Aggressive Light-weighting through use of Composites

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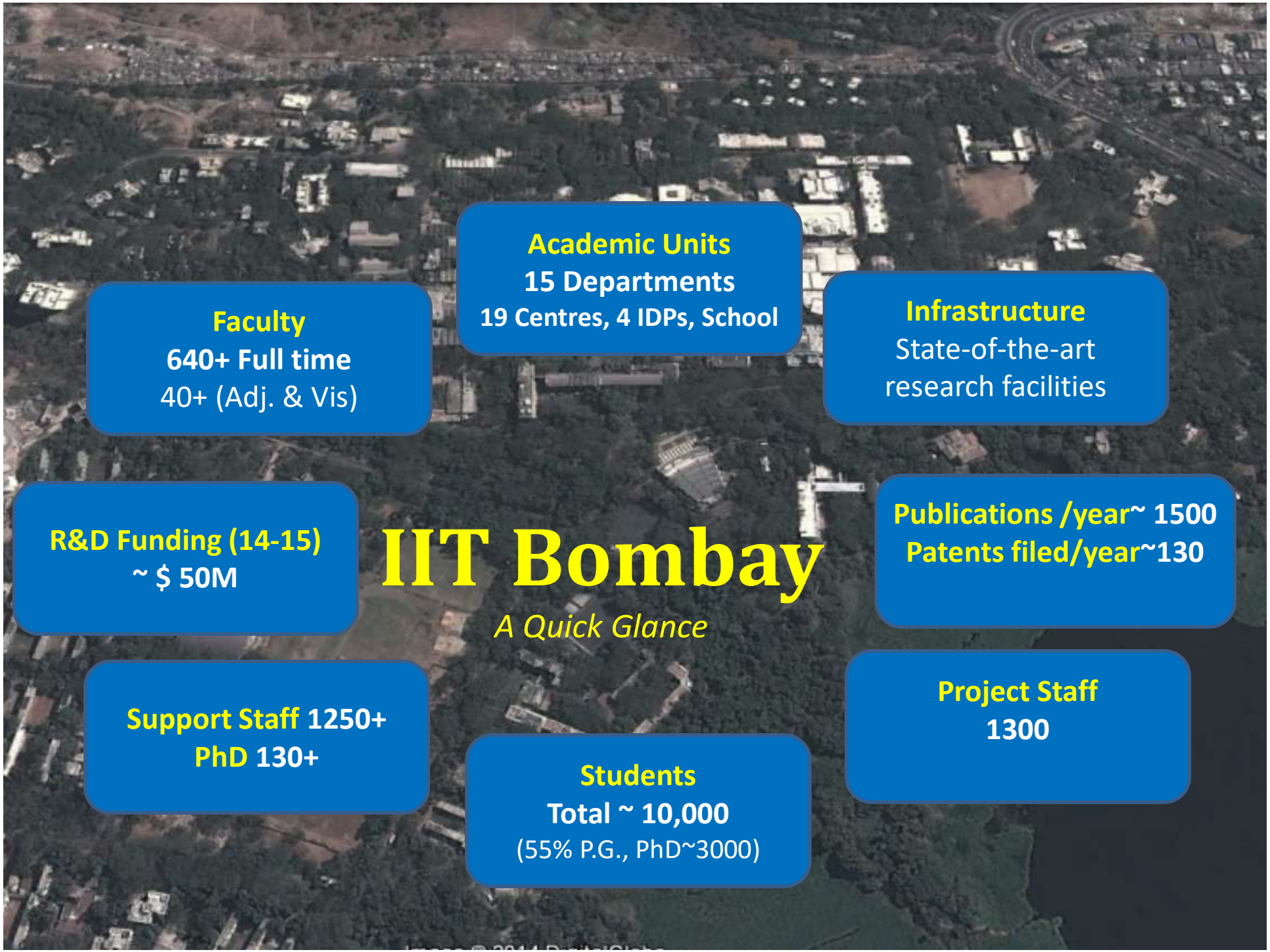
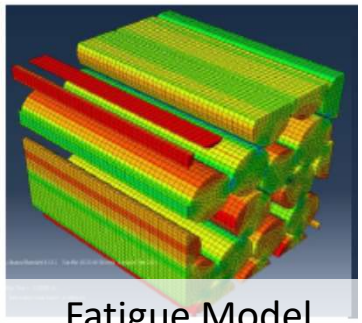
QS World University Rankings

Indian Institute of Bombay, Mumbai India

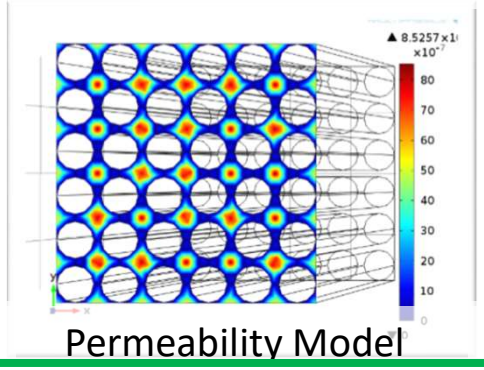

Academic Units
15 Departments
19 Centres, 4 IDPs, School
Faculty
640+ Full time
40+ (Adj. & Vis)
Infrastructure
State-of-the-art
research facilities
R&D Funding (14-15)
~ $ 50M
IIT Bombay
A Quick Glance
Publications /year~ 1500
Patents filed/year~130
Support Staff 1250+
PhD 130+
Project Staff
1300
Students
Total ~ 10,000
(55% P.G., PhD~3000)

