Carbon Fiber Line Capacity

Historical Perspective

Carbon Fiber Systems
Industry Trends

- 35 Year History in the Carbon Fiber Industry
- First System 1973 still in operation, 36" Wide (915mm)
- First system > 1m 1978 40" wide (1015mm) with 2 out of 3 systems still in operation today
- 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 (Today >12 systems @ 3000mm wide)

> 100 Units Carbon Fiber Projects to date

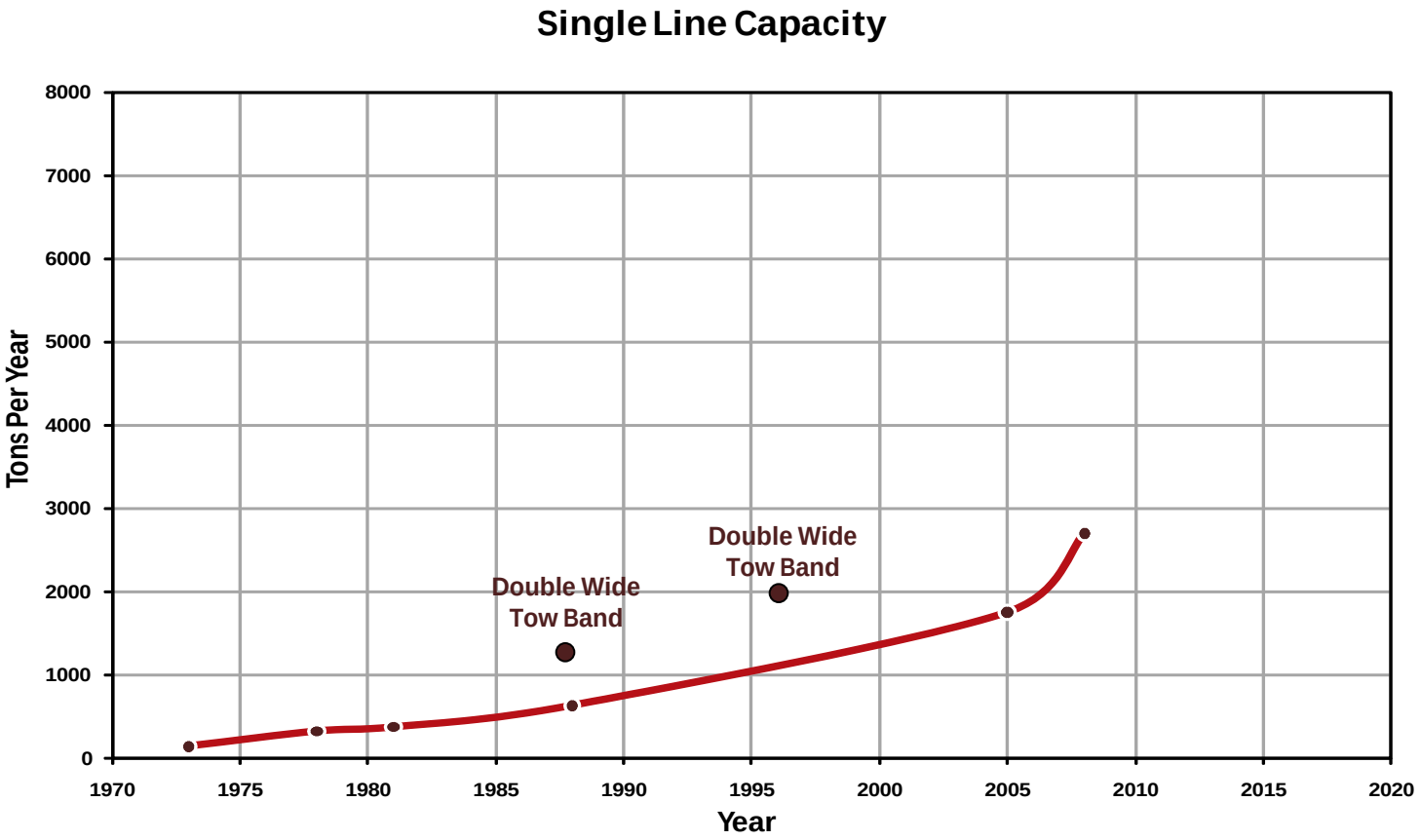
Carbon Fiber Systems Industry Trends

Year	Width (mm)	LT Length (mm)	HT Length (mm)	Line Speed* (m/min)	Capacity* (TPY)	Notes
1973	915	5488	2744	2.7	140	
1978	1016	8232	5488	5.5	320	
1981	1169	8232	7317	5.5	370	
1988	1677	10671	6504	6.5	630	
1988	3354	10671	6504	6.5	1260	Double Wide
1997	4141	13516	10239	8.3	2000	Double Wide
2005	3049	14278	10290	9.9	1750	
2008	3049	14278	14050	15.3	2700	

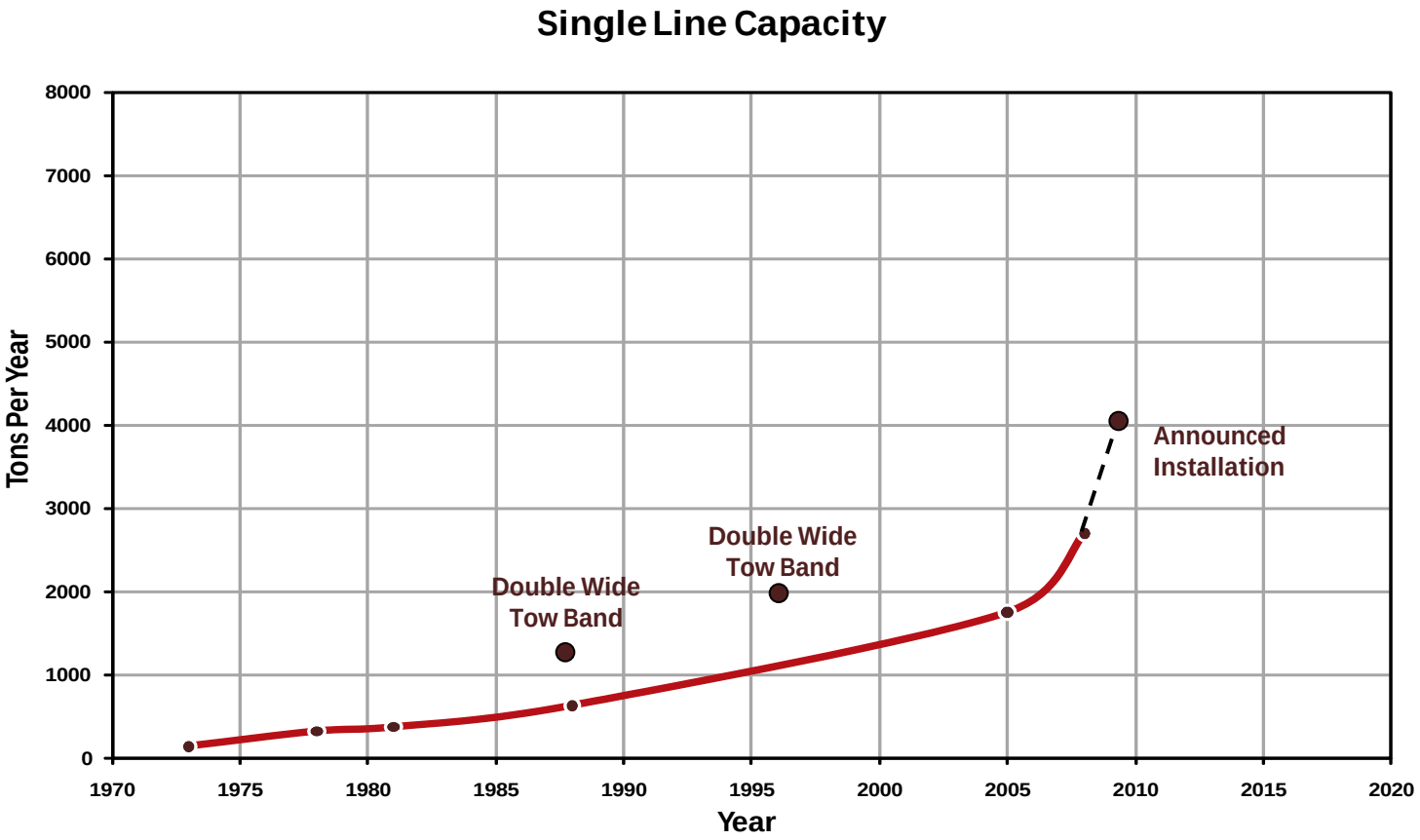
* Capacity and Line Speed have been calculated based on assumptions of:

- 24k Fiber on common Pitch Spacing
- Common LT Retention Ranges Times
- Common HT Retention Ranges Times

