Summary of Methods used to Manufacture PMCs

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall “quality” of the composite material/part, the manufacturer must:

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)
  - Achieve uniform fiber volume fraction throughout part (e.g., avoid resin-rich or resin-starved regions)

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)
  - Achieve uniform fiber volume fraction throughout part (e.g., avoid resin-rich or resin-starved regions)
  - Eliminate void content (e.g., eliminate air bubbles)

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)
  - Achieve uniform fiber volume fraction throughout part (e.g., avoid resin-rich or resin-starved regions)
  - Eliminate void content (e.g., eliminate air bubbles)
  - Insure good adhesive bonding between fiber/matrix, between plies, and from part-to-part

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)
  - Achieve uniform fiber volume fraction throughout part (e.g., avoid resin-rich or resin-starved regions)
  - Eliminate void content (e.g., eliminate air bubbles)
  - Insure good adhesive bonding between fiber/matrix, between plies, and from part-to-part
  - Eliminate all contaminants

Preliminary Manufacturing Considerations

- To maximize the stiffness, strength, and overall "quality" of the composite material/part, the manufacturer must:
  - Maintain fiber volume fraction at ~65% (optimum fiber volume fraction depends on details)
  - Achieve uniform fiber volume fraction throughout part (e.g., avoid resin-rich or resin-starved regions)
  - Eliminate void content (e.g., eliminate air bubbles)
  - Insure good adhesive bonding between fiber/matrix, between plies, and from part-to-part
  - Eliminate all contaminants
- Steps taken to achieve these goals typically increase material and manufacturing costs…

Preliminary Manufacturing Considerations

- Composite manufacturing process(es) selected for use often depends on the premium the customer is willing to pay for reduced variability (and therefore for lighter weight and/or improved properties)

Reinell Runabout

Americas Cup Racing Yacht

Preliminary Manufacturing Consideration

A basic decision…does the manufacturer of a composite part:

Preliminary Manufacturing Consideration

A basic decision…does the manufacturer of a composite part:

- 'Preimpregnate' the fiber with resin, forming an intermediate product called 'pre-preg'. Composite part then produced in a subsequent manufacturing process using pre-preg as the 'raw' material…known as a 'dry' process. In general: the use of prepreg reduces material variability but increases costs

Preliminary Manufacturing Consideration

A basic decision…does the manufacturer of a composite part:

- 'Preimpregnate' the fiber with resin, forming an intermediate product called 'pre-preg'. Composite part then produced in a subsequent manufacturing process using pre-preg as the 'raw' material…known as a 'dry' process. In general: the use of prepreg reduces material variability but increases costs

….OR….

- Combine fiber and liquid resin matrix while simultaneously producing the (final) composite part….known as 'wet' manufacturing processes. In general: wet processes result in increased material variability but are relatively inexpensive

Preliminary Manufacturing Consideration

- Another basic decision is the physical form of the fiber reinforcement…fibers are available as:
  - Discontinuous (chopped) fibers
  - Roving spools
  - Mat fabrics
  - Unidirectional plies (layers)
  - Woven or braided fabrics

- Reinforcements in any of these forms (or some combination thereof) can be used in either pre-preg ("dry") or wet manufacturing processes.

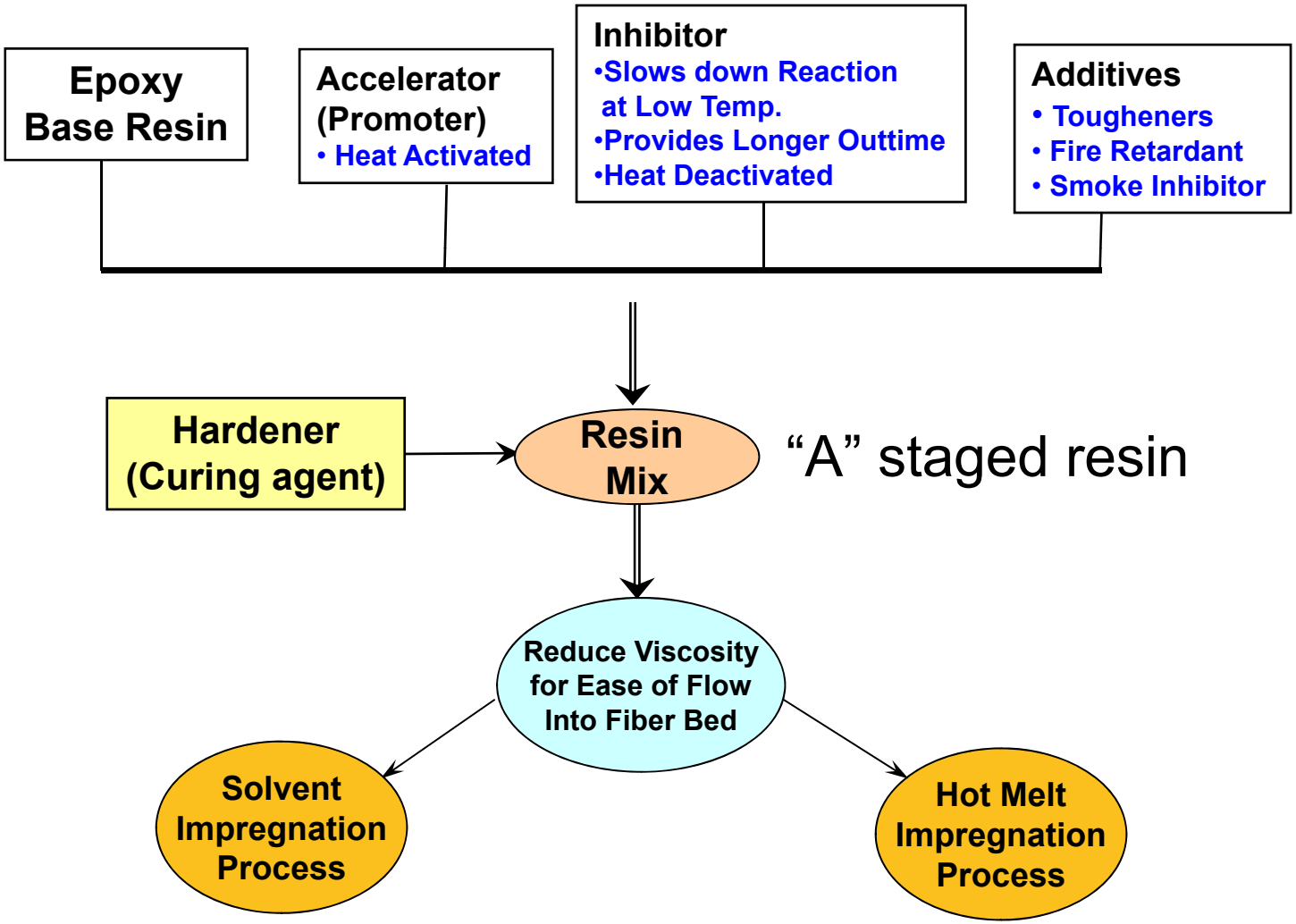
Summary of Manufacturing Methods

Following discussion divided into two categories

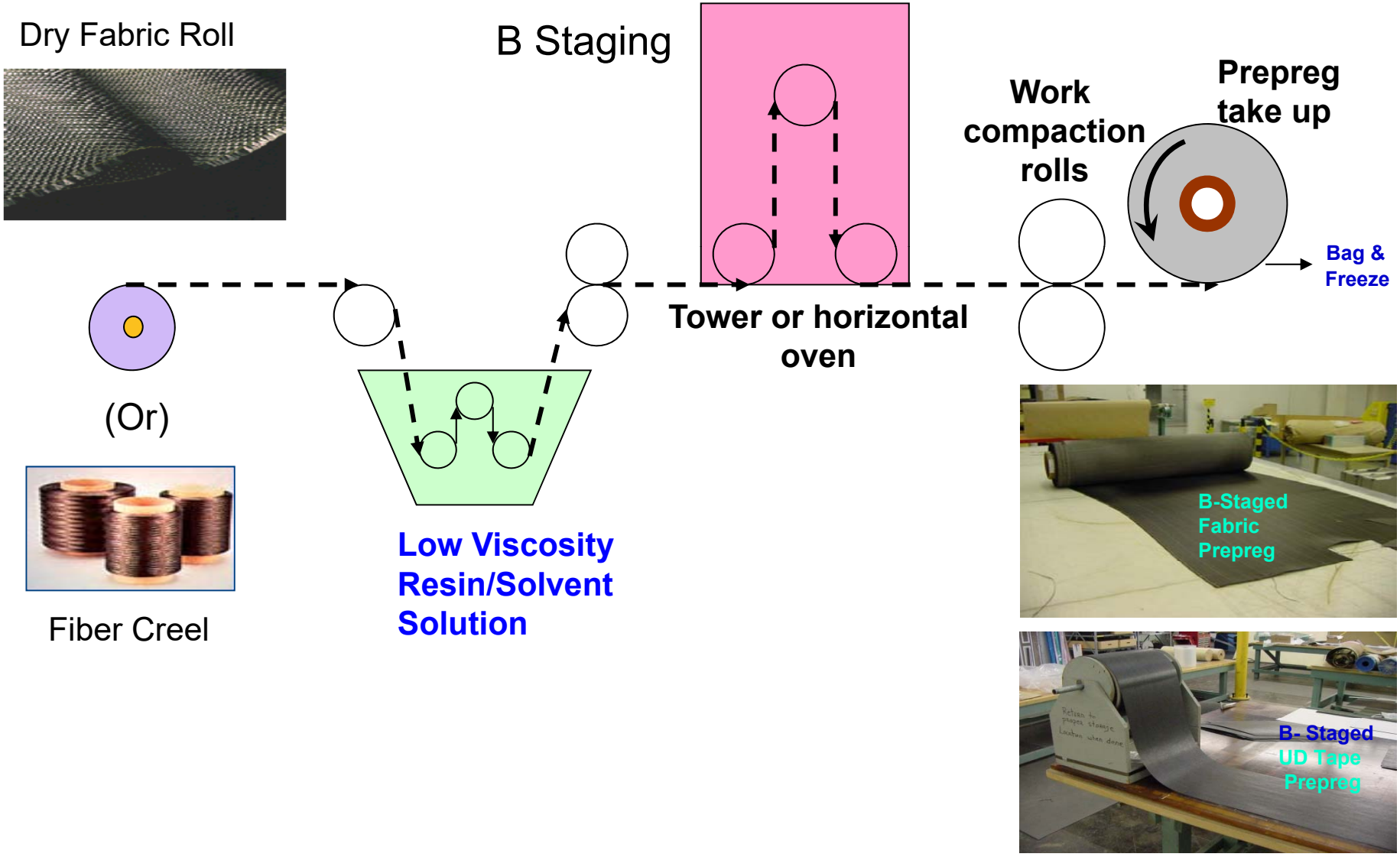
- Prepreg based processes (“dry”)
- Non-prepreg based processes (“wet”)

