Designing for Energy Efficiency in Thermal Processing

Webinar 1 in Harper's Series on Maximizing Production Economics

Welcome!

Designing for
Energy Efficiency
in Thermal Processing

Meet your Presenters:

- Robert Blackmon, VP of Integrated Systems
  - Chemical Engineering, Northwestern University
  - Leads Carbon Fiber Systems Division

- Doug Armstrong, Process Technology Engineer
  - Mechanical Engineering, University at Buffalo
  - Senior Engineer for Integrated Projects

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Agenda

Designing for Energy Efficiency in Thermal Processing

- About this Webinar Series
- Introduction to Harper
- Keys to an Energy Efficient Design
  - Moving from batch to continuous
  - Considerations in furnace selection
  - Mitigating risk in scale up
  - Practical solutions for existing systems
- Case Study Example
- Wrap-Up / Question & Answer

About This Webinar Series

Maximizing the Production Economics of Your Thermal Processing System

- Your inside access to Harper's deep technical expertise
- Recording of the event will be available on demand for 60 days after the event
- Future Events in this Series

  -Planning for Success: Sensibly Scaling Up Production – August 2012

  -Thermal Processing Research: Designing Flexibility & Performance – October 2012

  -Maintenance Optimization – Planning Downtime Efficiently – December 2012

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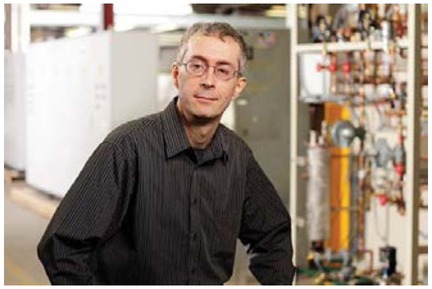
Introduction to Harper

- Headquartered outside of Buffalo, NY
- Decades of thermal processing experience
- Dedicated Technology Centers for customer process development & testing
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration



Introduction to Harper

We work with developers & producers of advanced materials to provide innovative technologies:

- 200°C – 3000°C
- Batch to continuous processing
- Precise atmospheric controls
- High purity requirements
- High temperature GSL reactions

- Refinement
- Scale Up
- Optimization

Introduction to Harper

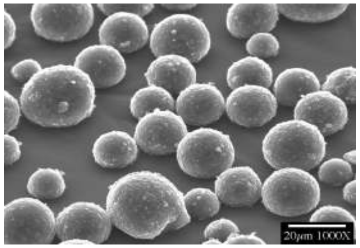
Focus on Processing System Solutions for…

<u>Advanced Materials</u>:

- Fibers & Filaments
- Metal Oxides & Powders
- Technical Ceramics
- Energy Materials
- Nano Materials
- Rare Earths
- Graphene

<u>Processes:</u>

- Sintering
- Drying
- Calcination
- Reduction
- Oxidation
- Carbonization
- Carburization
- Solid-solid reaction
- Gas-solid reaction
- Purification
- Metalizing
- Debinding
- Parts processing
- Phase transformation



Introduction to Harper

Whether in refinement, scale up or optimization…

…we solve challenges that no one else can.

Helping customers turn the next generation of material innovations into profitable new markets.

Ignite™

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Keys to Energy Efficient Design

Deeply considering energy efficiency when scaling advanced materials processing can directly impact commercial viability…

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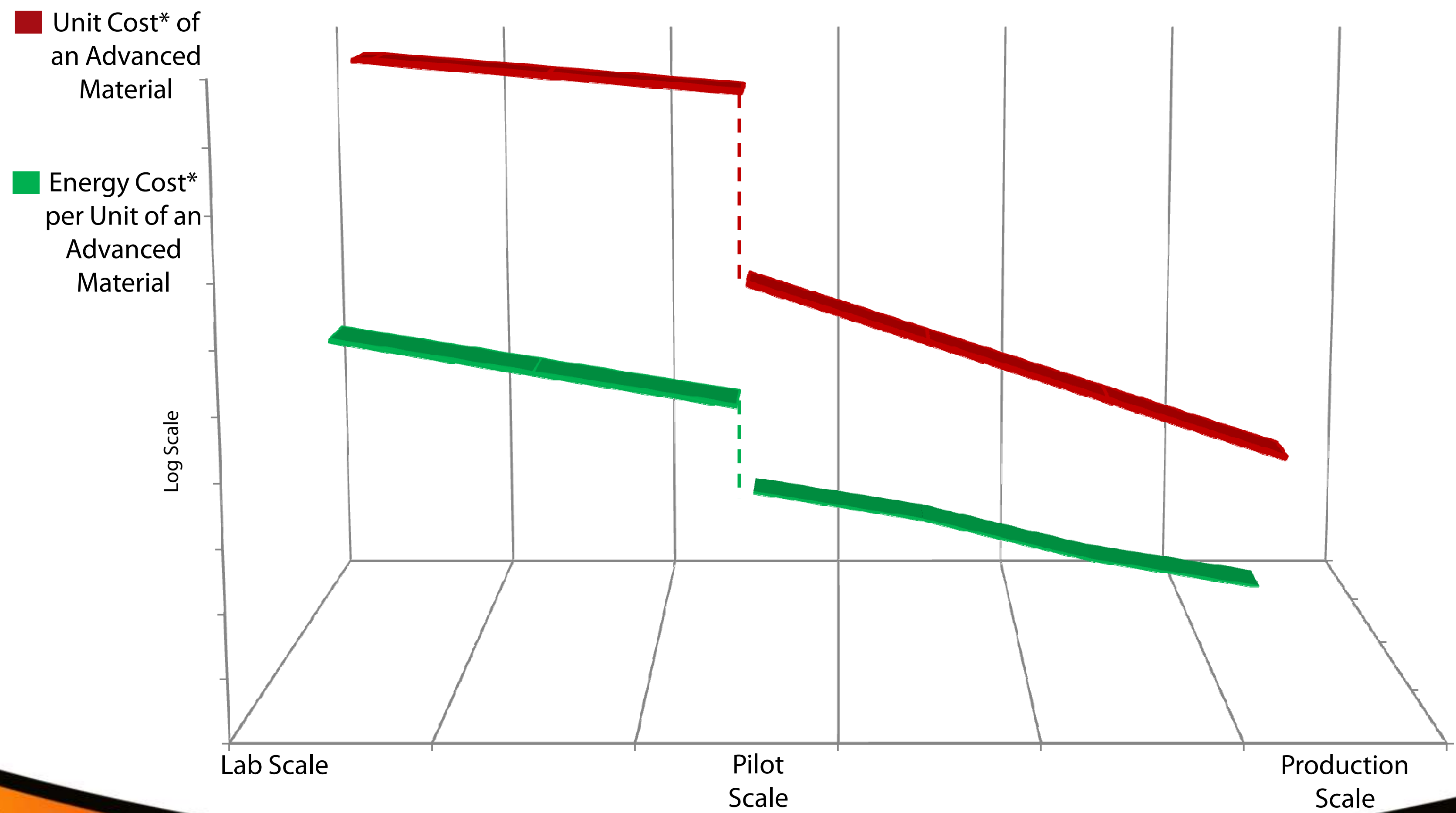