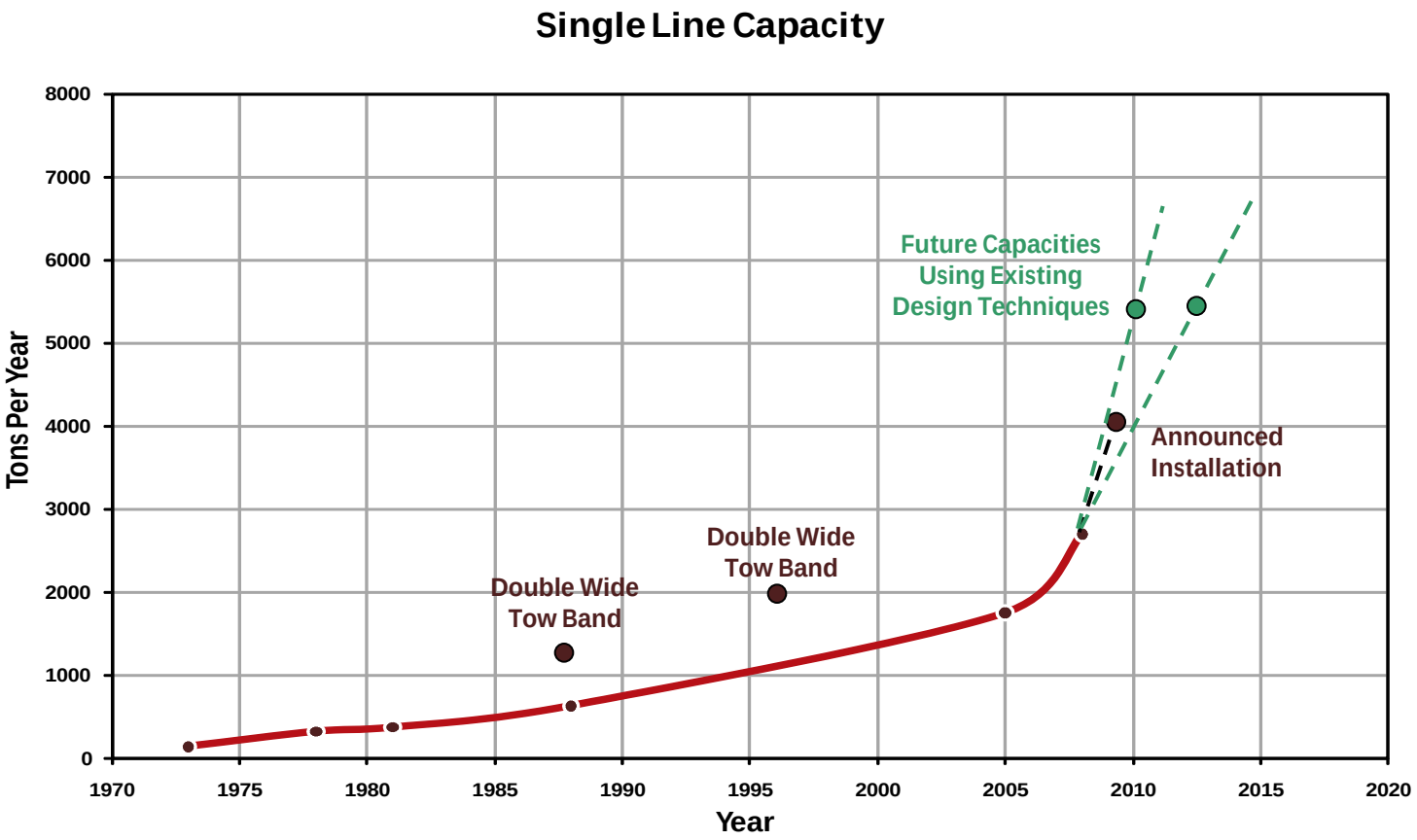
Carbon Fiber Systems Industry Trends



Harper International Led Industry Trends



Carbon Fiber Systems Industry Trends



Carbon Fiber Systems
Industry Trends – Economy of Scale

Production	mTPY	2000	4000
Capex	USD	X	<1.5X
Depreciated Cost	USD/kg	$3.62	$2.72
Power	kW/kg	36.5	30.3
<	kW/h	10125	16825
NG	Nm3/h	400	700
Opex	USD/kg	$6.12	$5.11
Cost of Production	USD/kg	$9.74	$7.82

Notes:

- Electricity assumed to be $150 / MW
- Natural Gas assumed to be $37.50 / MW and 12 kW / Nm3
- Straight Line Depreciation of Capital
- Estimate Exclusive of factors such as Nitrogen, CW, Maintenance, etcetera

Carbon Fiber Systems
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10% - 20% Savings in Cost of Production

Through Reduced CAPEX and OPEX

Carbon Fiber Systems

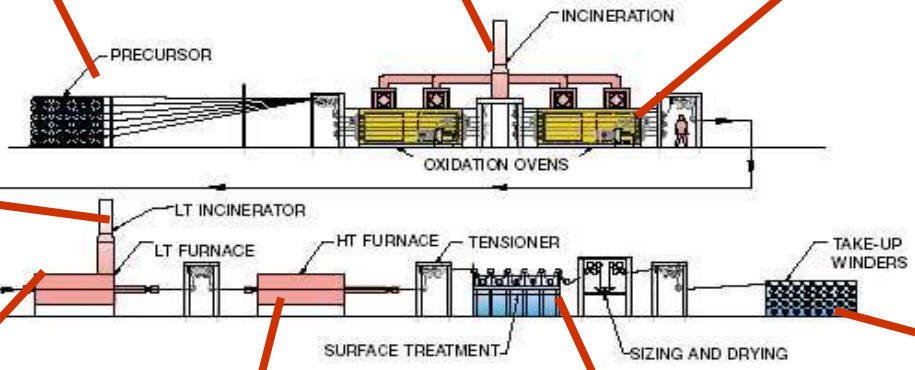
Cost Modeling

Manufactured By / Supplied Through Harper

Courtesy of Texkimp

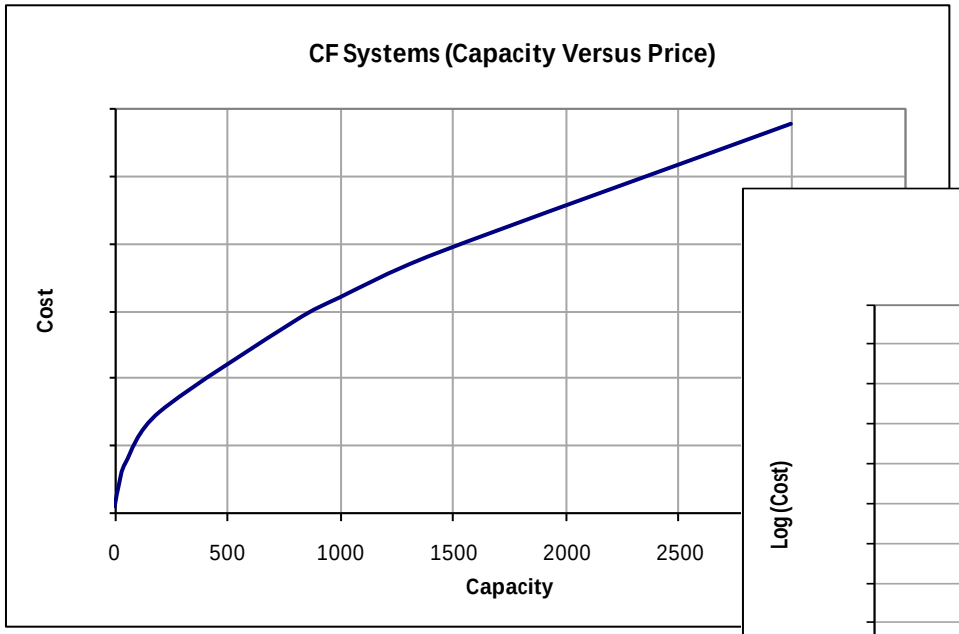
Courtesy of PCC

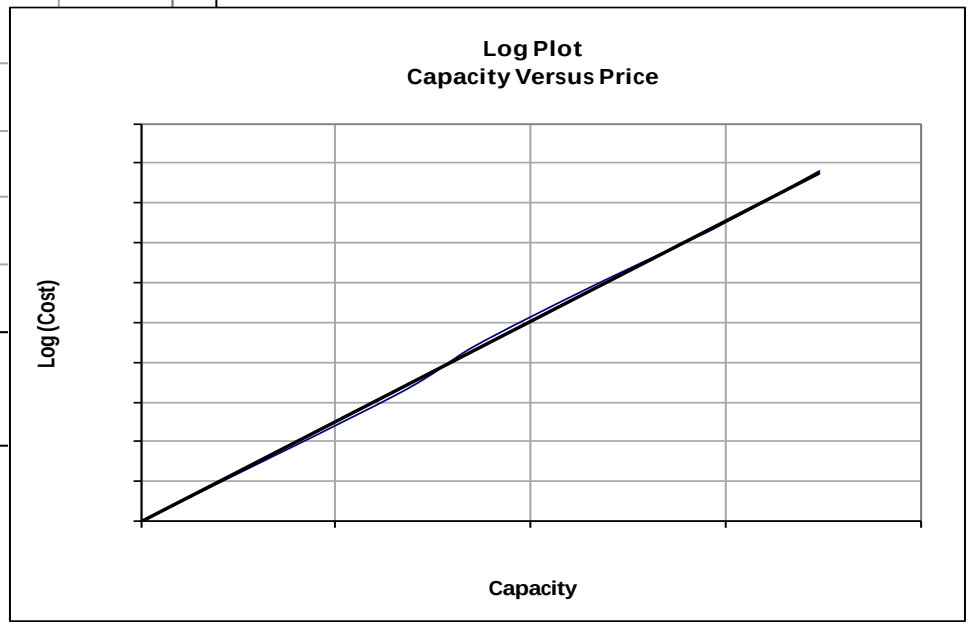
Courtesy of PCC



Courtesy of Sahm

Carbon Fiber Systems
Cost Versus Capacity





Extension of data set through (<>10) multiple data points

Cost Model Basis

Can a more accurate cost model help guide decisions about the format of 'future' / next generation line capacities?

What will serve as the basis for the cost model?

Involves making assumptions about cost drivers for each unit operation

Carbon Fiber Cost Model Refinement

Detailed Modeling of Cost and Utility Consumption of each Unit Operation:

- Oxidation Ovens
- LT Furnace
- HT Furnace
- Surface Treatment
- Winders

Carbon Fiber Cost Model Refinement

Power Factor Modeling of:

- Thermal Oxidizer
- Creel
- Driers
- Infrastructure

Carbon Fiber Cost Model Refinement

Also has involved estimation of:

- Developmental & Project Engineering
- Cost of Production of Nitrogen
- Infrastructure
- Manpower (large area for variability)

Exclusions:

- Maintenance Costs
- Cooling Water Consumption
- Peripheral Material Handling
- Others…

Carbon Fiber Cost Model Refinement

- Nitrogen Consumption F(x) = width, capacity (mtpy)
- Oxidation Oven Exhaust F(x) = width, length, height
- Oxidation Oven Power F(x) = width, length, height, capacity
- LT Power F(x) = width, length, height, capacity
- HT Power F(x) = width, length, height, capacity
- Thermal Oxidizer F(x) = Exhaust Flows, Nitrogen Consumption
- Energy Recovery F(x) = Exhaust Flows, Recovered Air Temp
- Drier Power F(x) = line width, capacity
- Surface Treatment F(x) = line width, capacity (velocity)

- Most equations well fit (linear fit with $R > 0.98$)
- Based on Multiple Data Point

