Enabling Low Cost Carbon Fiber Composites

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Topics

- **Carbon Fiber Composites Market**
  - Automotive, aerospace, construction, energy etc.
  - Russia's Role
- **Building a Carbon Fiber Ecosystem**
  - From scientific research to production
- **Responding to Challenges with Technology Innovations**
  - Barriers to realization of growth potential – identifying cost centers
  - Raw materials & processing technologies – enabling research through prototyping
  - Operating costs – managing cost and efficiency with energy recovery
  - Online utilization – squeezing the most from each investment

Market Overview

- **Key attributes of carbon fiber composites**:
  - High strength & stiffness
  - Lightweight
  - Non-corrosive
  - High temperature tolerance and low thermal expansion
  - High thermal and electrical conductivity
  - High durability and fatigue resistance

- **Key challenges**:
  - Lowering per-unit cost of CF materials production
  - Removing composites production bottlenecks from supply chain

- **Russia's Role:**
  - Robust scientific research
  - Innovative product development
  - Scalable manufacturing potential


Aerospace


Automotive

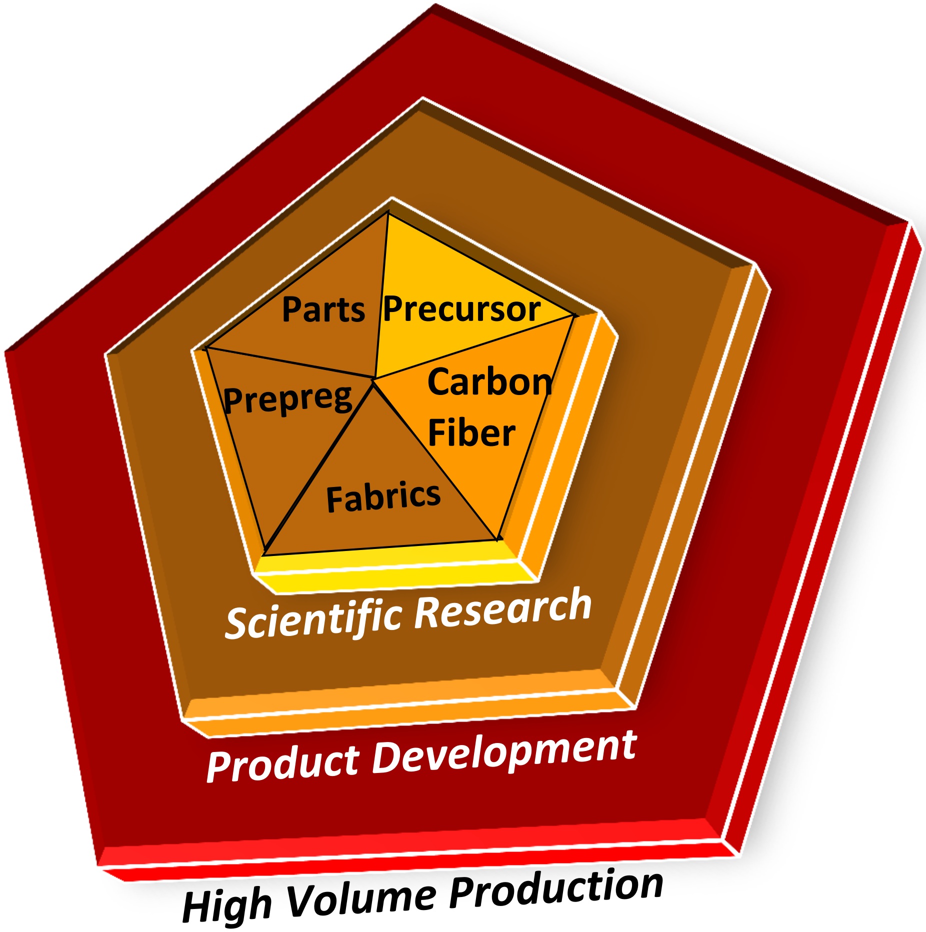

Oil & Gas Exploration


Energy Storage


Wind Energy

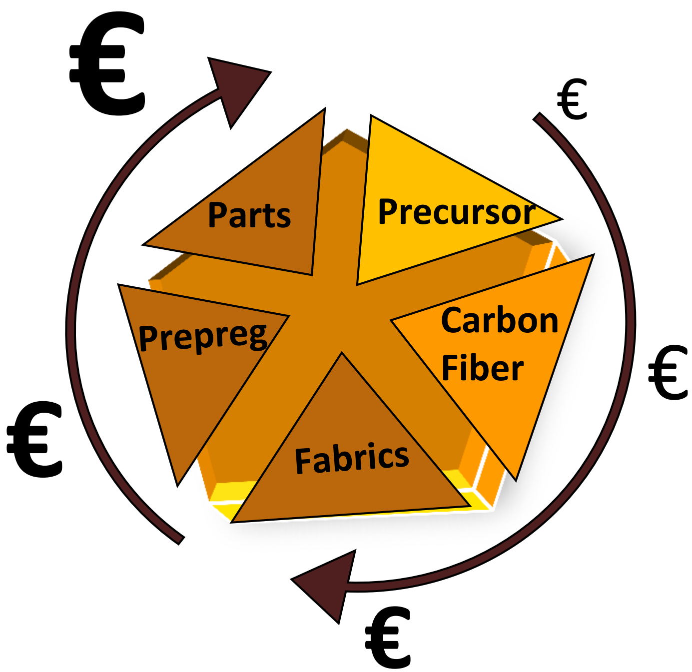

Electronics

Building a Carbon Fiber Ecosystem



Supply Chain Cost Centers

- High costs in converting **CF → CF Composite**…and…**CF Composite → Composite Parts**