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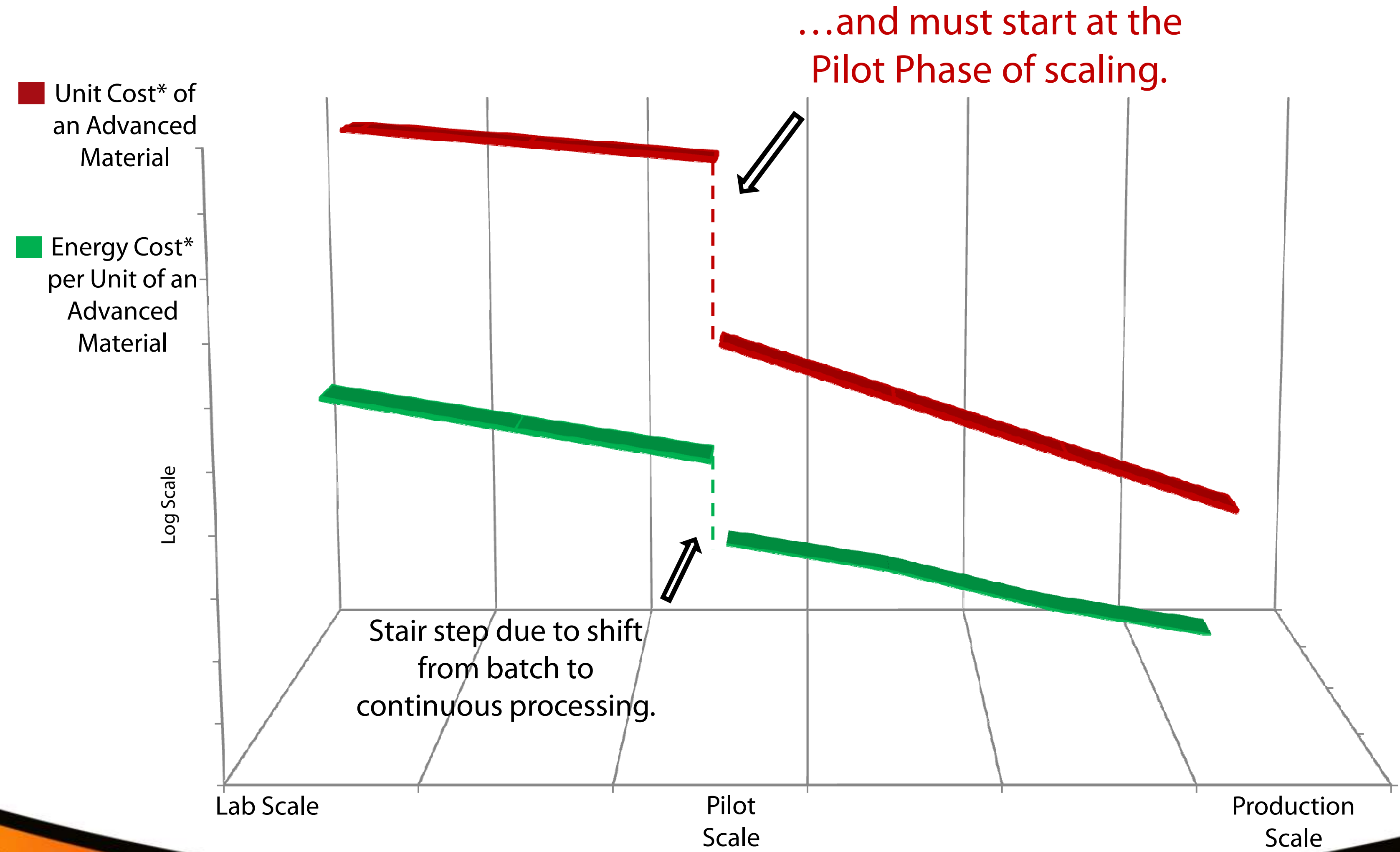