Carbon Fiber Cost Model Refinement

Oxidation Retention Time:	60 Minutes – 120 Minutes
LT Retention Time:	60 Seconds – 120 Seconds
HT Retention Time:	60 Seconds – 120 Seconds
Surface Treatment:	Oxygen Content
Washing & Drying:	Drier Type
Sizing & Drier:	Drier Type
Winders:	Largest Tow, Package Size
Thermal Oxidation:	Ox Ovens, LT Gases, HT Gases
	Energy Recovery
	RTO, Incineration, Direct Discharge
	NOX Levels, HCN, NH3

Carbon Fiber Cost Model Refinement

Model Inputs:

- Capacity, Tow Size, Tow Spacing
- Unit Operations Present
- Retention Times
- Winder Positions
- Energy Recovery, Recovery Temp.,
- Nominal Energy Consumption (%),
- Hours per year operating (up-time),
- Cost of Electricity, Natural Gas,
- Cost of Labor, Cost of PAN
- Years depreciation (equipment, infrastructure),
- Cost of Nitrogen,
- Creel Size, Package Size,
- Carbon Recovery,
- Equipment Dimensions,
- Type and Quantity of Process Off Gas Technologies
- etcetera…

Carbon Fiber Cost Model Refinement

Model Inputs:

- Capacity, Tow Size **(12k)**, Dtex, Tow Spacing **(6mm)**
- Unit Operations Present **(Creels to Winders + Tensioning)**
- Retention Times **(90 Minute Oxidation, 90 Sec LT, 90 Seconds HT)**
- Winder Positions, Heat Recovery **(Yes – 75% Efficient),**
- Recovery Temp **(350C),**
- Nominal Energy Consumption **(75%),**
- hours per year operating (up-time) **(7000 hours per year),**
- Cost of Electricity **($0.05/kWhr),** Natural Gas **($0.10 / kWhr equiv.),**
- Cost of Labor **($100,000 Per Employee),**
- Cost of PAN **($6.00 /kg)**

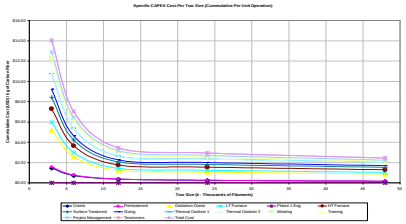
Carbon Fiber Cost Model Refinement

- Years depreciation (equipment, infrastructure) **(7 yrs, 20 yrs),** Infrastructure Factor **(2.5x capital equipment investment)**
- Cost of Nitrogen **($0.025/m3 plus cost of electricity),**
- Creel Size **(300 kg),** Package Size **(10 kg),**
- Carbon Recovery **(50%),**
- Equipment Dimensions **(User Input),**
- Type and Quantity of Process Off Gas Technologies **(Thermal Oxidation with Heat Recovery)**
- Maintenance Costs **(assumed 2% - 3% per year)**
- Cooling Water Consumption **(Cost assumed to be zero)**
- etcetera…

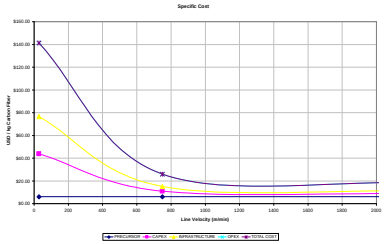
CF Systems

Development of ‘Future’ Line Configurations

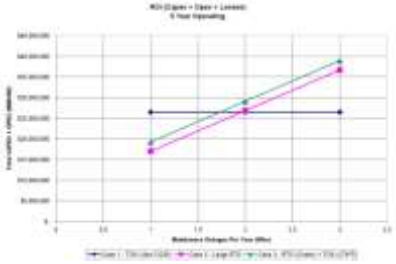
Carbon Fiber Business Model & Cost Analysis



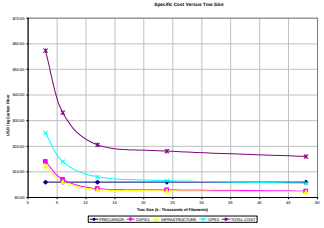
- Costs as a Function of Fiber Type, Spacing (Packing Density)



- Production Costs as a Function of Capacity, Width

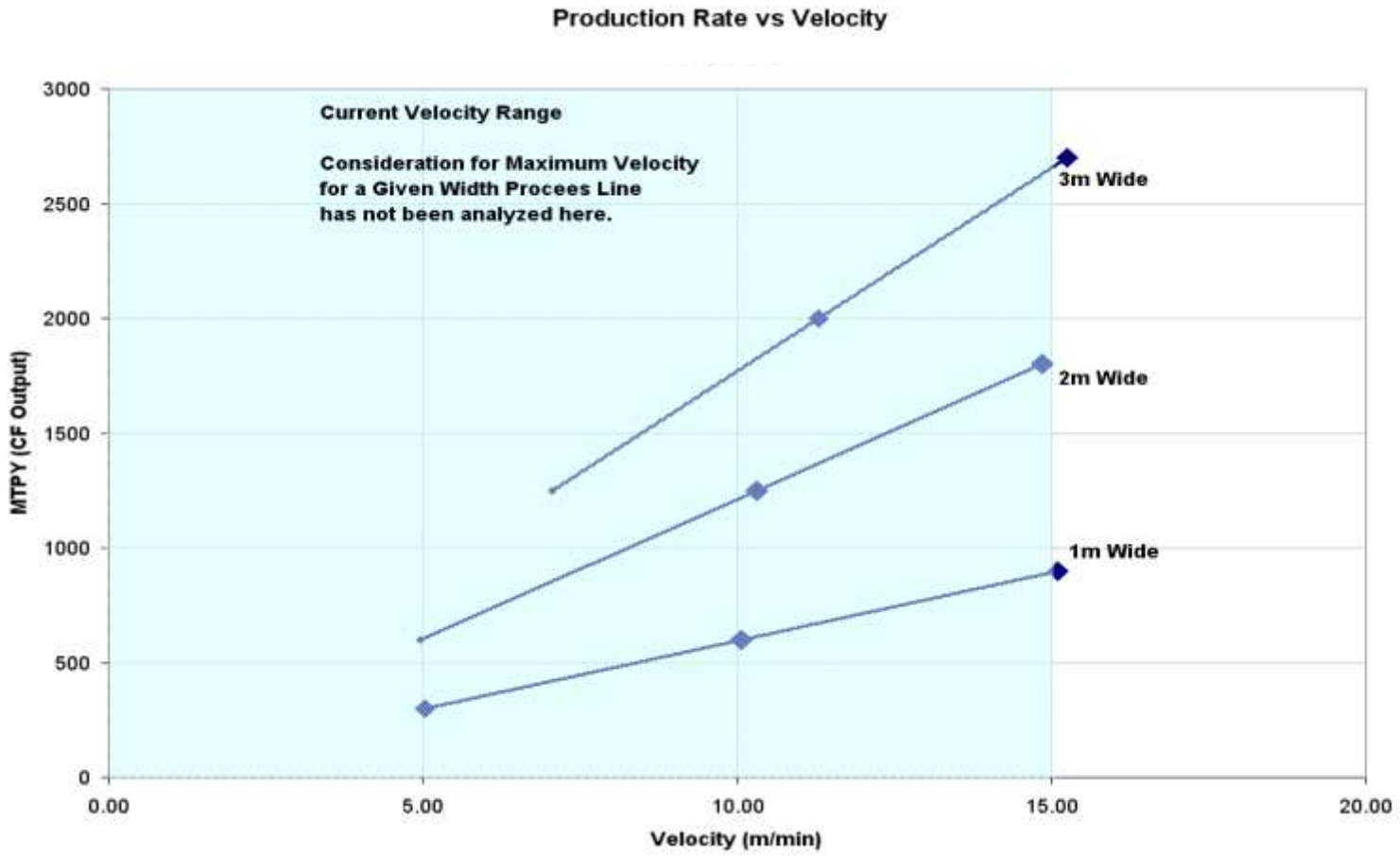


- Return on Investment Analysis for Auxiliary Unit Operations (Effluent Treatment)



