical Challenges | | | | |
|---|---|---|---|---|---|
| Carbon-fiber Composites | Low-cost fibers | High-volume Mfg. | Recycling | Joining | Predictive Modeling |
| Aluminum | Feedstock Cost | Manufac-ing | Improved Alloys | Recycling | |
| Magnesium | Feedstock Cost | Improved Alloys | Corrosion Protection | Manufac-ing | Recycling |
| Advanced High-strength Steels | Manufacturability | Wt. Red. Concepts | Alloy Development | | |
| Titanium | Low-cost Extraction | Low-cost Production | Forming & Machining | Low-cost PM | Alloy Development |
| Metal-matrix Composites | Feedstock Cost | Compositing Methods | Powder Handling | Compaction | Machining & Forming |
| Glazings | Low-cost Lightweight Matls. | Noise, T$^{o}$ struc. models simulations | Noise reduction techniques | UV and IR blockers | |
| Emerging Materials and Manufacturing | Material Cost | Mfg-ability | Design Concepts | Performance Models | |

*Chart is provided courtesy of Robert McCune - Ford Motor Company*

# 1978 Ford LTD

**$1M Demonstration Vehicle**

# Composites in the Automotive Industry

## Ford GT

Carbon fiber composite rear deck lid and seat (4500 units total)

## 2006 Z06 Corvette


Carbon fiber fenders, wheel house, and floorpan (7000 units/year)

## 2006 Dodge Viper

Carbon fiber LH/RH fender/sill supports, LH/RH door inner reinforcements, windshield surround reinforcement (2000 units/year)

# Composites in the Automotive Industry

## BMW M3 CSL


Carbon fiber roof
(3000 units/year)

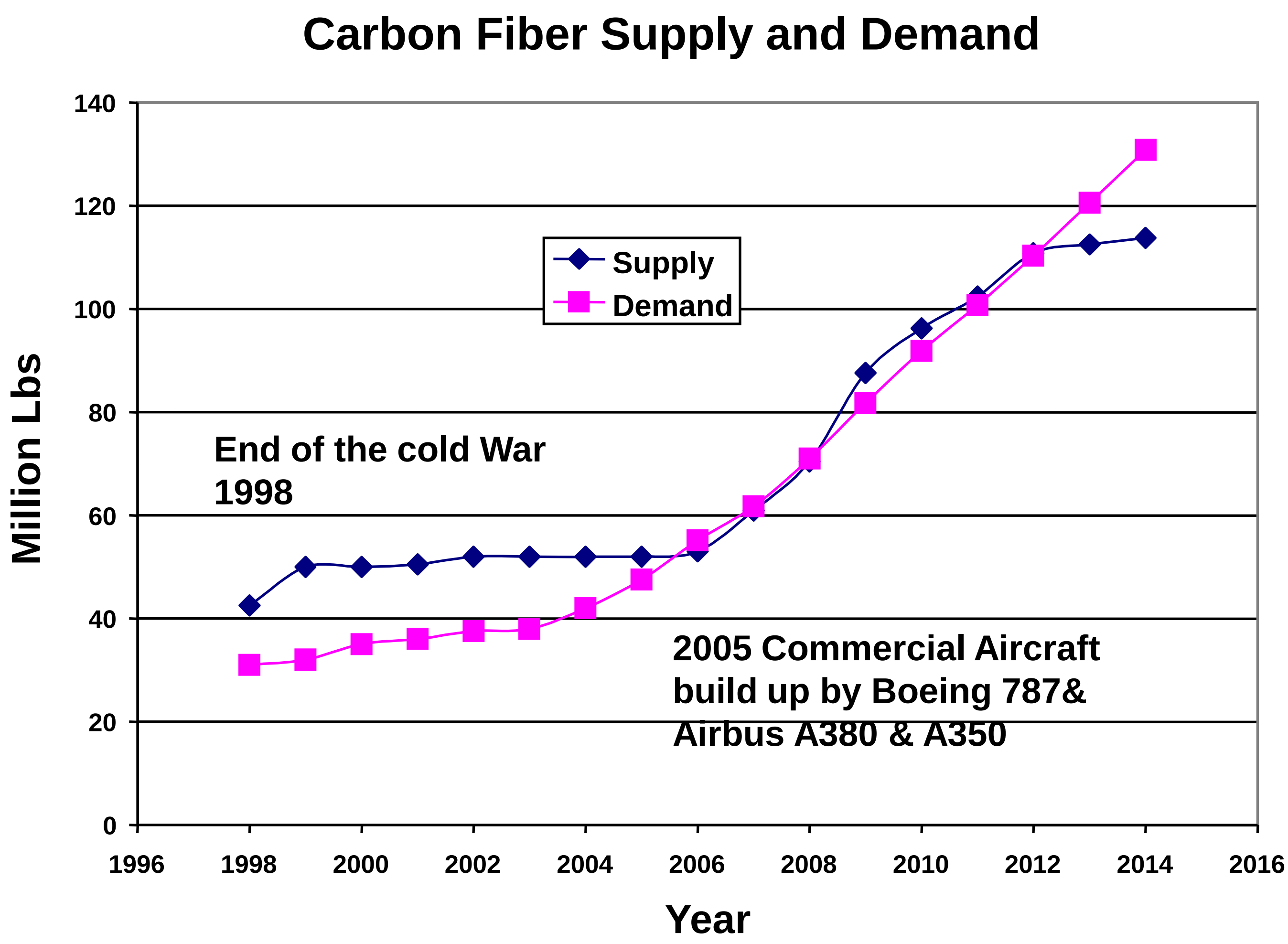
## 2005 Mercedes Benz SLR McLaren

Carbon fiber intensive
(500 units/year)

## Aston Martin Vanquish

Carbon fiber composite transmission tunnel, braided A-pillar, front end crash structure
(400-800 units/year)

# Carbon Fiber Demand and Supply

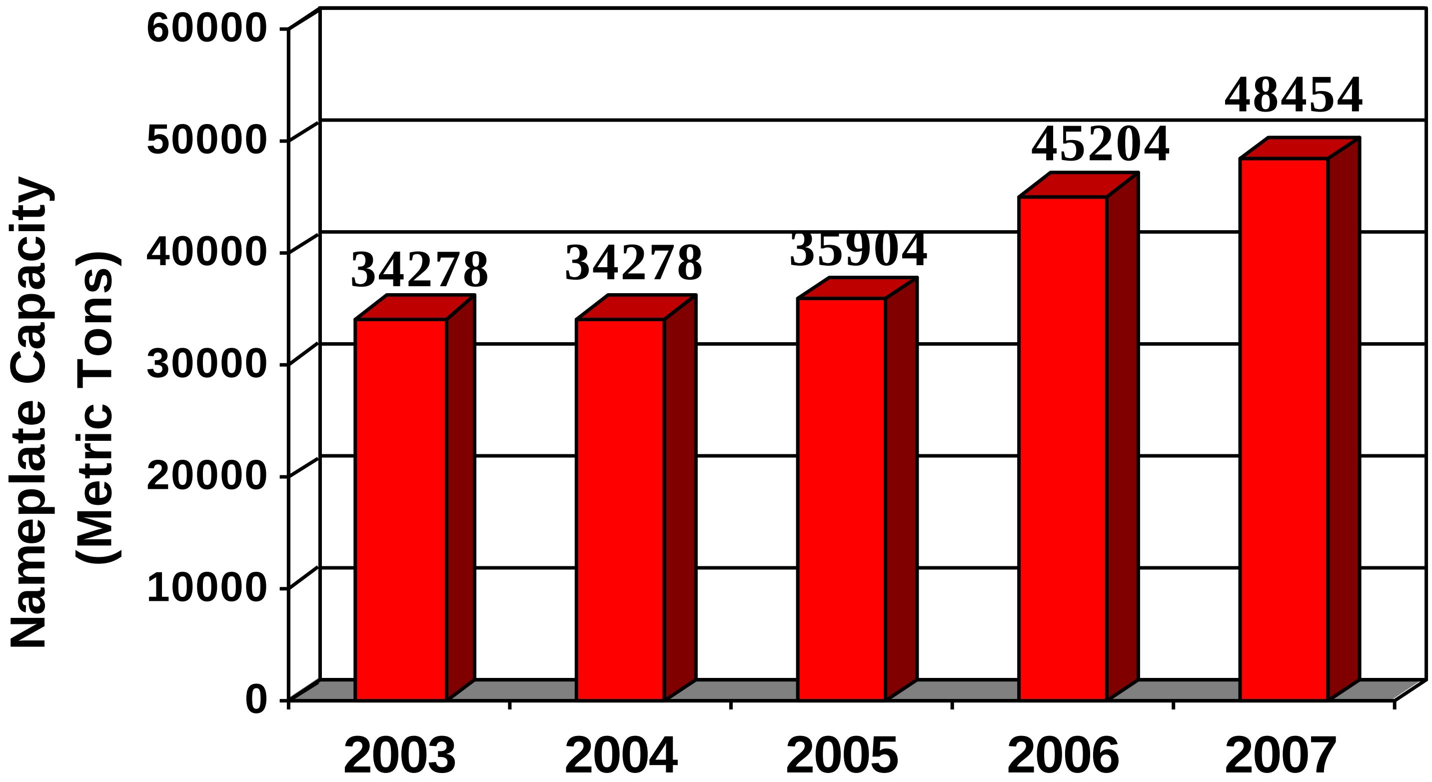



Source: Cliff Eberle, ORNL and Mohamed Abdullah, MGA Consultants

# Carbon Fiber Capacity

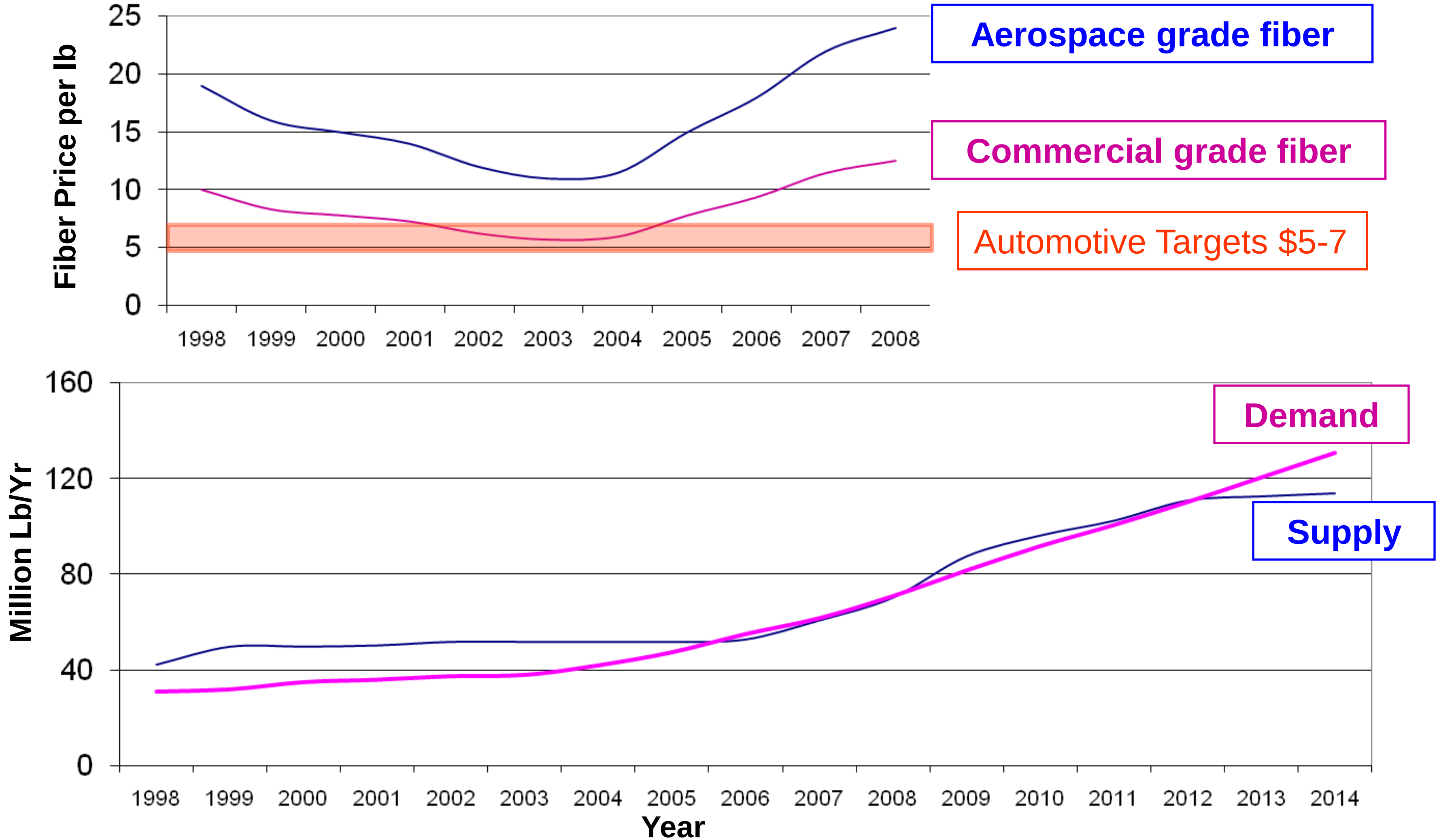
North American Vehicle Production > 16 / year
12 pounds of Carbon Fiber per Vehicle: 192M lb/year