Composites Technology Research center

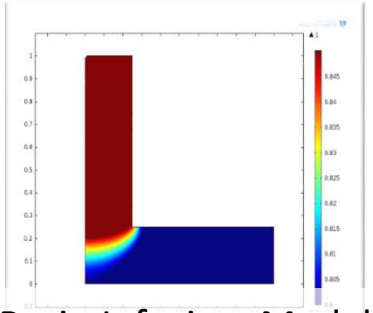
Composite Simulation and Modeling



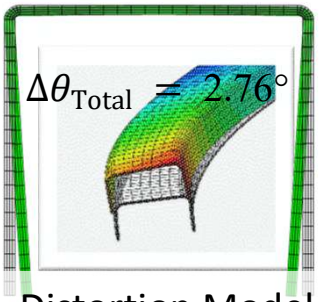
Fatigue Model



Permeability Model



Resin Infusion Model



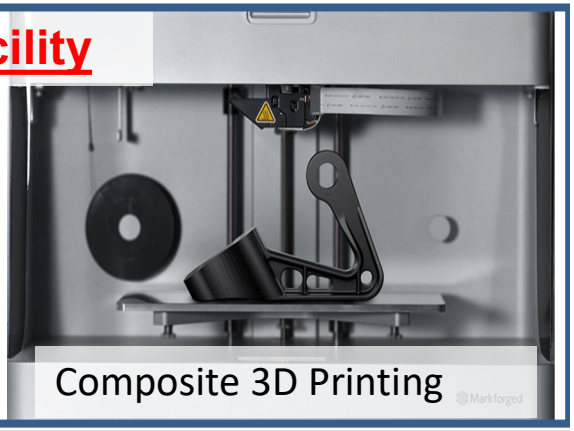
Distortion Model

Composite Manufacturing facility

Product Design

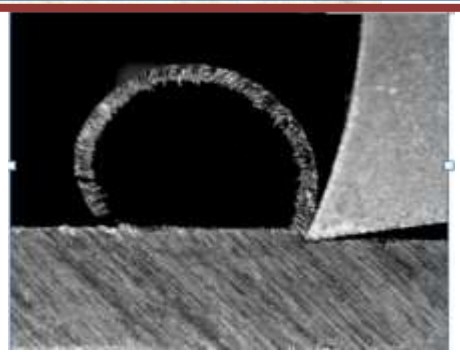
VaRTM

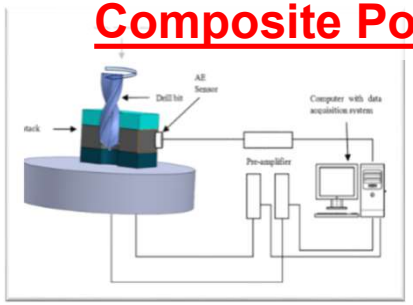
Autoclave

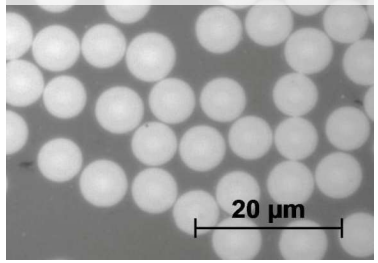


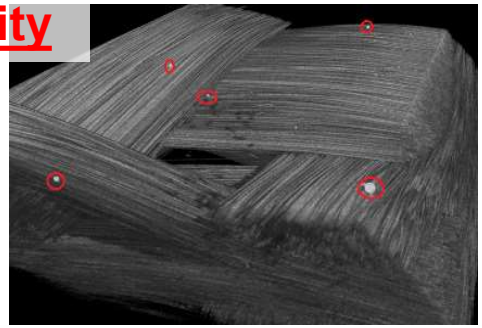
Composite 3D Printing

Composite Post Processing facility

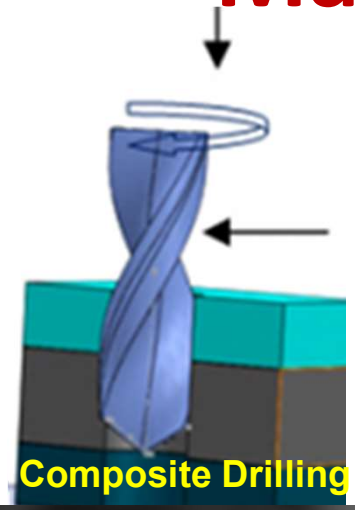


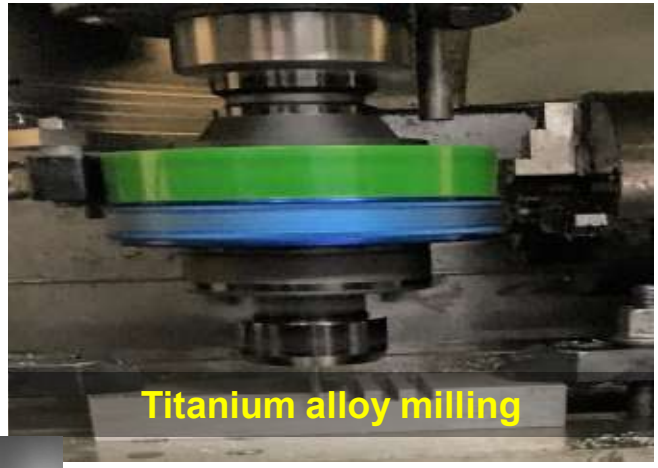




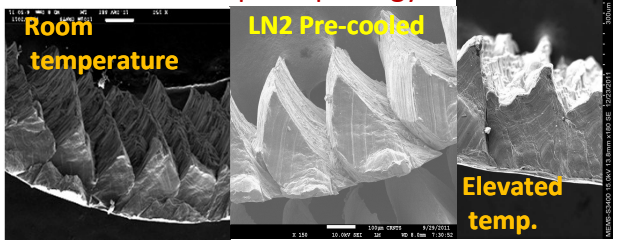


Machining Technology Research

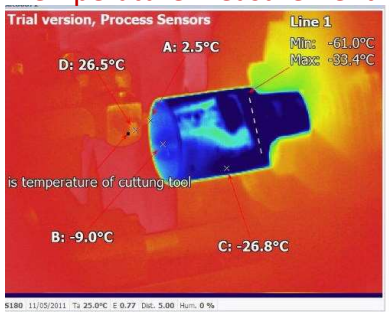




Chip morphology

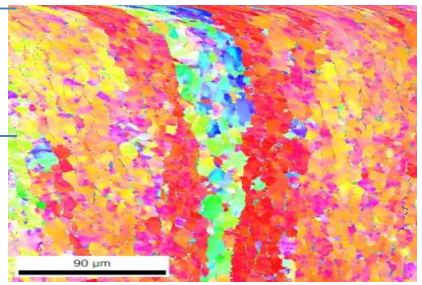


Temperature measurement

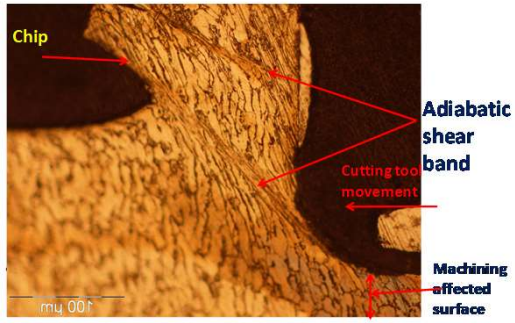


Machined direction **Machined edge**

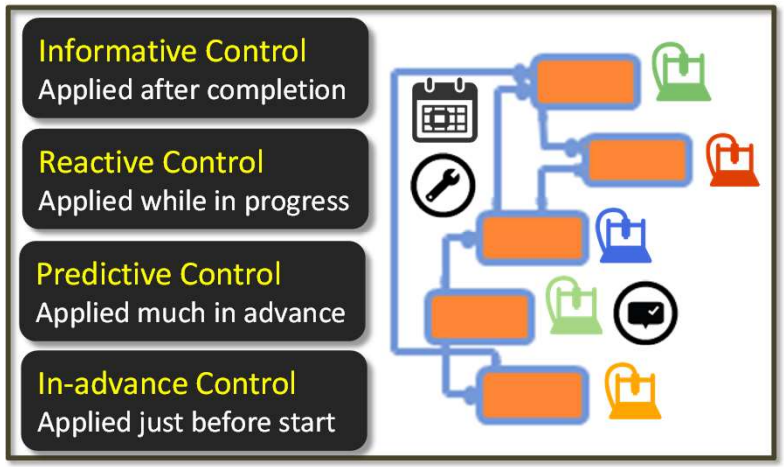
Machining affected zone

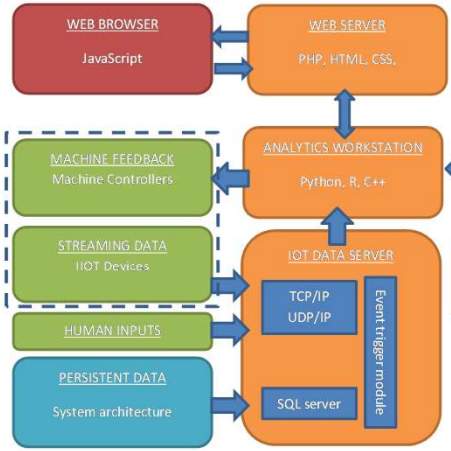


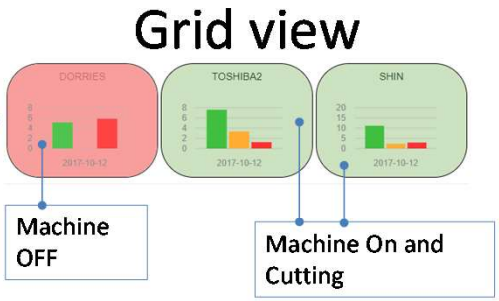
Adiabatic shear band



Smart Factory: Data Analytics and IoT Research



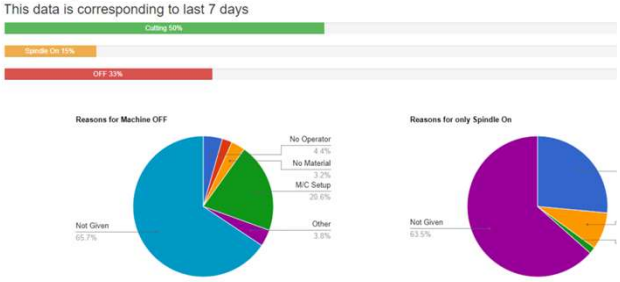


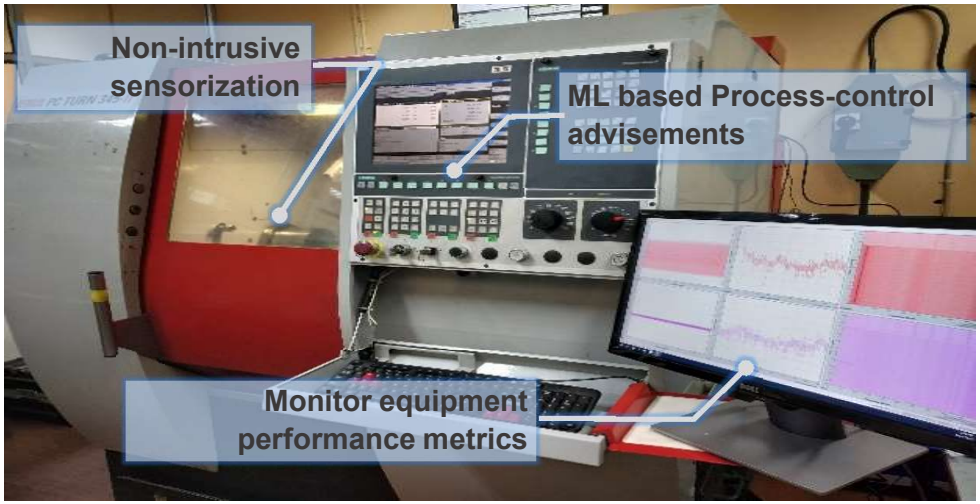


Smart machines facilitate production control on the shop-floor

- Machine ranking

- Weekly/Monthly Statistics



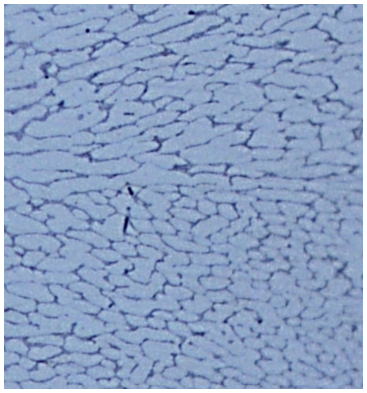


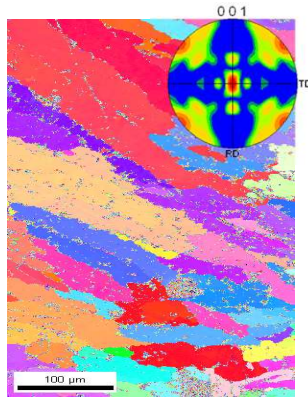
Machine Learning Capabilities at NCAIR

- **Information-based Learning**
  - Decision Trees
  - Shannon's Entropy
  - Information Gain
- **Similarity-based Learning**
  - Feature Space
  - Distance Metrics
- **Probability-based Learning**
  - Naïve Bayes Model
  - Markovian model
- **Error-based Learning**
  - Multivariable Regression
  - Linear discriminate analysis
  - Multinomial Logistic Regression
  - Support Vector Machines
- **Expert-system based learning**
- **Deep Learning**
  - Convolutional neural network
  - Recurrent neural network

