Novel Oxidation Oven Technology for the Next Generation of Carbon Fiber Manufacturing

GOCarbonFiber

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About Harper

- Headquartered in Buffalo, NY
- An Employee-Owned Company
- State-of-the-art Technology Center
- Access to carbon fiber piloting facilities
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration



About Harper

-> Established Leader in Thermal Processing Systems

-> Key Partner in Carbon Fiber Scale Up

Primary Technical Focus:

- New / Challenging / Advanced Material Processing
  - 200°C – 3000°C
  - Batch and continuous processing
  - Precise atmospheric controls
  - High purity requirements
  - Complex gas-solid interactions

HT Furnace

Agenda

1. How insights gained from advanced CFD modeling and full-scale testing can guide design improvements
2. How utilities for Ovens, as the highest energy consumer in the carbonization process, can be optimized for flexibility and performance
3. How modular designs can offer improvements to typically long lead time installations

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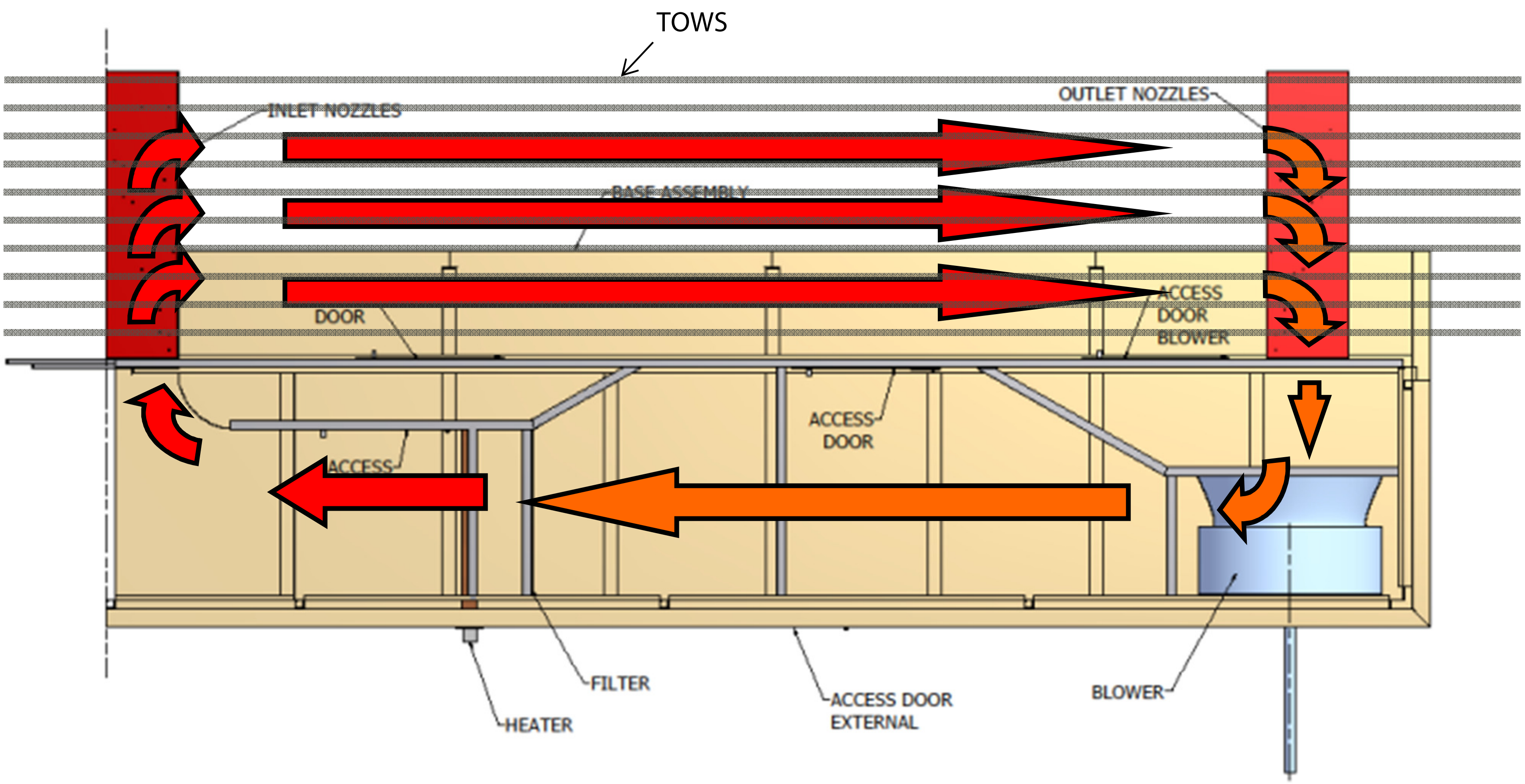
1: How insights gained from advanced CFD modeling and full-scale testing can guide design improvements

- Air velocity uniformity is considered critical in PAN stabilization ovens
  - It is essential to get the same CF properties across the towband
  - PAN stabilization is an exothermic reaction – if there are low velocity regions the reaction can run away
  - PAN fiber is somewhat delicate – if there are high velocity regions it can cause filament damage

Oxidation Oven Design Challenges

- Higher production rate CF lines have led to wider, taller, and longer ovens
- New CF composite applications have expanded the number of CF specifications
- *A critical design challenge is to improve velocity uniformity while simultaneously increasing the oven size*

