Harper International

Ensuring the future of carbon fiber in automotive and beyond

JEC Americas 2012: Carbon Forum,
Wednesday November 7, Boston

Agenda

- Introductions
- State of The Industry
- Challenges to Automotive Market
  - Diminishing Returns on Economies of Scale
  - The Carbon Footprint of CF
  - Time and Investment for Technology Advancements
  - Supply Chain Risks
  - Optimizing the Project Development Timeline

Introduction: About Harper

About Harper

Core Skills:

- Scale up of New or Challenging Processes
  - 200°C – 3000°C
  - Atmospherically Controlled
  - Continuous Processing
- Construction Techniques in
  Metallic > Ceramic > Graphitic
- Integrated Systems Design – Plant Supply
- Complex Flows of Advanced Materials
- Precise Control of Gas - Solid Interactions

About Harper

Advanced Thermal Systems for Fiber Processing

- PAN based C-fiber
- Pitch based C-fiber
- Rayon based C-fiber
- Alternative Precursor Development
- Carbon Nano Tubes / Fibers
- Carbon Fiber Recycling

A Broad Experience Base in a Range of Carbon Processes

About Harper

Services to the Carbon Fiber Market

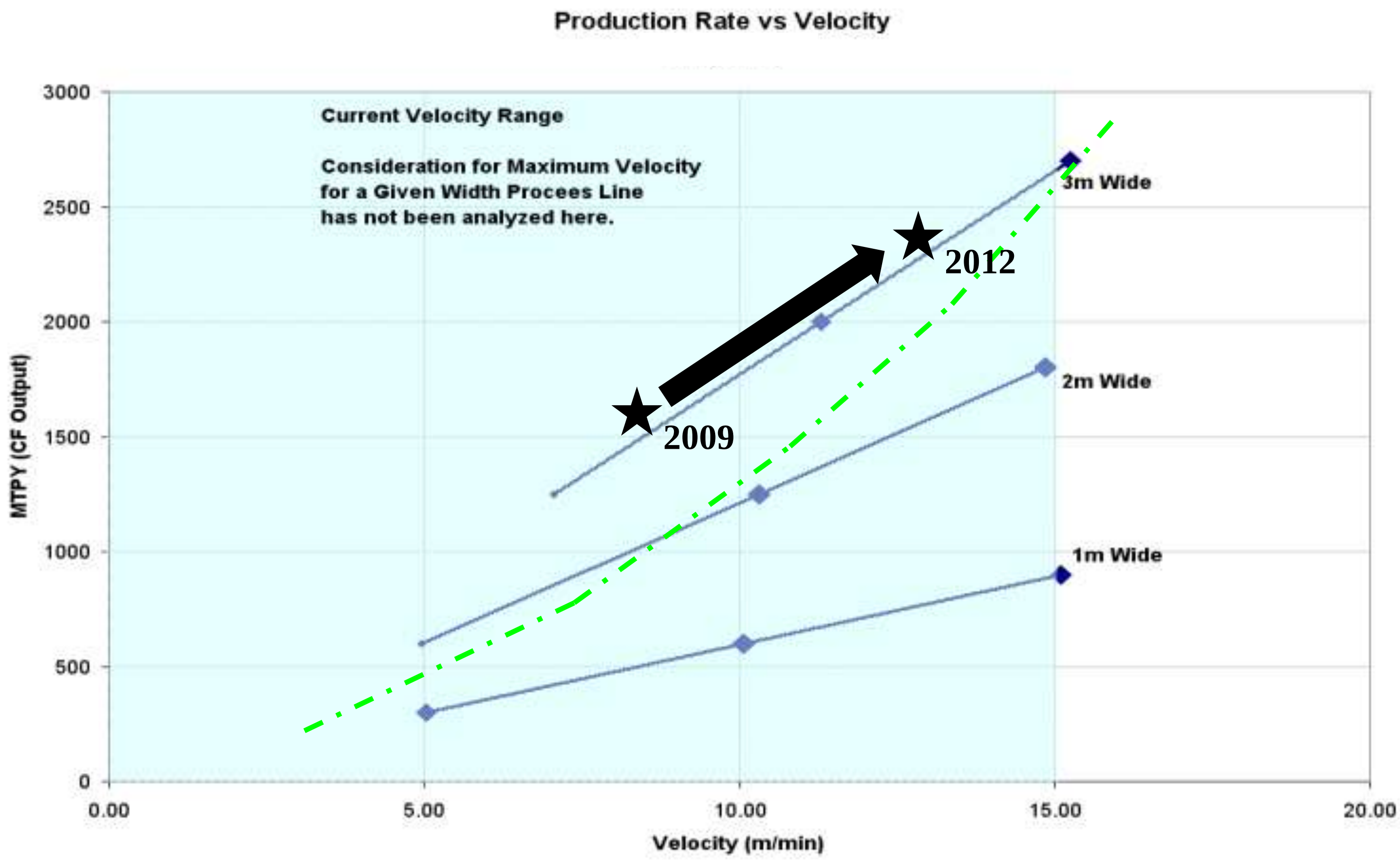
- Equipment Supply (~40 Years)
  - LT Furnaces, HT Furnaces and UHT Furnaces
  - Atmospherically Controlled Oxidation Ovens
  - Surface Treatment & Drying
  - Material Mass Transport & Waste Gas Treatment
- Complete System Supply (~15 Years; >10 contracts)
  - Systems Integration and Energy Recovery
- Feasibility Studies & Modeling
- Retrofits, Revamps & Upgrades
- Business Development & Consulting
- Training & Optimizations

State of the Industry

State of the Industry:
Review of Scales of Operations

Scales	Size Range (mm Width)	Capacity
Production	1000mm-4200mm	100tpy to more than 4000tpy
Industrial Scale Pilot	300mm-1000mm	20tpy-100tpy
Micro Scale (University, Institute)	<100mm	Less than 3 tpy

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

State of the Industry: Review of Scales of Operations

- Modern Line Speeds

  At 10m/min – 20 m/min for a state of the art line

- Oxidation Oven Capacities

  More Than 500 – 750 kg/hr feed of PAN

  More than 500 m – 1000m Overall Heated Length

  4 Zones Minimum; Typically 6 – 8 Zones

  Widths up to 4m -- 3m wide designs are becoming more common

  Unsupported Heated Lengths typically less than 15m

- LT and HT Furnaces Understand Your Process and the Impact of Technical Specifications

  Widths up to 4m -- 3m wide designs wide are dominant state of the art

  Unsupported Heated Lengths 15 m – 20m

  HT Temperatures Regimes <1450C, 1600C, and 1800C or greater

Harper

Recent Production Capacities (2010)

GLOBAL CARBON FIBER PRODUCTION (ESTIMATED ANNUAL CAPACITY IN 2010)

Manufacturer	Small tow (metric tonnes)	Small tow (lb)	Large tow (metric tonnes)	Large tow (lb)	ID#*
AKSA	1,800	4,000,000			27262
Cytec Industries	2,300	5,000,000			24960
Dalian Xingke Carbon Fiber	600	1,320,000			27750
Formosa Plastics	7,300	16,000,000			27264
Grafil	2,000	4,400,000			26890
Hexcel	7,300	16,000,000			25238
Kemrock	650	1,430,000			26142
Mitsubishi Rayon	6,150	13,530,000	2,750	6,060,000	27836
SGL Carbon			6,500	14,300,000	25642
Toho Tenax	13,500	29,620,000			26204
Toray Industries	17,900	39,440,000	300	660,000	26964
Yingyou Group	220	484,000			72402
Zoltek Corp.			8,750	19,300,000	26150
TOTAL	**59,700**	**131,240,000**	**18,300**	**40,320,000**	

A list of the world's current carbon fiber manufacturers, compiled by HPC. Capacity estimates for the year 2010 are based on public information about ongoing expansions that was available to HPC in December 2008. Source: CompositesWorld