Prepreg Manufacturing

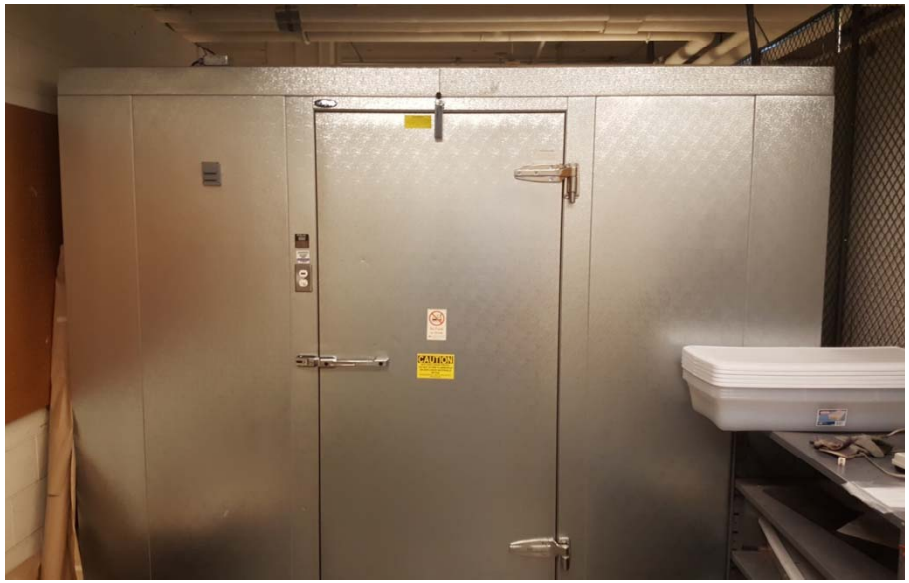
Thermoset (Epoxy) Resin Mix



Prepreg Manufacturing
Solvent Impregnation



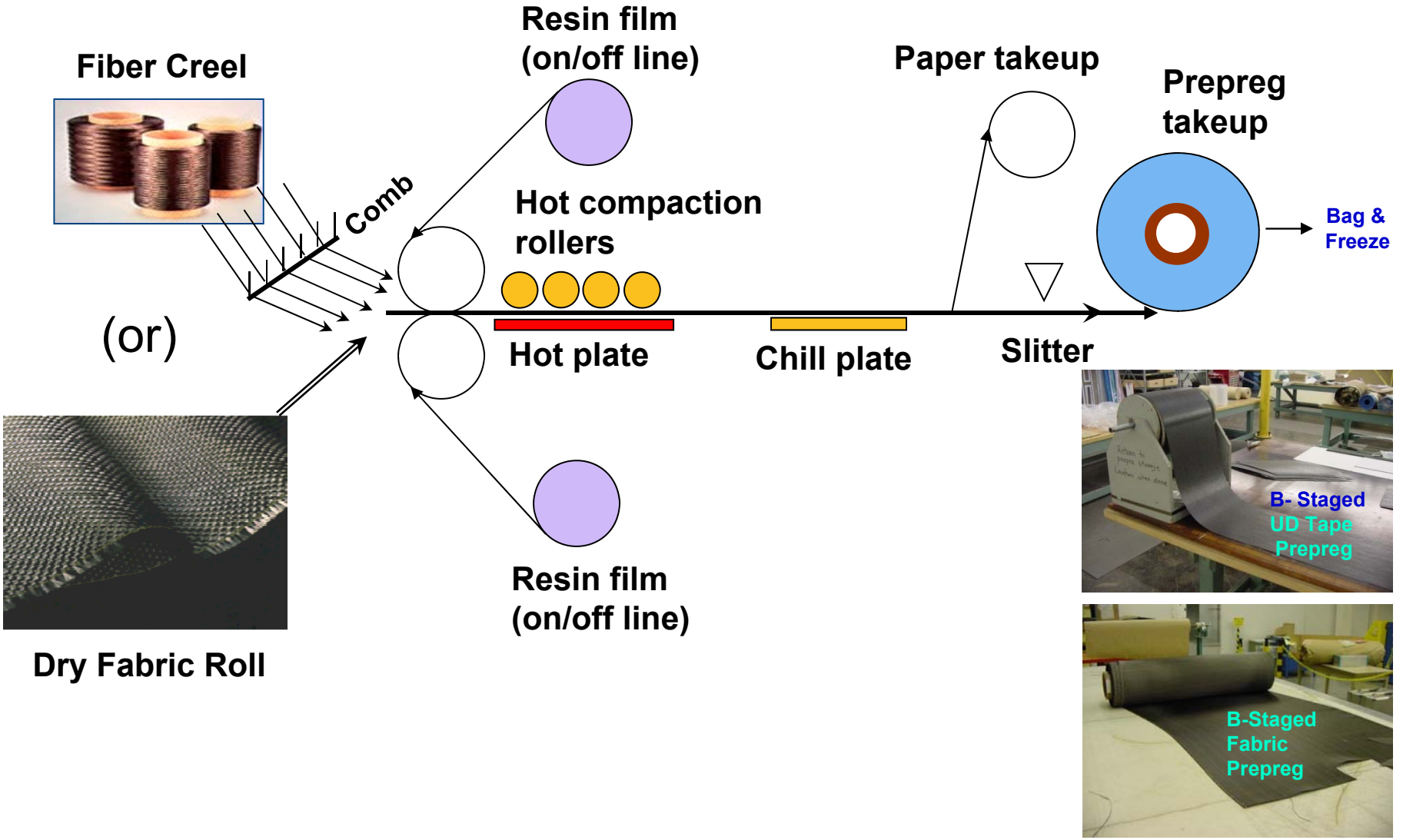
Prepreg Manufacturing
Freezer Storage



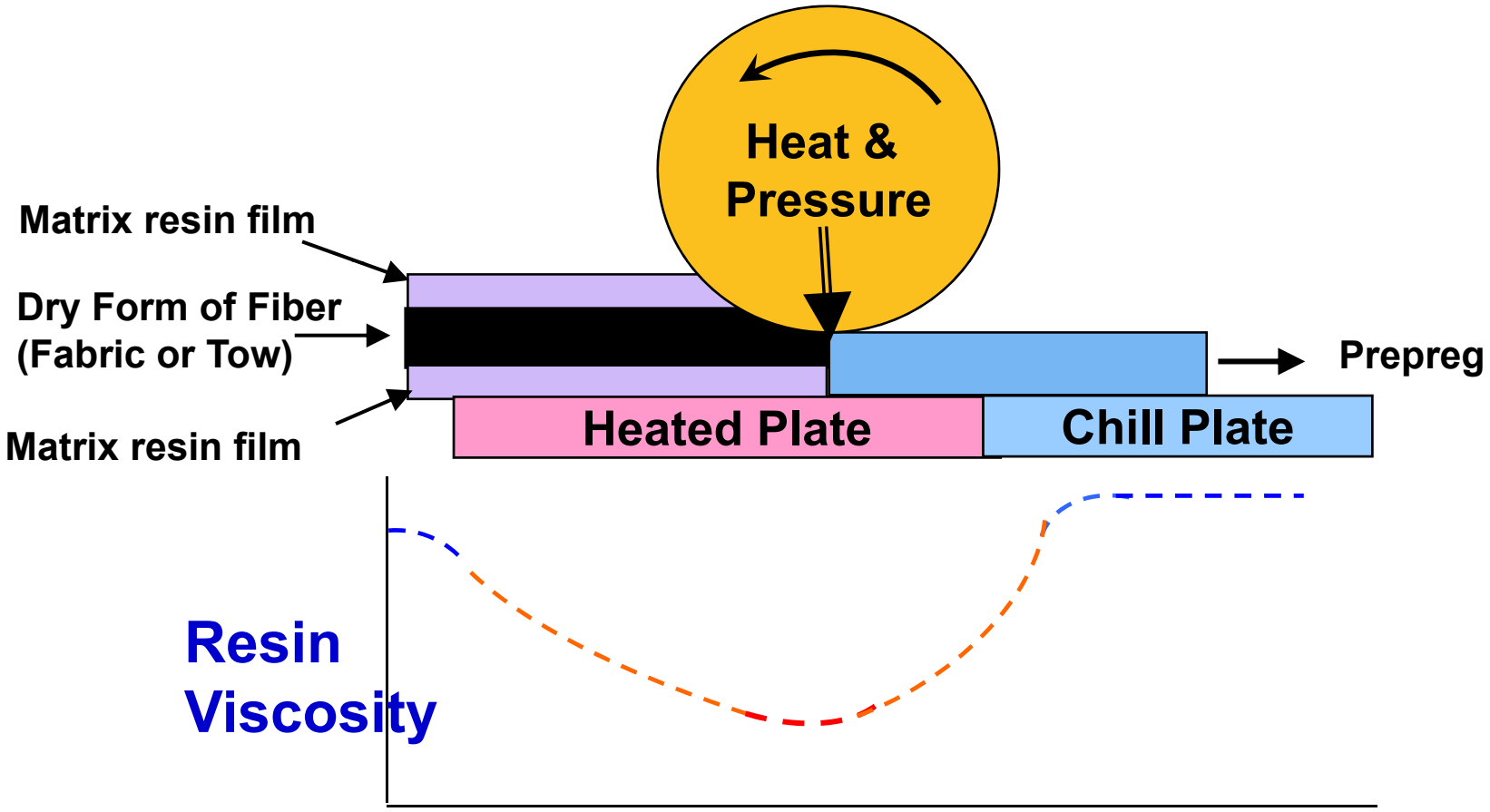
The ME Department walk-in freezer is used to store prepregs, thin-film adhesives, etc, and maintains a temperature of -18ºC (0ºF)

Prepreg Manufacturing

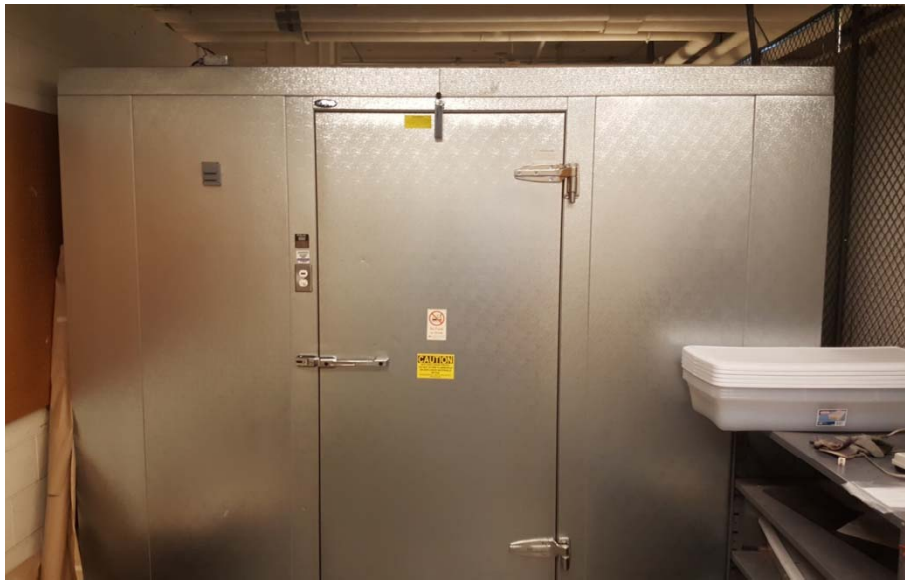
Hot Melt Impregnation



Hot Melt Fiber Impregnation



Prepreg Manufacturing
Freezer Storage



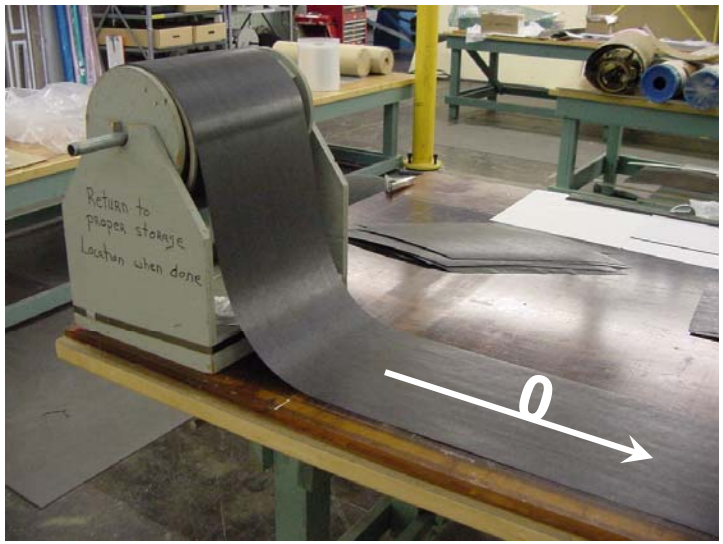
The ME Department walk-in freezer is used to store prepregs, thin-film adhesives, etc, and maintains a temperature of -18ºC (0ºF)

Prepreg Manufacturing

Creel Setup – Unidirectional Tape

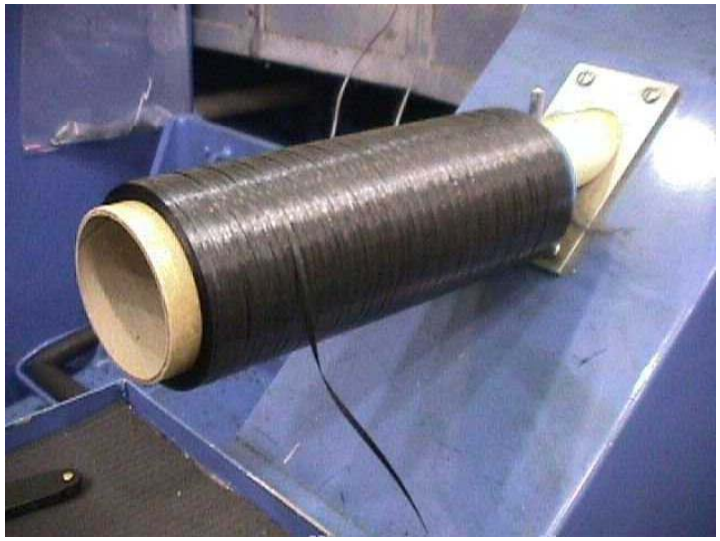
Prepreg Material Forms

Unidirectional



UD Tape

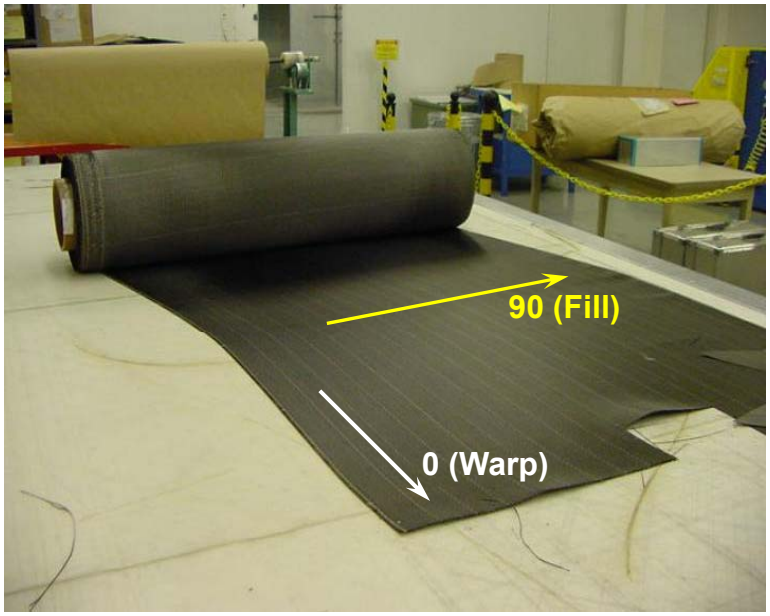
- Automated equipment
- Higher laydown rates
- Fiber orientation tailorable
- Good material usage
- Limited contour use