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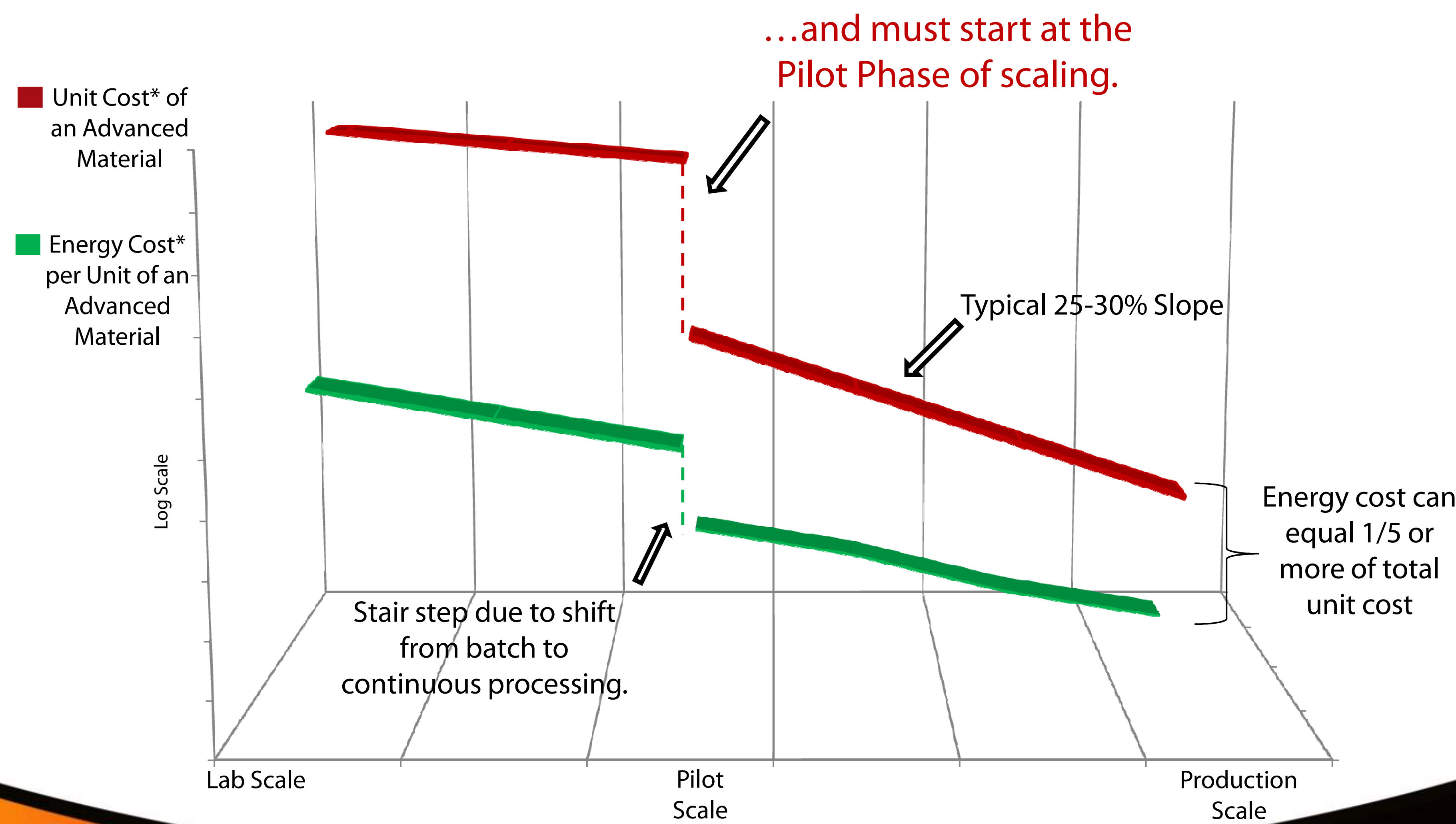

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Keys to Energy Efficient Design

The largest gain in efficiency comes from transitioning from Batch to Continuous – WHY?

Keys to Energy Efficient Design

The largest gain in efficiency comes from transitioning from Batch to Continuous – WHY?

Three key design aspects to consider:

- Refractory design & heat cycling
- Process gas management
- Effluent / Off gas processing

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Energy Efficiency – Refractory Design

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Batch

- Balance thermal containment vs. heating / cooling rates

Energy Efficiency – Refractory Design

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- Energy recovery possible

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  - Presence of particulates
  - Energy content

Energy Efficiency – Off Gas Processing

Abatement vs. Clean and Recycle

Abatement

- Commonly viewed as a cost center
- Generally does not relate to or enhance production quality
- Exhaust is considered a by product requiring treatment and disposal
- High temperature thermal process that creates opportunity for energy reutilization, if needed

Clean and Recycle

- Involves investment of capital equipment to achieve recycle needs to be weighed against cost for producing the gas

Energy Efficiency – Off Gas Processing

Key Decisions in Abatement vs. Clean and Recycle

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- Dangerous off gases almost always need to be abated limited opportunity for recycle

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Energy Efficiency – Off Gas Processing

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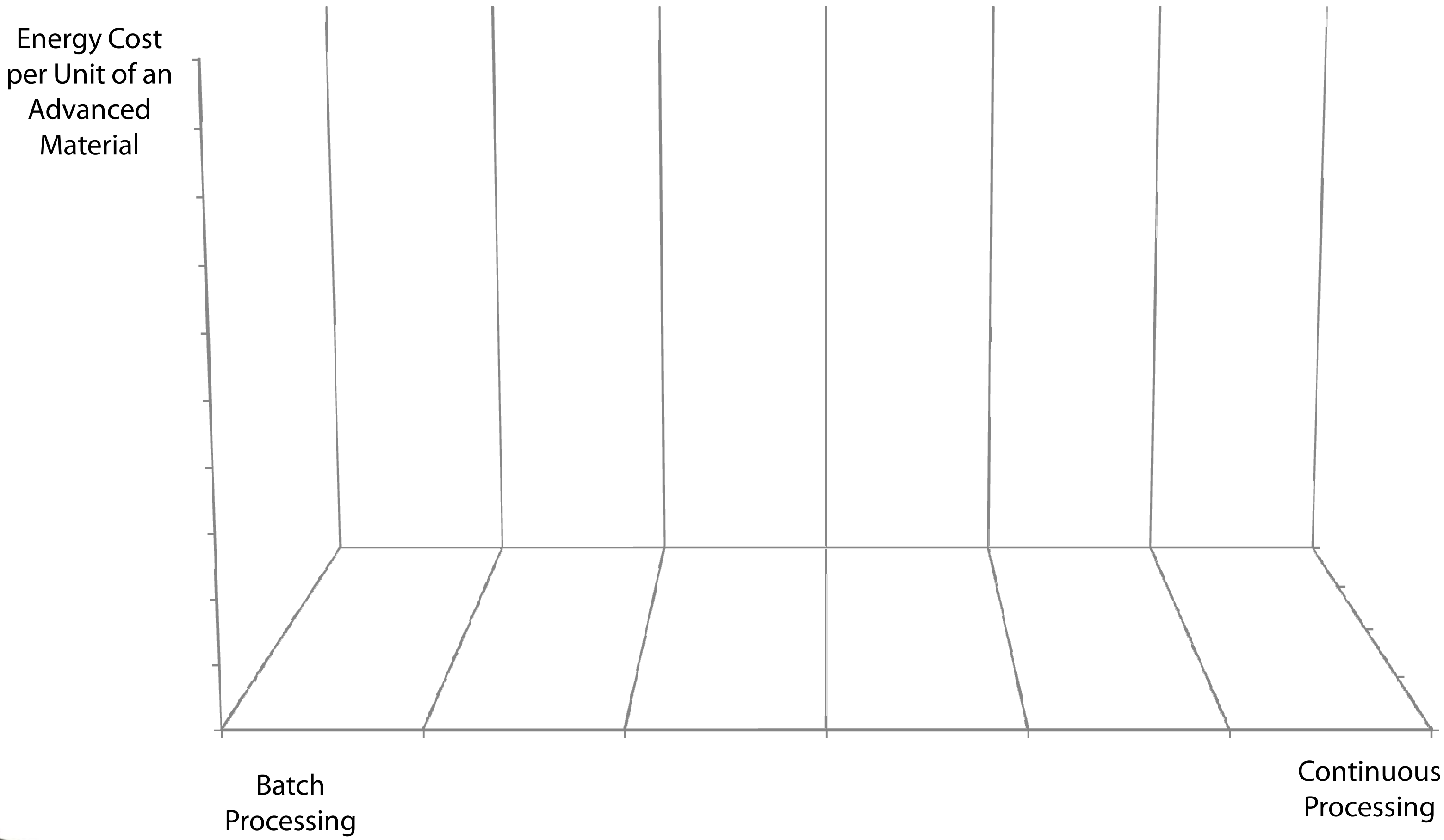
- Not all processes have off gas that needs to be abated
- Dangerous off gases almost always need to be abated limited opportunity for recycle
- ROI must make sense. Larger scale, more continuous processing, and elevated temperatures yield an economic advantage.
- Identify auxiliary process or utilities to use recovered energy