Typical Air Recirculation Path
Parallel Airflow Oxidation Oven



TOP VIEW

Design Approach for Oven Airflow Control

- Bench scale air velocity testing
- CFD modeling
- Full scale oven testing

Bench Scale Inlet Nozzles Test Setup

3 to 5 Nozzles; 1 - 3 meters wide

Velocity probes

Nozzles Used in a 3000mm Wide Oven

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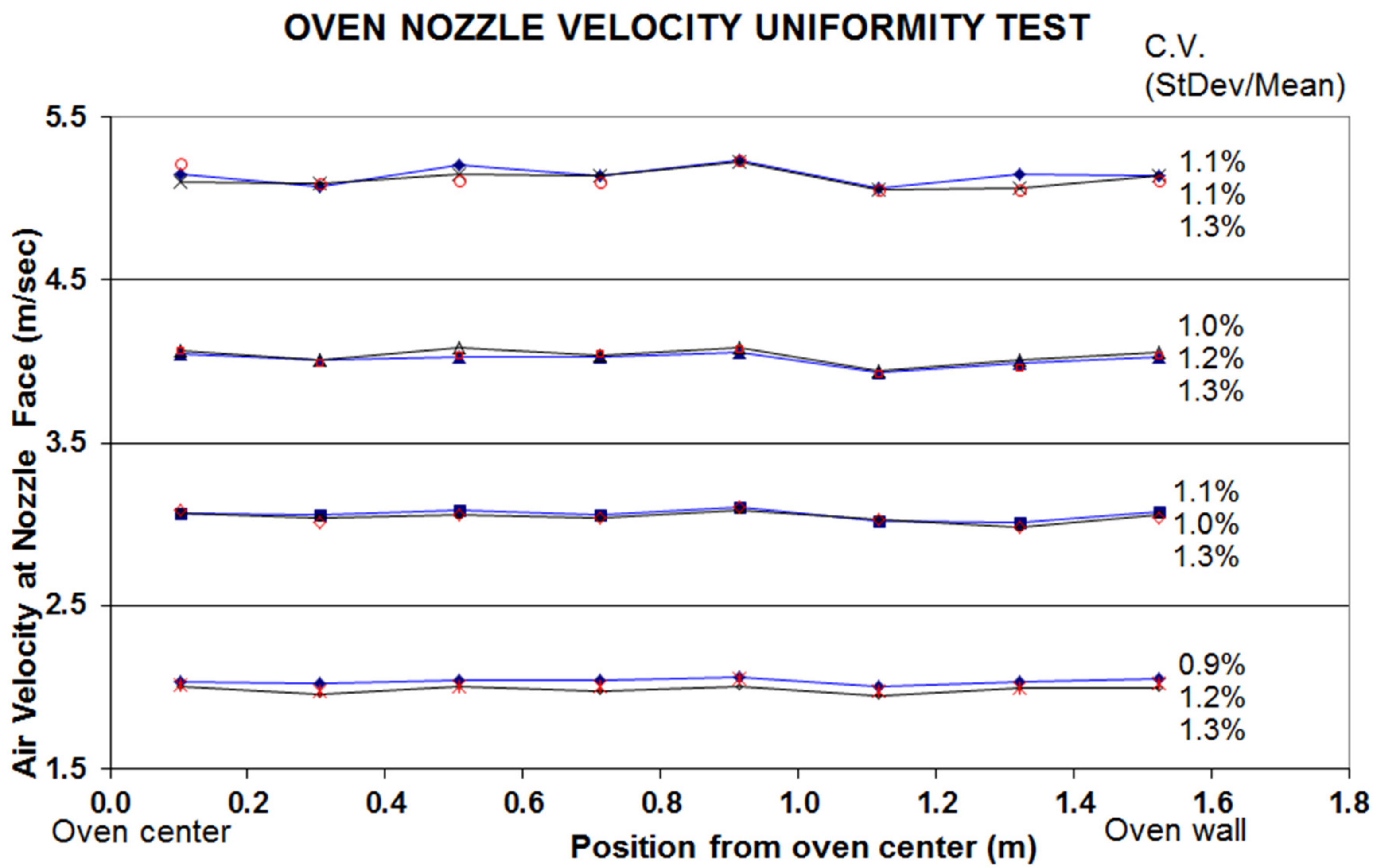
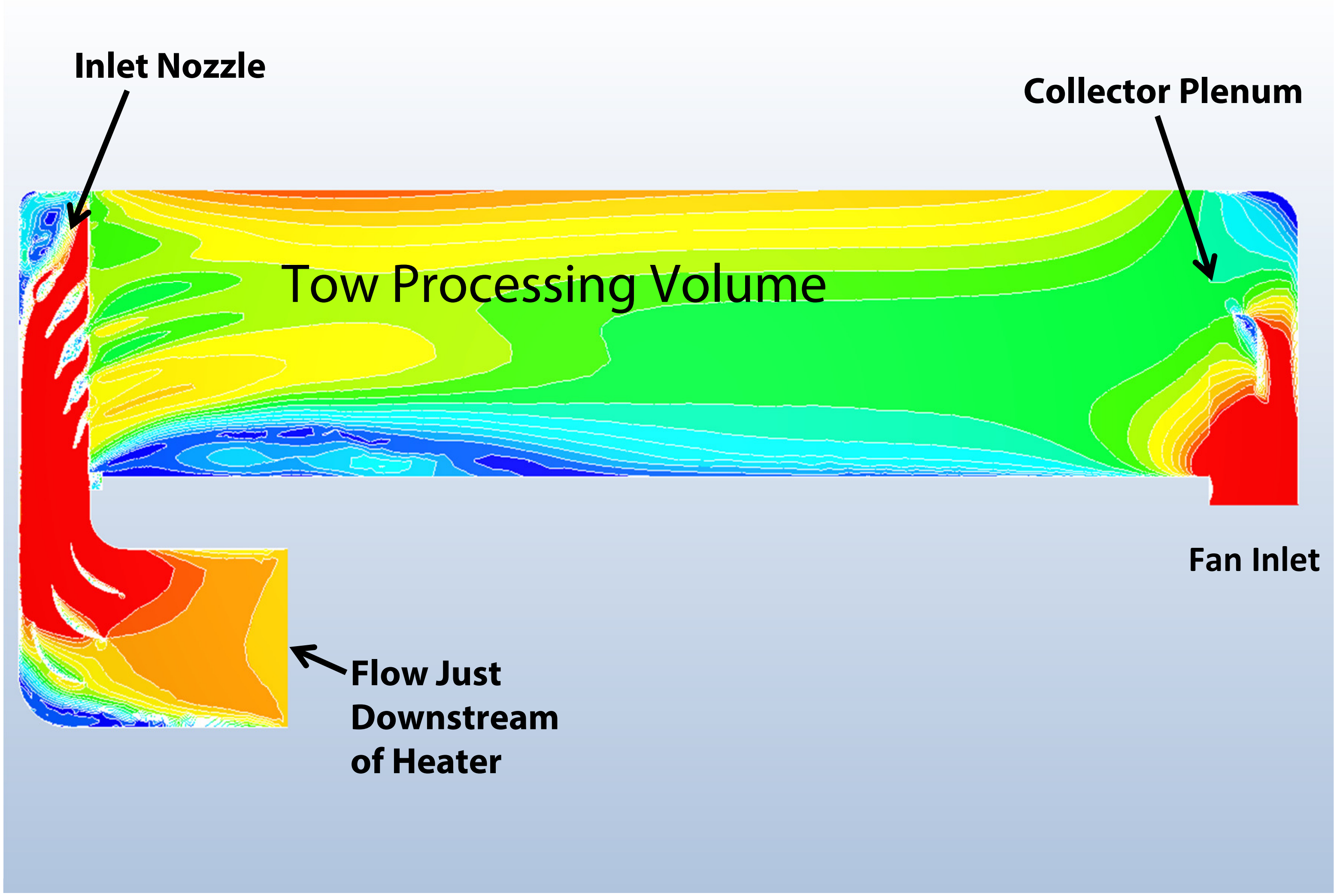
Air-Flow Measurements –
Bench Scale Nozzle Example Data



