The Economics of Composites

focusing on

Filament Winding & Pultrusion

by

Michael L. Skinner, President

Skinner Creative, Inc.

- Creative Consulting for the Composite Industry
  - Product, Process & Business Development
  - Automation & Software
- Expertise in

  Filament Winding Fiber Placement

  Pultrusion Process Control & Automation
- On the web at www.SkinnerCreative.com

Overview of Presentation

- An economic view of the US composite markets focusing on filament winding and pultrusion
- Filament winding & pultrusion processes
- A look at budgets and costs for specific filament winding and pultrusion examples

The US Composite Market

The US Composite Market

- In the United States, about 1.7 million tons of composite products are manufactured each year.

Compare – In the US

- 100 million tons of steel are produced each year
- 60 times larger than the composites industry

Compare – In the US

- 78 million tons of lumber are produced each year
- 46 times larger than the composite industry

Compare – In the US

- 36 million tons of un-reinforced plastic are produced each year
- 21 times larger than the composite industry

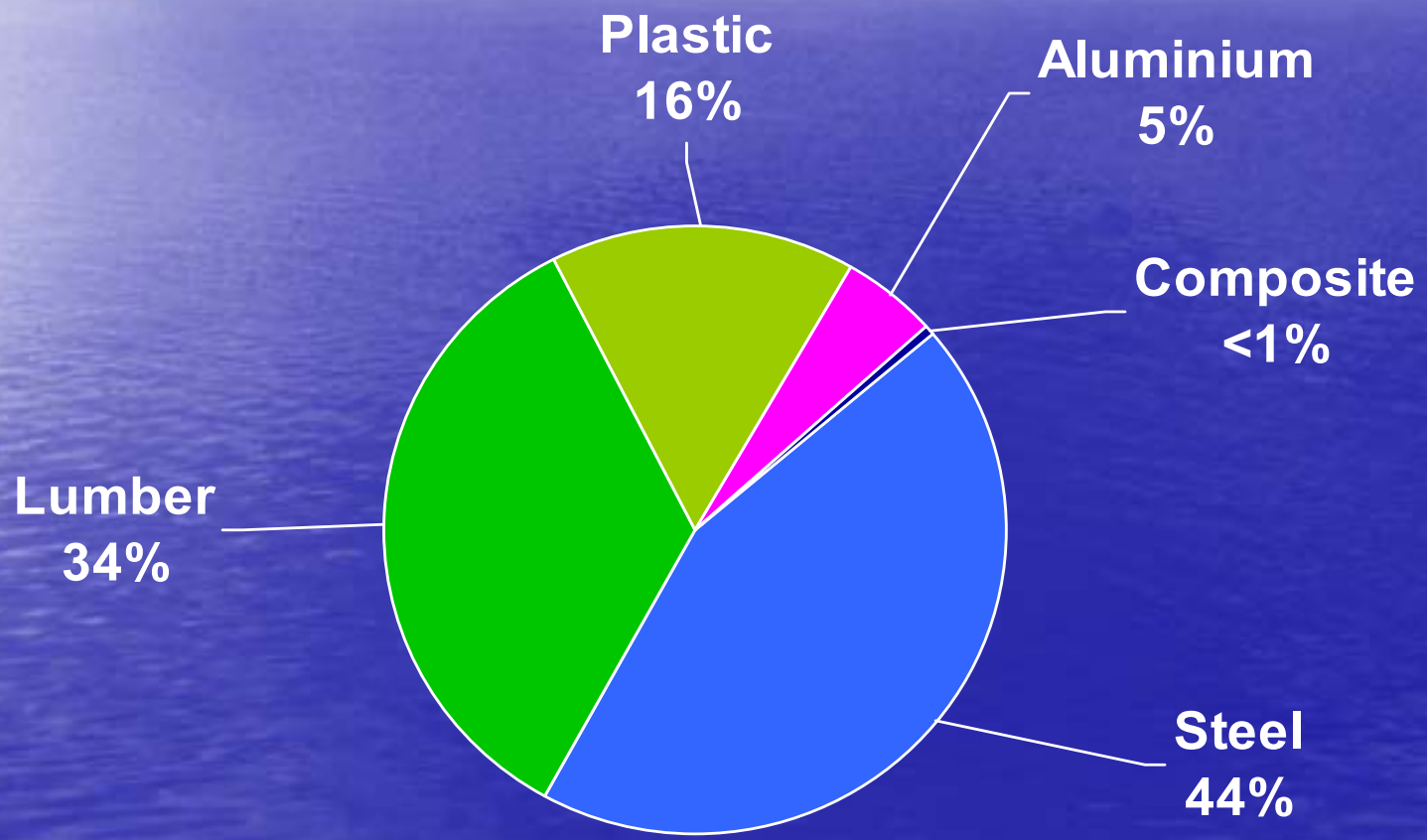
Compare – In the US

- 11 million tons of aluminum are produced each year
- 6.5 times larger than the composite industry

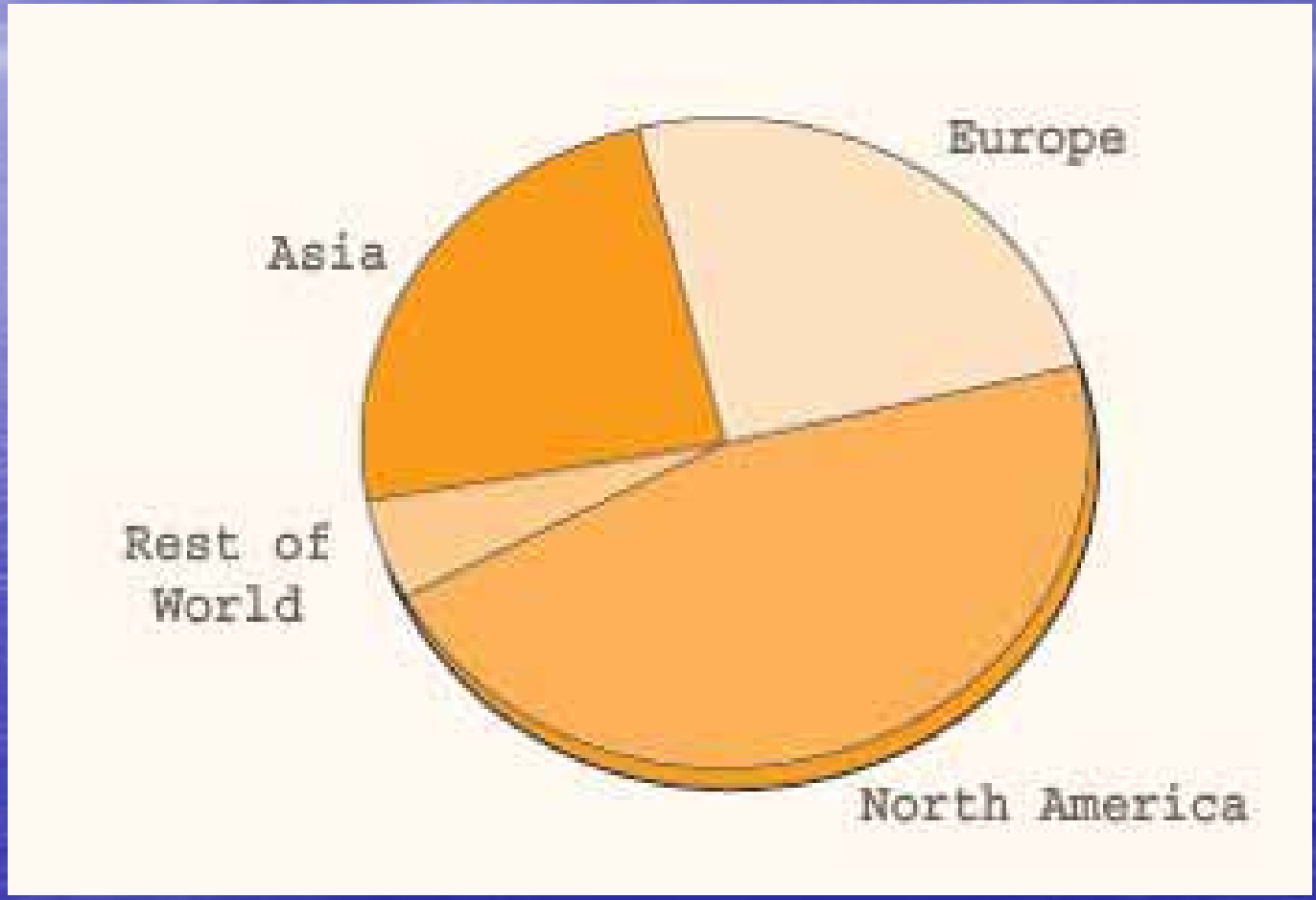
Compare – In the US

- 1.6 million tons of chocolate are produced each year
- About the **same weight** as all of the US composite industry output!