2010 Total Capacity Estimated at 78,000 MTPY

With 10% - 15% Growth Per Year Since

Challenges and Expectations for Automotive Market

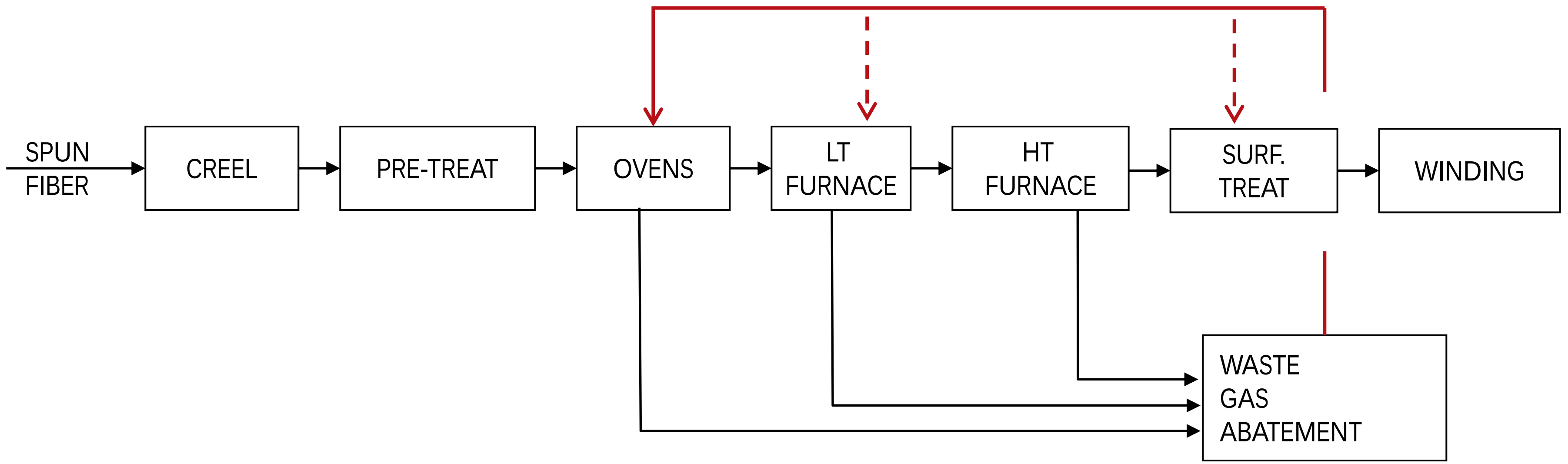
Challenges in Carbon Fiber Operations to Growth for Automotive Market

1. Diminishing Returns on Economies of Scale
2. The Carbon Footprint of CF
3. Investment in Technology Advancements
4. Supply Chain Risks
5. Optimizing the Project Development Timeline

Harper

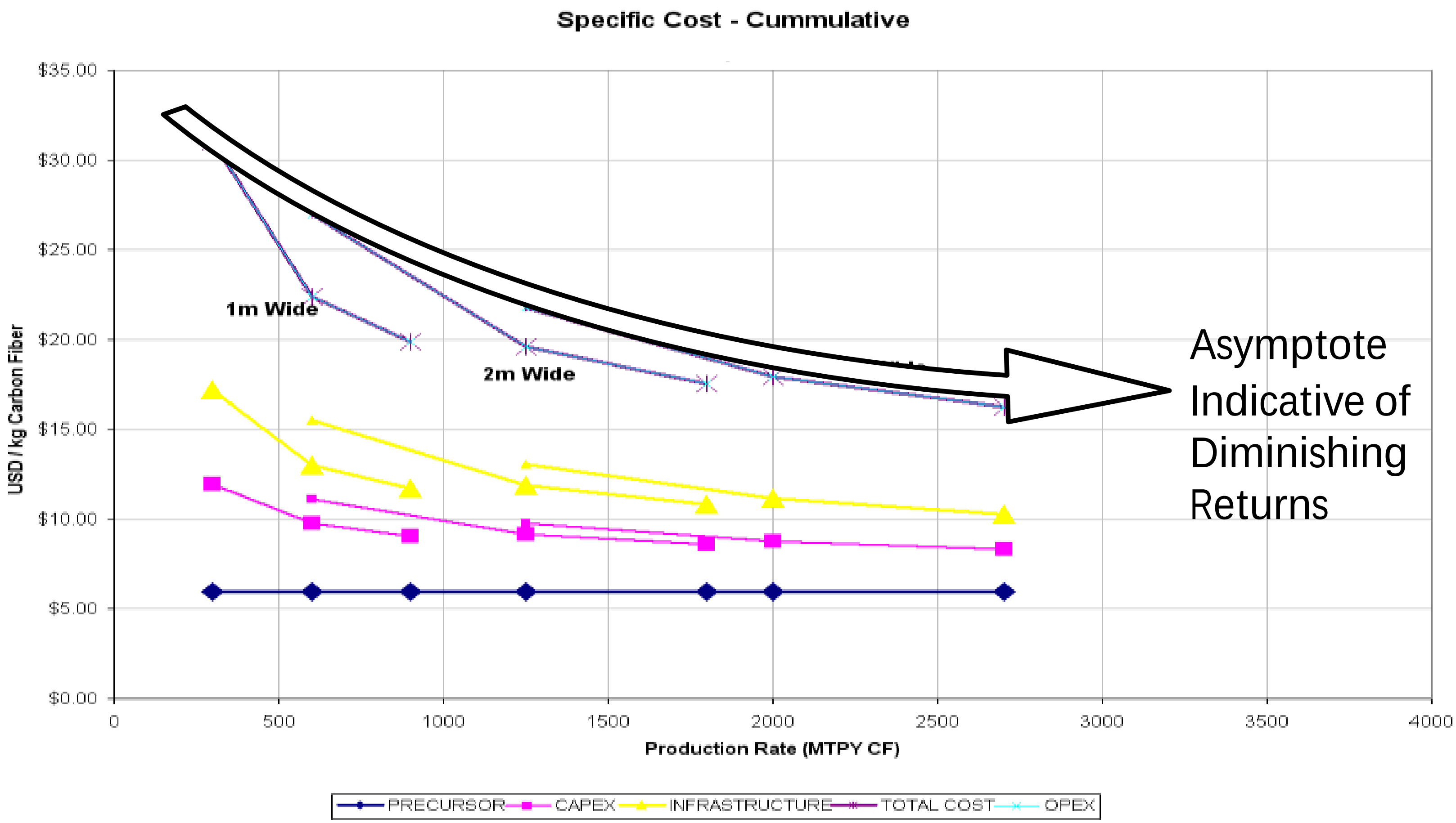
Challenges and Expectations for Automotive Market:
1) Diminishing Returns on Economies of Scale

Diminishing Returns on Economies of Scale: Carbon Fiber Conversion Process



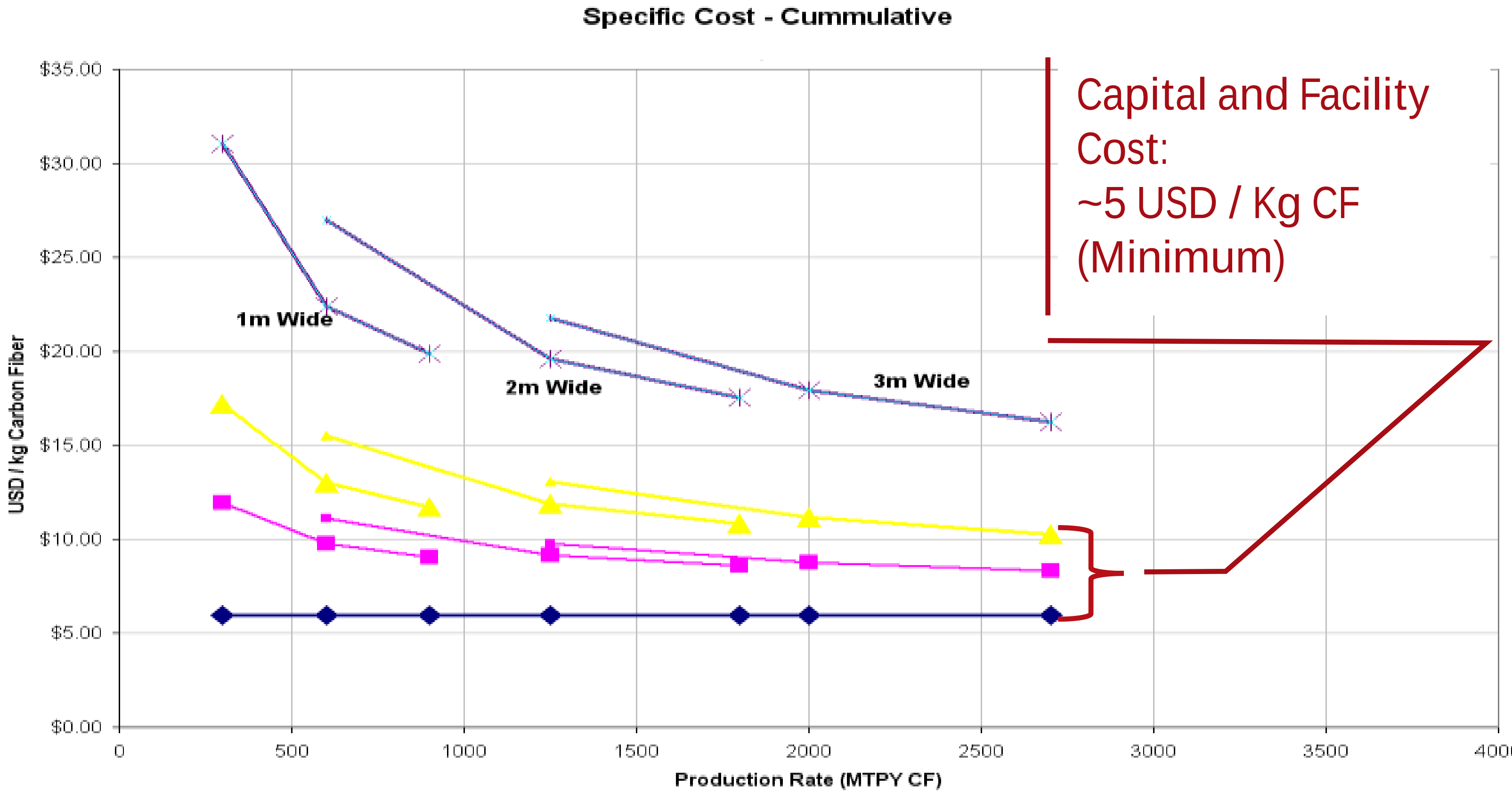
- Complexity and Cost added through Waste Gas Treatment
- Significant Opportunity for Energy Recovery and Cost Reduction; through further Flowsheet sophistication
- A State of the Art Integrated Plant yields 15 – 25 kW / kg CF