CFD Modeling of Air Velocity



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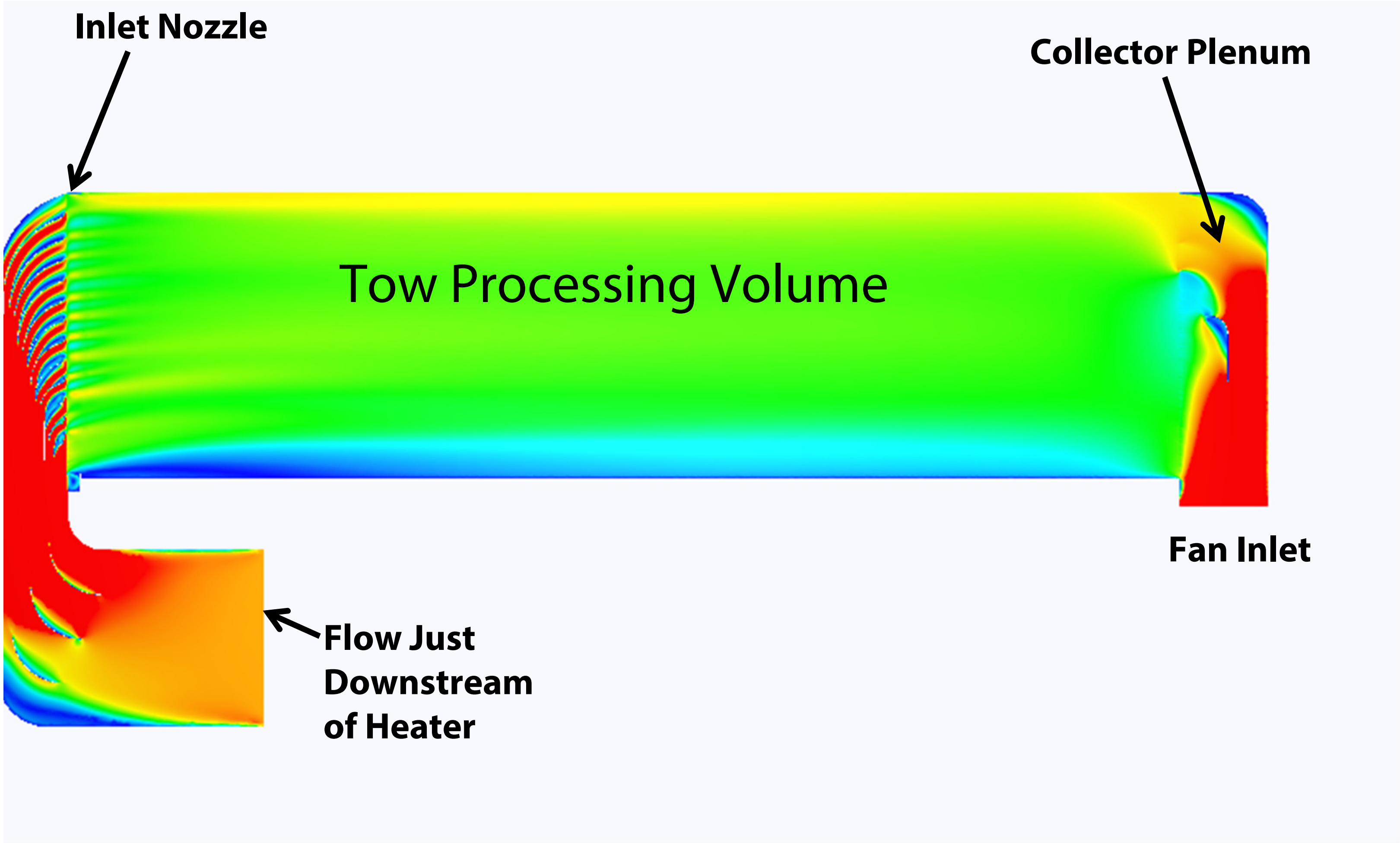
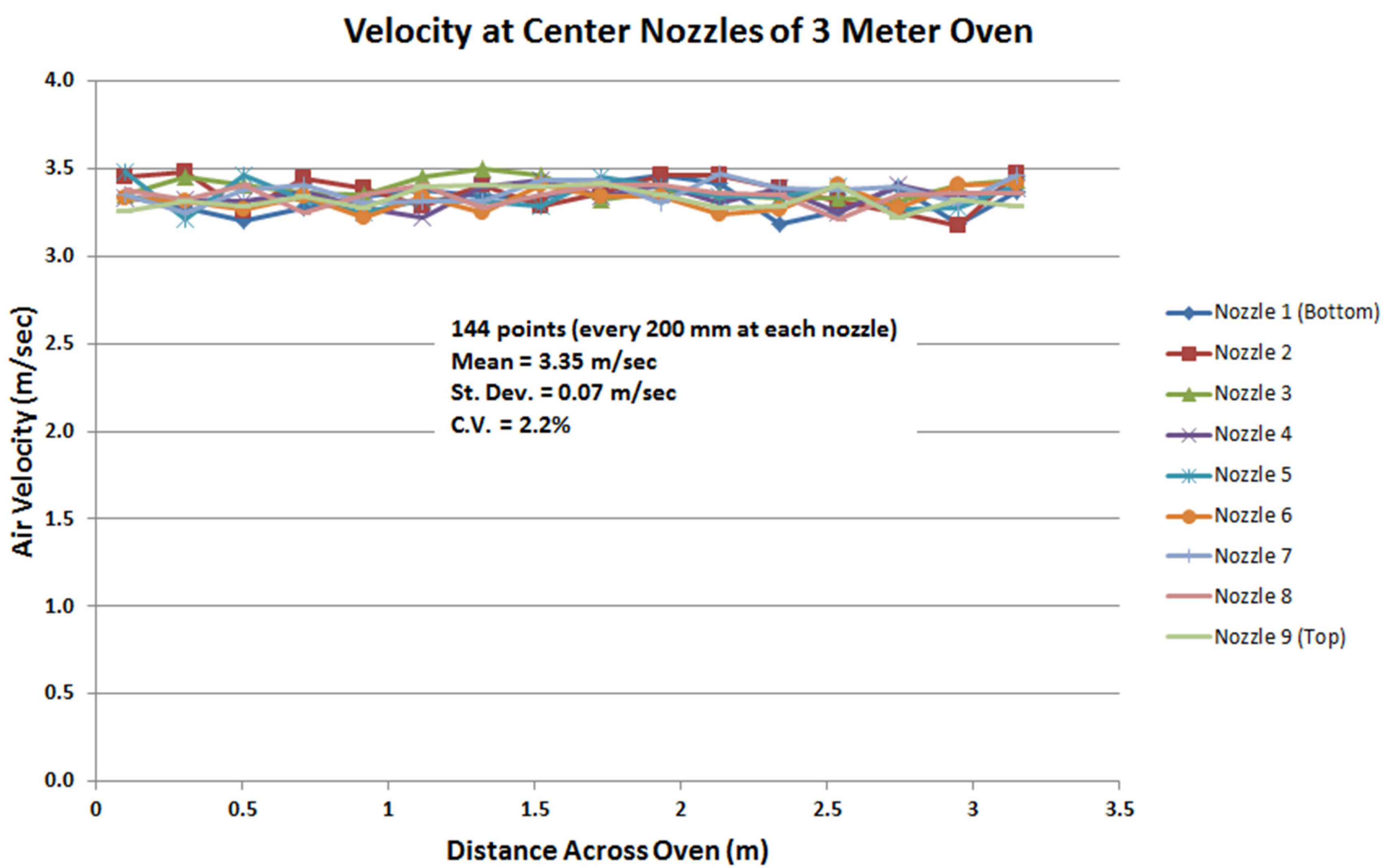


Testing - Production Scale Oxidation Oven

- 3 Meter Width
- 300 deg C Max
