Contents

1 Table of Figures 4

2 Table of Tables 6

3 Scope 7

4 Legend 10

5 Methodological Notes 10

6 Vital Statistics 12

7 Distillation Columns 13

7.1 Market Overview 13
7.1.1 Demand 13
7.1.2 Supply (Capacity) 16
7.1.3 New contracts 19

7.2 Analysis 20
7.2.1 Costs 20
7.2.2 Profit Margins 21
7.2.3 Prices 22
7.2.4 Price Differences by Technology, Model, and Feature 26
7.2.5 Should-Cost Analysis 29

7.3 Price Negotiation Strategies 30

8 Component Removal and Reforming Towers (Towers) 31

8.1 Market Overview 31
8.1.1 Demand 31
8.1.2 Supply (Capacity) 33
8.1.3 New contracts 36

8.2 Analysis 38
8.2.1 Costs 38
8.2.2 Profit Margins 39
8.2.3 Prices 40
8.2.4 Price Differences by Technology, Model, and Feature 43
8.2.5 Should-Cost Analysis 45

8.3 Price Negotiation Strategies 46

9 Hydrocracking Reactors 47

1. Market Overview 47
1. Demand 47
2. Supply (Capacity) 50
3. New contracts 54

9.2 Analysis 56
9.2.1 Costs 56
9.2.2 Profit Margins 57
9.2.3 Prices 59
9.2.4 Price Differences by Technology, Model, and Feature 61
9.2.5 Should-Cost Analysis 63

9.3 Price Negotiation Strategies 64

10 Hydrotreating Reactors 66

10.1 Market Overview 66

10.1.1 Demand 66
10.1.2 Supply (Capacity) 69
10.1.3 New contracts 71

10.2 Analysis *74*
10.2.1 Costs 74
10.2.2 Profit Margins 75
10.2.3 Prices 76
10.2.4 Price Differences by Technology, Model, and Feature 78
10.2.5 Should-Cost Analysis 80

10.3 Price Negotiation Strategies *81*

11 Coke Drums **82**

11.1 Market Overview *82*
11.1.1 Demand 82
11.1.2 Supply (Capacity) 84
11.1.3 New contracts 87

11.2 Analysis *89*
11.2.1 Costs 89
11.2.2 Profit Margins 90
11.2.3 Prices 91
11.2.4 Price Differences by Technology, Model, and Feature 94
11.2.5 Should-Cost Analysis 97

11.3 Price Negotiation Strategies *97*

12 Spherical LPG Tanks **98**

1. Market Overview *98*
1. Demand 98
2. Supply (Capacity) 99
3. New contracts 102

12.2 Analysis *104*
12.2.1 Costs 104
12.2.2 Profit Margins 107
12.2.3 Prices 108
12.2.4 Price Differences by Technology, Model, and Feature 109
12.2.5 Should-Cost Analysis 111

12.3 Price Negotiation Strategies *112*

13 Heat Exchangers **113**

13.1 Market Overview *113*
13.1.1 Demand 113
13.1.2 Supply (Capacity) 115
13.1.3 New contracts 118

13.2 Analysis *121*
13.2.1 Costs 121
13.2.2 Profit Margins 122
13.2.3 Prices 123
13.2.4 Price Differences by Technology, Model, and Feature 125
13.2.5 Should-Cost Analysis 128

13.3 Price Negotiation Strategies *128*

14 Reference product definitions and scope. **129**

14.1.1 Distillation Columns 129
14.1.2 Component Removal and Reforming Towers (Towers) 129
14.1.3 Catalytic Hydrocracking Reactors 129

14.1.4 Hydrotreating Reactors 129
14.1.5 Hydrotreating Reactors 129
14.1.6 Spherical LPG Tanks 129
14.1.7 Heat Exchangers 129

15 Notes 130

1 Table of Figures

Figure 1: Demand for Distillation Columns 15
Figure 2: Capacity Margin - Distillation Columns 18
Figure 3: Demand vs. Capacity - Distillation Columns 19
Figure 4: Cost Structure of Distillation Columns 21
Figure 5: Overall Price Forecast for Distillation Columns 24
Figure 6: Distillation Column size vs. Cost – by Diameter 27
Figure 7: Cost per unit of Output 28
Figure 8: Economies of Scale in Distillation Columns 29
Figure 9: Should-Cost for Distillation Columns 30
Figure 10: Demand for Towers 32
Figure 11: Capacity Margin - Towers 35
Figure 12: Demand vs. Capacity - Towers 36
Figure 13: Cost Structure of Towers 39
Figure 14: Overall Price Forecast for Towers 42
Figure 15: Towers Size vs. Cost – by Diameter 44
Figure 16: Cost per Barrel of Capacity for Towers 44
Figure 17: Economies of Scale in Towers 45
Figure 18: Should-Cost for Towers 46
Figure 19: Demand for Hydrocracking Reactors 48
Figure 20: Capacity Margin - Hydrocracking Reactors 52
Figure 21: Demand vs. Capacity - Hydrocracking Reactors 53
Figure 22: Cost Structure of Hydrocracking Reactors 57
Figure 23: Overall Price Forecast for Hydrocracking Reactors 60
Figure 24: Hydrocracking Reactor Size vs. Cost – by Diameter 62
Figure 25: Cost of Hydrocracking Reactors per Barrel per Day of Output 62
Figure 26: Economies of Scale in Hydrocracking Reactors 63
Figure 27: Should-Cost for Hydrocracking Reactors 64
Figure 28: Demand for Hydrotreating Reactors 68
Figure 29: Capacity Margin - Hydrotreating Reactors 70
Figure 30: Demand vs. Capacity - Hydrotreating Reactors 71
Figure 31: Cost Structure of Hydrotreating Reactors 75
Figure 32: Overall Price Forecast for Hydrotreating Reactors 76
Figure 33: Hydrotreating Reactor Pressure Rating vs. Cost – by Metallurgy 79 Figure 34: Cost per Barrel of Capacity for Hydrotreating Reactors 79 Figure 35: Economies of Scale in Hydrotreating Reactors 80 Figure 36: Should-Cost for Hydrotreating Reactors 81 Figure 37: Demand for Coke Drums 83 Figure 38: Capacity Margin – Coke Drums 85 Figure 39: Demand vs. Capacity – Coke Drums 86 Figure 40: Cost Structure of Coke Drums 90 Figure 41: Overall Price Forecast for Coke Drums 93 Figure 42: Coke Drum Size vs. Cost – by Metallurgy 95 Figure 43: Cost per Barrel of Capacity for Coke Drums 96 Figure 44: Economies of Scale in Coke Drums 96 Figure 45: Should-Cost for Coke Drums 97 Figure 46: Demand for Spherical LPG Tanks 99 Figure 47: Capacity Margin – Spherical LPG Tanks 101 Figure 48: Demand vs. Capacity – Spherical LPG Tanks 102 Figure 49: Cost Structure of Spherical LPG Tanks 106 Figure 50: Overall Price Forecast for Spherical LPG Tanks 108 Figure 51: Spherical Tank Diameter vs. Cost by Pressure Rating 110 Figure 52: Cost per Barrel of Holding Capacity for Spherical LPG Tanks 110 Figure 53: Economies of Scale for Spherical LPG Tanks 111 Figure 54: Should-Cost for Spherical LPG Tanks 112 Figure 55: Demand for Heat Exchangers 115 Figure 56: Capacity Margin – Heat Exchangers 117 Figure 57: Demand vs. Capacity – Heat Exchangers 118 Figure 58: Cost Structure of Heat Exchangers 122

Figure 59: Overall Price Forecast for Heat Exchangers 123
Figure 60: Tube Length vs. Cost - by Material for 36" Shell Diameter 125
Figure 61: Heat Transfer Surface Area vs. Cost - by Material 127
Figure 62: Economies of Scale in Heat Exchangers 127
Figure 63: Should-Cost for Heat Exchangers 128

2 Table of Tables

Table 1: Demand, Order Lead Time, Capacity Utilization, and Prices 12
Table 2: Key Indicators for Distillation Columns 13
Table 3: Reported or Estimated Capacity Utilization Rates at Selected Distillation Column Suppliers 18
Table 4: Summary of New Contracts and Estimated Values for Distillation Columns 19
Table 5: Regional Price Variations over Time for Distillation Columns 26
Table 6: Incremental Cost per Extra Parameter or Feature for Distillation Columns 27
Table 7: Key Indicators for Towers 31
Table 8: Reported or Estimated Capacity Utilization Rates at Selected Tower Suppliers 35
Table 9: Summary of New Contracts and Estimated Values for Towers 37
Table 10: Regional Price Variations over Time for Towers 43
Table 11: Incremental Cost per Extra Parameter or Feature for Towers 44
Table 12: Key Indicators for Hydrocracking Reactors 47
Table 13: Reported or Estimated Capacity Utilization Rates at Selected Hydrocracking Reactor Suppliers 53
Table 14: Summary of New Contracts and Estimated Values for Hydrocracking Reactors 55
Table 15: Regional Price Variations over Time for Hydrocracking Reactors 61
Table 16: Incremental Cost per Extra Parameter or Feature for Hydrocracking Reactors 62
Table 17: Key Indicators for Hydrotreating Reactors 66
Table 18: Reported or Estimated Capacity Utilization Rates at Selected Hydrotreating Reactor Suppliers 70
Table 19: Summary of New Contracts and Estimated Values for Hydrotreating Reactors 73
Table 20: Regional Price Variations over Time for Hydrotreating Reactors 77
Table 21: Incremental Cost per Extra Parameter or Feature for Hydrotreating Reactors 79
Table 22: Key Indicators for Coke Drums 82
Table 23: Reported or Estimated Capacity Utilization Rates at Selected Coke Drums Suppliers 86
Table 24: Summary of New Contracts and Estimated Values for Coke Drums 87
Table 25: Regional Price Variations over Time for Coke Drums 94
Table 26: Incremental Cost per Extra Parameter or Feature for Coke Drums 94
Table 27: Key Indicators for Spherical LPG Tanks 98
Table 28: Reported or Estimated Capacity Utilization Rates at Selected Spherical LPG Tanks Suppliers 101
Table 29: Summary of New Contracts and Estimated Values for Spherical LPG Tanks 104
Table 30: Regional Price Variations over Time for Spherical LPG Tanks 109
Table 31: Incremental Cost per Extra Parameter or Feature for Spherical LPG Tanks 110
Table 32: Key Indicators for Heat Exchangers 113
Table 33: Reported or Estimated Capacity Utilization Rates at Selected Heat Exchangers Suppliers 118
Table 34: Summary of New Contracts and Estimated Values for Heat Exchangers 120
Table 35: Regional Price Variations over Time for Heat Exchangers 124
Table 36: Incremental Cost per Extra Parameter or Feature for Heat Exchangers 125

3 Scope

"Pressure Vessels" is a broad category of equipment comprised of units that range from small tanks to hold pressurized gas to nuclear reactors. Our focus for the purpose of this study is on large process and storage units for crude oil refining. Specifically, we have subdivided the market into the following subcategories:

- Crude Distillation Columns
- Stripper Columns
- Catalytic Hydrocracking Reactors
- Hydrotreating Reactors
- Coke Drums
- Spherical LPG Tanks
- Heat Exchangers

Crude Distillation Columns: Distillation is one of the most common and energy-intensive separation processes. In a typical chemical plant, it accounts for as much as 40% of the total energy consumption, depending on the number and type of downstream processing units. There are two main types of distillation tower covered in this study:

- Atmospheric distillation unit (ADU): also known as a fractionating tower. It is used to separate hydrocarbons with boiling points less than 77° F apart. The crude is heated (first by a fired heater, then residually by a reboiler, which are separate pieces of equipment and not in scope), causing the crude stream to separate into fractions with tighter ranges of boiling points that are then refined further. Atmospheric distillation columns are typically vertical, cylindrical columns ranging from 2' to 20' in diameter and 20' to 200' or more in height. The tower internals most commonly consist of inlet dispersion nozzles, outlet nozzles, instrument nozzles, and valve trays to help maintain fractional distribution.
- Vacuum distillation unit (VDU): vacuum distillation takes place after fractionating, on the atmospheric bottoms fractions, because at atmospheric pressures crude oil cannot be heated beyond about 720° F before it starts to deposit coke and foul the tower and piping. Under vacuum, the remaining fractions separate at lower temperatures. Outputs are light vacuum gas oil (which goes to a hydrotreater and often an FCC unit), heavy gas oil (which goes to a hydrocracker), and vacuum residuum (which goes to a coker). Diameter typically ranges up to 46 feet, heights up to about 164 feet. VDUs are typically both trayed and packed, with as many as 14 alternating rows of trays and packing.

Component Removal and Reforming Towers (Towers): Throughout the refinery, there are smaller towers to recover or remove specific hydrocarbon or diluent components. These components range from saleable light hydrocarbons such as propane, butane, or methane, to undesirable contaminants including CO2 and H2S. A typical unit is 4' in diameter and 40' long, rated to withstand pressures of

up to 900 psig. Internals routinely consist of either trays, packing, or both, depending on the application. Subcategories include:

- Debutanizers
- Depropanizers
- Demethanizers
- CO2 Strippers
- Sour Water Strippers
- Reformers

Catalytic Hydrocracking Reactors (Hydrocrackers)*:* Hydrocracking reactors are the heavy-wall, high pressure reactors that house the hydrocracking process, which saturates residual fractions of hydrocarbons with hydrogen, converting them to diesel, kerosene, and, to a smaller extent, gasoline. This process ranges in severity from 260-480 °C and 70-200 bar. At the lower range of severity, the process is known as mild hydrocracking. As a result, wall thicknesses range from 8" to 16", and metallurgy requirements from 2 ¼ Cr-1 Mo (¼V) or 3 Cr-1Mo with stainless steel cladding. This study focuses on units at the higher end of the severity spectrum, able to withstand temperatures up to 930 F and pressures up to 2200 psig. Internals consist of catalyst beds, distributor trays, feed distribution nozzles, impingement plates or mixing chambers, quench rings, and support beams. Typical hydrocracking units employ 2-3 reactors each, and as many as six.