- Disparate supply chain generates cost in transport, duties, storage, redundancies
- Yet still much room for cost improvement upstream in CF production…



Market Research[1]
Production Cost Estimates[2]
- *High strength CF ≈ $26,000 / ton*
- *High modulus CF ≈ $33,000 / ton*

Reducing Costs of CF Material Production

- Raw materials
- Product output – scale of operations
- Operating costs – energy consumption
- Operational efficiency – online utilization

[1] Courtesy of A. Coker; J. Goh; K. Patel, "Carbon Fiber", Nexant, Process Evaluation Research Planning, May 2012
[2] Assumptions based on given production scale and precursor chemistries

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Carbon Fiber Building Blocks

Three-stages apply to each wedge in building the ecosystem

CF Production Cost Reduction Strategy

1. **Product Output**
   - Right-sizing scale of operations
2. **Raw Materials**
   - Research & prototyping of alternate precursor chemistries
3. **Operating Costs**
   - Evaluating & reducing energy consumption
4. **Operational Efficiency**
   - Maximizing online utilization

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Ranging Scale of Operations
Sizing Operations to Needs

Courtesy of Georgia Institute of Technology

Scale	Size Range (Tow-Band Width)	Capacity
Scientific Line	Fractional tows (<1k or less than 1,000 filaments)	Less than 1 ton/year
Microline™	≤100 mm	Less than 10 ton/year
Pilot Line	300 -1000 mm	20 - 100 ton/year
Commercial Production Line	1000 – 4200 mm	500 - 4000 ton/year