- 14 Meter Pass Length
- 2 to 4 m/sec Air Velocity

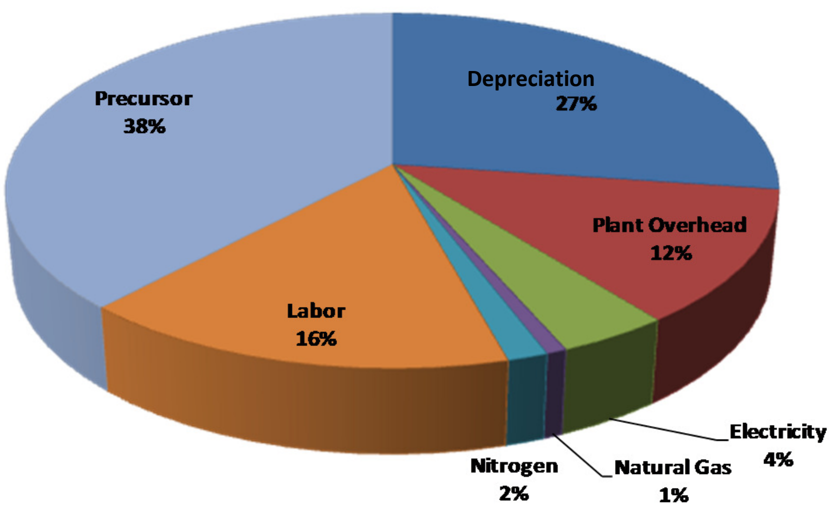
Velocity Uniformity



2: How utilities for ovens, as the highest energy consumer in the carbonization process, can be optimized for flexibility and performance