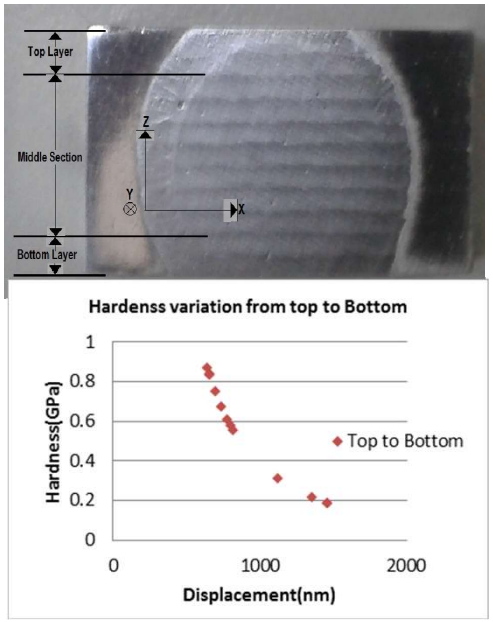
Data Analytics is the discovery, interpretation, and communication of meaningful patterns in data.

ADDITIVE SUBTRACTIVE MANUFACTURING (ASM)





Additive Subtractive Machine (ASM)



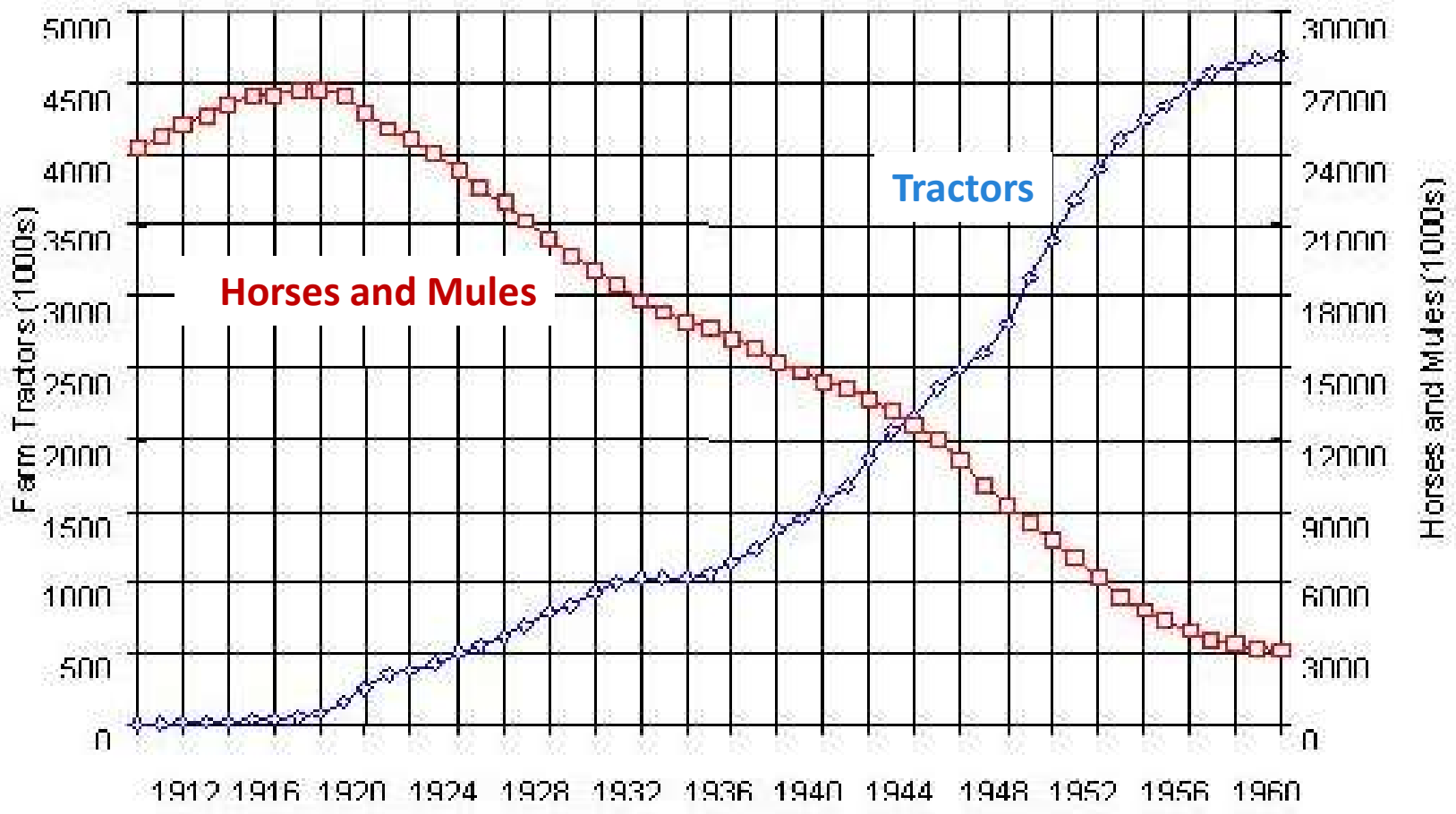
Major challenges

- Optimal part-decomposition
- Slicing and build orientation
  - geometric complexity, cutting tool accessibility
  - multi-bridged structures
  - overhangs
- Part distortion
- Non-uniform & anisotropic properties

Facilities

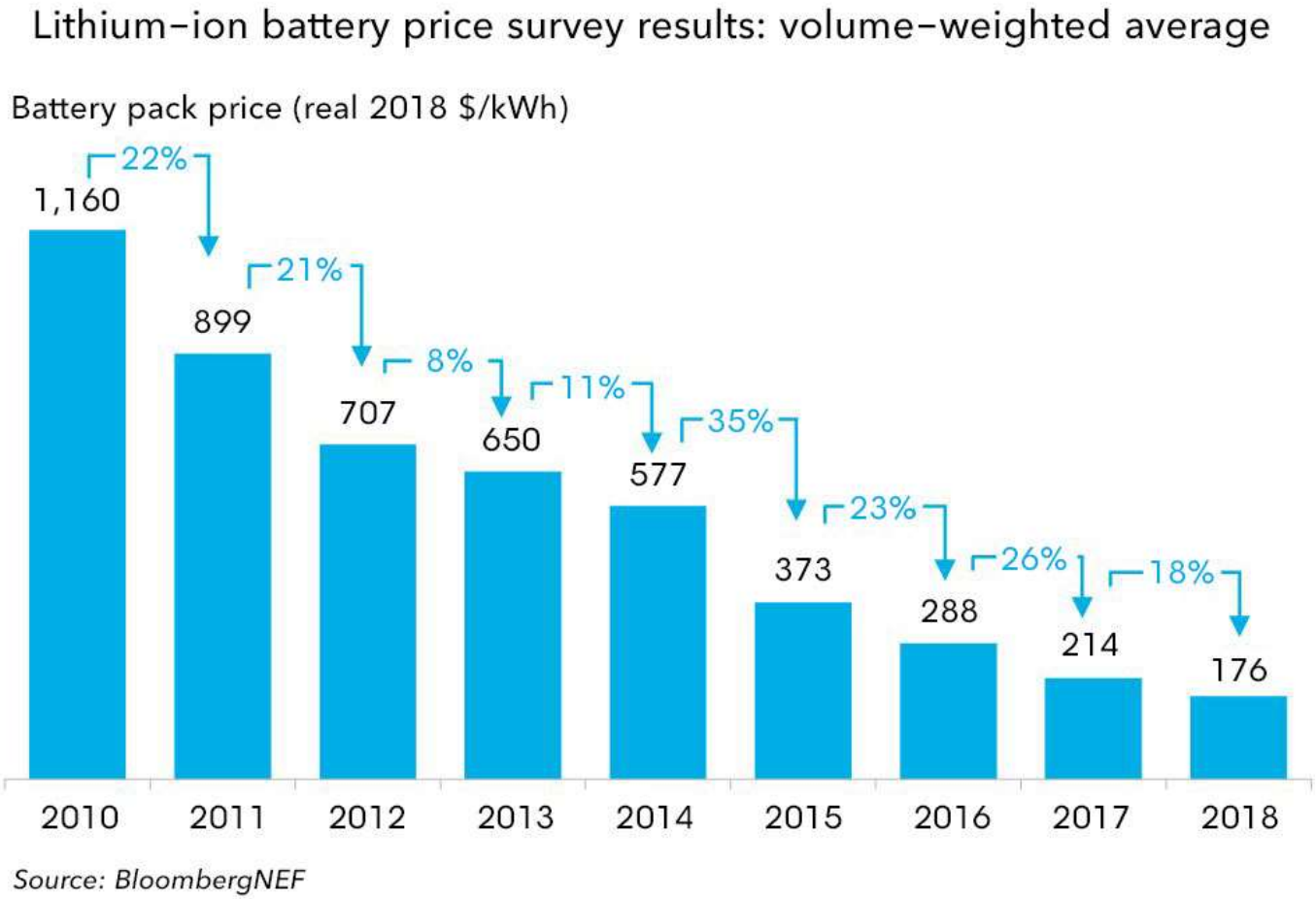
1. In-house hybrid M/C(5-axis+MIG weld)
2. EOS M 280 Build volume 250 mm x 250 mm x 325 mm