Courtesy of Oak Ridge National Laboratory

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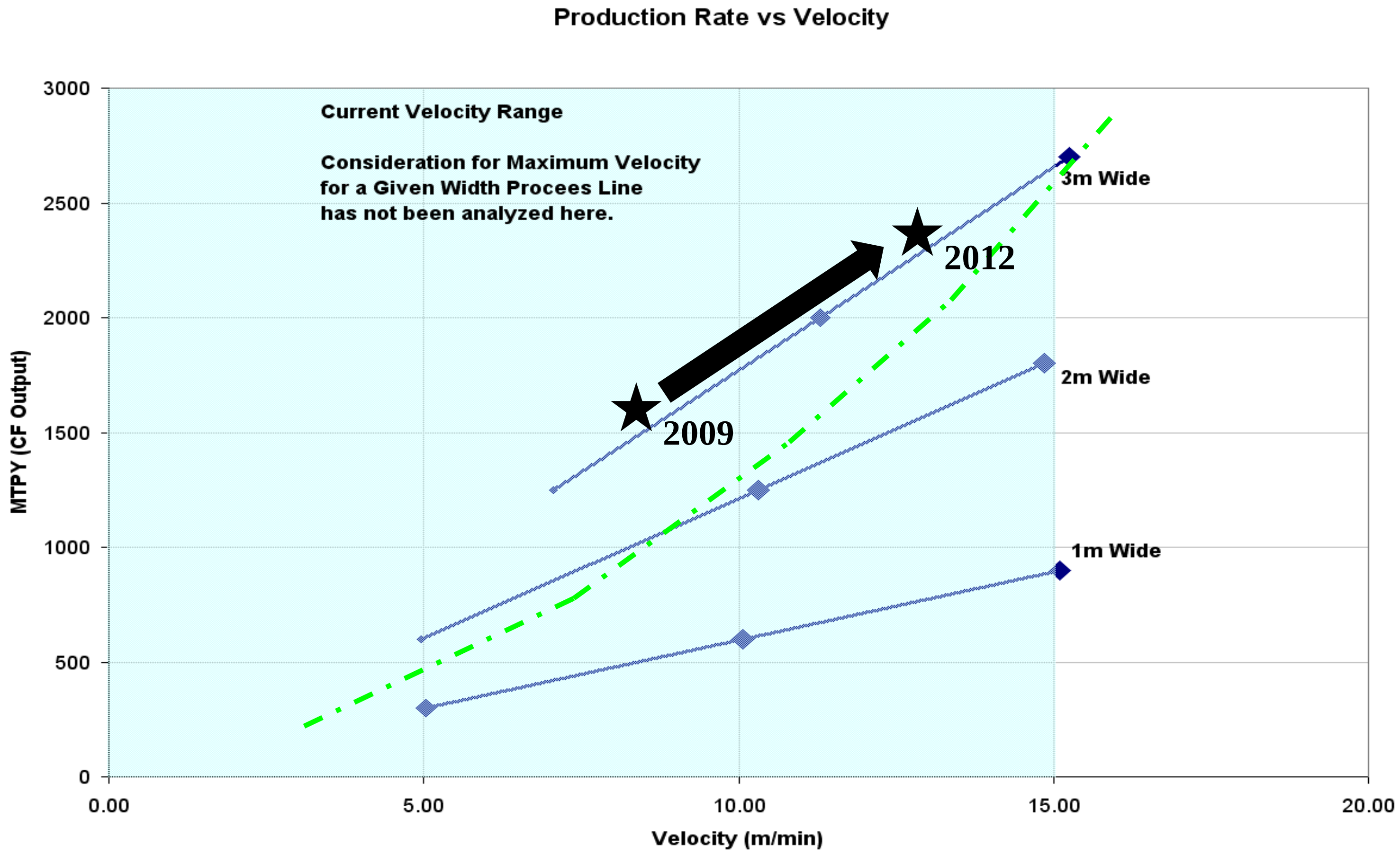