2X World Capacity



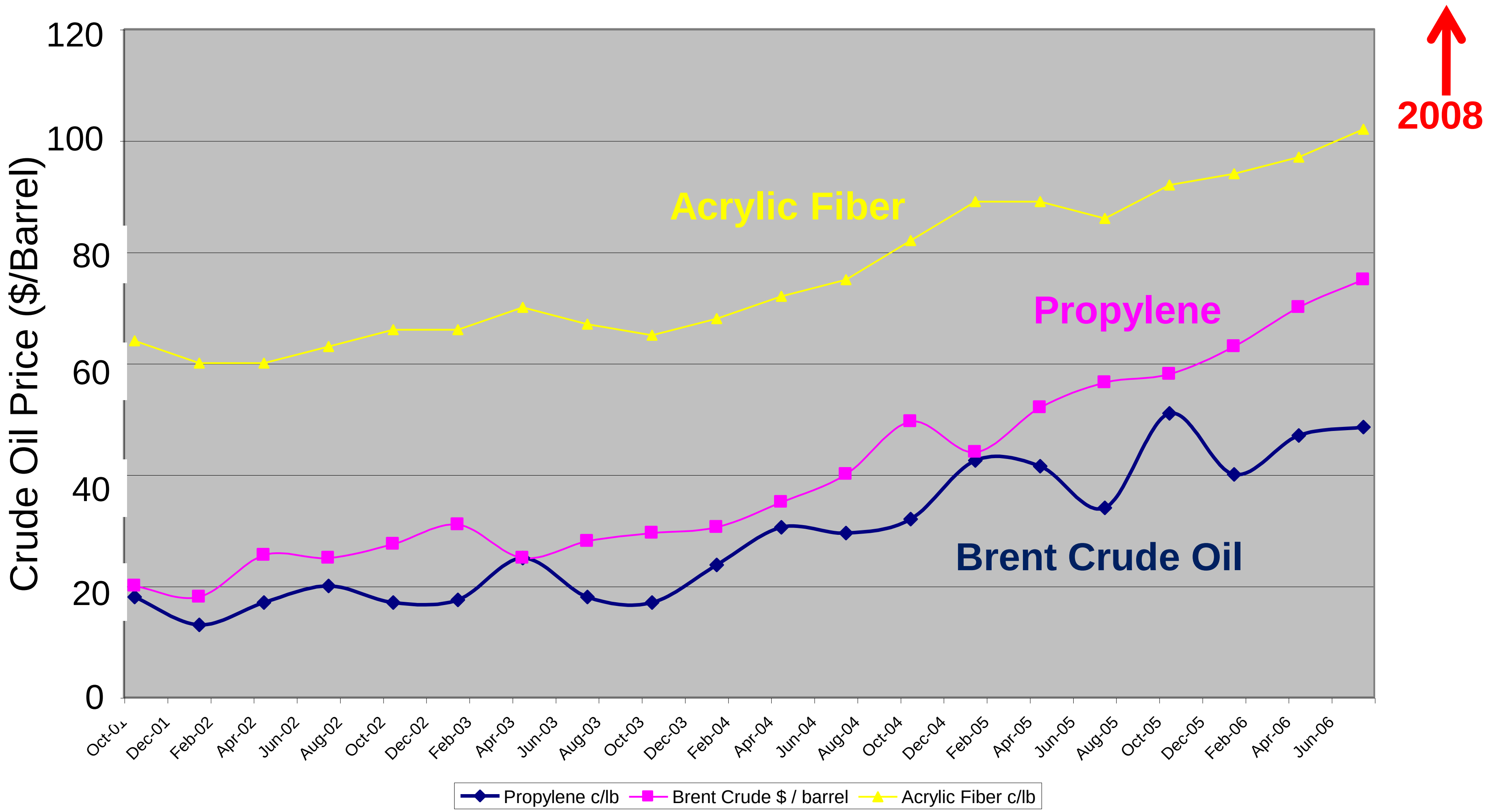

Source: U.S. Department of Defense, "Polyacrylonitrile (PAN) Carbon Fibers Industrial Capability Assessment", OUSD(AT&L) Industrial Policy, October 2005.

# Carbon Fiber Market History



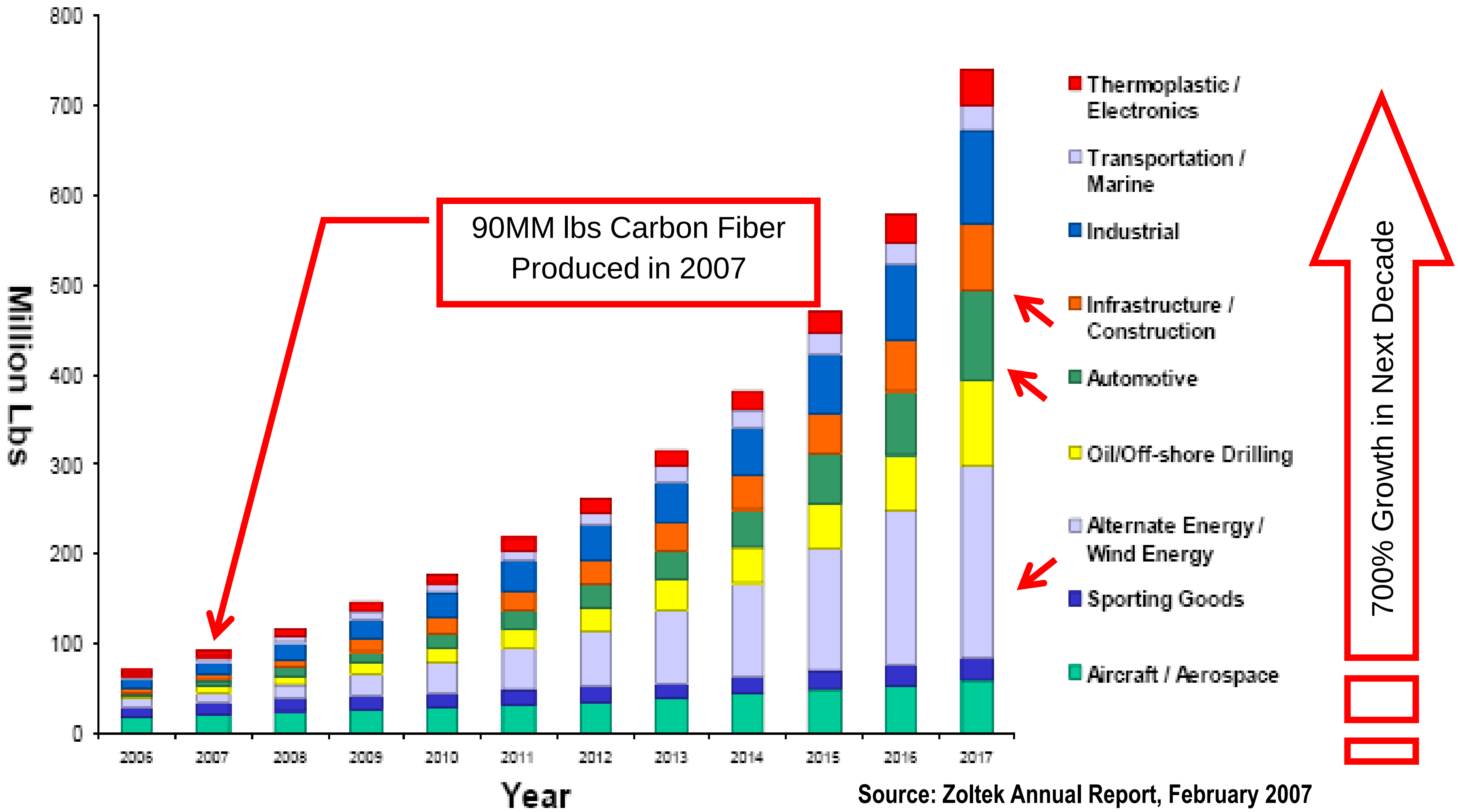

Sources: High performance Composites Magazine
Proceedings of the Global Outlook for Carbon Fiber 1998 to 2007
CEH Marketing Research Report: Carbon Fibers, SRI Consulting
The Market Prespective for PAN-Based Carbon Fiber 1999 - 2005 Kline& Company

# PAN Dependence on Oil Price




**Current Carbon Fiber Raw Materials are Tied to Oil**

# Projected Carbon Fiber Market Demand




Source: Zoltek Annual Report, February 2007

The Growth and Challenges are Multi-Industry

# Automotive

Carbon fiber is a leading candidate for mass reduction.

- 10% Mass Savings = 6-7% Fuel Savings
- Mass reduction allows earlier introduction of alternative propulsion systems.

Price too high for medium to large volumes.
Supplies are insufficient.
Processing technologies undeveloped.

Longer blade design requires use of CF.

- Energy captured is greater with longer blades
- Blades must be both stiff and light.


Insufficient volume of CF at any price.
Lower price needed for more efficient designs.

Needs: Higher volume at lower price.
(Needed now for rapid deployment)

# Oil & Gas

In deeper waters strength/weight and stiffness/weight becomes critical.

Pipes, drill shafts and other structures must support their own weight while being constructed.

Need stable, larger supply.
Significant materials development.
Materials processing development.
Competitive pricing.


# Power Transmission

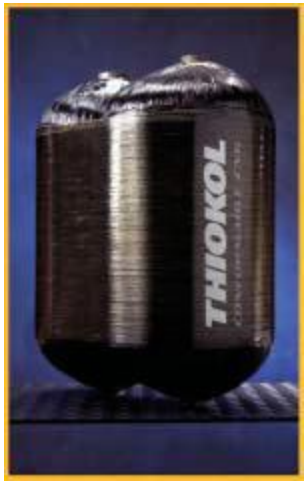
Carbon fiber could replace steel with Equivalent stiffness - similar "packing factor" of reinforcement

- Increased strength - higher tension permissible
- Low (slightly negative) CTE - less sag compensation needed for low temps
- Reduced weight (~94 lbs vs 344 lbs) - more conductor for equivalent sag

Need ready supply of materials at volume pricing and development of materials and processing technologies.

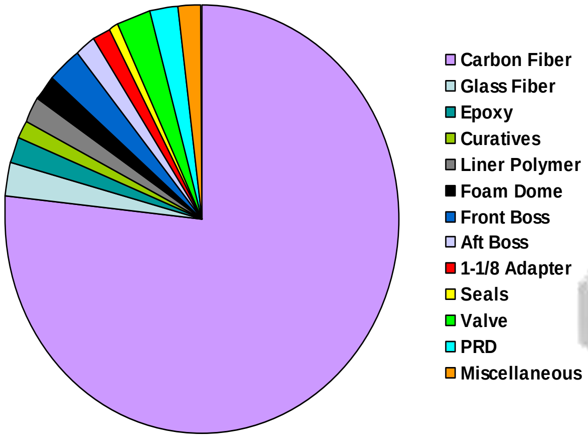
# Hydrogen and NG Storage

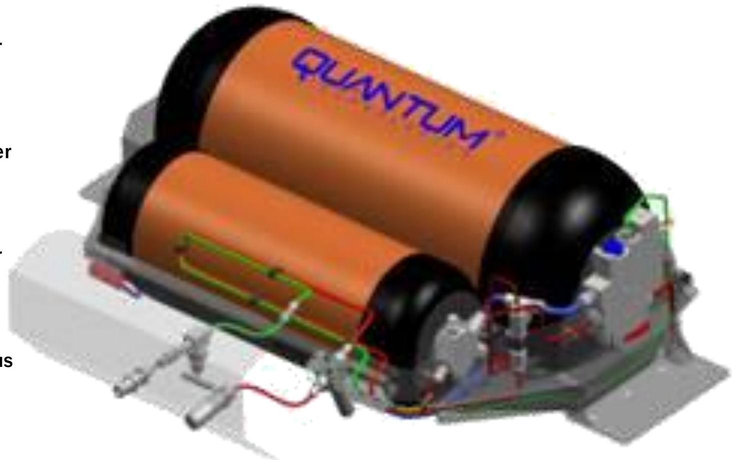
Strength to weight demands CF for pressurized H2 storage.
Could make more compact NG storage with higher pressures.
Cost of fiber makes designs prohibitively expensive.

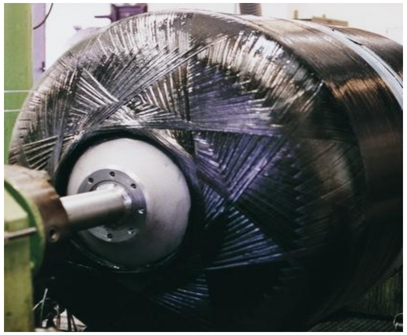



Cost of fiber makes Designs prohibitively expensive.
Insufficient volume of CF available.