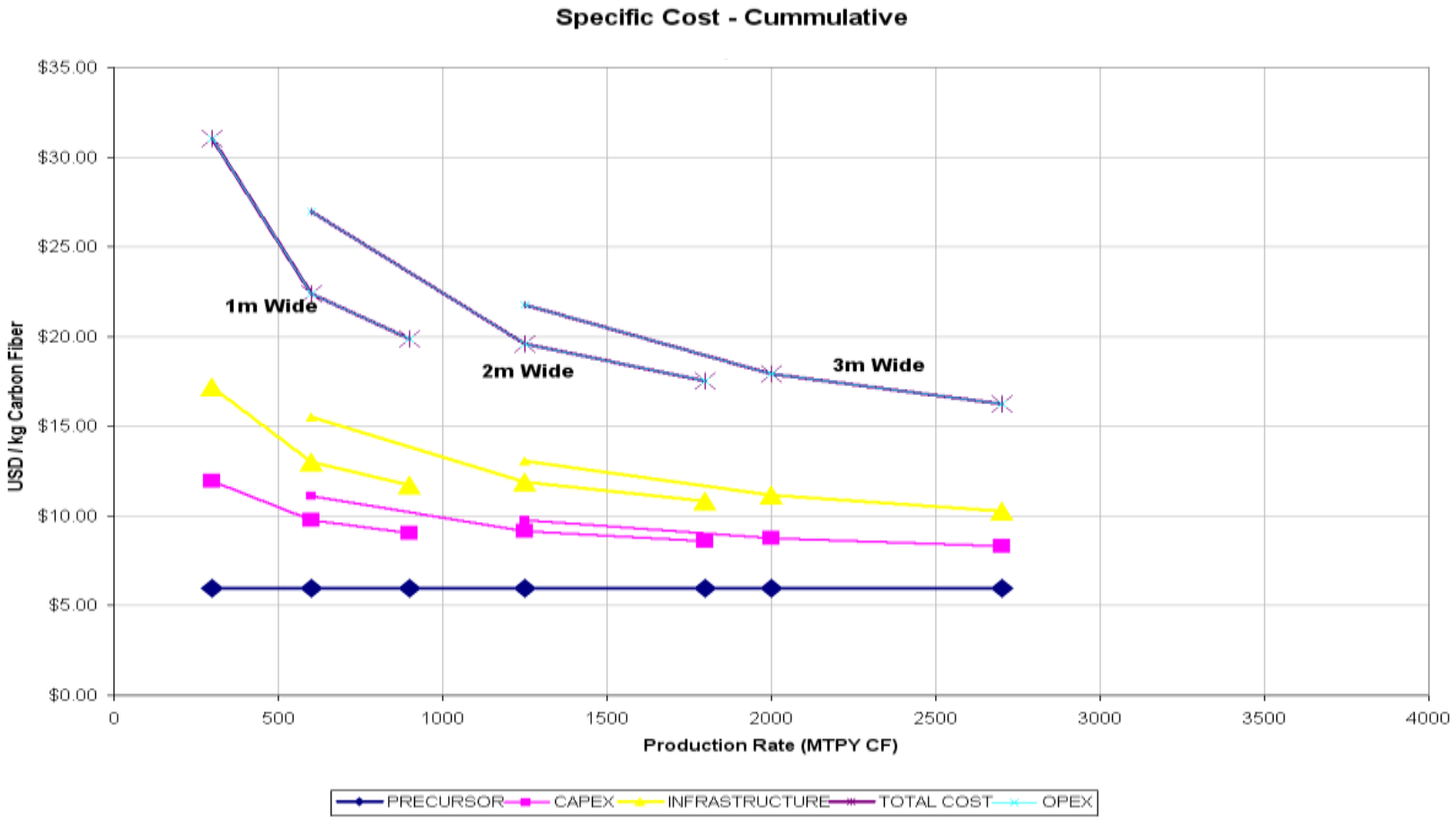
- Operating Cost Optimization

Helping Clients with Carbon Fiber Business Model & Cost Analysis



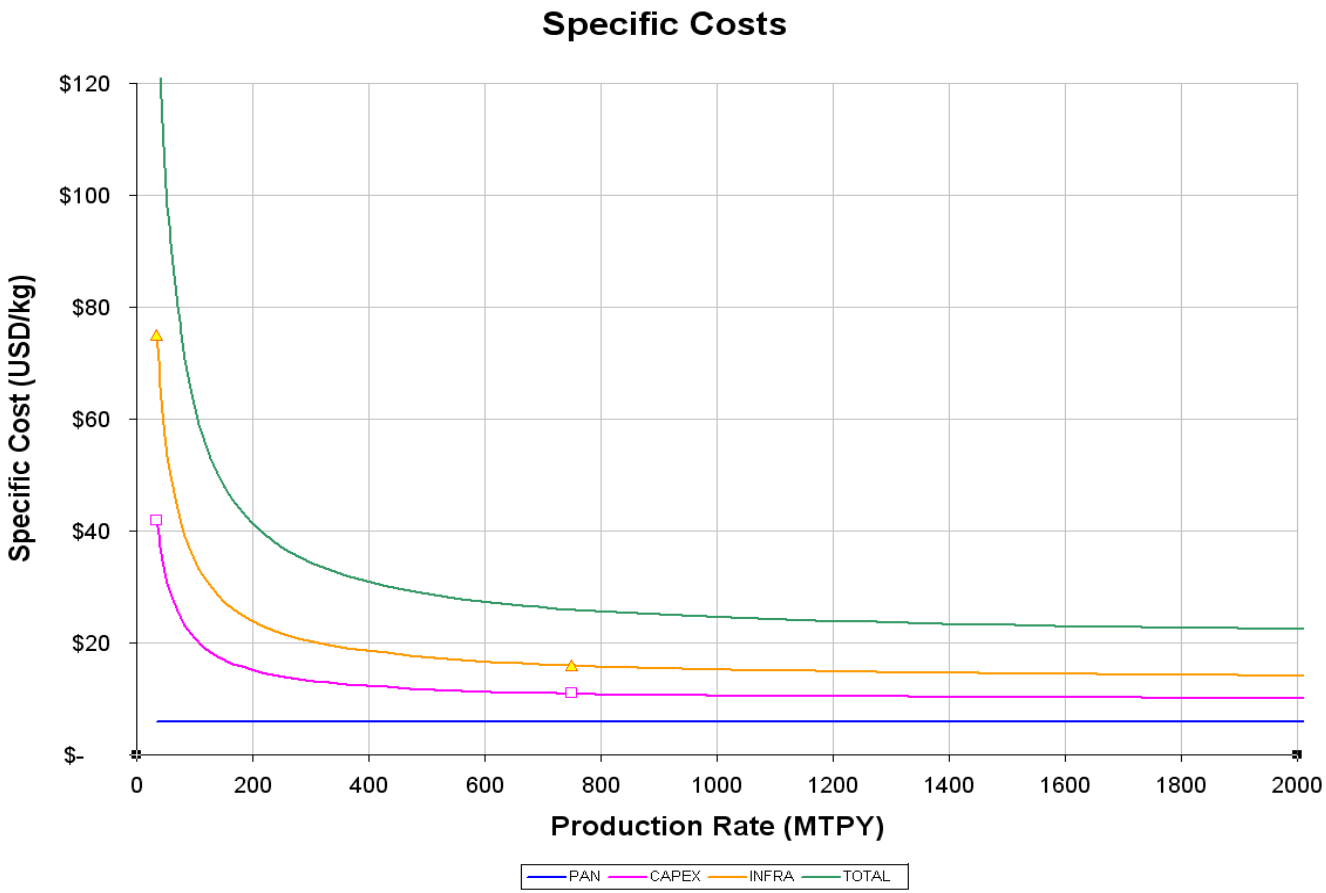
Not a true velocity field. Velocity limits are extended with line width and incremental equipment advances.

Carbon Fiber Business Model & Cost Analysis



Cost Dynamics as a Function of Scale-Up

Carbon Fiber Cost Model Analysis



Production Costs as a Function of Capacity, Width

Evaluation of Capacity Options

1750mm Width –vs- 3000mm Width
Overview and Cost Model Summary

Cost Model Output
Assumptions / Inputs

Capacity carbon fiber at HT exit (mton/yr):		1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
Availability (hours/year):		7000	7000	7000	7000
1000's of filaments per tow (K):		12	12	12	12
Tow spacing (mm):		6.0	6.0	6.0	6.0
Number of tows		284	284	284	475
Linear Density (gr / m tow)		1.66	1.66	1.66	1.66
Line speed (m/min)		5.1	7.6	10.1	9.1
Target Oxidation residence time (min)		90	90	90	90
Target LT residence time (sec)		90	90	90	90
Target HT residence time (sec)		90	90	90	90
Oxidation oven feed rate (kg/hr)		142.8	214.3	285.7	428.5
Oxidation exit mass rate (kg/hr)		135.7	203.5	271.4	407.1
LT exit mass rate (kg/hr)		84.1	126.2	168.3	252.4
Carbon fiber HT exit mass rate (kg/hr)		71.4	107.1	142.9	214.3
Number of Ovens		3	3	3	3
Estimated tow-band width (mm):		1704	1704	1704	2850
Number of Control Zones in Oven Set		6	6	6	6
Design - Total Heated Length - (m):		485	687	900	840
Actual Oven Residence (@ system speed) (min):		96	90	89	93
LT Heated length (m)		8.0	12.0	14.6	14.3
LT Number of Control Zones		6	9	11	7
Actual LT Residence (@ system speed) (sec):		94	94	87	94
HT Heated length (m)		8.0	12.0	14.6	13.7
HT Number of Control Zones		6	9	11	8
Actual HT Residence (@ system speed) (sec):		94	94	87	91

Cost Model Output
Utilities List

Power		1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
CF Production (kg/hr)		71.4	107.1	142.9	214.3
Total Installed Power (Line Load)		**7545**	**9237**	**10661**	**14683**
kw/kg (based on Installed)		105.6	86.2	74.6	68.5
Nominal Consumption Efficency		75.0%	75.0%	75.0%	75.0%
Nominal Consumption (kW) with Recuperation		**4333**	**5077**	**5584**	**7250**
kW/kg (Nominal) with Recuperation		**60.7**	**47.4**	**39.1**	**33.8**
Heat Recovery Present (1/0 = yes/no)		1	1	1	1
Heat Recuperation Possible (kW)		1768	2467	3216	5016
kw/kg (Max Installed) with Recuperation		**80.9**	**63.2**	**52.1**	**45.1**
Creels (kW)		30	30	30	50
Pretreatment (kW)		1	2	2	5
Oxidation Ovens (kW)		3841	4293	4644	5255
LT Furnace (kW)		400	567	674	1051
HT Furnace (kW)		947	1303	1540	2337
Surface Treatment - Elect., Wash, Dry (kW)		255	331	400	738
Surface Treatment - Sizing & Drying (kW)		266	346	417	771
Thermal Oxidizer 1 (kW)		1546	2105	2695	4090
Thermal Oxidizer 2 (kW)		0	0	0	0
Winding (kW)		74	74	74	124
Tensioners (Assumed) (kW)		185	185	185	263
Total (kW) with Recuperation		**5777**	**6769**	**7445**	**9667**