Replacement of Horses by Tractors in US farms



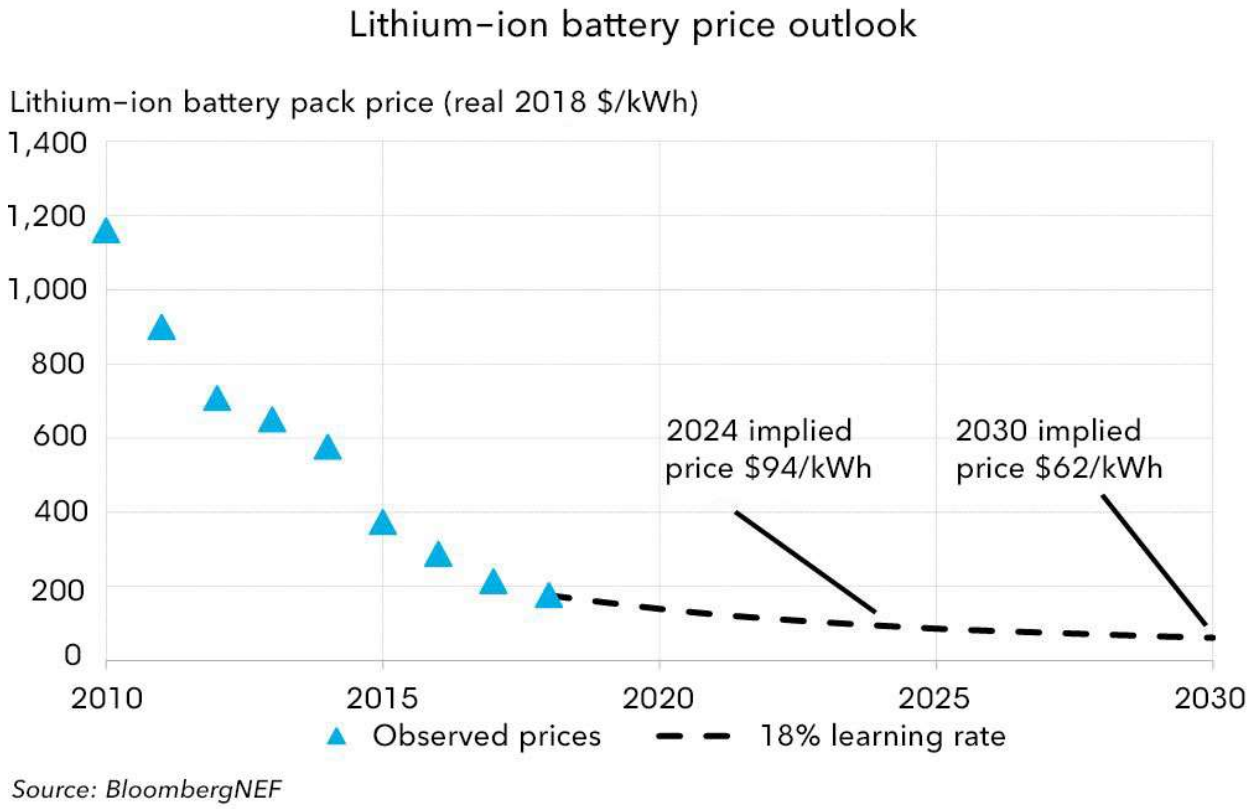
Lithium-ion Battery Prices

Volume weighted average battery pack fell 85% from 2010-18

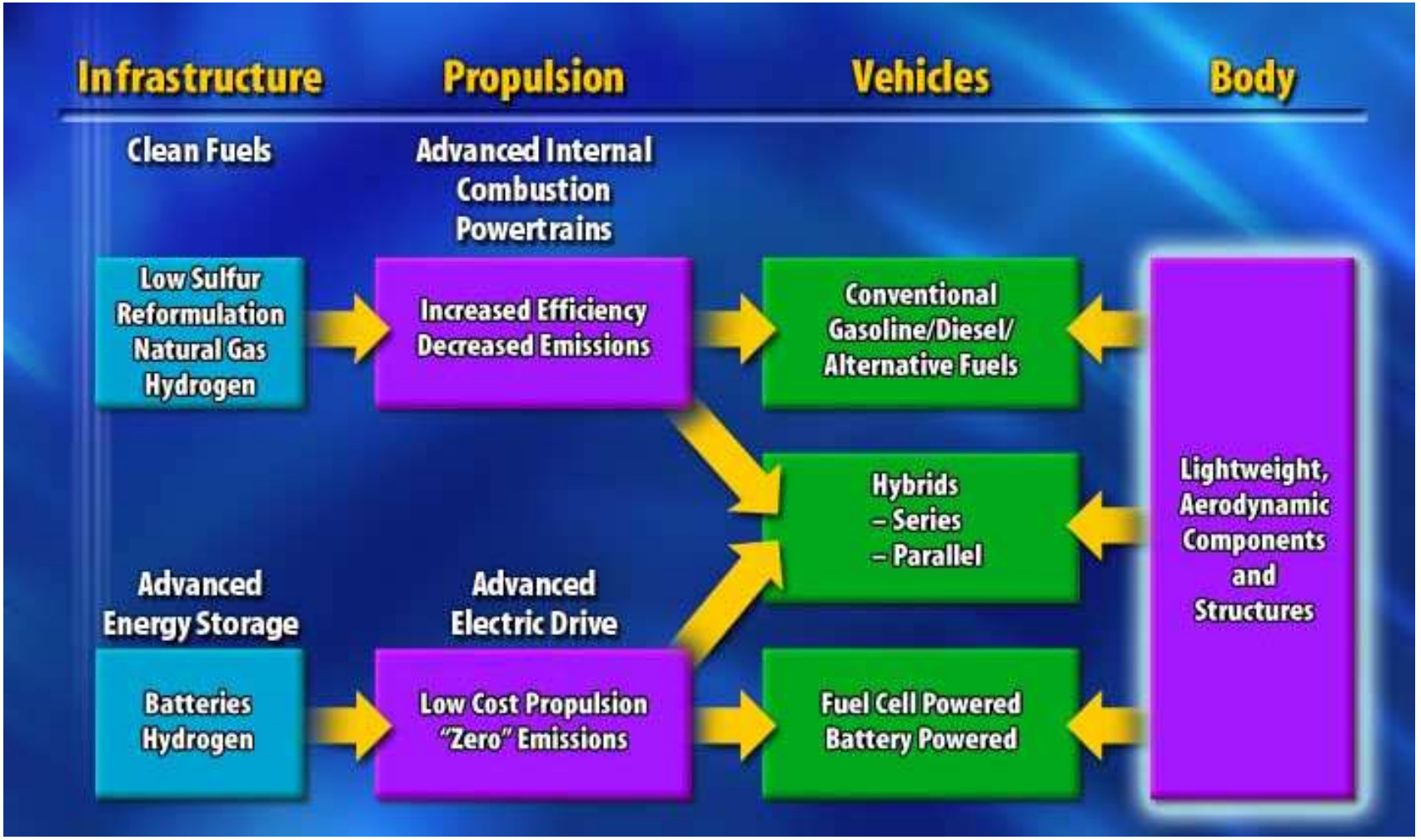


Lithium-ion Battery Prices

For every doubling of cumulative volume there is an 18% reduction in price



Automotive Technology options



Weight Reduction Benefits
Automotive sector

Internal Combustion powered vehicle

- 10% weight reduced => 6–8% improve fuel economy
- Lower CO2 emissions

Battery-powered vehicle

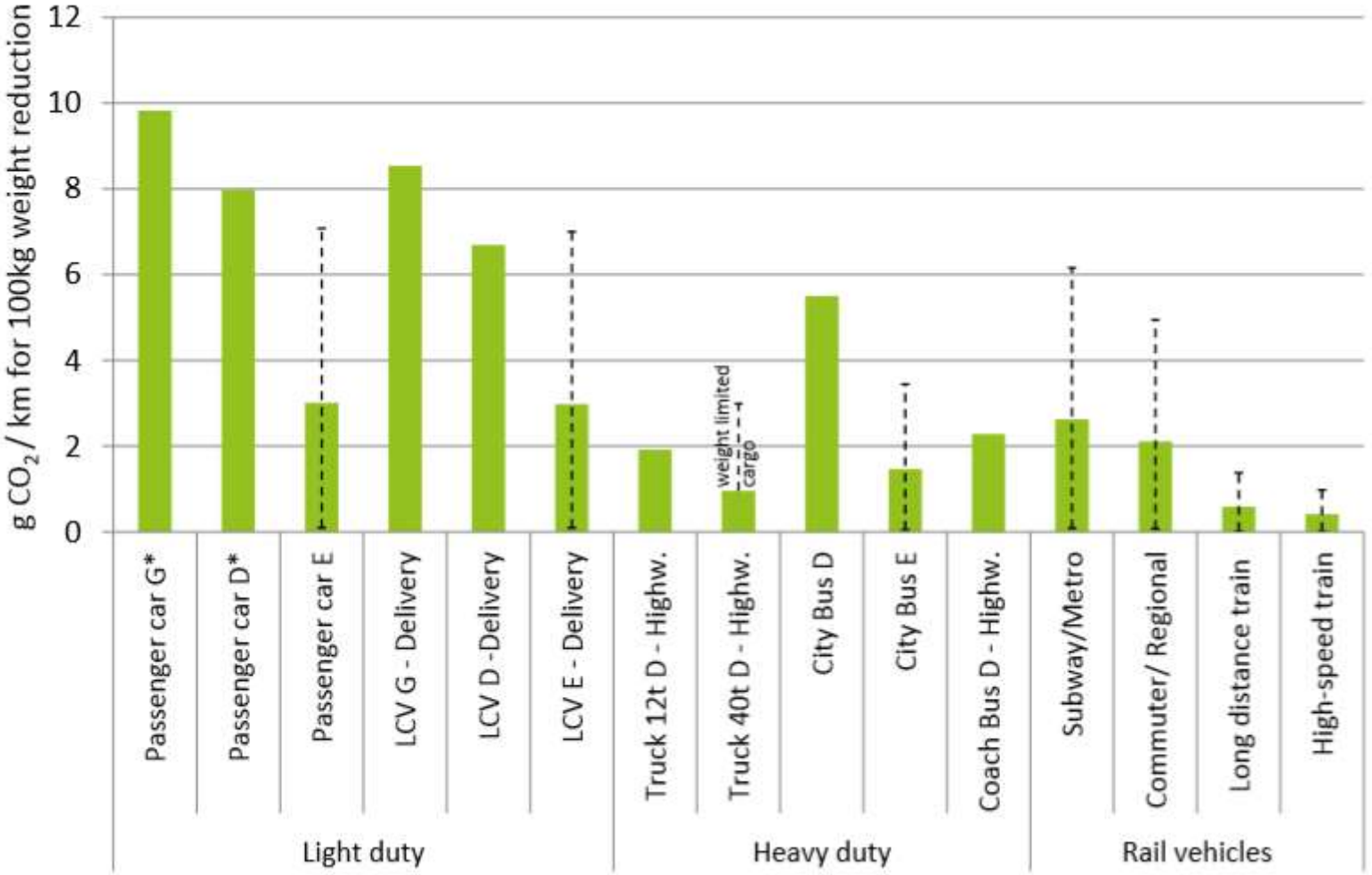
10% weight reduced => 10% increase in range

Mass De-compounding

- Lighter body requires smaller powertrain
