Expansion Trends in Carbon Fiber, Challenges to Capturing Growth, and a Path to Achieve Greater Capacities

Presented at JEC Asia 2012

June 27, 2012

Agenda

- About Harper International
- Historical Growth & Expansion Trends
  - Review of Scales of Operations
  - Five Important Historical Steps
- Challenges to Capturing Growth
- A Path to Achieve Greater Capacities

About Harper

- Headquartered outside of Buffalo, NY
- Established in 1924
- 45,000 ft^2 manufacturing facilities
- 5,500 ft^2 dedicated Technology Center
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration

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

Services to the Carbon Fiber Market

- Equipment Supply (~40 Years)
  - LT Furnaces, HT Furnaces and UHT Furnaces
  - Next-Generation 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

Carbon Fiber Historical Growth & Expansion Trends

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 1tpy

Carbon Fiber Historical Growth & Expansion Trends

Five Important Historical Steps Towards Efficiency
that have Supported 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 Historical Steps Towards Efficiency

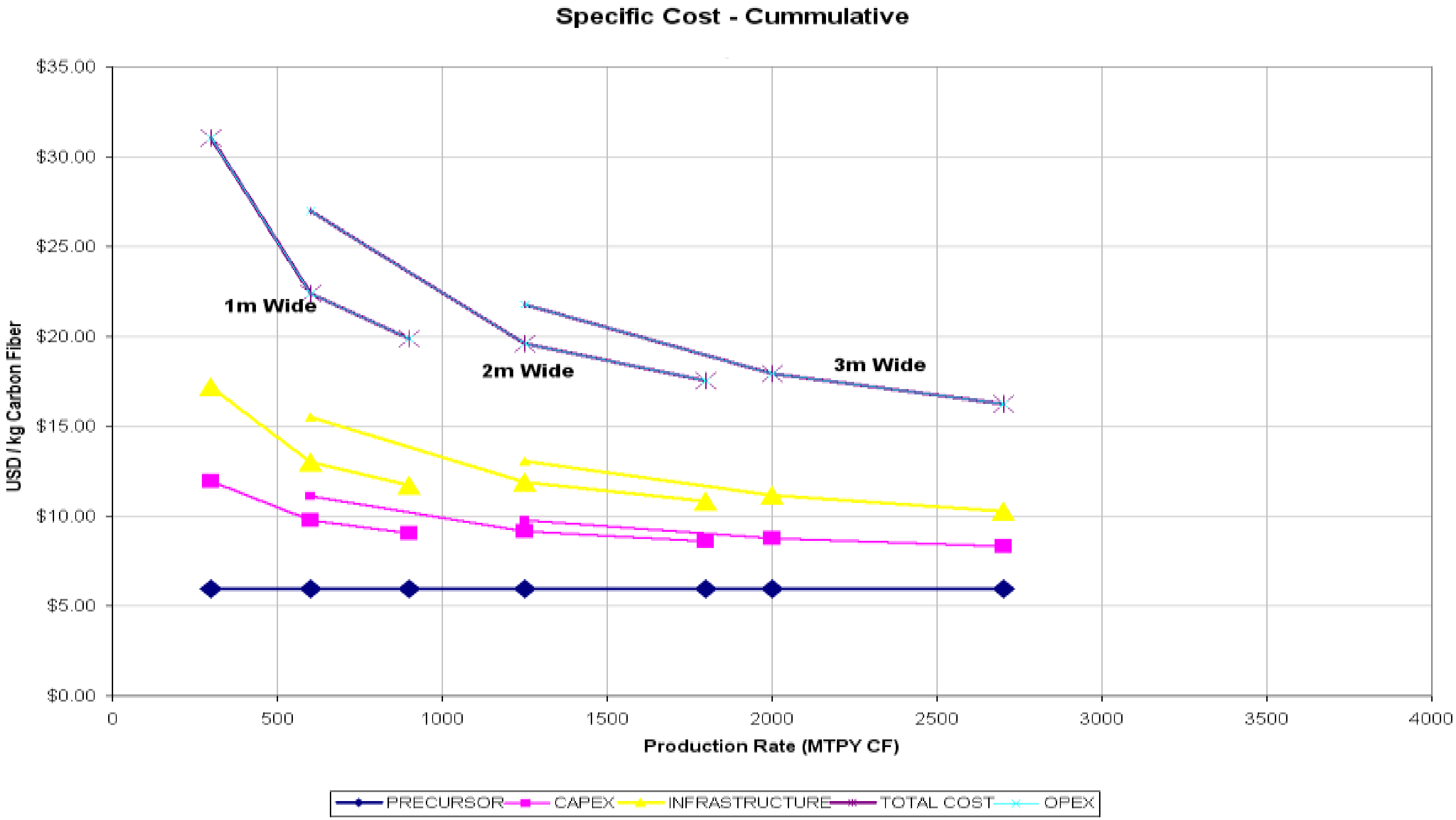
Step 1:
Increase of Scale

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:
Carbon Fiber Conversion Cost Model