Ancillary equipment and supplies included in a hydrocracking process unit that are out of scope: Catalysts, Feed filters, Surge Drums, Charge Heaters, Charge Pumps, Separators, Flash Drums, and gas compressors.

Hydrotreating Reactors (Hydrotreaters): These vessels house a similar process to hydrocracking, simply less severe – maximum temperatures of 750 F and pressures of 1675 psig. As a result, the reactors are smaller, with thinner walls – 3" to 6" – and metallurgy is less advanced – typically 1Cr-.5 Mo with 410 stainless cladding.

Coke drums: are used to thermally crack bottoms residue (typically from an FCC unit) into lighter fractions. The drums must withstand intense and varying temperatures – up to 950° F during the heat cycle, down to near ambient temperatures during the quench cycle, but comparatively low pressures of 80 psig. Metallurgy ranges from carbon - ½ Mo steel to 2 ¼ Cr 1 Mo. Drum diameters range from 20-30', mostly on the higher end to reduce capital costs per barrel of output. Delayed coking units typically consist of 4-8 drums. Conventional, horizontal plate coke drums use progressively thicker walls toward the base of the drum to combat "bulging" as the plates bend under the higher pressure toward the bottom of the unit. As a result, wall thickness is typically 1.37-1.5" at the bottom plate and as little as .875" at the top plate. Vertical plate units maintain a constant thickness throughout.

Spherical LPG Tanks: are designed to hold gases too highly pressurized for cylindrical tanks. Construction is typically carbon steel, and diameters range from 10' to 150'. Wall thicknesses range from 75mm for small diameter spheres to as much as 300mm. The relevant codes governing spherical tank design are ASME VIII division I, and API 650-620-520.

Heat Exchangers: pass heat from one fluid to another without allowing them to mix. This transfer can use heated process fluids to boil water and create steam that is then used to power rotating machinery. Fluids include process liquids such as crude oil and refined products, water, and gases such as air. Applications by industry within the scope of this study include petroleum refining, chemicals, natural gas processing, LNG, and power generation – these industries account for approximately 70% of total heat exchanger sales. Other industry applications, not included in scope because they are not as specialized as the process units used in the oil and gas industry, include space heating, refrigeration, and air conditioning.

Subcategories include:

- Shell and tube
- Double pipe
- Plate and frame
- Air coolers
- Fin and tube
- Finned air coolers
- Coil-wound
- Box coolers

This study excludes reboilers (such as those used to maintain the heat balance in a distillation column) from scope, as they are, while similar in design, functionally a furnace rather than a heat exchanger.

4 Legend

Abbreviations

API: American Petroleum Institute
ASME: American Society of Manufacturing Engineers
b: billions
Bpd: barrels per day
Bbl: barrel of crude oil
BTU: British Thermal Unit
Capex: capital expenditure
CCGT: Combined Cycle Gas Turbine
CHP: Combined Heat and Power
Cfm: cubic feet per minute
E&P: Exploration and Production
EPC: Engineering, Procurement, and Construction
FPSO: floating production, storage and offloading
GW: gigawatts
k: thousands
kW: kilowatts
m: millions
MW: megawatts
M&A: Merger and Acquisition
MENA: Middle East and North Africa
Mmbtu: one million BTUs
MRO: maintenance, repair and operating
NGL: Natural Gas Liquids
Nm: Newton-meter
Psi: pounds per square inch
ROP: Rate of Penetration
t: trillion
Tonnes=metric tons
Tons: short tons
Tpy: tons per year
WTI: West Texas Intermediate crude oil
YOY: year over year
YTD: year to date

Alerts:

Yellow Alert (applies to any time period)

- Capacity margin < $150 million per year
- Capacity Utilization > 85%
- Important news

Red Alert (applies to next year only)

- Prices change 5%+
- Capacity margin < $100 million per year
- Capacity Utilization > 90%

Chart Symbols:

≡ Stable, ▲= Increasing, ▼ = Decreasing, LO = Low supplier concentration, ► = Moderate supplier concentration, HI= High supplier concentration

5 Methodological Notes

1. Demand is nominal (not real, inflation-adjusted), and is based on Sales excluding backlog that has not yet been recognized as revenue.
2. Prices are for new commitments. Average market prices typically lag the index based on the time it takes for pre-existing contracts to end or roll over. Price changes are nominal (not real, inflation-adjusted). Price changes are net of the cost of quality improvements, so actual market prices may exceed the amounts indicated.
3. Capacity includes base production capability plus plant openings and temporary capacity increases such as extra shifts, minus plant closings and temporary capacity reductions such as reductions of working hours or suspension of operations. Capacity estimates are unadjusted for possible efficiencies from process improvements. Capacity is adjusted for productivity improvements.
4. Capacity utilization means output as a percent of possible production, given no major investment. Capacity utilization rates are either self-reported or estimated. Orders above capacity to produce are considered backlog and do not result in capacity utilization rates above 100%. Overtime increases the capacity utilization rate and could make capacity utilization rates exceed 100%, whereas extra shifts count toward capacity and would not normally result in capacity utilization rates exceeding 100%.
5. Capacity Margin is the aggregate amount of available (unutilized) capacity based on utilization rates and total capacity. It is not adjusted for capacity that suppliers may have reserved for specific customers, so actual available capacity may be lower.
6. Order Lead Time is for Configure-to-Order (also called Assemble-to-Order), Make-to-Order, and where specified, Engineered-to-Order items, not for stocked/inventories items (for which lead time is very short). If categories consist only of stocked/inventoried items, lead time is not tracked. The basis is ex-works (from the time the order is placed until it is ready for shipping). Where there is a choice, Order Lead Time is based on oil and gas applications of higher-value items within each category (e.g., stainless steel rather than carbon steel, or with customizations such as ceramic coating).

6 Vital Statistics

Table 1: Demand, Order Lead Time, Capacity Utilization, and Prices

Metric	Time Horizon	Distillation Columns		Component Removal and Reforming Towers		Hydro-cracking Reactors		Hydro-treating Reactors		Coke Drums		Spherical LPG Tanks		Heat Ex-changers	
Demand ($M, per quarter)	Q1 2013		424		886		268		292		200		147		4,168
	Q1 2015	▲	467	▲	975	▲	297	▲	323	▲	219	▲	161	▲	4,539
	Q1 2020	▲	657	▲	1,439	▲	432	▲	474	▲	308	▲	224	▲	6,146
	'13-'15	▲	10.0%	▲	10.0%	▲	10.7%	▲	10.8%	▲	9.8%	▲	9.6%	▲	8.9%
	'13-'20	▲	54.7%	▲	62.4%	▲	61.0%	▲	62.4%	▲	54.2%	▲	53.1%	▲	47.4%
Order Lead Time (Weeks)	Q1 2013		52		45		47		56		57		60		47
	Q1 2015	▲	52	▲	46	▲	49	▲	57	▼	57	▲	60	▲	48
	Q1 2020	▼	51	▼	45	▼	46	▲	57	▼	54	▲	60	▼	47
	'13-'15	▲	0.6%	▲	1.4%	▲	3.7%	▲	2.1%	▼	0%	▲	2%	▲	2.6%
	'13-'20	▼	-0.9%	▼	-0.3%	▼	-2.1%	≡	1.3%	▼	-5%	≡	1%	▼	-0.3%
Capacity Utilization (%)	Q1 2013		74%		75%		68%		75%		76%		76%		72.7%
	Q1 2015	▲	76%	▲	78%	▲	74%	▲	78%	▲	77%	▼	76%	▲	76.6%
	Q1 2020	▲	78%	▲	81%	▲	75%	▲	80%	▲	79%	▼	76%	▲	80.0%
	'13-'15	▲	1.9%	▲	2.6%	▲	5.0%	▲	3.4%	▲	0.7%	▼	-0.8%	▲	4%
	'13-'20	▲	3.8%	▲	6.3%	▲	6.8%	▲	5.4%	▲	2.7%	▼	0%	▲	7.3%
Prices (Index 2005Q1 =100)	Q1 2013		125.5		123		149		148		150		163		168
	Q1 2015	▲	132	▲	128	▲	154	▲	156	▲	155	▲	170.4	▲	177.2
	Q1 2020	▲	146	▲	142	▲	170	▲	173	▲	168	▲	187.7	▲	194.7
	'13-'15	▲	4.8%	▲	4.8%	▲	3.9%	▲	5.2%	▲	3.2%	▲	4.7%	▲	5.3%
	'13-'20	▲	16.0%	▲	15.7%	▲	14.5%	▲	16.8%	▲	12.2%	▲	15.4%	▲	15.7%

7 Distillation Columns

7.1 Market Overview

Table 2: Key Indicators for Distillation Columns

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	10.0%	▲	54.7%
Demand ($m)	▲	424-467	▲	424-657
Capacity Utilization	▲	2.0%	▲	4.0%
Prices	▲	4.8%	▲	16.0%

7.1.1 Demand

Demand for Distillation Columns rose 1.2% in Q4. Growth has slowed to 0.2% per quarter in 2013 on weak fuel demand. Sales increases will accelerate to 1.6-1.8% per quarter (a total of 55%) through 2020 Q1 on refinery orders from Asia, South America, and the Middle East.

Distillation Column orders are limited to, and dependent upon, the refining industry. All refineries require these immense towers, meaning that every greenfield project will have at least one, and often 2-3. The refinery's overall capacity is dictated by the capacity of the crude distillation unit (when a refinery is referred to as having a certain number of barrels per day of capacity, that number is the distillation units input capacity), so major expansions typically include new or expanded distillation columns as well.

Refinery capital spending grew modestly from 2010-2011, at annual rates of 3% globally as refiners went ahead with projects they postponed in 2009. Examples include Motiva's Port Arthur expansion in the US, Sinopec's Fujian Refinery in China, and Indian Projects in Bathinda and Vadinar. Capital expenditures in the refining sector surged 6% in 2012 as refineries scheduled to open this year took delivery of, and in some cases even erected, their distillation columns. Examples include:

- SATORP (Saudi Aramco Total Refining Project) has installed most of the equipment (Zamil Steel supplied the distillation columns) for its 400k bpd refinery in Jubail, Saudi Arabia, and will commence full operations later this year.
- IOCL's 300k bpd Paradip refinery has completed pre-commissioning tests at its 300k bpd crude unit (including one atmospheric tower and one vacuum tower from Essar).
- Sinochem is also preparing to commission its 240k bpd Quanzhou refinery, with distillation columns from Sinopec Engineering.
- Petrobras' Premium I refinery has suffered multiple delays, and is not scheduled to begin operating until 2015, but the distillation columns are already purchased (from Larsen & Toubro).

The above glut of investment has robbed 2013 of some of its growth, along with slow fuel demand and economic activity in the US and Western Europe, and global sales will only 0.7% this year. Growth rates for Distillation Columns are slightly slower than those for overall refinery spending, as many investments scheduled for this year are for hydroprocessing units to help refiners meet fuel standards such as Euro 6 and the comparable regulations recently announced in China.

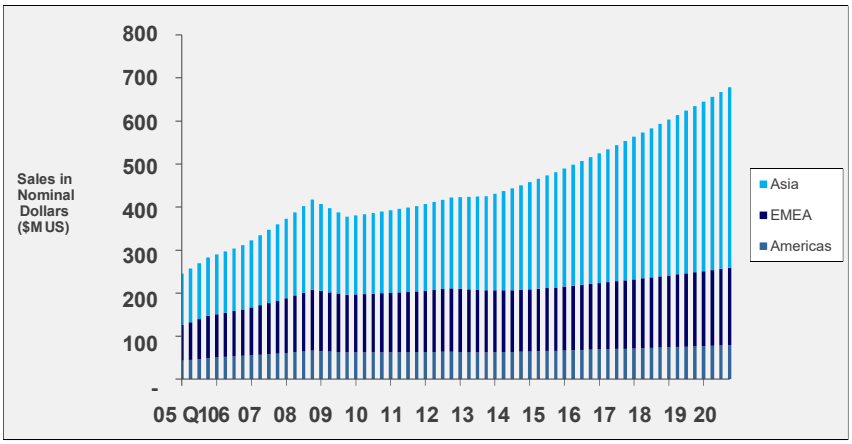
Asia is driving global growth this year, where Distillation Column sales will rise 3.5%. The Chinese government has promised to enact emissions regulations comparable to Euro 6 by 2017, and hold refiners responsible for meeting them with stiffer fines. Corollary to this decree, Beijing has also ordered China's major refiners, CNPC, CNOOC, and CPC to upgrade refining facilities to meet these standards. In part to comply with this directive, the above firms have multiple refineries in various stages of construction. The following units are scheduled for completion in 2014 or 2015, and some have already ordered Distillation Columns:

- CNOOC is building a 220k bpd refinery in Huizhou.
- Sinopec has two new refineries under construction, a 350k bpd complex in Zhanjiang (in cooperation with Kuwait Petroleum Corporation) and one half that size in Zhenhai.
- Petrochina is building a 200k bpd refinery in Dagang.

Distillation Column sales will drop 2.7% in the Americas this year on slow US spending. US fuel consumption has fallen every year since 2007, with the exception of 2010, due to slow economic growth and a transition to more fuel efficient vehicles. Fuel demand receded 1.3% in 2011, 1.6% in 2012, and is down another 1.5% on average in 2013. Overall economic growth in the world's largest economy remains sluggish as well, at 1.8% in 2012 Q2 and 2.2% in 2012 Q4, and the slow spending will contribute to a 5% drop in US refinery investments compared to 2012. Also in the Americas, Pemex kept its Tula refinery on hold, as US buyers are no longer importing as much light product (due to shale oil production). Other Latin American investments will slow the rate of decline, including ongoing refinery projects such as Petrobras' Premium II and PDVSA's El Palito.

