

Complete Carbon Fiber Solutions

Innovation. It's the fiber of our being.



 **Harper**
International
Spark the future.™

Making bright ideas brilliant.

Harper International is a global leader in complete thermal processing solutions and technical services essential for the production of advanced materials. From concept to commercialization, from research scale to full production line operations, Harper is perpetually on the cutting edge.



Your Complete Carbon Fiber Partner

Harper is the most trusted partner in thermal processing technologies for the Carbon Fiber industry. Our value proposition is unequalled - with decades of industry experience and installations worldwide from small scale scientific research lines to full scale Carbon Fiber production lines, our expert team lives to custom engineer furnace systems that meet your unique scale-up needs.

We don't shoehorn a standard line of products to fit our customers' requirements. We specialize in first-of-a-kind solutions using our exceptional depth and breadth of knowledge and our extensive set of engineering building blocks. Harper's culture is one of genuine ingenuity and creativity, which ensures we are constantly challenging ourselves to craft the best engineered technology solution for our customers' unique thermal processing needs.

Our capabilities span from research scale with our scientific line and Microline™ systems, pilot scale lines such as our installation at Oak Ridge National Laboratory, and full production scale plants to 3M and 4M wide and beyond, giving our clients the most comprehensive technology offering no matter what stage of commercialization they may be in. Our experience includes a variety of precursors including PAN, pitch, lignin, polyethylene, and rayon in tow, nonwoven mat, or discontinuous, loose fiber form.

From initial material handling to final product collection, working with Harper as your singular partner helps enable the most seamless and fluid plant operation possible. Harper's unique ability to integrate the many process steps in a production line ensures the most efficient performance for your organization.

Table 1: Harper's Development Complete Carbon Fiber Lines

	Scientific Line	Microline™	Pilot Line	Production Line ¹
Line Width (mm)	25	65	300	3000
Line Speeds min/nominal/max (m/min)	0.03/0.1/0.3	0.86/1.12/1.5	0.6/1.7/3.0	
System Capacity (kg/hr)	0.0326	0.428	4.2	200
Maximum Tows				
QTY	4	8	24	175
Minimum Tow Size	<1k	1k	3k	3k
Maximum Tow Size	12k	12k	24k	48k+
Ovens				
Heated Length (m)	21.95	105	154	400 - 1,000
Control Zones	6	4	4	4 to 8
Passes	6	22	22	30 - 90
Temp (°C)	300	300	300	300
Precision	+/-2.5°C	+/-2.5°C	+/-2.5°C	+/-2.5°C
Airflow Directions	Parallel	Parallel	Parallel, Cross, Down	Parallel
LT Furnace				
Heated Length (m)	0.9	2.7	3.3	12 to 16
Control Zones	3	6	4	6 to 8
Temp (°C)	1000	1000	1000	800
Precision	+/-2.5°C	+/-2.5°C	+/-2.5°C	+/-2.5°C
HT Furnace				
Heated Length (m)	0.6	2.7	3	12 to 16
Control Zones	3	6	5	6 to 8
Temp (°C)	1600	1600/1800	1800	1,450 / 1,600 / 1,800
Precision	+/-2.5°C	+/-2.5°C	+/-2.5°C	+/-2.5°C
Connected Load (kW)	113	480	1500	8,000
Nitrogen Composition (Nm ³ /hr)	1	6	150	1500
Cooling Water Consumption (kg/hr)	0	0/4200	10,000	11,000
Natural Gas Consumption (Nm ³ /hr)	0	4	60	1,500
Space Requirements LxWxH (m)	20x6x3	53 x 9.6 x 7.7	118 x 7.5 x 7.9	300 x 11 x 12

1. Production Lines are highly customized. Values listed here are for reference only.

Complete Carbon Fiber Lines - Scientific Scale

Even our smallest scale Carbon Fiber conversion line emulates real world production across all equipment, yet delivers the precision and flexibility needed to aid research efforts and future scale up. Requiring only one person to operate, this inventive system is designed to handle very few filaments - from 10 to 20 filaments up to 6k, and operates at about .15 meters per minute or .005kg per hour, as shown here (right) in this R&D system installed at Georgia Institute of Technology.