Composites Industry
Plenty of Room for Growth

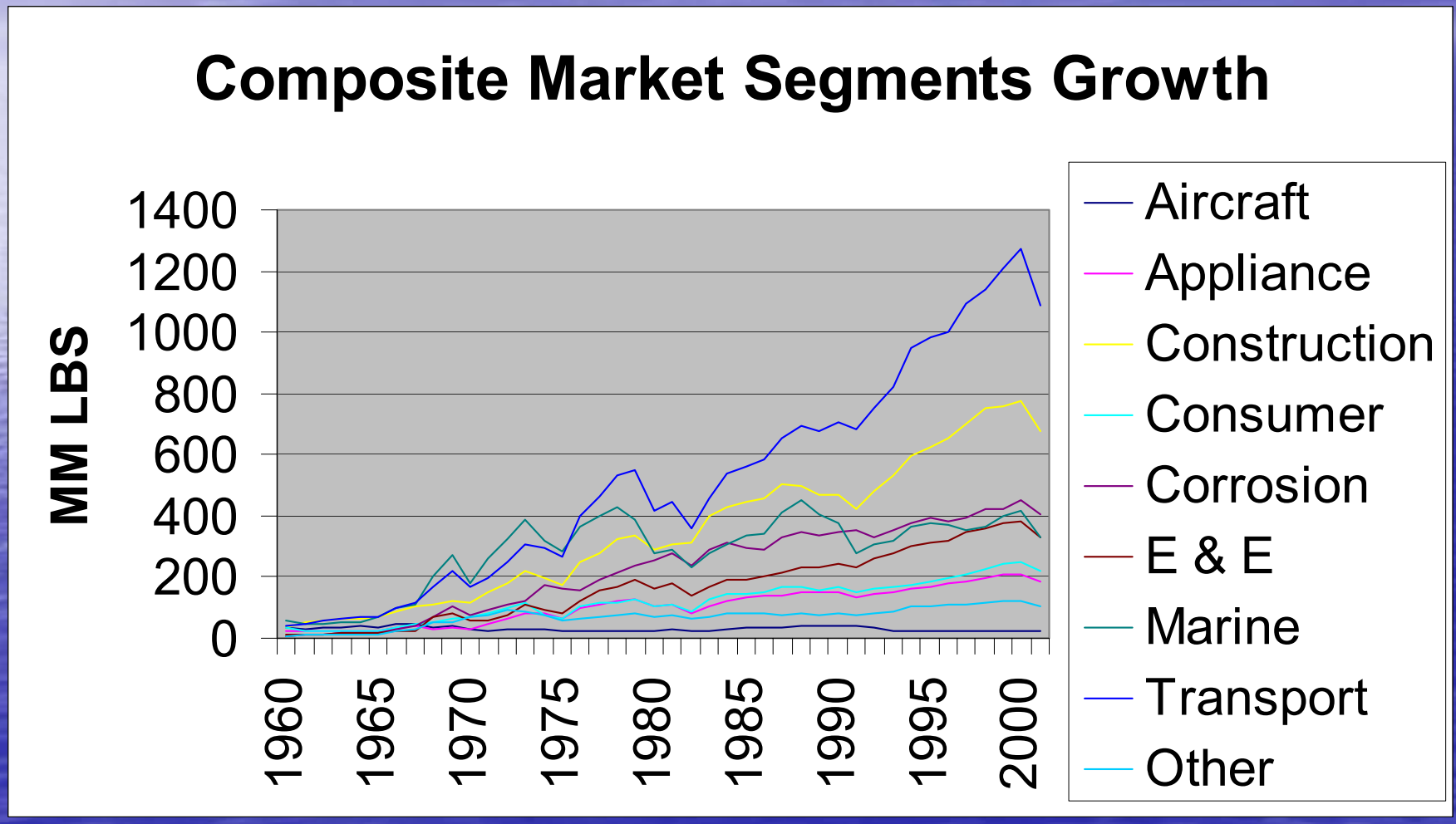


The Global Composites Market



Total 4.6 million tons – Source Owens Corning

The Composite Market
A Downturn Since 2000



From the CFA

Long Term - The Composite Market, Small But Still Growing

- Since 1960 growth has averaged 6.5%
- Growth rate has slowed in the 1990's – only 4.9%
- Forecast for 2003 – 2.8% growth
- Next 5 years about 5%/year - with Asia & Europe greater than the US
- Since 1960 there have been six cycles of downturn and recovery – currently in a new downturn
- Composites growth has been much larger than growth in the GDP ~2x

Composite Fabricators

- Approximately 2000 composite fabricators in the US
- CFA has 900 members worldwide
- Of companies in the CFA
  - Nine companies have sales over $75 million per year – about 1%
  - 270 have sales under $2 million – about 30%
- Very few public companies whose primary business is composites

Composite Fabricators

- Many composite parts are being built by companies that are not composite companies
- Continuing innovation in composite materials and fabrication methods leads to new products
- Dispersal of knowledge leads to new producers

Composite Fabricators

- Mostly small
- Mostly low to medium volume
- Almost all are private companies
- Conservative
- Proprietary
- Fewer new products and companies

- Growing
- Innovative
- Moving to new processes & materials
- Beginning high volume production
- Entering the main stream
- Consolidating (becoming larger)

Why use composites

What drives the growth of the composite industry? (Or any industry?)

- Money!
- Performance
- Suitability = Performance/Cost

Why use composites

- Performance per weight
- Corrosion resistance
- Processability
  - Combine multiple parts into one
  - Complex shapes
  - Aesthetics
- Electrical, magnetic and thermal properties
- Combinations

Obstacles to composites

- Cost
- Regulations & Bureaucracy
- Lack of support infrastructure
- Over selling – Under delivering

Composites cost more!?

- Composite costs are "Front end loaded"
  - Higher material costs
  - Higher fabrication costs
  - Higher design costs
  - Higher qualification & certification costs
- Must justify or recover these costs to be competitive

Composites cost less!?

- Lower life cycle costs
  - Reduced maintenance
  - Longer life
- Lower cost to install
- Benefits due to lower weight, higher performance, aesthetics, etc.

Regulations and Bureaucracy favor traditional solutions

- Building codes
- Federal regulations
- Unions
- Good old boys network – hard for new comers to break in
- Established solution providers will actively fight to exclude new solutions – protect their turf

Lack of support infrastructure

- The lack of bureaucracy hinders acceptance
- Lack of product and design standards
- Lack of trained labor – fabrication, installation and design
- Lack of experience and training in maintenance & repair

Why is the Composite Industry so small?

- Composites have only a narrow niche where they are cost efficient
- To significantly broaden the composite market, costs must become lower
- Composites can't compete in markets were there are "good enough" traditional solutions unless the cost is significantly lower

The Future:

- Growth
  - Slow recovery from current recession
  - Long term growth of 3-5%
  - Limited by slow down in innovation
- Consolidation
  - Fewer companies making more parts
  - Less opportunity for small companies
- Innovation
  - Most of the easy things have been done
  - More money, research & development required for new products now

Skinner's Prognostication

- Growth areas
  - Wind mill blades
  - Off shore applications – risers, choke and kill lines, tethers, etc.
  - Power poles and towers
  - New application areas – need innovation
- Slow and steady
  - Automotive
  - Marine
  - Construction
- Over sold
  - Infrastructure

Composite Fabrication Methods

Composite Fabrication Methods

- Methods that use materials in intermediate or preprocessed forms
  - Prepregs – includes resin
  - Preforms
  - Woven fabrics
  - Non-woven fabrics and mats
  - Knit fabrics
  - Stitched material
  - Braids
  - Compounds

Composite Fabrication Methods

- Methods that use materials in the most basic form
  - Roving
  - Resin
- Combinations

Composite Fabrication Methods

- Materials in Intermediate Form
  - Closed molding – matched metal tools
    - Sheet Molding Compound - SMC
    - Bulk Molding Compound - BMC
  - Lay-up
    - Preforms, stitched, braids – RTM, VARIM
    - Prepreg - Low Pressure Press
    - Prepreg - Vacuum bag / Autoclave
  - Filament Winding with prepreg tow
  - Fiber Placement with prepreg tape / tow

Composite Fabrication Methods

- Materials in Basic Form
  - Pultrusion
  - Filament Winding with wet roving
  - Chop Spray – Robotic spray / Mold
  - Chop Spray – Hand spray / Roll out

Composite Fabrication Methods

- Materials in Intermediate Form
  - Low Volume Production
  - Higher Performance Parts
  - Higher Cost

- Typical when performance and quality are the drivers

Composite Fabrication Methods

- Materials in Basic Form
  - Medium (to high) Volume Production
  - Lower Performance Parts
  - Lower Cost

    - Typical when cost is the driver

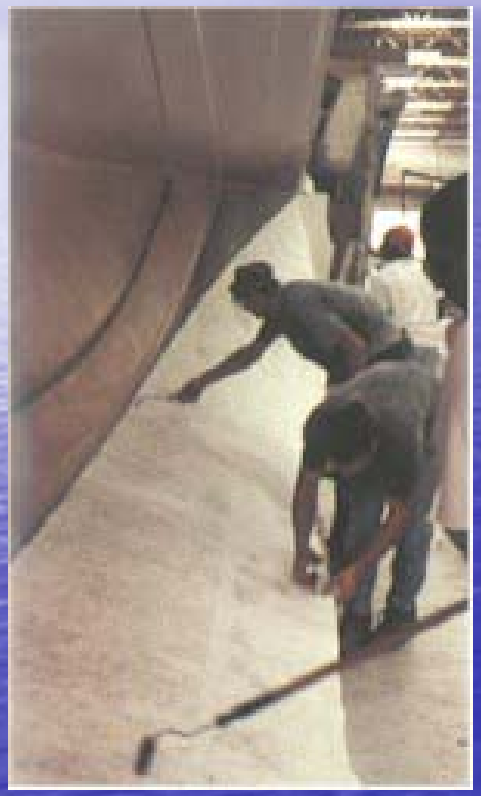
SMC / BMC
The exception to the rule

- SMC/BMC is in intermediate form – but because of the high speed, quality, processability and reliability of processing (closed mold) it is used extensively for medium to high volume production of parts – especially for automotive, bus and truck panels and interiors
- It is relatively inexpensive to convert raw materials to SMC/BMC

Composite Fabrication Methods

- Most current fabrication methods have been developed for low / medium volume production
- New methods and materials being developed for increased speed and volume of production
  - Higher speed – faster process, faster cure
  - Larger volumes – boxed product, bulk resin
  - Larger parts – bigger presses, machines

Most Composite Products are Still Low Technology



About **65%** of all composites produced use glass fiber and polyester or vinyl ester resin, via the open molding method.