Cost Dynamics as a Function of Scale-Up

Five Important Historical Steps Towards Efficiency

Step 2:
Treatment of
Oxidation Oven Exhaust

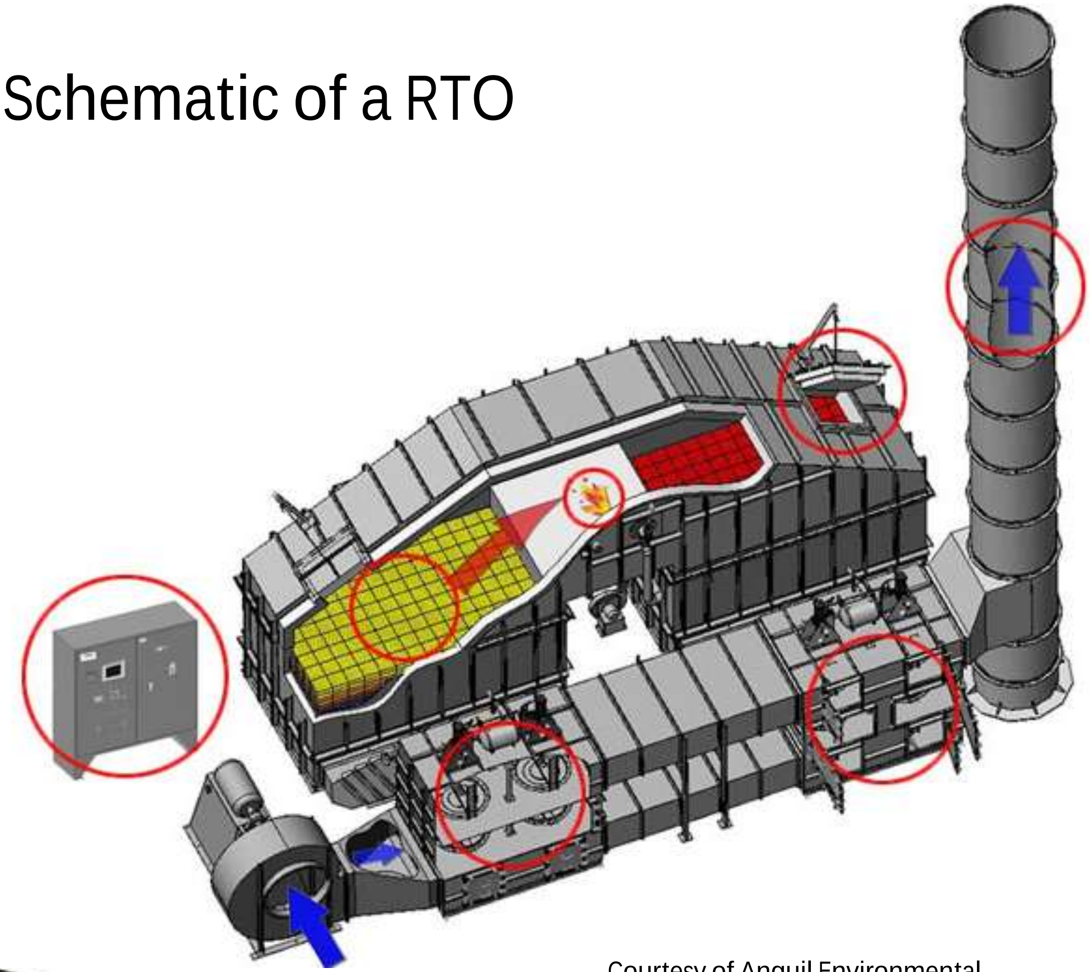
Treatment of Oxidation Oven Exhaust:

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

<u>RTO Pros / Cons</u>

- 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

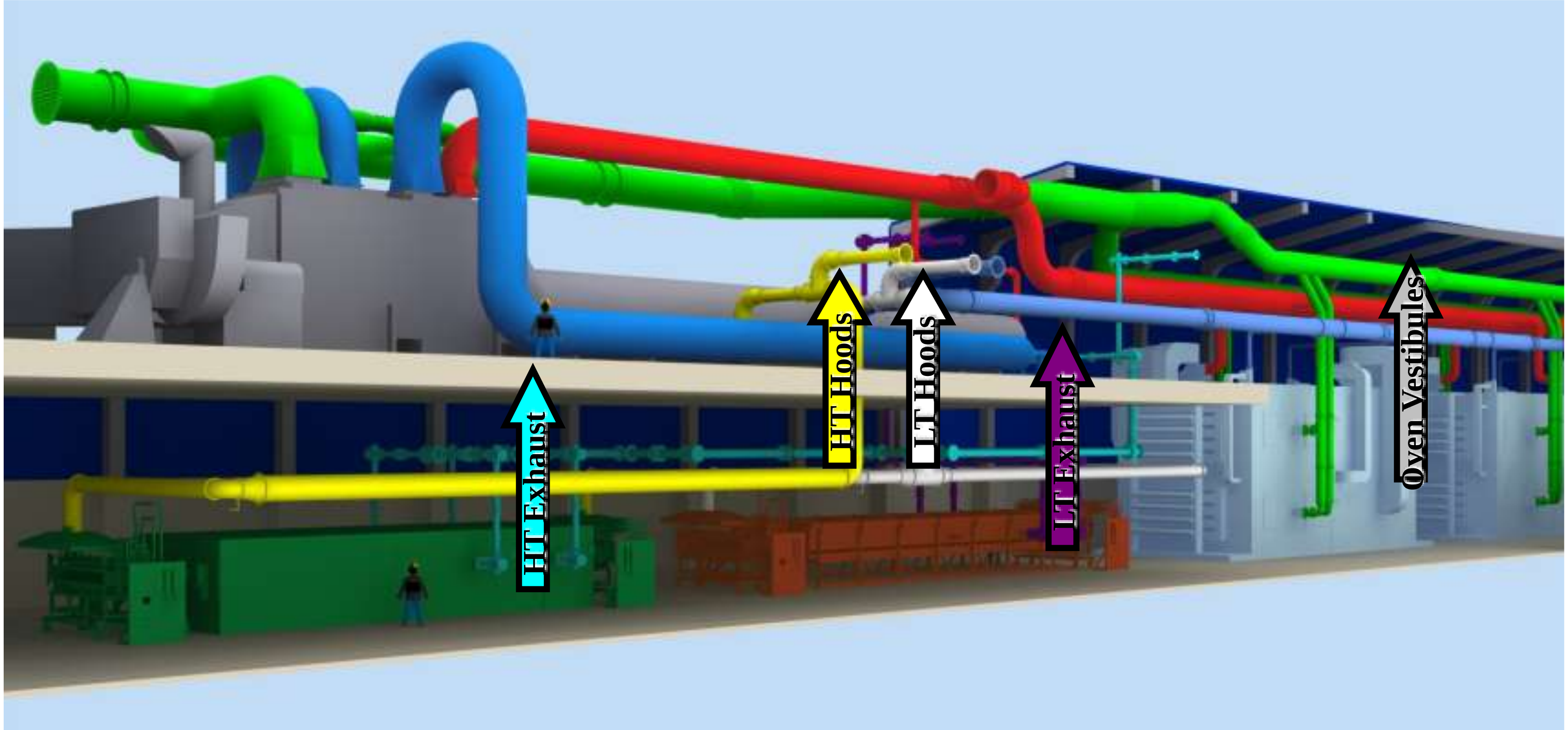
Treatment of Oxidation Oven Exhaust

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

Five Important Historical Steps Towards Efficiency

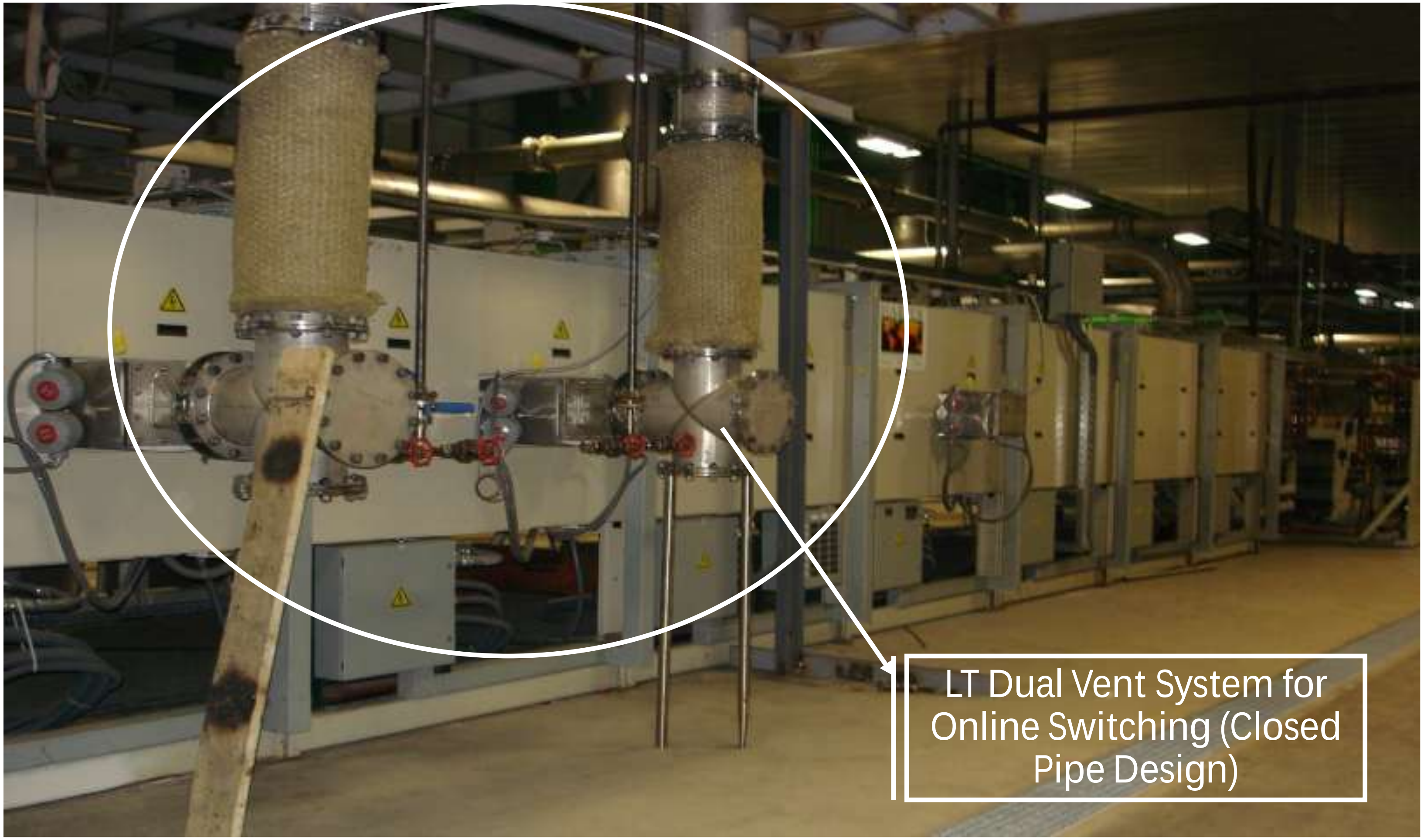
Step 3:
Closed Pipe Treatment of Furnace Exhaust

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



LT Dual Vent System for Online Switching (Closed Pipe Design)