The scientific line size is ideal for precursor development and validation, as material property data can be obtained from small samples. It does not require cooling water of natural gas and uses low emissions so that volatiles can be safely vented to outdoors without abatement equipment.

Harper designs with the end in mind to help facilitate the transition to the next scale step while enabling research goals. Some examples include:

- Individual zone temperatures that mimic larger scale oven and furnace designs
- Tensioning designed similar to production systems - adjust draw rate in between oven passes and in between furnaces, even with very small tow sizes
- Ability to change air velocity in the oven for more flexibility in precursor chemistries to handle different exothermic reactions

For investment and technical configuration considerations, the system can also be designed with:

- Single or multiple dip systems for surface treatment
- Optional UHT furnace for investigation of high modulus fibers up to 2800°C
- Configuration of control system for preferences regarding remote access and data historian
- Material handling for emerging precursors including those requiring belt transportation

Complete Carbon Fiber Lines - Microlines™

Harper pioneered the Microline™ concept based on the flexibility and versatility to change and modify equipment parameters for the needs of customers in Carbon Fiber research for experimentation with traditional or emerging precursors, process tweaking and development of samples for up to 1.5 tons per year. Our system accommodates line speeds ranging from 0.1 m/min to over 1 m/min and tows from 10 filaments to 48000 filaments, enabling the study of effects of various process parameters using small amount of precursor.



The Microline is the ideal size for research and development and quality control, with continuous processing of up to 8 tows. It is highly customizable and can be configured as a complete system including oxidation ovens, LT, HT, and UHT furnaces up to 2800° C, material handling equipment, and all pre and post treatment process stages found on commercial scale plants.

Advanced design features designed to better assist in research goals and future scale-up include:

- Precise pressure and temperature data from every oven pass
- The ability to bring up to temperature and stabilize quicker
- Controls that better analyze and adjust atmosphere and off gassing conditions
- Low minimum loading point to enable research on minimal filament counts

Start-up for Harper equipment from ambient conditions takes 8 to 12 hours. Shut down can occur in a shorter time frame. To optimize the life of the equipment and minimize thermal cycling, we recommend that the LT and HT furnaces be idled at temperature for short downtime durations (i.e. over a weekend). This also optimizes power, when considering the requirements for heat-up. Harper's Pulse™ team can recommend additional operational procedures to maximize efficiency and productivity of the line based on your unique business objectives.

Complete Carbon Fiber Lines - Pilot Scale

Harper's fully integrated pilot scale Carbon Fiber systems offer features and conditions aligned with production scale systems for customers making higher amounts of material for sampling and trialing yet at smaller quantities than full scale Production Lines.

Pilot Line size systems are ideal for process optimization, as well as for producing adequate volumes of materials for market development and downstream research. Pilot Lines provide nearly identical conditions as full commercial scale lines, but with the ability to train operators without risk to commercial production, evaluate changes in processing parameters before deploying on full lines, and the ability to identify possible process issues at a smaller scale.

As an example, this cutting-edge 4.3kg per hour line installed at Oak Ridge National Laboratory's (ORNL) Carbon Fiber Technology Center (pictured right) accommodates small tow size ranges of four 12k or sixteen 3k, a minimum 48k total, and boasts a design centered around advanced Carbon Fiber piloting.



Whatever the customer's research and business needs, Harper develops fully integrated lines that support today's goals and tomorrow's scale up needs. As an example, our Pilot Line at ORNL was designed with more advanced features to facilitate the customer's alternative precursor development needs, such as:

- Three discreet airflow directions
- Driven pass-back rollers for slip-prevention at low loading
- Belt transport in Furnaces and Ovens for matted or felted product formats
- Internals with a high degree of resistance for alternative precursor use

Harper's unique ability to link the many process steps in a Carbon Fiber processing line helps ensure the most efficient performance possible, as evidenced by our leadership position in the Carbon Fiber market. From initial material handling to final product collection, working with one partner in Harper helps enable the most seamless and fluid plant operation possible. As experts in process integration, our multi-disciplined team is specifically positioned to help customers meet their specific technology goals while implementing a line maximized for performance and efficiency.