Refinery investments will fall 2% in EMEA, where there is excess refining capacity. Petroplus Holdings, once the largest refiner in Europe, filed for insolvency in 2012, shutting down major refineries such at Coryton in the UK and Petit Couronne, in France. Despite Western Europe's torpor, ongoing investments in projects such as Jazan and Yanbu in Saudi Arabia (Saudi Aramco) and Volgograd in Russia (Lukoil) will prevent a steeper drop in spending this year.

Figure 1: Demand for Distillation Columns



Aggressive refinery investments in Asia and Russia to modernize refining capacity and meet local demand growth, along with continued project activity in the Middle East, Brazil, and Venezuela will drive cumulative demand growth of 52.5% through 2020.

China accounts for a third of global oil demand growth, according to the International Energy Agency, which, combined with the government's modernization imperative, will drive Asian demand for Distillation Columns up 85% by 2020 Q1.

- CNPC and PDVSA are building a 400k bpd complex (Nanhai) to process Orinoco crude.
- Sinopec is planning a 100k bpd expansion of its Zhenhai refinery, with construction scheduled to begin in 2014.
- More than a dozen other Chinese projects are in various stages of planning, with a combined total of 1.85m bpd in refining capacity on the table.

China is not the only Asian country with major plans underway, for example:

- Indian refiner CPCL is planning to add another 500k bod in capacity with two expansions (Manali and Cuddalore).
- In Malaysia, Petronas has started construction on two refineries (Johor and Melaka II), with 475k bpd in combined capacity.
- PetroVietnam is also planning two refineries, Nghi Son and Dung Quat, which together will process 400k bpd.

In the Americas, most of the impetus will come from Brazil and, to some extent, Venezuela. However, multiple refining projects are underway or in the planning stages in the US and Canada that will contribute to the region's 22% increase in Distillation Column sales by 2020. Petrobras, determined to supply all of Brazil's diesel needs, in order to stop importing the fuel at a loss, has five refinery projects scheduled for completion between 2014 and 2018 with a combined 1.625m

bpd in capacity: Abreu e Lima, ComperjI, Premium I, Premium II, and Comperj II. In Venezuela, the 140k bod El Palito expansion is scheduled to begin operating in 2015.

Valero is adding a new 90k bpd distillation column at its Houston refinery to handle additional volume from shale plays in the region. The tower is not accompanied by cracking capacity due to the lighter production slate from the region, which has increased the supply of light, sweet crude available, leaving the Houston refinery's cracking capacity underutilized due to the lower bottoms fractions in the crude slate. Canadian bitumen producers such as Suncor are considering multiple processing paths to market for oil sands mined at projects such as Fort Hills and Joslyn. Now that Suncor and Total have canceled the Voyageur upgrader, partial processing and export may be the most economical means of monetizing the bitumen.

EMEA orders will primarily come from the Middle East and Russia, where multiple megaprojects will drive Distillation Column sales up 19% by 2020. Saudi Arabia's Yanbu and Jazan projects (800k bod in total capacity), are scheduled to finish in 2014 and 2017, respectively. Iraq's state oil company is in the process of auctioning off the rights to develop a 300k bpd refinery adjacent to the Nassiriya field. KNPC in Kuwait will expand two refineries, adding 264k bpd in capacity. In Russia, Gazpromneft is expanding its Omsk plant, while Rosneft is doubling capacity at Novokuybishevskiy.

2. Supply (Capacity)

Capacity is stable for 2013 as suppliers wait for orders to pick up due to low utilization rates. Larsen & Toubro, Sinopec, and Sungjin, among others, are ready to add capacity or shift it from other operations to meet rising demand beginning in 2014.

The top Distillation Column manufacturers are:

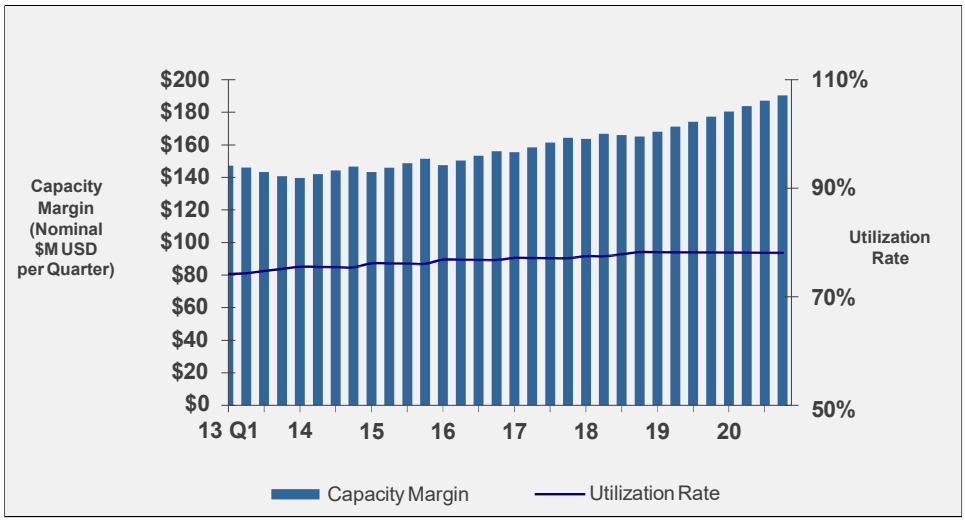
- Larsen & Toubro
- Essar Group
- POSCO (Sungjin)
- Sinopec Engineering
- Hitachi Zosen
- IDESA
- Doosan
- Zamil Group
- Cryostar Tanks and Vessels
- CPDTC

Capacity for Distillation Columns is stable and so is Capacity Margin, at $570m and $147m per quarter, respectively. This is more than adequate to handle forecast demand in 2013.

Average capacity utilization is 74%, low enough to give buyers negotiating leverage if they have major orders. Utilization rates of 74% are low enough to cause worry for most manufacturers, restraining their ability to absorb overhead costs, and they are targeting rates of 80%.

- Larsen and Toubro is 70% utilized due to recent expansions at two yards in India. The firm considers capacity for large column walls and internals adequate at this point, and its utilization rate will rise with orders for the foreseeable future.
- Sinopec Engineering is 80% utilized on strong orders from Chinese refinery expansions (such as the one at Hainan) and greenfield projects (including Guanzhou, and Huizhou). The firm has enough comparable machinery to shift work allocations and maintain utilization rates at roughly 80%.
- In the US, NRG Manufacturing and Patterson Industries are both about 75% utilized. Both manufacturers are keeping occupied with expansion projects, such as Kinder Morgan's NGL processing plant in Texas and two new small-scale refineries in North Dakota.
- In Europe, IDESA is 80% utilized, higher than average for the region on recent orders from Russian refinery expansions.
- Turkish Cimtas has two plants, one in Turkey (80% utilized), and a recently expanded location in China (70% utilized).
- KNM, based in Malaysia, is 75-80% utilized.

Figure 2: Capacity Margin - Distillation Columns



The only reason suppliers are willing to sustain utilization rates this low is that they all have other lines of business across which to amortize their capital equipment. By the same token, many of the milling, bending, cutting, and welding machines that are used in other manufacturing operations can be repurposed to column manufacturing operations if necessary, making a reserve of flexible capacity.

More often, the bottleneck for Distillation Column delivery and commissioning is construction labor. For example, Olayan Descon's plant in Saudi Arabia is only 50% utilized, but its installation crews are 100% utilized. In the global market however, manufacturers and EPCs have enough installation capacity as well.

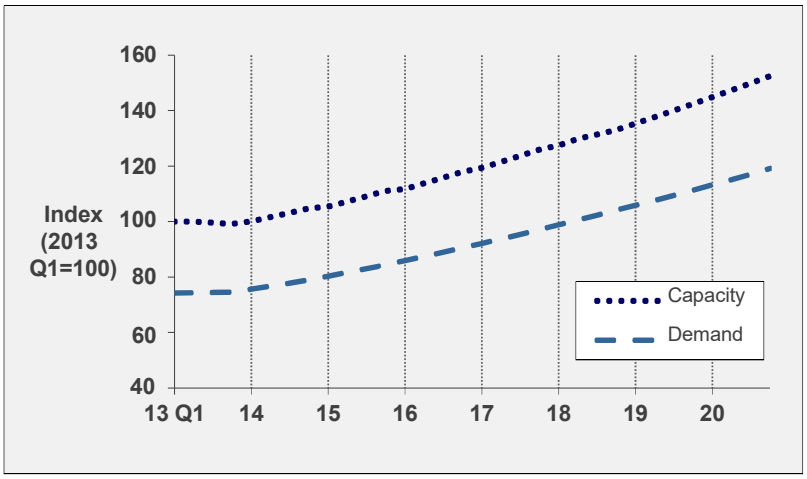
Table 3: Reported or Estimated Capacity Utilization Rates at Selected Distillation Column Suppliers

Company	Country	Current Level	12-Month Forecast
KNM	Malaysia	75%	80%
Larsen & Toubro	India	70%	74%
Sinopec Engineering	China	80%	80%
NRG Manufacturing	US	75%	75%
Hitachi Zosen	Korea	70%	70%
CPTDC	China	70%	70%
IDESA	Spain	80%	80%
Cimtas	China	70%	75%
Cimtas	Turkey	80%	82%
Olayan Descon	Saudi Arabia	50%/100%*	55%/100%

*Manufacturing/installation

Capacity utilization will rise with demand beginning in 2014, first to 75% early next year and progressively to 78% in 2018. At forecast demand growth rates, buyers will maintain their ability to put pressure on prices due to low manufacturing utilization.

Figure 3: Demand vs. Capacity - Distillation Columns



3. New contracts

Saudi Arabian contracts dominate the current project list, followed by orders from South America.

Saudi Aramco's joint venture projects have been the largest single contract wins in recent years.

- The larger of the two orders, at $9m, was for the SASREF project in Yanbu. Zamil Group, a local Saudi supplier, booked the contract for six columns; four ADUs and two VDUs, at an average unit price of $1.5m.
- Sungjin won the order for distillation column fabrication for SATORP, an $8m contract, this one for two larger ADUs and two VDUs.

South American orders from Petrobras and EcoPetrol followed up the list of large, visible contracts. Petrobras ordered columns from Larsen & Toubro, the largest global supplier, for its Premium I refinery. The $6.8m contract is for three towers, two 300k bpd ADUs and one VDU of approximately the same size. Ecopetrol revamped its Barrancabermeja crude unit, overhauling the ADU and adding a VDU to allow it to process heavier crudes.

Table 4: Summary of New Contracts and Estimated Values for Distillation Columns

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)

Saudi Aramco - Yanbu	Saudi Arabia	Zamil	ADU and VDU (2 columns each)	$9.00	$1.50
SATORP - Jubail	Saudi Arabia	Sungjin	ADU and VDU (2 columns each)	$8.00	$2.00
Petrobras - Premium I	Brazil	Larsen & Toubro	Two 300k bpd ADUs, 1 VDU	$5.74	$1.91
Ecopetrol - Barrancabermeja	Colombia	Unknown	ADU revamp and new VDU	$5.00	$2.50
IOCL - Paradip	India	Essar	300k bpd CDU	$4.70	$2.35
Gazpromneft - Omsk	Russia	IDESA	ADU and VDU	$4.50	$2.25
Sinochem - Guanzhou	China	Sinopec	240k bpd ADU and VDU	$4.30	$2.15
YPFB - Gran Chaco	Bolivia	Duro Felguera	NGL separation fractionator	$2.80	$2.80
Dakota Oil Processing - Trenton	US	Titan	20k bpd, SS clad column	$2.00	$2.00
Kinder Morgan - Galena Park	US	Patterson	Two 50k bpd fractionators	$1.50	$0.75

7.2 Analysis

7.2.1 Costs

Distillation Column costs will rise 2% in 2013, below global inflation rates due to slow demand growth. Costs will increase steadily and gradually at about 1% per year in the Americas and EMEA, and 2% annually in Asia, due to faster labor cost increases.

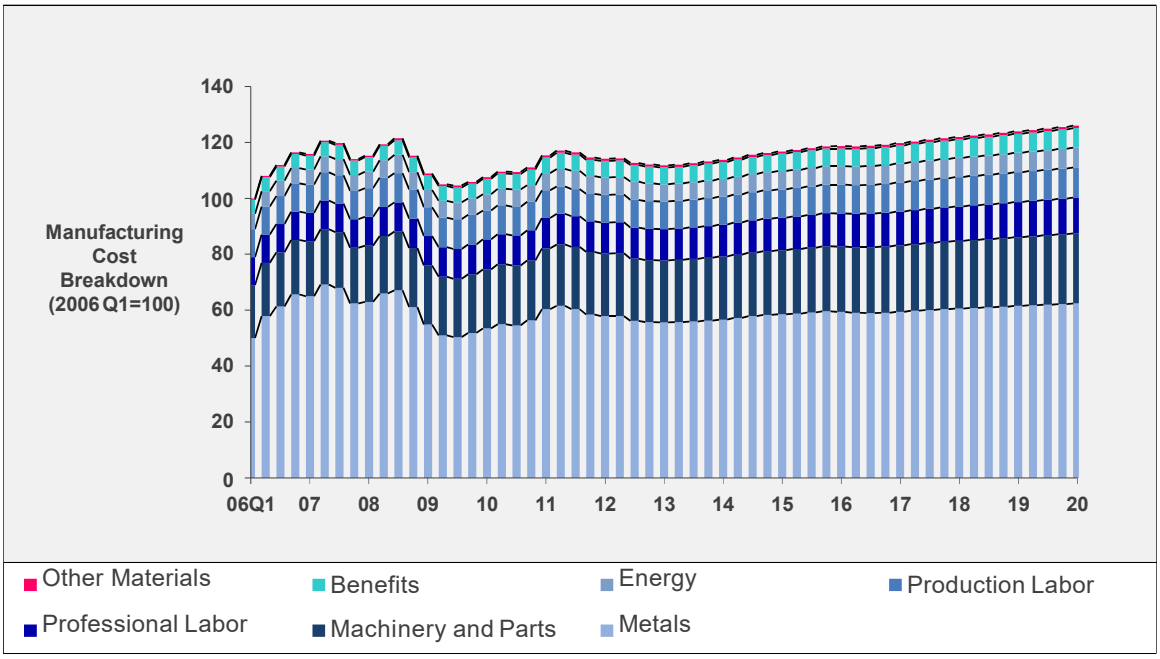
Metals, primarily carbon and chrome steel, make up more than 50% of the cost structure for Distillation Columns. In some instances, particularly when high sulfur crudes are being processed, columns and internals are clad with stainless steel to increase their resistance to corrosion.

