Nanocellulose Reinforced Polymers

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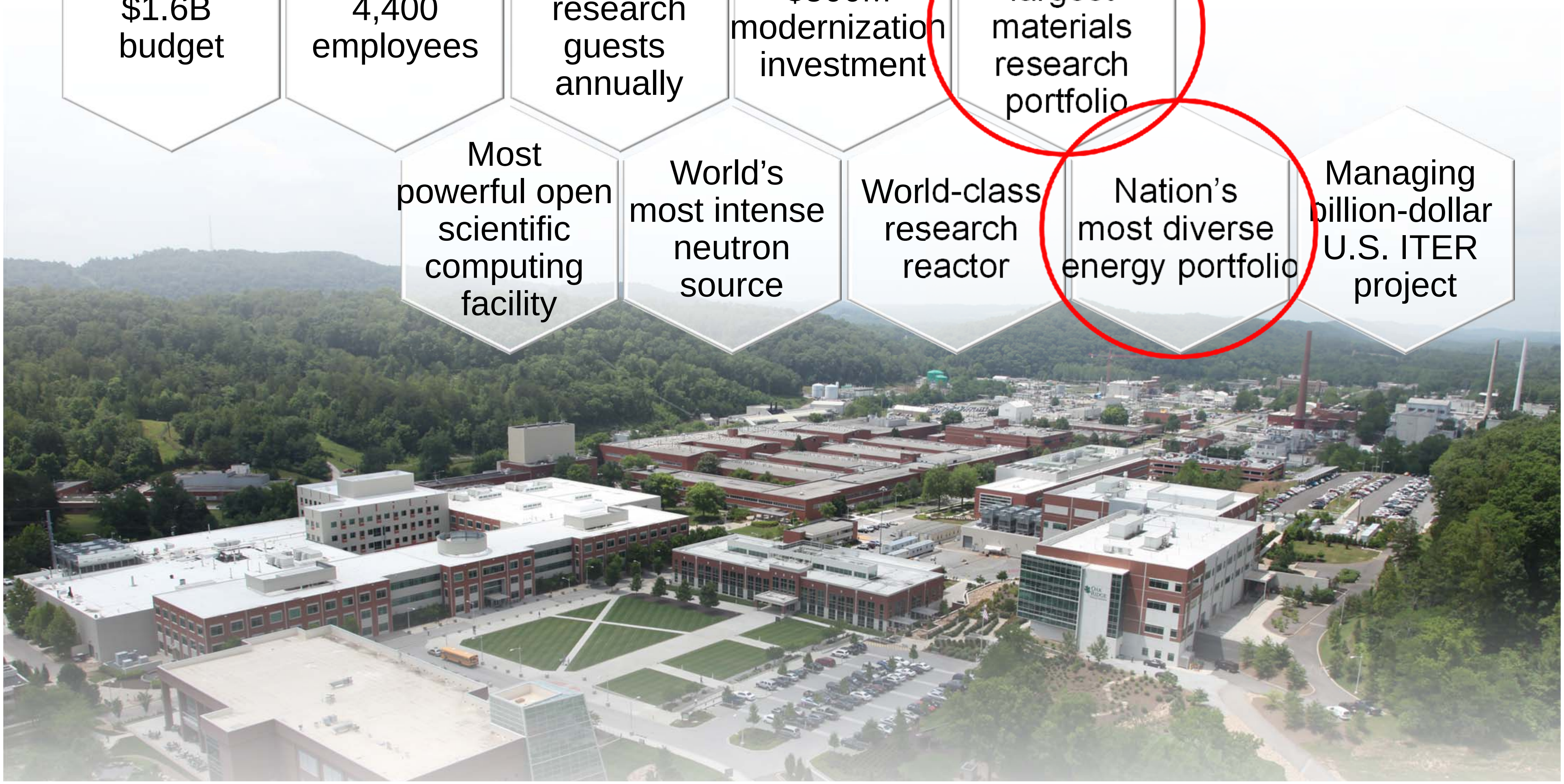
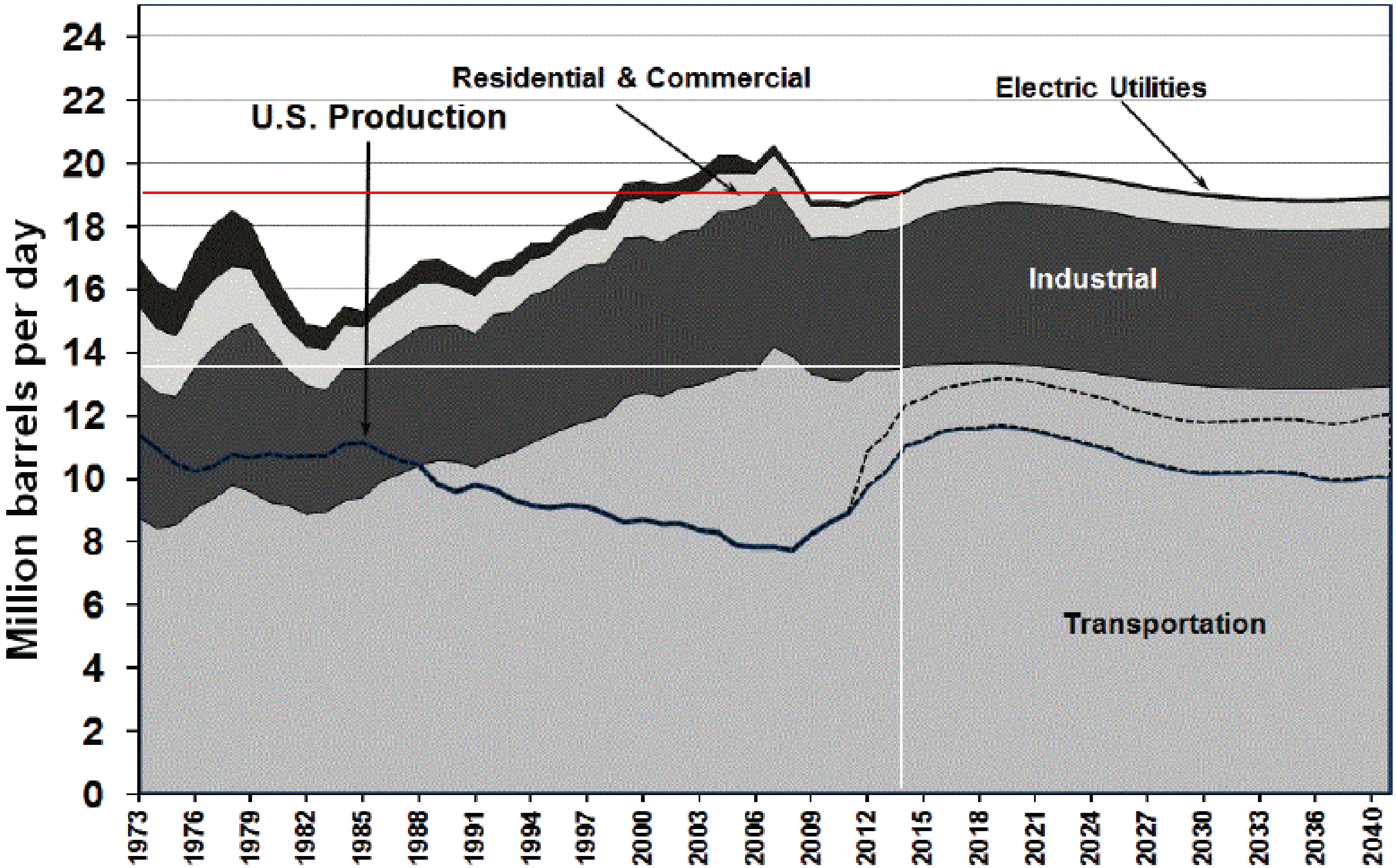
National Laboratory