Complete Carbon Fiber Lines - Production Scale

When you've reached production scale, Harper's 3M and 4M Carbon Fiber lines are the ideal choice, focused on process effectiveness, product quality and operational optimization. Born from our years of experience in helping customers from around the world grow from fractions of kilograms per hour to tons per year, Harper's unique expertise with Carbon Fiber production equipment is in linking the process steps offering a seamless and fluid line with maximum efficiency. Our focus is on the continual advancement of core technologies, to support the growth of the Carbon Fiber market to newer and greater heights.

Harper International's fully integrated process lines include:

- Material Handling, Treatment & Conditioning
- Gas Treatment & Handling
- Advanced Control Systems
- Oxidation Ovens
- LT, HT and UHT Furnaces

Carbon Fiber Slot Furnaces

Harper is the industry standard for continuous furnace technologies for the Carbon Fiber industry, offering LT, HT and UHT furnaces rated to 1000°C, 1800°C, and 2800°C, respectively. We are proud to also be one of few who can offer UHT (ultra-high temperature) continuous furnace systems for use in the production of high modulus Carbon Fiber, primarily used in applications requiring high rigidity.

Harper's team of engineering experts makes use of innovative design techniques to navigate the difficulties of developing a system that must operate at such high temperatures for extended periods of time. Most materials used in the construction of a furnace, such as the heating elements and insulation, will be consumed as part of the reaction with exposure to such high temperatures. Harper employs its years of experience and multiple proprietary features to implement systems that perform reliably for extended periods at these elevated temperatures.

Harper Slot Furnace Design Enhancements

- Unique end-seal design delivers excellent process gas flow uniformity
- Strategic heating element design achieves optimal temperature uniformity
- Advanced insulation designs to reduce energy consumption
- Inboard and outboard louvers used to minimize ingress of air
- Proven atmosphere purge chamber designs

Harper Slot Furnace Capabilities

- Temperatures to 2800°C
- Electric or gas fired
- Carburization resistant muffle
- Easy internal access to facilitate maintenance
- Unique atmospheres (argon, nitrogen, CO₂, steam)
- Vertical HT furnaces, high modulus and other custom designs
- Multiple independently controlled temperature zones
- Fully pre-assembled and carefully broken down to minimize field installation effort

Oxidation Oven Technologies

Harper offers advanced Oxidation Oven technology to complement its industry-leading furnaces for Carbon Fiber processing. Our state-of-the-art oven designs are available for tow-bands from 300mm to greater than 4000mm. Harper's designs incorporate a multitude of improvements beyond what's available on the market today, including energy efficient designs.

Harper's most recent 3 meter wide production scale Oxidation Oven demonstrates outstanding performance for key metrics including air velocity uniformity measuring at 2.2% and temperature uniformity of $\pm 2.5^{\circ}\text{C}$ throughout the entire heated length. This innovative design enables enhanced performance with higher and more efficient rates of production.

For the customer, our technology advancements equal faster oxidation through elimination of the chimney effect, improved velocity uniformity and range, assurance of temperature uniformity at a variety of flow rates, and optimal control of the reaction ultimately enhancing fiber quality. Some of these design innovations include:

- Superior atmospheric seals
- Continuous monitoring of supply, recirculation, and exhaust flow rates
- Improved, patent-pending nozzle design
- Process based instrumentation array
- Quadrant construction for improved installation

The most distinctive feature of Harper's cutting-edge design, the innovative atmospheric end seal, reduces fugitive emissions, increases the active volume of the oven, and offers reduced energy consumption over alternatives. The seals have independent adjustment of the top and bottom inside and outside slots. Each pass has an independent vent with adjustable draw control and the exhaust plenum connects to a dedicated fan/VFD. As a result of these innovative design features, there is no vertical mixing in the seal, less air ingress, and virtually no process gas escape.