Costs for carbon steel used in Distillation Column manufacturing have fallen a cumulative 13% over the past year due to oversupply; to per-tonne prices ranging from $515-$650m on the spot market in 2013 Q1. The drop in steel costs held global cost growth down to 1% in 2012 (labor and machinery costs rose 4-5% for the year). Carbon steel costs are beginning to rebound, and will rise a total of 3% in Q3 and Q4, supporting global cost growth of 2% in 2013.

Labor is the next most important cost category, on average accounting for 25% of the overall cost to make a unit based on US cost levels, although it makes up a smaller percentage in Asia and the Middle East – only 5-15%. Welding and machining labor costs are rising at a global rate of about 1% per year. In contrast, engineering and management labor costs are rising twice that fast (and faster in Asia) due to the more limited number of qualified professionals entering the workforce.

Machinery accounts for most of the remaining cost structure, at 19% of the total. These machines include forging, rolling, milling, bending, CNC, cutting, and welding systems as well as drills, lathes, and cranes in a variety of sizes. Machinery costs retreated slightly in 2012, along with carbon steel, but have returned to growth of about 2% per year globally, which will continue through 2020.

Figure 4: Cost Structure of Distillation Columns



Note: Prices are ex-works.

7.2.2 Profit Margins

Industry margins are thin due to low capacity utilization and the common buying practice of levering prices down through economies of scope.

Distillation columns are high-value, custom-designed pieces of process equipment, which would suggest a high rate of return for manufacturers – for example, engineered pump manufacturers earn a gross margin of more than 14%. However, distillation columns are dwarfed in terms of investment scale and complexity by the refinery's more advanced processing units (e.g. hydrotreaters and hydrocrackers), so suppliers accept single digit, and even negative, margins on the relatively simple columns in order to win large bid packages, of which distillation columns are a part. Moreover, most of the major column manufacturers also bid on the more complex processing units above, and are often willing to cut margin on individual portions of their bids in order to win a larger package. Finally, manufacturers are often negotiating with the project's EPC rather than the

end-user – providing an additional incentive to bid low in order to establish or maintain a relationship with an EPC that may be a current or future partner on additional projects.

Asian suppliers, particularly Koreans Sungjin and Samsung, bid low to win projects from 2009-2011, and now are losing money due to the combination of low price points and cost overruns. EPCs Samsung and GS Engineering & Construction, working on multiple Middle Eastern refineries, are posting losses now, as are the fabricators for many of the components at the plants they are building. For example, GS E&C expects an operating loss of $730m this year. The losses will continue through next year, and Korean suppliers have no choice but to bid more consistently with the market to return to profitability. Examples at specific companies include:

- Sungjin's operating margin was -3% in 2012, on gross margin of only 1.6% due to a combination of slow order bookings and underbidding on the orders it did win.
- Doosan Heavy Engineering's net margin was -1.15% for the first half of 2012 (the latest reporting period available), for the same reasons.
- Hitachi Zosen's operating margin was -6% in 2012, partially due to currency factors, but primarily because of cost overruns on projects that it bid low to win.

In contrast, Spanish IDESA and Saudi Arabian Zamil Group earned higher than average margins on orders from Gazpromneft and Saudi Aramco, respectively. IDESA's refinery process equipment division had a net margin of 6% last year, while Zamil earned 5.3%.

Larger, more specialized units typically earn higher margins, although this again depends somewhat on the size of the overall project and the other equipment that the supplier is bidding on. One Asian manufacturer's gross margin on a 300k bpd column is typically 10-15%, compared to 7-10% for a 120k bpd column. Stainless steel cladding also increases a manufacturer's margin. There are fewer suppliers capable of handling the cladding operation, and they can leave more room for profit in their bids.

The highly-competitive nature of the market for Distillation Columns leaves buyers with little leverage to bring unit price down (more than market forces have already accomplished for most projects) while only bidding the column itself. Most of the potential for cost reduction – and putting margin pressure on suppliers – comes from economies of scale or scope: ordering more units or bidding multiple types of equipment together.

7.2.3 Prices

Asian labor cost inflation drove slight price increases in Q1, and will support 1.5% price growth this year. Annual price growth will accelerate from 1.5-2% to 2-2.5% beginning in 2017 as higher orders and capacity utilization rates take some of the pressure of off manufacturers.

Average global prices for Distillation Columns have increased 20% since 2005 Q1, mostly due to rapid increases in costs for carbon and chrome steel. Carbon steel costs have risen 27% over the same period, and chrome steel costs 36%. Muting the impact of metals, machinery costs have only risen about 15%. US production labor costs have actually fallen 2% since 2005, helping to slow price increases in the region. Costs and prices both rose sharply in 2006 and 2007, but retrenched somewhat with the global recession.

Rising labor and machinery costs only narrowly overpowered a drop in carbon steel prices last year, for average price inflation of just 1.5%.

- In Asia, a tight labor market drove factory wages up 4%, and professional salaries up 5%, for regional price growth of 2% for the year.
- Prices rose about 2% in EMEA as well, where machinery costs increased 4-5%.
- Prices actually fell almost 1% in the Americas, due to the drop in carbon steel, which was more distinct in the US due to high steel inventories there.

Prices rose another 1% in 2013 Q1, mostly driven by a 2% surge in Asian labor costs as manufacturers handed out annual raises, and they will increase a total of 2% this year on a broad swell in metal costs.

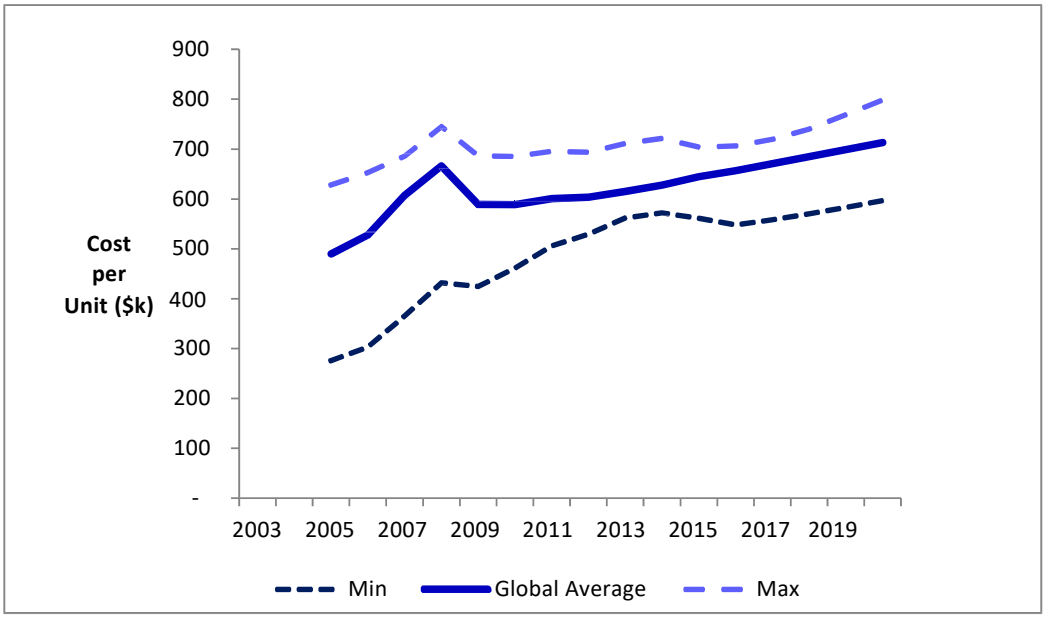
Global prices will increase a total of 16% from 2013 Q1 to 2020 Q1. The increase will be fastest in Asia (18%), compared to 14% in the Americas and 13% in EMEA. Much of the faster rates of increase in Asia and the Americas will be driven by large orders in those regions, rather than costs – notably the large-scale expansion programs in China and Brazil, respectively. In Asia, costs will rise approximately 14%, leaving 4% of the increase to be driven by demand dynamics. Costs will rise by about 14% in the Americas, and 11% in EMEA.

This forecast inflation beyond cost growth suggests that, while the recent recession has restricted supplier's margins, more aggressive demand growth starting in 2016 will give suppliers the flexibility to raise prices somewhat faster than costs increase.

Given the current single-digit and negative margins on Distillation Column sales, manufacturers' relevant business units are only making 1% net margin on average, buyers will be more effective at

limiting price increases than negotiating discounts from current levels. Furthermore economies of scale and of scope will be the best negotiating levers.

Figure 5: Overall Price Forecast for Distillation Columns



The reference unit for Distillation Columns is 30'x100', made of carbon steel, using valve trays, with daily throughput capacity of 75k bpd, rated for a maximum temperature of 800° F. The benchmark cost for this unit is $653k.

Japan, Western Europe, and the United States have the highest base prices (index levels of 109, 103, and 100).

- Higher prices from Japanese producers are driven by high electricity costs, more than double the benchmark cost in North America. Power costs are a major factor for column manufacturing, factored into the steel itself, the forge presses, and the cutting and welding processes. Labor costs in Japan are also higher (175% of the benchmark), due in part to Japan's high cost of living and shrinking population base. As a result, the benchmark unit, which would cost $653k in the US, would cost $714k from Japan.
- Western Europe has the high labor costs characteristic of mature economies, 12% higher than the US due to comparatively high costs of living, and similar costs for machinery and materials, leading to a slightly higher overall cost basis. Metals costs are slightly lower on average due to cheap imports from Russia, but power costs are higher, leaving the two regions with similar cost levels.

- US costs for materials and labor are higher than in most global regions, putting it at up to an 18% cost disadvantage compared to low-cost countries such as Malaysia.

Production costs are lowest in Asia, by a substantial margin.

- Manufacturing and materials costs are lowest in Southeast Asia – at an index level of 82. Labor costs are low, even compared to China and India, and comparatively little competing demand from heavy equipment manufacturers for steel produced by regional mills contributes to lower metal costs. KNM, based in Malaysia, is possibly the best-positioned of any manufacturer to take advantage of the low production costs in Southeast Asia.
- China and India have slightly higher price levels, at 87 and 86, respectively. Labor costs for machinists and welders are about 20% of US levels (80% cheaper) accounting for much of the difference. Lower electricity and slightly lower metals costs account for much of the rest. For example, Essar manufactured two distillation columns for IOCL's Paradip refinery, one ADU and one VDU, clad in stainless steel, for a total of $4.7m. Comparable units would have cost a total of $5.8m manufactured in the US or Western Europe.

Table 5: Regional Price Variations over Time for Distillation Columns

Region/Country	Today	2014	2015	2020
North America	1.00	1.00	0.98	1.05
Latin America	0.96	0.98	1.01	1.14
Europe	1.03	1.03	1.02	1.07
Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.88	1.02
Russia	0.89	0.94	0.94	1.12
China	0.87	0.88	0.86	0.91
Japan	1.09	1.11	1.08	1.08
Other Asia	0.82	0.83	0.81	0.85

7.2.4 Price Differences by Technology, Model, and Feature

All other things equal, distillation column costs are dictated primarily by size (diameter and number of trays), and material.

Using a baseline unit that is 10’ in diameter, 100’ tall, with 30 trays (benchmark cost of $653k), significant variations include:

- Each additional foot of diameter adds approximately $76k, although cost increases at a slightly increasing rate (2% more per increment of one foot), due to the slightly higher wall thickness requirement. Increasing the diameter of the unit to 20’ therefore raises the cost to $1.74m
- Adding height, typically in 10’, 5-tray increments, adds 13% to the cost of the tower. So a 120’ tall column (12’ in diameter) would cost $1m.
- Adding stainless steel cladding for corrosive applications adds 42-47% to the cost of the unit, depending on the wall thickness.