Challenges to Capturing Growth: Diminishing Returns on Economies of Scale



Cost Dynamics as a Function of Scale-Up

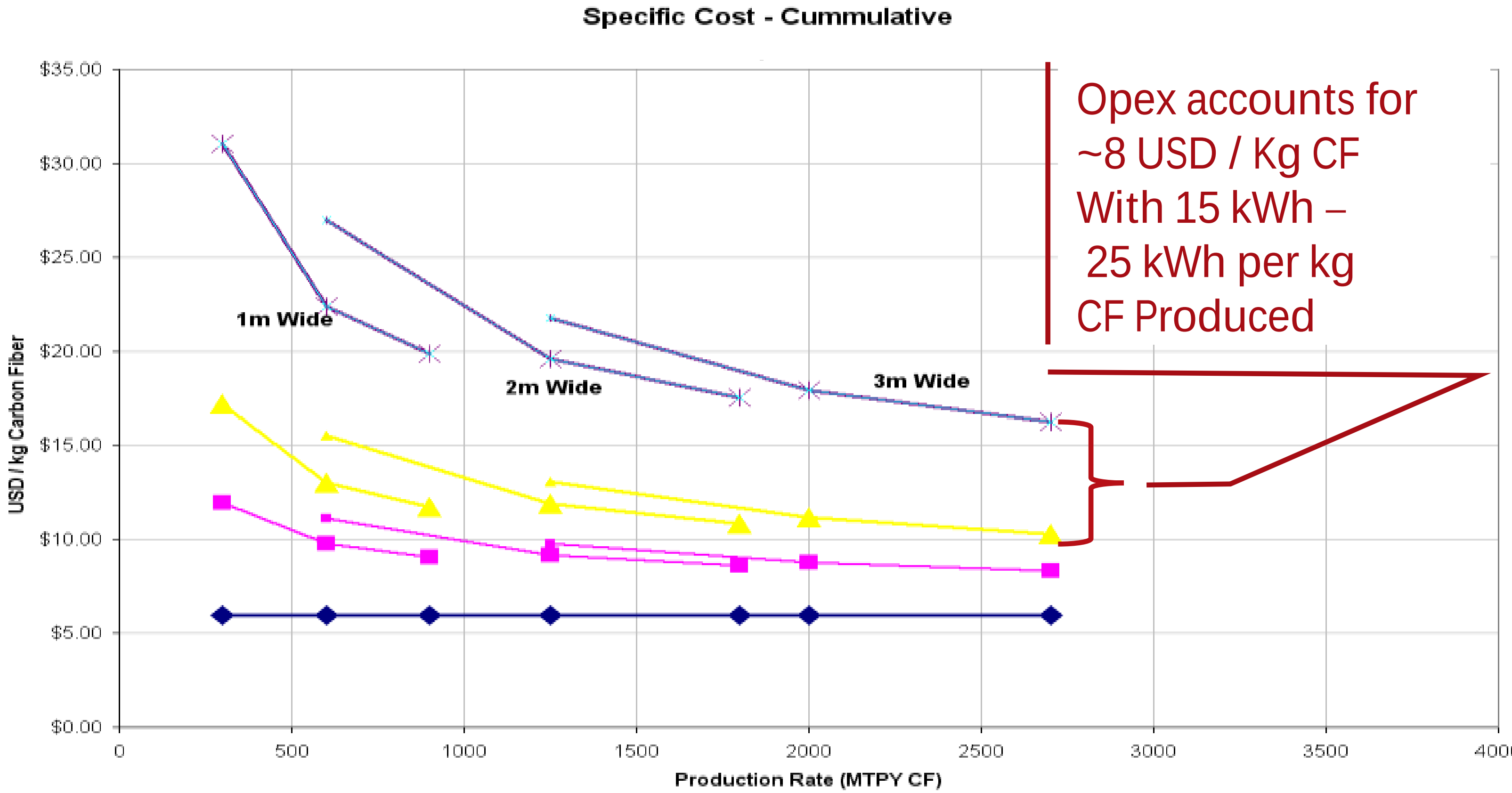
Challenges to Capturing Growth: Diminishing Returns on Economies of Scale



Capital and Facility Cost:
~5 USD / Kg CF
(Minimum)

Even by removing the Capital and Facility Cost, you do not arrive at a LCCF Benchmark of $10 USD / kg

Challenges to Capturing Growth: Diminishing Returns on Economies of Scale

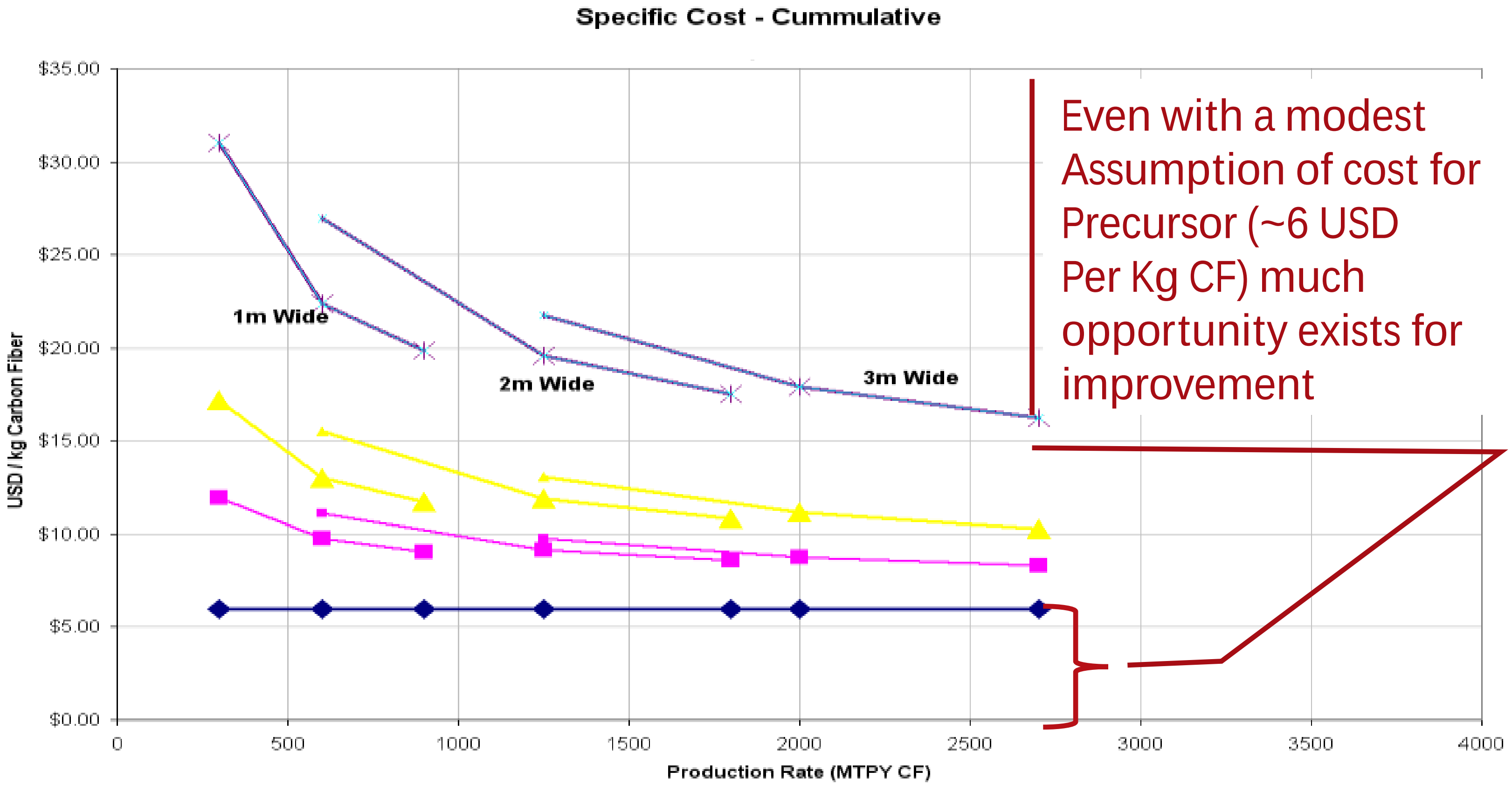


Opex accounts for ~8 USD / Kg CF With 15 kWh – 25 kWh per kg CF Produced

A 50% Reduction in Energy Consumption would yield a savings of $0.53 - $0.88 Per Kg of CF (at $0.07 Per kWh)

Harper

Challenges to Capturing Growth: Diminishing Returns on Economies of Scale



Precursor costs and precursor chemistry should be a major target for future cost improvements and process optimizations

Challenges and Expectations for Automotive Market: 2) The Carbon Footprint of CF

Challenges to Capturing Growth: The Carbon Fiber Footprint

Challenges:

1) Diminishing Returns: The Opportunity for Increased Efficiency In Scale is Declining
2) Consumer Market Adoption: At Higher Volumes a Better Understanding of Environmental Impact is Required (Automotive)

Opportunities:

1) Create Tool to Rank Environmental Impact of Various Production Schemes
2) Understand Impact of Scale and Configuration on Environmental as well as Cost
3) Use the Tool to Identify Opportunities for Greater Total Efficiency

Beacon
Give efficiency the green light.