ORNL is DOE's largest science and energy laboratory

- $1.6B budget
- 4,400 employees
- 3,000 research guests annually
- $500M modernization investment
- Nation's largest materials research portfolio
- Most powerful open scientific computing facility
- World's most intense neutron source
- World-class research reactor
- Nation's most diverse energy portfolio
- Managing billion-dollar U.S. ITER project

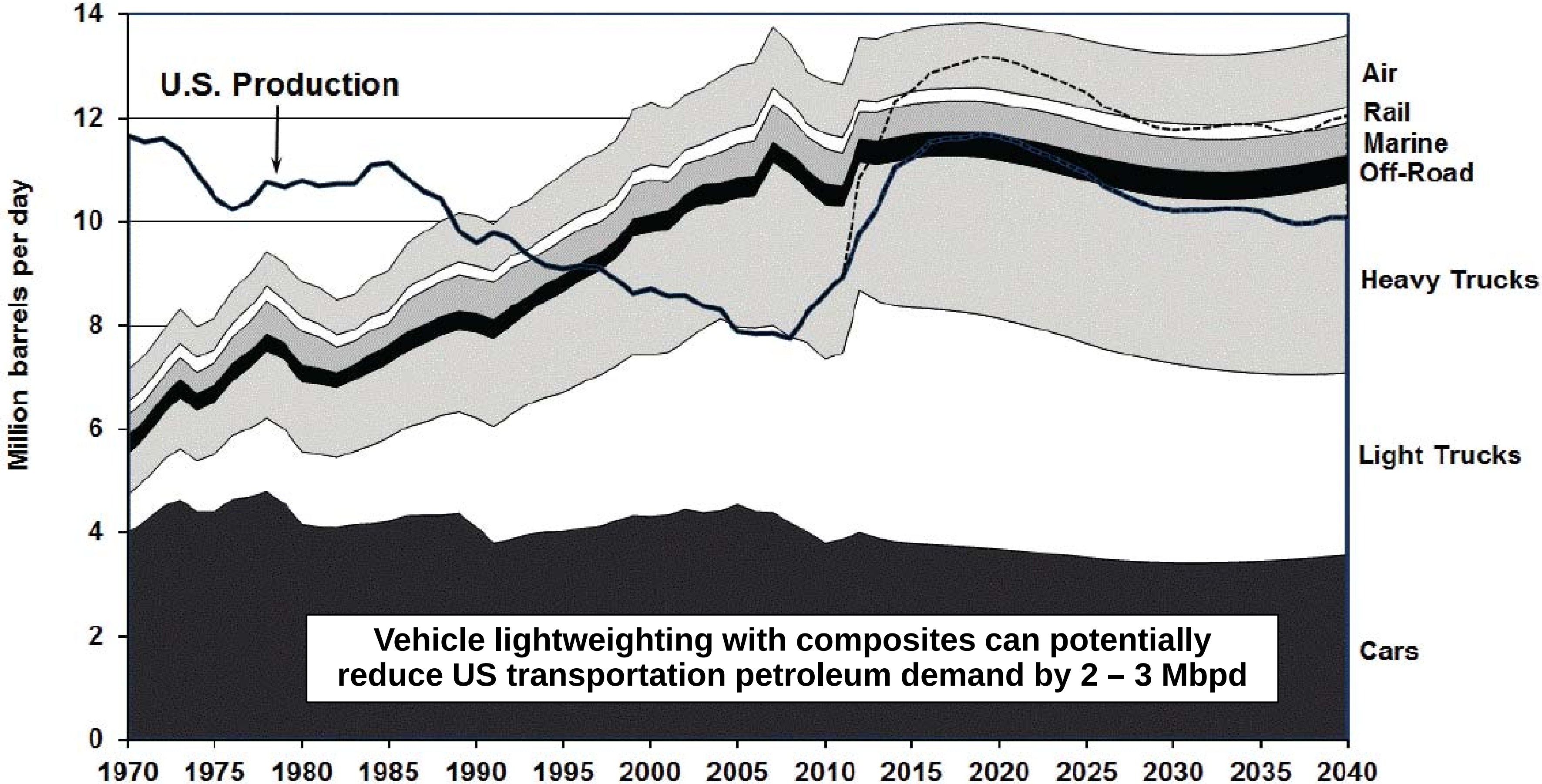


40% of US Energy Demand Uses Oil....



Source: 2012 Transportation Energy Data Book

....2/3 Being Used for Transportation



Source: 2012 Transportation Energy Data Book

Nanocellulose Has Interesting Properties

Material	Density	Tensile Strength	Tensile Modulus	Cost
	g/cc	MPa	GPa	$/kg
Hi Strength Steel	7.9	600	210	~1
Aluminum 6061-T6	2.7	275	70	~2
E-glass fiber	2.5	3,500	80	~2
Carbon fiber	1.8	4,000	230	>20
Cellulosic Nanocrystals*	1.5	7,500	135	4-10