Harper's instrumentation improvements include a two-tier balancing methodology, responsive quench system and rapid cool down system, emissions monitoring, and inherently safer pressure relief system. Additionally, Harper's modular construction design is another advancement that sets us apart from the competition. Our ovens show a 90% reduction in labor versus similar field erection times into a full line pilot system (300mm).



Material Handling

We take on a comprehensive view of issues pertaining to material transport that extend beyond individual unit operations. Our expertise designing material handling, raw material through product packaging, ensures best functionality, maximizes throughput, minimizes scrap and maintains consistent product quality. Harper offers a variety of feeding and material handling solutions, including creel stations, winders, drive stands, and material conditioning such as combs, moisteners, spreader bars, bypass rollers, and centering roll systems.



Pre & Post Treatment and Material Conditioning

Harper engineers bring a wealth of experience in pre and post treatment and material conditioning using a variety of solutions. Whether traditional or emerging methods – chemical, electrochemical, plasma, or gaseous treatments – we work with your process to ensure thoughtful management of chemical preparation and minimization and treatment of the effluent solutions from the conditioning. Harper aims to design technologies that integrate seamlessly into the line and deliver on desired technical and business objectives.



Gas Treatment and Handling

Harper approaches gas treatment and handling with several objectives. Not only do our designs focus on managing emissions and treatment of off-gas in an environmentally conscious manner, we also carefully consider opportunities for energy recovery within the process.



We help customers explore expansive opportunities for efficiencies and heat and energy integration – all aimed at reduced operating expenses and garnering a competitive advantage. Harper's approach goes beyond the simple task of treating and abating from the plant and focuses on points of chemical process interface between the heat treatment and gas abatement equipment. Our expertise includes staged oxidizers, regenerative oxidizers, flares, wet scrubbers, dry scrubbers, filters, heat exchangers, condensers, and hydrogen recycling.

Fully Integrated Control Systems

From first point of engagement, Harper carefully designs a production plant with rigorous and thoughtful consideration of how the facility will be operated. Our controls group develops sequence of operations (SOP's) that drive simultaneously toward efficiency and enhanced product quality. Our fully integrated systems connect all process equipment to one centralized control system, ensuring operation is that of a cooperative plant all functioning on the same control platform.



Harper's advanced operator-interface enables simple control of temperature, alarm management, sensor calibration, program recipe storage and retrieval, archiving of data and interface to central control systems of the thermal units, as well as advanced functions such as remote monitoring and proactive predictive maintenance.

Our designs not only allow for function of the system under normal operation, but also focus on enhancements of plant safety and protective measures in transitional states. This can range from start up regimes and shut down regimes where the individual unit operations are coordinated in proper sequence to protect both the operator and equipment, to disruptive events such as exotherms and loss of utilities where multi-level security helps to manage the facility in a safe fashion.

Process Scale Up & Optimization

From spark to finish, get to market faster and more efficiently with Harper's Ignite™ process. Harper enables companies in the development of advanced materials, from the lab to full commercialization, helping make their innovations a reality. Utilizing our depth and breadth of experience in thermal processing, we partner with our customer to ensure success as they scale up their process operations.



Harper's support begins in the early stages of research and development, whether at corporate R&D centers, universities, government institutions, or start-ups. Our mission is to assist these customers in turning the next generation of material innovations into profitable new markets.