Slit Tape

- AFP (Automated Fiber Placement) equipment
- Low laydown rates
- Fiber orientation very tailorable
- Excellent material usage (Buy to Fly Ratio)
- Better for Compound contour

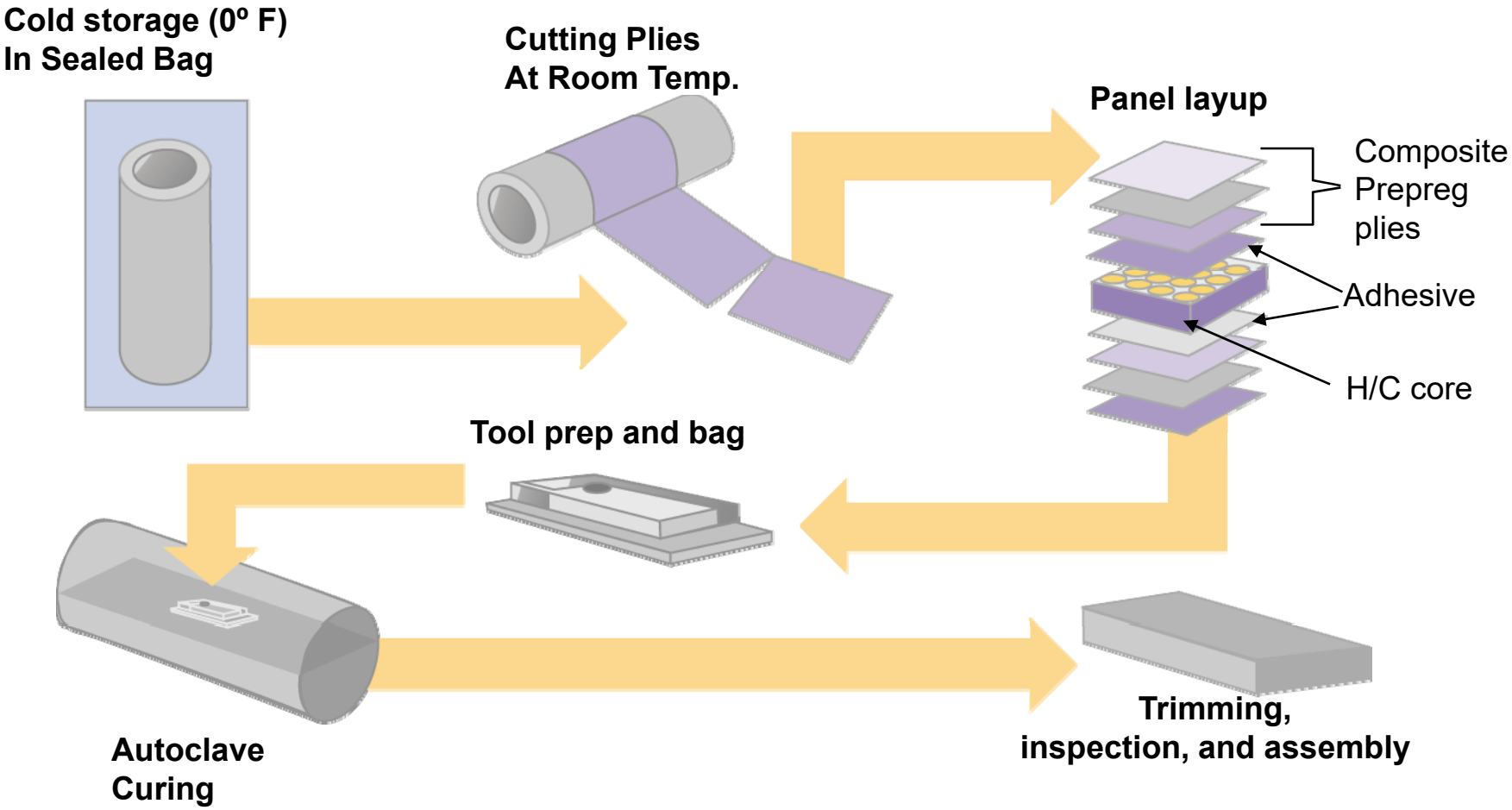
Prepreg Material Forms
Woven Fabric



Woven fabric

- Drapability good
- Fiber orientation less tailorable (0/90, +/-45)
- Poor material usage (buy-to-fly ratio)
- Mostly used for hand lay up of H/C sandwich structures

General Prepreg-Based Manufacturing Flow

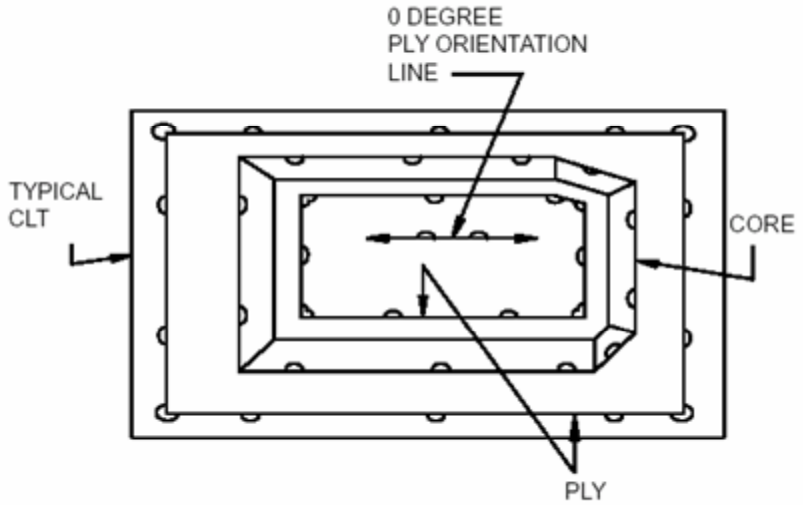


Creating the Laminate Stack

- Hand layup processes
  - Plies cut from parent prepreg role to desired shape, either
    - Manually or
    - With NC-controlled ultrasonic knife (minimizes edge fraying)
  - In hand-layup plies are usually woven or braided fabrics, but can be unidirectional tape
  - Hand layup often involves ply kits:
    - Plies cut from prepreg
    - Stack sequentially in intended laminate
    - Sealed in air-tight bag and returned to freezer to retain tack
    - Efficient production flow
- Automated (computer-controlled) layup processes
  - Mostly involve UD tape, but can also be used with fabric
  - NC controlled cutting during automated layup of each course directly on tool
  - Sometimes combined with hand layup

Hand Layup

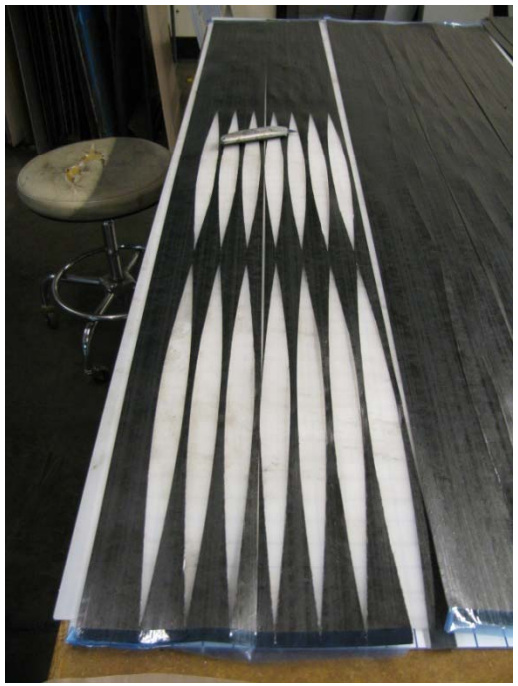
- Hand layup implies
  - Hand placement of precut plies
  - Very flexible
  - Low capital investment
  - Labor intensive
  - Can involved safety issues/repetitive trauma
- Applications
  - Used on most secondary structure in aerospace composites
  - Not used for very large parts



Hand Layup

Producing "precut plies" from parent roll

- Pre-preg can be to desired shape by hand (i.e., using a razor blade, utility knife, etc), but
- Various types of computer-controlled cutters available and are far more precise and convenient

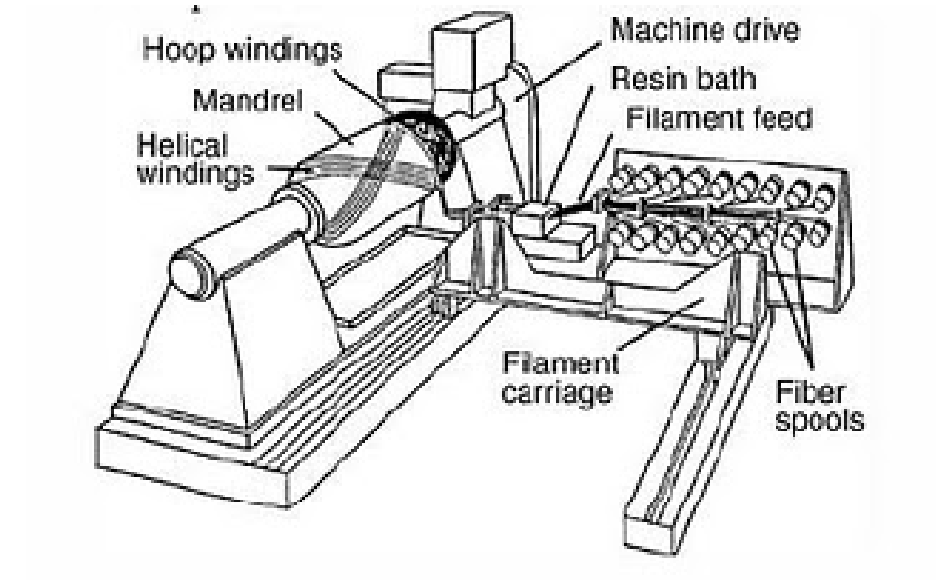


Automated (Computer-Controlled) Layup Processes

- Three major categories, in chronological order of development:
  - NC Filament winding (bodies of revolution)
  - Automated Tape Laying machines
    - Flat tape laying machines
    - Contoured Tape Laying Machine
  - Automated Fiber Placement (AFP) machines (a hybrid of filament winding and automated tape laying machines)

Filament Winding

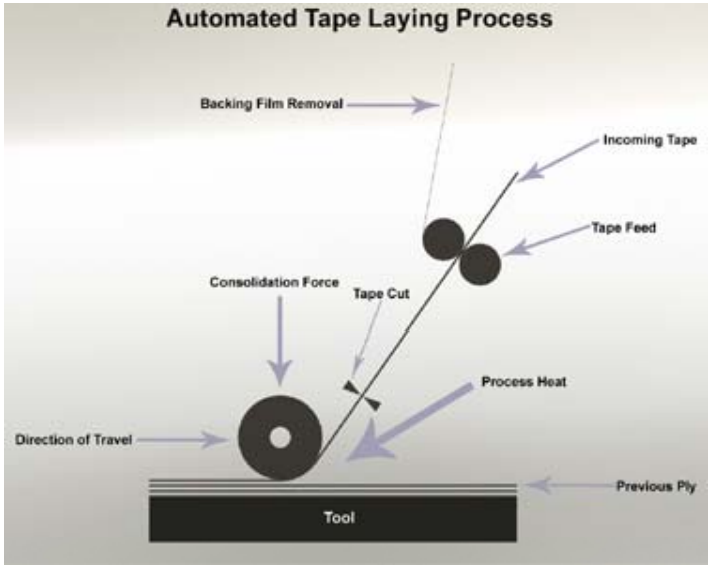
- Used for decades (computer-controlled winders developed in 70's)
- High lay-down rates (400 lbs/hr)
- Either pre-preg or wet winding
- Bodies of revolution only (can't wind concave surface)