Selecting an Energy Efficient Reactor Process



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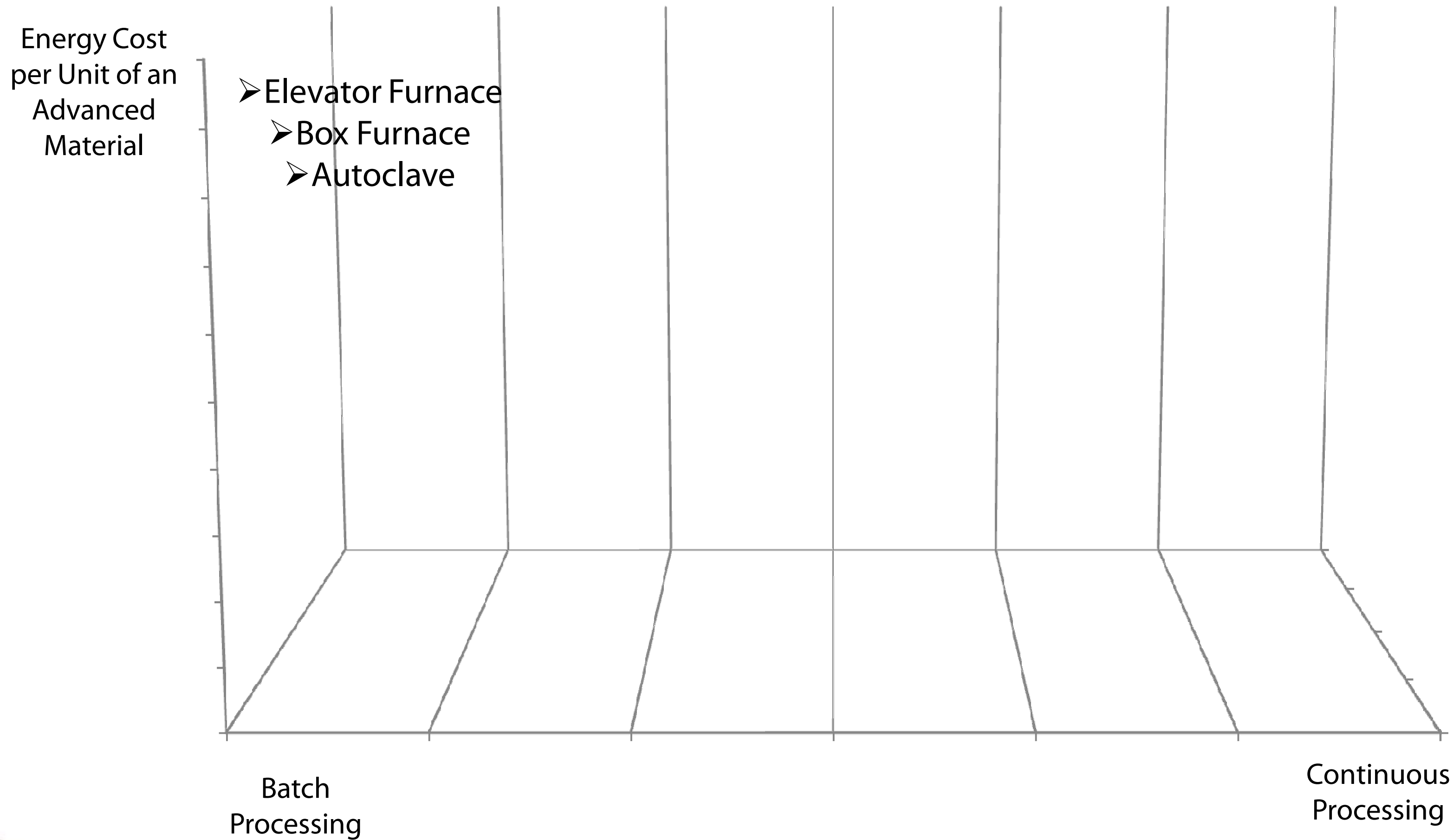