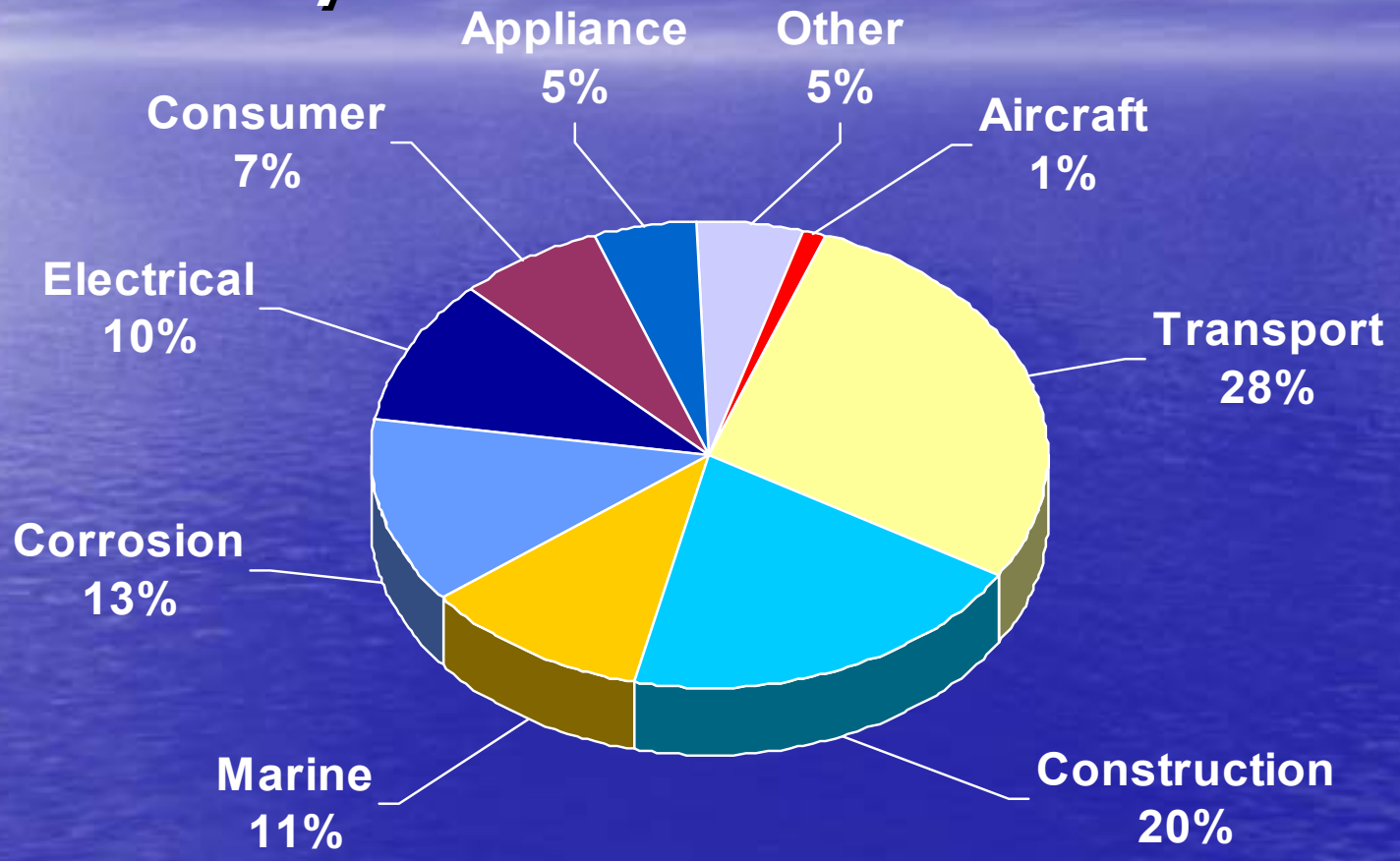
Source CFA

US Composite Market Segments

- Markets by Industry
- Markets by Fabrication Method

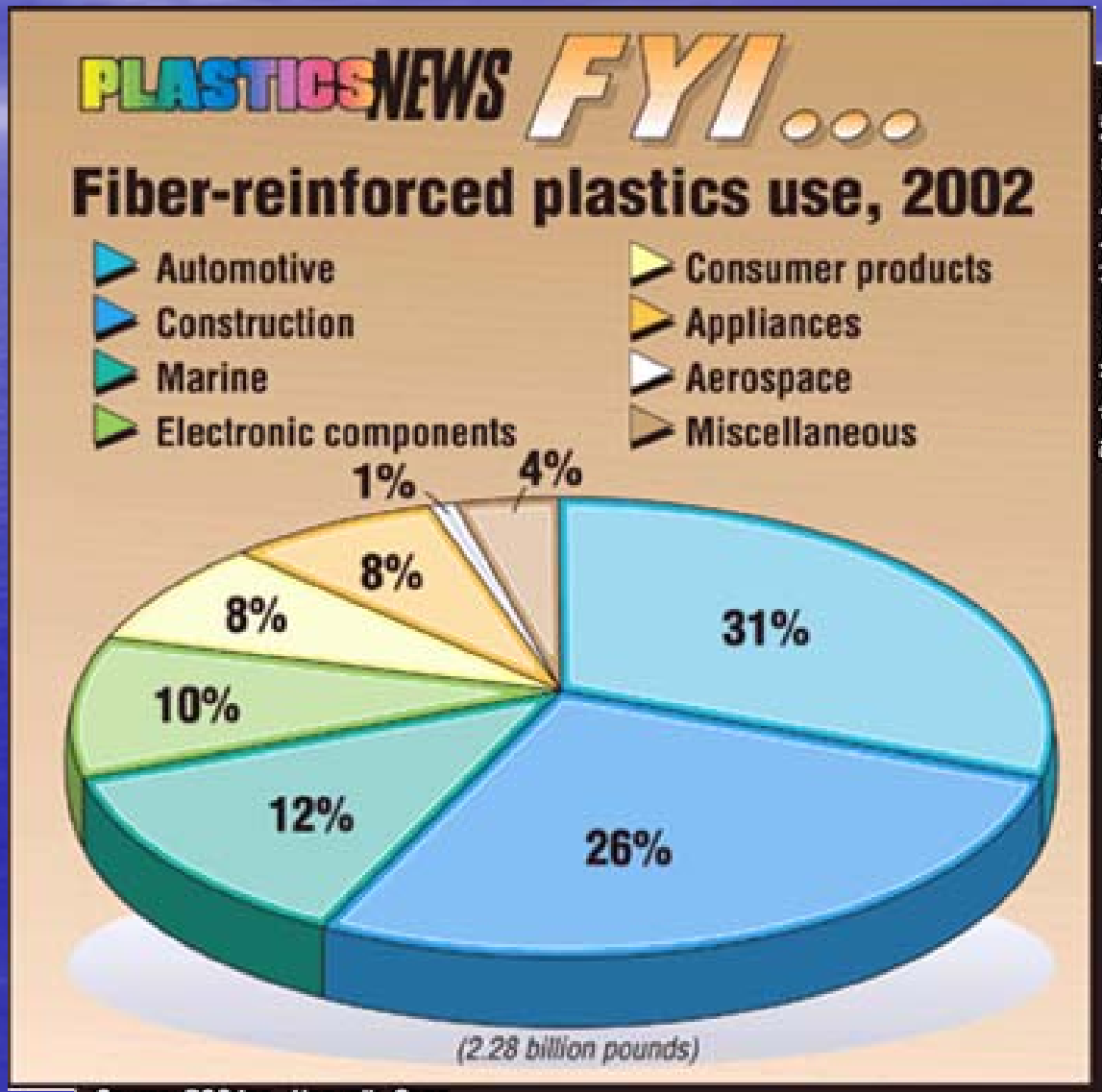
Data from CFA and others

US Composite Market by Industry



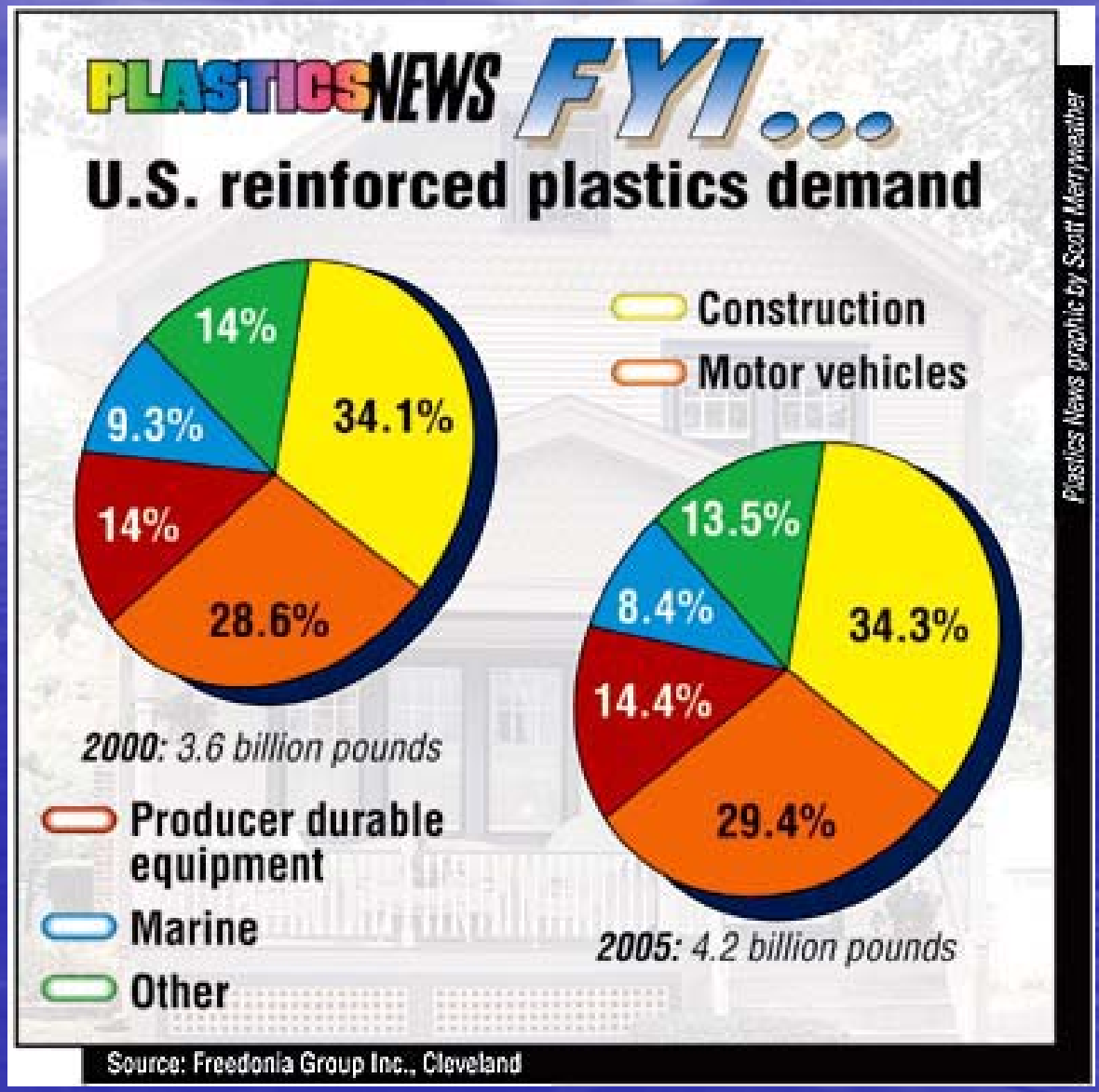
By weight

Another Estimate of the Composite Market



US Composite Market

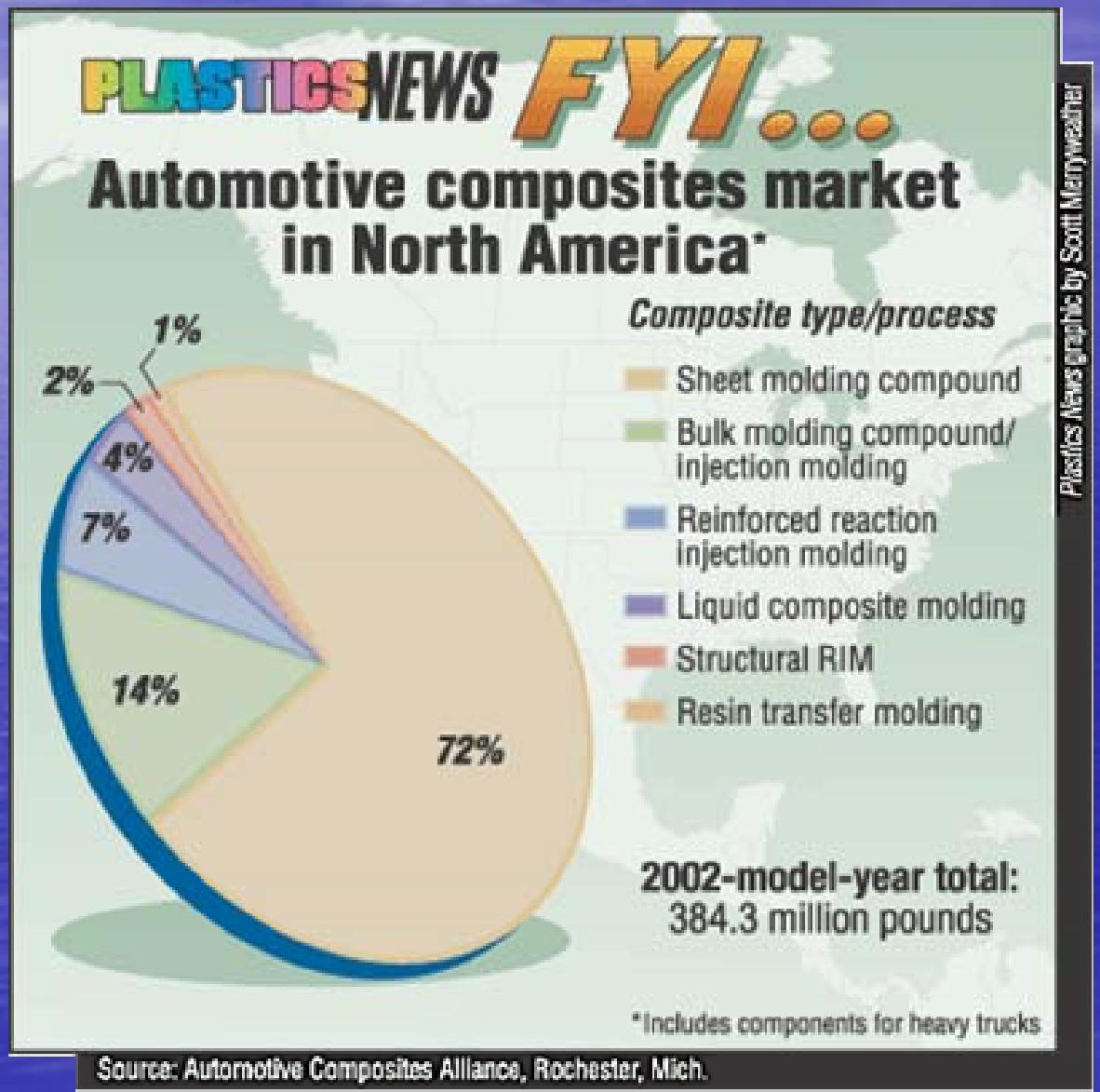
- 1.8 Million Tons in 2000
- 2.1 Million tons in 2005
- Total 16.6% Growth



Transportation – about 28%

- Large amounts of composite are used in cars, trucks, buses, railcars and other vehicles

Automotive Composite Use



Construction – about 20%

- Sanitary ware, pools, architectural features, structural components, fascia, window frames, panels, etc.