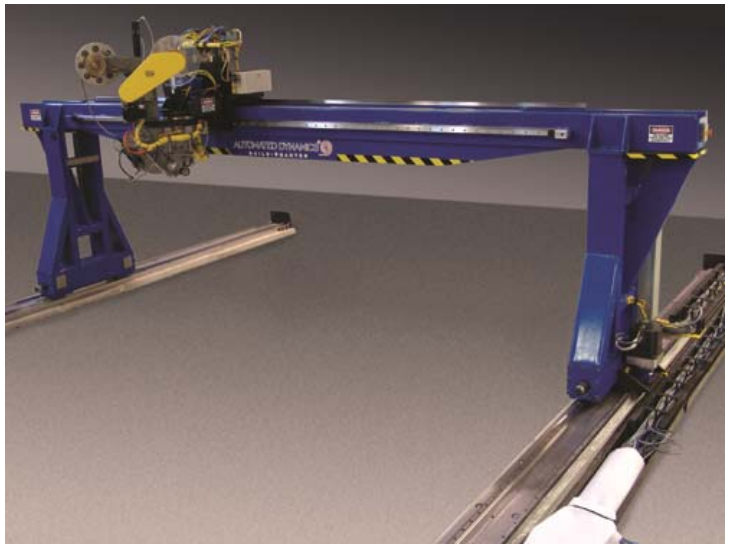


http://compositetechnology.blogspot.com

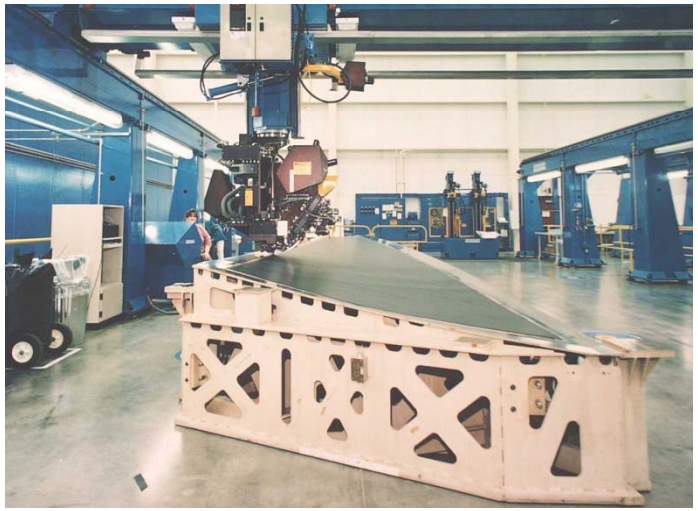
Automated Tape Laying Machines

(http://www.automateddynamics.com/gallery/)





Automated Tape Laying Machines

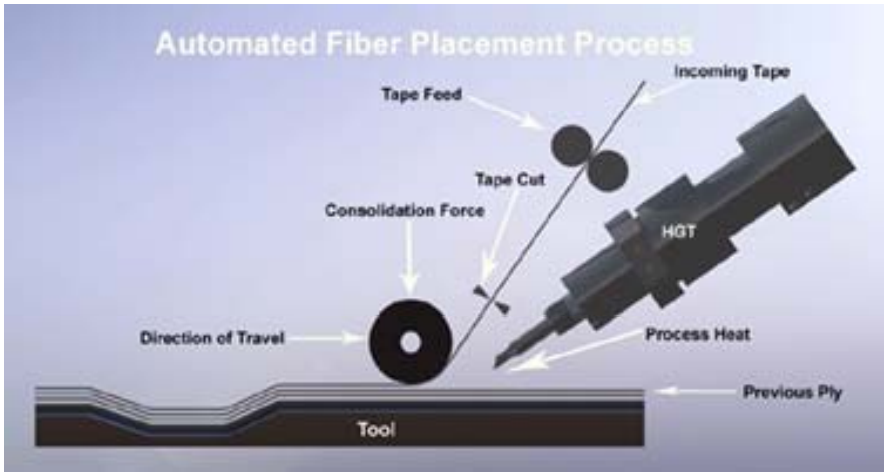


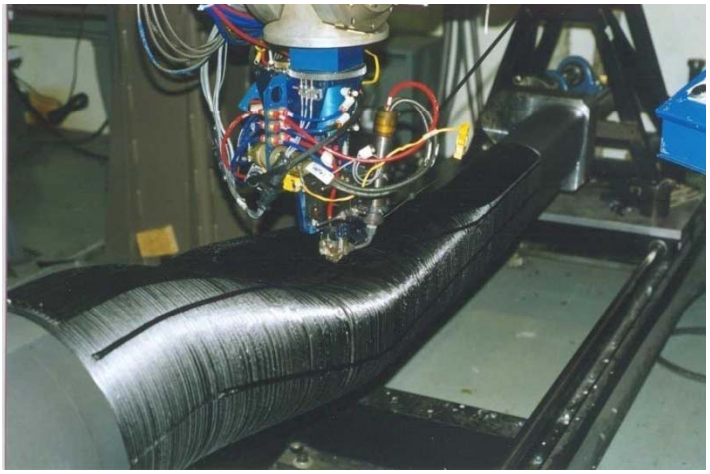
Can produce parts with modest curvatures

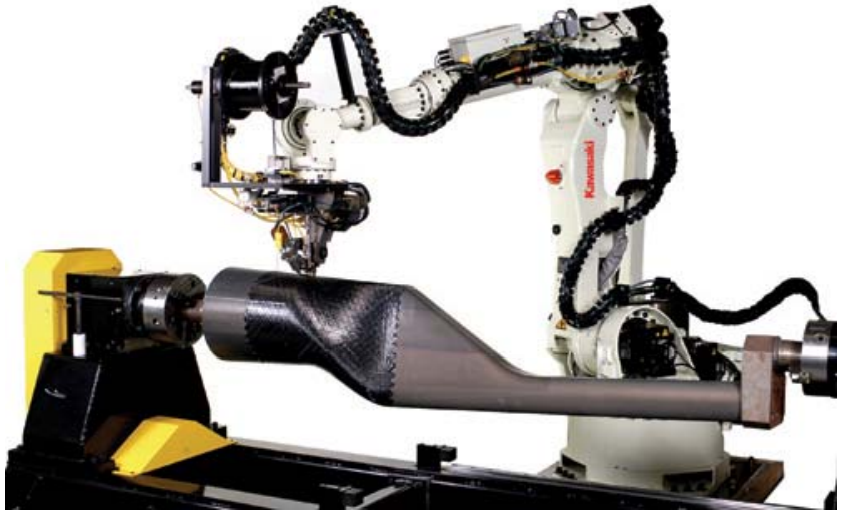
ATLP machines available that dispense 1”, 3”, 6”, or 12” UD pre-preg

Automated Fiber Placement Machines

(http://www.automateddynamics.com/gallery/)



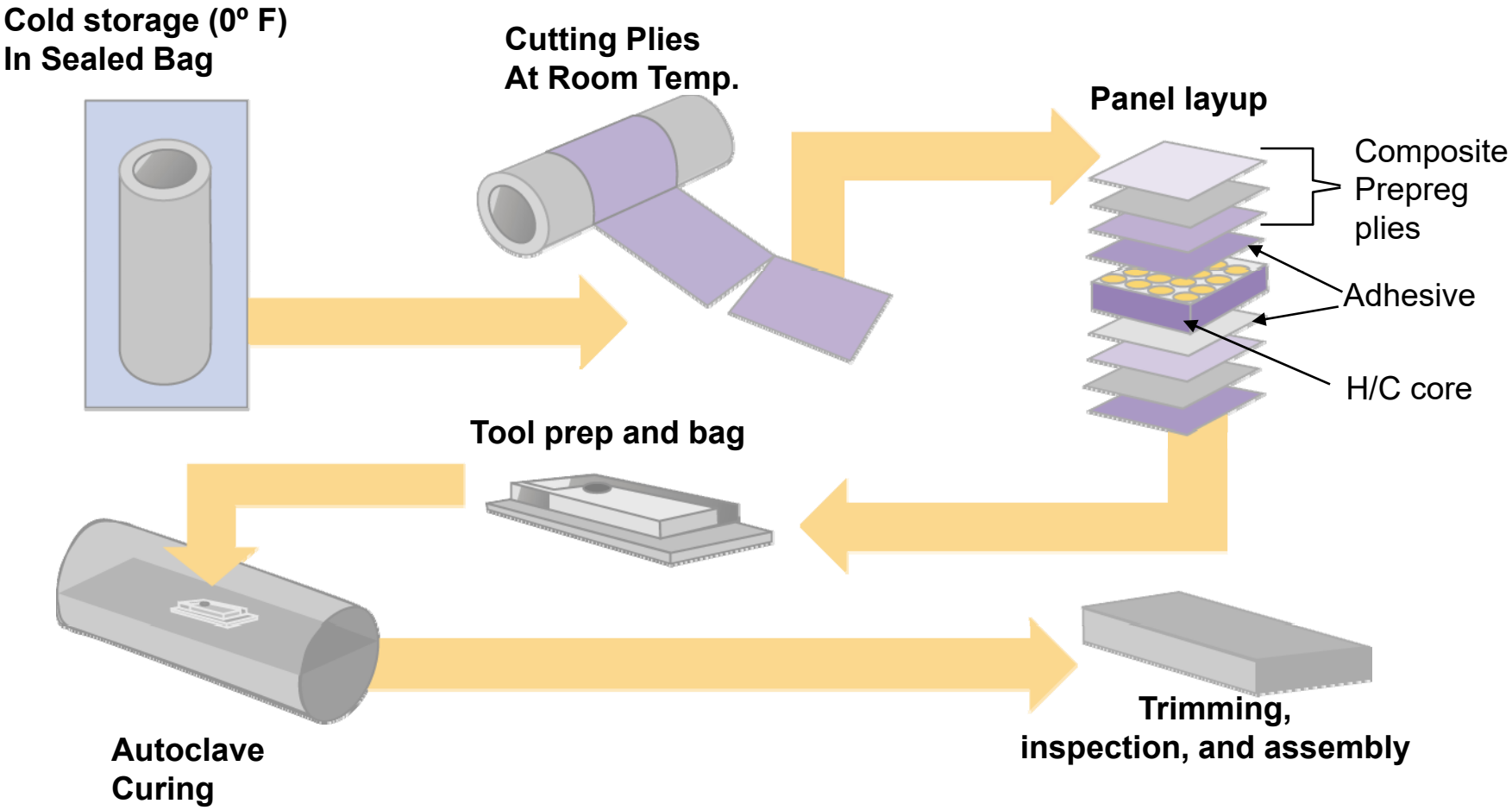




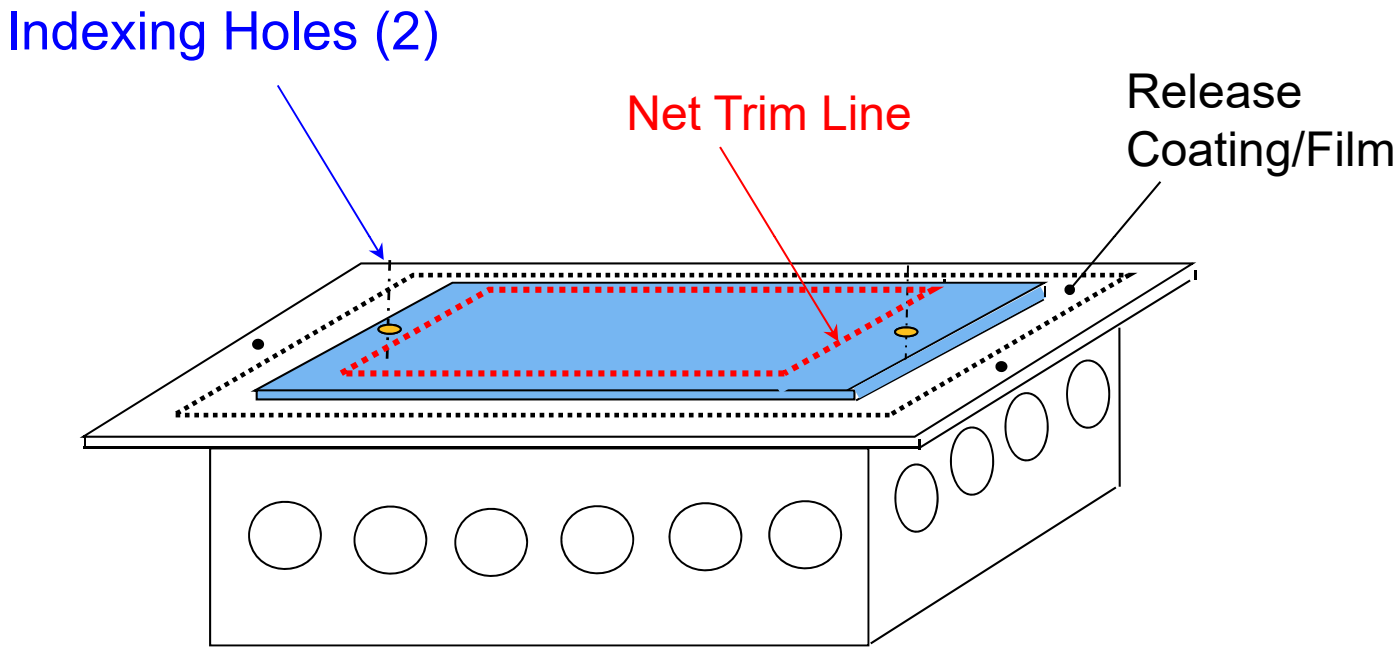
Automated Fiber Placement Machines
(http://www.electroimpact.com/)