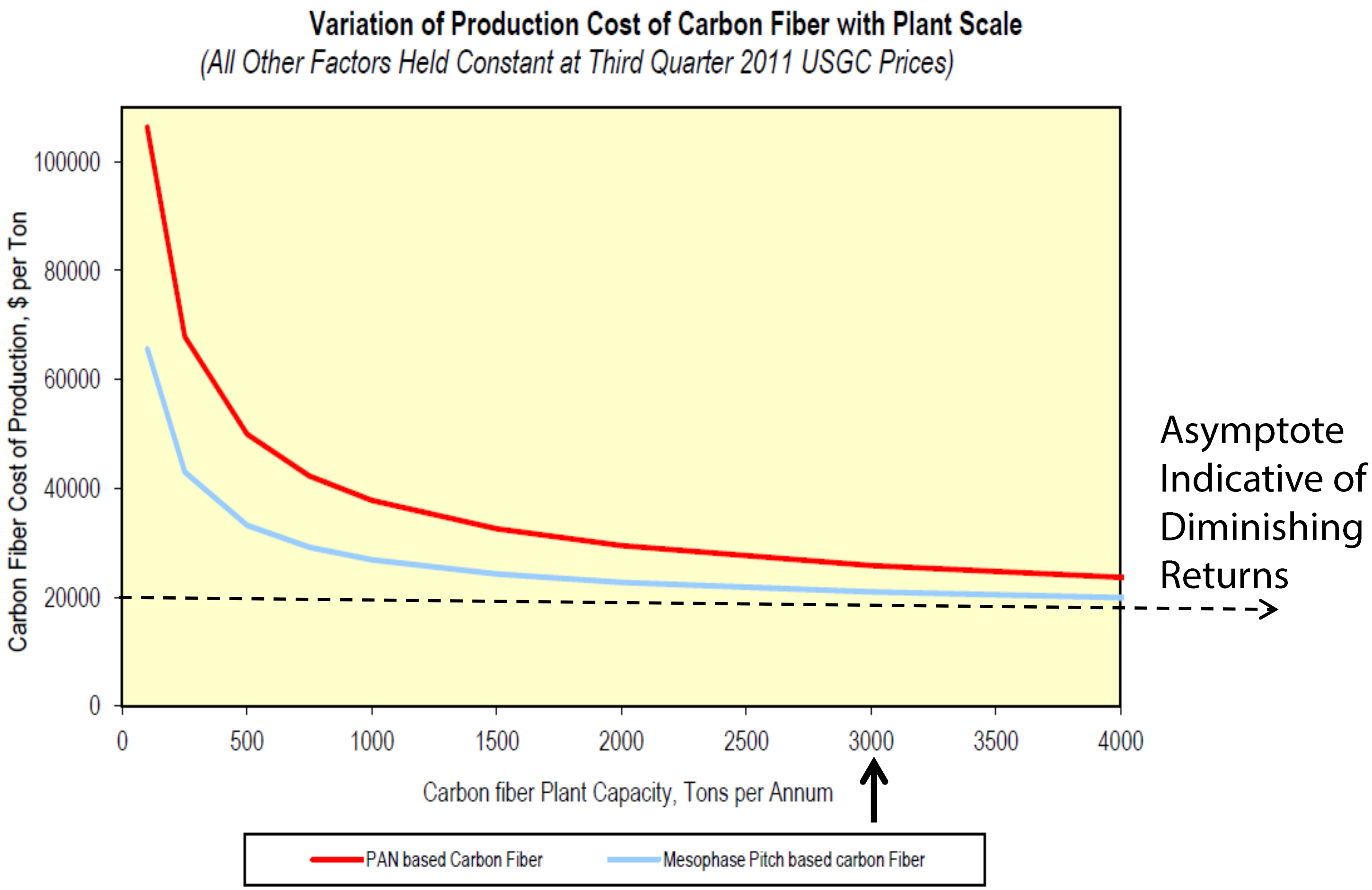
State of the Industry:
Review of Scales of Operations