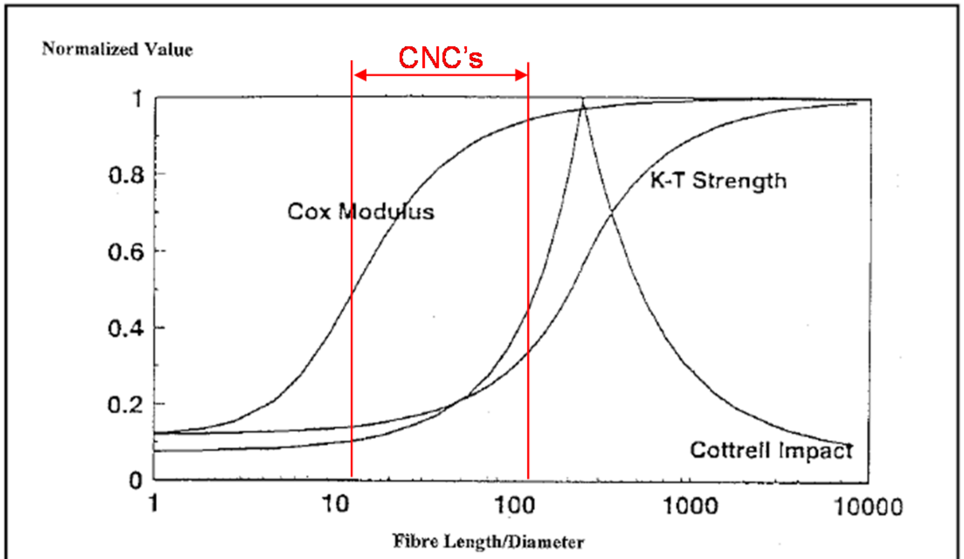
Cellulosic nanomaterials are potentially useful as either primary or secondary reinforcements in polymer matrix composites

*Source: Ted Wegner, seminar at Oak Ridge National Laboratory, Nov 2012

Functional Attributes

- Piezoelectric constant similar to that of quartz
  - Sensing, dynamic shape control
- Forms nematic liquid crystal phase yielding control over optical properties
  - In-molded color, transparency
- NCC exhibits excellent, tailorable barrier properties
- Magnetically responsive
- Aerogel/ foam capable, highest surface area among cellulosic aerogels
- Can be made highly hydrophobic or hydrophilic
- Can be generated by bacteria including certain algae

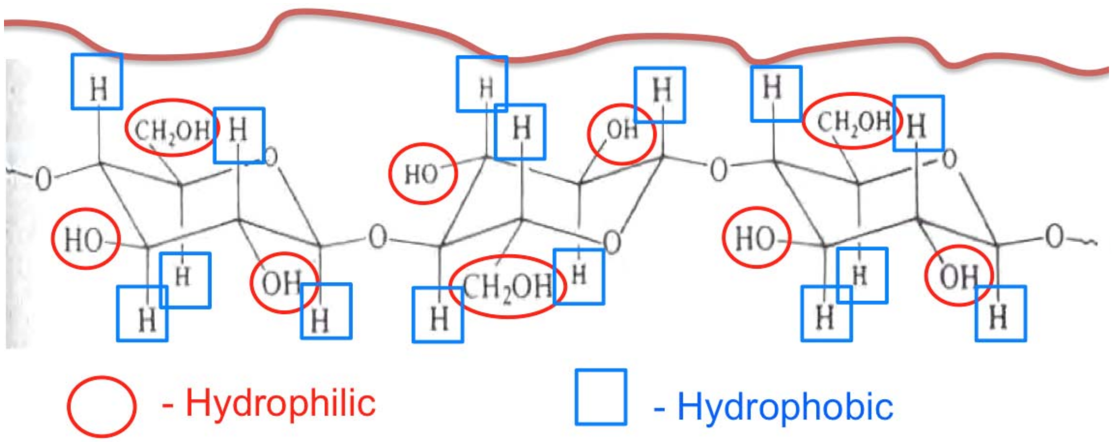
Challenges: Strength Translation



Normalized theoretical properties of a 30% w/w unidirectional Glass fibre/polypropylene

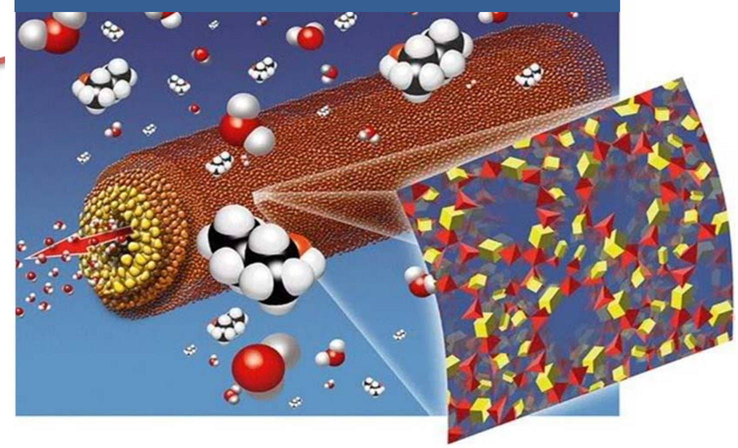
CNC aspect ratio limits strength translation in composite