Boeing 787 fuselage barrel sections produced using an automated fiber placement machine designed/built by Electroimpact (Mukilteo, WA)

General Prepreg-Based Manufacturing Flow

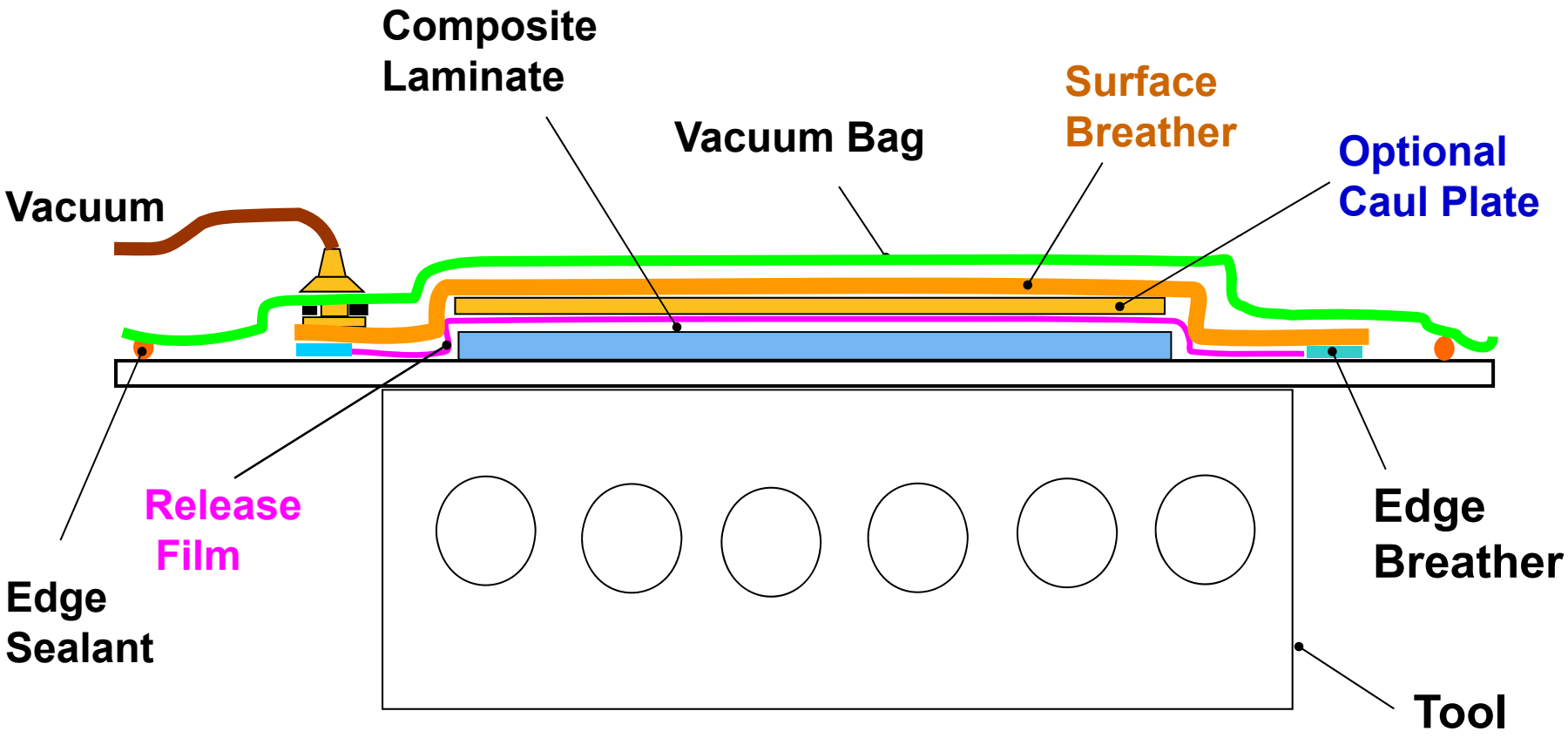


Vacuum Bagging

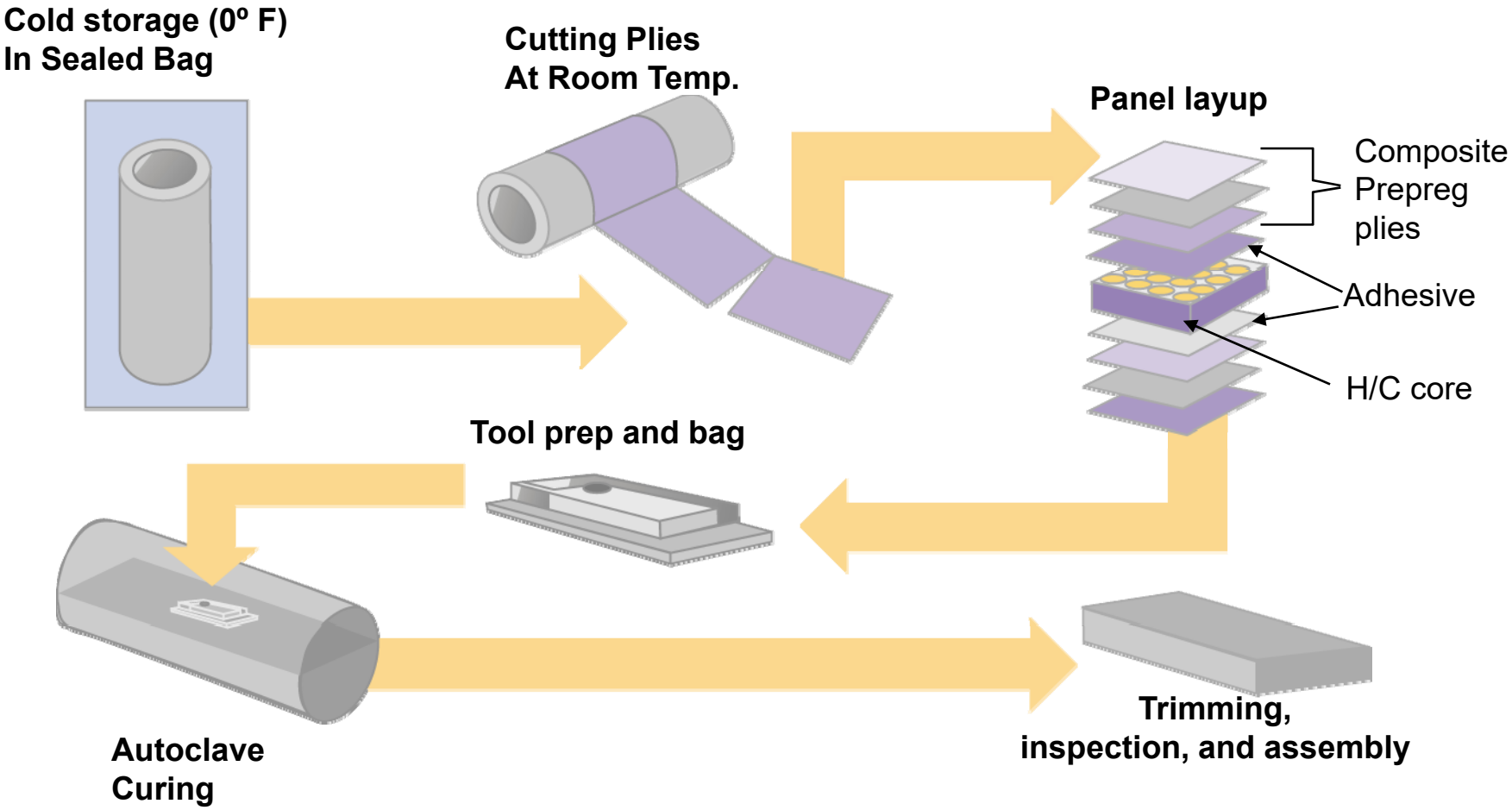


Generic Composite Tool

Vacuum Bagging



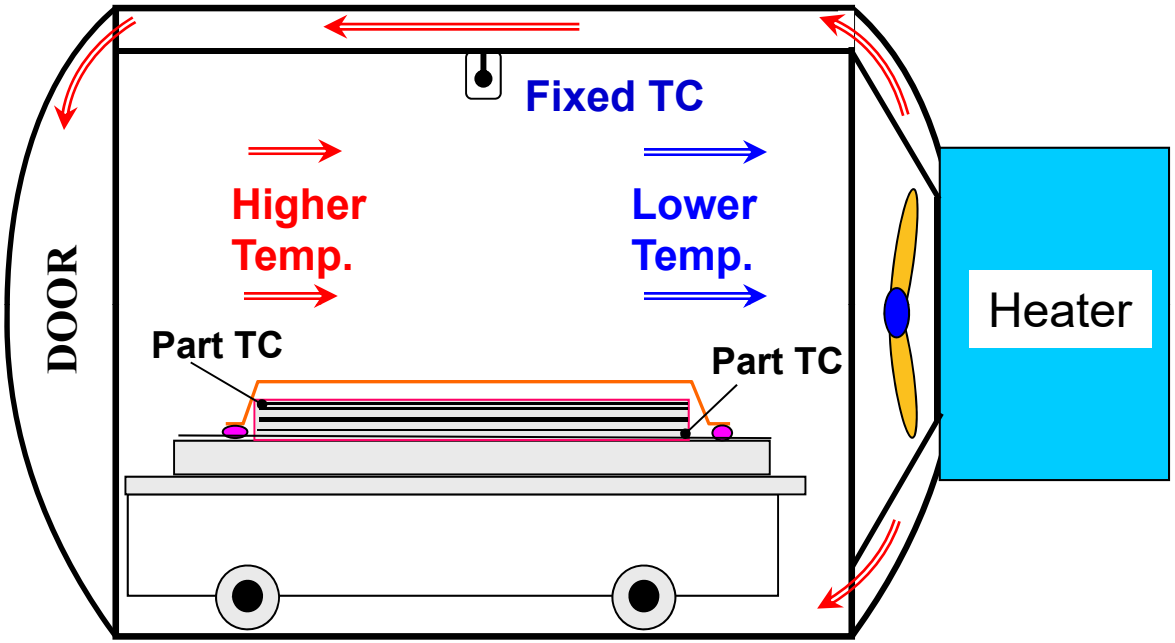
General Prepreg-Based Manufacturing Flow



Autoclave Cure

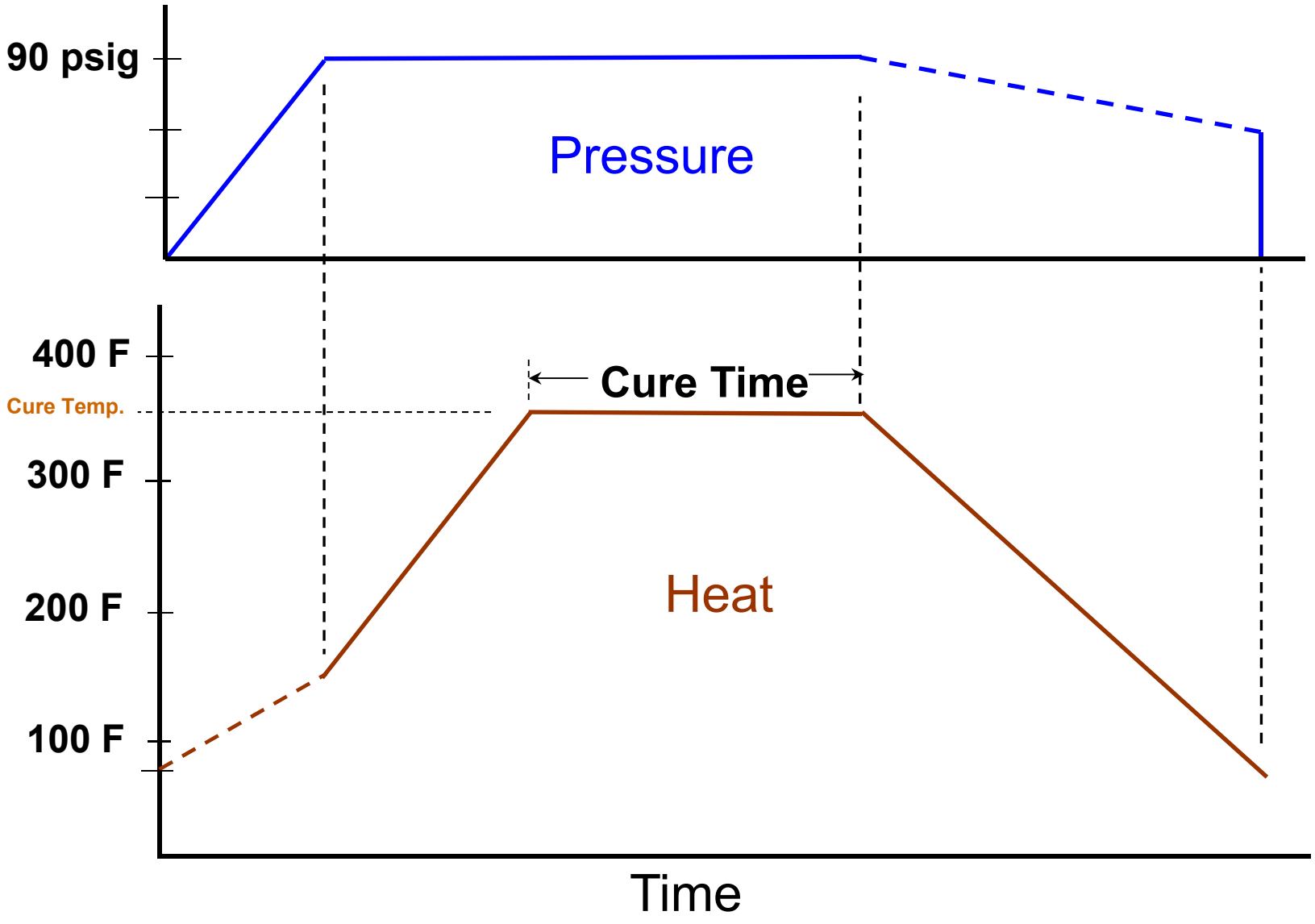
- An autoclave is a heated pressure vessel that allows
  - Vacuum to be drawn in interior region(s)
  - Heatup and cooldown rates to be precisely controlled
  - Internal pressure applied using inert gas (usually N_2, rarely air)
- Autoclave sizes vary widely
- Most structures produced using pre-preg are cured using an autoclave (some exceptions)