Capacity Expansion 2011 - 2012 Based on Faster Line Velocities;
Higher Production Rates from 3m Single Muffle

Economies of Scale



Carbon Fiber Production Cost by Plant Capacity
(Cost Per Ton Carbon Fiber)

Courtesy of A. Coker; J. Goh; K. Patel, "Carbon Fiber", Nexant, Process Evaluation Research Planning

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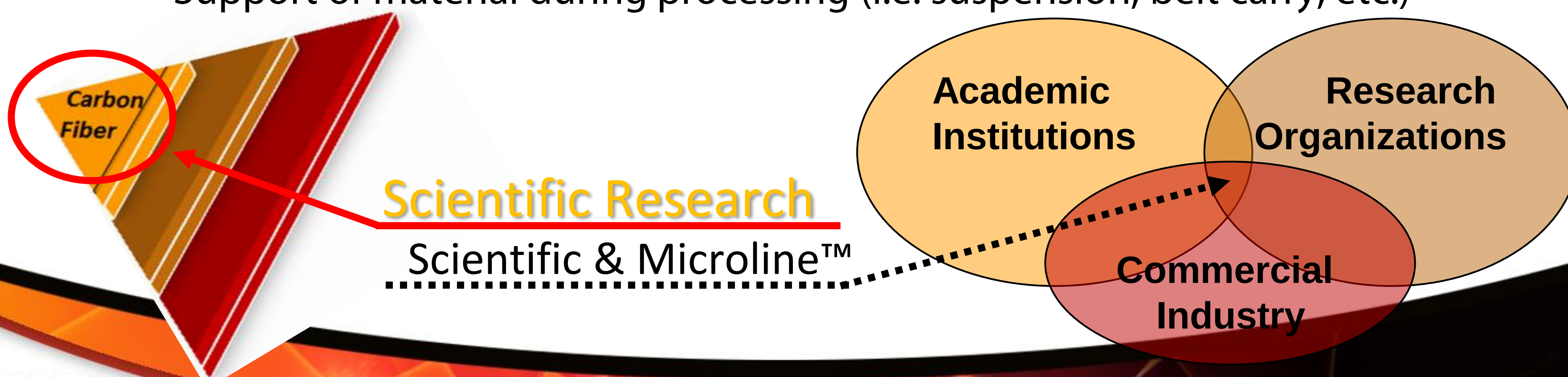
Raw Materials

- Polyacrylonitrile (PAN): >95%
  - Research shows raw materials may contribute 27-38% of production cost