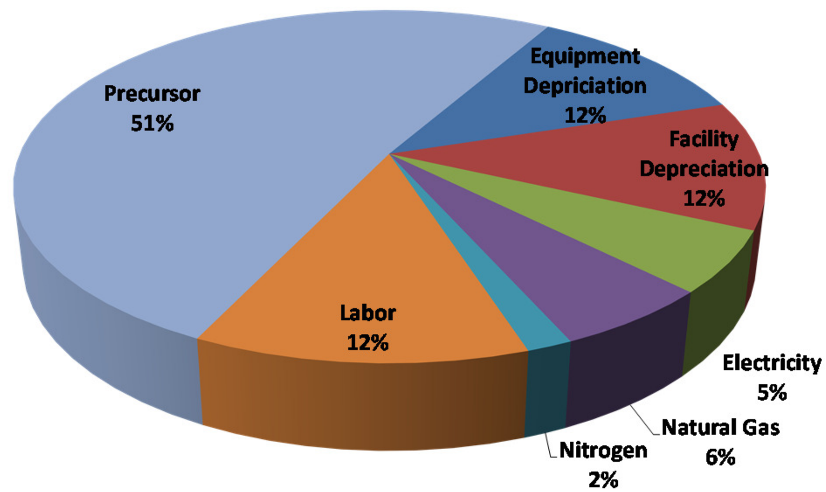
- Brief review of energy costs
- Options for CF oxidation ovens

Utilities account for anywhere from 7 to 13% of manufacturing total costs. This is only for the carbonization line.