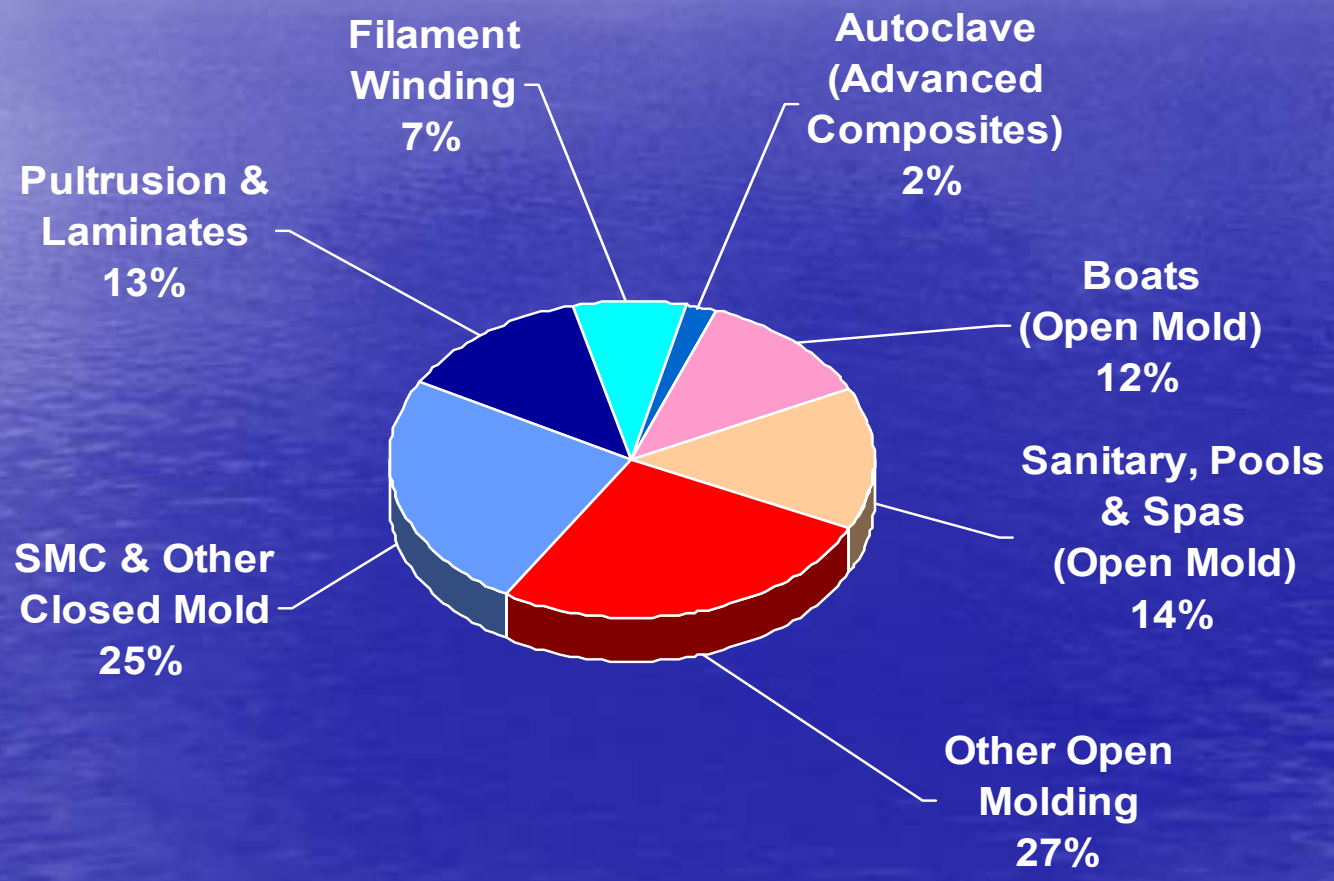
Marine – Boats – about 11-12%

- About 400,000 boats (including personal watercraft) are built in the US every year