Challenges to Capturing Growth: The Carbon Fiber Footprint

CO2 Emissions Modeling

Theoretical CO2 Emission for CF Production*:

Polymer Losses (Footprint of Polymer Production Ignored)

Sensible Heat of Reaction (Polymer and Purge Gases)

Source of Energy

Actual CO2 Emission for CF Production*:

Polymer Losses(Footprint of Polymer Production Ignored)

Sensible Heat of Reaction (Polymer and Purge Gases)

Energy Summarized by Unit Operation

Thermal Losses

- Heat Rejected to Atmosphere
- Heat Rejected To Cooling Water

Waste Gas Abatement Technology (Major Schemes Considered)

Source of Energy

* Energy Requirement to Produce Purge Gas Ignored

Challenges to Capturing Growth: The Carbon Fiber Footprint

CO2 Emissions Modeling

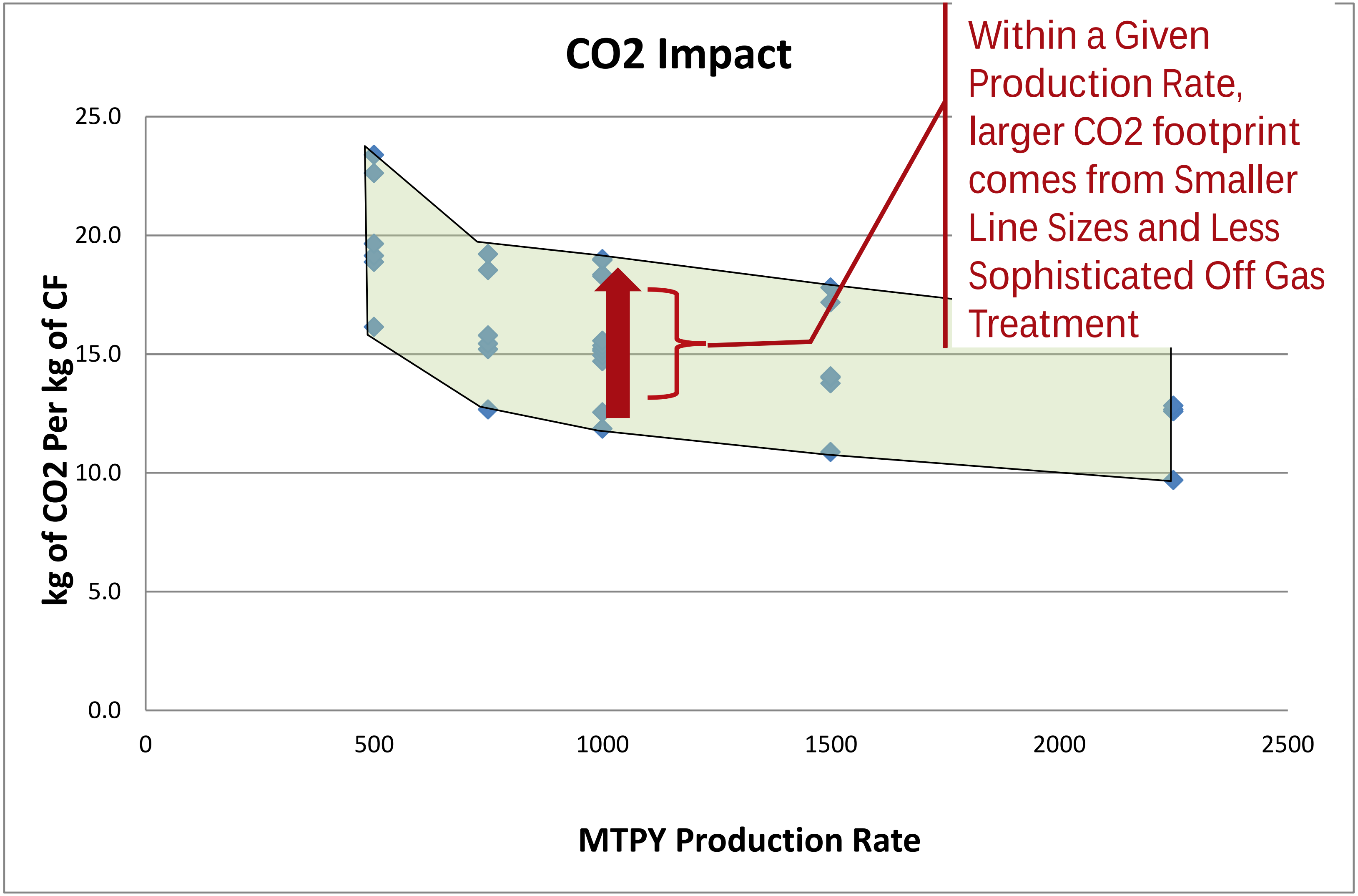
Primary Results from Sample Evaluation:

Production Rates:	500 – 2250	TPY
Line Sizes:	1750 & 3000	mm Wide
CO2 Emissions*:	**9.7 – 23.4**	kg CO2 Per kg CF
Theoretical CO2*:	**2.7 (average)**	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 Per kg 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*

CO2 Emissions Modeling



Sample Data from *harperbeacon.com*

Challenges to Capturing Growth: The Carbon Fiber Footprint

CF Precursors & Recovery

Chemistry	Maximum C- Recovery	Typical C-Recovery
▪PAN	68% max	(50% typical)
▪Cellulose	44% max	(20% - 30% typical)
▪Lignin	67% max	(typical ?)
▪Pitch	85% max	(w/o solvent)
		(25% - ?? w/ solvent)
▪Polyethylene	85% Max	(typical ?)
▪Polypropylene	85% Max	(typical ?)

The Precursor can have a significant impact on Plant Economics and CO_2 Footprint.

Beacon

Harper International

Challenges and Expectations for Automotive Market:
3) Investment in Technology Advancements

Harper

Investment in Technology Advancements

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

1. Increase of Scale (Wider and Longer)
2. Treatment of Oxidation Oven Exhaust & Potential for Energy Recovery
3. Closed Pipe Treatment of Furnace Exhausts & Potential for Energy Recovery
4. Low Profile Furnace Muffles for Reduced Gas Consumption
5. Movement Towards Sealed Oxidation Oven Design