Typical Autoclave Features
(up to 700F and 300 psi)



- Thermocouples:
  - Fixed TC (permanent, controls power input)
  - Part TCs (disposable, monitor local heat-up and cool-down rates
- Electric, gas, or steam heat
- Chilled water (or occasionally oil) cooling system
- Internal fan to circulate pressurizing gas (air, N_2, or CO_2) and minimize thermal gradients

Autoclave Cure Cycle



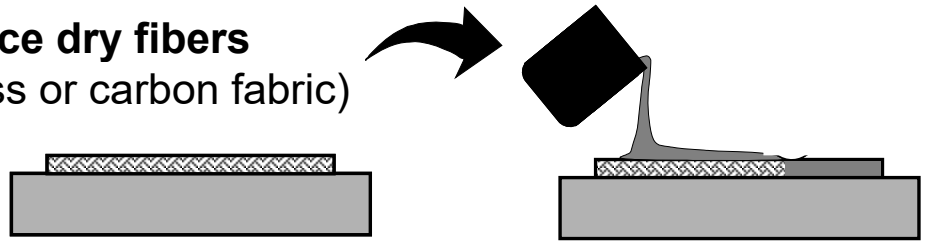
Summary of Manufacturing Methods

Following discussion divided into two categories

- Prepreg based processes (“dry”)
- Non-prepreg based processes (“wet”)

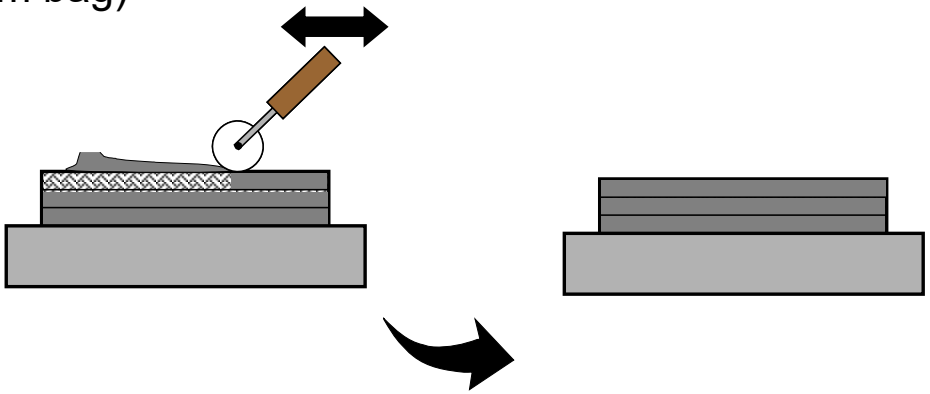
Wet Hand Layup
Lowest Cost/Highest Variability

1. Hand place dry fibers
(usually glass or carbon fabric)



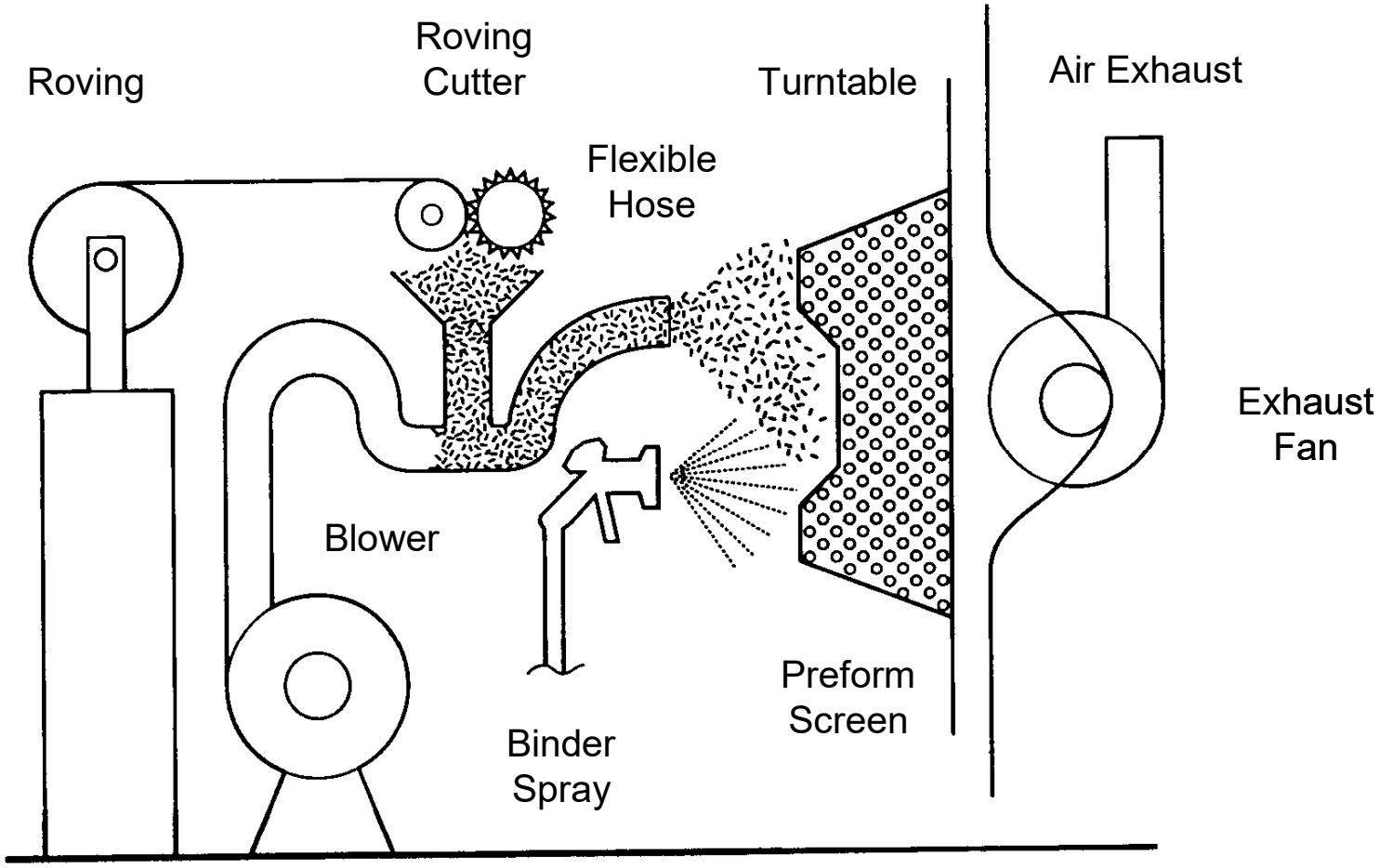
2. Apply low viscosity resin
(pour, brush or spray)

3. Wet out/remove air
(squeegee, roller
or vacuum bag)



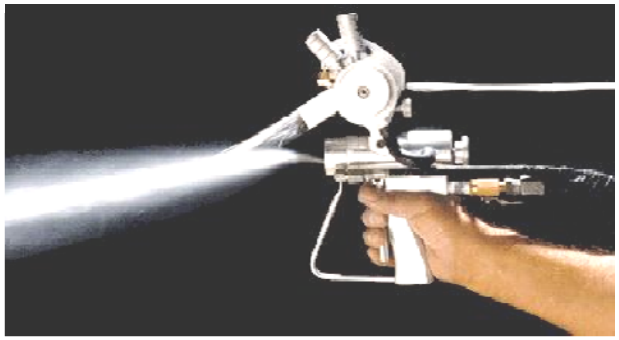
4. Cure:
Room temp w/o vacuum bag,
Room temp w/vacuum,
Vacuum bag w/oven
Vacuum bag w/autoclave

Chopped Fiber Spray-Up



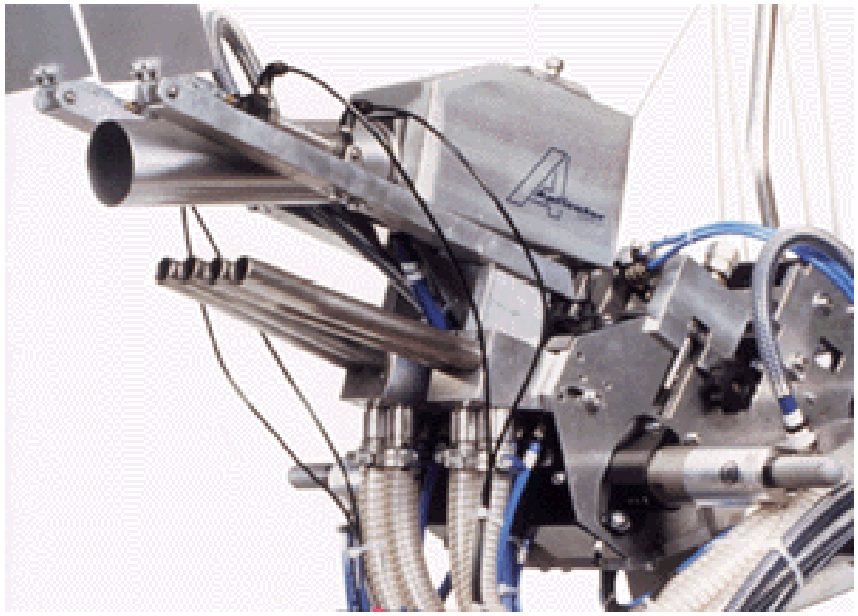
Chopped Fiber Spray-Up

- Can produce complex shapes, and medium-to-large parts
- Continuous fiber fed, chopped (1-3“), and combined/sprayed with catalyzed resin
- Laminate densified and air removed manually (rollers, squeegies) or with vacuum bag



Chopped Fiber Spray-Up

- A highly automated (computer-controlled) version of fiber spray-up, called the Programmable Powdered Preform Process (P4), is used to produce lightweight automobile and truck parts

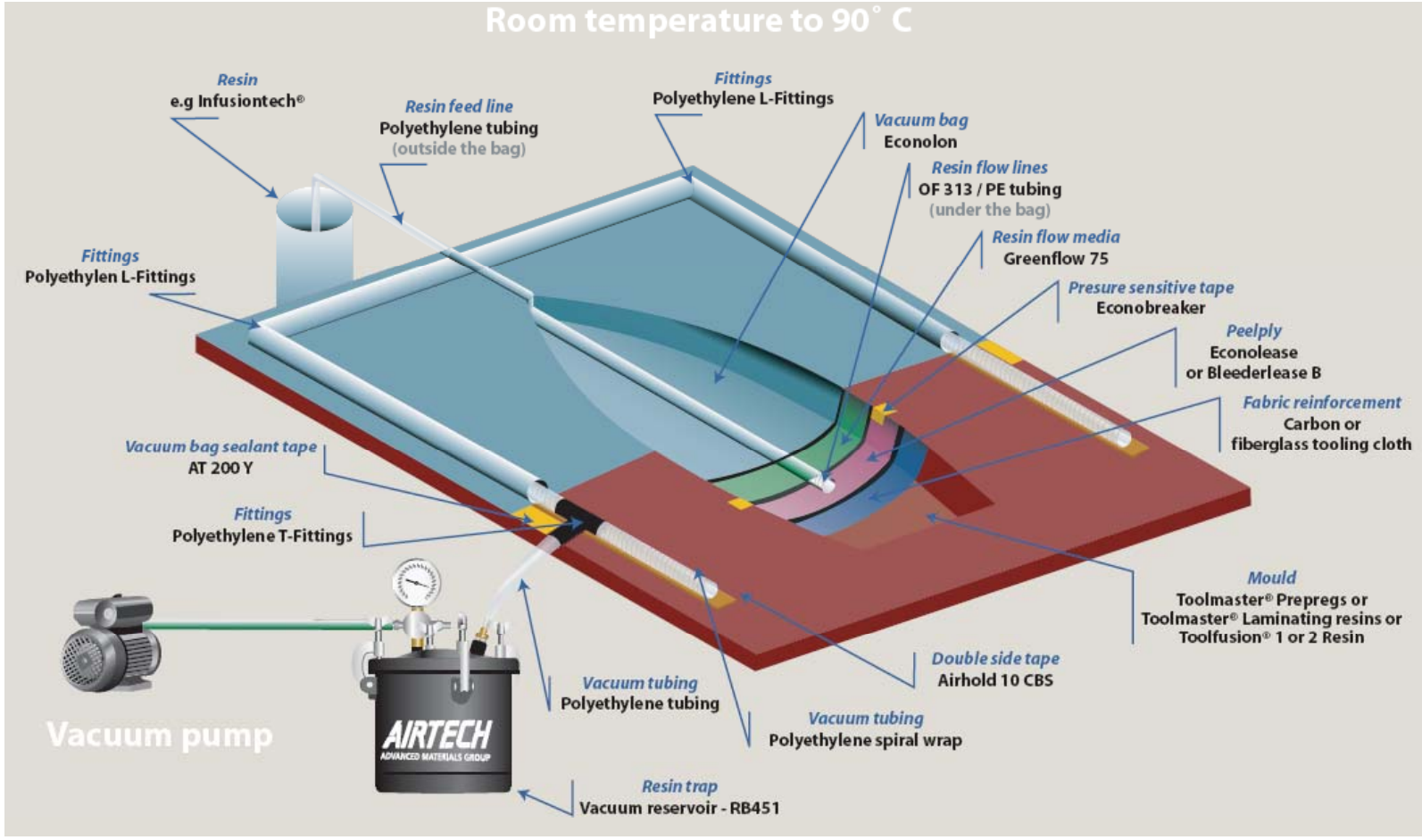


Applicator P4 gun developed by Aplicator System AB (Sweden)