Gas Abatement - Collection

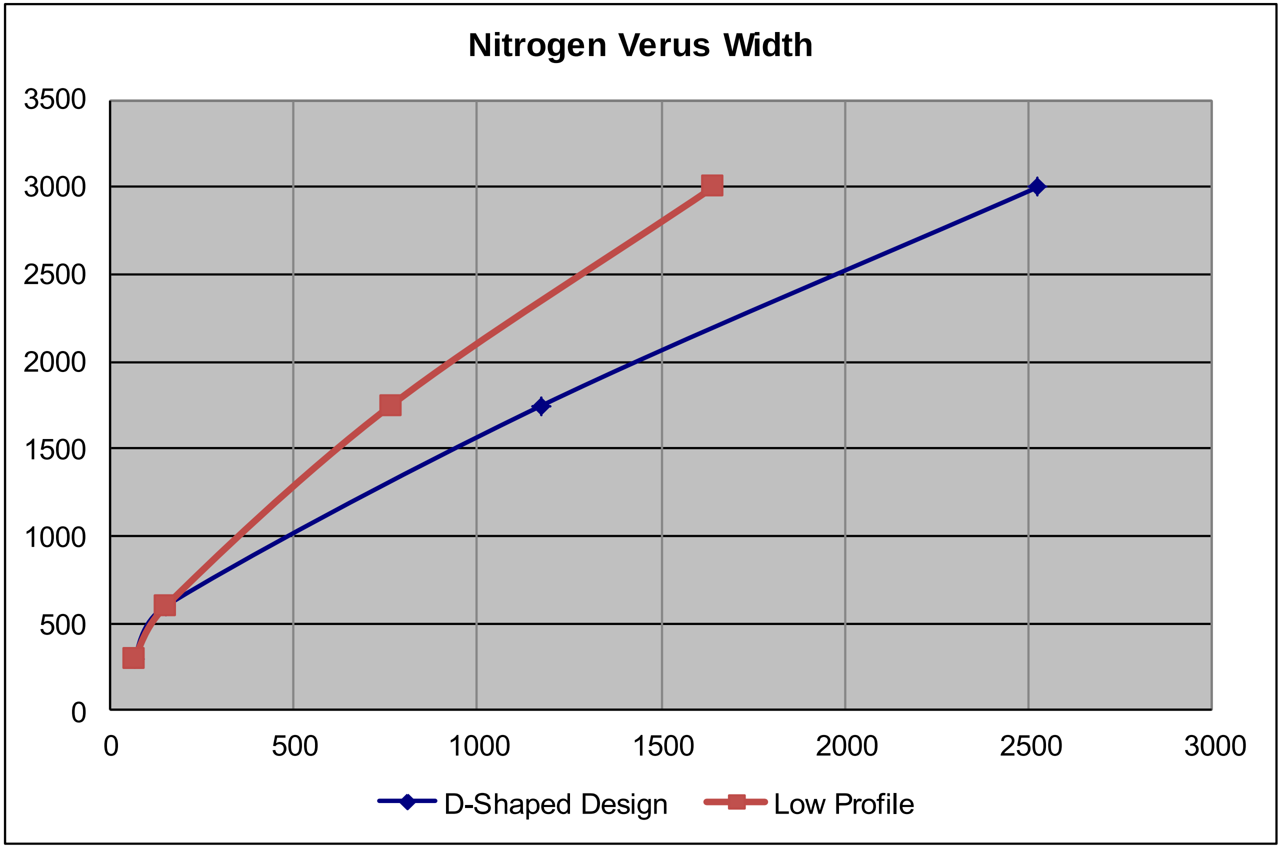
Five Important Historical Steps Towards Efficiency

Step 4:
Low Profile Muffle Design To Reduce Nitrogen Consumption

Low Profile Muffle Design
To Reduce Nitrogen Consumption

Harper LT Furnace
3 meter wide low-profile muffle

Low Profile Muffle Design
To Reduce Nitrogen Consumption



Nitrogen Consumption Model Reduction Based on Muffle Design

Five Important Historical Steps Towards Efficiency

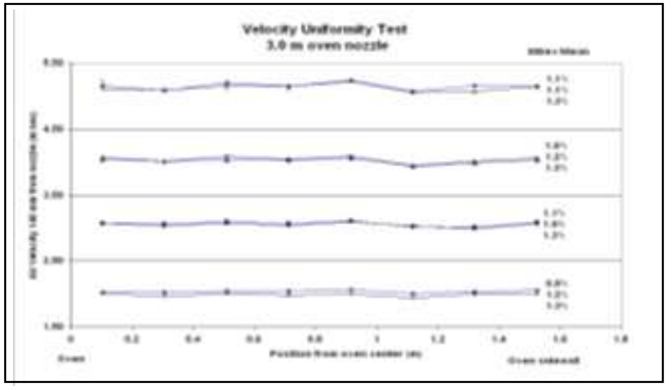
Step 5:
Shift Towards Sealed Oxidation Oven Design

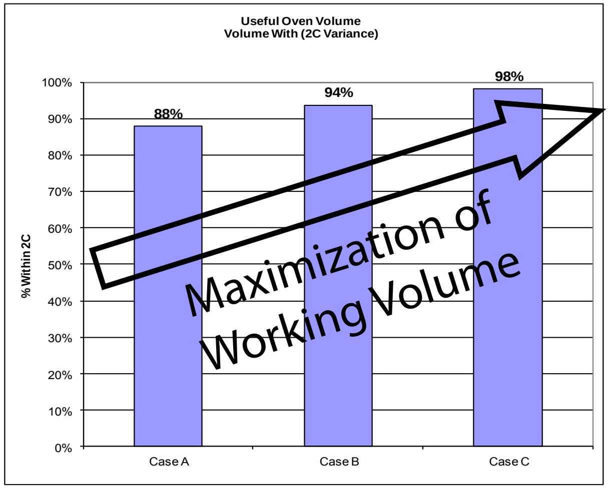
Shift Towards Sealed Oxidation Oven Design