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

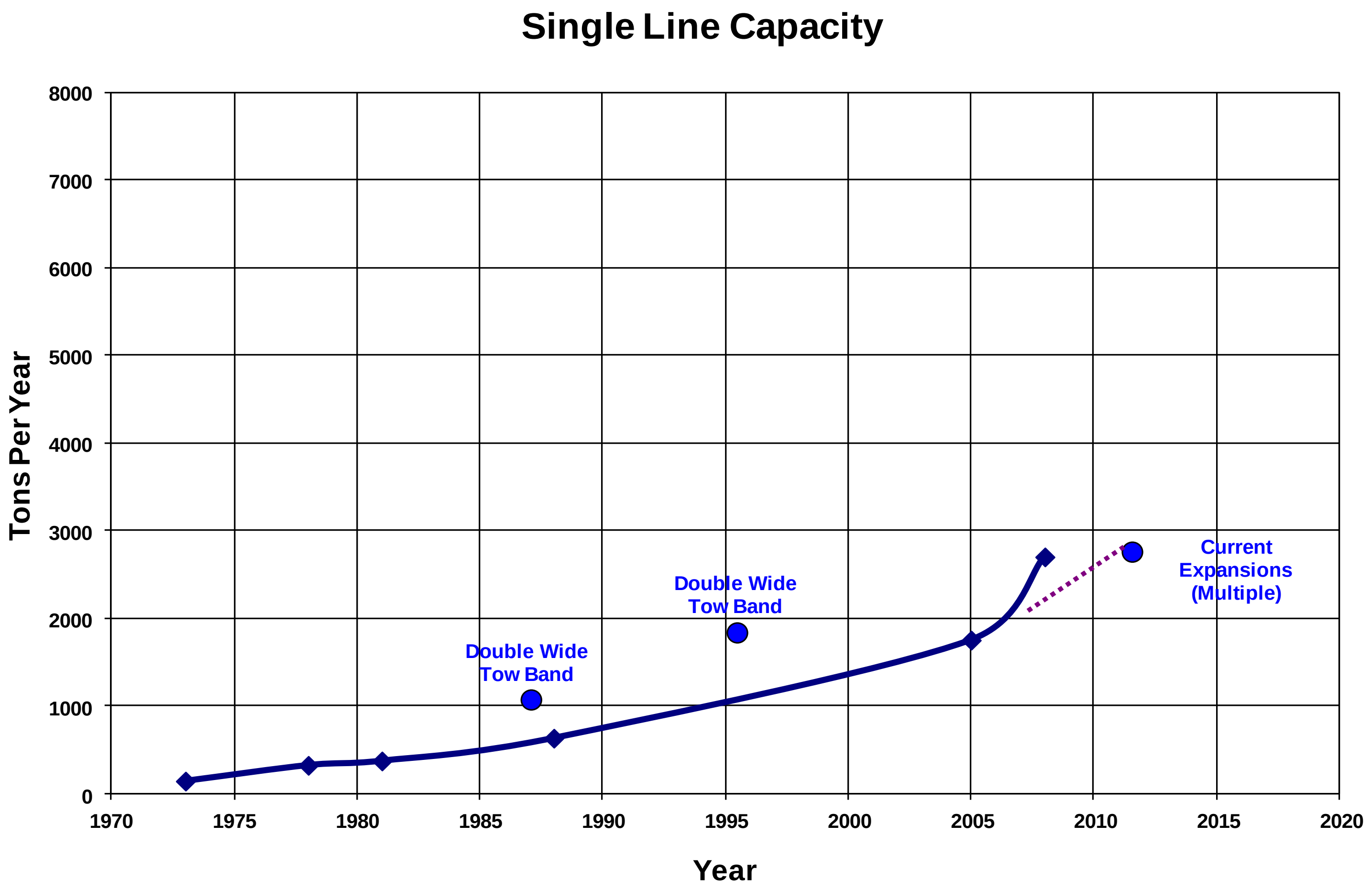
Step 1:
Increase of Scale

Increase of Scale Trends, as Led by Harper International

- First System in 1973 still in operation: 36″ Wide (915mm)
- First System > 1m in 1978: 40" wide (1015mm) with 2 of 3 systems still in operation
- 1981: 46" wide (1200mm wide)
- 1988: 68" (1750mm wide)
- 1997: 72" wide (1800mm wide)
- 1997: 163″ wide (4141mm wide)
- 2005: 120" wide (3000mm wide)
- 2008 to Today: >12 systems @ 3000mm wide

> 100 Units Carbon Fiber Projects to date

Trend of Increase in Scale



Harper

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

Step 2:
Treatment of
Oxidation Oven Exhaust

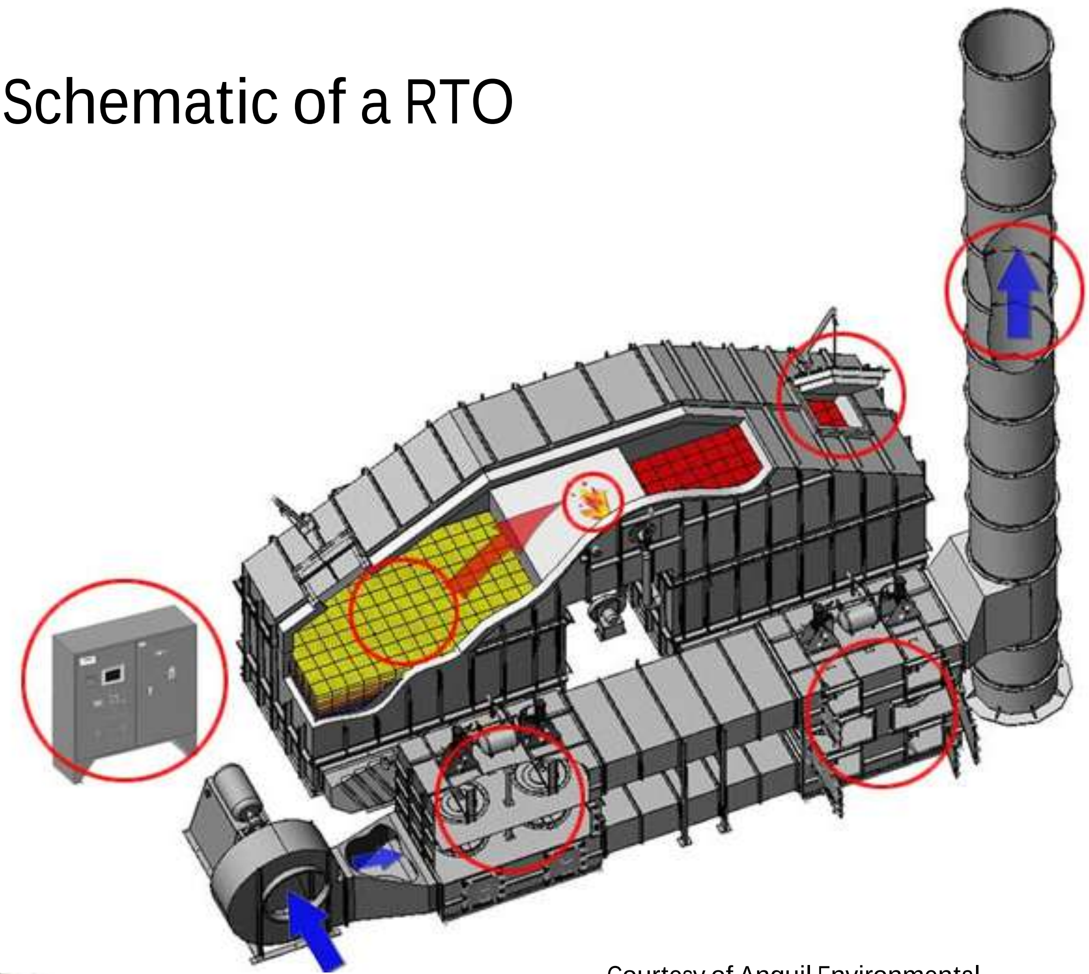
Treatment of Oxidation Oven Exhaust:

Integration & Heat Recovery
2m and 3m (6 Zone Designs)

Line Width	m	2m Wide	3m Wide
Oxidation Oven Zones	#	6	6
Exhaust Rate	Nm3/hr	20760	43200
Exhaust Temp	C	260	260
Ambient Temp	C	25	25
Delta T	C	235	235
Energy Lost	kw	1633	3399

Treatment of Oxidation Oven Exhaust: Waste Gas Treatment Systems

Schematic of a RTO



Courtesy of Anguil Environmental

RTO Pros / Cons

- Lower Capital Cost
- Lower Operating Cost
- Relies on in Media to Store / Transfer Energy
- Media Susceptible to Fouling - Not Ideal for Fouling Streams
- Some Techniques Exist for Reduction of Maintenance Cleaning (Sacrificial Fouling Surfaces)
- Self Contained Energy Recovery