Sources:
(1) Henning and Gleich, Composites Tutorial at SPE Automotive Composites Conference and Exposition, Troy MI Sept 2012
(2) Ted Wegner, seminar delivered at Oak Ridge National Laboratory, Nov 2012



Surface has to be engineered to achieve good dispersion and bonding to matrix

Proprietary Atmospheric Plasma Technique



Challenges: Stability

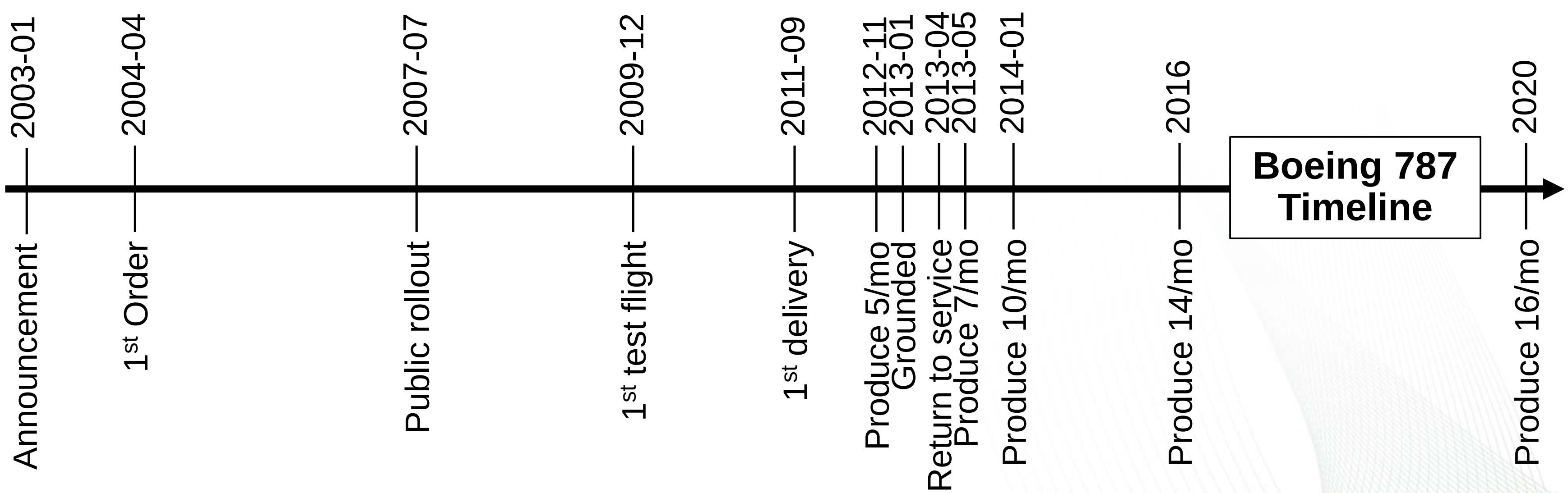
- For the automotive environment:
  - Thermal: E-coat process can be 200°C for up to an hour
  - Must maintain dimensional stability, structural integrity, and appearance for 15 years in
    - Desert heat and arctic cold
    - UV exposure – intense sunlight
    - Wet and humid conditions, including summer heat (hot-wet)
    - Chemical exposures – fuel spills, hydraulic fluids, acids, etc.
    - Mild impacts (insects, pebbles, etc)

Challenges: Qualification

- Aircraft
  - Limited/incremental material qualification can cost > $1M
  - Material or process changes require requalification
  - Cost of a revolutionary platform qualification program (e.g., Boeing 787) can approach $100M
- Automotive
  - Qualification requirements less regulated
  - Combination of liability and large volumes drives risk
  - Extreme penalties for suppliers that fail to deliver

Challenges: Timing

- Insertion into aircraft and automotive programs is excruciatingly slow
  - Major aircraft programs can require well over a decade from concept to full production (see 787 timeline below)
  - 2018 automotive platform design decisions are being made NOW
  - Automotive production schedules WILL NOT be delayed