40 - 80% is carbon fiber cost



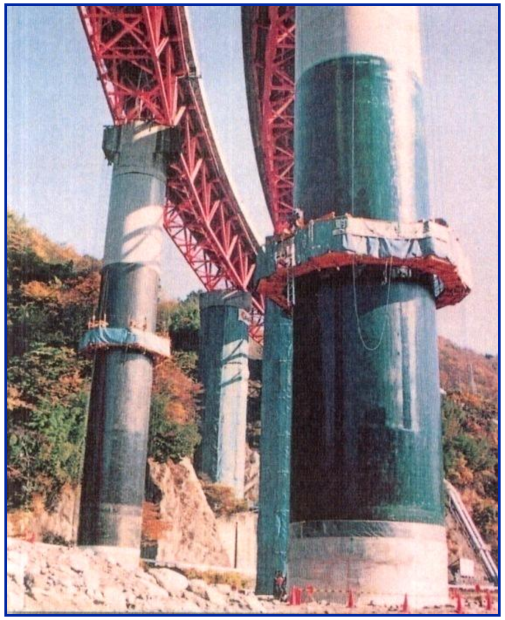



# Civil Infrastructure

Retrofit and new construction in days rather than months.
Large structures fabricated in plants rather than on site.
High demand for rebar.

Need standard materials.
Standard construction processes.
Affordable materials.
Steady supply of materials.
Rapid Repair



Strong History in Aerospace
Needed for lightweight portable ground and sea systems.

Affordable materials for rapid deployment of ground systems.

non-flying equipment.

# Bio-Fuel Refining

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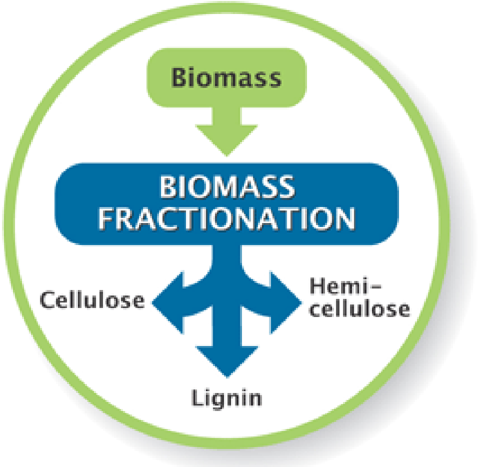
1. Oil refinery profitability is in making fuel AND other products from input material.
2. Virtually all input Crude is turned into a value-added product.
3. To be economically viable, a bio-refinery will have to operate in much the same manner.



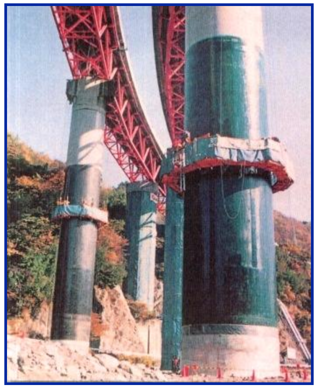

Lignin Based Carbon Fiber may be one Value-Added Product to make Bio-Refineries economically Attractive

| Millions of Barrels/Year US Refineries | 2006 | 2007 |
|---|---|---|
| Liquified Refinery Gases | 209.0 | 229.0 |
| Motor Gasoline | 2225.4 | 1964.4 |
| Aviation | 570.4 | 546.7 |
| Kerosene | 23.9 | 17.3 |
| Fuel Oil | 1672.4 | 1706.6 |
| Petrochemical Feedstocks | 141.9 | 143.9 |
| Lubricants | 61.2 | 66.8 |
| Waxes | 5.8 | 5.4 |
| Petroleum Coke | 304.7 | 309.4 |
| Asphalt and Road Oil | 186.7 | 184.7 |
| Still Gas | 249.5 | 258.9 |
| Miscellaneous | 21.4 | 25.2 |

Source: Energy Information Administration

# Common Issues and Needs

Civil Infrastructure
Rapid Repair and Installation, Time and Cost Savings



Bio-Mass Materials
Alternative Revenue
Waste Minimization

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Hydrogen Storage
Only Material With Sufficient Strength/Weight


**Fiber Cost**
**Fiber Availability**
**Design Methods**
**Manufacturing Methods**
**Product Forms**

Wind Energy
Needed for Longer Blade Designs


Power Transmission
Less Bulky Structures
Zero CLTE

Oil and Gas
Offshore Structual Components

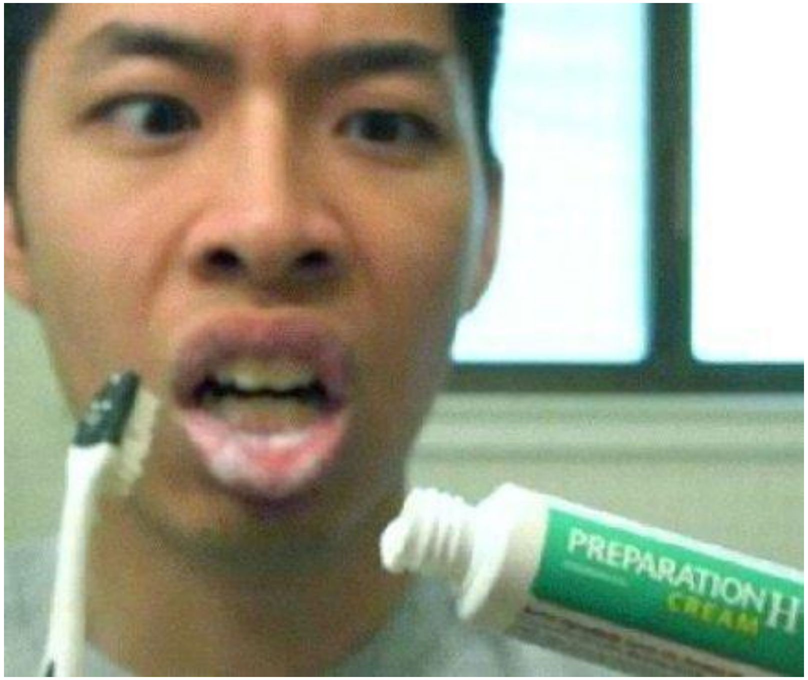
Vehicle Technologies
Necessary for 50+% Mass Reduction

# If the Demand is so Great, Why Don't we see more applications in Automotive and other Industries?

#1 Reason
$$$$$$

But there are other Reasons

Designers are not comfortable with composites, especially in Crash critical applications. Full system & subsystem demonstration needed.


Many composite processing methods are optimized for performance not production rate efficiency. Cost optimization of production methods needed.

Capital investment already sunk into metal forming equipment. Must be ready for the next generation.

Size of the carbon fiber industry cannot support large scale utilization. Must choose applications and ramp up capacity.

Boom or bust nature of the market. Automotive industry needs long term pricing and stable long term partners.

The secret art of sizing. Collaborative development efforts are needed.

The lack of resin targeted systems. Need sizings optimized for specific classes of resins that are of interest to the automotive companies.

# Carbon Fiber United States

## Companies with US Facilities

| Company | US Facilities | Non-US Facilities |
|---|---|---|
| Hexcel (US) | Decatur, AL; Salt Lake City | Spain |
| Cytec (US) | Greenville, SC; Rock Hill, SC | None |
| Toray (Japan) | Decatur, AL | Japan |
| SGL (Germany) | Evanston, WY | Scotland, Germany |
| Zoltek (US) | Abilene, TX; St. Louis, MO | Mexico, Hungary |
| Mistubishi (Japan) | Sacramento, CA | Japan |
| Toho Tenax (Japan) | Rockwood, TN | Japan, Germany |

Source: Polyacrylonitrile (PAN) Carbon Fibers Industrial Capability Assessment, Department of Defense

## Universities with significant research in Carbon Fiber production

Clemson University
University of Kentucky
Virginia Tech

Note: Large efforts in carbon fiber composite development and many laboratories and universities.

# Carbon Fiber Globally

- Aircraft orders straining Capacity Worldwide – Boeing (787), Airbus (380)
- Current Carbon Fiber manufacturers replicating Capacity. Announcements from all manufacturers regarding expanded capacity.
- Japanese moving into automotive by vertically integrating into Tier I supply chain Announcements made by large teams from fiber supplier throught OEMs
- Attempts to entice development of capacity in Middle East in at least 2 different countries
- EU developing automotive, infrastructure & wind applications but only with existing business models for fiber production
- UB Koltrefjar ehf in Iceland investigating the development of a carbon fiber plant to be located there due to the reduced cost of energy and potential homeland applications.

# Carbon Fiber Globally

- Chinese quietly developing a 40 Million lb/year plant for industrial grade fiber
  - Claimed applications are wind, power transmission and automotive

- Russia, China and Japan have increase R&D efforts significantly

- United States – Expanded interest on all fronts
  - Strong interest from end user communities
  - . Growing interest from potential new carbon fiber producers
  - R&D for Carbon Fiber Production focused on high volume

# To Rapidly Expand the Carbon Fiber Industry

| Carbon Fiber Obstacles to High Volume, Affordable Supplies | What can be done? |
|---|---|
| Industry Age < 50 years | Accelerate Learning Curve |
| Limited Precursors – Pitch, PAN, Rayon | Develop Lower Cost Precursors |
| Aerospace Mind-Set – | Develop New Applications |
| High Margin, Low Volume | Investment by High Vol Industry |
| Limited Technical Advances | Involve other R&D Organizations |
| Prohibition against process changes | Develop New Processing Methods |
| Bound to epoxy chemistry | Develop Non-Epoxy Chemistry |
| Small Industry and Company Size – 100M lb/yr | Large Manufacturers Enter the Market |
| Limited resources | Invest in high volume plants |
| Specialty material mentality | Develop commodity mat'l forms |
| | Industry Standards |
| Limited Research Community | Bring together toward 1 Goal |
| Few Scientists (handful worldwide) | Sponsor graduate degrees in US |

## To Rapidly Expand the Carbon Fiber Industry

1. Develop a multiple End Use sector approach.
2. Large investment in NEW production methods required.
3. Development of Lower Cost Precursors.
4. Product forms amenable to High Volume industries needed.
5. Development of a larger EXPERT base required.
6. Industry Standards

# Carbon Fiber Price Goal

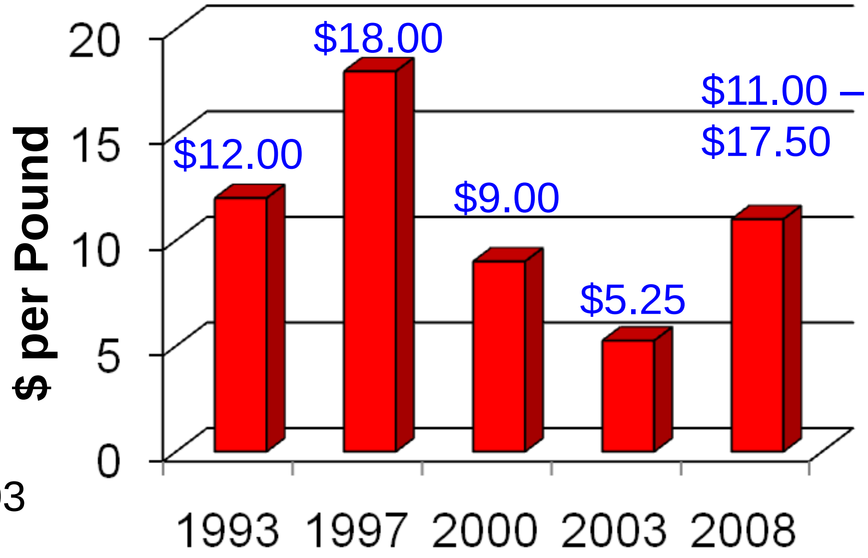
# #1 Priority

## $5 - $7 Per Pound

## $11 - $15.50 Per Kilogram

Strength: ≥ 250 Ksi (1.73 GPa)
Modulus: ≥ 25 Msi (173 GPa)
Strain: ≥ 1%

12/24k: $12/lb 1993, $18/lb 1997, $9/lb 2000
[Walsh, Zoltek 8/2000]
All time low $5.25/lbs std grade (mid-grade) 2003



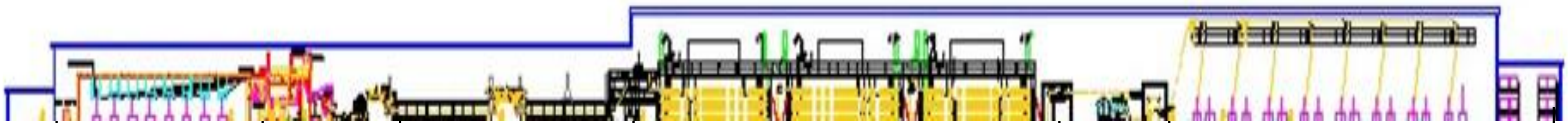
# Carbon Fiber Production

Thermal reduction of a limited number of precursors by pyrolysis of all but the carbon followed by heat treatment of the carbon to obtain desired structure.