P4-SRIM truck bed and tailgate on 2001 Chevy Silverado is 50 lb and 15 lbf lighter, respectively, than steel counterparts

Resin Infusion

with low temperature cure resins



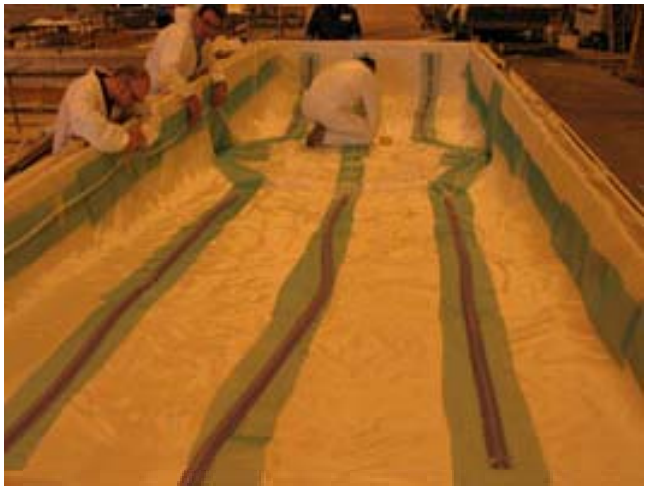
www.airtech.lu/site/medias/_pdf/france/procedeEN.pdf

Resin Infusion

with low temperature cure resins

Resin Infusion

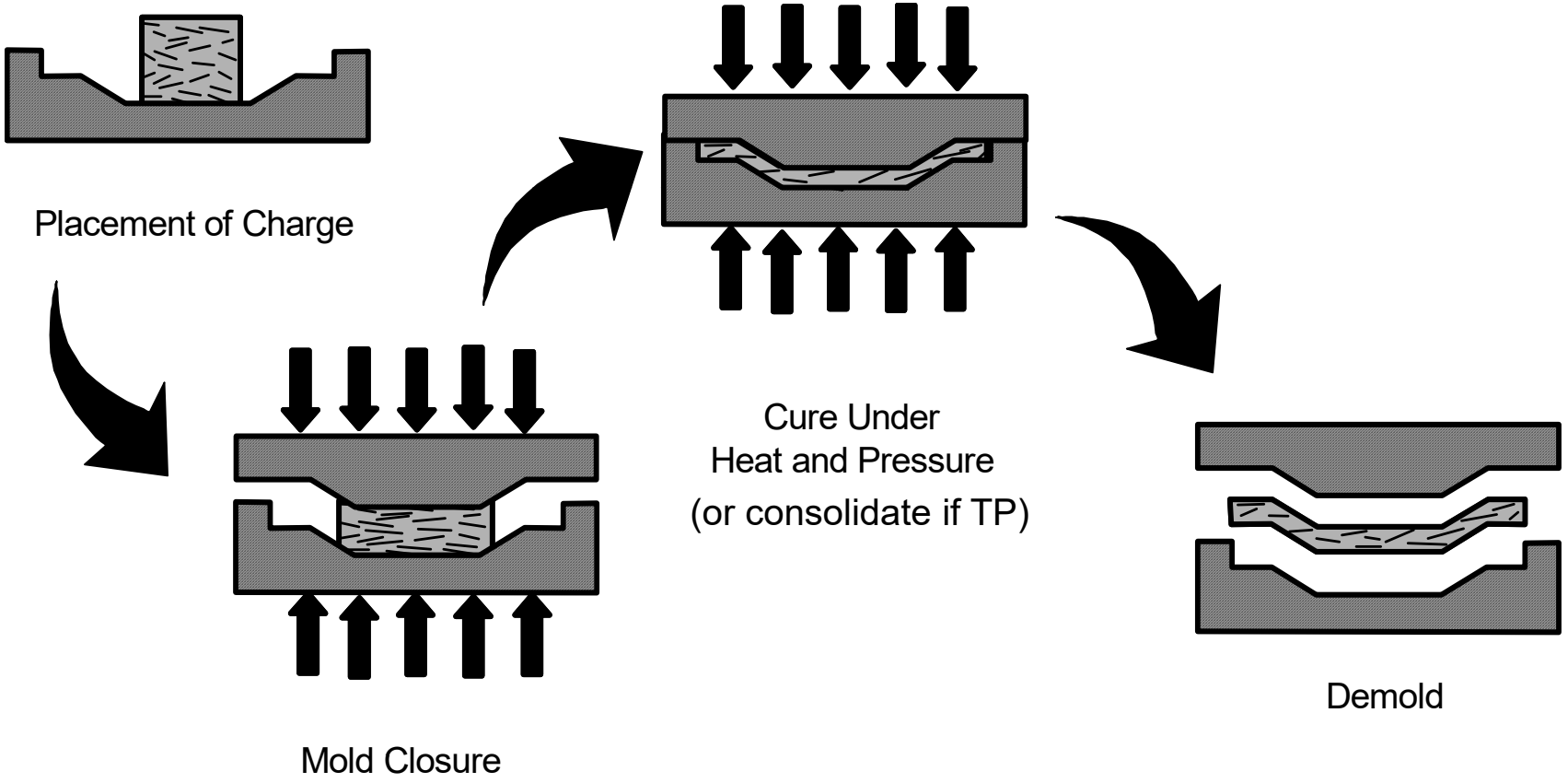
avoids the need for very large autoclaves



http://www.tygavac.co.uk/markets/wind-energy.html

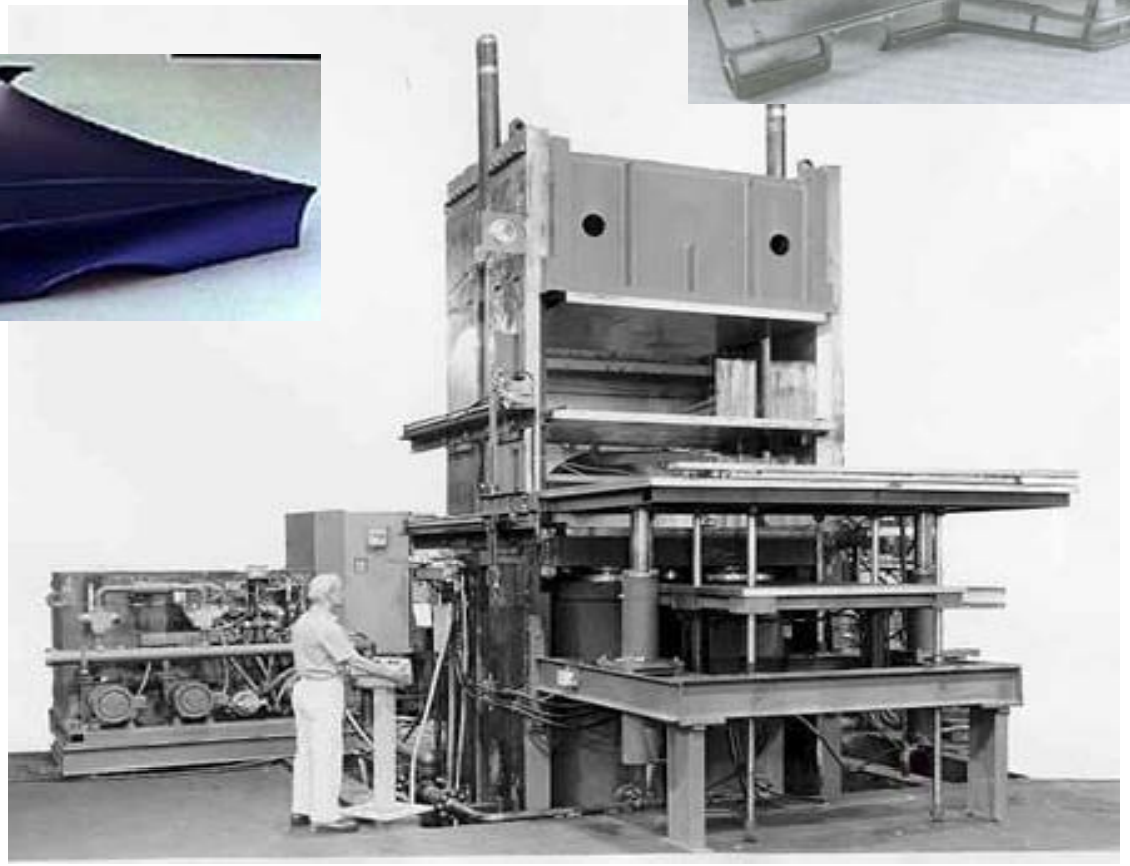
(www.rnp.org/Projects/stateline.html)