Engineering Studies

Customers count on our extraordinarily experienced engineering staff to conduct in-depth studies to determine equipment requirements and help define process parameters for optimal plant design to assist with technical and business strategy and financial planning. Our vast capabilities in thermal processing engineering studies include, but are not limited to:

- Process cost model
- Engineering of material handling solutions for unique processing systems
- Investigation of solutions for transition from batch to continuous processing
- Identification of opportunities for improved product quality and cost reduction
- Economics of increased production capacity with current and future state technologies
- Analysis of best-suited thermal process technology system for new material innovations

Piloting Facility

Unlike any other provider, Harper offers its continuous Carbon Fiber pilot process line in Portugal as an open reference and capabilities demonstration to select Harper clients. This facility includes Harper's proprietary multi-flow oxidation ovens, advanced LT and HT slot furnaces rated for 800°C and 1800°C respectively, surface treatment and waste gas abatement systems, and winders.

Here, Harper clients can utilize the facility for their Carbon Fiber process, confirmation of material quantities to enable downstream research, assessment of feasibility of continuous operations, and validation of design parameters for further scale-up.



Offering a complete solution for your process plant, from material handling to final product collection and everything in between, Harper is focused on helping customers link the process steps to achieve greater efficiencies in reduced operating costs, increased quality and productivity, and strategic risk mitigation. From first point of engagement, Harper rigorously designs thoughtful operations sequences that ensures a comprehensive perspective is maintained.

Comprehensive Service & Maintenance

Harper's comprehensive Pulse™ team service offers one-call technical support, domestic and overseas field service, proactive preventative maintenance programs, fast-turnaround genuine replacement parts, and engineered solutions for a broad spectrum of your service and maintenance requirements.



The Pulse team brings a passionate, collaborative and innovative focus nurtured by years of process technology know-how to bring timely and practical solutions to the most difficult challenges.

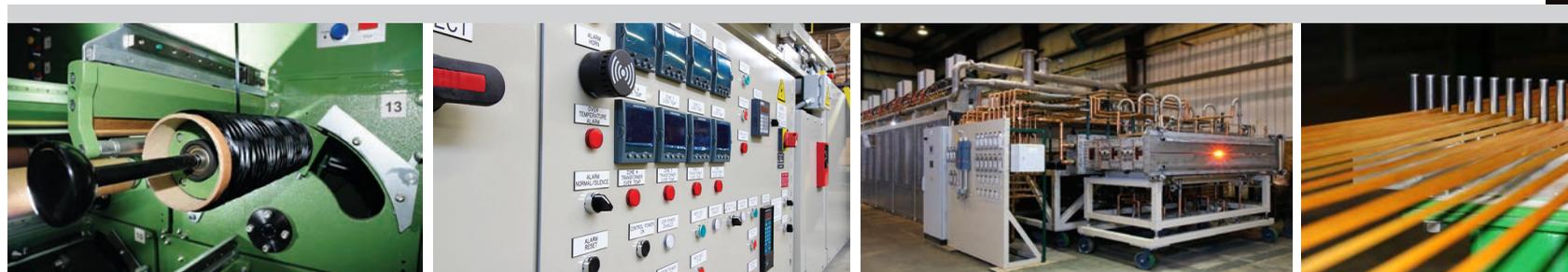
With the demands of today's competitive business environment and ever-escalating downtime cost, timely replacement with quality parts is a must. Our experienced engineers and technical specialists will collaborate with you to identify the optimal replacement parts or design solution to meet your needs. Our team is also available for consultation on any aspect of our process technology equipment from installation through operations, troubleshooting and general maintenance support.

Visionary customers appreciate collaboration with the Pulse team of experienced engineering professionals to develop innovative solutions to a number of diverse technical and engineering challenges ranging from upgrading equipment for process or production optimization, energy management or to increase reliability and performance. Harper also provides enhanced control systems, instrumentation and technologies tailored to meet the stringent control requirements and specialized needs of emerging technologies and complex applications.

Innovations in Alternative Precursor Processing

Although Carbon Fiber is predominantly produced from polyacrylonitrile (PAN) and pitch, there is an increasing necessity for alternative, low cost and renewable precursors as the industry grows to applications such as use in the automotive industry. Harper has the unique ability to adapt our technology to process nontraditional precursors throughout the entire thermal process. By using nontraditional precursors such as lignin, rayon, polyethylene, and blends, customers can lower their operation costs and reduce the residence time in the oven.