- This requires smaller suspension
- This requires smaller braking system

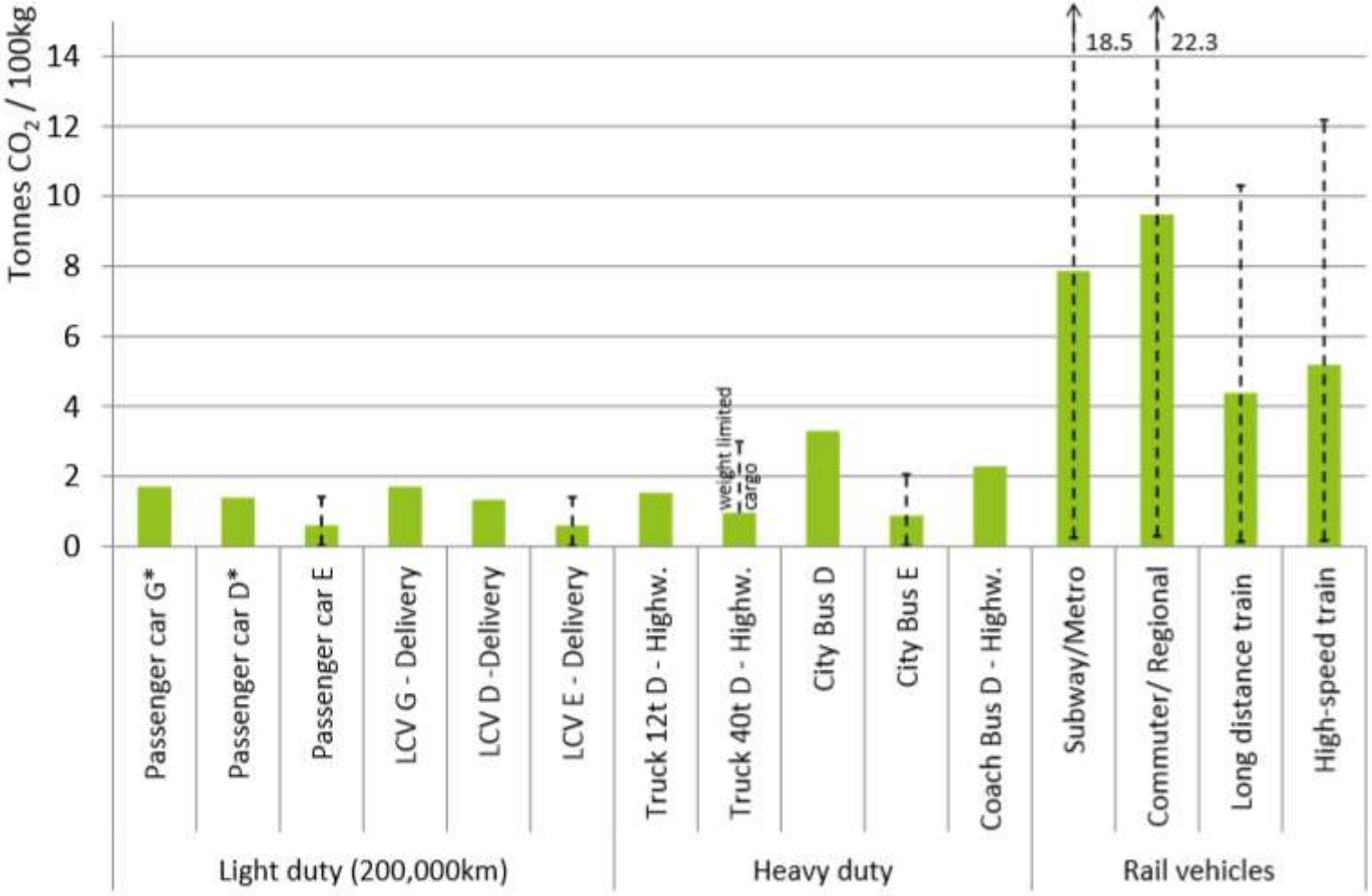
- All these further reduce weight and the mass gets de-compounded

CO2 reduction per kilogram saved



Ref: ifeu-Energy savings by light-weighting -2016

Life-time CO2 savings



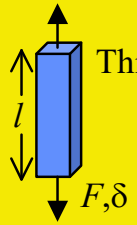
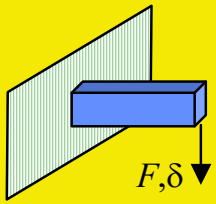
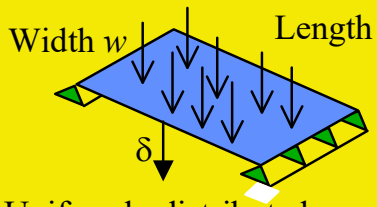
Ref: ifeu-Energy savings by light-weighting -2016

Well-to-Tank analysis

	Well-to-Tank CO2
Gasoline (EN 16258)	0.46 kg CO_2/l
Diesel (EN 16258)	0.56 kg CO_2/l
Electricity (EU28)	0.47 kg CO_2/kWh
Electricity (China)	1.10 kg CO_2/kWh
Electricity (Norway)	0.01 kg CO_2/kWh