Performance Metrics

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

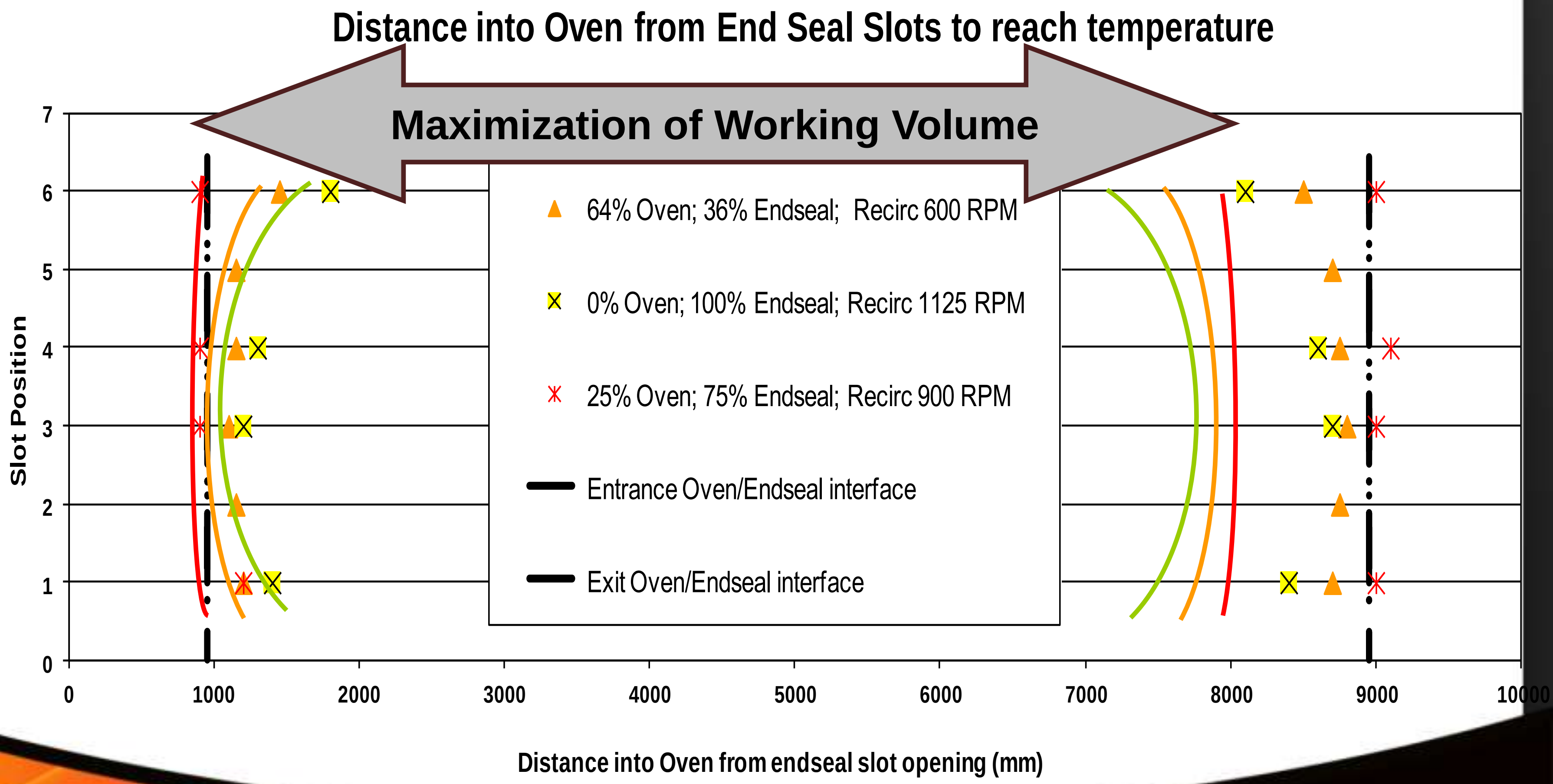
(Efficiency, Guaranteed)





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

Historical Growth & Expansion Trends – Why are These Steps Important?

1. Increase of Scale (Wider and Longer)

   -> Over 40 years, scale of operation has reduced costs by half

2. Treatment of Oxidation Oven Exhaust & Potential for Energy Recovery

   -> At modern production scales, more than 12 kW-hr / kg of CF can be removed through energy reuse (35 kw-hr / kg -> 20 kw-hr / kg)

3. Closed Pipe Treatment of Furnace Exhausts & Potential for Energy Recovery

   -> Reduces NOx discharge from plants, allows for greater single site capacity
   -> Opportunity for kw-hr / kg energy reduction through recovered fuel value

4. Low Profile Furnace Muffles for Reduced Gas Consumption

   -> Change of Furnace muffle design has allowed for 40% - 50% reduction in Nitrogen Consumptions (kg N2 / kg CF)