NEXANT Cost Model

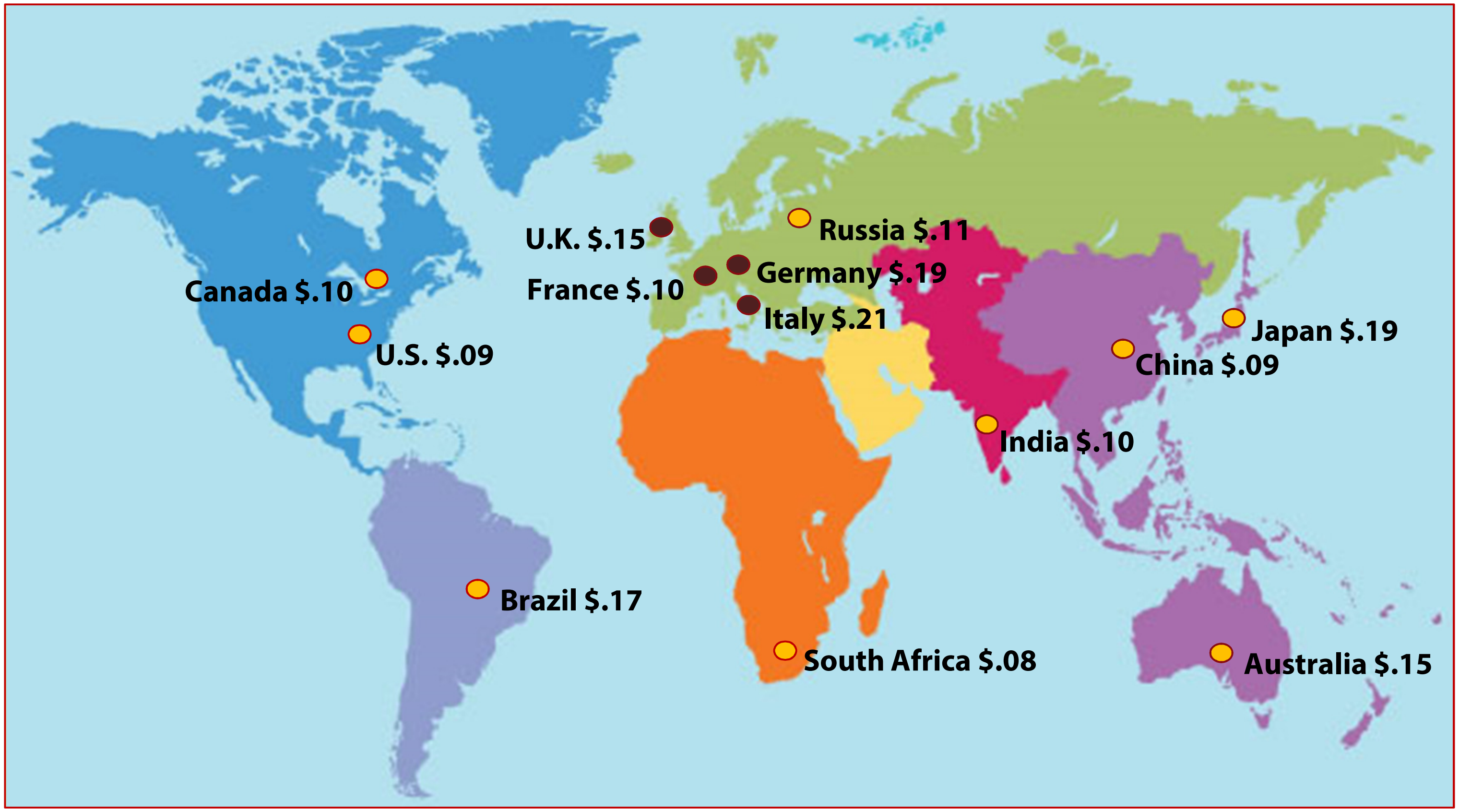
Nexant Inc. ChemSystems Report 2013



Harper Cost Model

Global Electric Prices

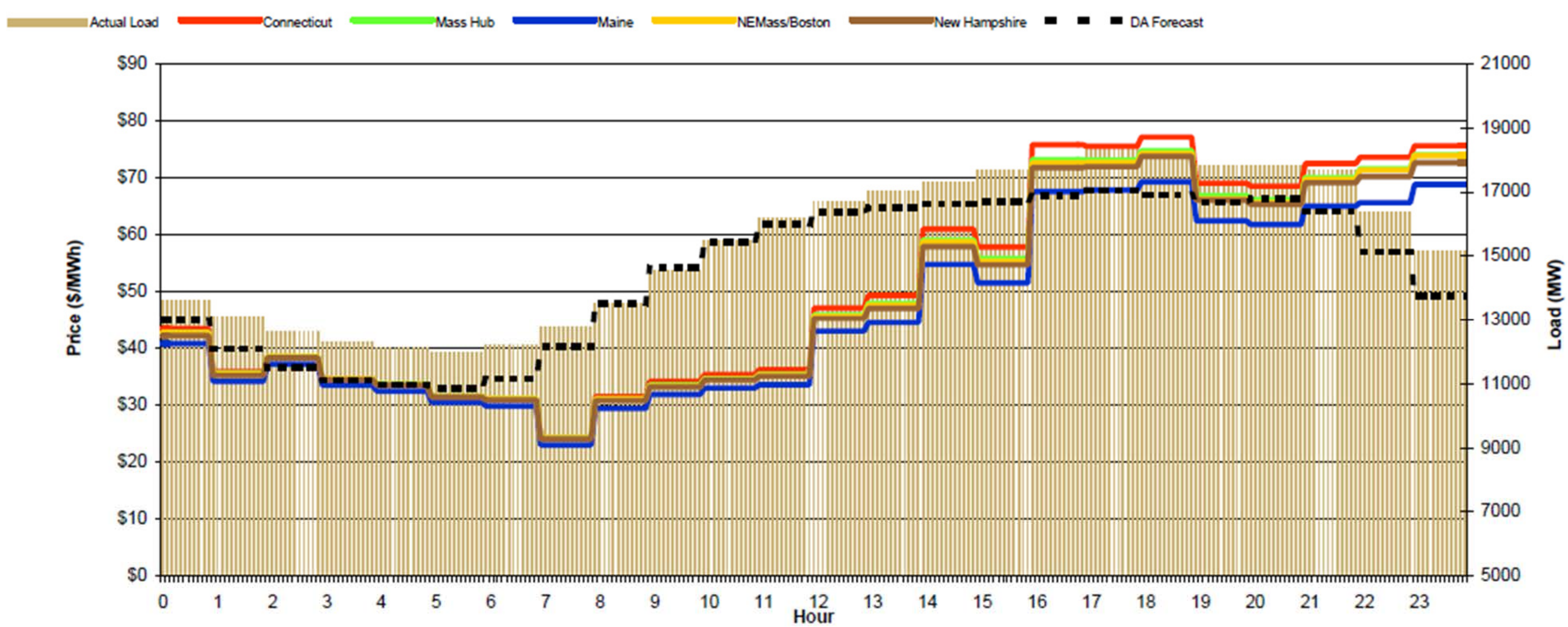
Estimated 2014 Industrial Electric Prices (Cents/Kwh)



Sources: IEA, EIA, OANDA

Electrical Fluctuations

Utilities costs fluctuates during the day
and throughout the year



Source: http://www.ferc.gov/market-oversight/mkt-electric/isone/isone-iso-archives.asp

Global Gas Markets

World LNG Estimated November 2013 Landed and Hub Prices ($US/mmbtu)

	Production (bcm)	
	2008	2035
Russia	662	881
Iran	130	279
Turkmenistan	71	136
Canada	175	192
United States	575	779
Norway	102	127
Australia	45	155
Qatar	78	260
Indonesia	74	119
Nigeria	32	119
Algeria	82	168
Latin America Total	148	292

	Reserves (bcm)
Mozambique	2825
Tanzania	565
Israel	407

Source: IEA, FERC

Observations

- Utilities are a major cost factor in Carbon Fiber production
- Global utility prices are highly unpredictable and demand changing
- Volatility evident on all continents
- Pressure persists for further cost savings to support automotive and aerospace applications

Conclusion

- Minimizing risk through equipment design brings short and long term benefits

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Oxidation Ovens – Gas or Electric

Ovens require approximately 8 to 15 times the energy of an LT system - it is the energy hog of the carbonization line. Therefore…

Selecting the best value in energy is critical for long term success.

Potential Utility Saves with Gas Fired Oven

Per Oven zone potential savings with Natural Gas

	Unit Cost	Consumption / Year	Yearly Cost
Natural Gas	0.02 $/kWh	3,800,000 kWh	$81,000
Electric	0.07 $/kWh	3,200,000 kWh	$227,000
	Savings per Oven with Natural Gas		$146,000
	Savings with six Ovens zones		$876,000

*Assumes 7200 hrs/year operation,
US Prices for calculation

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Hybrid Powered Ovens Utilize Gas AND Electric Heating

- Oven has both fuel fired heaters and electric heaters
- Can use both at once for fast heat up
- Can use either / or once at steady operation