Cost Model Output
OPEX Estimates

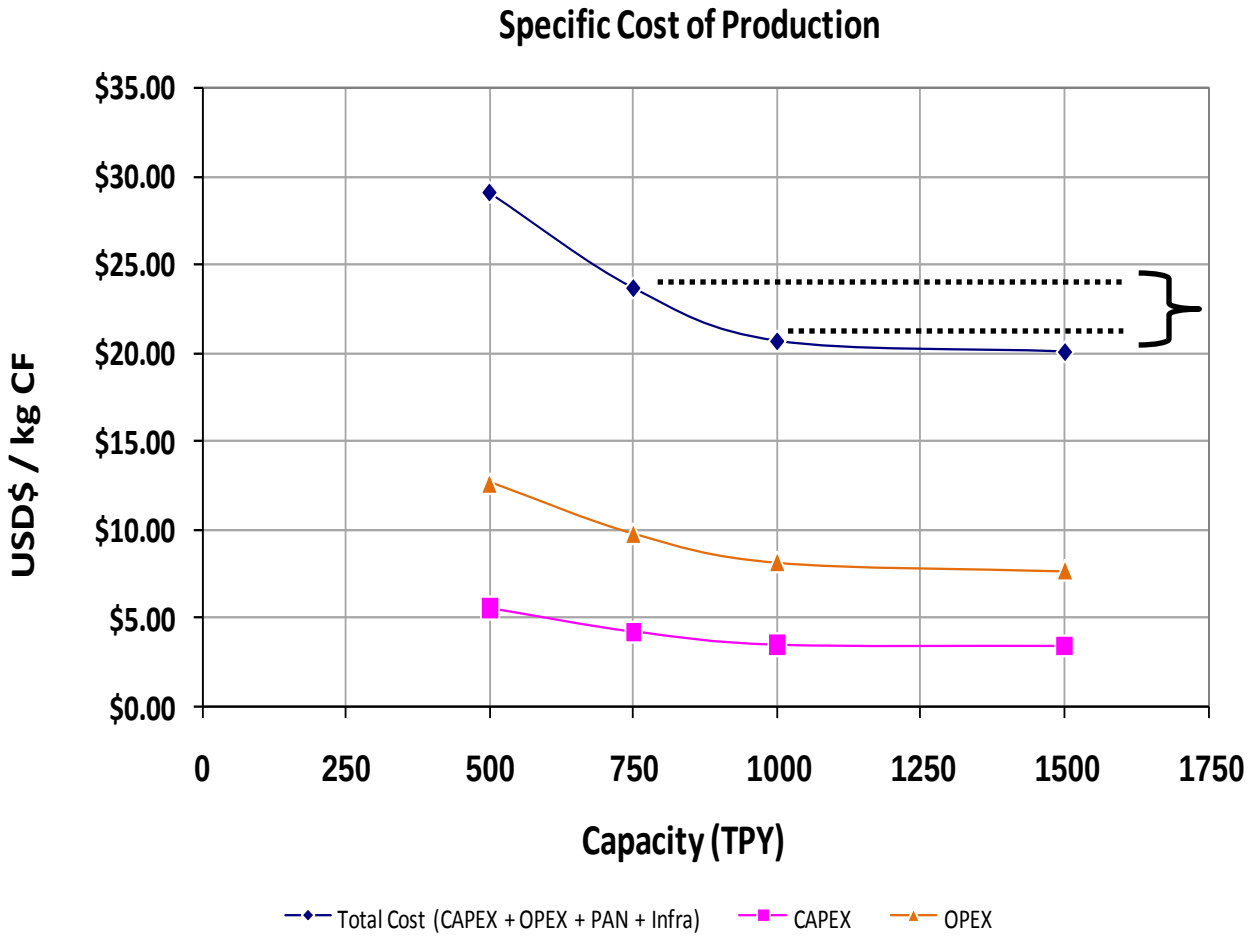
Operating Cost (OPEX)		1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
CF Production (kg/hr)		71.4	107.1	142.9	214.3
Operating Hours Per Year		7,000	7,000	7,000	7,000
Heat Recovery Present? (1/0 = Yes/No)		1	1	1	1
Nominal Consumption Efficency		75.0%	75.0%	75.0%	75.0%
Nominal Consumption (kW) with Recuperation		4332.6	5077.0	5584.0	7250.5
kW/kg (Nominal) with Recuperation		60.7	47.4	39.1	33.8
As Electricity (kW)		3428.3	3814.8	3939.1	4684.8
As Natural Gas (kW)		904.3	1,262.2	1,644.9	2,565.7
Electrical Cost (USD/kW)		$0.05	$0.05	$0.05	$0.05
Natural Gas Cost (USD/kW)		$0.10	$0.10	$0.10	$0.10
Nitrogen Consumption (Nm3/hr)		841.5	1,031.3	1,190.3	1,909.5
Nitrogen Cost (USD/hr)		$33.03	$40.47	$46.71	$74.94
Operators		37.0	40.0	42.0	59.0
Cost Per Operator (USD/year)		$100,000	$100,000	$100,000	$100,000
Total Operator Cost Per Year (USD/year)		$3,700,000	$4,000,000	$4,200,000	$5,900,000
Minutes Per Creel (Minutes)		8.4	5.6	4.2	2.8
Minutes Per Package (Product)		126.0	84.0	63.0	42.0
Kilograms Per Year		500,000	750,000	1,000,000	1,500,000
Cost Electricity (USD/year)		$1,199,898	$1,335,188	$1,378,689	$1,639,676
Cost Natural Gas (USD/year)		$633,014	$883,507	$1,151,451	$1,795,986
Cost Nitrogen (USD/year)		$289,307	$354,543	$409,207	$656,485
Cost Operators (USD/year)		$3,700,000	$4,000,000	$4,200,000	$5,900,000
Total Cost (USD/year)		$6,322,219	$7,323,238	$8,139,348	$11,492,148
Cost Electricity (USD/kg)		$2.40	$1.78	$1.38	$1.09
Cost Natural Gas (USD/kg)		$1.27	$1.18	$1.15	$1.20
Cost Nitrogen (USD/kg)		$0.58	$0.47	$0.41	$0.44
Cost Operators (USD/kg)		$7.40	$5.33	$4.20	$3.93
Total Cost (USD/kg)		$12.64	$9.76	$8.14	$7.66

Cost Model Output
Total Cost

Total Cost Model		1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
Cost PAN (USD/kg PAN)		$3.00	$3.00	$3.00	$3.00
Cost Pan / kg CF (USD / kg CF)		$6.00	$6.00	$6.00	$6.00
Cost PAN (USD/yr)		$2,999,634	$4,499,451	$5,999,268	$8,998,902
Cost CAPEX (USD) / Per Line		$24,379,000	$27,725,000	$30,528,000	$44,871,000
Systems Required for Desired Total Capacity		1	1	1	1
Infrastructure (fx CAPEX)		2.5	2.5	2.5	2.5
Infrastructure (USD)		$60,947,500	$69,312,500	$76,320,000	$112,177,500
Building Dimensions Length (m) - Estimated		180	230	270	300
Building Dimensions Width (m) - Estimated		30	30	30	40
Building Dimensions Foot Print (m2) - Estimated		5,400	6,900	8,100	12,000
		$24,379,000	$27,725,000	$30,528,000	$44,871,000
		$60,947,500	$69,312,500	$76,320,000	$112,177,500
Cost PAN (USD/kg CF)		$6.00	$6.00	$6.00	$6.00
Cost CAPEX (USD/kg CF)		$5.57	$4.22	$3.48	$3.41
Cost Infrastructure (USD/kg CF)		$4.87	$3.69	$3.05	$2.99
Cost OPEX (USD/kg CF)		$12.64	$9.76	$8.14	$7.66
Total Cost (USD/kg CF)		$29.08	$23.68	$20.67	$20.06

CUMMULATIVE Total Cost Model		1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
Total Cost (USD / kg CF)		$29.08	$23.68	$20.67	$20.06
Cost PAN (USD/kg CF)		$6.00	$6.00	$6.00	$6.00
Cost CAPEX (USD/kg CF)		$11.57	$10.22	$9.48	$9.41
Cost Infrastructure (USD/kg CF)		$16.44	$13.91	$12.53	$12.40
Cost OPEX (USD/kg CF)		$29.08	$23.68	$20.67	$20.06
Cost PAN (%)		20.6%	25.3%	29.0%	29.9%
Cost CAPEX (%)		39.8%	43.2%	45.9%	46.9%
Cost Infrastructure (%)		56.5%	58.8%	60.6%	61.8%
Cost OPEX (%)		100.0%	100.0%	100.0%	100.0%

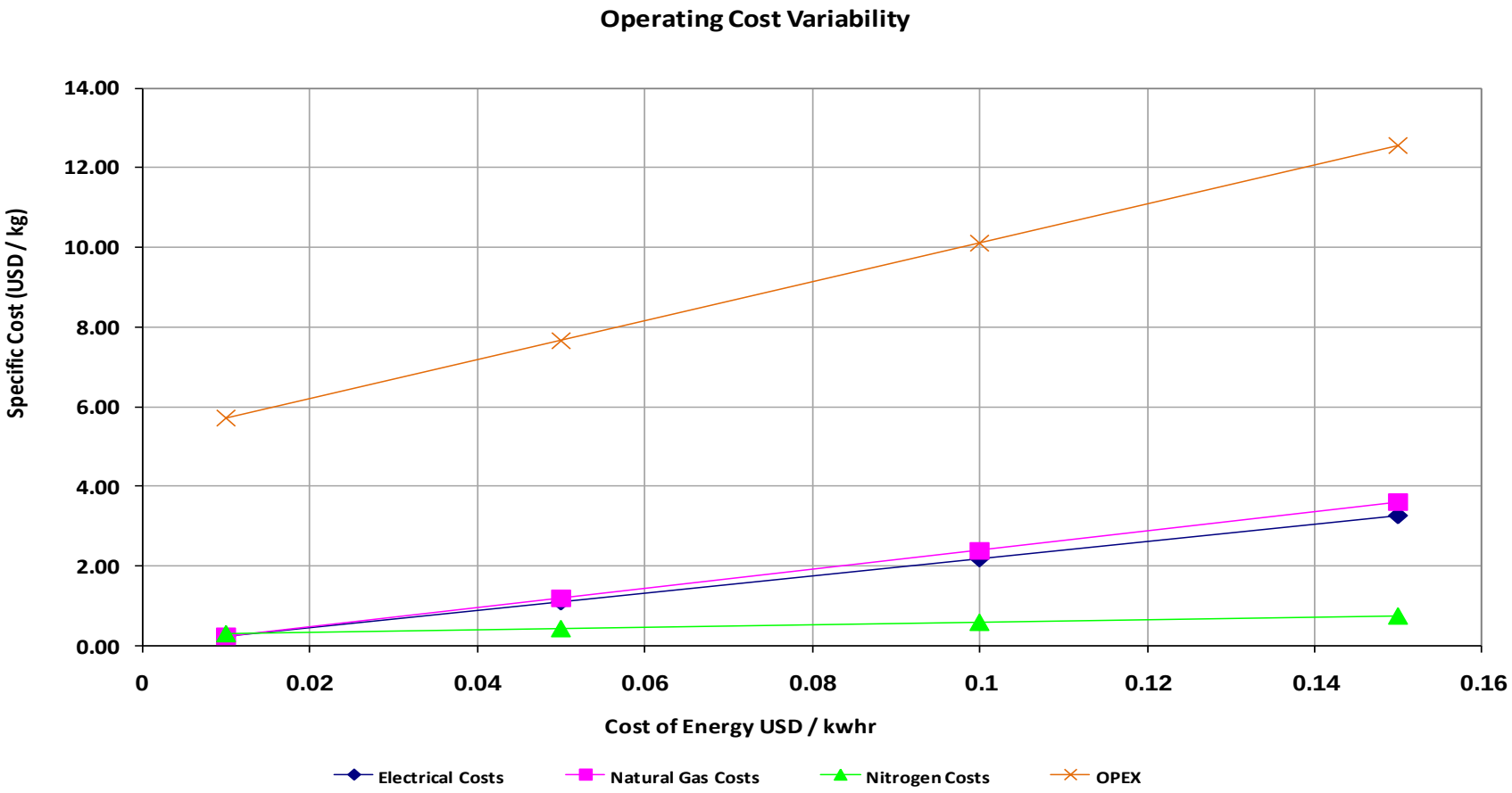
Cost Model Output
Total Cost



Benefit of jumping to a 3000mm wide system depends on the max capacity reached at 1750mm wide system config.