5. Movement Towards Sealed Oxidation Oven Design

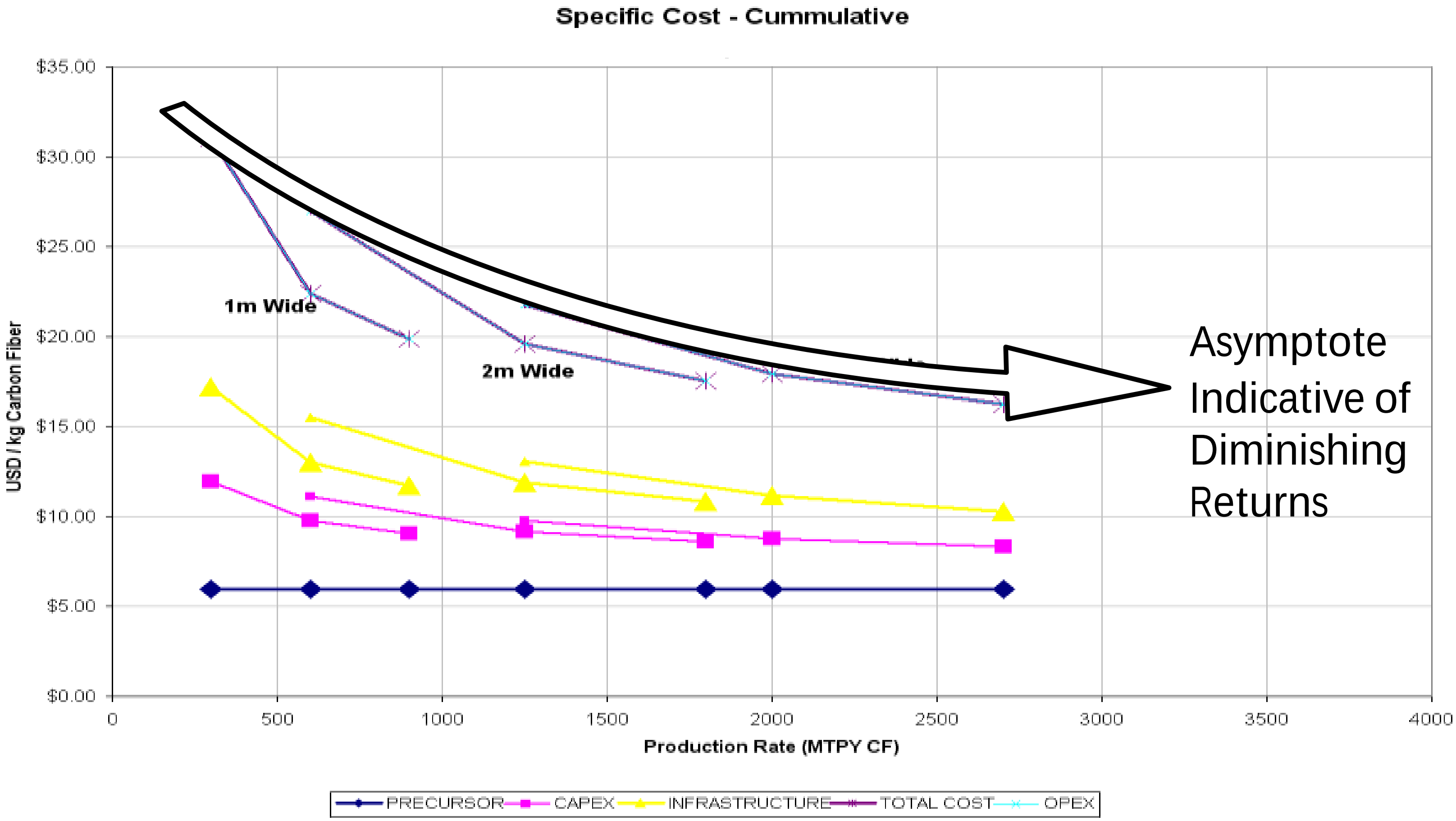
   -> Further energy reductions in oxidation and abatement are possible

Carbon Fiber Expansion:
Challenges to Capturing Growth

Challenges in Carbon Fiber Operations to Capturing Projected Growth

- Diminishing returns in optimization of current scale systems
- Development costs associated with next generation technology
- Need for increased efficiency of chemical reaction
- Reducing carbon footprint

Challenges in Carbon Fiber Operations to Capturing Projected Growth



Asymptote
Indicative of
Diminishing
Returns

Cost Dynamics as a Function of Scale-Up

A Path to Achieve Greater Capacities

Harper Beacon

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.

Harper Beacon: Inputs

Harper's

Process-Based Cost Model

82 Variable Cost Model

Cost Factors:

41 Variables

in Core Cost Model

Line Sizing Factors:

41 Variables

in Core Cost Model

Harper Beacon: Inputs

Harper's

Beacon
Model

70
Variable

Beacon
Model

Waste Gas Treatment Configuration:

15 Variables

Energy Source:

15 Variables

Theoretical Factors:

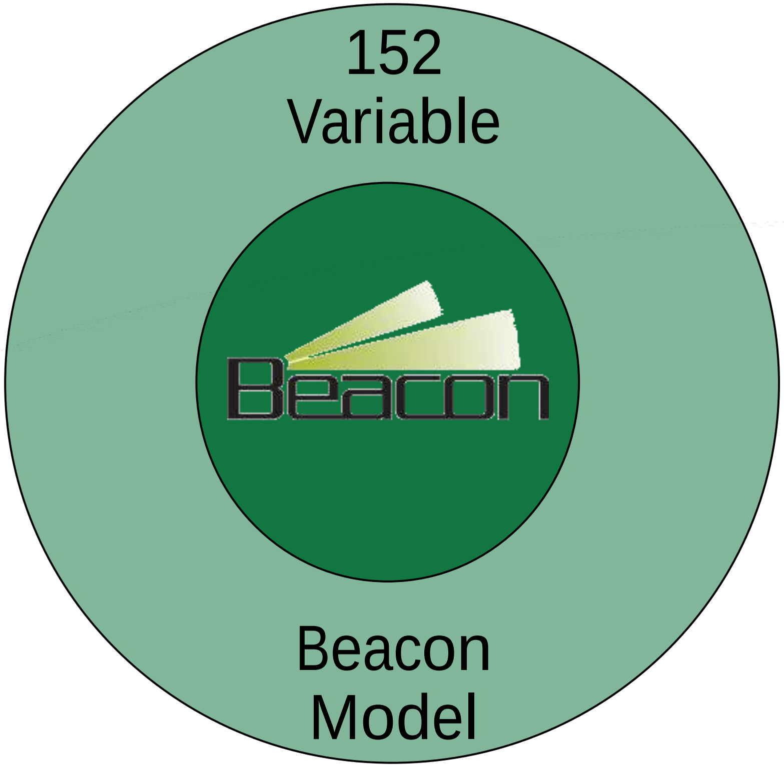
10 Variables

Environmental Losses:

30 Variables

Beacon Comprehensively Evaluates 152 Variables

Harper Beacon: Outputs
Quantifies Environmental and Energy Efficiency



Cost Model Outputs:

CAPEX and OPEX Per Unit Operation for Various Line Configurations.

Outputs Tailored to Specific Site Conditions and Client Circumstances

Carbon Footprint:

kg/hr of Carbon Dioxide Per kg of CF

Compares to Theoretical Minimum as Benchmark of Efficiency

Comprehensive Function

For a Full List of Capabilities Consult Harper

Harper Beacon: Outputs
Quantifies Environmental and Energy Efficiency

152
Variable

Beacon
Model

Nitrogen Oxides Emissions:

kg/hr of Nitrogen Oxides Per kg of CF

Varies with Selection of Waste Gas Abatement and Line Configuration

Impact of HCN Destruction:

CAPEX, OPEX and Environmental Impacts of Achieving Lower Levels of HCN.

Evaluate Trade of Lower HCN and Higher CO2

Thermal Losses:

kWh of Losses as a function of Scale & Operating Parameters

Allows for Quantification of Anticipated Thermal Losses and Design Optimization

For a Full List of Capabilities Consult Harper

Harper Beacon

Carbon Dioxide Emissions:

- Expressed in total kg/hr of CO2 Emitted and kg/hr of CO2 Per kg of CF
- Compare to Theoretical Minimum. <u>Baseline Value based on</u>:
  - Carbon Recovery of Feedstock
  - Specific Heat to Reach Process Temperatures
- Comparison of Carbon Emission to Theoretical Limit Provides a Metric for Optimization and Continued Process Refinement

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)

Energy Summarized by Unit Operation

Thermal Losses

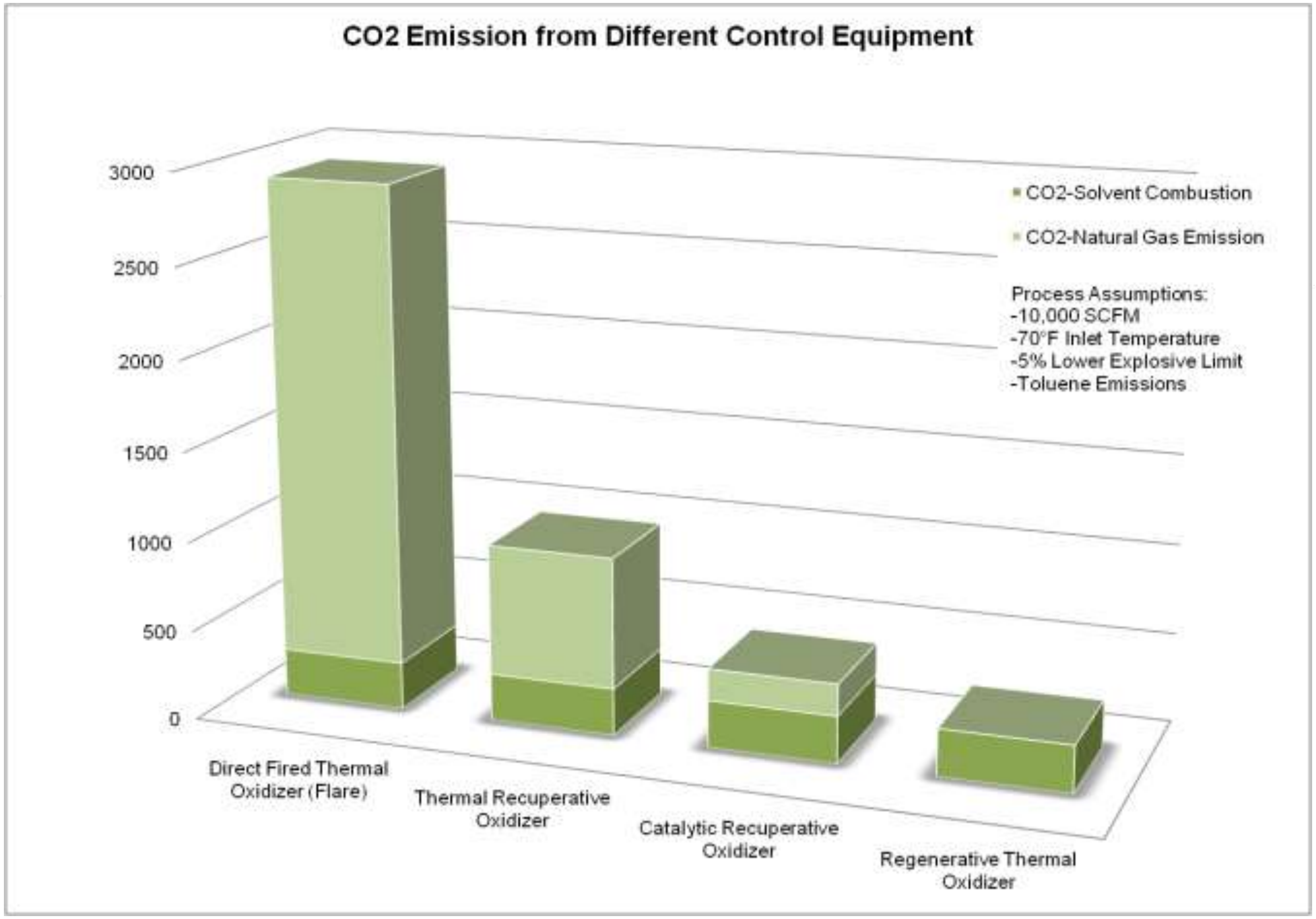
- Heat Rejected to Atmosphere
- Heat Rejected To Cooling Water