**Are these the only materials and the only way?**

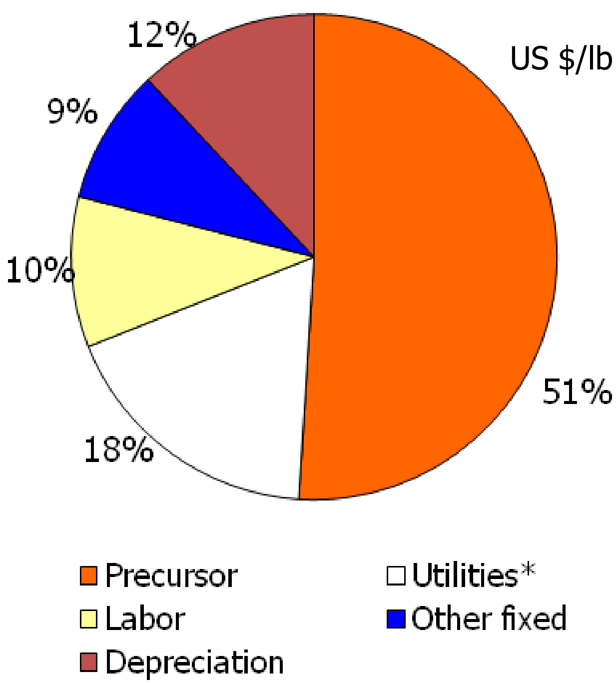

*Historically: No cost driver for lower cost. Only better Performance.*

# Carbon Fiber Costs (Production Costs)



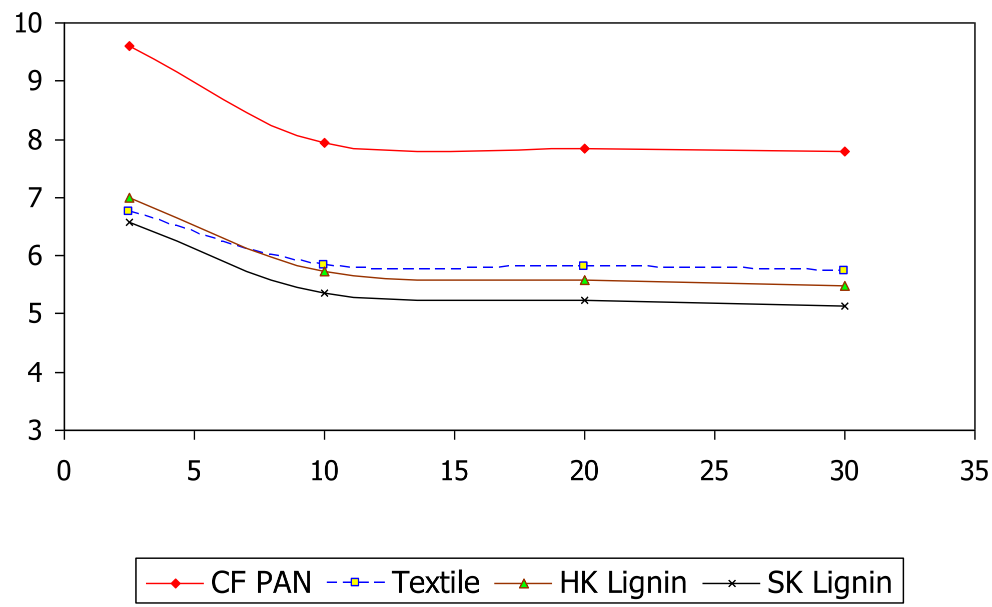
| Spooling & Packaging | Surface Treatment | Carbonization/ Graphitization | Stabilization & Oxidation | | Precursors |
|---|---|---|---|---|---|
| $0.61 | $0.37 | $2.32 | $1.54 | Baseline Today - $9.88 | $5.04 |
| $0.41 | $0.33 | $1.48 | $0.99 | High Volume - $7.85 | $4.64 |

## Baseline $9-10/lb




## Effect of Large Volume and Alternate Precursors

**Cost versus Volume for Conventional Technology**



# Carbon Fiber Costs (Production Costs)

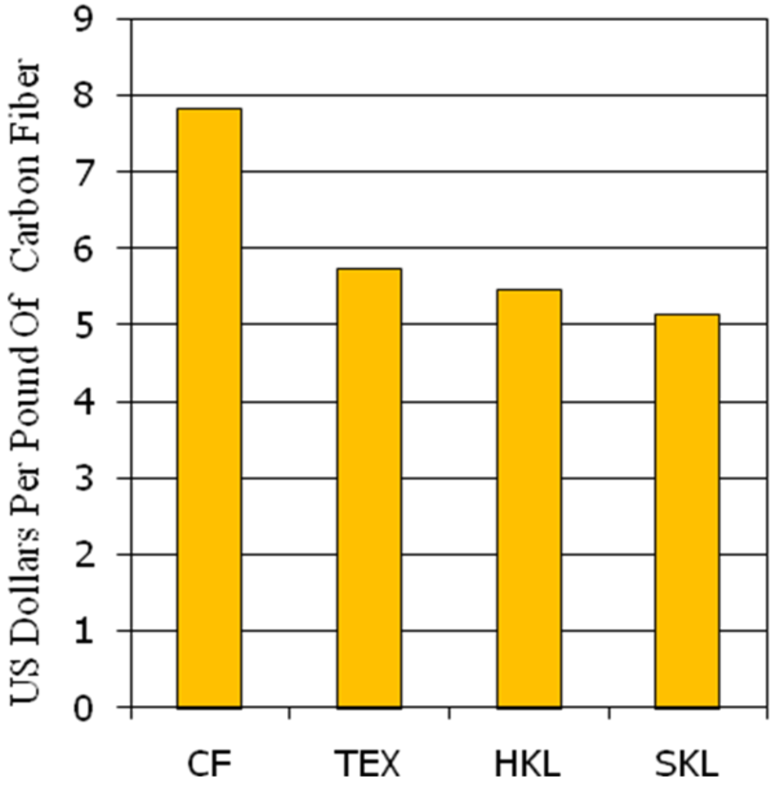
<u>3 Precursor Options</u>

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

<u>Other Important Precursor Technologies</u>:

1. Melt-Spun PAN
2. Scaling to Pilot Plant
3. Cost Studies

Alternative Precursors and Conventional Processing

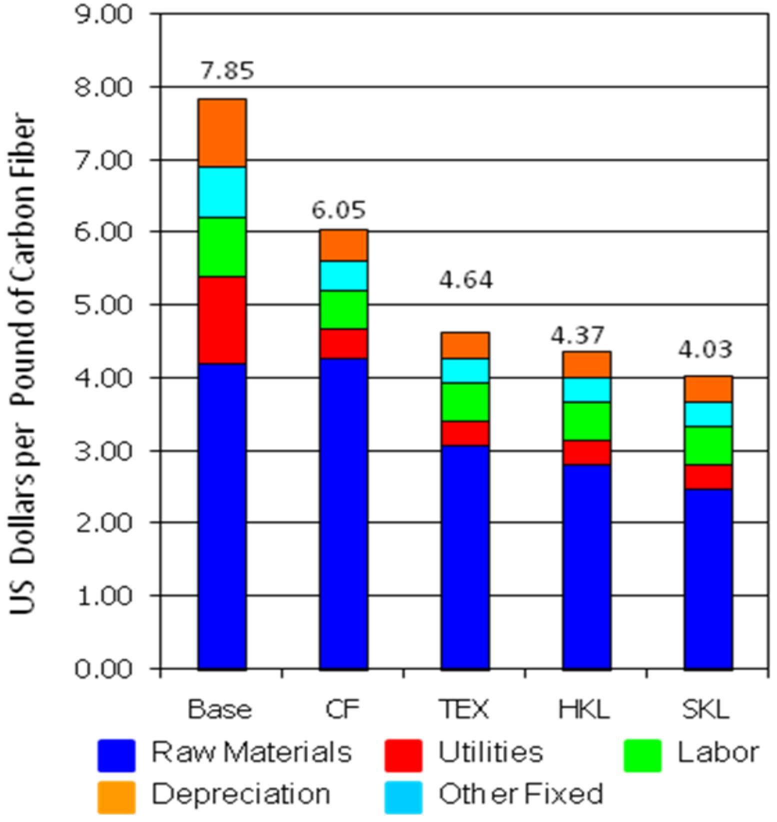


# Carbon Fiber Costs (Production Costs)

Alternative Processing

3 Processing Options

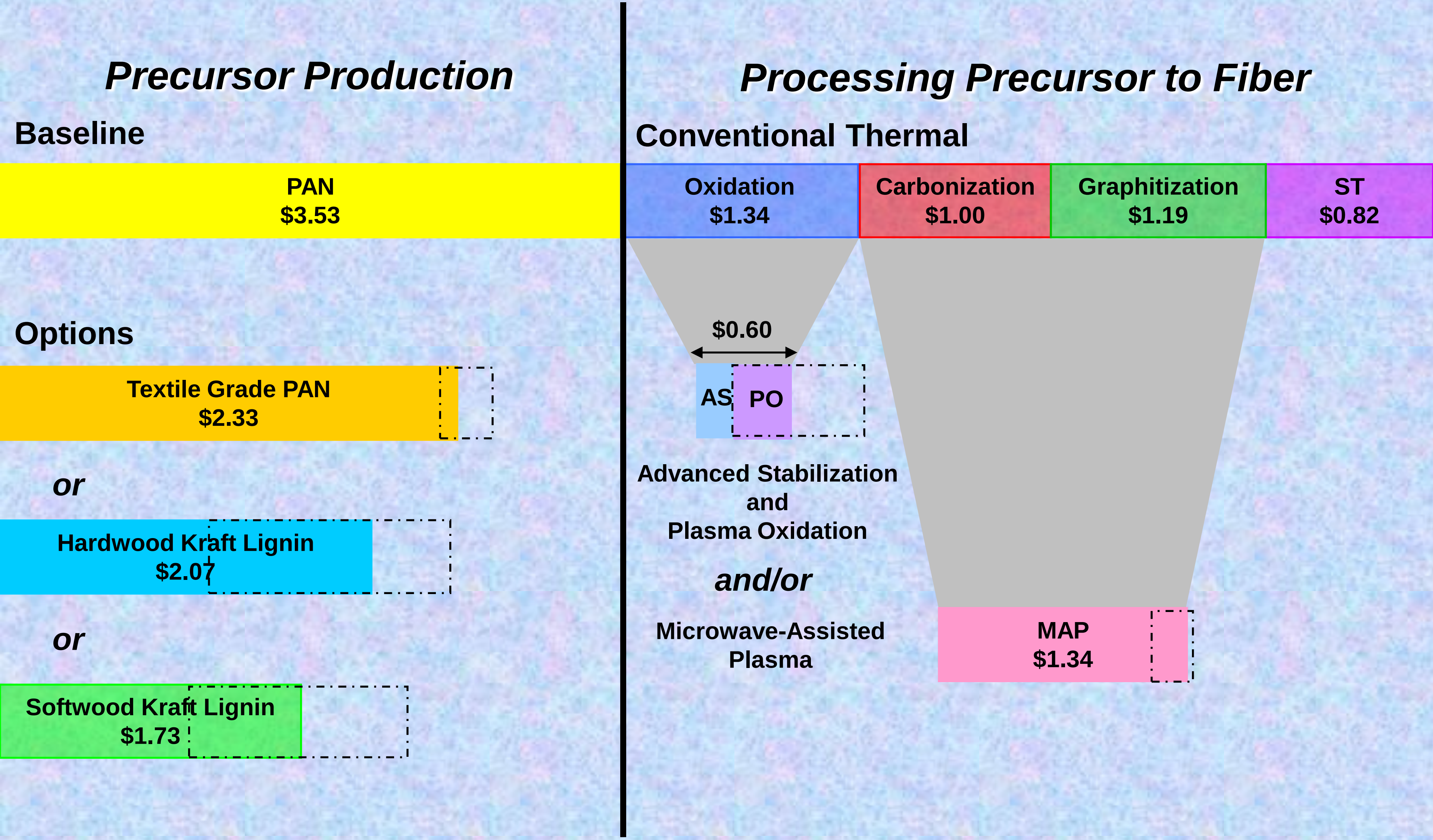
1. Advanced Stabilization
2. Plasma Oxidation
3. MAP Carbonization