Table 6: Incremental Cost per Extra Parameter or Feature for Distillation Columns

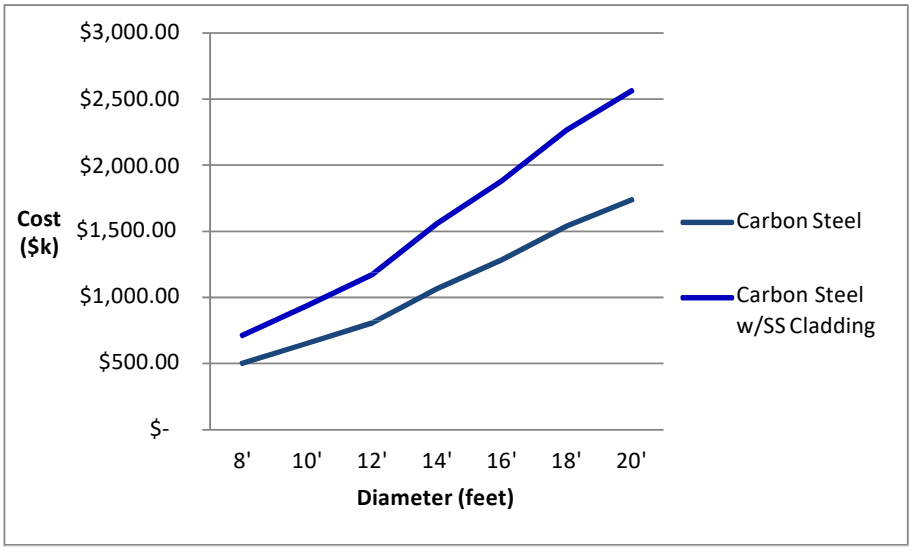
(Reference unit is 10' X 100', with 30 valve trays, made of carbon steel)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Diameter	Feet (base diameter is 10')	-$150.5k for 8' dia, +$154k for 12' dia	Cost increment accelerates by 2% per foot of diameter due to increased wall thickness
# of Trays	30, 35, 40 (base is 30)	Adding 5 trays (10 feet in height) increases cost by $81.7k	Cost trend is linear for each tray increment at a constant diameter
Material	Carbon steel as reference point	Stainless steel 316L cladding adds $284.5k to reference unit cost	Cost increment accelerates by 2-3% per foot of diameter due to increased wall thickness

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

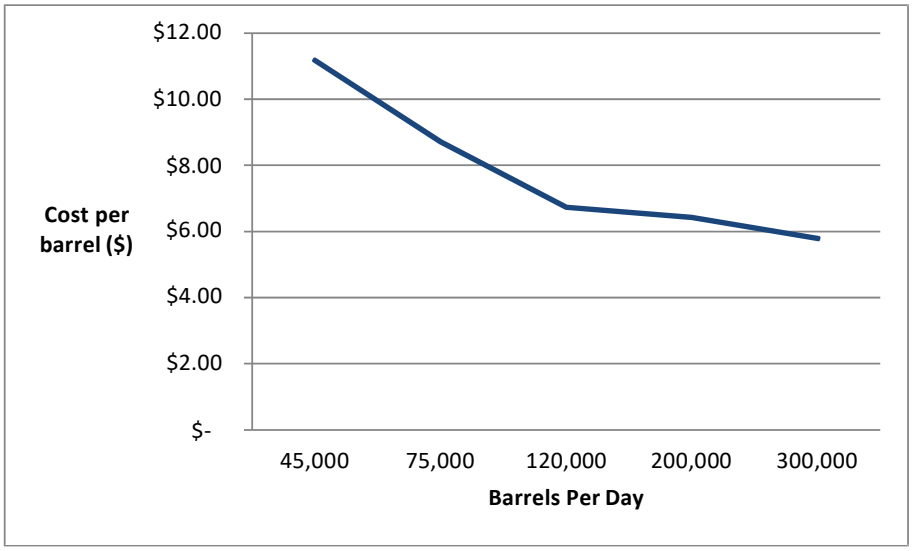
As illustrated in Figure 7, the cost of a distillation column rises at a slightly increasing rate with diameter. This effect is more pronounced with stainless steel cladding, due to the higher base cost of the material.

Figure 6: Distillation Column size vs. Cost – by Diameter



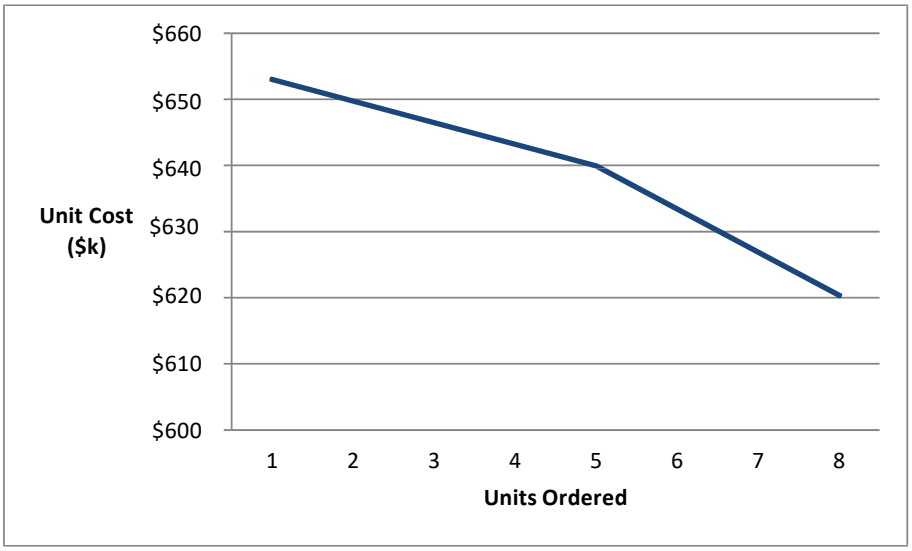
While increasing the size of the column raises the cost, it lowers the cost per barrel of processing capacity for most combinations of diameter and height. Cost per barrel of capacity falls dramatically from the benchmark unit ($8.71) to just under $6 per barrel for a 300k bpd column

Figure 7: Cost per unit of Output



Economies of scale are an effective way to bring down the unit cost for Distillation Columns, although most individual projects do not have the flexibility to vary the number of columns purchased without drastically altering the size of the planned refinery. Buyers with multi-project expansion plans, however, could realize up to a 10% discount to the unit cost by increasing the order size.

Figure 8: Economies of Scale in Distillation Columns



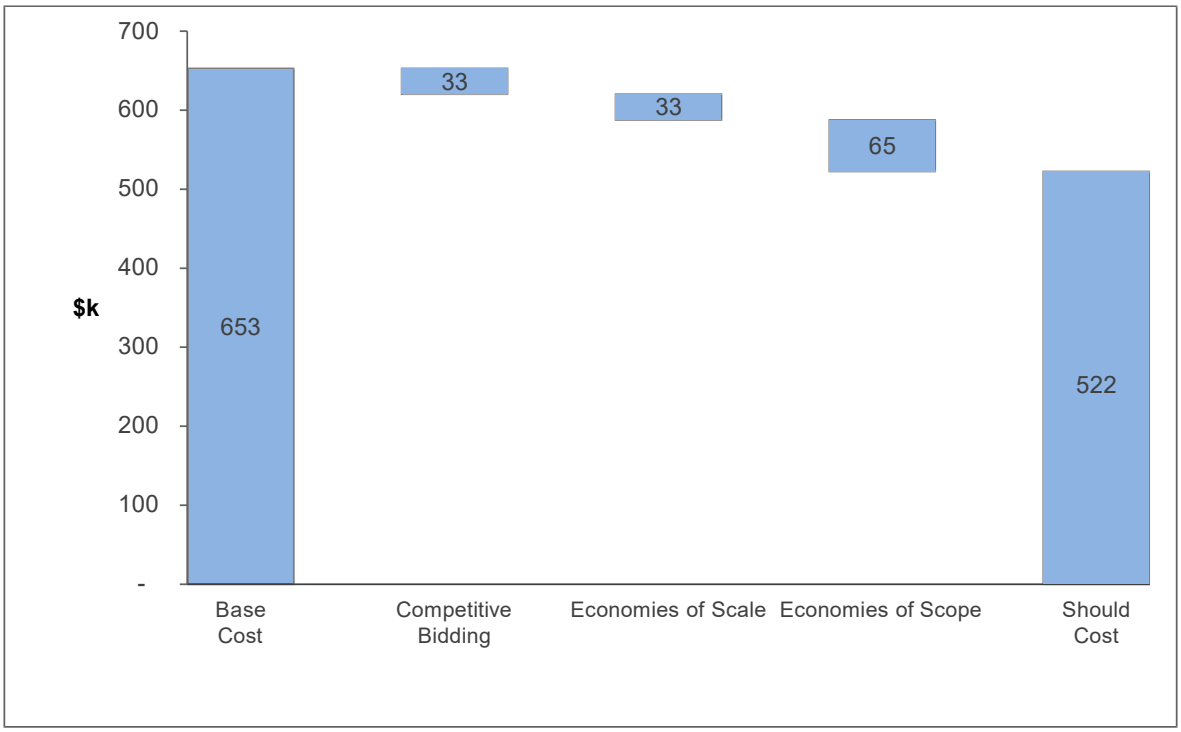
7.2.5 Should-Cost Analysis

Major refiners, and EPCs acting on their behalf, are well-rehearsed at wringing cost reductions from process equipment suppliers, primarily through competitive bidding and economies of scope. Cost-conscious refiners typically conduct multi-round bids for many types of process equipment, gaining up to a 5% price reduction through competitive bidding. They also typically award the distillation column along with other equipment contracts, which is the main incentive for the supplier to reduce its bid, and gain up to another 10% discount.

Economies of scale are often not fully utilized over multiple projects, as each project has its own management team, EPC, and design requirements. Economies of scale are therefore usually at most 5%, even for the largest orders. KNPC (Kuwait National Petroleum Company) is one exception to this general rule – it ordered multiple units for multiple projects from Larsen & Toubro. The columns are for expansions at the Mina Abdullah and Mina Al-Ahmadi Refineries as part of its Clean Fuels Project.

Figure 10 illustrates the potential savings per unit for a large order of four distillation columns.

Figure 9: Should-Cost for Distillation Columns



7.3 Price Negotiation Strategies

1. Negotiate framework agreements with 1-2 major suppliers. Suppliers are eager for the volume to raise utilization rates, and ordering more towers from one supplier would allow a buyer to achieve economies of scale that are typically only available for megaprojects. Ordering eight towers vs. four could double economies of scale benefits – from 5% to 10%.
2. Approach suppliers based in Europe such as IDESA and Duro Felguera. Home markets for these suppliers in Western Europe will remain stagnant in terms of refinery investment, helping keep prices low.

8 Component Removal and Reforming Towers (Towers)

8.1 Market Overview

Table 7: Key Indicators for Towers

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	10.0%	▲	62.5%
Demand ($m)	▲	886-975	▲	886-1,439
Capacity Utilization	▲	2.6%	▲	6.3%
Prices	▲	4.8%	▲	15.7%

8.1.1 Demand

Tower demand rose 6% in 2012, primarily on orders from Asia and the Middle East. Falling fuel demand in the US and Europe will curb demand growth in 2013 – to just 0.5% – but Asian and Latin American projects will drive demand up a total of 62.5% by 2020 Q1.

Spending on Towers is the most closely linked to overall refinery investments of any of the subcategories covered in this study. Towers of various types are the most common structures in a refinery and both greenfield developments and any expansion projects will include them. As a result, Tower demand moves in virtual lockstep with overall refinery spending.

Refinery capital expenditures plummeted 10% in 2009 as the global economy sank into recession, and only recovered 3% per year in 2010 and 2011. Despite investments in major projects over this period (including Sinopec's Fujian Refinery in China, Indian Projects in Bathinda and Vadinar, and Motiva's Port Arthur expansion in the US), multiple refineries in the US and Europe either closed or have been converted to terminals, slowing demand growth. In 2012, multiple projects installed towers prior to commissioning. These projects include:

- Sinochem's 240k bpd Quanzhou refinery installed 32 towers, including reformers, sour water strippers, and multiple aromatics extraction units, in preparation for commissioning this year.
- Chesapeake installed three demethanizer towers at its Kensington NGL plant, which will enter commercial operations in 2013 Q2.
- Although not all of the towers are completed, Lukoil ordered six units for its Volgograd refinery expansion. Progress payments on the units contributed to demand growth in 2012.

Demand growth has slowed in 2013 on soft spending in the US and Western Europe due to falling fuel demand and refinery closures. In the US, fuel demand is falling at a rate of 1.5% per year, and

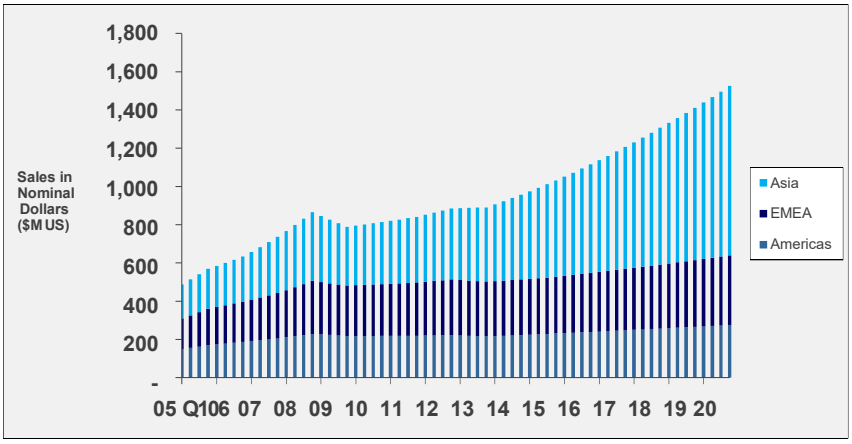
with Motiva's recently completed Port Arthur expansion, refiners are reluctant to invest during the prolonged economic slowdown. As a result, Tower demand will drop a total of 2.5% this year in the Americas. In Europe, multiple refineries scheduled for turnarounds or upgrades have closed instead, which will cause a similar 2% drop in EMEA demand this year. For example:

- Shell closed its 100k bpd Hamburg refinery in 2012, which was due for an upgrade.
- Petroplus sudden insolvency has shuttered units including the Petit Couronne refinery in France and the Coryton refinery in the UK.
- TNK BP's 140k Lisichansk refinery in Ukraine closed, instead of carrying out modernization plans.

Tower demand will rise 4.5% in Asia in 2013, preventing a drop in global sales this year. Beijing has ordered refiners to build facilities capable of complying with Euro 6 fuel standards by 2017, and multiple refineries under construction will order towers this year.

- Sinopec is building two new refineries, a 350k bpd complex in Zhanjiang and a 180k bod unit in Zhenhai.
- CNOOC's 220k bpd Huizhou refinery is scheduled for completion in 2014.
- Petrochina and Rosneft are cooperating to build 200k bpd refinery in Dagang.