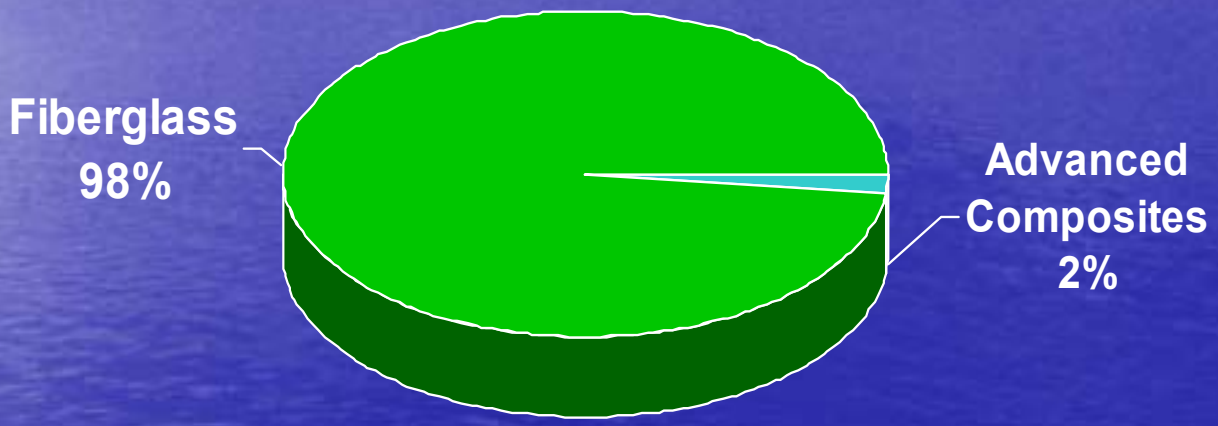
Corrosion – about 13%

- Pipes
- Ducts
- Tanks
- Liners
- Grates
- Structural
- Panels

US Composite Market by Fabrication Method

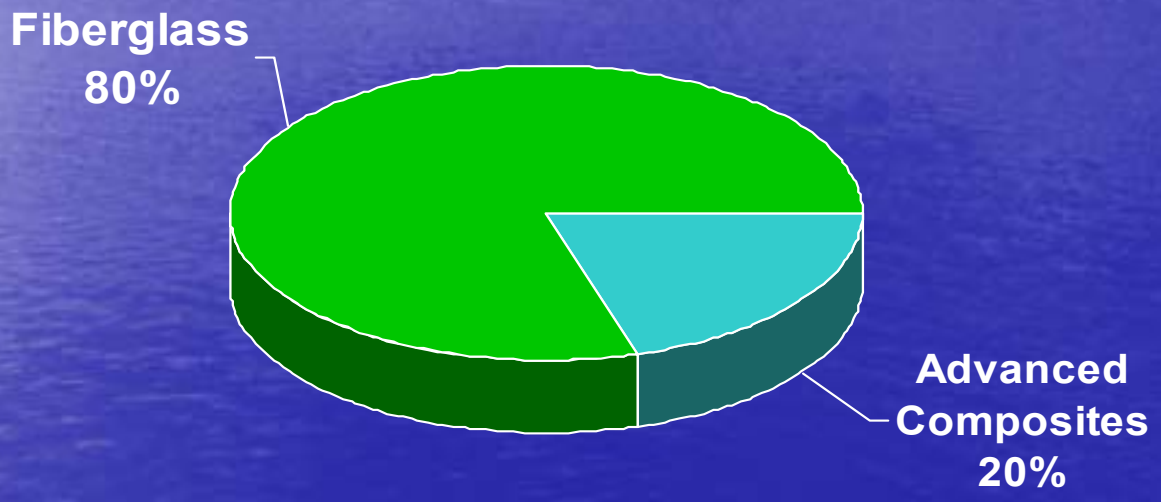


The Advanced Composite Market by Weight

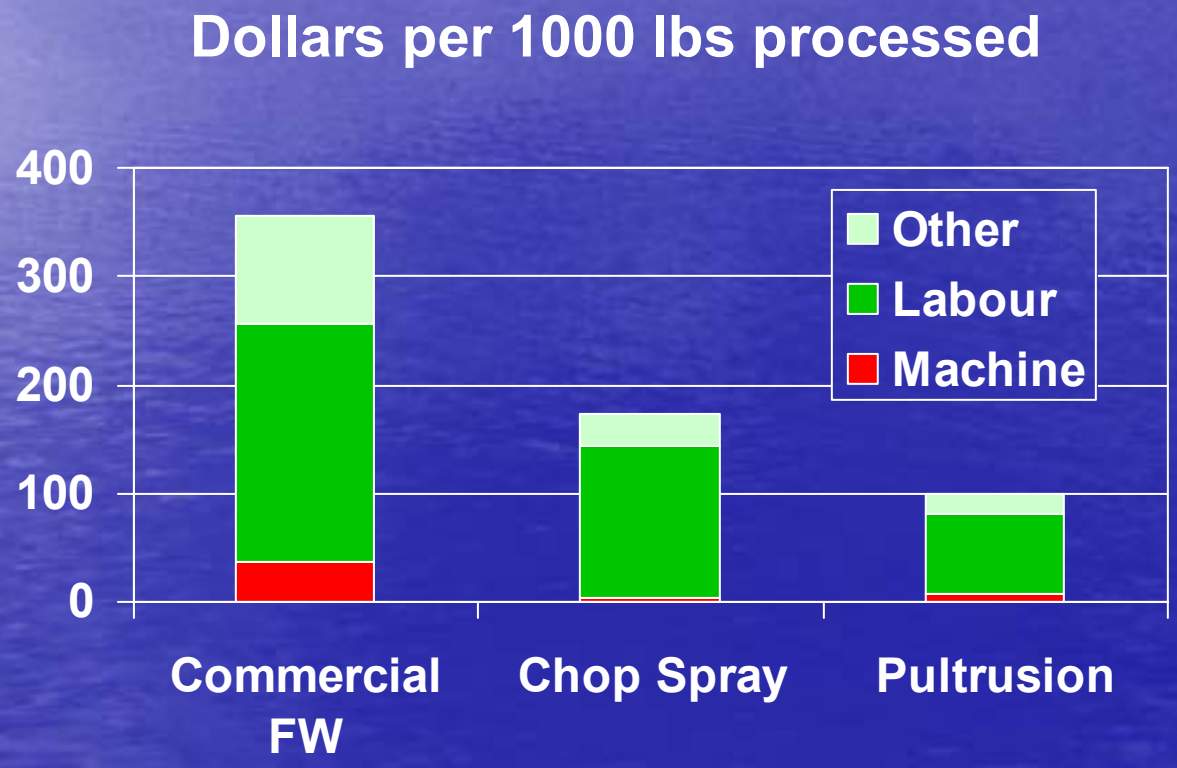


Includes carbon, aramid, boron and other advanced fibers

The Advanced Composite Market by $$



Comparison of Costs for Selected Fabrication Methods

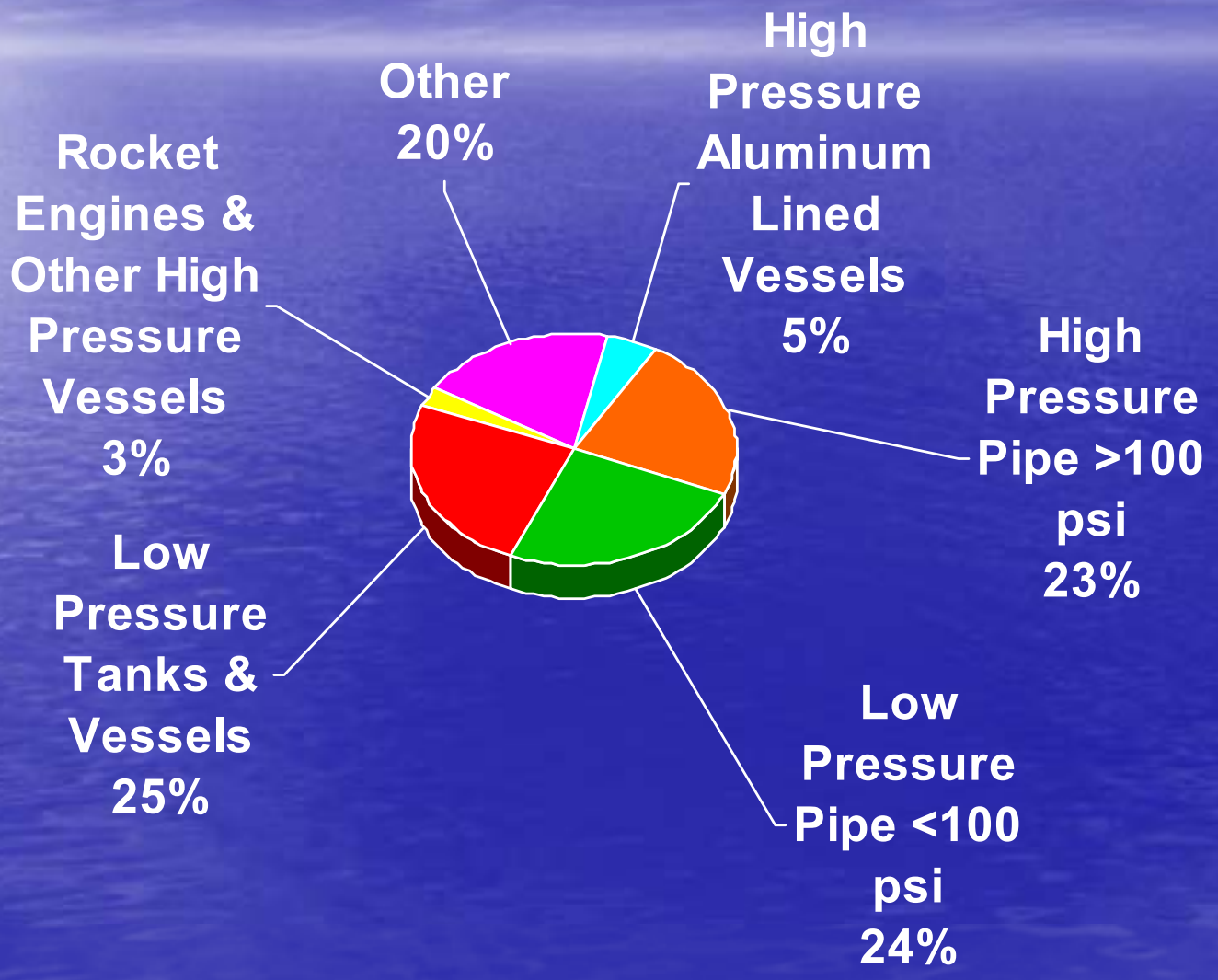


US Filament Winding and Pultrusion Markets

Why Filament Winding?

- Low cost manufacturing method
- Automated
- Repeatable
- Best for cylinder shapes
- Best for bottle shapes
- Good for figures of revolution
- Uses fibers in the best way
- Produces balanced laminate

US Filament Winding Markets



High Pressure Pipe

- About 23% of the FW market
- Used in the oil industry for line pipe and down hole tubing
- Up to 4000 psi

High Pressure Pipe

- About 300,000 joints (30 ft sections) of pipe are produced in the US each year

High Pressure Pipe

- Also used in the chemical industry

High Pressure Pipe

- Off shore oil platforms

Low Pressure Pipe

- About 25% of the FW market

Low Pressure Pipe

- Large diameter
- Pipe for waste water
- Potable water
- Ducts for ventilation
- Exhaust pipes and stacks
- Pipes for corrosive gases and liquids
- Conduits

Low Pressure Vessels

- About 25% of the FW market
- Large tanks for gasoline storage

Low Pressure Vessels

- Small tanks for water conditioning

Low Pressure Vessels

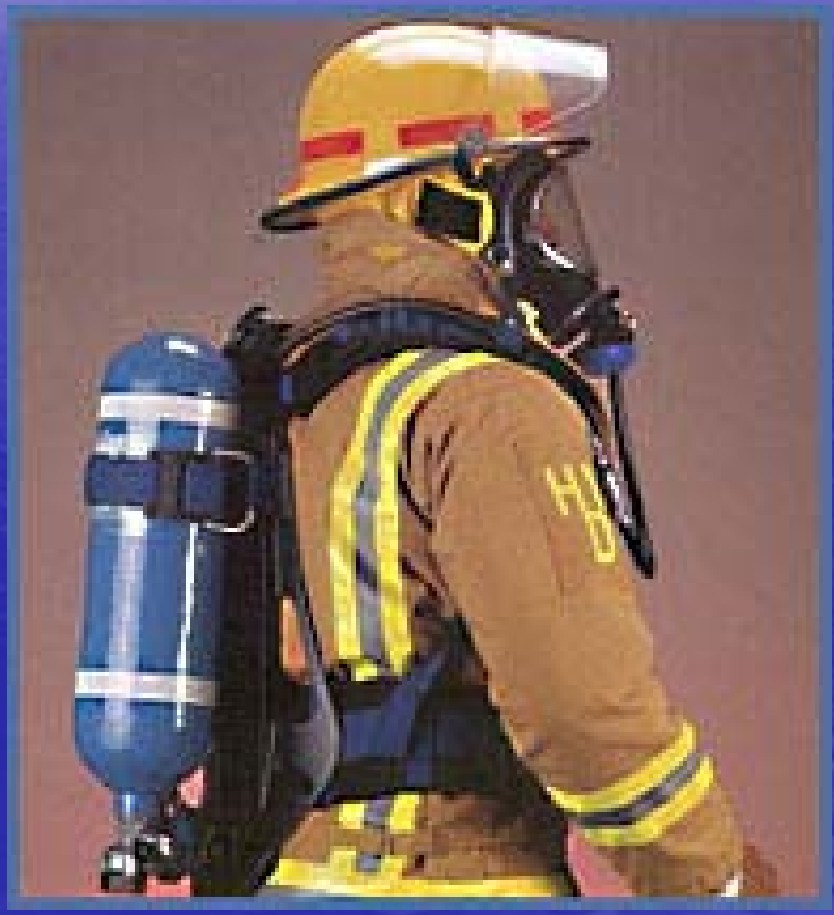
- Large tanks for corrosive liquids

Low Pressure Vessels

- Large vessels and pipes for chemical plants

High Pressure Aluminum Lined Vessels

- About 5% of the filament winding market
- About 340,000 cylinders are produced each year in the US
- SCBA, CNG, other cylinders



Rockets & Other High Pressure Vessels

- Only 3% of the filament winding market
  - Rockets
  - Reverse osmosis tanks
  - Filter vessels
  - Chemical reaction vessels

Other Applications

- About 20% of FW products – many different and creative applications
- Sporting goods – golf shafts, sticks, rackets
- Rollers, bearings, bushings
- Electrical insulators & components
- Pressure vessels, cylinders for pistons
- Utility poles, structural columns, architectural
- Filter elements – fiber only
- Bladders – elastomeric matrix