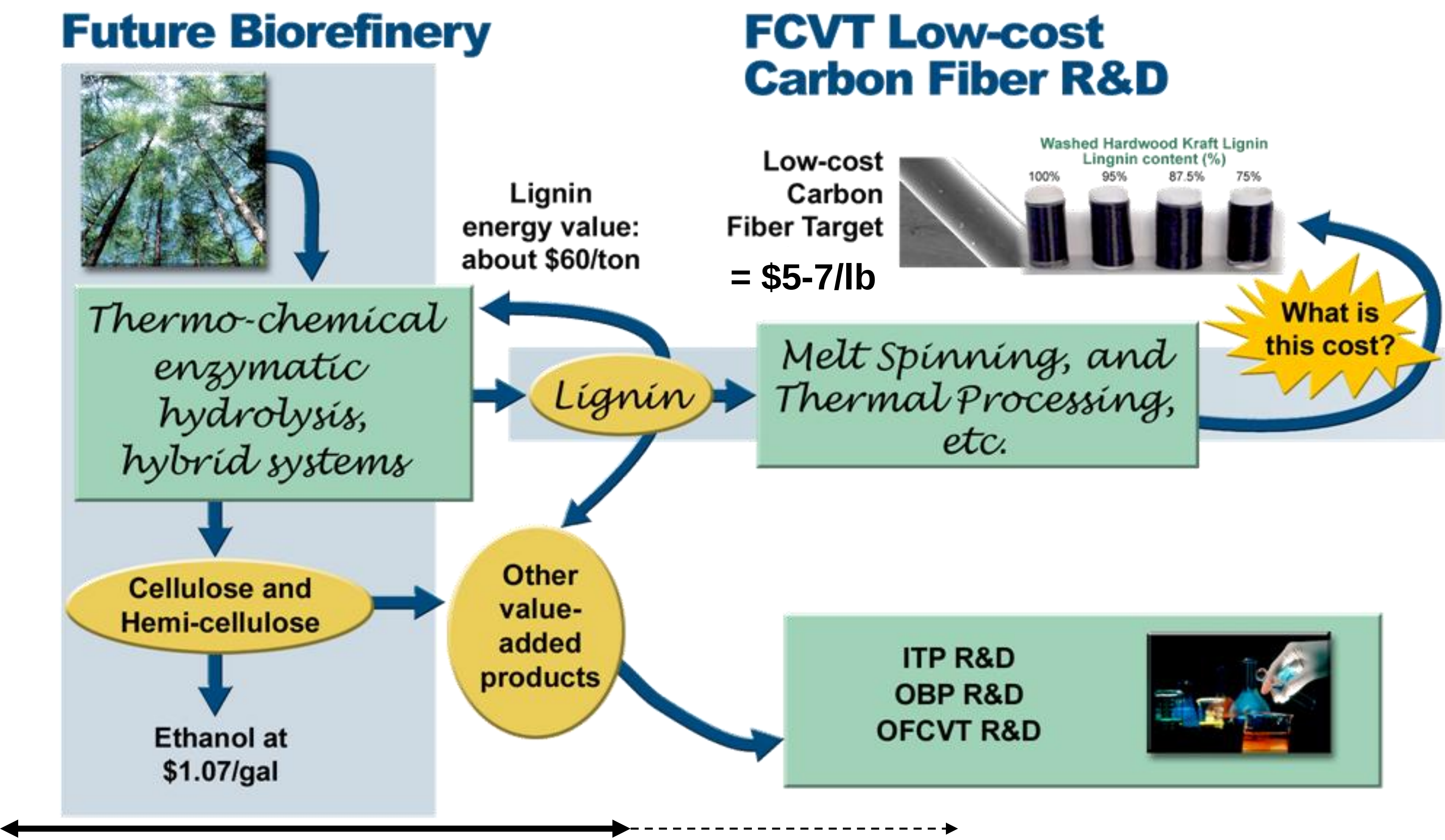

Other Important Processing Technologies:

1. Tow Splittng
2. On-line Feedback
3. Scaling to Pilot Plant
4. Development of carbon fiber SMC
5. Plasma Modification of Surfaces
6. Cost Studies

# Program Integration



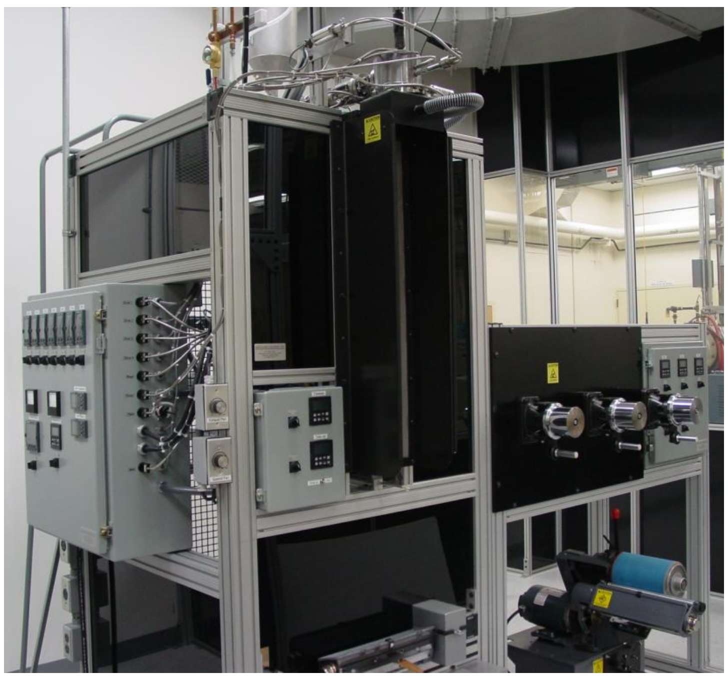
# Lignin Precursors



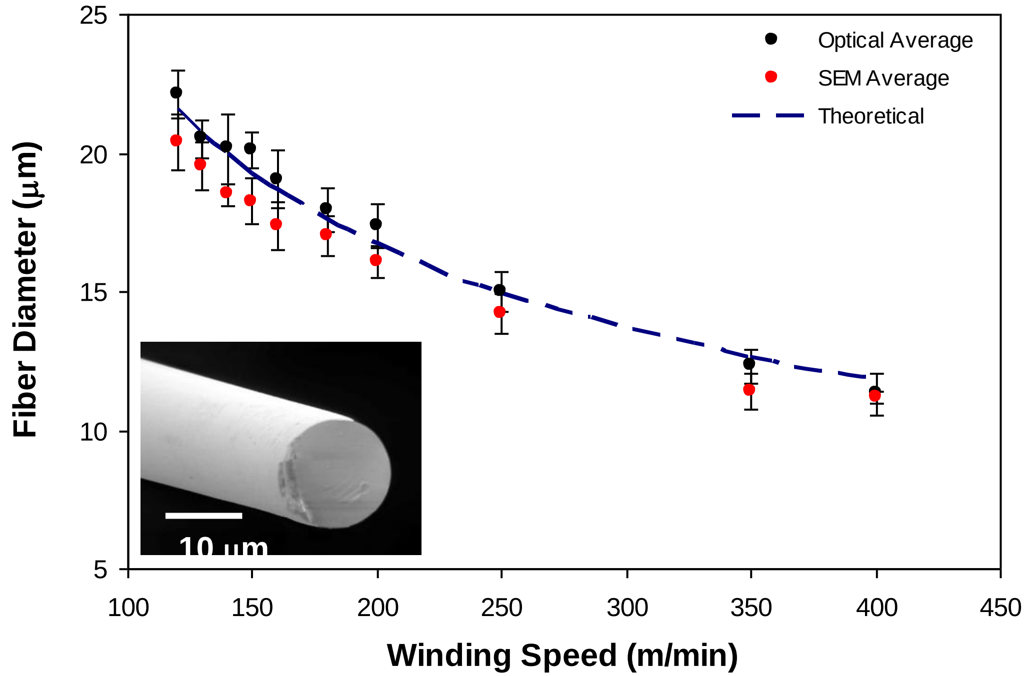

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
| $3.53 (44.8%) | $1.34 (17.0%) | $1.00 (12.7%) | $1.19 (15.1%) | $0.82 (10%) |

# Lignin Precursors

- Demonstrated that solvent-extracted, purified hardwood lignin (provided by MeadWestvaco) can be continuously melt-spun into fiber form
- Successfully Spun 12 filament tows with no additives and no problems using lignin from MeadWestvaco's "Organosolv" process
- Lignin fiber diameters were successfully varied under controlled conditions from 20 down to 10 microns.



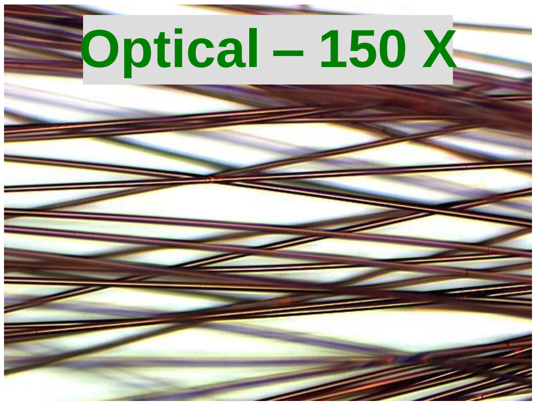
Plot of average fiber diameter vs winder speed

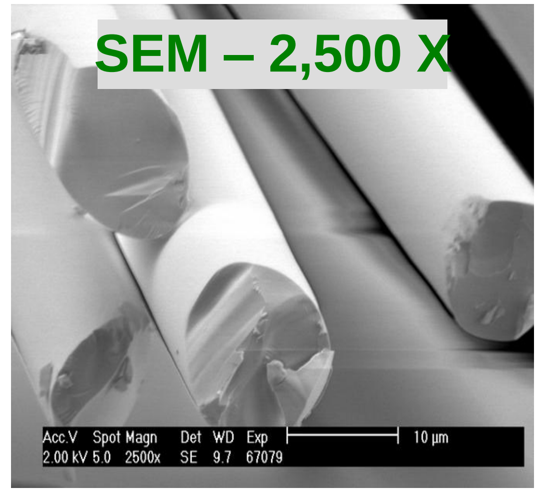


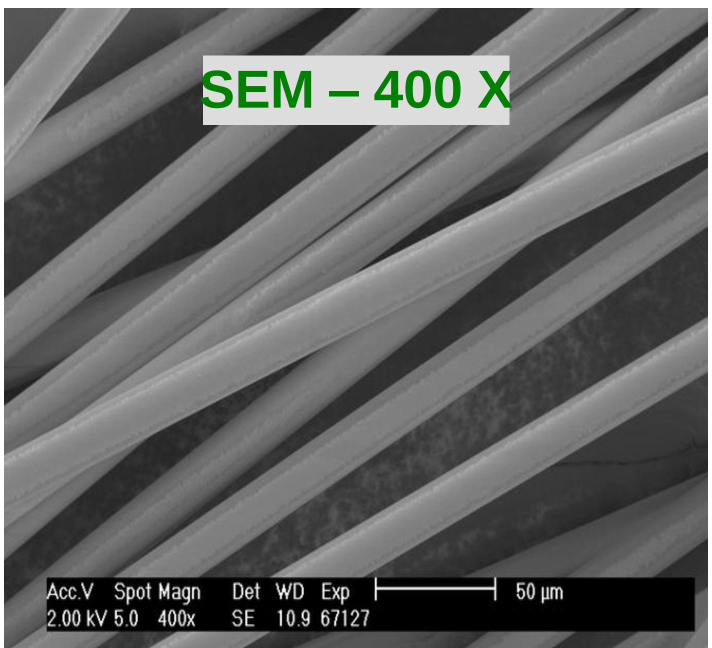

Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
| $3.53 (44.8%) | $1.34 (17.0%) | $1.00 (12.7%) | $1.19 (15.1%) | $0.82 (10%) |

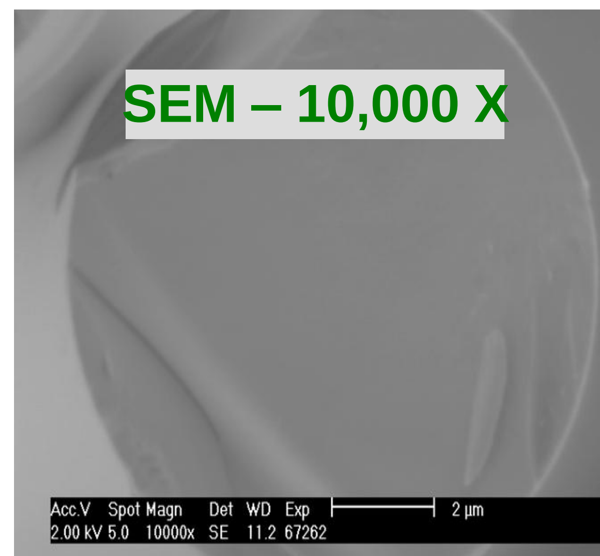
# Achieved Excellent Structural Characteristics in Melt Spun Lignin Fiber:



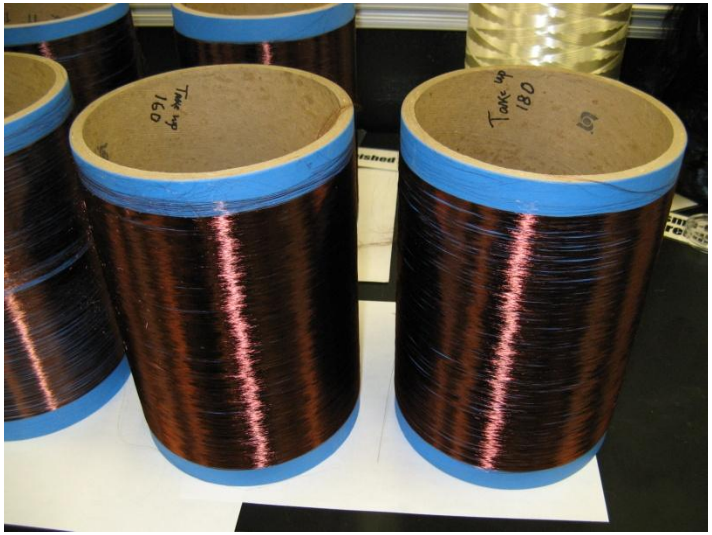




12-filament fiber spun from solvent-extracted hardwood lignin (HWL-SE1)