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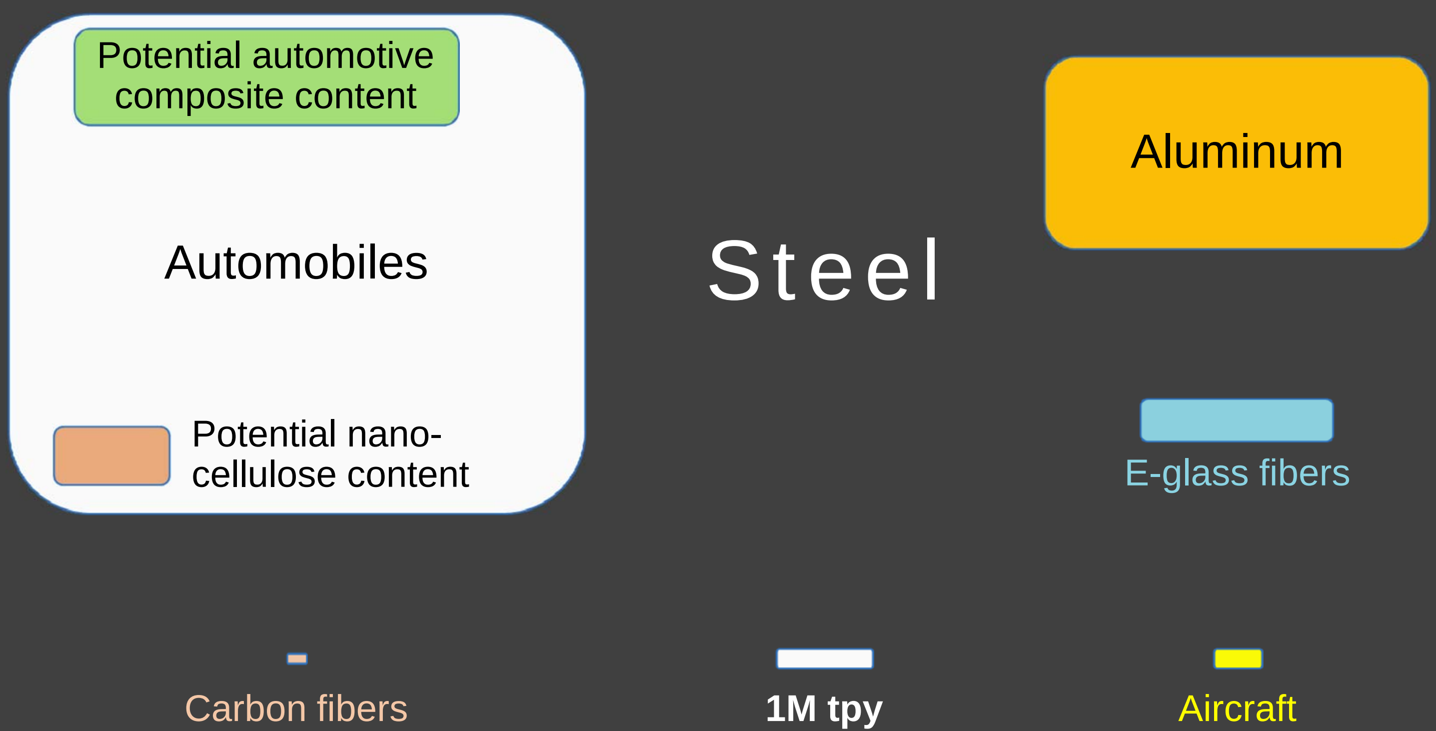
Challenges: Scale – "The Million Ton Question"

How to manage cost and start small but grow big?



Annual global production tonnage is proportional to area shown

Sources: WorldSteel Association; International Aluminum Institute; Owens Corning; Chris Red, Carbon Fibers 2012; 2012 Transportation Energy Data Book

Key Drivers for Deployment

- Aircraft – operational efficiency and passenger comfort
- Freight- increased payload
- Automotive – fuel economy, emissions regulations, safety and reliability
- Buildings, infrastructure, etc – energy efficiency, enhanced functionality

Summing it up

- Cellulosic nanomaterials potentially offer a unique and wonderful combination of properties and cost as a polymer reinforcement
- High volume, cost-sensitive markets are likely to be good cellulosic nanomaterials applications
- The road to commercial deployment is long and difficult
- There are markets that will reward those who stay the course