Ref: ifeu-Energy savings by light-weighting -2016

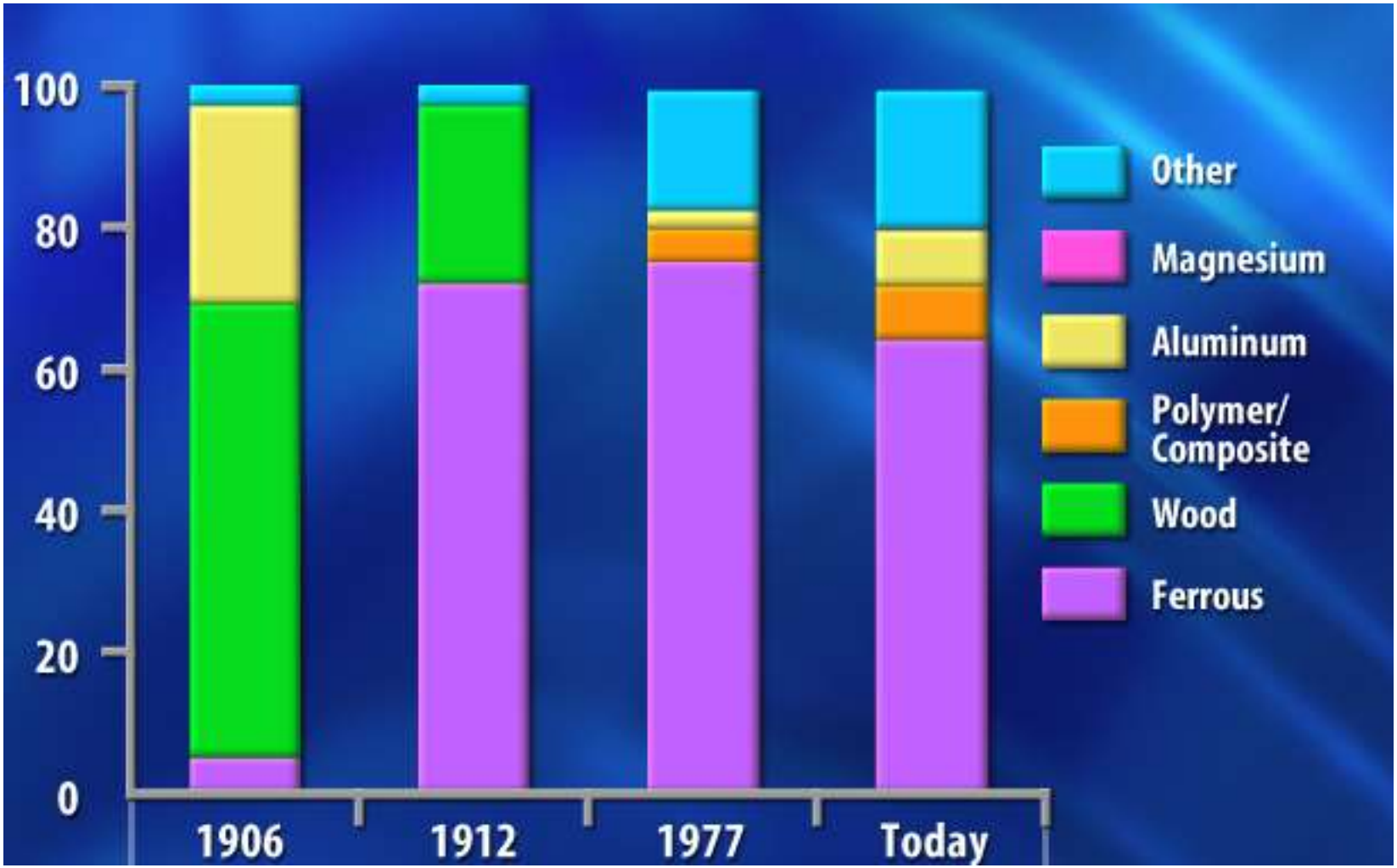
On the choice of structural materials

Loading Mode	Stiffness	Strength
 **Tie**	$\delta = Fl/(Et^2)$ Maximize $\left(\frac{E}{\rho}\right)$ $M = \rho l t^2 = \left(\frac{\rho}{E}\right)\frac{l^2 F}{\delta}$	$\sigma_Y = F/t^2$ Maximize $\left(\frac{\sigma_Y}{\rho}\right)$ $M = \rho l t^2 = \left(\frac{\rho}{\sigma_Y}\right)Fl$
 **Beam**	$\delta = 4Fl^3/(Et^4)$ Maximize $\left(\frac{E^{1/2}}{\rho}\right)$ $M = \rho l t^2 = 2\left(\frac{\rho}{E^{1/2}}\right)\left(\frac{l^5 F}{\delta}\right)^{1/2}$	$\sigma_Y = 6Fl/t^3$ Maximize $\left(\frac{\sigma_Y^{2/3}}{\rho}\right)$ $M = \rho l t^2 = l\left(\frac{\rho}{\sigma_Y^{2/3}}\right)(6Fl)^{2/3}$
 **Plate**	$\delta = 5Fl^3/(32Ewt^3)$ Maximize $\left(\frac{E^{1/3}}{\rho}\right)$ $M = \rho l w t = l^2\left(\frac{\rho}{E^{1/3}}\right)\left(\frac{5w^2 F}{32\delta}\right)^{1/2}$	$\sigma_Y = 3Fl/(4wt^2)$ Maximize $\left(\frac{\sigma_Y^{1/2}}{\rho}\right)$ $M = \rho l t^2 = \left(\frac{\rho}{\sigma_Y^{1/2}}\right)\left(\frac{3Fl^3 w}{4}\right)^{1/2}$

Force F, Displacement δ, Mass M, Stiffness (Young's) Modulus E, Mass Density ρ, Yield Strength σ_Y

Reduction in density will have the highest impact for plates

Material in Typical US vehicle



Necessity of a portfolio approach to structural materials

Material	Density ρ (g cm^{-3})	Young's Modulus E (GPa)	Strength σ_Y (MPa)	Fracture Toughness K_{IC} (MPa m$^{1/2}$)	E/ρ Ties	$E^{1/2}/\rho$ Beams	$E^{1/3}/\rho$ Plates	σ_Y/ρ Spec. Strength	Cost $US/lb
Steel (AHSS>550 MPa)	7.8	207	400-1000	180-30	27	1.8	0.76	50-130	0.50
Al alloys	2.8	71	50-600	50-20	25	3.0	1.5	20-215	1.00
Mg alloys	1.8	45	70-300	30-10	25	3.7	1.95	40-170	1.50
Titanium	4.5	104	925	50	23.1	2.26	1.0	205	10.00
Epoxies [TS]	1.2-1.4	2.1-5.5	40-85	0.6-1.0 (20°C)	1-5	1-2	1-1.5	28-70	1.00
Polyesters [TS]	1.1-1.4	1.3-4.5	45-85	0.5 (20°C)	1-4	1-2	1-1.5	32-75	1.00
Polypropylene [TP]	0.91	1.2-1.7	50-70	3.5 (20°C)	1-2	1-1.4	1-1.3	55-77	1.00
CFRP, 58% uniaxial C/epoxy	1.5	189	1050	32-45	126	9	3.8	700	6.00 (500 in 1960)
GFRP, 50% uni-axial glass polyester	2.0	48	1240	42-60	24	3.5	1.8	620	1.20

- **Mg alloys: creep and corrosion problems. Al: excellent on corrosion, creep can be a problem (all yellow entries).**
- **Polymer composites are stiff, strong, corrosion and fatigue resistant, generally recyclable (especially polypropylene-based TP's), but can be expensive (low investment, high piece cost, especially carbon fibers), poor in compression, and prone to creep; forming and surface quality can be problematic. Claddings and fascias often do not require high tensile strength and may require a low flex modulus. [TS: Thermoset; TP: Thermoplastic]**

Advanced Composite Materials

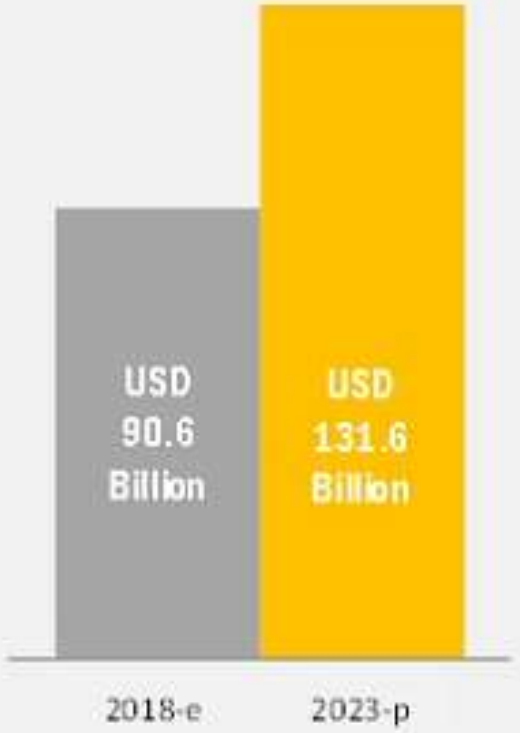
Advantages

- 50 to 65% reduction in weight
- Crashworthy
- Design Flexibility
- Durability
- Manufacturing ease

Disadvantage

- Cost

Composite Market growth



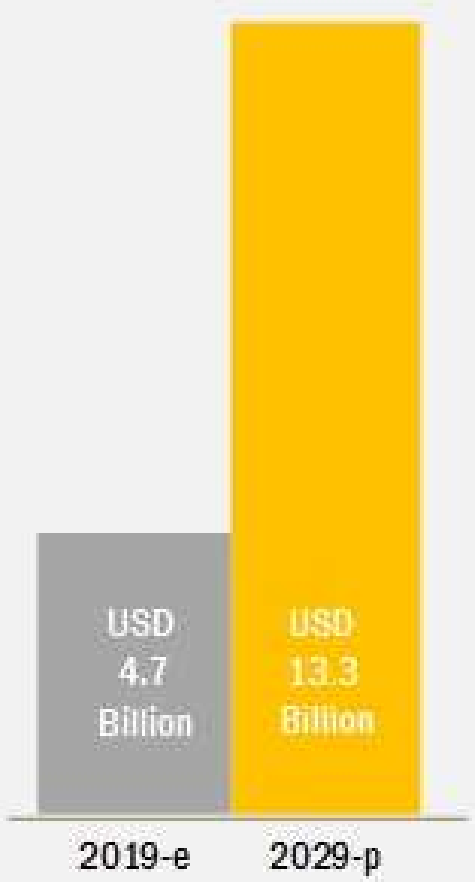
CAGR

7.7%

- The global composites market size is estimated at USD 90.6 billion in 2019 and is projected to reach USD 131.6 billion by 2024, at a CAGR of 7.7% during the forecast period
- The market growth is attributed to the rising demand for lightweight, high performance solutions for various end-use industries.
- Transportation is the major end-use industry in the composites market

Note e-estimated; p-projected.