- Alternate chemistries under investigation:
  - Lignin, Polyethylene, Pitch, Carbon suffused PAN

Courtesy of Oak Ridge National Laboratory CFTF

Alternatives to decrease input materials costs?

- Considerations:
  - Material form (i.e. continuous tow, non-woven matt, loose chopped, etc.)
  - Support of material during processing (i.e. suspension, belt carry, etc.)



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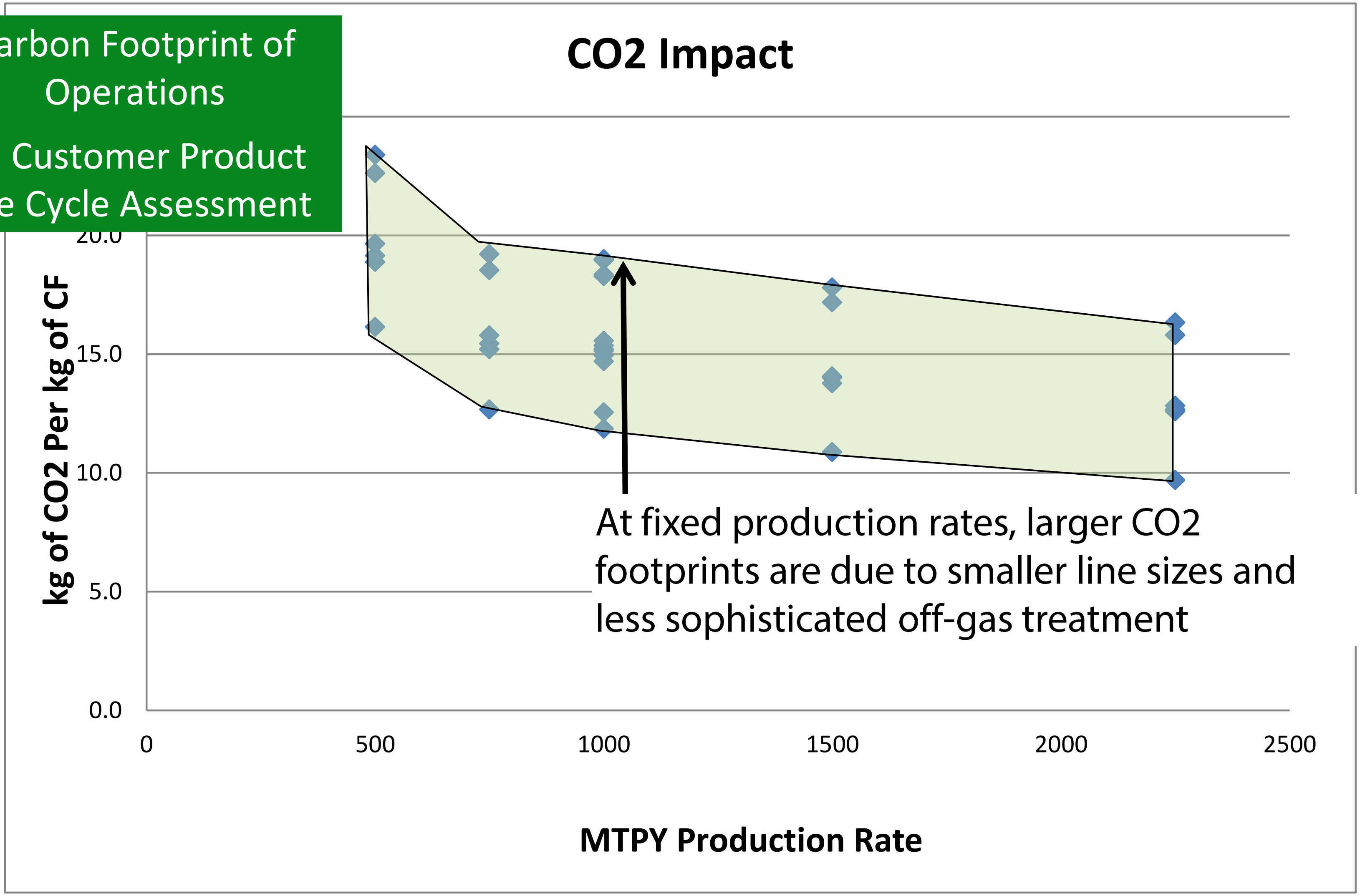
Review of Base Data