Filament Winding Markets

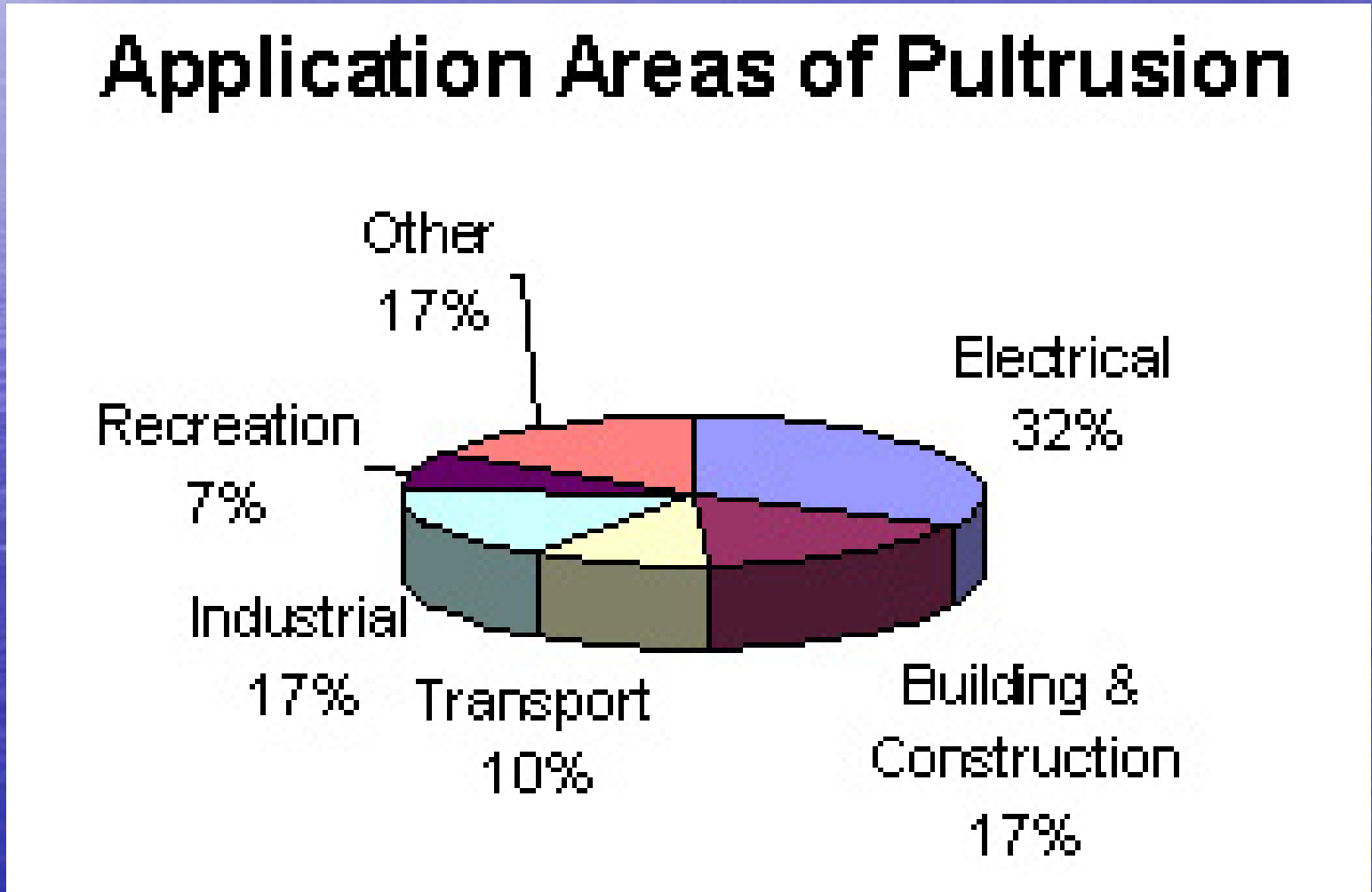
- High Cost / High Value - Epoxy
  - Rockets and aerospace
  - High pressure vessels including alum liner
  - CNG tanks – carbon fiber
  - Other carbon parts
- Low Cost / Lower Value – Polyester
  - Low pressure pipe
  - Low pressure vessels
  - Corrosion components


Boom

Why Pultrusion?

- Very low cost fabrication method
- Repeatable, highly automated
- Best for constant cross section profiles
- Best for tension products
- Must include mats or fabrics to get transverse strength

US Pultrusion Market



Major pultruded products

- Electrical insulators – cable tray
- Structural shapes
- Grating
- Cable strength members
- Ladder rails
- Window & door lineals

Filament Winding
and
Pultrusion Processes

Pick a Processes

- Pick a process that is applicable to the part
- Filament winding lends itself to pipes, bottles and shapes that are “round”
- Pultrusion lends itself to long, constant cross section objects
- Composite processing only part of the manufacturing process
- Costs are highly dependent on part complexity, post processing and part volumes

The Filament Winding Process

- How much does it cost to make a pipe, a CNG bottle, or some new hot product?
- This is a common question from potential fabricators
- Well……. it depends!

The Filament Winding Process

- Many factors affect the cost of a filament wound part - Not just the cost of the filament winding machine
  - Number of parts per year
  - Part shape and complexity
  - Raw materials – type and form
  - Mandrels and tooling
  - Curing and extracting
  - Finishing and testing
  - Certifications and standards testing

The Filament Winding Process

- Manufacturing volume
  - Number of parts per year
  - Size of parts – range of sizes
  - Number of machines – multiple spindles
  - Degree of automation
  - Number of mandrels required
  - Transport – raw materials, mandrels, parts in process, finished parts – storage
  - Extent of curing and post processing
  - Factory layout

The Filament Winding Process

- Part shape and complexity
  - Winding machine size and number of axes
    - 2 axes for pipe
    - Up to 6 axes for complex shapes
    - Computer control – software pattern generation

The Filament Winding Process

- Resin system
  - Wet winding or prepreg
    - Resin behavior – temperature control of part, resin bath and delivery system, gel time
  - Curing
- Fiber
  - Glass – inside pull, outside pull
  - Carbon – outside pull, dust containment
  - Tensioning system

The Filament Winding Process

- Mandrels
  - Simple to very complex
  - Cheap to very expensive
  - Easy to impossible

The Filament Winding Process

- Curing
  - Room temperature
  - Oven
  - Autoclave

The Filament Winding Process

- Extraction
  - Type of mandrels
  - Size of mandrels
  - Complex mandrels - very time consuming to extract and to prepare

The Filament Winding Process

- Post processing
  - Mandrel cleaning and assembly
  - Part cutting
  - Part finishing
  - Testing / Certification
  - Shipping

The Pultrusion Process

- Factors that affect the cost of a pultruded part
  - Materials – resin, roving and fabrics
  - Size of part – size of pultrusion machine
  - Required volume – multiple machines and/or multiple cavities, die plating, material handling
  - Line speed – resin additives, resin heating, cooling
  - Complexity of part – die complexity
  - Amount and kinds of mats and fabrics
  - Resin bath or resin injection
  - Post processing required – drilling, painting, etc.

Project Examples

Filament Winding Project

- What are the factors that influence cost?
- Infrastructure required
- Evaluation of the trade offs
- Highly dependent on the anticipated volume of production

Filament Winding Project
- Rollers for paper machine

- Carbon Fiber – high stiffness (low angle)
- High tolerances – very straight & round (including the OD)
- 18 feet long
- Six different dia. from 4 inch to 14 inch
- 1,000 parts of each size per year
- 6,000 parts total per year – 24 per day

Paper Roller Project

- About 1:00 to 2:30 hours to wind
- Average winding time plus prep 2:00 hr
- 4 parts per shift per spindle
- Need 24 parts per day
- Need multiple spindles, machines or shifts
- Or faster winding……

Paper Roller Project

- Use 6 to 10 rovings
- Enclosed creel required for carbon fiber
- Each tensioner ~$4000
- Use 48k tow - 4X more pounds per hour
- Multiple spindles for small diameter
  - Awkward for larger diameters
- Use 2 spindle machine – up to 32 parts per day

Paper Roller Project

- Cure time 3:00 hours
- Batch or continuous oven?
- Continuous oven more expensive
- Batch oven requires more mandrels
- Continuous flow – 4 of each part per day
- Batch process oven
- 4 mandrels for each size
- Oven large enough for 24 parts

Paper Roller Project

- Extractor for big mandrels
- Expensive
- Mandrel preparation – clean, prepare, preheat
- Storage for mandrels – extra mandrels
- Must process 3 parts per hour
- Part and mandrel transportation – crane or carts

Paper Roller Project

- Cut off saw – cut to length
- Can be expensive
- Center-less grinder (sanding machine)
- Can be expensive
- Surface finish – paint, gel coat
- Must process 3 parts per hour
- Finished part storage