Carbon fiber market



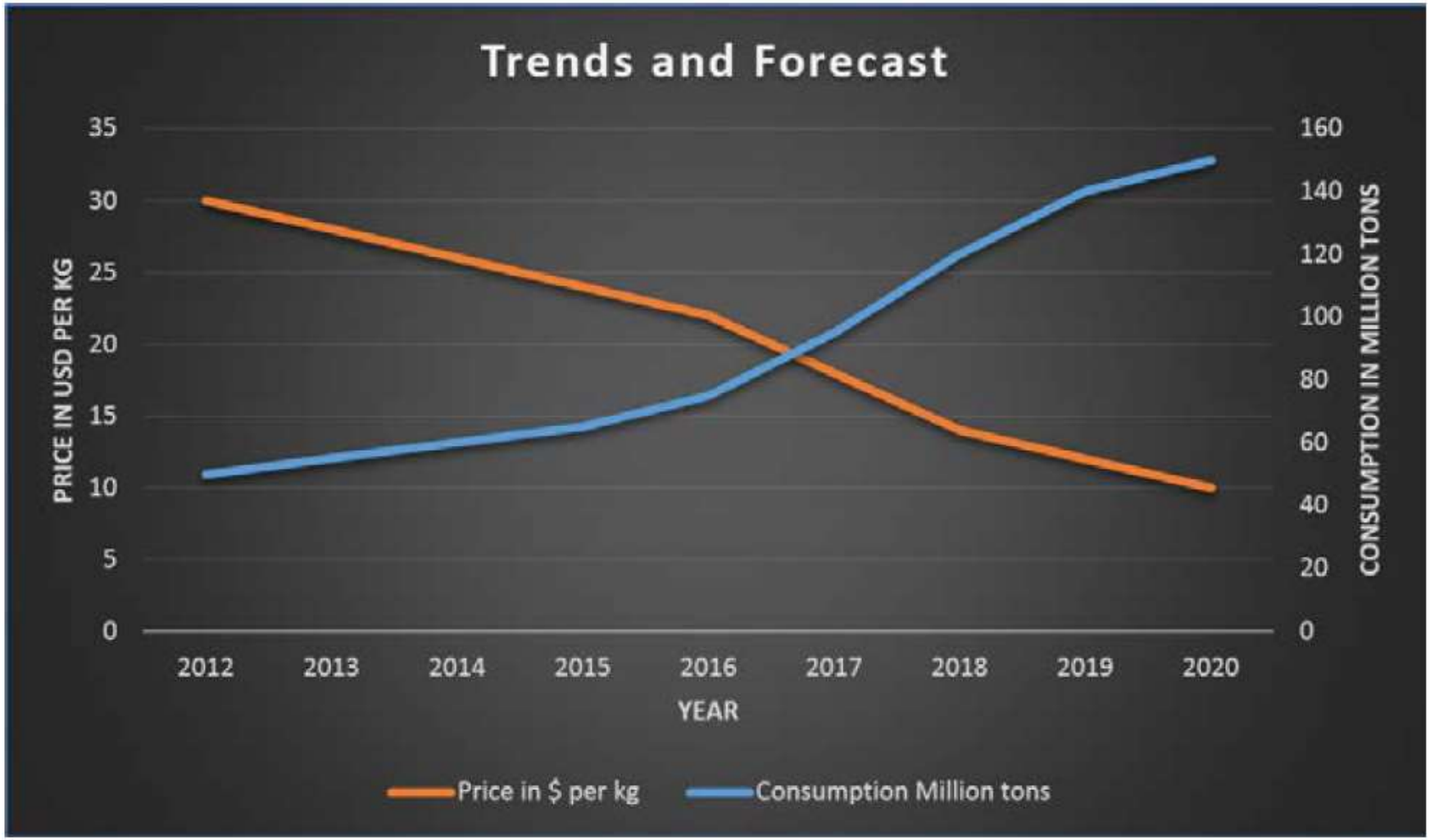
CAGR
11.0%

- The carbon fiber market is expected to grow from USD 4.7 billion in 2019 to USD 13.3 billion by 2029, at a CAGR of 11.0% during the forecast period.
- The market growth is attributed to the increased demand for carbon fiber from CNG and hydrogen cylinders, electric cars and rising commercial aircrafts production.
- Europe is expected to be the largest market for carbon fiber owning to its growing aerospace & defense, automotive and wind energy industry.

Source: MarketsandMarkets Analysis

Note: e= estimated; p= projected.

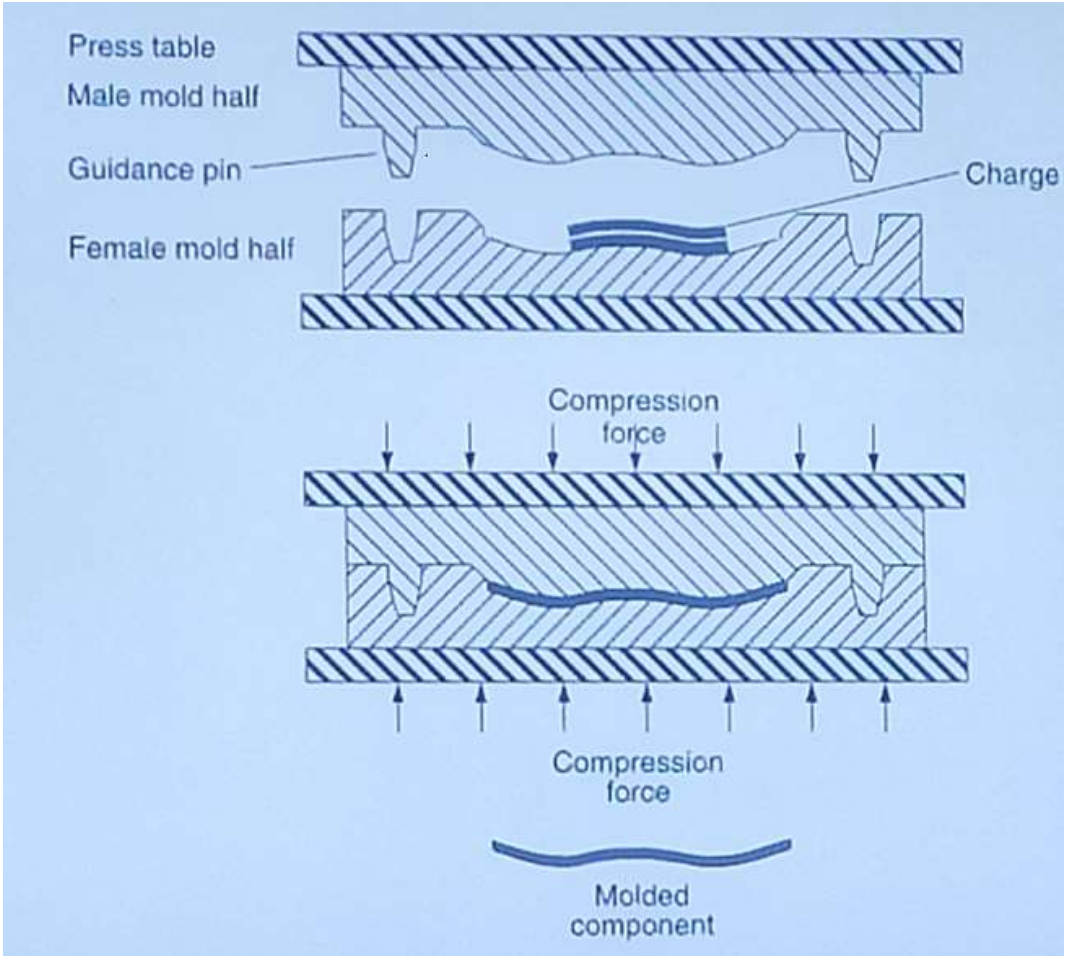
Carbon fiber market



Ref: Carbon composites are becoming competitive and cost effective.. *http://www. infosys. com*.