Figure 10: Demand for Towers



Tower demand growth will accelerate to 7% in 2014, 8% per year through 2020 on refinery investments in Asia, Russia, the Middle East, and Latin America, for cumulative growth of 63% by 2020 Q1.

Asian demand will double over the forecast period (to $800m per quarter), as refiners add capacity in China, India, and throughout Southeast Asia. These plans include:

- Chinese refiners plan to add approximately 2.35m bpd of refining capacity by 2020, including a 400k bpd complex at Nanhai (CNPC and PDVSA) and a 100k bod expansion at Hainan (Sinopec).
- CPCL in India will add a total of 500k bpd in refining capacity at Manali and Cuddalore.
- Petronas plans to add 475k bpd In Malaysia, with two refineries at Johor and Melaka.

Demand for Towers will increase 21% in the Americas, primarily driven by Petrobras aggressive agenda of refinery expansions aimed to make Brazil a net exporter of diesel. The firm has five refinery projects scheduled for completion between 2014 and 2018 with a combined 1.625m bpd in capacity: Abreu e Lima, ComperjI, Premium I, Premium II, and Comperj II. Venezuela's 140k bpd El Palito expansion will also contribute to demand growth, as will two small new refineries in the US state of North Dakota to process liquids from the Bakken Shale.

Orders from Russia and the Middle East will support demand growth of 24% in EMEA. In Russia, Gazpromneft is expanding its Omsk plant, a planned investment of $3.7b, while Rosneft is doubling capacity at Novokuybishevskiy. Also, NefteGazIndustria Group's Afipsky refinery expansion will order three towers, a sour water stripper, a reformer, and a sulfur removal unit. Saudi Aramco has selected Hyundai Heavy Industries and JGC Corp, for work that will include towers at its Jazan refinery, scheduled for completion in 2017. The firm's JV with Sinopec in Yanbu will be ready for commissioning next year. Iraq's state oil company is in the process of auctioning off the rights to develop a 300k bpd refinery adjacent to the Nassiriya field. KNPC in Kuwait will expand two refineries, adding 264k bpd in capacity.

8.1.2 Supply (Capacity)

Suppliers are postponing any capacity investments until demand picks up; utilization rates are steady at 75%. Capacity Margin will remain adequate to support even the largest projects, although utilization rates will rise to 82% in 2020.

The major global Tower manufacturers are:

- Larsen & Toubro
- Belleli Energy
- Zamil Group
- POSCO (Sungjin)
- Doosan
- Cimtas
- Hitachi Zosen

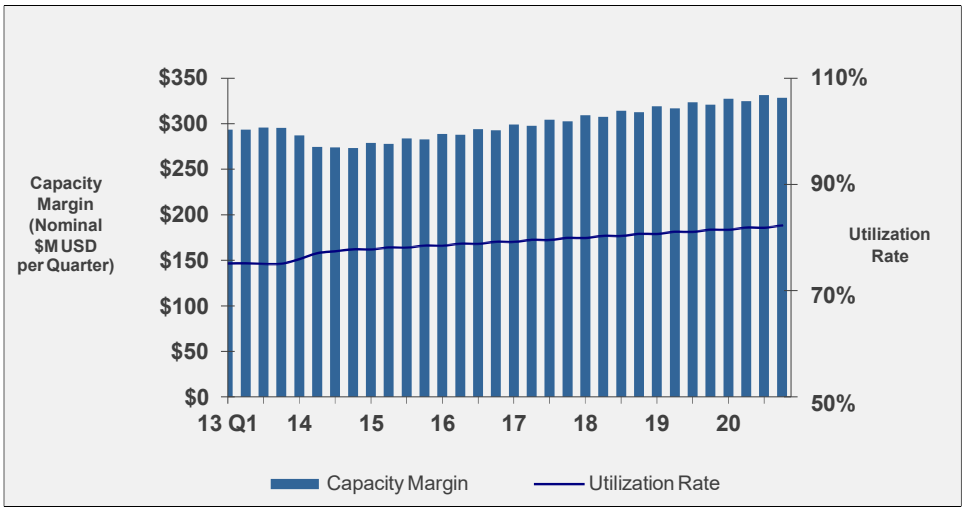
- Sinopec Engineering
- KNM Group
- Essar Group

Quarterly capacity for Towers is $1,180m as of 2013 Q1, with Capacity Margin of $290m – enough for even the largest potential projects. As with Distillation Column suppliers (many of which are the same companies), manufacturers have the ability to flex capacity between refinery equipment types and similar structures for chemical plants, which provides both a buffer if additional capacity is needed and a means of keeping their equipment utilized.

Suppliers are 75% utilized, on average, as demand has not fully recovered following the 2009 recession.

- Larsen and Toubro recently added machinery at two plants in India, leaving it 70% utilized.
- Sinopec Engineering is also 70% utilized for Towers (lower than its utilization rate for Distillation columns because it has more machinery that can handle the smaller tower sizes).
- Hitachi Zosen is 70% utilized as well, after expanding its main plant in Osaka in 2011 to make room for orders it hopes to win in Southeast Asia.
- In contrast, CPDTC is 90% utilized, as it has diverted equipment investments toward capacity for its upstream product lines.
- Turkish Cimtas is 80% utilized at its Turkish headquarters, and 70% utilized at a new facility in China.
- KNM, based in Malaysia, is 75-80% utilized.

Figure 11: Capacity Margin - Towers



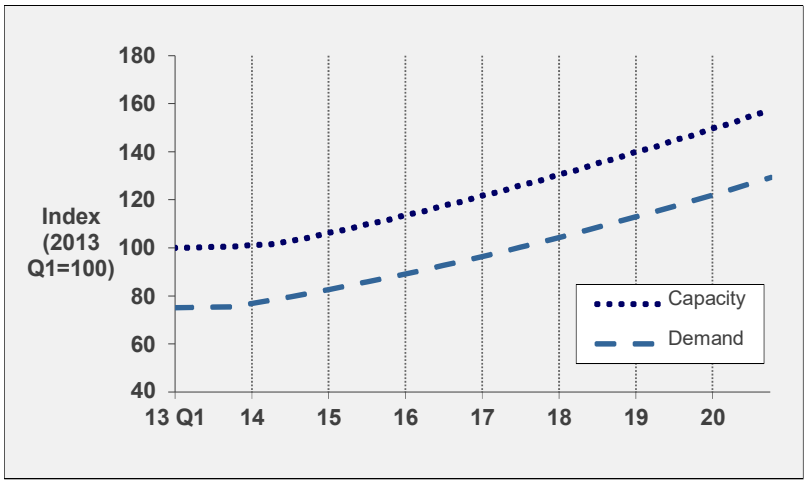
Suppliers are unwilling to add more capacity until orders pick up, which will not be until 2014, and capacity will remain stable. According to Larsen and Toubro, its recent capital expansion should last it through at least 2014. KNM states that it can raise capacity quickly enough (within a few weeks) if it is needed. The firm has roofline and welding machinery to spare from other product lines, and would only have to install bending machinery in the event of multiple large orders.

Table 8: Reported or Estimated Capacity Utilization Rates at Selected Tower Suppliers

Company	Country	Current Level	12-Month Forecast
Larsen & Toubro	India	70%	75%
Sinopec Engineering	China	70%	70%
Hitachi Zosen	Japan	70%	72%
CPTDC	China	90%	90%
Cimtas	Turkey/China	80/70%	80/70%
KNM Group	Malaysia	75-80%	75-80%
NRG Manufacturing	US	75%	80%

Capacity utilization will rise with demand beginning in 2014, increasing gradually to 82% in 2020. According to several manufacturers' target minimum utilization rate of 80%, buyers will lose some of their bargaining edge in late 2017, when utilization rates will exceed that threshold.

Figure 12: Demand vs. Capacity - Towers



8.1.3 New contracts

Refinery-scale orders in China and India are the largest recent contract awards.

Contracts for Towers are not readily transparent in most cases, as orders for the units are typically awarded in a package that includes larger equipment (such as distillation columns or hydroprocessing units). The fabrication and installation also happen concurrently with the larger equipment as well, leaving orders small orders for expansion projects the most visible to those not directly involved with the project.

Unit prices vary widely depending on the type of unit. For example, three large demethanizer columns for Chesapeake energy cost more than four stripper towers and two reformers for Lukoil, while a stainless steel demethanizer cost 12% more than a larger depropanizer, noth bound for Saudi Arabia.

Of the contracts identified, the largest were part of package awards for refineries in Asia (Sinopec's Guanzhou project and IOCL's Paradip refinery). Together, these orders totaled approximately $17.5m in order volume. These large contracts are the ones that suppliers bid most competitively for, as evidenced by the average unit prices when factoring in that the unit sizes for these greenfield projects are larger than those for most refinery revamps or expansions.

Table 9: Summary of New Contracts and Estimated Values for Towers

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
IOCL (Paradip)	India	Larsen & Toubro	35 towers	$8.9	$0.255
Sinochem (Guanzhou)	China	Sinopec Engineering	32 towers; reformers, sour water strippers, aromatics	$7.2	$0.23
Chesapeake Energy (Kensington)	US	M3 Midstream	3 demethanizers	$1.58	$0.53
Lukoil (Volgorad)	Russia	OMZ	6 towers; water and CO_2 strippers, reformers	$1.29	$0.22
NefteGazIndustria (Afipksy)	Russia	OMZ	Stripper, regenerator, SRU	$0.59	$0.20
SK Engineering (Wasit)	Saudi Arabia	Doosan	Depropanizer	$0.33	$0.33
Samsung Engineering (Shaybah)	Saudi Arabia	Gulf Heavy Industries	Stainless steel demethanizer	$0.37	$0.37
Samsung Engineering (SATORP)	Saudi Arabia	Gulf Heavy Industries	Reformate splitter	$0.25	$0.25

8.2 Analysis

8.2.1 Costs

After falling almost 1% in 2013 Q1 due to a temporary drop in metals and power prices, costs to manufacture Towers will rise consistently through 2015 on labor costs and a rebound in carbon steel prices.

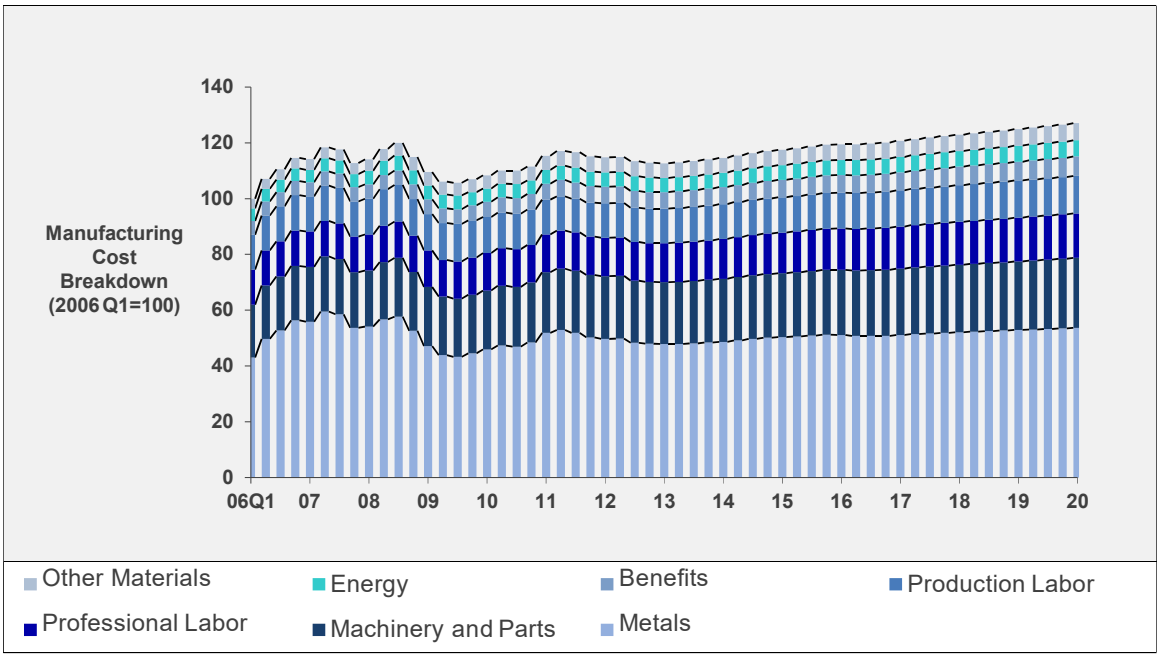
Metals make up 43% of the manufacturing cost for Towers. This can vary by region – largely due to differences in labor costs – and type of steel used (stainless steel used for corrosive applications can raise the overall metal costs and their proportion of the total).

- Carbon steel is typically about 20% of the cost structure. Costs for carbon steel are volatile, cycling up 25% in 2011 and then back down 21% by mid-2012, and by themselves account for most of the changes in production costs for towers. In 2013 Q1, carbon steel costs fell another 3%, due to slower than expected orders and high inventories as a result. Going forward, carbon steel costs will increase anywhere from 1% to 6.5% per quarter until 2016, when they will retrench slightly.
- Chrome steel is approximately 10% of the cost structure, used as cladding in applications that require mild to moderate corrosion resistance (e.g. sour water or CO_2 strippers). Chrome steel costs have also fallen in recent quarters – 8.6% over the past year – but they will begin to increase steadily in 2014 along with more stable demand growth.
- Purchased piping and tubing, primarily for column internals and side draws, is 5% of the overall cost. Costs for these components have been stable for the past four quarters, but they will begin to increase steadily by about 2% per year as orders pick up.
- Other metals, including structural components for tower supports and skirts, make up the other 8%.