Compression Molding



Compression Molding

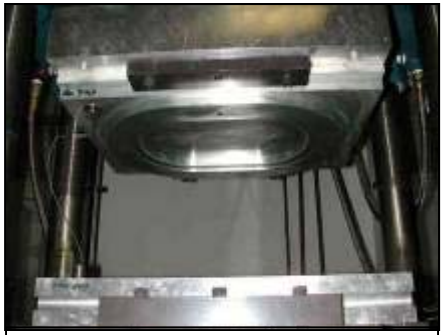
widely used to produce auto/truck parts



Compression Molding

prototype HexMC aircraft window frames

Rule Die Kit and Stage



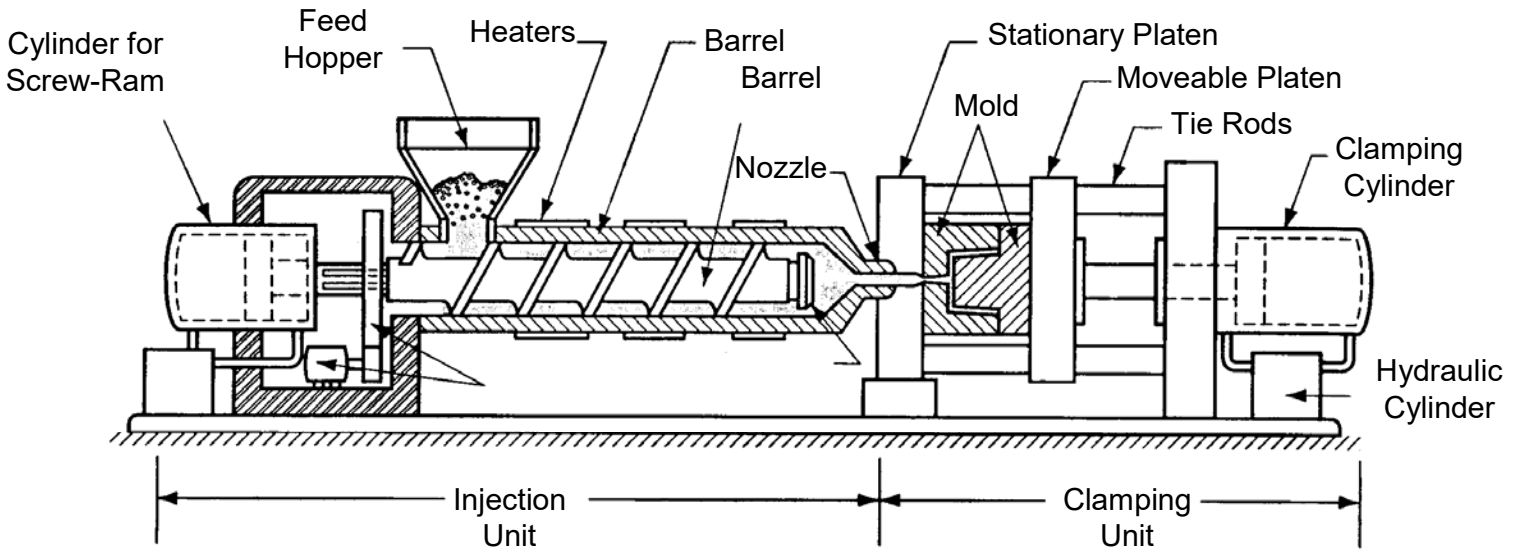
Prep and Heat Mold

Lay-in L-shaped Front and Back Rib Plies

Lay-in Flange Plies

De-mold Net Shaped Part

Injection Molding

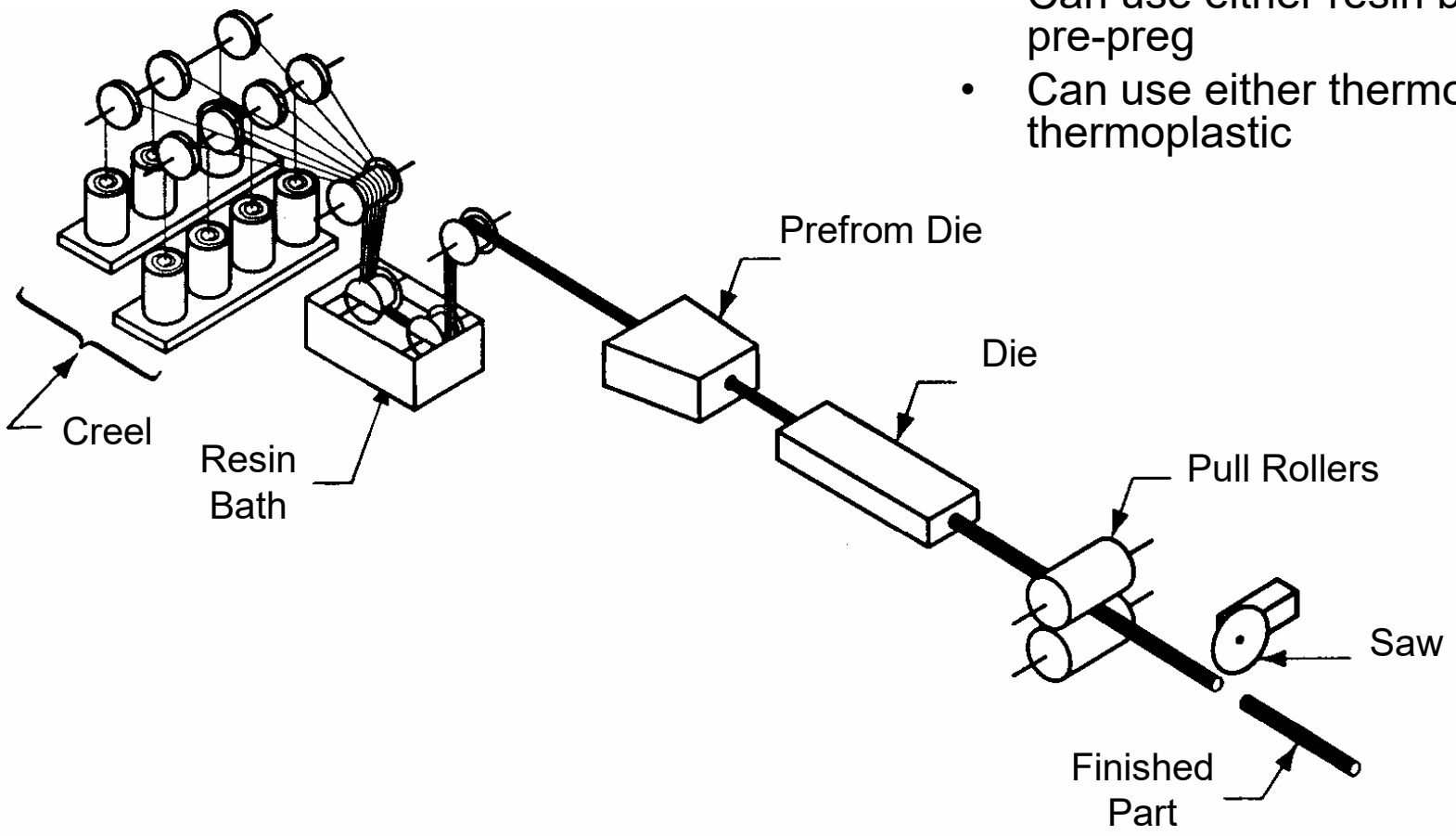


Injection Molding

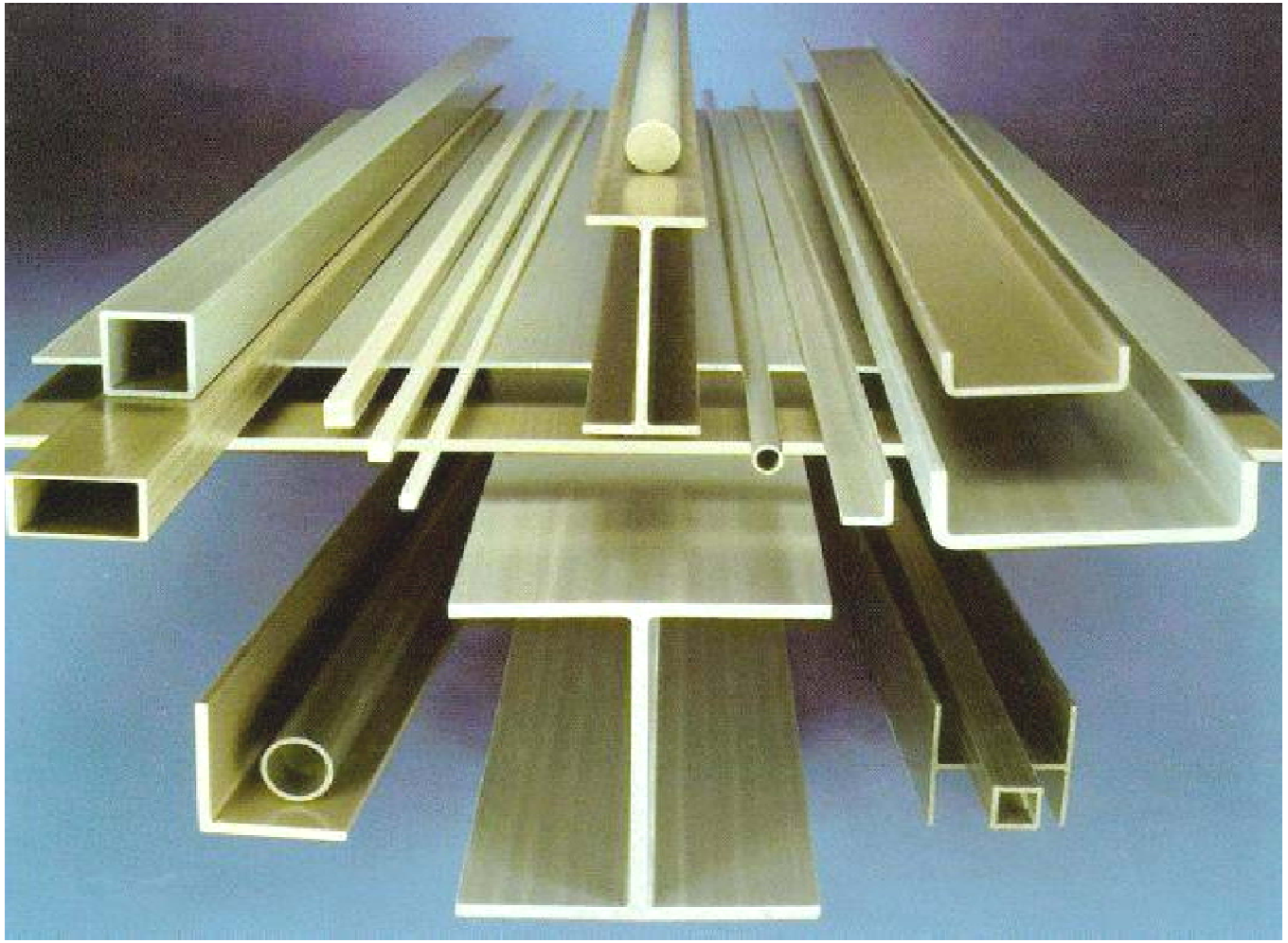
- Base and frame of K2 inline skates produced using injection molding and short fiber glass/PP and glass/nylon composites

Pultrusion

- High-volume process
- Constant cross-section
- Can use either resin bath or & pre-preg
- Can use either thermoset or thermoplastic



Pultrusion

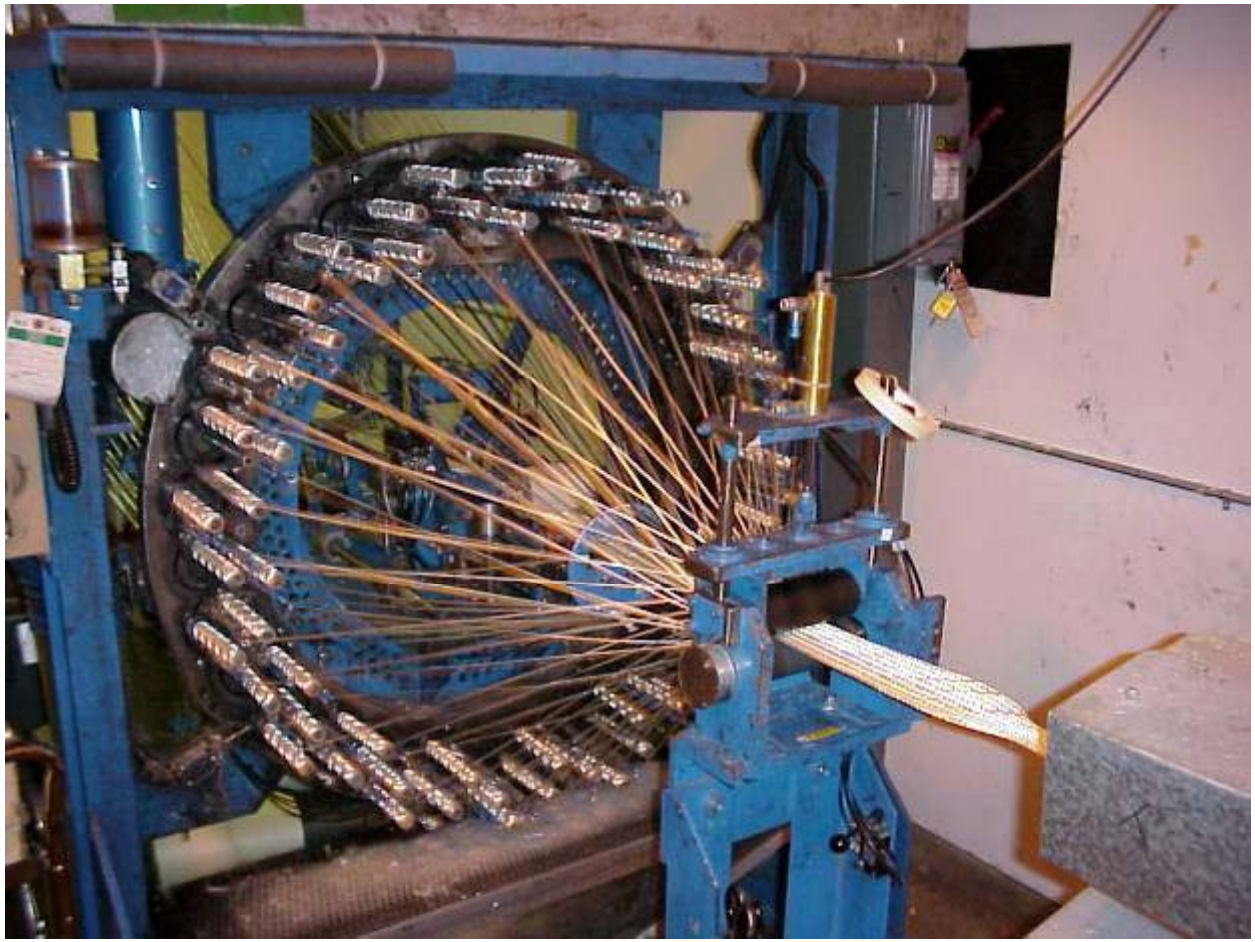


Hybrid manufacturing processes

- K2 downhill skis and snowboards produced using
  - Wood core (fir, aspen, bamboo…)
  - Several plies, including
    - Short glass fiber mat
    - Stitched unidirectional glass and carbon plies
    - Continuous glass fiber triaxial overbraid
  - Wet layup epoxy with amine curing agent

Overbraiding of wood core and short-fiber glass mat

Overbraiding of wood core and short-fiber glass mat



Unidirectional Glass Fabric

Preparing for Impregnation w/Wet Epoxy Resin

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Compression and Heat Used to Consolidate and Cure Composite

Finished Product