$4.00 / kg * 1,500,000 kg/yr = $6MM USD/yr

Cost Model Output
OPEX Estimates – Variable Energy Costs



Variance of OPEX as a function of Electrical and Natural Gas Costs for a 3m Wide 1500TYP facility (with natural gas = 2x electrical)

Cost Model Output
OPEX Estimates – Effects of Heat Recovery

Total Cost Model	1.75m Wide 500tpy w/o HT Recovery	1.75m Wide 750tpy w/o HT Recovery	1.75m Wide 1000tpy w/o HT Recovery	3m Wide 1500tpy w/0 HT Recovery
Cost PAN (USD/kg PAN)	$3.00	$3.00	$3.00	$3.00
Cost Pan / kg CF (USD / kg CF)	$6.00	$6.00	$6.00	$6.00
Cost PAN (USD/yr)	$2,999,634	$4,499,451	$5,999,268	$8,998,902
Cost CAPEX (USD) / Per Line	$23,024,000	$26,040,000	$28,527,000	$42,127,000
Systems Required for Desired Total Capacit	1	1	1	1
Infrastructure (fx CAPEX)	2.5	2.5	2.5	2.5
Infrastructure (USD)	$57,560,000	$65,100,000	$71,317,500	$105,317,500
	$23,024,000	$26,040,000	$28,527,000	$42,127,000
	$57,560,000	$65,100,000	$71,317,500	$105,317,500
Cost PAN (USD/kg CF)	$6.00	$6.00	$6.00	$6.00
Cost CAPEX (USD/kg CF)	$5.26	$3.96	$3.26	$3.21
Cost Infrastructure (USD/kg CF)	$4.60	$3.47	$2.85	$2.81
Cost OPEX (USD/kg CF)	$13.57	$10.63	$8.98	$8.54
Total Cost (USD/kg CF)	$29.43	$24.06	$21.09	$20.55

1.75m Wide 500tpy	1.75m Wide 750tpy	1.75m Wide 1000tpy	3m Wide 1500tpy
$3.00	$3.00	$3.00	$3.00
$6.00	$6.00	$6.00	$6.00
$2,999,634	$4,499,451	$5,999,268	$8,998,902
$24,379,000	$27,725,000	$30,528,000	$44,871,000
1	1	1	1
2.5	2.5	2.5	2.5
$60,947,500	$69,312,500	$76,320,000	$112,177,500
$24,379,000	$27,725,000	$30,528,000	$44,871,000
$60,947,500	$69,312,500	$76,320,000	$112,177,500
$6.00	$6.00	$6.00	$6.00
$5.57	$4.22	$3.48	$3.41
$4.87	$3.69	$3.05	$2.99
$12.64	$9.76	$8.14	$7.66
$29.08	$23.68	$20.67	$20.06

Annual Savings Per Year.....	**$174,037**	**$287,040**	**$415,833**	**$729,308**
Return On Investment	**7.3**	**5.5**	**4.5**	**3.4**

3000 TPY Capacity Options

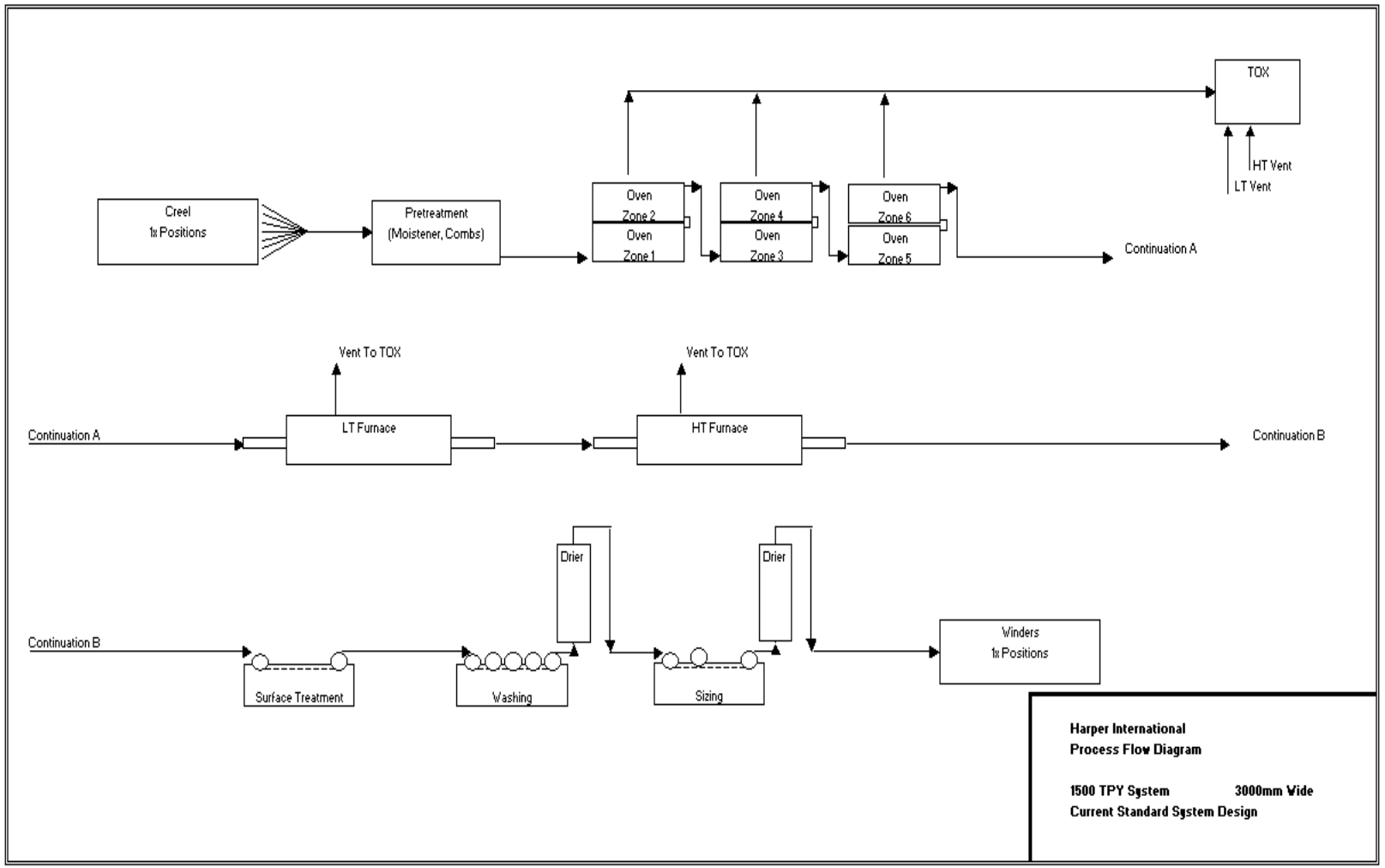
Overview and Cost Model Summary

Future Line Capacity Evaluation

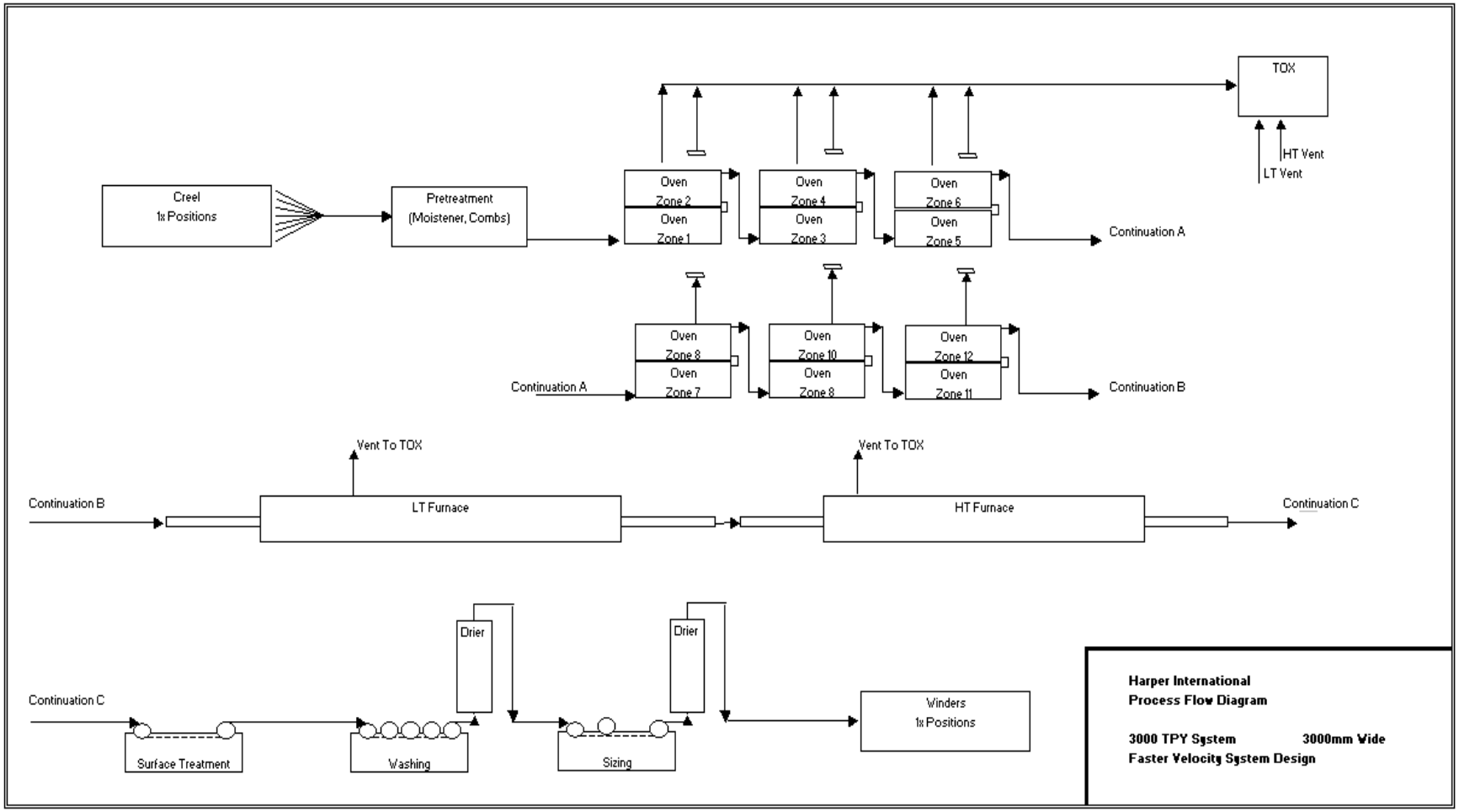
- Current Capacities: 1500 tpy to >2000+ tpy
- Next Generation Line Capacities >3000 tpy (following the tendency for doubling of capacities)
- Evaluated Scenarios for Next Generation Line Design
  - Faster Lines, Existing Widths
  - Novel Configurations (Multiple, Stacked Tow Bands)
  - Wider Lines, Existing Speeds