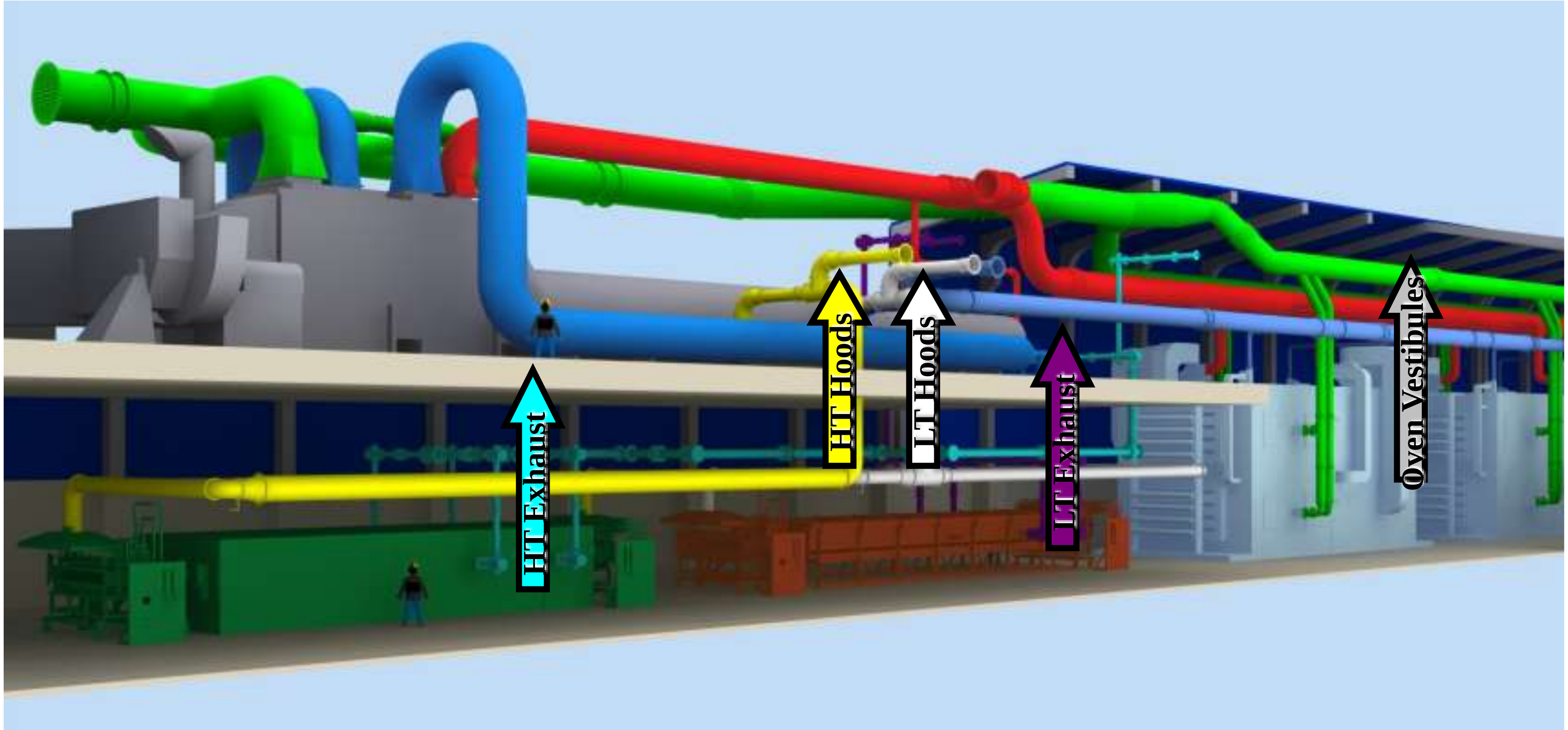
Treatment of Oxidation Oven Exhaust

Oven Make Up Air Preheated to >200C in the 2nd Stage Preheater

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

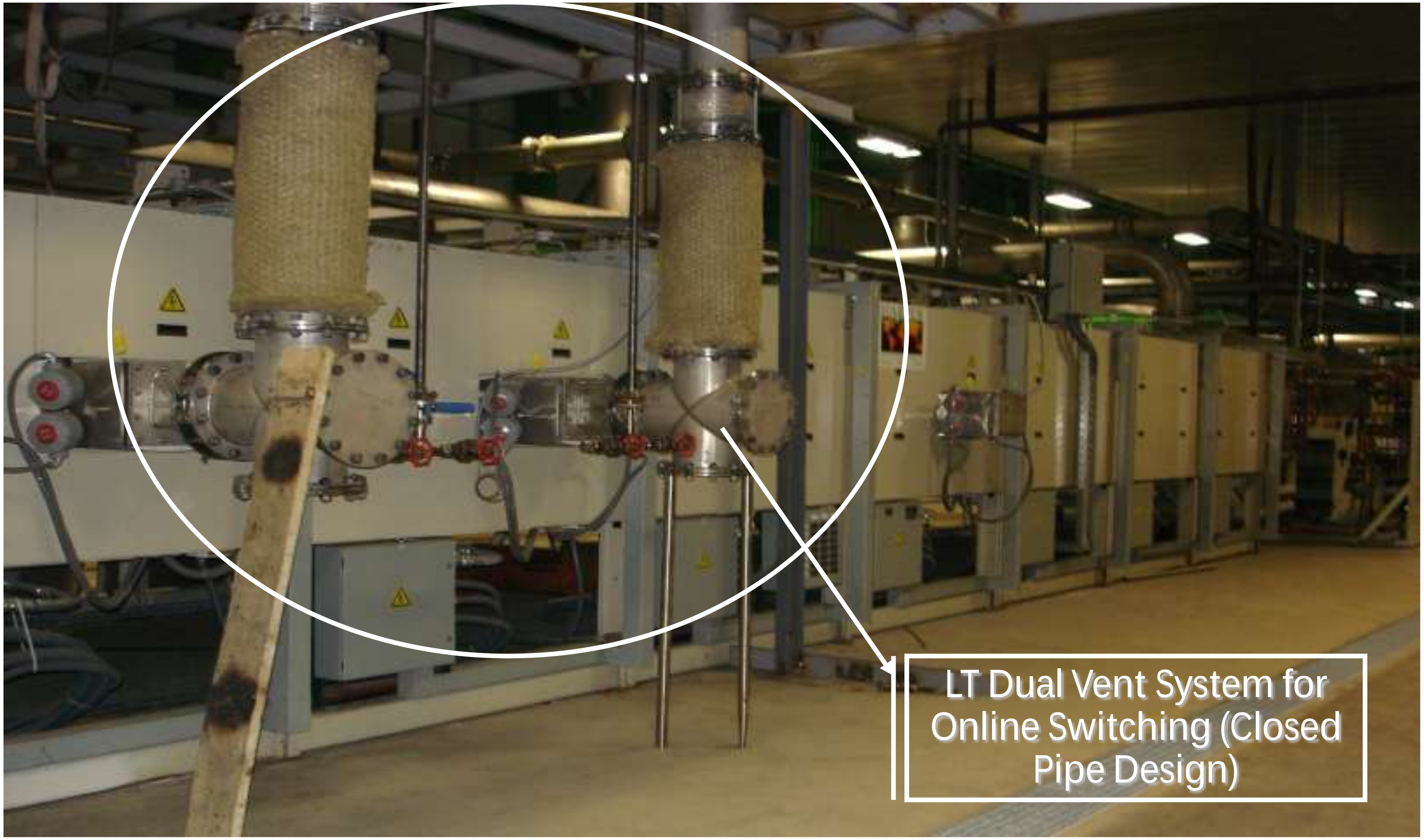
Step 3:
Closed Pipe Treatment
of Furnace Exhaust

Closed Pipe Treatment of Furnace Exhaust



TOX capable of also treating LT & HT Process Exhausts as well the Ventilation Hoods (LT Hoods, HT Hoods, Oven Vestibules)

Closed Pipe Treatment of Furnace Exhaust



Gas Abatement - Collection

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

Step 4:
Low Profile Muffle Design
To Reduce Nitrogen
Consumption

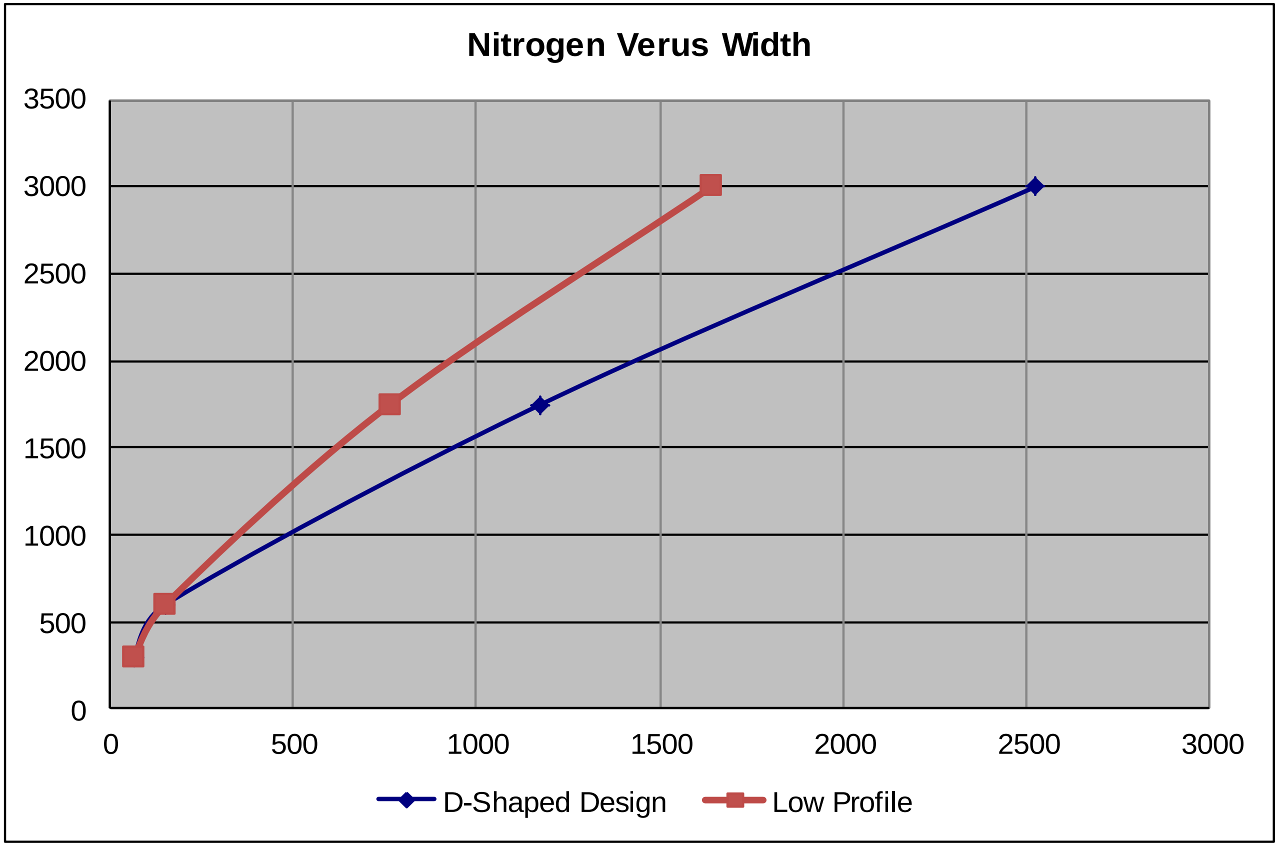
Harper

Low Profile Muffle Design
To Reduce Nitrogen Consumption

Harper LT Furnace
3 meter wide low-profile muffle

Harper

Low Profile Muffle Design
To Reduce Nitrogen Consumption



Nitrogen Consumption Model Reduction Based on Muffle Design

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

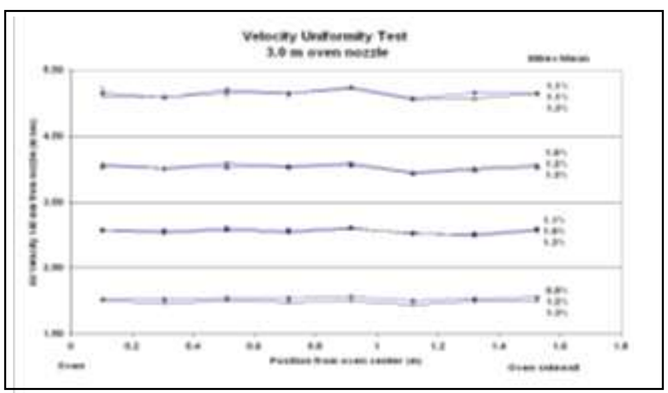
Step 5:
Shift Towards Sealed Oxidation Oven Design