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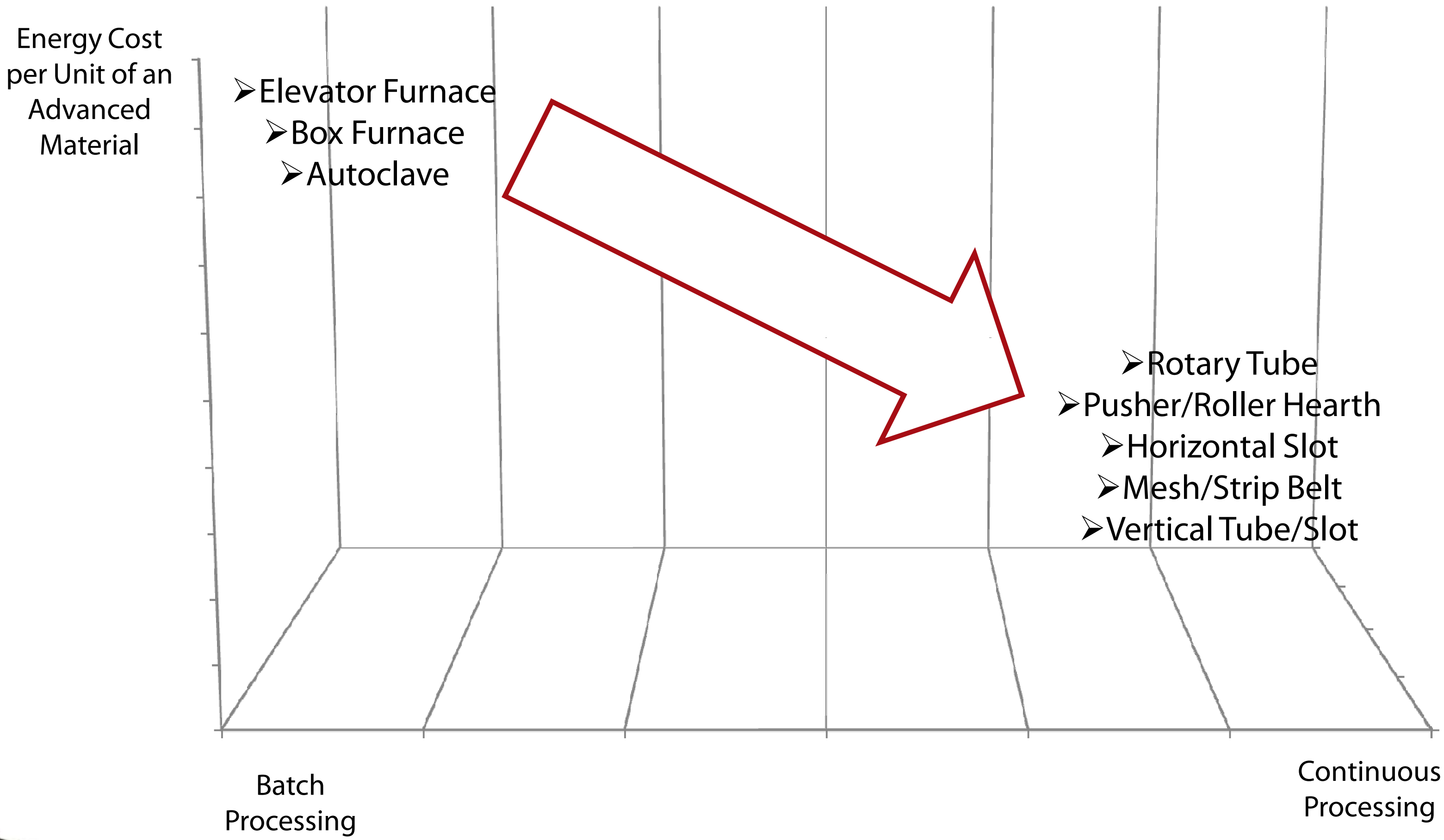

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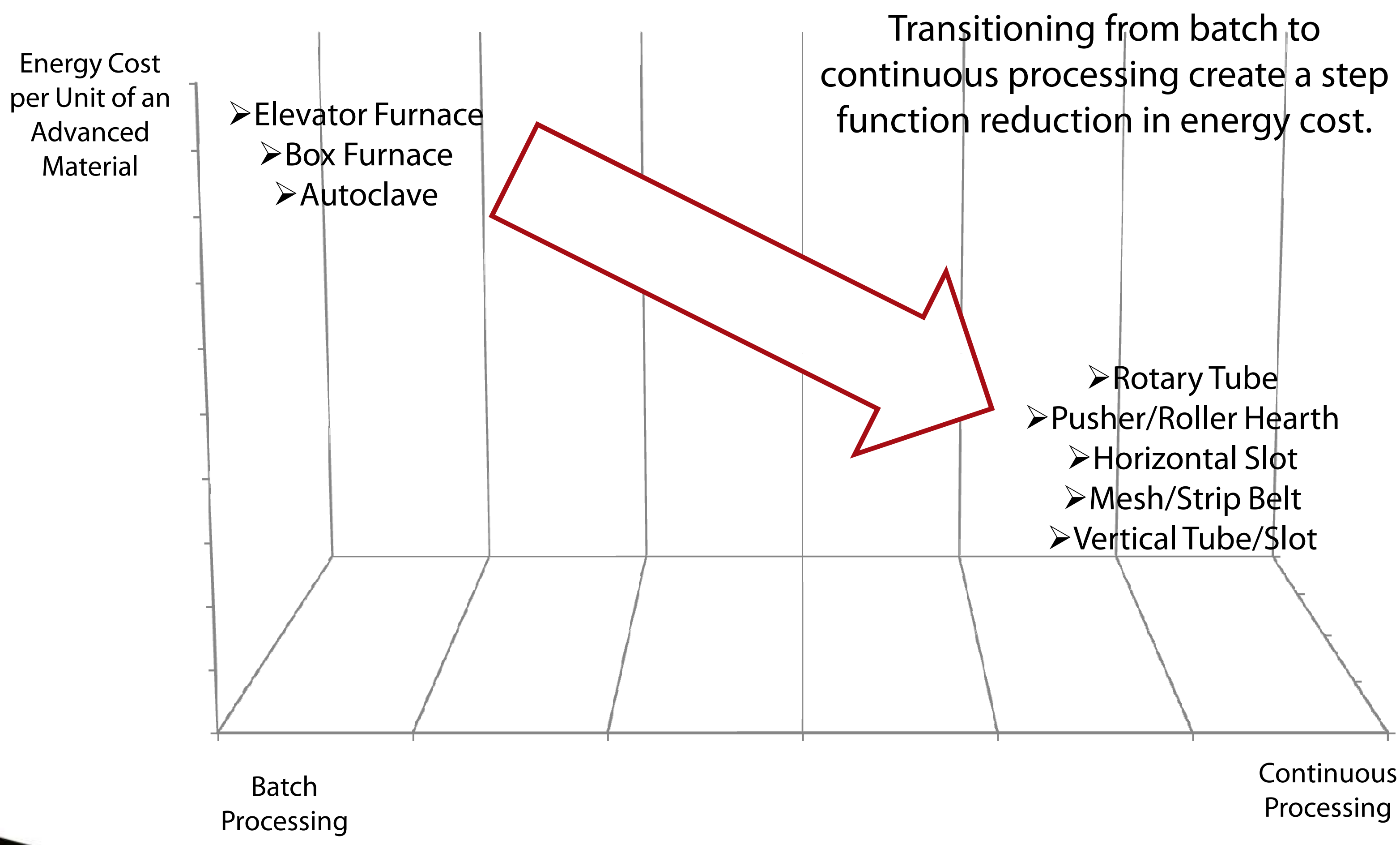