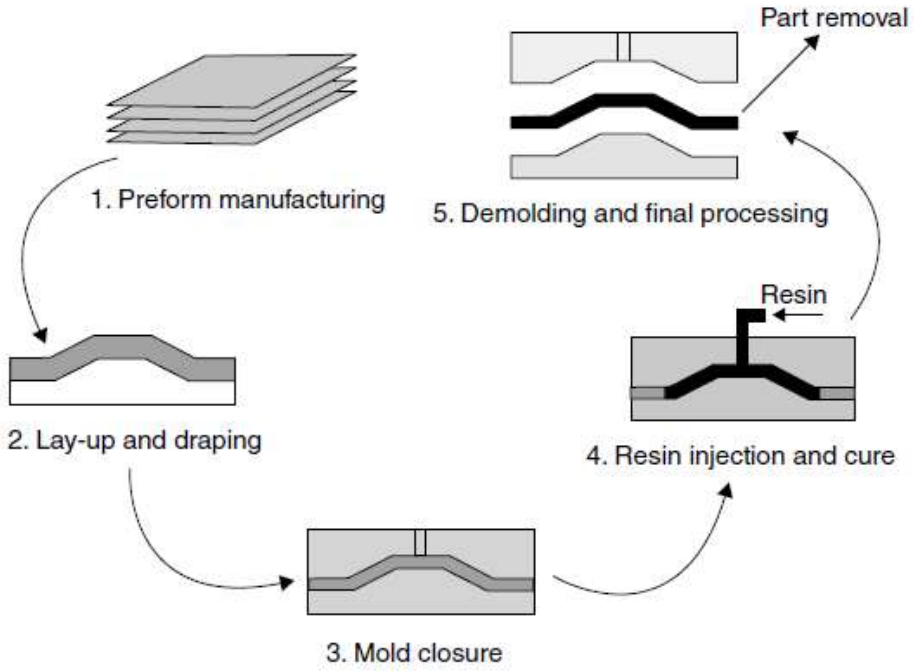
Composite Manufacturing Process

Compression Molding



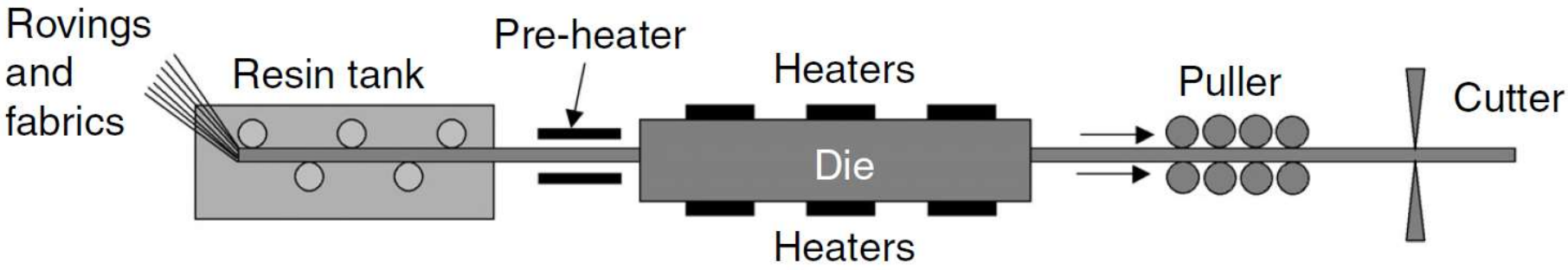
Composite Manufacturing Process

Resin Transfer Molding



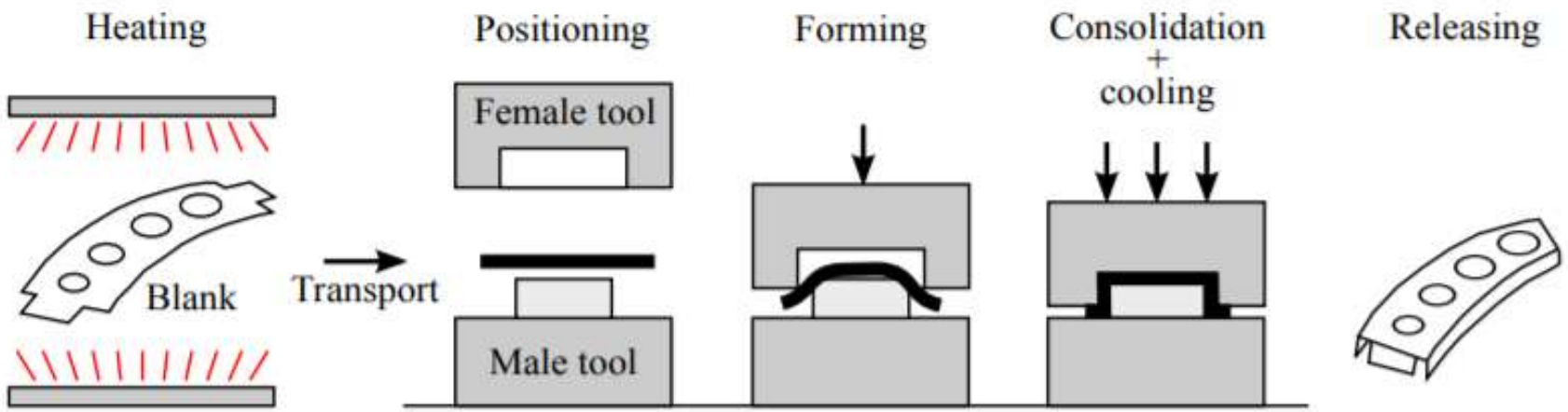
Composite Manufacturing Process

Pultrusion



Composite Manufacturing Process

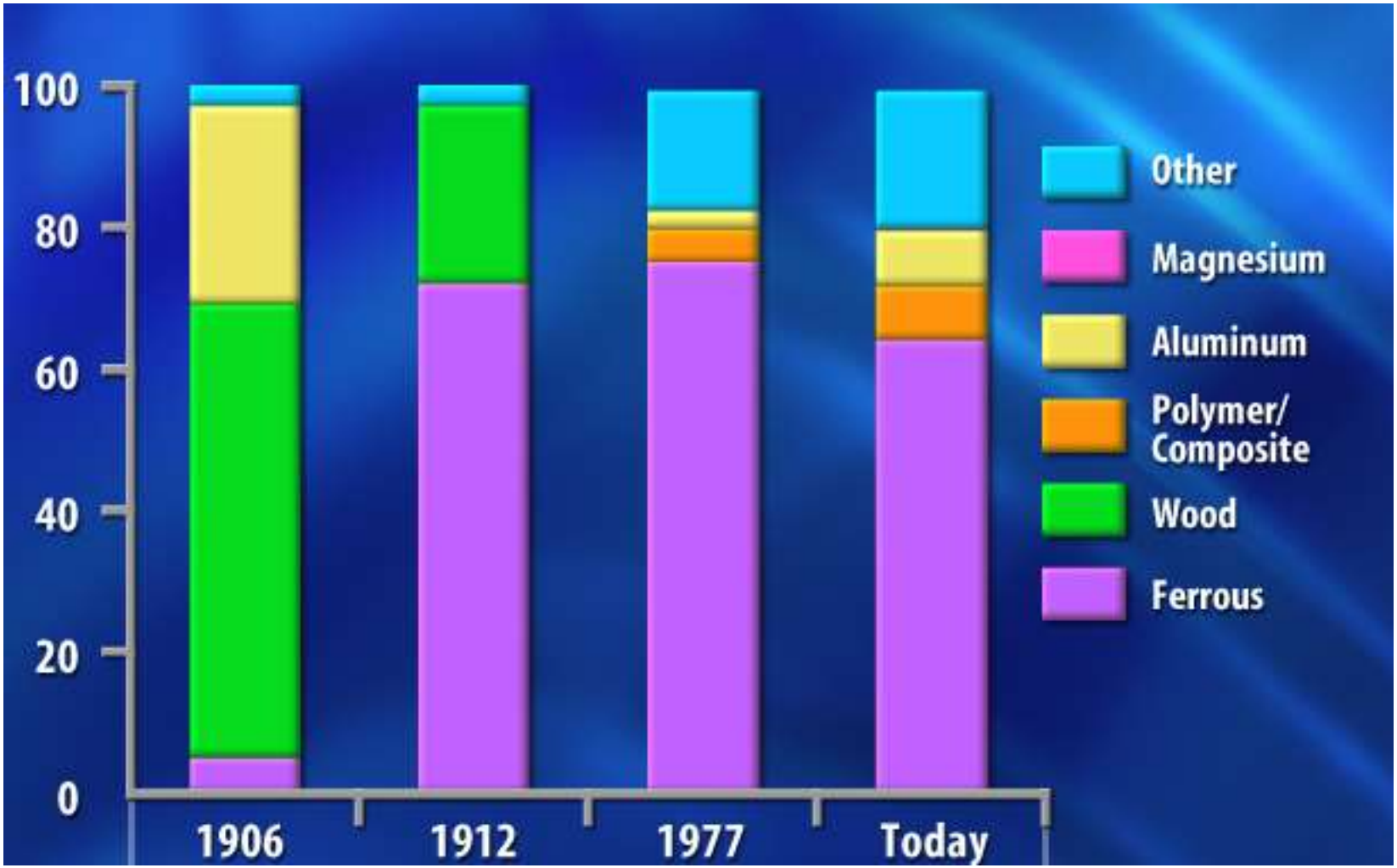
Thermoplastic Stamping



Nanocomposites: summary of tangible benefits

- **Mass savings up to 21%**
  - Specific gravity of 0.92 vs. 0.96-1.13 g/cm^3
  - Lighter weight reduces cost and requires less adhesive for attachment
- **Improved appearance**
  - Sharper feature lines & grain patterns
  - Improved scratch/mar performance
  - No fiber read-out
  - Improved colorability & paintability
- **Large processing window**
  - Enhanced shear thinning, melt elasticity and processability
  - Consistent physical and mechanical properties
- **Reduced Paint Delamination**
  - Increased cohesive strength
- **Retains low temperature ductility**
- **Improved recyclability**
- **Lower flammability**

Material in Typical US vehicle



Nanocomposite Applications

- **GM:** > 1 M lbs PP based nanomaterials

  - Exterior: H2SUT trims around cargo, spoiler on STS-V

  - Interior: Center consol of Saturn Vue, HHR

- **Toyota:** Nylon nanocomposite for under hood application

- **Honda:** PP based nanomaterial for seat back in Acura TL

- **Nissan:** Carbon nanotube reinforced materials in fenders of XTrail

Application Opportunities: Semi-Structural

- **Exterior Trim**
  - Fascia, Rockers, Side Trim, Grilles, Hood Louvers
- **Interior Structure and Trim**
  - Instrument Panels, Seat/IP Foams, Door Inners, Trim – i.e., Pillar Covers,
- **Body Panels**
  - Vertical and Horizontal Body Panels, Closure Panels
- **Underhood**
  - Engine Shields, Fan Shrouds, Air Intakes
- **Fuel System**
  - Fuel Tanks, Fuel Lines

In summary

Change is the only constant

Adaptation is the only resort

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