Labor costs represent 30% of the cost structure, based on benchmark prices in North America. In regions where labor costs are lower, e.g. Asia and the Middle East, rates for welders and machinists are as little as 20% of the corresponding age levels in the US. Labor costs are rising four times as fast in these low cost regions though, at about 2% per year compared to a fraction of a percentage in more mature economies.

Machinery accounts for 20% of the total cost structure, including forging, rolling, milling, bending, CNC, cutting, and welding systems as well as drills, lathes, and cranes in a variety of sizes. Machinery costs retreated slightly in 2012, along with carbon steel, but have returned to growth of about 2% per year globally, which will continue through 2020.

Figure 13: Cost Structure of Towers



Note: Prices are ex-works.

8.2.2 Profit Margins

Manufacturers accept low margins on Tower projects to win bids that include more profitable units. Industry margins will rise by about two percentage points by 2020 as demand grows and supplier capacity utilization rates improve.

Suppliers are willing to accept lower margins on Towers than for any other refinery process units. They typically bid low on this portion of larger projects in order to win a larger bid package. Towers are relatively unsophisticated compared to reactors, and suppliers frequently bid on both types of equipment. An average of supplier feedback indicates that net margin on Towers is 2-4%, compared to an average of 6% for the companies as a whole, which includes margins for reactors, heat exchangers, construction works, and other types of equipment:

- KNM typically makes a final profit of about 3% on towers, according to a source within the company. This compares with 4-5% for at KNM for Distillation Columns and as much as 6-8% for reactors.
- US supplier NRG Manufacturing, which specializes in demethanizers and depropanizers, makes slightly lower margins on towers (1-2%) than the other major component in its refinery equipment business, because it wants to win Distillation Column sales and because it has to compete with lower cost manufacturers from Asia.

- Sinopec Engineering reportedly makes 4-5% on Towers, higher than average because it has a strong market share in China, and does not compete with most global manufacturers due to domestic refiners' preference for local content.

These margins compare to an average net profit margin (across all the companies' products) of 6% for a sampling of major suppliers:

- Larsen & Toubro's net margin was 8% in 2012, higher than the industry average on orders from South America, Saudi Arabia, and India.
- Belleli Energy's net margin was 4%, lower than many because it bid low for work on multiple refinery projects in Russia.
- Sinopec Engineering's net margin was 7%, slightly higher than the global average, once again due in large part to its position as the leading Chinese supplier in this market.
- Sungjin (POSCO) made 5% net margin, admitting that it gave away some margin by bidding aggressively on projects in the Middle East and Asia.

Margins typically increase with tower diameter. This is partially an effect of value-based pricing, as unit throughput increases exponentially with diameter, making it more valuable in terms of the product it can process.

Towers clad with stainless steel also typically make more margin, but only by about 2-3 percentage points, according to one US manufacturer.

Margins will increase slightly starting in 2016, as solid demand growth and rising capacity utilization rates give manufacturers more flexibility when bidding. The increase will be small but significant, amounting to two percentage points by 2020. Buyers with big projects should be able to avoid most or all of this margin creep, as suppliers will continue to bid aggressively on greenfield refinery projects where they can substitute volume for margin.

8.2.3 Prices

Steady metal costs and slow demand growth will keep price increases to 1.6% for 2013, with most of the increase in Asia. Orders and carbon steel prices will pick up starting next year, driving prices up 3% annually through 2015, and 2% annually from 2016-2020.

Tower prices have risen a net 24% since 2005 Q1. Similar to prices for Distillation Columns, Tower prices depend mostly on costs for carbon steel, chrome steel, labor, and machinery. The major difference is that Towers use more chrome steel compared to carbon steel, and chrome steel prices

are somewhat more volatile. Carbon steel costs rose 27% over the same period, and chrome steel costs 36%. Muting the impact of metals, machinery costs have only risen about 15%, while US production labor costs have actually fallen 2% since 2005. Costs and prices both rose sharply in 2006 and 2007, but retrenched somewhat with the global recession.

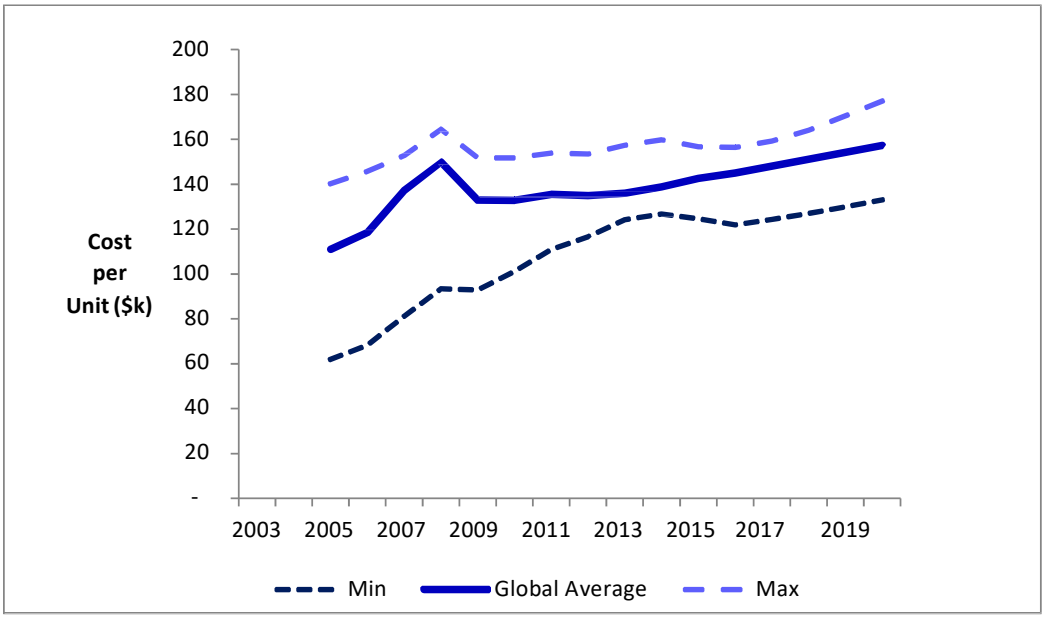
Prices were stable in 2012, as a 6% drop in chrome steel prices canceled out slight increases in costs for machinery and labor.

Global prices rose 1% in 2013 Q1, on average, despite a 1% drop in the Americas (on another decline for both carbon and chrome steel due to high inventories). Asian professional labor costs (management and engineering), rose 3% driving the overall increase.

Average prices will increase a total of 15.7% from 2013 Q1 to 2020 Q1. Asian prices will rise fastest at 18%. Labor costs in China and India are rising 3-4% per year, which will combine with annual carbon steel cost increases of 4% to drive regional cost levels up 26% by 2020 Q1. The rest of the price increase will be attributable to margin increases. In the Americas, prices will rise 14%, on underlying cost increases of 13%. Prices in EMEA will rise just 14%, on cost growth of 12%.

Most of the price increases beyond cost growth will occur in 2016 and beyond, as accelerating demand growth and higher capacity utilization rates give manufacturers the ability to increase profits.

Figure 14: Overall Price Forecast for Towers



The reference unit for this category is a 4'x40' stripper tower, with valve trays, made of carbon steel designed to operate from pressures of 150 psi to full vacuum, at temperatures up to 800° F. Using US manufacturing costs as a benchmark, the reference unit would cost $144k.

Cost component weightings and regional differences match those for Distillation Columns closely. Japan, Western Europe, and the US are the highest-cost regions on a combination of high labor and power costs, and somewhat higher costs for steel. As a result, the benchmark unit, which would cost $144k in the US, would cost $157k from Japan, and $146k from Europe. Production costs are lowest in Asia, by a substantial margin, where low labor and steel costs keep overall price levels in Southeast Asia at index levels of 82. Labor costs are low, even compared to China and India, and comparatively little competing demand from heavy equipment manufacturers for steel produced by regional mills contributes to lower metal costs. Price levels in India and China are the next lowest, at index levels of 86 and 87. As a result, a tower that would cost $144k in the US would cost only about $125k in either country.

Table 10: Regional Price Variations over Time for Towers

Region/Country	Today	2014	2015	2020
North America	1.00	1.01	0.99	1.06
Latin America	0.96	0.98	1.01	1.14
Europe	1.03	1.03	1.02	1.08
Middle East/North Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.89	1.03
Russia	0.89	0.94	0.95	1.13
China	0.87	0.88	0.86	0.92
Japan	1.09	1.11	1.08	1.09
Other Asia	0.82	0.83	0.82	0.86

8.2.4 Price Differences by Technology, Model, and Feature

Based on physical characteristics, tower costs are dictated primarily by size (diameter and number of trays), and material – mostly the proportion of carbon to chrome steel, and whether stainless cladding is required for more corrosive applications.

Using a stripper tower that is 4’ in diameter, 40’ tall, with 15 trays (benchmark cost of $144k) as a baseline unit, significant variations include:

- Each additional inch of diameter adds approximately $3.6k. Increasing the diameter of the unit to 5’ therefore raises the cost to $185.5k
- Adding height, typically in 10’, 5-tray increments, adds $28k per increment. So a 60’ tall tower (4’ in diameter) would cost $196k.
- Adding 316 stainless steel cladding for corrosive applications adds 39% to the cost of the unit, depending on the wall thickness.

Table 11: Incremental Cost per Extra Parameter or Feature for Towers

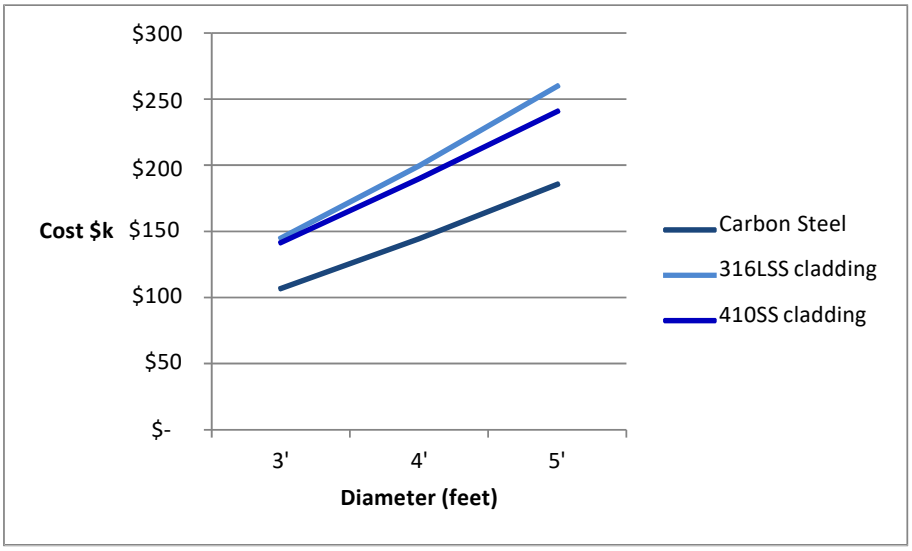
(Reference unit is 4' X 40', with 15 valve trays, made of carbon steel)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Diameter	Feet (based on 4')	-$37.7k for 3', +$41.1k for 5'	Cost per barrel of processing capacity falls as diameter increases
# of Trays	15, 20, 25 (based on 15)	+$25k/ additional foot of height (5 trays)	Cost increases peak at 20 trays, then fall from 20-25.
Material	Carbon steel as reference point	+38% for stainless steel 316 cladding on the reference unit	Cost only increases 31.5% for 410 stainless due to lower wall thickness

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

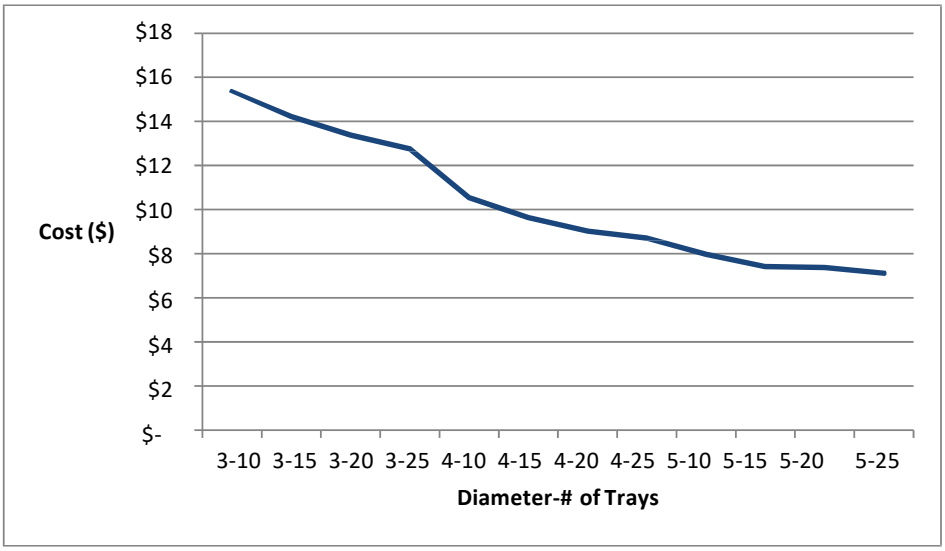
Cost increases are linear with height, as wall thicknesses do not increase, but they increase at an accelerating rate with diameter, a wall thickness increases slightly. The rate of increase also accelerates if stainless steel cladding is used, however, as the more expensive metal makes up a higher percentage of the overall cost structure.