Keys to an Energy Efficient Design – Furnace Selection

Reactor Type	Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Rotary Tube						
Pusher / Roller Hearths						
Mesh / Strip Belt						
Vertical Tube / Slot						
Horizontal Slot						

Keys to an Energy Efficient Design – Furnace Selection

Reactor Type	Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Rotary Tube	Ideal for Powder and Bulk Materials	Via Rotating Tube and Angle of Inclination	Low (10% - 20% Filled)	Low	Moderate	High
Pusher / Roller Hearths	Used for Powders, Bulk Materials and Net Shapes	Via Transport in Saggers	Moderate	Highly Uniform	High	Low
Mesh / Strip Belt	Used for Powders, Bulk Materials and Net Shapes	Via Mechanical Belt	Moderate	Highly Uniform	Moderate	Moderate
Vertical Tube / Slot	Ideal for Powders	Via Gravity or Set by Rotary Valve or Auger	High	Low	Low	High
Horizontal Slot	Ideal for Fibers, Filaments and Webs	Material Generally Not in Contact with Furnace	Low	Moderate	High	High

Furnace Selection – Pusher/Roller

Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Used for Powders, Bulk Materials and Net Shapes	Via Transport in Saggers	Moderate	Highly Uniform	High	Low

Energy Efficiency Considerations:

- Requires saggers to go through heating and cooling cycle
- Recovered heat from product carriers can be used to minimize impact on system efficiencies
- Material flows can be engineered so that exiting material is directly cooled by association with cool, incoming reactants, which are concurrently preheated

Furnace Selection - Rotary Tube

Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Ideal for Powder and Bulk Materials	Via Rotating Tube and Angle of Inclination	Low (10% - 20% Filled)	Low	Moderate	High

Energy Efficiency Considerations:

- No need for containers; conveyance is energy efficient. Only reactant powder is heated and cooled, not the conveying system.

- Built in stirring action
  -> enhances thermal transfer to the bed
  -> improves removal of product gases
  -> increases solid/gas exchange in cases where the furnace gas is also a reactant

However, process hetrogenity increases (variance of time at temperature)

Furnace Selection – Vertical Tube / Slot

Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Ideal for Powders	Via Gravity or Set by Rotary Valve or Auger	High	Low	Low	High

Energy Efficiency Considerations:

- Energy use is primarily related to heating the product and reaction, and is thus relatively efficient
- Opportunity for highest volumetric utilization
- Design allows for minimal interaction with the furnace wall, thereby providing improved options where contamination is an issue

Furnace Selection – Mesh / Strip Belt

Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Used for Powders, Bulk Materials and Net Shapes	Via Mechanical Belt	Moderate	Highly Uniform	Moderate	Moderate

Energy Efficiency Considerations:

- No container required but belt must be heated and cooled
- Choice in open weave or uniform plate – difference in heat load and gas interactions
- With open weave, more targeted gas solid interaction as gas can flow through the belt
- Scalable within limits
  - Long belt creates of stresses
  - Thermal lag influences time temperature curve for the process material
  - Lower maximum temperatures

Furnace Selection – Horizontal Slot

Typical Material Profile	Material Handling Transport	Volumetric Efficiency	Homogenity of Reaction	Typical Production Volume	Relative Energy Efficiency
Ideal for Fibers, Filaments and Webs	Material Generally Not in Contact with Furnace	Low	Moderate	High	High

Energy Efficiency Considerations:

- Represents near ideal design for energy efficiency
  - Minimal or no interactions between reactor and flow of material
  - Low to moderate volumetric utilization of the reactor – lots of empty space
  - Options exist for improving volumetric utilization through mass transport

Keys to an Energy Efficient Design – Furnace Selection

Ideal state is:

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✓ requirements for reaction homogenity are met
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No one furnace design perfectly captures these objectives. Compromises during the design process are common. Hence experimentation/scaling is critical in process optimization.

Keys to an Energy Efficient Design – Scale Up

Scaling thermal processes
seldom follows linear extrapolation.

KG
per
hour

Tons
per
hour

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Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

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- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements

Keys to an Energy Efficient Design – Scale Up

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- Evaluate whether production volumes warrant continuous operation

Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
- Evaluate whether production volumes warrant continuous operation
- Consider if material handling can be automated

Keys to an Energy Efficient Design – Scale Up

How to Mitigate Risk During Scale Up

- Structure test work to evaluate whether the process thermal requirements can be decoupled from the equipment thermal requirements
- Evaluate whether production volumes warrant continuous operation
- Consider if material handling can be automated
- Consider magnitude of scale up; go stepwise
  1 to10 Scale Up = Typical
  1 to 100 Scale Up = More Difficult
  1 to 10000 Scale Up = Risky

Keys to an Energy Efficient Design

Practical Solutions for Existing Systems

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- Upgrading to more energy efficiency refractories

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- Improving seal technology with a newer design
- Addition of heat exchangers downstream of installed abatement systems
- Consider the life of your elements and other proper maintenance
- Consider power conditioning and filtering to minimize line losses
- Conduct process audits to optimize consumables such as purge gases and electricity

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Case Study Example – Carbon Fiber

A Model of Step-Wise Scale Up

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A Model of Step-Wise Scale Up

- Harper's first system in 1973 still in operation: 36" Wide (915mm)

Case Study Example – Carbon Fiber

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Case Study Example – Carbon Fiber

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- 1997: 72" wide (1800mm wide)
- 2005: 120" wide (3000mm wide)
- 2008 to Today: >12 systems @ 3000mm wide

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Important Historical Steps Towards Efficiency that have Supported Carbon Fiber Commercialization:

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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)

Important Historical Steps Towards Efficiency that have Supported Carbon Fiber Commercialization:

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Case Study Example – Carbon Fiber