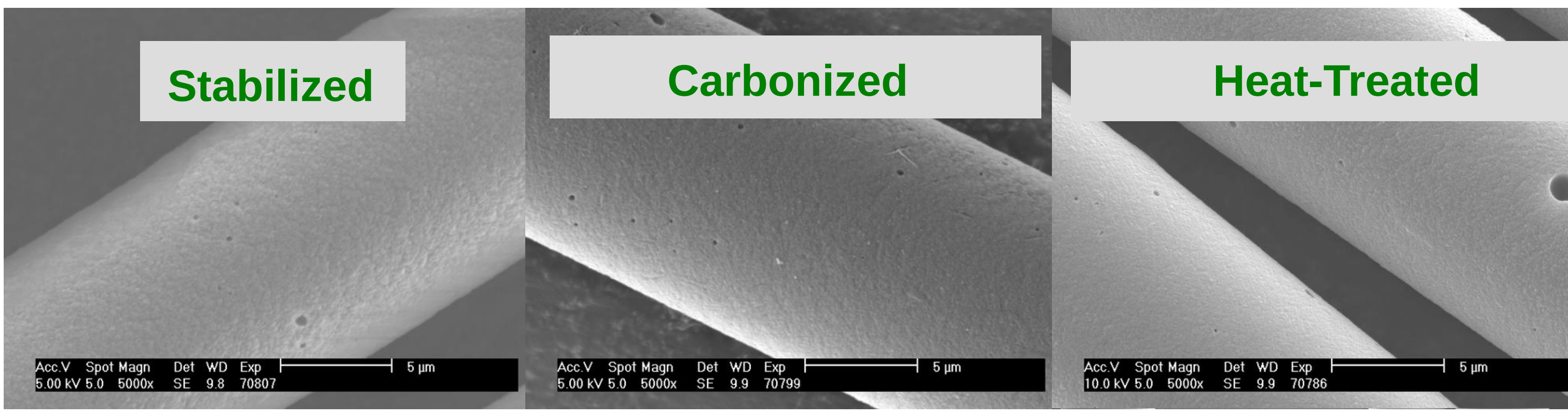


# Lignin Precursors



Processed carbon fibers from a Hardwood/Softwood lignin blend.

A Hardwood lignin was used as the plasticizer for the softwood lignin.




| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
| $3.53 (44.8%) | $1.34 (17.0%) | $1.00 (12.7%) | $1.19 (15.1%) | $0.82 (10%) |

# Textile Precursors

- *Chemical Modification* of textile acrylic fibers reduces stabilization time and increases CF mechanical properties.
- Established recommended "recipes" to produce carbon fiber from chemically modified or radiated commodity textile acrylic tow
- Reduced Oxidation time from 85 min down to 50 minutes

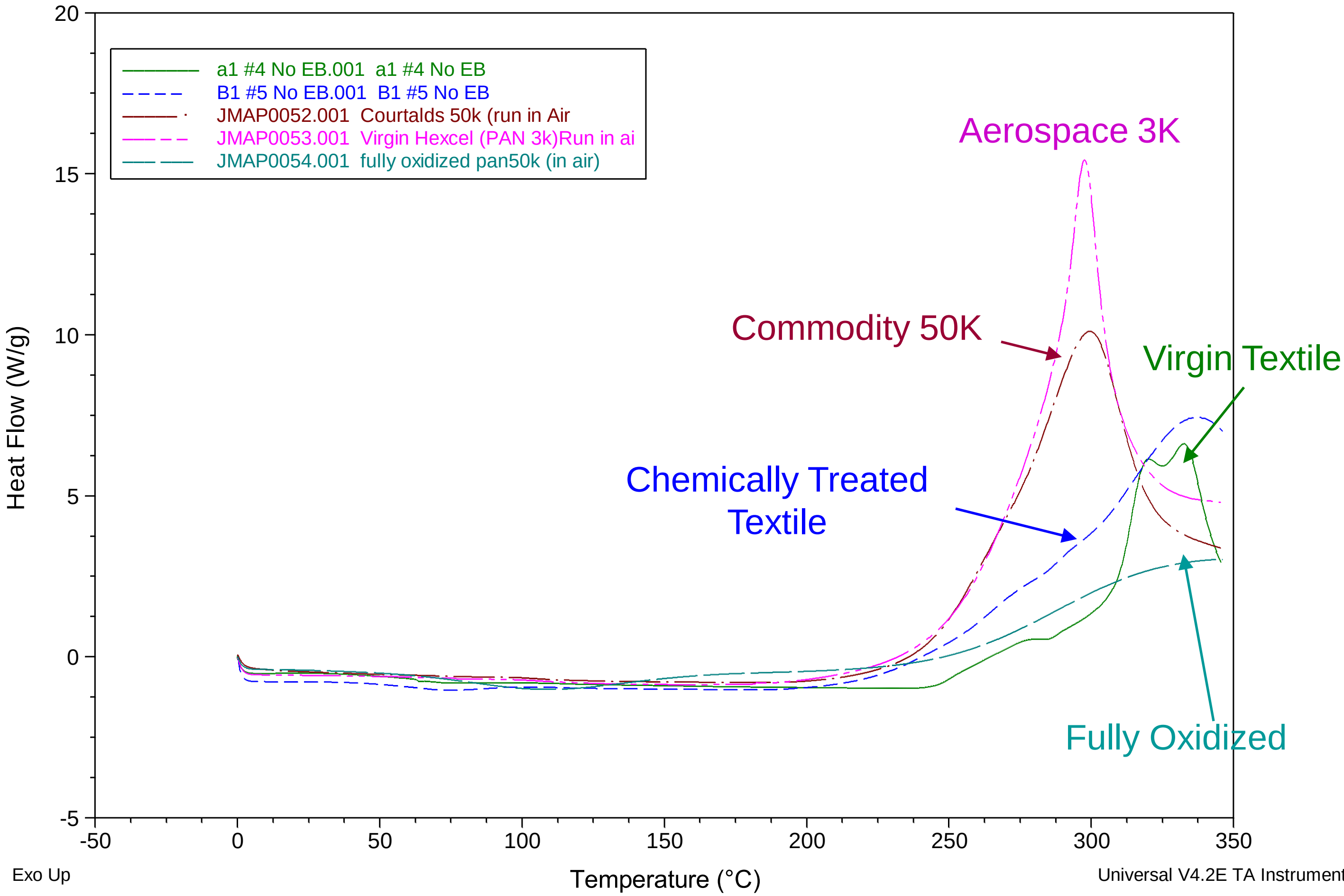
Data from Hexcel Development Project

| | TEXTILE | | CONVENTIONAL | | Program Goals GPA |
|---|---|---|---|---|---|
| | Spool 1 | Spool 2 | Zoltek Panex 33 | Fortafil F3(C) | |
| **Production Line Speed (in/min)** | | | **-** | **-** | |
| **Modulus (GPA)** | **212** | **208** | **180** | **214** | 172 |
| **Ultimate Strength (GPA)** | **2.75** | **2.71** | **2.81** | **3.35** | 1.72 |
| **Elongation at Break (%)** | **1.30** | **1.30** | **1.56** | **1.57** | 1.0 |

Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
| $3.53 (44.8%) | $1.34 (17.0%) | $1.00 (12.7%) | $1.19 (15.1%) | $0.82 (10%) |

# Textile Precursors

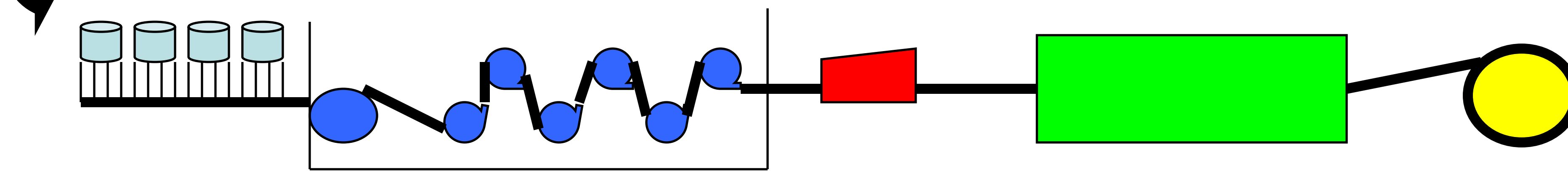



Steepest part of slope determines speed of stabilization.
Location of ramp up start & peak determine oxidative stabilization temp range.

Chemically treated textile could be undergo oxidative stabilization in less time but a slightly higher temperature.

# Textile Precursors

Starts with a large "tank farm" which polymerizes PAN and other co-monomers



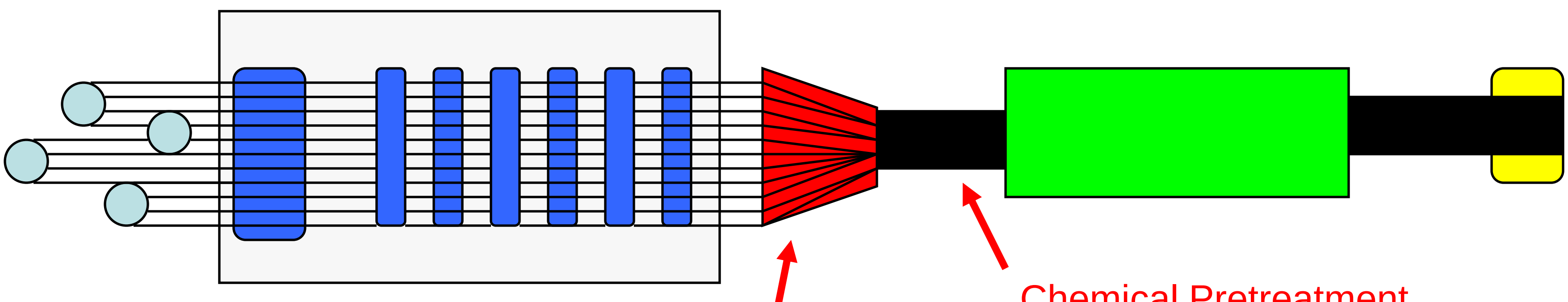
Multiple Spinnerettes

Solvent Extraction, Washing and Tensioning

Crimping

Drying with Tension

Spooling or Bailing in Bulk

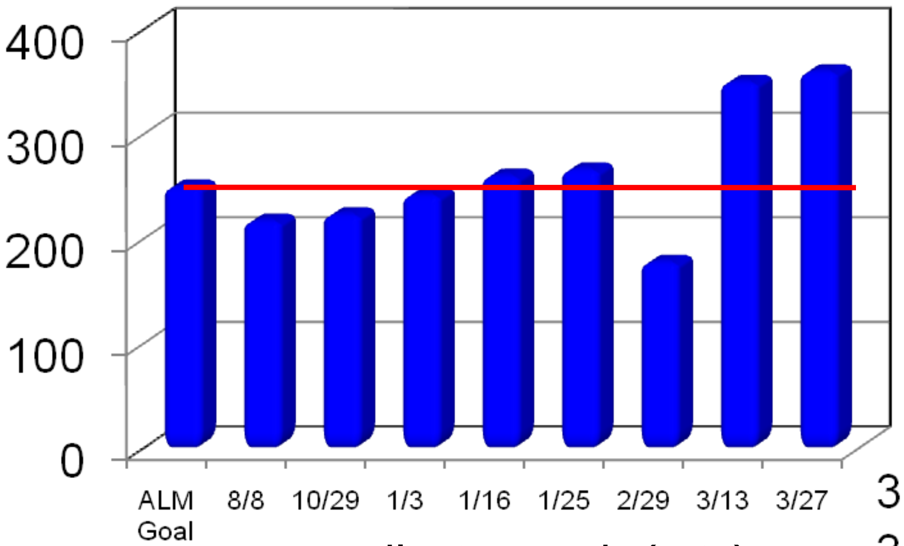


Slightly Modified versions of polymer selected

Gathering during Crimping will Be Deleted

Chemical Pretreatment

# Textile Precursors



Tensile Strength (KSI)

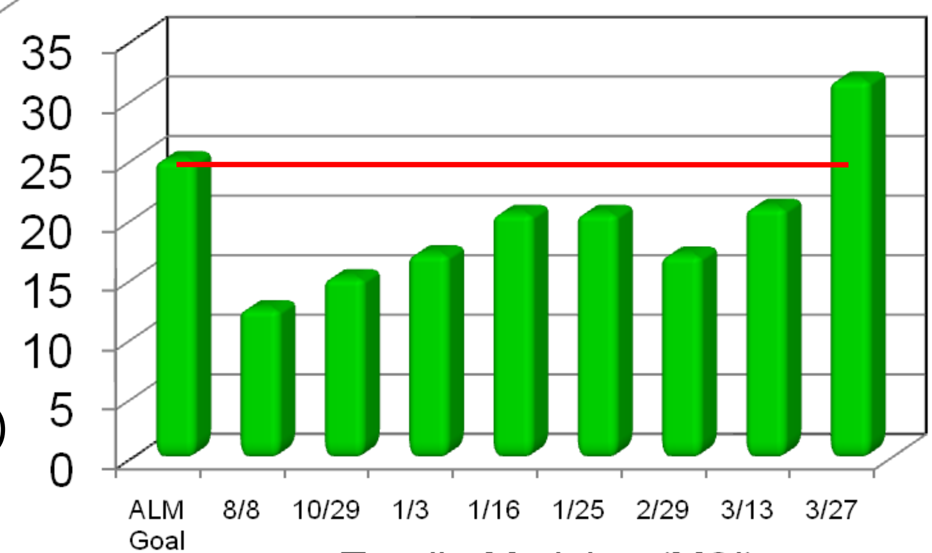
## Carbonized Textile Precursor

Target Properties:

Strength: 1.72 GPA (250 KSI)
Modulus: 172 GPA (25 MSI)

Current Properties:

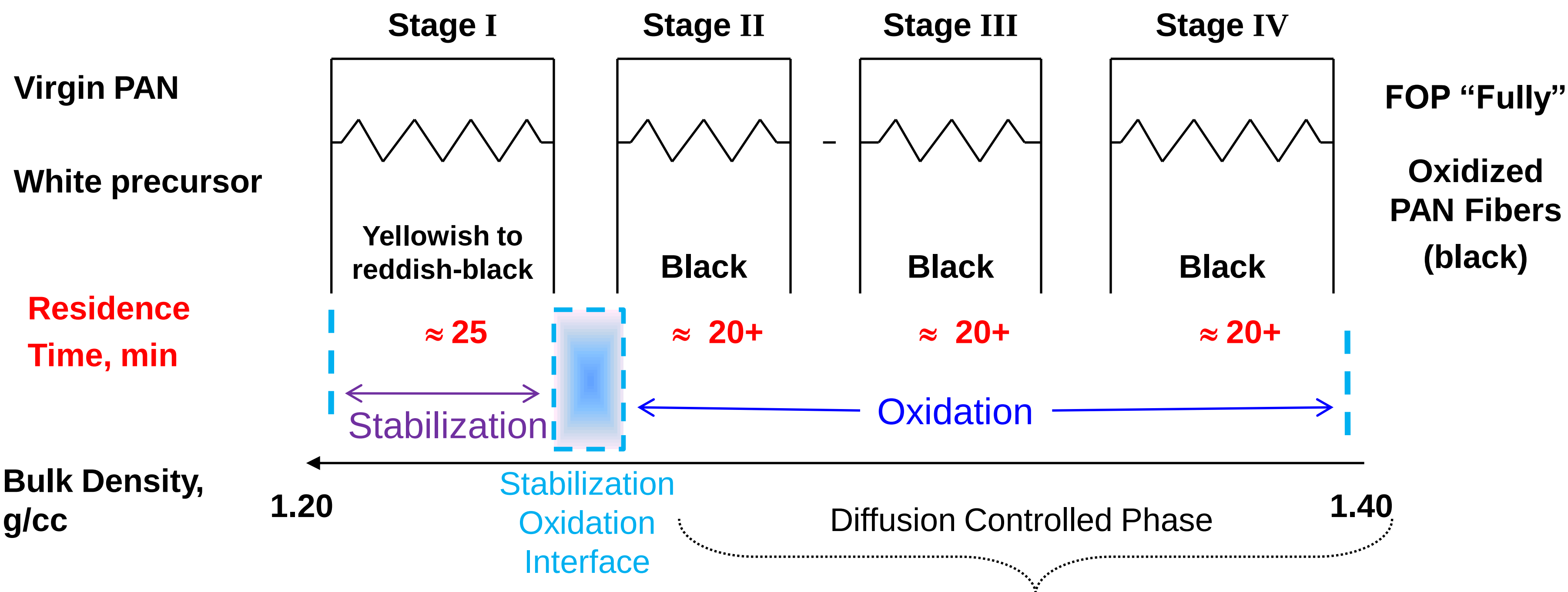
Strength: 2.41 GPA (350 ± 27 KSI)
Modulus: 218 GPA (31.7 ± 1.0 MSI)



Tensile Modulus (MSI)

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
| $3.53 (44.8%) | $1.34 (17.0%) | $1.00 (12.7%) | $1.19 (15.1%) | $0.82 (10%) |

# Oxidative Stabilization




Transforms PAN from a thermoplastic linear polymer structure to an infusible, highly condensed cyclized structure (thermoset) capable of further processing at high temperatures

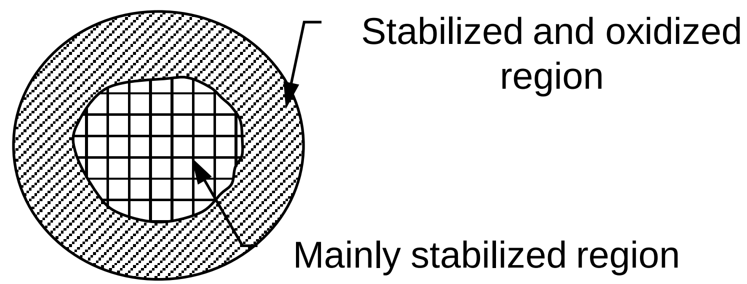
- Conducted in an oxidizing medium (e.g., air) at ~ 200 - 250°C

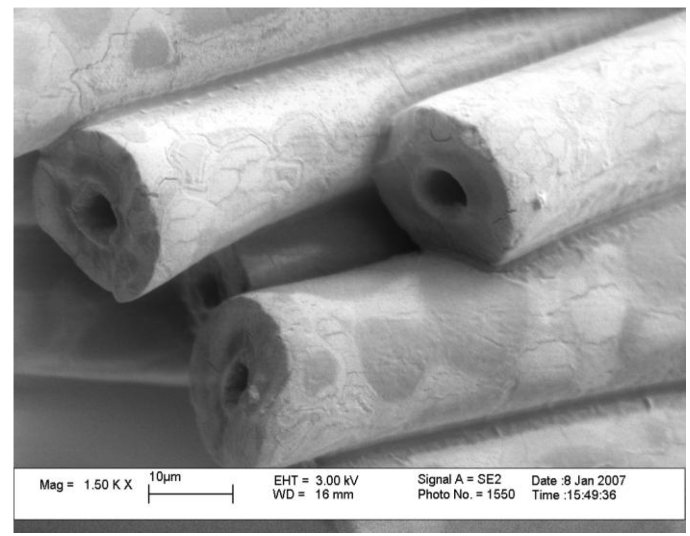
# Oxidative Stabilization

Left: Before stretching. Right: Entry end of 1st oxidation oven.

- ✓ **Oxygen needs to diffuse through the stabilized "skin"**

Single Filament Cross-Section




**Oxidative Stabilization represents 75-80% of fiber residence time and 18-20% of cost.**

Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
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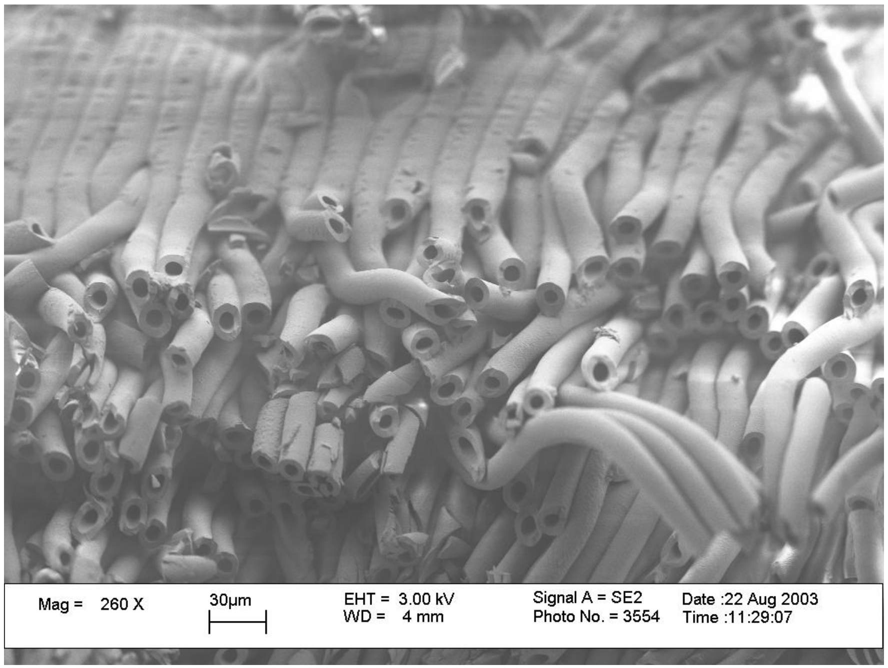
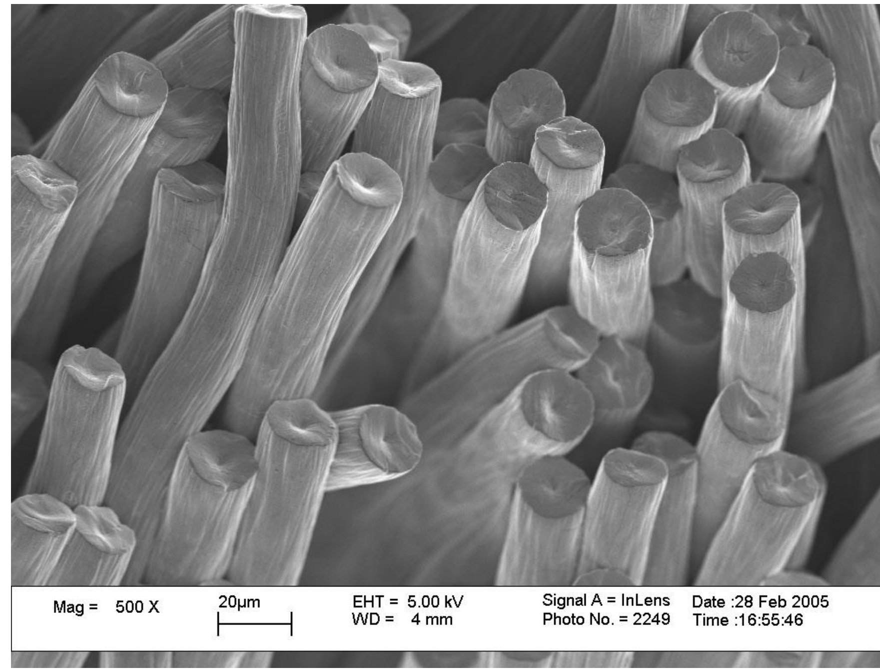
# Acid Digestion Removes Unstabilized Material




Poorly Stabilized but Typical for Many Lower Cost Fibers




Fully Stabilized Core

Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
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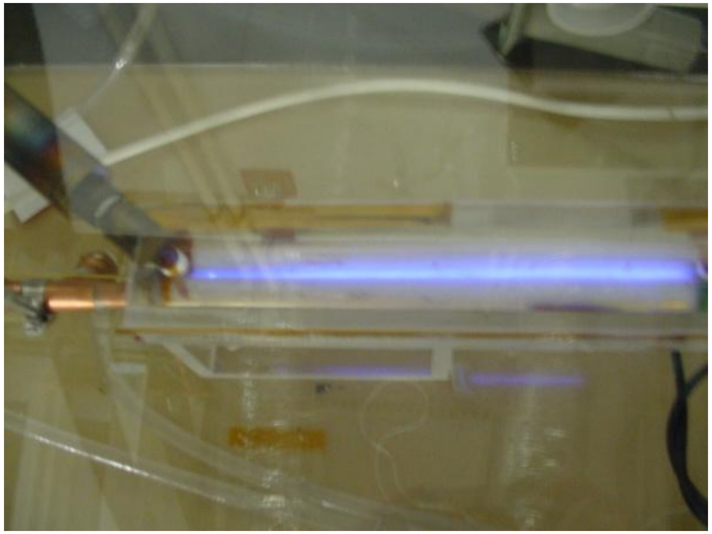
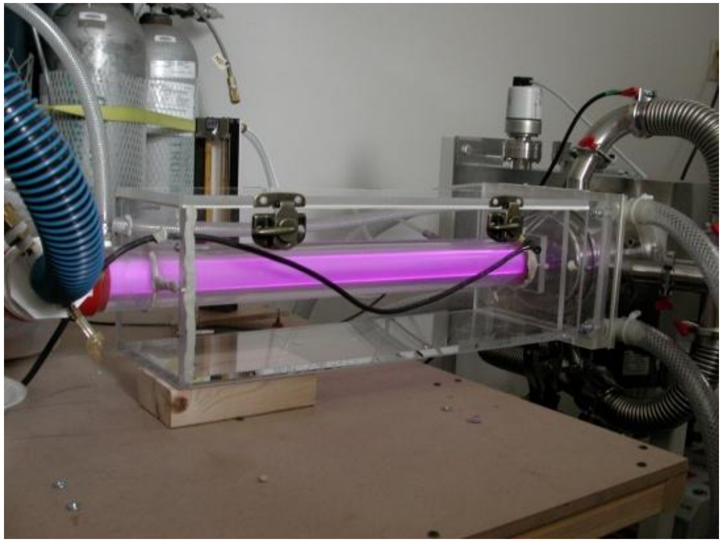
# Oxidative Stabilization





Two Early Generation Oxidation Modules

**Proprietary Oxidation Process Developed based on Non-Thermal Atmospheric Plasma**

Process able to replace later ¾ of conventional oxidation but requires the use of slightly pre-stabilized precursor.