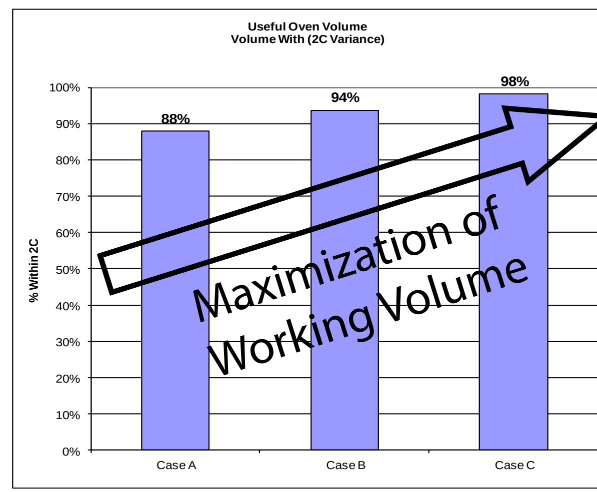
Shift Towards Sealed Oxidation Oven Design

Performance Metrics

- Temperature (+ or – 2 C)
- **Velocity** **(2x – 3x More**)
- **Seal Performance** **(Absolute)**
- Construction Techniques (Modular)
- Inst. & Control Advances (Flow Control)
- **Heat Reutilization** **> 75%**

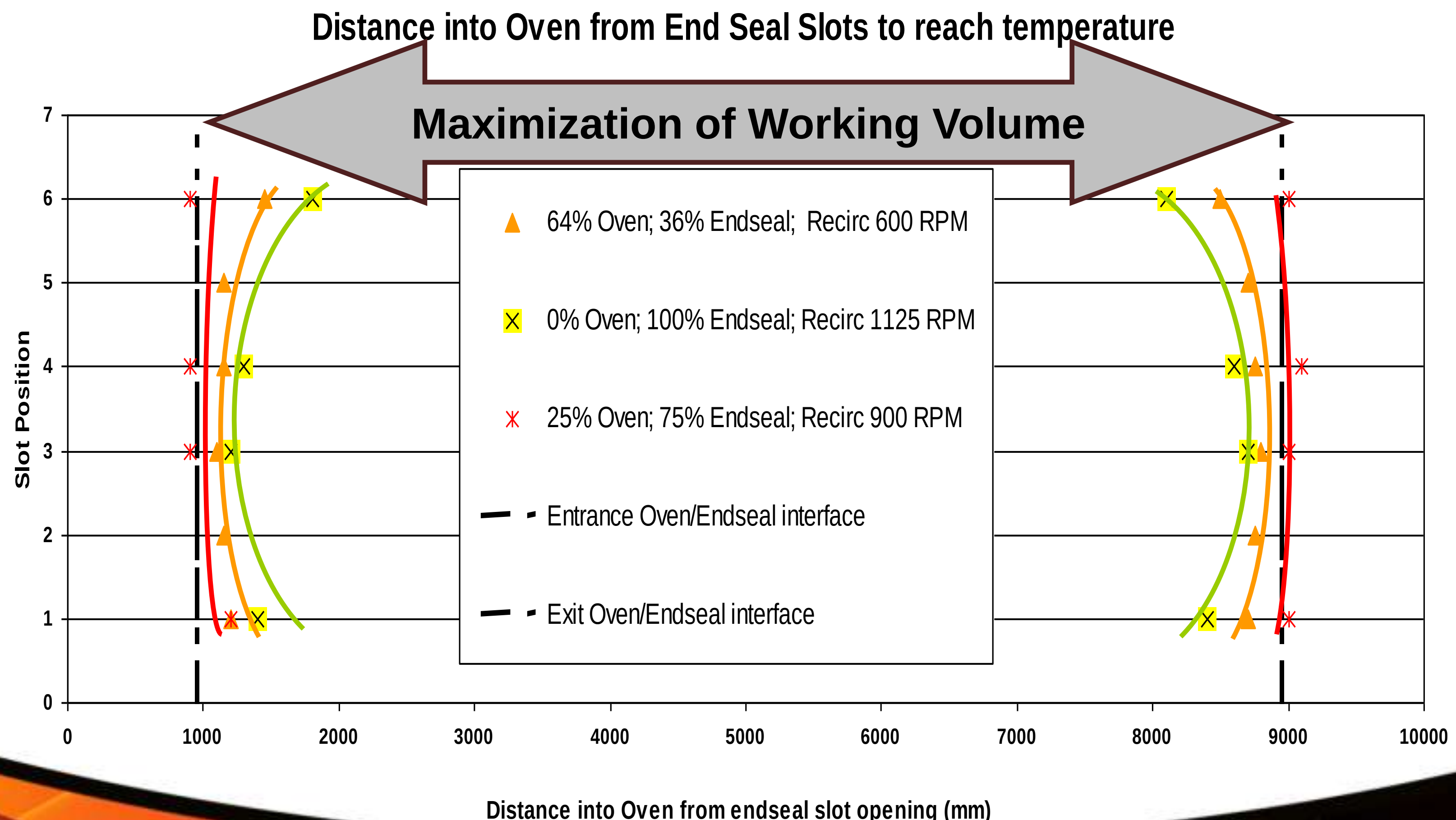
(Efficiency, Guaranteed)





Shift Towards Sealed Oxidation Oven Design

Greater Active Volume Due to Seal Advances



Shift Towards Sealed Oxidation Oven Design

Integration & Heat Recovery 2m and 3m (6 Zone Designs)

Line Width	m	2m Wide	3m Wide
Oxidation Oven Zones	#	6	6
Total Exhaust Rate	Nm3/hr	20760	43200
Exhaust Temp	C	260	260
Ambient Temp	C	25	25
Delta T	C	235	235
Energy Lost	kw	1633	3399

% MakeUp to Exhaust	%	0.75	0.75
Preheated Make Up	Nm3/hr	15570	32400
Make Up Temperature	C	260	260
Ambient Temp	C	25	25
Offset	kw	1225	2549
Hours Per Year	kw	>7000	>7000
USD$ / kw-hr	$	$0.10	$0.10
USD$ / year	$	$903,150	$1,879,385

Harper

Investment in Technology Advancements

Five Important Technology Advancements focused on Efficiency for Carbon Fiber Capacity Expansion:

1. Increase of Scale (Wider and Longer)
2. Treatment of Oxidation Oven Exhaust & Potential for Energy Recovery
3. Closed Pipe Treatment of Furnace Exhausts & Potential for Energy Recovery
4. Low Profile Furnace Muffles for Reduced Gas Consumption
5. Movement Towards Sealed Oxidation Oven Design

=> As we reflect on these advancements which have enabled the current state of capacity, we must consider what additional advancements will be necessary to support growth at the economics needed for automotive.