To custom engineer the equipment for unique process needs, we take into consideration the chemistry of the precursor to determine the materials of construction. Whether the precursor is unsupported by its weight requiring a belt furnace or is a tow, Harper provides solutions for these emerging precursors throughout the full process. We have designed our equipment to be able to produce these emerging precursors throughout all line sizes, from research to production scale, demonstrated in our complete line installed at Oak Ridge National Laboratory's Carbon Fiber Technology Center.



Our client testimonials speak for themselves. The relationships that we form with our customers, based on confidence, collaboration, and mutual success, are what have made us one of the world's foremost providers of thermal processing solutions for advanced materials. But don't just take our word for it – read what real customers have to say about Harper...

"Right from the very first meeting, Harper's engineers demonstrated a high level of enthusiasm that was key to Applied NanoStructured Solutions' successful development of unique solutions to meet the challenge of bringing a new technology to market. We were especially pleased with Harper's high level of professionalism, focus and availability during the entire project."

Harry C. Malecki
Manager, Research & Development
Applied NanoStructured Solutions LLC
A Lockheed Martin Company

"Harper's Microline™ installation supervision and start up supervision was one of the highlights of our operations. Harper made a serious effort to make it a smooth and efficient process."

Luciano Pagano Jr.,
Head of Operation
CTMSP

"Harper's ultra-high temperature (UHT) graphite furnace system has been rock solid in its performance. With the potential challenges a system that operates at 2500°C can offer, Harper's design has been dependable, consistent and reliable since 2006. With minimal rebuild and operation at 2500°C, the system remarkably still has original heating elements and graphitic parts, which would normally degrade quickly at such high temperatures. The furnace is used for process development of multiple applications and it has proven versatile for this purpose."

Nicholas Gagliardi
Composite Research Engineer
University of Dayton Research Institute (UDRI)

"The Harper Pulse group's outstanding performance on our recent HT Furnace upgrade and rebuild was key to a successful project that will deliver savings for our company's bottom line. Across our many experiences with Harper's team, we have seen that they share the Cytec vision for safety and quality of work, along with an urgency to get production systems back in operation. With their strong technical and operational support, we completed the project ahead of schedule, below budget, and reduced the total downtime for this equipment, ultimately delivering significant savings in capital expenses and an increase in revenue through additional uptime of the production line."

Simon C. Harvey
Operations Manager
Cytec Carbon Fibers

"Harper is very innovative. They have provided excellent, intuitive service, looking ahead into the future as to what we might need."

Timothy A. Dye
Engineering Manager
Toho Tenax America

"The quality of the major equipment and design solutions reveal a very accurate care and a systematic approach to boost performance."

Jose Miguel Contreiras
Commercial Manager / Board Member
FISIPE



Thermo. Dynamic.™

Harper International is a global leader in complete thermal processing solutions and technical services essential for the production of advanced materials. From concept to commercialization, from research scale to full production line operations, Harper is perpetually on the cutting edge. For decades, we have pioneered some of the world's most innovative, customized systems, with a focus on processing materials at high temperatures and in non-ambient atmospheres.

Harper's philosophy is not only to deliver comprehensive systems with the latest technologies, resulting in distinctive solutions, but also to design features that ensure the most efficient and effective operations to support our customer's growth. Whether it's optimized waste gas treatment, control systems with predictive maintenance, or energy efficiency techniques, Harper always has the complete solution in mind.

Of course, saying we're the partner for you doesn't get the job done — we're eager to prove it.

"There's nothing standard here at Harper, almost everything we do is one-of-a-kind."

*– William Stry Ph.D.
Senior Process Technology Engineer*



"In the field we work one-on-one with everyone, from the site supervisor to the contractors, to the engineers and the project manager."

*– Renee Bagwell Ph.D.
Senior Process Technology Engineer*

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