Waste Gas Abatement Technology (Major Schemes Considered)

Source of Energy

* Energy Requirement to Produce Purge Gas Ignored

Carbon Dioxide Emissions:

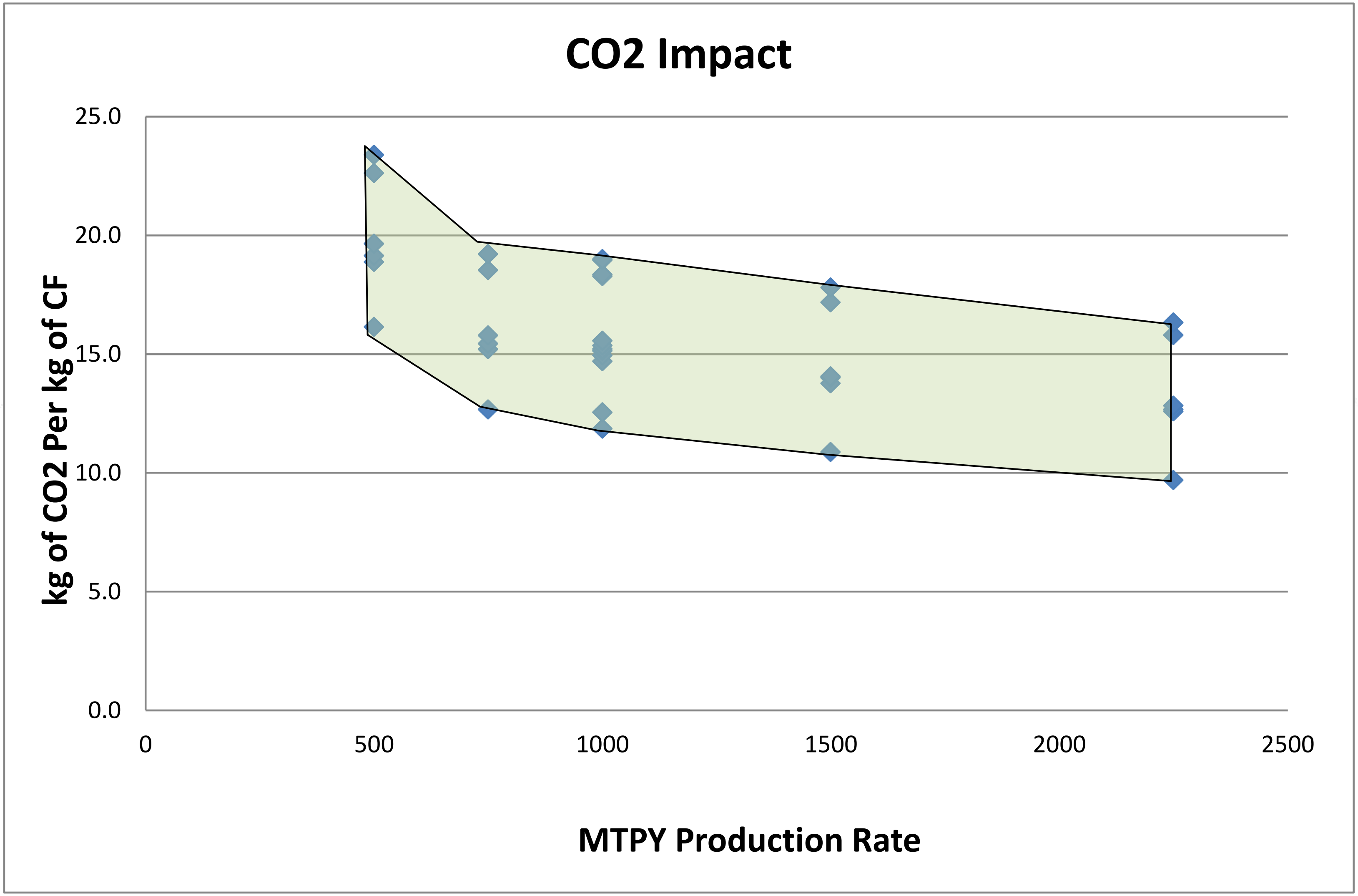


CO2 Emission from Different Control Equipment

Process Assumptions:
-10,000 SCFM
-70°F Inlet Temperature
-5% Lower Explosive Limit
-Toluene Emissions

Courtesy of ANGUIL Environmental

CO2 Emissions Modeling



Sample Data from *www.harperbeacon.com*

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

Sample Data from *www.harperbeacon.com*

Summary

Plan to capture greater opportunities ahead must include continued equipment improvements with a holistic operating economics perspective.

Thank you for your time!

Spark the future.™

Visit us at harperintl.com and harperbeacon.com