Carbon Footprint of Operations

→ Customer Product Life Cycle Assessment



Data from www.harperbeacon.com

Challenges to Capturing Growth: The Carbon Fiber Footprint

CO2 Emissions Modeling

Primary Results from Sample Evaluation:

Production Rates:	500 – 2250	TPY
Line Sizes:	1750 & 3000	mm Wide
Theoretical CO2*:	**2.7 (average)**	kg CO2 Per kg CF
Actual CO2 Emissions*:	**9.7 – 23.4** kg CO2 Per kg CF	
	(*Energy to Produce Purge Gas Ignored)	
CAPEX	$2.17 – $4.55	USD / kg of CF
OPEX	$6.27 – $14.58	USD / kg of CF

- A CO2 Foot Print that is 3x – 9x the theoretical value leaves much room for improvement and optimization.
- The practical consequence of a lower CO2 footprint will be reduced operating costs (per kg of CF)

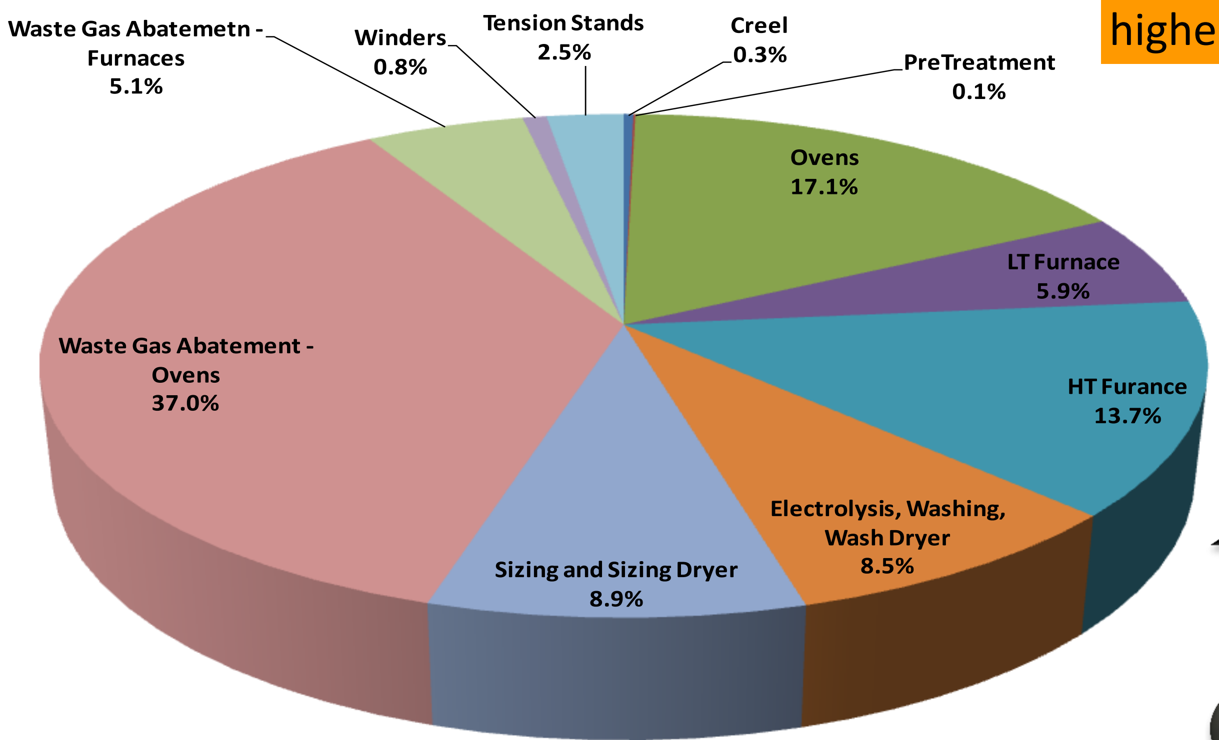
Sample Data from *harperbeacon.com*

Cost Structure Per Unit Operations

Target Oxidation Ovens & Furnaces for Energy Savings & Optimization

Electrical energy and natural gas fuel costs are highest utility costs

Energy Input for Production
3000 TPY, 3000mm Wide
90 Min. Ovens, 90 Sec. LT, 90 Sec. HT
Total Operating Input Approximately 8,250 kW (20 kW / kg)