Challenges and Expectations for Automotive Market:
4) Supply Chain Risks

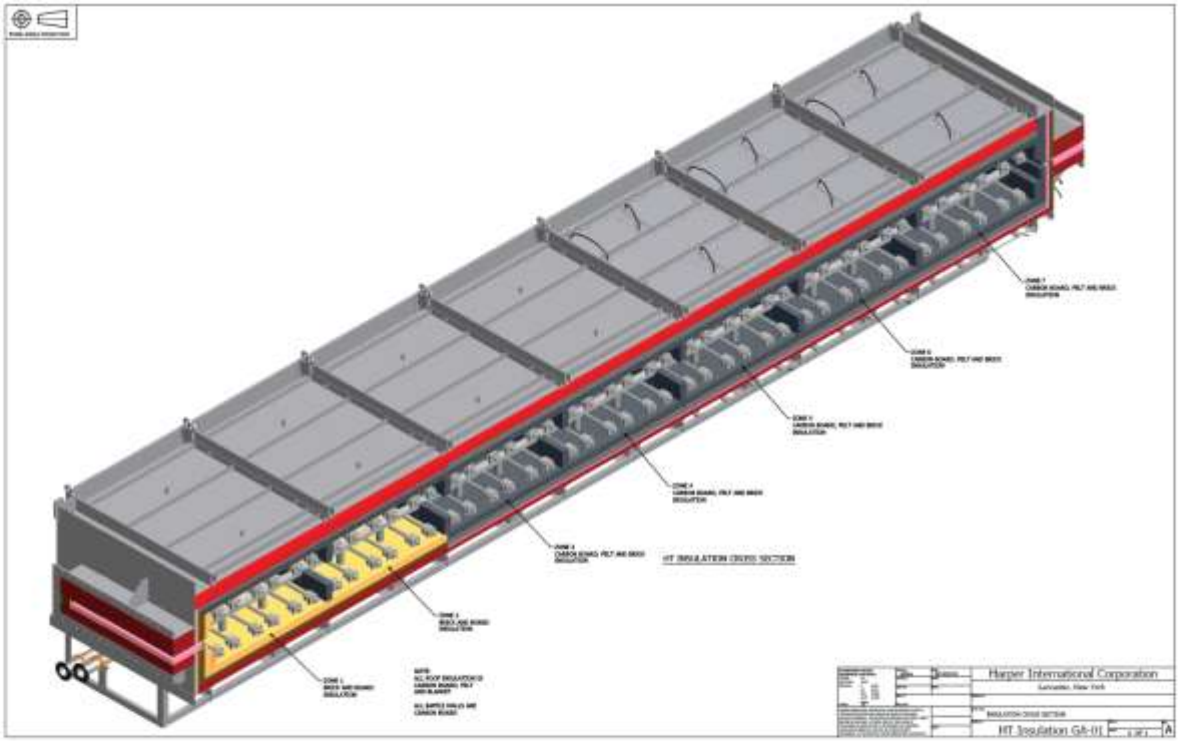
Current Supply Chain Status

- Modern Production Rates
  - 1500 TPY – 2750 TPY Per Line
- Production Capacity Growth Rate
  - 4 - 6 Line Major Industrial Fiber Expansions Per Year
  - 12 Months – 18 Months Per Line Execution
  - Current Industry Capability to Support 6000 TPY – 16,500 TYP Expansion
- Line Availability
  - Most Lines are rated for 7200 hours / year or less (82% Availability)
  - Most lines operating at less than nameplate capacity, due to:
    - Operational Experience
    - Material Packing Efficiency
    - Online Availability

Forthcoming expansions should consider the supply capacity within the market place and partner with suppliers for dedicated capacity. Opportunities exist for debottlenecking as well.

Supply Chain Risk Mitigation

- Module Standardization (Platform Design) yields Fast-Cycle Manufacturing and Delivery



Harper's Platform Design HT Furnace

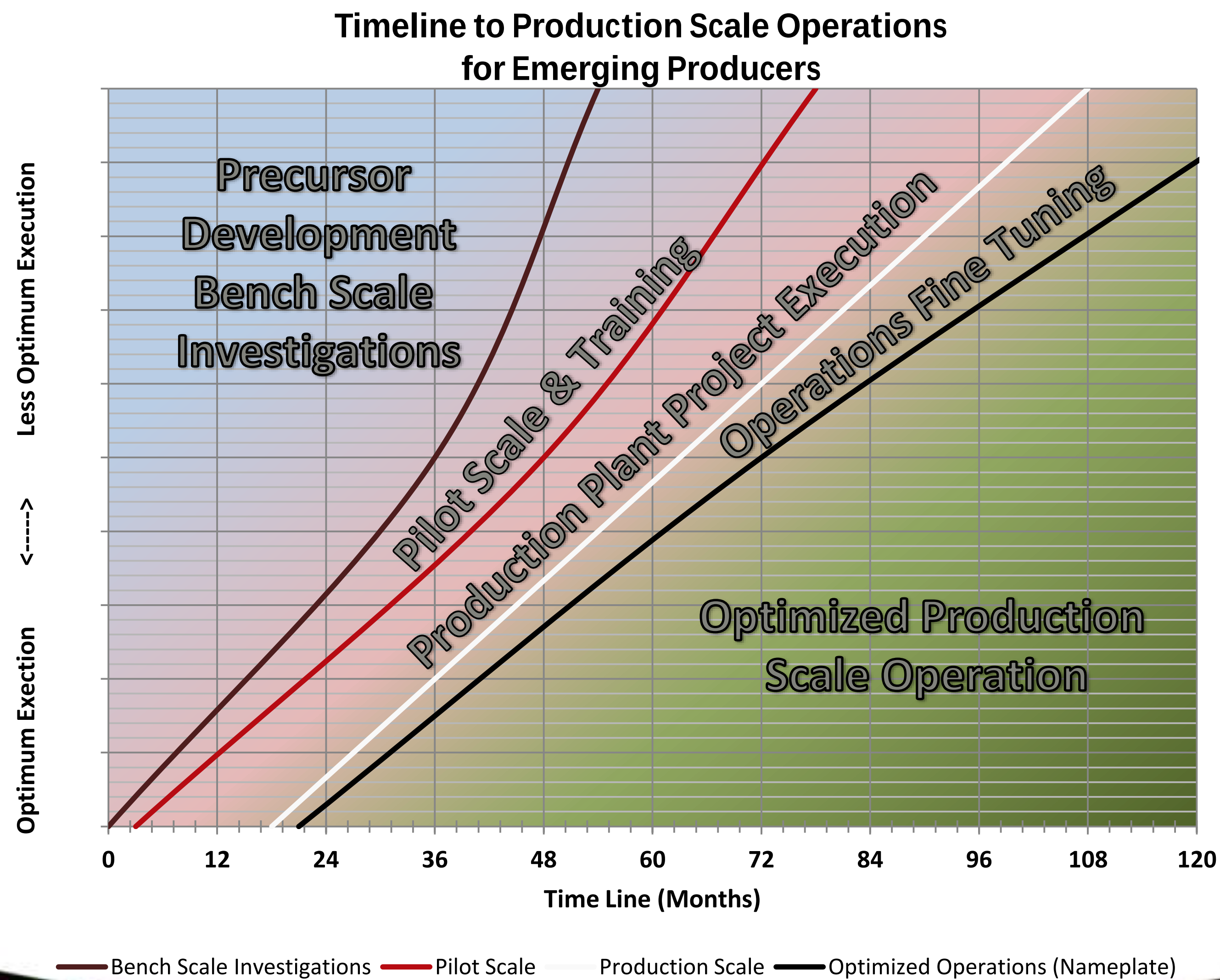
✓ Custom Design Provided through Assembly of Standardized Modules of Varying Design and Capabilities

✓ Each Module Optimized for delivery with Standard Shipping Containers

✓ 20% - 30% Reduction in Manufacturing Time

Challenges and Expectations for Automotive Market:
5) Optimizing the Project Development Timeline

Optimizing the Project Development Timeline



Harper

Optimizing the Project Development Timeline

- Precursor Development & Bench Scale Investigation
  0 – 60 Months in Duration (Buy, Develop, License)
- Pilot Scale Investigation, Scale Up, Validation & Training
  3 – 24 Months in Duration (Test at Harper Facility –vs- Own)
- Production Scale Project Execution
  15 – 30 Months in Duration (Experience & Execution Plan)
- Operations Fine Tuning
  3 – 24 Months in Duration (Oper. Experience & Training)
- Production Scale Operation: Total Time Line

Total Time Line for Reaching Production Scale Operation
20 Months to More than 10 Years

Harper

Optimizing the Project Development Timeline

- How to Establish a Technology Position

  Buy, Joint /Venture, License Technology, Develop Technology
  What about a Process Design Package

- First Target Fiber Uses; then Type, Properties and Capacity

  Led By Business Planning and Market Development Efforts

- Understand Your Process and the Impact of Technical Specifications

  Empirical Investigation of Material Packing Density (Tow Spacing is Critical)
  Empirical Investigation of Residence Time and Each Process Step

  <u>Market Size and Empirical Data Will Determine Line Size and Unit Op. Design</u>

- Consider Capacity and Other Needs – Is a Single Line Enough?

  Capacity Limitations of Single Lines
  How is Product Development Handled
  How Is Training and Staff / Operations Development Handled
  Partnerships, Industrial Pilot Plants and MicroLine Options

Harper

Summary of Challenges for Automotive Adoption

1. Diminishing returns in optimization of current scale systems

   Further Expansion beyond 3,000 TYP Line is within Reach

   Modest Reductions on Cost of Production from Scale

2. Reducing carbon footprint

   3x – 9x the Theoretical CO_2 footprint is unacceptable

3. Development costs associated with next generation technology

   Need to Focus on Technology advancements

   Opportunity for Reduction of CO_2 footprint is Key

4. Supply Chain Risks

   Major expansion plans should be coordinated with Supply Chain to avoid bottle necks

5. Optimizing the Project Development Timeline

   Various paths to commercialization that players may take must be considered as automotive adoption is forecasted

Thank you for your time!

Harper International

Spark the future.™

Visit us at harperintl.com and harperbeacon.com