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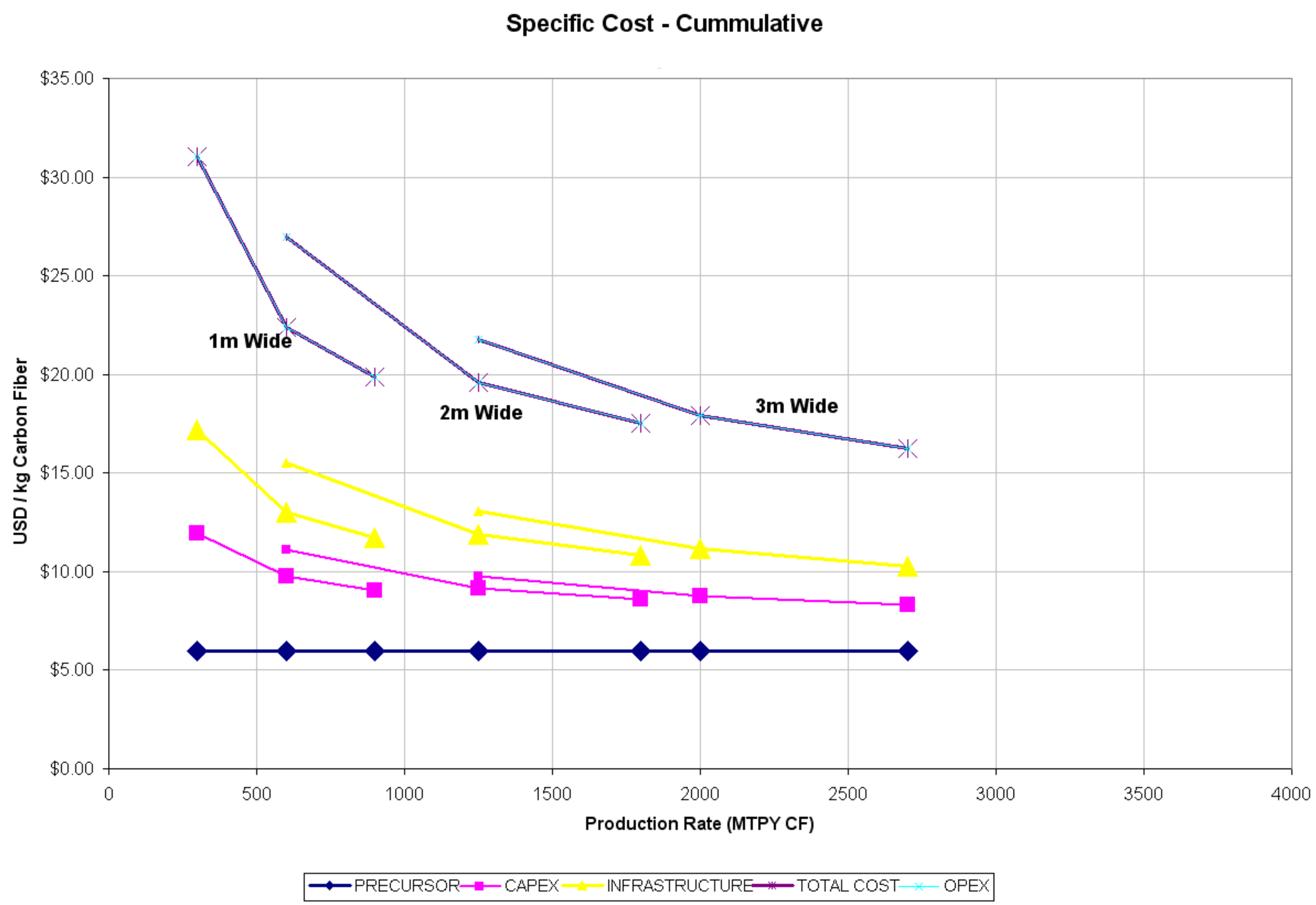
However, Challenges Remain…

1. Diminishing Returns: opportunity for increased efficiency in scale is declining
2. Consumer Market Adoption: at higher volumes, a better understanding of environmental impact is required (automotive)

Case Study Example – Carbon Fiber



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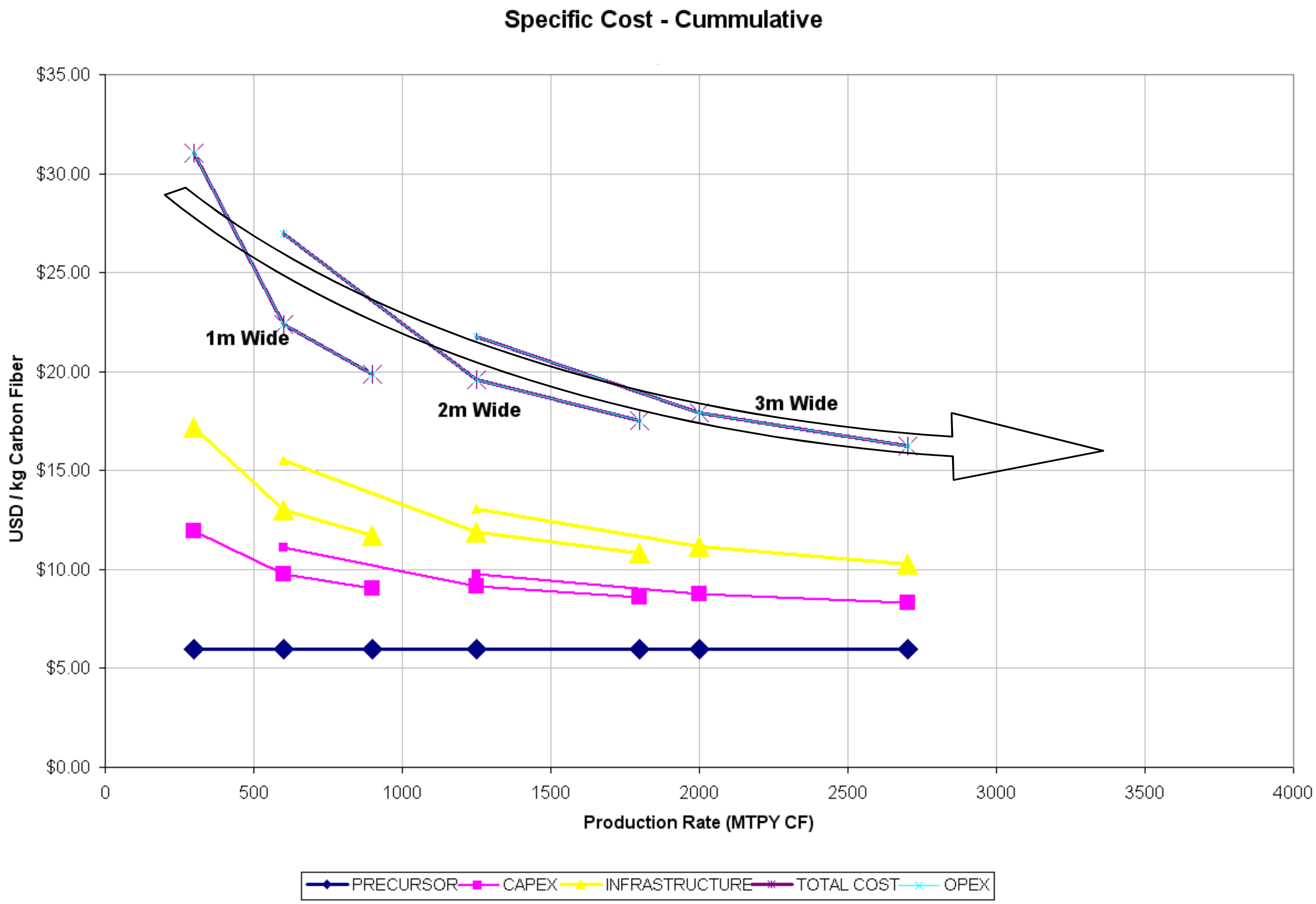