Filament Winding Plant

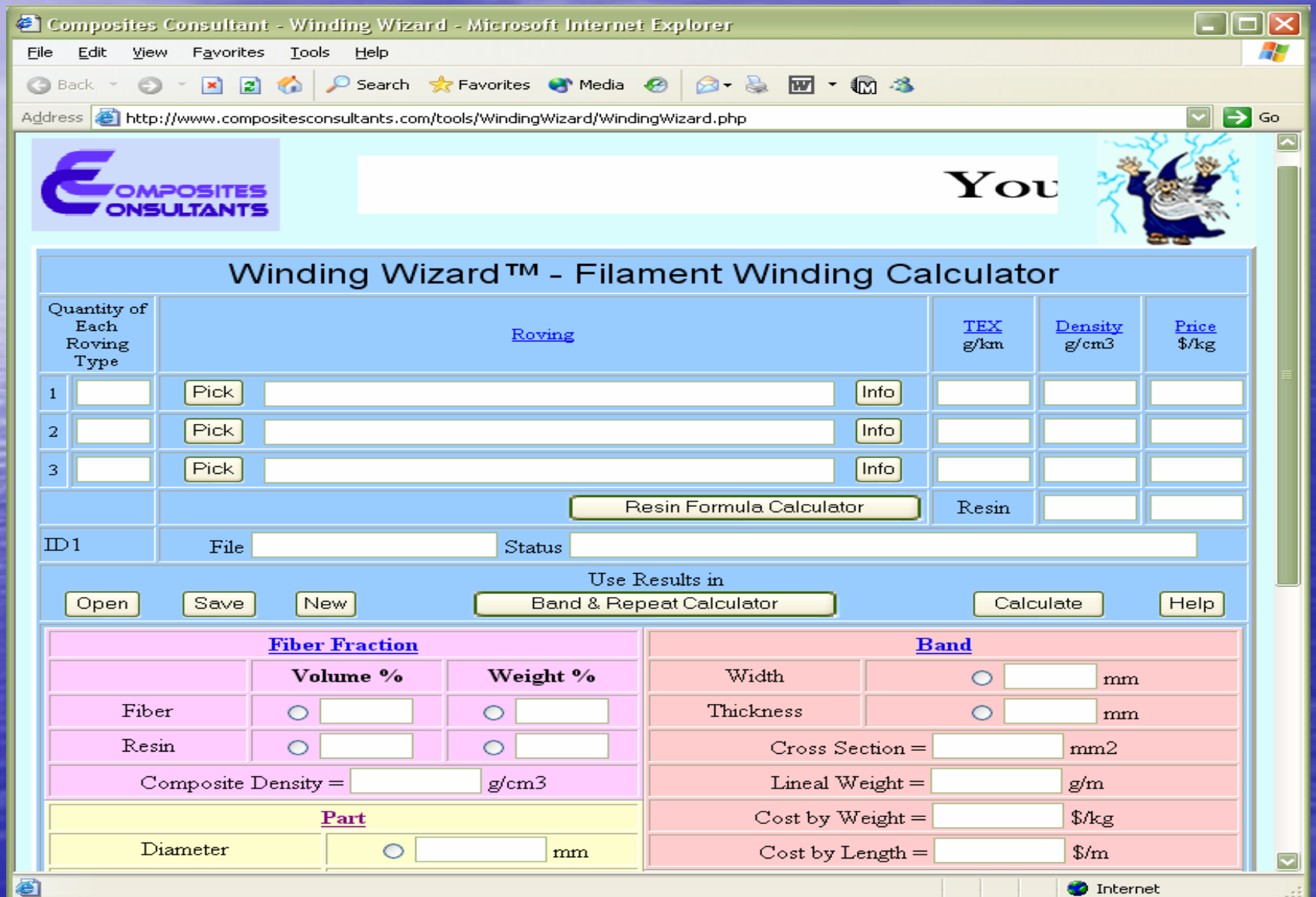
- A series of trade offs
- Driven by volume and potential volume
- Highly dependent on part complexity, raw materials, size and product mix
- Winding can be a small part of the cost

Winding Wizard ™
and
Pultrusion Calculator

Composites Consultants Web Site

- www.CompositesConsultants.com
- An online resources for composite professionals
- Categorized listings of consultants and other resources
- Online tools for Filament Winders and Pultruders
- Published by Skinner Creative, Inc.

Winding Wizard™



Winding Wizard™

- An online calculator for filament winders
- Online data base of materials
- Other calculators
  - Resin Formulas
  - Pultrusion Calculator

Winding Wizard™

- An online program to calculate material costs and time to fabricate for filament wound products
- Uses material properties – density, cost, volume or weight fraction – to calculate material cost
- Uses number of rovings and winding speed to calculate winding time

Winding Wizard™

- Calculates geodesic diameters and angle for a pressure bottle
- Calculates number of circuits required for coverage
- Calculates pattern repeat, K and Fractional M value
- Pattern number for Cadwind patterns

Example FW Problem

- Fiberglass/vinylester pipe
  - 360 inches long
  - 10 inches in diameter
  - 54 degree winding angle
  - 0.5 inch wall thickness
  - 11,600 cubic inches of composite
- How much does each part cost and how long does it take to wind?

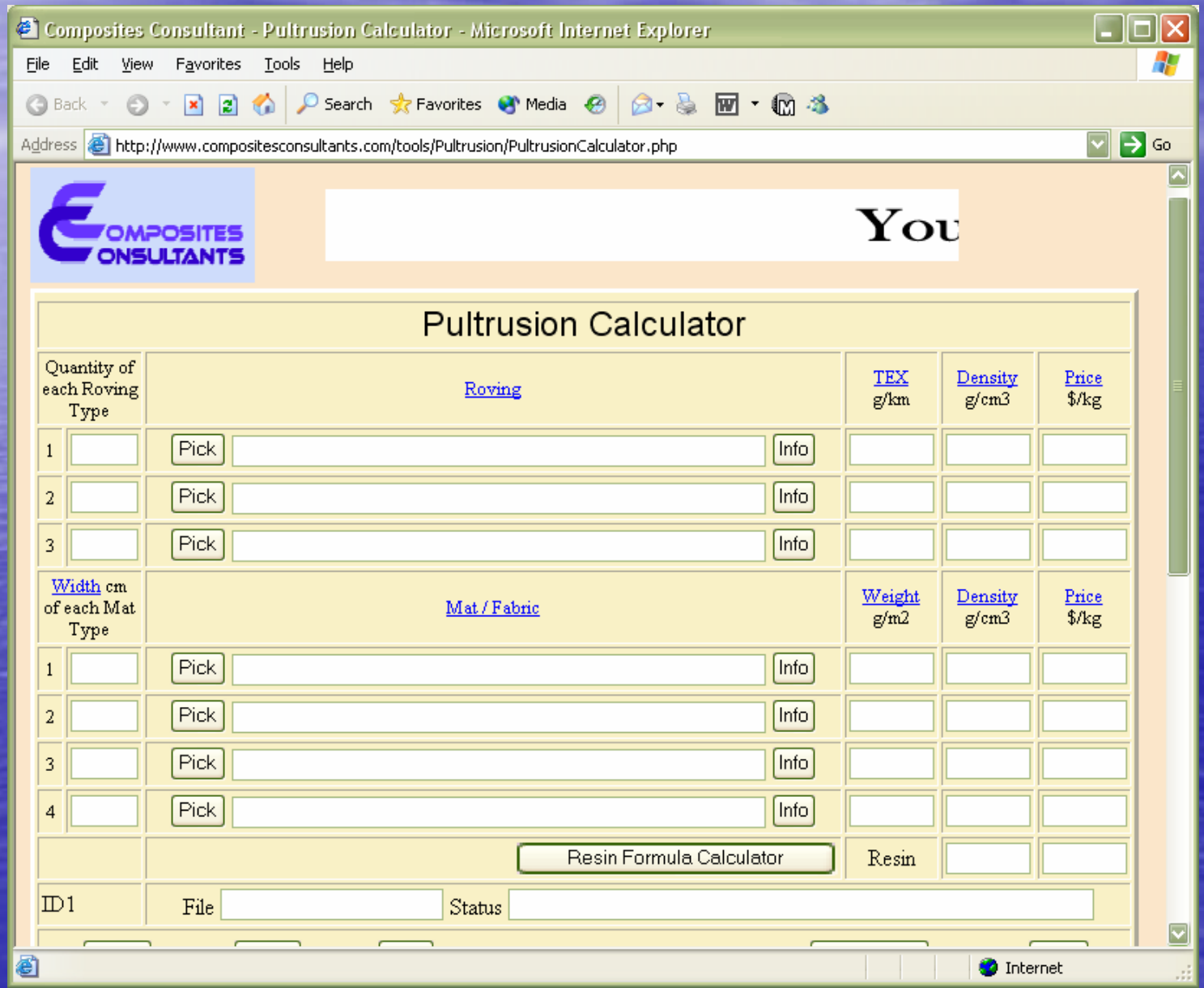
Example FW Problem

- Fiberglass/Epoxy Pressure Vessel
  - 50mm pole openings
  - 300mm diameter
  - 5kg finished composite weight
- How much does each part cost and how long does it take to wind?

Fabrication Time

- Winding speed boils down to pounds (or Kilograms) per hour
  - Faster roving speed
  - Wider and thicker bands
- Multiple spindles
- Multiple machines

Pultrusion Calculator



Pultrusion Calculator

- An online tool to calculate pultrusion parameters and costs
- Online database of materials
- Calculates fiber fraction given materials and die cross section or the die cross section required for a given fiber fraction
- Calculates cost and weight of end product

Example Pultrusion problem

Questions & Answers

Thank You

This presentation is Online at
www.CompositesConsultants.com or
www.SkinnerCreative.com

Advertising opportunities available on Composites Consultants web site