Effort began to develop a rapid Pre-Stabilization Technique

Project Impact

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|---|---|---|---|---|
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# Oxidative Stabilization

- Objective is to stabilize (cross-link) the precursor sufficiently that it can subsequently be plasma oxidized
- Needs to be fast (high throughput) and Inexpensive (<$0.05/lb)
- Three routes investigated

| Stabilization Method | Time ReQ'd | Thermal Post Treatment | Plasma Oxidation | Total |
|---|---|---|---|---|
| [A]E-Beam | Secs | 20-26 min | 20-24 min | 40-50 min |
| [B]ultraviolet | 6-7 min | None | 20-24 min | 26-31 min |
| [C]Thermo-Chemical | 5-10 min | None | 20-24 min | 25-34 min |
| Conventional | | | | 100-120 min |

[A]Post Treatment believed to be due to over processing. Potentially may be eliminated.
[B]6-7 minutes would require a huge amount of lamps at textile line speeds.
[C]By far the easiest to implement in existing plants

## Down Select – Thermochemical (E-Beam)

Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
|---|---|---|---|---|
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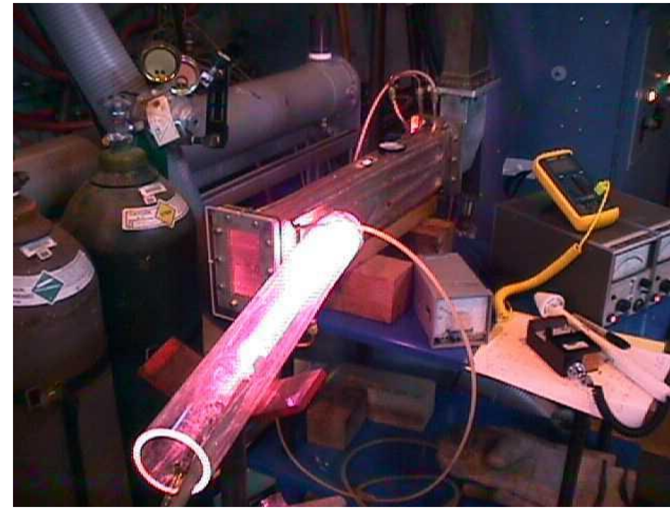
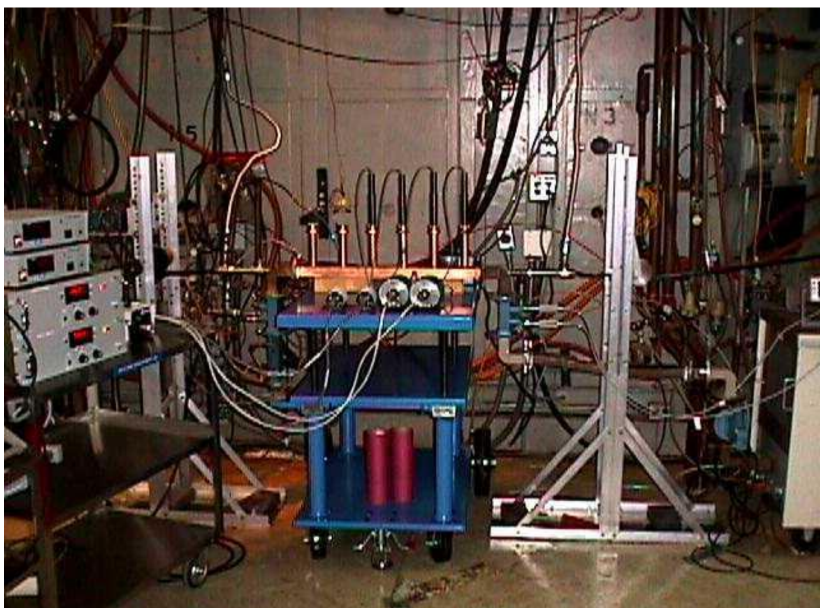
# Microwave Assisted PlasmaCarbonization

## Generation A

- VFME was discarded as primary energy source for this process.
- Single frequency microwave energy became a major player.
- Hand processed samples





## Generation B

- Microwave direct heating of carbon fiber using a long, tunable, resonant cavity.
- Capability to monitor fiber temperature
- Pre-heating of fiber with nitrogen/air to enhance microwave coupling.
- Line speed 2-4 inches/minute

Project Impact

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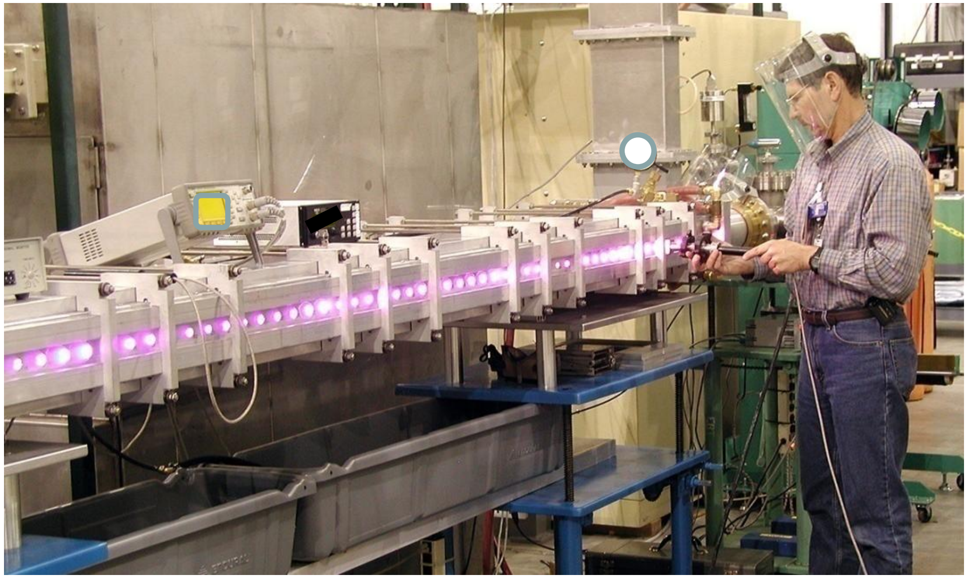
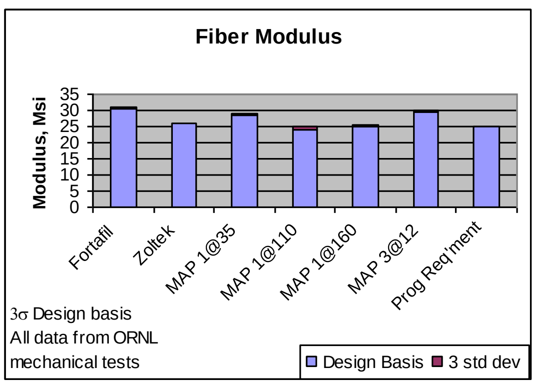
# Microwave Assisted PlasmaCarbonization

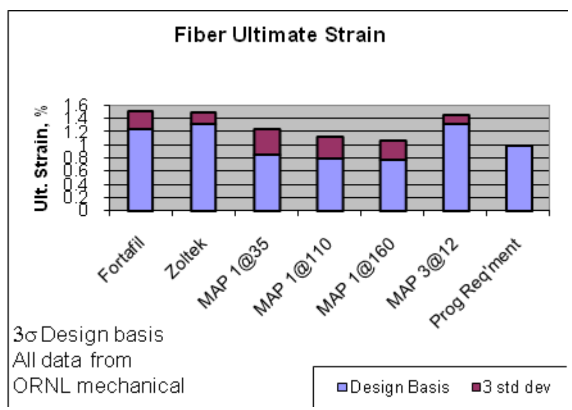


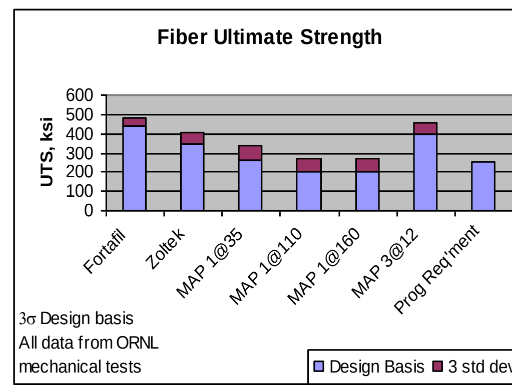
## *Met Final Milestone*

- Produced fibers for ACC testing
- Ran 3 large tows at 44in/min for > 1 hr in August 2006 with satisfactory mechanical properties

**Project paused While other Technologies Catch-up**




Project Impact

| PAN | Oxidation | Carbonization | Graphitization | ST |
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# Carbon Fiber Surface Tailoring

- Fiber surface chemistry, due mainly to treatment and sizing, is important to adhesion-sensitive mechanical properties
  - Oxygen concentration on fiber surface is very important
- Preliminary ORNL plasma surface treatment results far superior to conventional treatment results

Effect of varying plasma gas composition

| Condition | O | O/C | CV |
|---|---|---|---|
| Untreated commercial fiber | 4.7% | 0.051 | 0.21 |
| $O_3$ treated commercial fiber | 6.2% | 0.069 | 0.26 |
| AP-A | 24% | 0.42 | 0.38 |
| AP-B | 30% | 0.55 | 0.22 |
| AP-C | 29% | 0.52 | 0.40 |
| AP-D | 21% | 0.35 | 0.80 |
| AP-E | 28% | 0.54 | 0.19 |

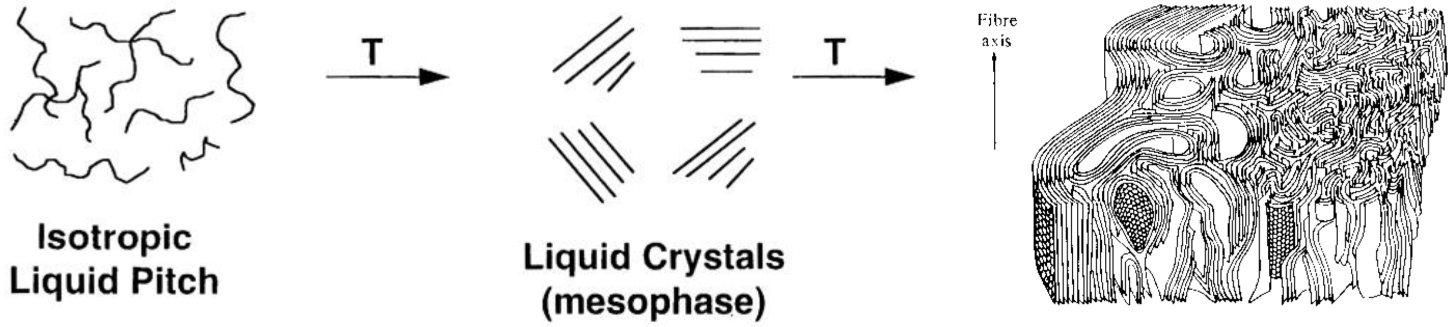
Oxygen content indicates density of available bonding sites

Data from XPS analysis

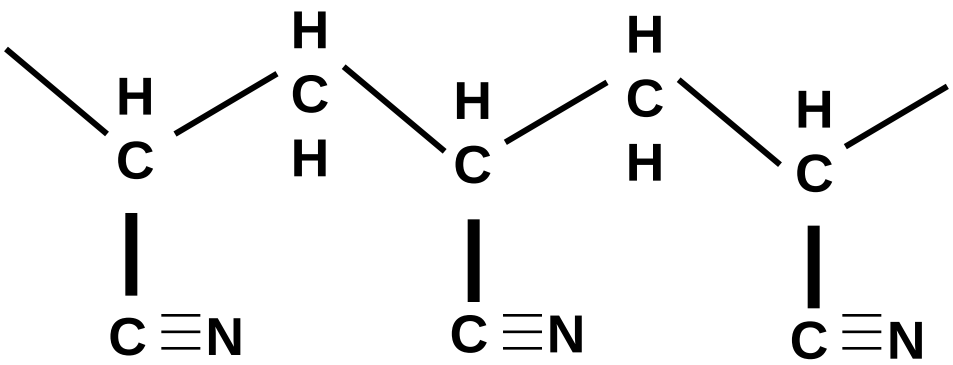
Project Impact ⟷

# Polyethelene

Pitch:

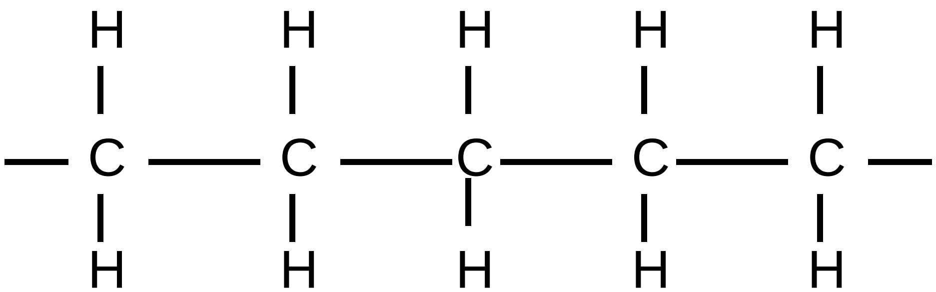



PAN:



63% C Content
48-49% Yield
Mono: $2150/MT
$ 1.09/lb
$1.31 - $2.43 /lb
Solution Spun

PE:



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

# Thank You