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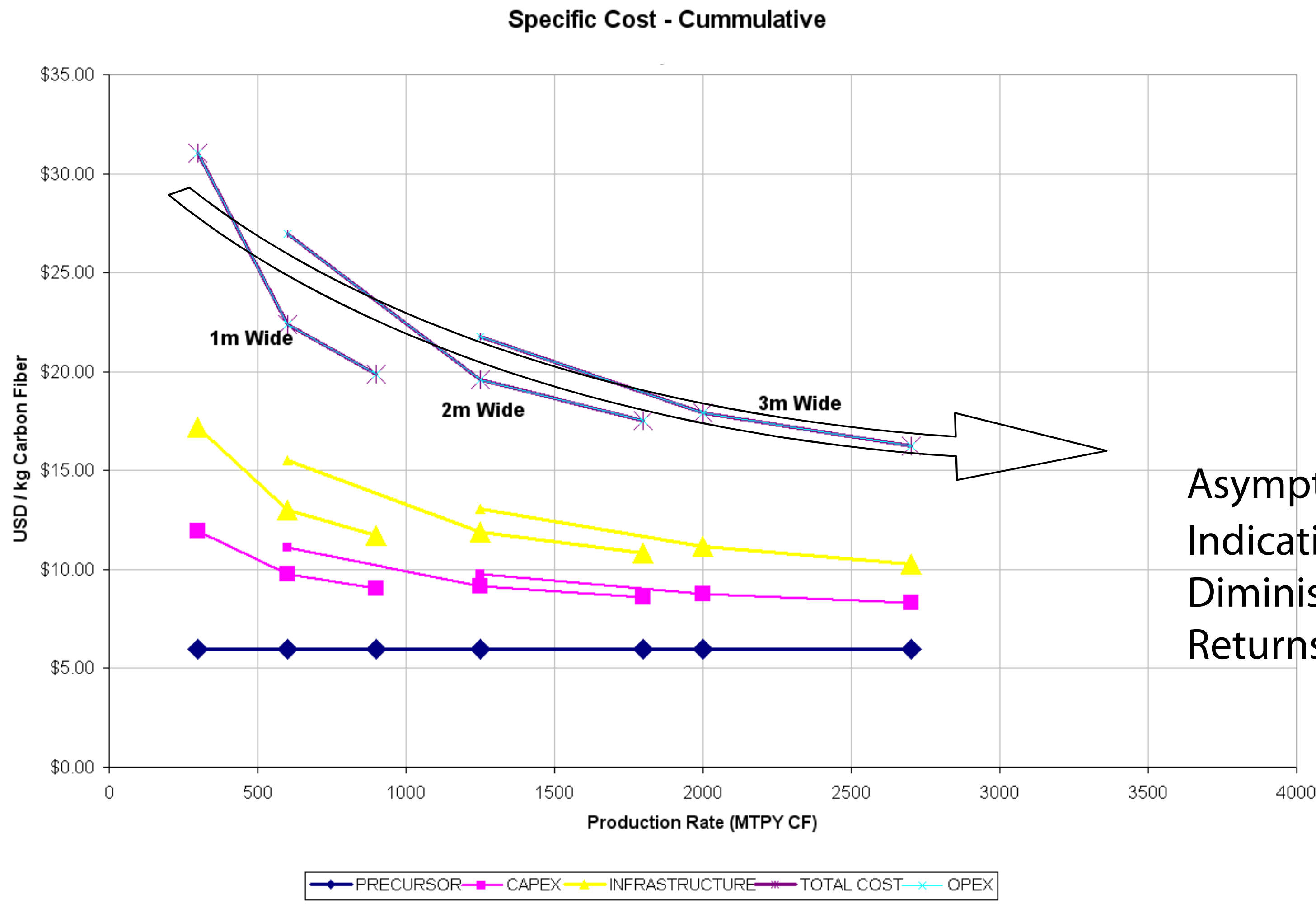

Asymptote Indicative of Diminishing Returns

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Beacon

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Outputs Tailored to Specific Site Conditions and Client Circumstances

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Thermal Losses - kWh of Losses as a function of Scale & Operating Parameters

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Give efficiency the green light.

Carbon Footprint - kg/hr of CO2 per kg of Material

Nitrogen Oxides Emissions - kg/hr of Nitrogen Oxides per kg of Material

Outputs Tailored to Specific Site Conditions and Client Circumstances

Impact of HCN Destruction - CAPEX, OPEX & Environmental Impacts of Achieving Lower Levels of HCN

CAPEX & OPEX Per Unit Operation for Various Line Configurations

Harper International

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5. Opportunities for improvement in efficiency need not be limited to new capacity expansions. Audit your process now.

Thank You!

Learn more at harperintl.com and harperbeacon.com