Indirect Gas Fired Heater

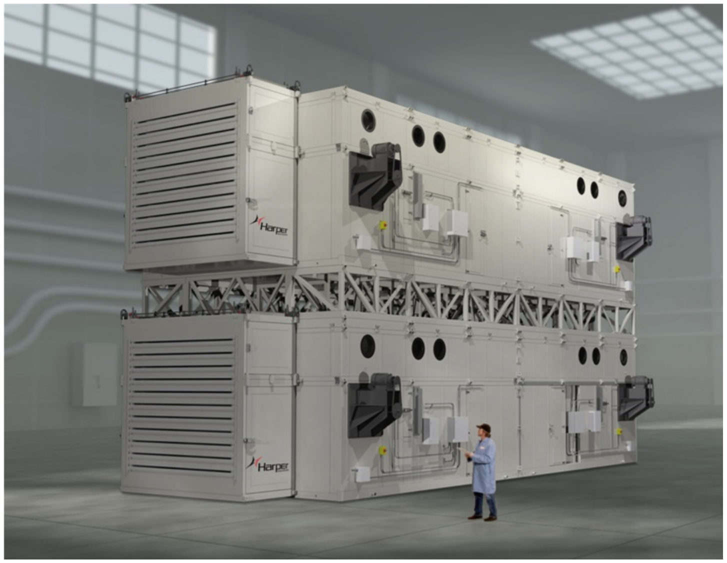
Electric Heater

Why Hybrid Ovens?

a. Increased availability from shorter start-up time

b. Flexibility to select fuel or electric based on real-time cost

c. Part of a universal plant (anywhere in the world)



3: How modular designs can offer improvements to typically long lead time installations

- Larger scale CF lines create shipping and installation challenges
  - Example: One 3-meter carbonization line requires over 60 truckloads (>100 ocean containers)
- Installation and interconnection to utilities involves managing thousands of labor hours encompassing multiple skilled trades

Shipping and Installation Lead Time

Two concepts for improving the situation:

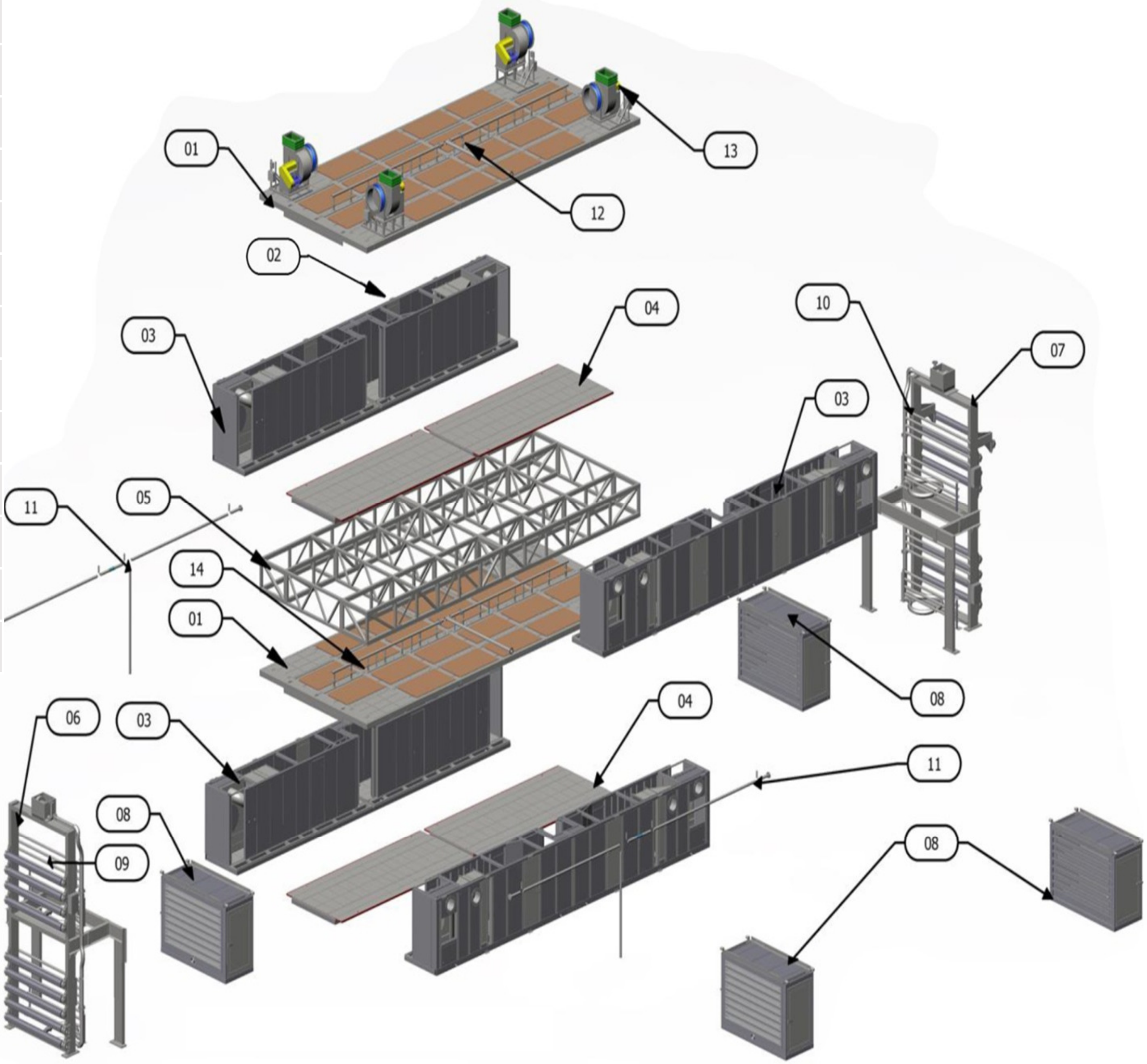
- Modular Construction
- Electro-Mechanical Integration

Modular Construction

- Truck (or container) sized, fully assembled building blocks
- Truck (or container) sequencing
- Minimum field welding

Modular Assembly of Ovens

No.	Description	QTY
01	ROOF	4
02	QUADRANT A	4
03	QUADRANT B	4
04	FLOOR	2
05	CTR SUPPORT	1
06	ROLL STAND A	1
07	ROLL STAND B	1
08	END SEAL	4
10	NOZZLES	2
11	WATER PIPING A	2
13	EXHAUST FANS	4
12	WATER PIPING B	2