Cost Differentials Must be Evaluated Against Developmental Risks

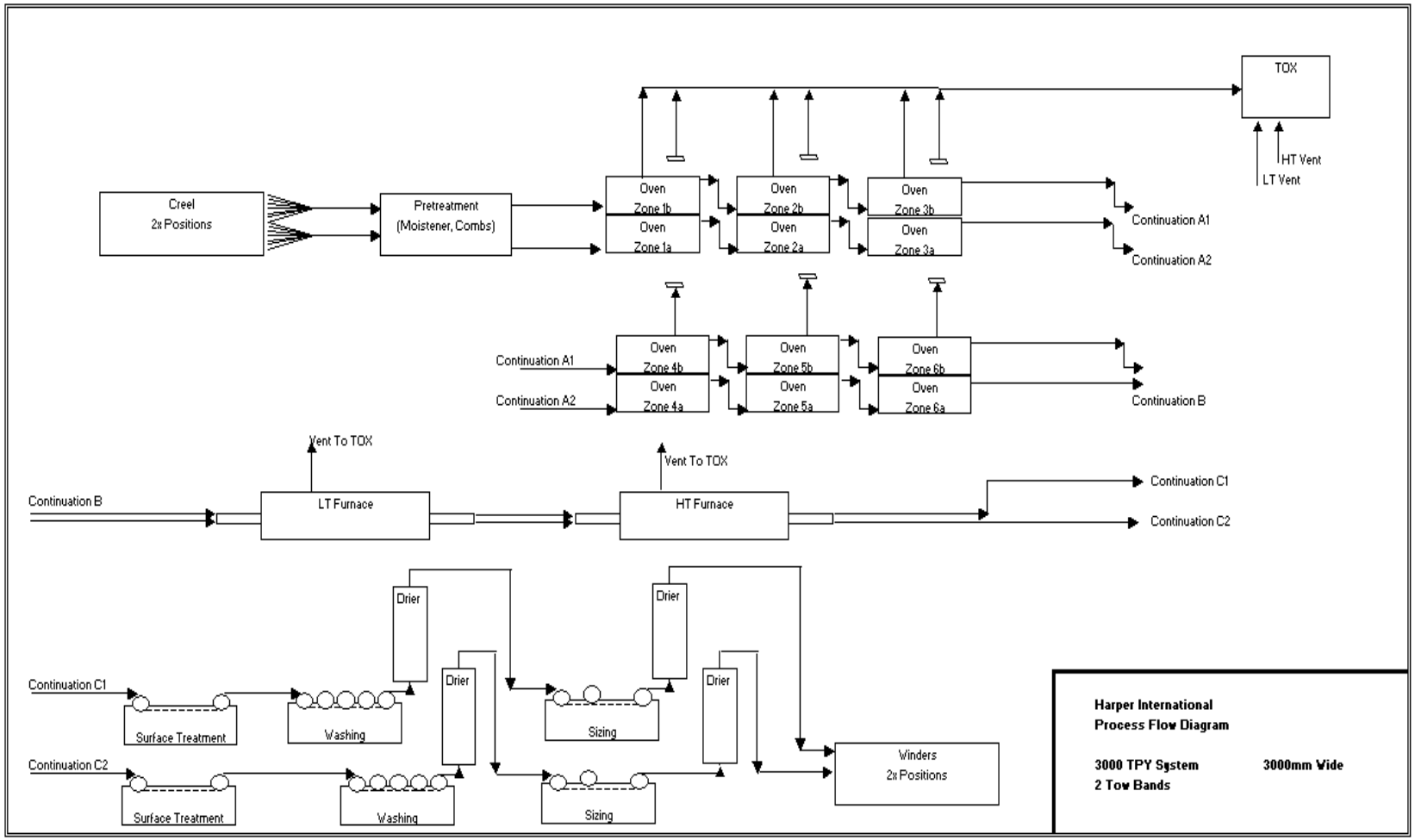
Block Diagram
1500 TPY – 3000mm Wide



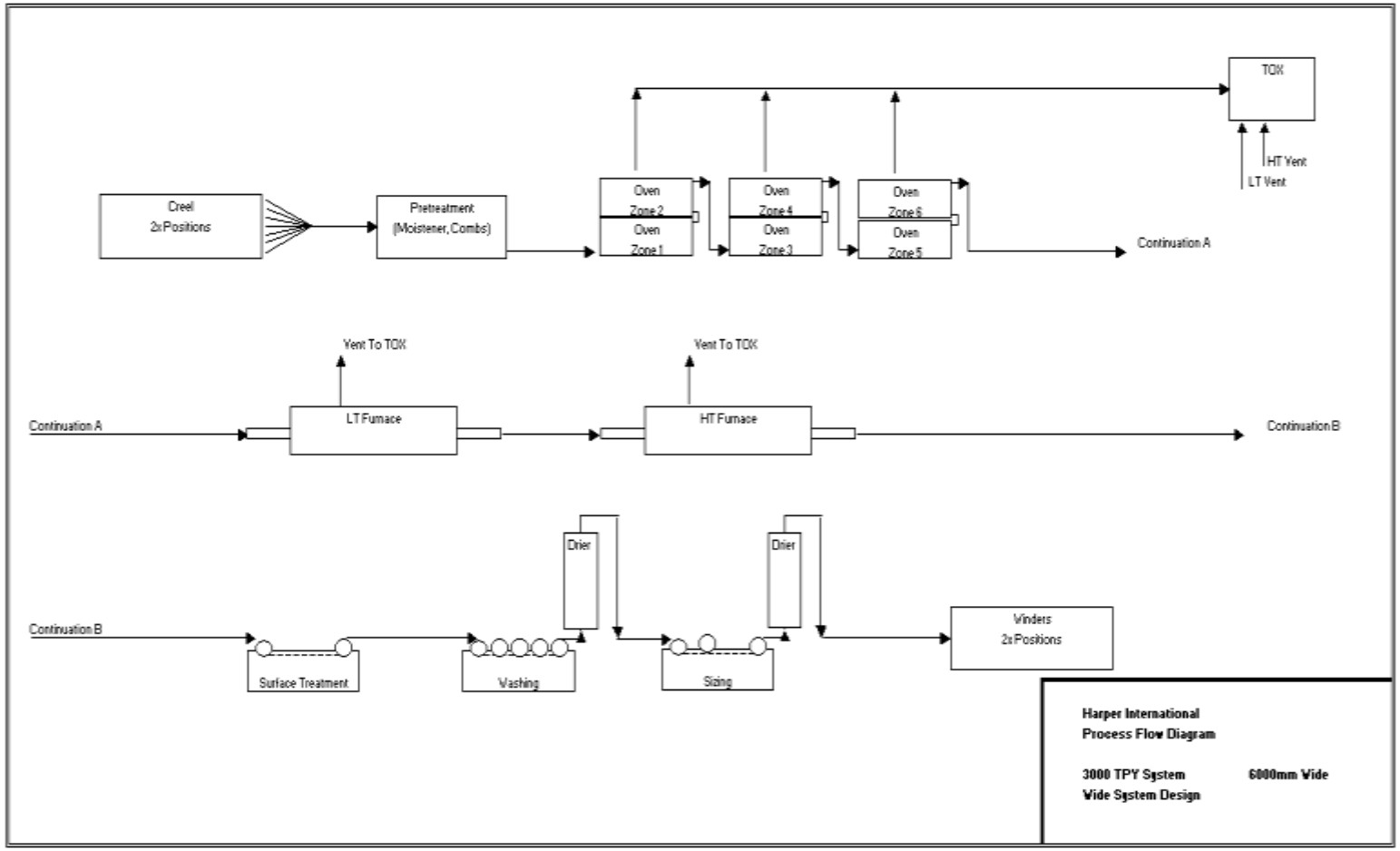
Block Diagram
3000 TPY – 3000mm Wide – Faster Line



Block Diagram
3000 TPY – 3000mm Wide – 2 Tow Bands (Stacked)