Precursor Fiber

Creel 0.3%

Ovens 54.1%

LT Furnace

HT Furnace

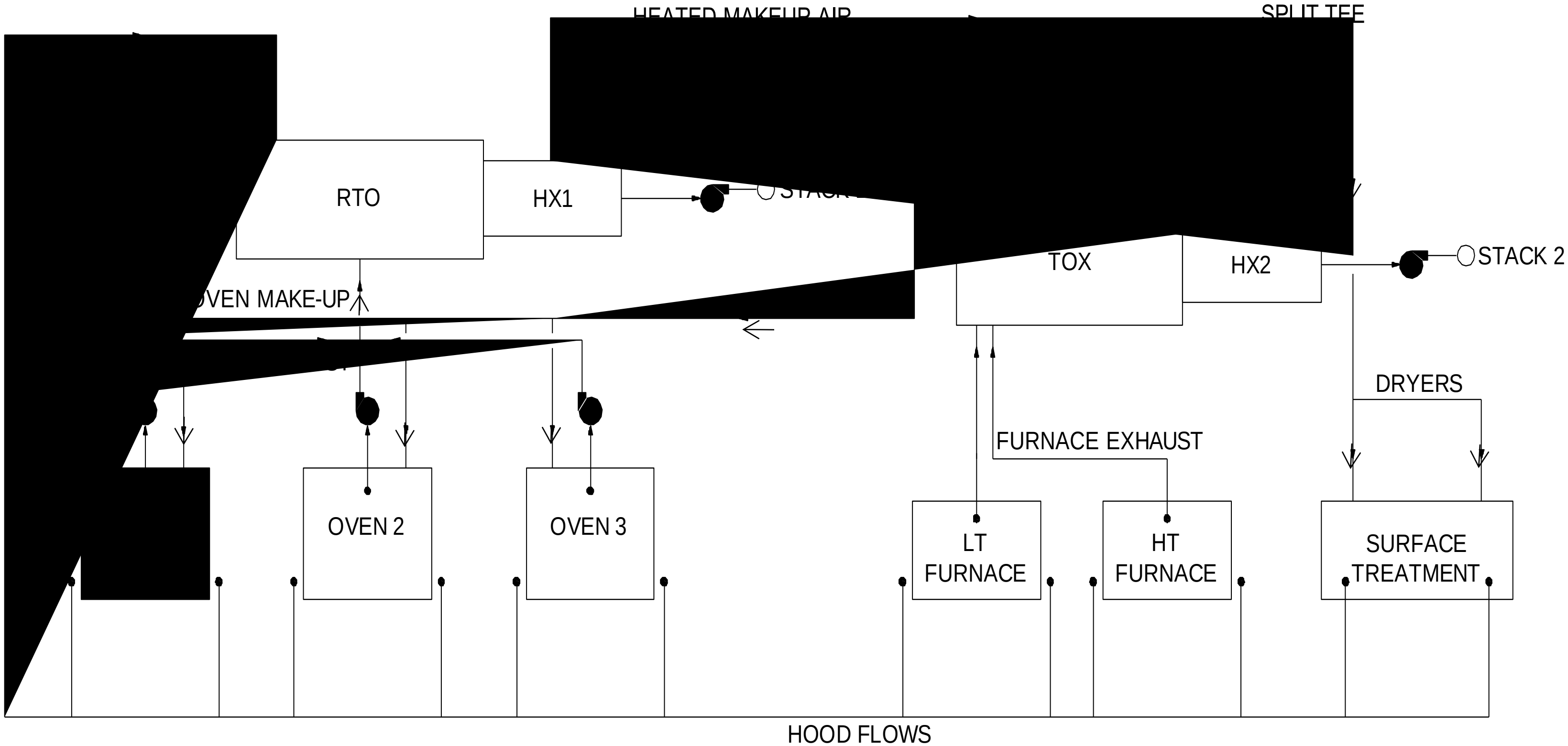
24.7%

ST 17.4%

Carbon Fiber

Winders 0.8%

Energy Focus
Advanced, Integrated Flowsheets



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- Energy recovery heat exchangers preheat oven & dryers make-up air to lower energy use

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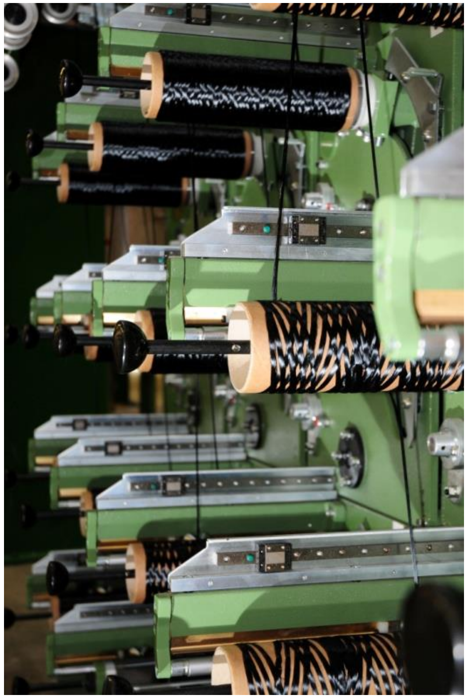
Efficiency Advances Within Reach

- Optimize Existing Unit Operations - Minimize the Timeline for Technology Development and Deployment
  - Start with R&D systems that mimic the production line to reduce recipe development time significantly
  - Time is money – reduce expense consumed to redevelop recipe from scale up to scale up



- Assess and Minimize Environmental Loss
  - Improve Insulation Profiles
  - Minimize Surface Area and Wall Losses
  - Minimize Exhaust Losses

Efficiency Advances Within Reach

- Managing Equipment to Maximize Up-time Long-term
  - Training of Line Operators & Managers
  - Regular System "Check-Ups"
    - Catch critical maintenance or operational challenges to prevent unplanned shut-downs
    - Enable more efficient use of resources
    - Identify safety or operation hazards before they occur
    - Extend life of systems and consumables
    - Increase Overall Equipment Effectiveness OEE

Conclusions

- Goal - design and build better composites that will meet the growing demand in aerospace, automotive, construction, power generation and energy storage
- For composites to reach their full potential, innovations and developments in carbon fiber is needed
- Russia has basic building blocks to be leader in CF composites
- Still requires common vision and collaboration to build a carbon fiber ecosystem