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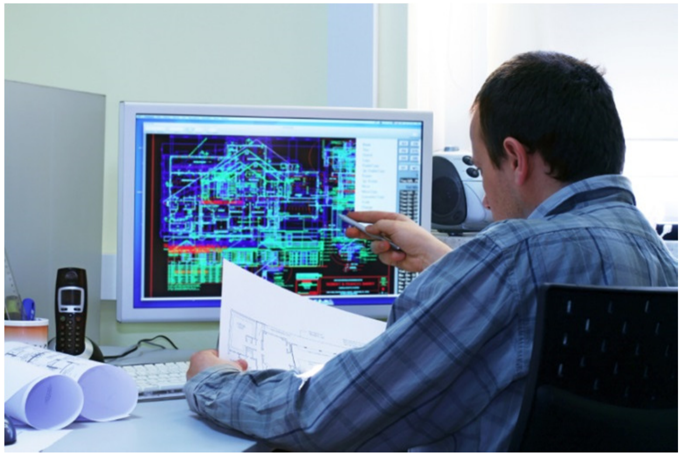
Electric – Mechanical Integration
- Preinstalled / Pre-Tested Instruments

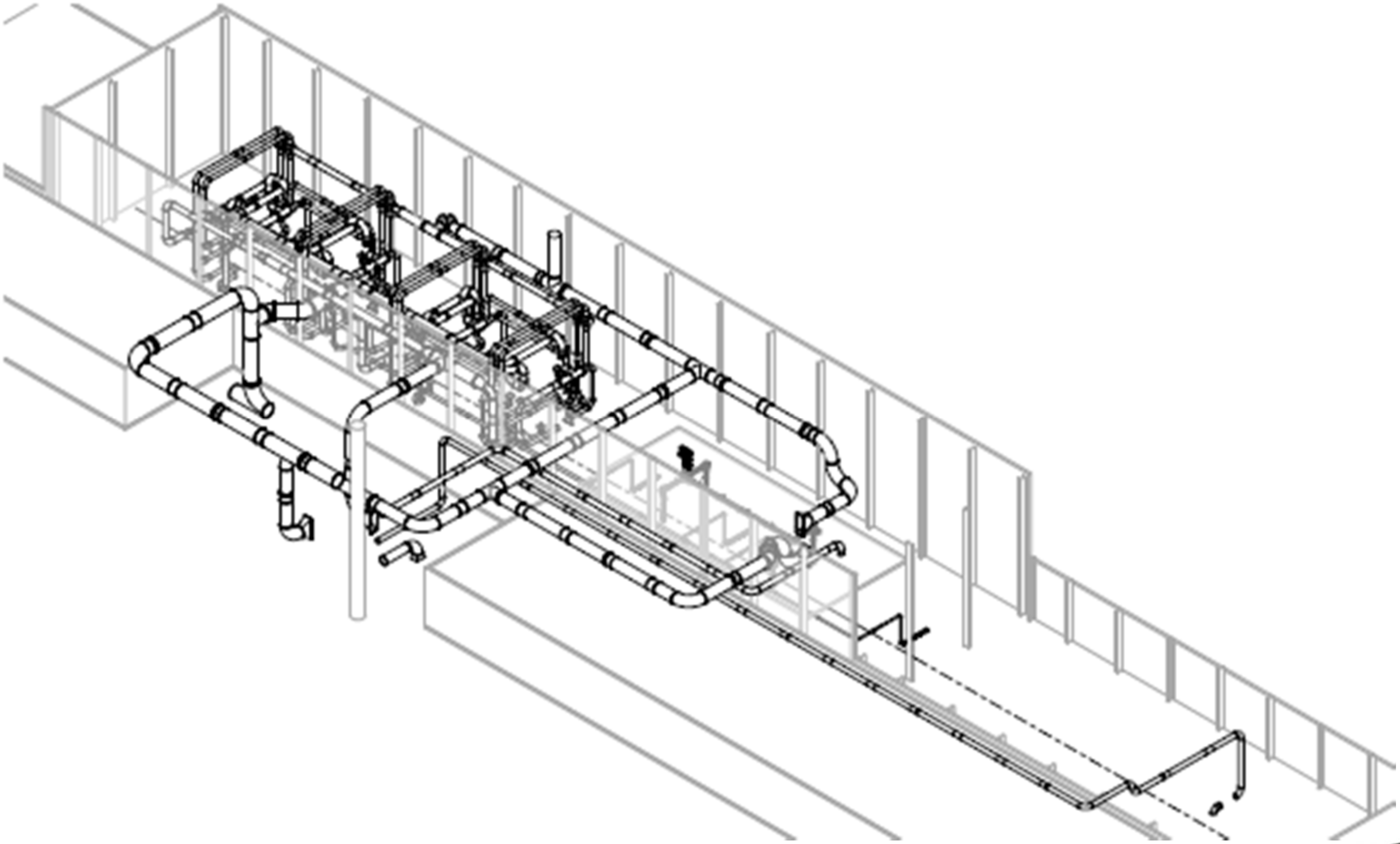
Electro-Mechanical Integration

- Factory installed and tested instruments, cabling, and conduit
- Smart junction boxes with Ethernet nodes
- Interconnection cabling (low voltage) becomes essentially one Ethernet ring



Electro-Mechanical Integration

- Pre-design of Interconnection piping
  - Utilize 3D models of plant and equipment
  - Pipe supports and tie points pre-defined



Final Thoughts

- Oven velocity can be very uniform even in large scale systems
- Energy cost reduction potential exists using fuel fired systems or hybrid fuel/electric systems
- Installation and interconnection costs can be reduced via modular oven construction and electro-mechanical integration

Thank you for your time!
We welcome any questions…

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