Block Diagram
30000 TPY – 6000mm Wide



System Design is Similar to 1500 TPY Plant, but Equipment is wider

Cost Model Output
Assumptions / Inputs

Capacity carbon fiber at HT exit (mton/yr):		3m Wide 1500 TPY	3m Wide x 2 Lines 3000tpy w / 2X	3m Wide - Faster 3000tpy	3m Wide x 2 Tow 3000tpy	6m Wide 3000tpy
Availability (hours/year):		7000	7000	7000	7000	7000
1000's of filaments per tow (K):		12	12	12	12	12
Tow spacing (mm):		6.0	6.0	6.0	6.0	6.0
Number of tows		475	475	475	475	950
Linear Density (gr / m tow)		1.66	1.66	1.66	1.66	1.66
Line speed (m/min)		9.1	18.2	18.2	9.1	9.1
Target Oxidation residence time (min)		90	90	90	180	90
Target LT residence time (sec)		90	90	90	90	90
Target HT residence time (sec)		90	90	90	90	90
Oxidation oven feed rate (kg/hr)		428.5	857.0	857.0	857.0	857.0
Oxidation exit mass rate (kg/hr)		407.1	814.2	814.2	814.2	814.2
LT exit mass rate (kg/hr)		252.4	504.8	504.8	504.8	504.8
Carbon fiber HT exit mass rate (kg/hr)		214.3	428.6	428.6	428.6	428.6
Number of Ovens		3	3	6	6	3
Estimated tow-band width (mm):		2850	2850	2850	2850	5700
Number of Control Zones in Oven Set		6	6	12	12	6
Design - Total Heated Length - (m):		840	840	1681	1681	840
Actual Oven Residence (@ system speed) (min):		93	46	93	185	93
LT Heated length (m)		14.3	14.3	28.6	14.3	14.3
LT Number of Control Zones		7	7	14	7	7
Actual LT Residence (@ system speed) (sec):		94	47	94	94	94
HT Heated length (m)		13.7	13.7	27.5	13.7	13.7
HT Number of Control Zones		8	8	16	8	8
Actual HT Residence (@ system speed) (sec):		91	45	91	91	91

Cost Model Output
Scale Up (3000 TPY) Scenarios - Utilities List

	3m Wide	3m Wide	3m Wide - Faster	3m Wide x 2 Tow	6m Wide
Power	**1500 TPY**	**3000tpy w / 2X**	**3000tpy**	**3000tpy**	**3000tpy**
CF Production (kg/hr)	214.3	428.6	428.6	428.6	428.6
Total Installed Power (Line Load)	**14683**	**29366**	**27540**	**24582**	**24903**
kw/kg (based on Installed)	68.5	68.5	64.3	57.4	58.1
Nominal Consumption Efficency	75.0%	75.0%	75.0%	75.0%	75.0%
Nominal Consumption (kW) with Recuperation	**7250**	**14501**	**13263**	**11045**	**11133**
kW/kg (Nominal) with Recuperation	**33.8**	**33.8**	**30.9**	**25.8**	**26.0**
Heat Recovery Present (1/0 = yes/no)	1	1	1	1	1
Heat Recuperation Possible (kW)	5016	10032	9856	9856	10059
kw/kg (Installed Net) with Recuperation	**45.1**	**45.1**	**41.3**	**34.4**	**34.6**
Creels (kW)	50	99	50	50	99
Pretreatment (kW)	5	9	7	7	14
Oxidation Ovens (kW)	5255	10510	10510	10510	6155
LT Furnace (kW)	1051	2102	1908	1051	1908
HT Furnace (kW)	2337	4674	4437	2337	4437
Surface Treatment - Elect., Wash, Dry (kW)	738	1477	1159	1159	1818
Surface Treatment - Sizing & Drying (kW)	771	1542	1210	1210	1899
Thermal Oxidizer 1 (kW)	4090	8181	7761	7761	7913
Thermal Oxidizer 2 (kW)	0	0	0	0	0
Winding (kW)	124	248	124	124	248
Tensioners (Assumed) (kW)	263	525	375	375	412
Total (kW) with Recuperation	**9667**	**19335**	**17684**	**14726**	**14844**

Cost Model Output
Scale Up (3000 TPY) Scenarios OPEX Est.

Operating Cost (OPEX)	3m Wide 1500 TPY	3m Wide 3000tpy w / 2X	3m Wide - Faster 3000tpy	3m Wide x 2 Tow 3000tpy	6m Wide 3000tpy
CF Production (kg/hr)	214.3	428.6	428.6	428.6	428.6
Operating Hours Per Year	7,000	7,000	7,000	7,000	7,000
Heat Recovery Present? (1/0 = Yes/No)	1	1	1	1	1
Nominal Consumption Efficency	75.0%	75.0%	75.0%	75.0%	75.0%
Nominal Consumption (kW) with Recuperation	7250.5	14501.0	13263.1	11044.8	11133.0
kW/kg (Nominal) with Recuperation	33.8	33.8	30.9	25.8	26.0
As Electricity (kW)	4684.8	9369.6	8221.4	6003.1	5987.8
As Natural Gas (kW)	2,565.7	5131.4	5,041.7	5,041.7	5,145.2
Electrical Cost (USD/kW)	$0.05	$0.05	$0.05	$0.05	$0.05
Natural Gas Cost (USD/kW)	$0.10	$0.10	$0.10	$0.10	$0.10
Nitrogen Consumption (Nm3/hr)	1,909.5	3819.0	2,700.0	2,700.0	3,818.3
Nitrogen Cost (USD/hr)	$74.94	$149.88	$105.97	$105.97	$149.85
Operators	59.0	118.0	66.0	101.0	101.0
Cost Per Operator (USD/year)	$100,000	$100,000	$100,000	$100,000	$100,000
Total Operator Cost Per Year (USD/year)	$5,900,000	$11,800,000	$6,600,000	$10,100,000	$10,100,000
Minutes Per Creel (Minutes)	2.8	1.4	1.4	1.4	1.4
Minutes Per Package (Product)	42.0	21.0	21.0	21.0	21.0
Kilograms Per Year	1,500,000	3,000,000	3,000,000	3,000,000	3,000,000
Cost Electricity (USD/year)	$1,639,676	$3,279,353	$2,877,487	$2,101,088	$2,095,726
Cost Natural Gas (USD/year)	$1,795,986	$3,591,972	$3,529,167	$3,529,167	$3,601,646
Cost Nitrogen (USD/year)	$656,485	$1,312,970	$928,259	$928,259	$1,312,712
Cost Operators (USD/year)	$5,900,000	$11,800,000	$6,600,000	$10,100,000	$10,100,000
Total Cost (USD/year)	$11,492,148	$22,984,295	$16,934,912	$19,658,513	$20,110,084
Cost Electricity (USD/kg)	$1.09	$1.09	$0.96	$0.70	$0.70
Cost Natural Gas (USD/kg)	$1.20	$1.20	$1.18	$1.18	$1.20
Cost Nitrogen (USD/kg)	$0.44	$0.44	$0.31	$0.31	$0.44
Cost Operators (USD/kg)	$3.93	$3.93	$2.20	$3.37	$3.37
Total Cost (USD/kg)	$7.66	$7.66	$5.64	$6.55	$6.70

Cost Model Output
Scale Up (3000 TPY) Scenarios Total Cost

Total Cost Model	3m Wide 1500 TPY	3m Wide 3000tpy w / 2X	3m Wide - Faster 3000tpy	3m Wide x 2 Tow 3000tpy	6m Wide 3000tpy
Cost PAN (USD/kg PAN)	$3.00	$3.00	$3.00	$3.00	$3.00
Cost Pan / kg CF (USD / kg CF)	$6.00	$6.00	$6.00	$6.00	$6.00
Cost PAN (USD/yr)	$8,998,902	$17,997,804	$17,997,804	$17,997,804	$17,997,804
Cost CAPEX (USD) / Per Line	$44,871,000	$89,742,000	$61,296,000	$79,343,000	$81,925,000
CAPEX Cost Factor (Over 1500 tpy line)		2.00	1.37	1.77	1.83
Systems Required for Desired Total Capacity	2	1	1	1	1
Infrastructure (fx CAPEX)	2.5	2.5	2.5	2.5	2.5
Infrastructure (USD)	$112,177,500	$224,355,000	$153,240,000	$198,357,500	$204,812,500
Building Dimensions Length (m) - Estimated	300	300	500	360	380
Building Dimensions Width (m) - Estimated	40	80	40	40	70
Building Dimensions Foot Print (m2) - Estimated	12,000	24,000	20,000	14,400	26,600
Cost PAN (USD/kg CF)	$6.00	$6.00	$6.00	$6.00	$6.00
Cost CAPEX (USD/kg CF)	$3.41	$3.41	$2.33	$3.02	$3.12
Cost Infrastructure (USD/kg CF)	$2.99	$2.99	$2.04	$2.64	$2.73
Cost OPEX (USD/kg CF)	$7.66	$7.66	$5.64	$6.55	$6.70
Total Cost (USD/kg CF)	$20.06	$20.06	$16.02	$18.21	$18.55

CUMMULATIVE Total Cost Model					
Total Cost (USD / kg CF)	$20.06	$20.06	$16.02	$18.21	$18.55
Cost PAN (USD/kg CF)	$6.00	$6.00	$6.00	$6.00	$6.00
Cost CAPEX (USD/kg CF)	$9.41	$9.41	$8.33	$9.02	$9.12
Cost Infrastructure (USD/kg CF)	$12.40	$12.40	$10.37	$11.66	$11.84
Cost OPEX (USD/kg CF)	$20.06	$20.06	$16.02	$18.21	$18.55
Cost PAN (%)	29.9%	29.9%	37.5%	32.9%	32.3%
Cost CAPEX (%)	46.9%	46.9%	52.0%	49.5%	49.2%
Cost Infrastructure (%)	61.8%	61.8%	64.8%	64.0%	63.9%
Cost OPEX (%)	100.0%	100.0%	100.0%	100.0%	100.0%

Future Line Capacity Evaluation

For Next Generation, Cost differential has been estimated via Cost Modeling:

	Capex	Total
▪ Multiple of Current State of the Art Line	(2.00x)	100%
▪ Faster Lines, Existing Widths	(1.37x)	79.8%
▪ Novel Configurations (Multiple Tow Bands)	(1.77x)	90.8%
▪ Wider Lines, Existing Speeds	(1.83x)	92.4%

Wider Lines and Stacking offer reduction of Consumed Energy, but large Benefits through Faster Velocities

Future Line Capacity Evaluation

Developmental Engineering should be directed toward:

- Evaluation of roller diameters – loading, deflection & effect on oven volume
- Evaluation of heat dispersion from rolls and transport systems
- System Logistics & operator ergonomics
- Structural limits for materials (LT Muffle & HT Muffle)
- Development of technology to manage cantenary (current limit on most equipment is ~15m heated length)
- Improved Heat Recovery
- Improved Process Gas Segregation

Projected Cost Differentials can be used to drive R&D Efforts