Figure 15: Towers Size vs. Cost – by Diameter



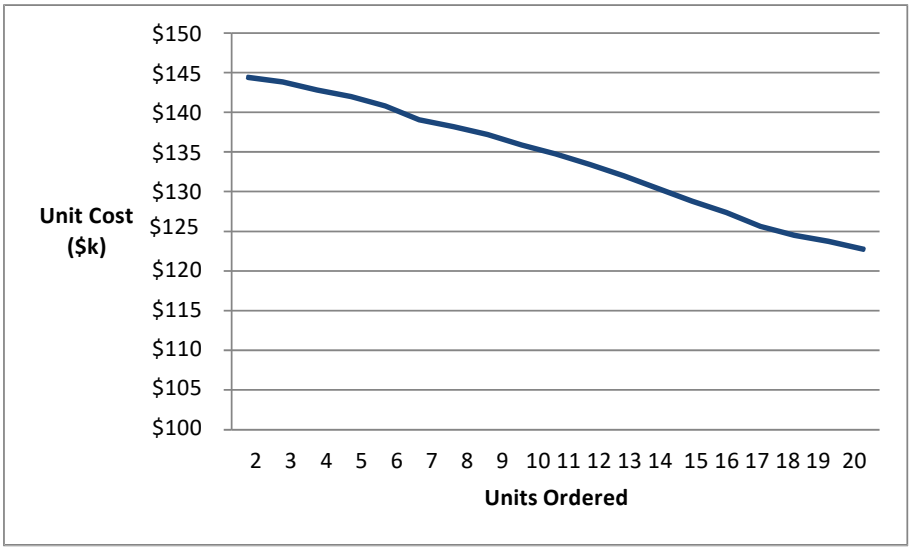
While increasing the size of the column raises the cost, it lowers the cost per barrel of processing capacity for most combinations of diameter and height. Cost per barrel of capacity falls dramatically from the benchmark unit ($9.6) to $7 per barrel for a 5' diameter, 60' tall stripper tower.

Figure 16: Cost per Barrel of Capacity for Towers



Buyers can expect discounts of up to 15% by increasing order quantities. Manufacturers can amortize equipment and engineering costs more effectively over a larger number of units, bringing down manufacturing costs. According to Malaysian manufacturer KNM, ordering five units will get a discount of about 5%, increasing to 15% for 20 or more. Larsen and Toubro concurred, with about a 15% expected discount for 20 units.

Figure 17: Economies of Scale in Towers



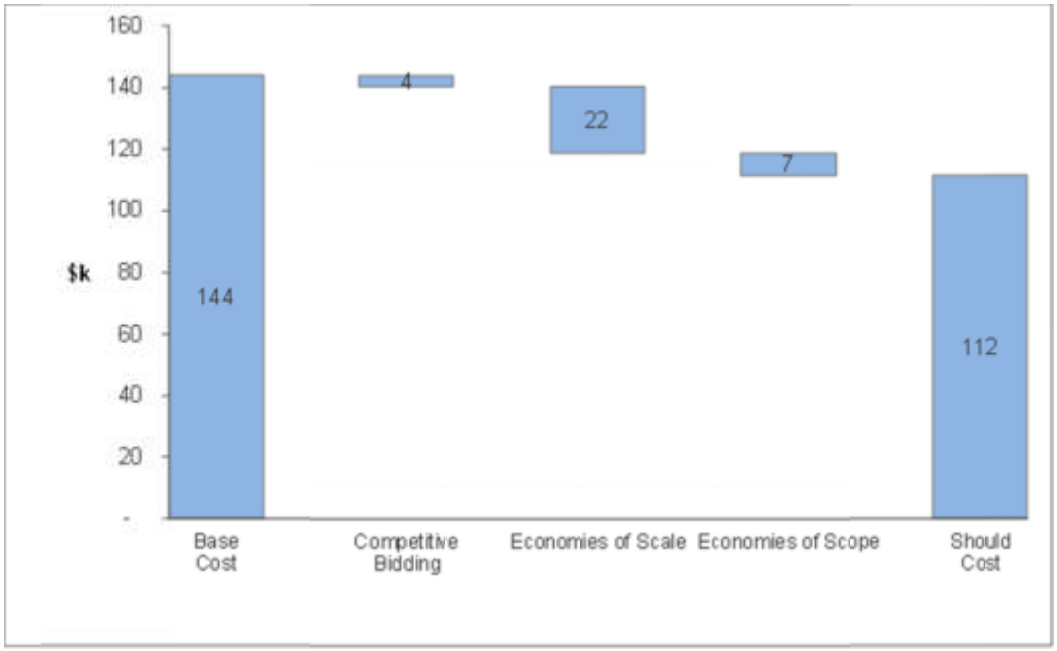
8.2.5 Should-Cost Analysis

Economies of scale and scope are effective methods of bringing units costs for Tower down. Value engineering creates little room for cost reduction, as each tower is designed to specification in the

first place. As explained above, suppliers are willing to cut prices substantially in exchange for order volume, and will give further discounts for contract awards that include other types of equipment as well.

The figure below illustrates the potential savings per unit for a large order of 20 towers, using the reference product as a cost basis.

Figure 18: Should-Cost for Towers



8.3 Price Negotiation Strategies

1. Place orders or reserve capacity as early as possible to preempt constantly increasing prices. Negotiating prices for estimated requirements in 2013 could potentially avoid price increases of 3% in 2014 and 2.8% in 2015.
2. Avoid excessive price inflation due to margin growth, especially with Asian manufacturers, by indexing prices to a basket of cost factors including carbon steel, chrome steel, labor, and machinery.

9 Hydrocracking Reactors

9.1 Market Overview

Table 12: Key Indicators for Hydrocracking Reactors

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	10.7%	▲	61.0%
Demand ($m)	▲	268-297	▲	268-432
Capacity Utilization	▲	5.0%	▲	6.8%
Prices	▲	3.9%	▲	14.5%

9.1.1 Demand

Demand for Hydrocracking Reactors rose 4% in 2012 as NOCs in China, India, and Saudi Arabia built new units. Sales will grow only 1% in 2013 on falling fuel demand in the US and Europe, but a total of 61% by 2020 Q1 on projects in Asia, Latin America, and the Middle East.

Hydrocracking Reactor demand is driven by refinery capital investments. The growth trend is slightly faster than for overall refinery spending, however, due to a preference for diesel fuel in Asia, Europe, the Middle East, and Latin America, and tightening emissions standards such as Euro 6 regulations governing sulfur and particulate emissions content from diesel fuel. Diesel has long been widely used as a transportation fuel, now it is becoming the preferred fuel in China and elsewhere in Asia. Hydrocracking is more selective to light cycle oil (diesel) and therefore refiners typically prefer it as a process route for producing diesel fuel, compared to fluid catalytic cracking (FCC). In addition, it produces cleaner fuels that require less additional treatment to comply with pending Euro 6 fuel standards (scheduled to go into effect in 2014), which Asian refiners are struggling to match.

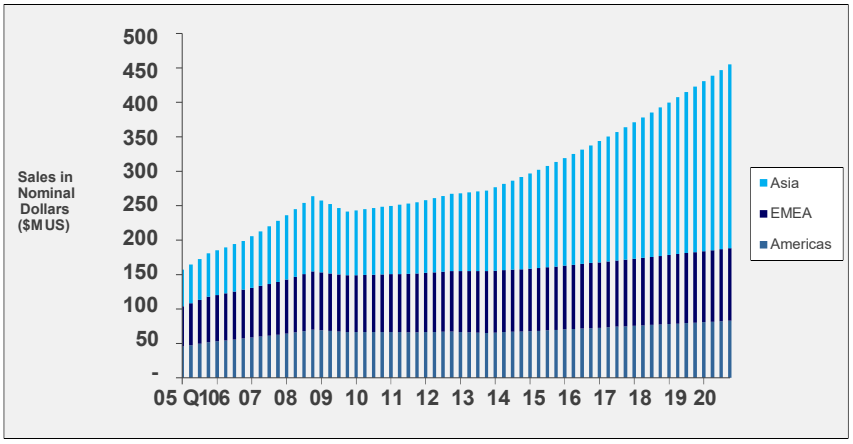
Reactor sales grew 4% in 2012, in parallel with global refinery capital expenditures. Sales grew fastest in Asia at 6.5%, on orders from projects in China and India.

- Sinopec's Zhanjiang refinery, scheduled for commissioning in 2014, made progress payments on reactors for a 44k bpd hydrocracking unit.
- PetroChina's JV project with Rosneft in Dagang ordered reactors from Sinopec Engineering.
- IOCL's greenfield Paradip refinery took delivery of six hydrocracking reactors from Essar in 2012, and began installing them in November.

In EMEA, reactor sales rose 3% last year, markedly slower than Asia but buoyed by reactor deliveries and progress payments for major refineries in Saudi Arabia and Russia. Saudi Aramco took delivery of four reactors for its Yanbu refinery in May 2012. The reactors will be part of a 124k bpd hydrocracking unit due for commissioning in 2014. Lukoil ordered three reactors from IDESA, for a planned hydrocracker unit at its Volgorad refinery.

In the Americas, demand crept up by 1.5%, primarily due to final delivery of four reactors for a new 60k bpd hydrocracking unit at Valero's St. Charles Refinery (due for commissioning in 2013), and Petrobras' order for multiple reactors from Larsen and Toubro for its planned Premium I refinery.

Figure 19: Demand for Hydrocracking Reactors



Hydrocracking reactor demand growth will slow for 2013, to only 1% globally, due to faltering refinery investments in Western Europe and North America (-2% and -4% growth for refinery capex this year, respectively) on a combination of weak fuel demand and a lighter production slate in the US, reducing the need for hydroprocessing capacity.

- Refiners in Europe (with the notable exception of Russia) are unwilling to invest in new capacity as regional fuel demand falls and after a number of refinery conversions to terminals or outright closures, including Petroplus' bankruptcy in 2012. As a result, demand growth for EMEA will slow to 2% this year, propped up by continuing projects in Russia and the Saudi Arabia. For example, Russian refiners Bashneft and Rosneft will take delivery of six reactors this year, for expansions at Achinsk, Ufa, and Novo. Yanbu in Saudi Arabia will receive the final four reactors for its 124k bpd hydrocracker.
- Demand will fall 3% in the Americas this year. Liquid fuel consumption in the US is falling at a rate of 1.5% per year, on a combination of economic malaise and increased vehicle fuel economy, while recent hydrocracker installations have already glutted the US market with capacity. In addition, the lighter crude currently being produced from shale plays including the Eagle Ford in Texas and the Bakken in North Dakota needs less processing to make

liquid fuels. Refiners Valero, Alon, Motiva, and ConocoPhillips collectively bought reactors for 200k bpd in additional hydrocracking capacity that were delivered over 2010-2012, saturating the US market. This has created a lull in hydrocracker investments in the US, which, in conjunction with delays for Petrobras' refinery expansion program, are driving the drop in regional demand.

- Asian Hydrocracking Reactor demand, growing at 4.5% this year, is driving global growth. Ongoing projects include CNOOC's Huizhou in China, CPCL's Manali in India, and Petronas' Melaka II expansion in Malaysia.

Demand growth will accelerate to annual rates of 6.5% in 2014 and 7% in 2015-2020, for a total increase of 56% from 2013 Q1 to 2020 Q1. Investments by national oil companies in Asia, the Middle East, and South America will drive the growth.

Asian demand will increase by 120% by 2012 Q1 as refiners invest to fulfill rapidly growing regional fuel demand and meet tightening emissions standards requirements. China's government has ordered major national oil companies CNPC, CNOOC, and CPC to upgrade or build new refineries to meet global emission standards such as Euro 6. Partially in response to this directive, Chinese refiners have more than 14 new refineries or upgrades planned or in progress:

- CNPC is building a 400k bpd complex (Nanhai) to process Orinoco crude, in partnership with PDVSA.
- Sinopec plans to start building a 100k bpd expansion of its Zhenhai refinery in 2014.
- More than a dozen other Chinese projects, with a cumulative capacity of 1.85m bpd, are in various stages of planning, with expected completion dates prior to 2020.

In addition to the above developments in China, refiners in India, Malaysia, and Vietnam are building refineries that will all include hydrocrcackers. Indian CPCL is building two refineries totaling 500k bpd in capacity, Petronas is also building two (475k bpd), while Petrovietnam is building refineries with 400k bpd in processing capacity. In Pakistan, Pakistani National Refinery Limited is building a 40k bpd hydrocracker with three reactors, scheduled for completion in late 2014.

Demand will rise 21% in the Americas as overall refinery spending increases 20%, mostly driven by Petrobras' Comperj and Premium refining projects, which will add almost 500k bpd in cumulative hydrocracking capacity. The expansions are specifically geared to produce diesel, and hydrocracking units will be the centerpieces of the refineries. Also in Latin America, Ecopetrol is expanding its Barrancabermeja refinery, adding an 80k bpd hydrocracker. In the US, Sunoco plans to revamp its Philadelphia refinery, in the process upgrading a middle distillate hydrotreater into a hydrocracking unit.

EMEA demand will grow 17% by 2020 Q1, despite continued reluctance on the part of Western European refiners, on underlying 16% growth in refinery capital spending in the region. Specific orders will come from Russia and Iraq, as well as small upgrade and modernization projects. Currently planned projects include:

- Lukoil plans to upgrade its Moscow refinery starting in 2016, after it completes the Volgograd expansion.
- TAIF's Nizhnikamsk refinery (in Russia) is building an 86k bpd hydrocracking unit, scheduled for completion in 2015 Q1.
- Iraq's planned Nassiriya refinery, currently in the contracting phase, will include a 52k bpd vacuum gas oil hydrocracker.
- Essar Oil plans to revamp the hydrocracking unit at its Stanlow refinery, with completion scheduled for 2015 Q4.
- Provided it can secure financing for the project, Egyptian Refining Company plans to build a 30k bpd vacuum resid hydrocracker at its Cairo refinery.

9.1.2 Supply (Capacity)

Capacity additions will lag demand growth until mid-2015, when industry utilization rates reach 75%, as most suppliers will not expand until order rates pick up.

The major global Hydrocracking Reactor manufacturers are:

- Japan Steel Works (JSW)
- Belleli Energy
- Larsen & Toubro
- GE (exiting the business)
- Kobe Steel
- Sinopec Engineering
- Carpenteria Corsi
- Doosan
- IDESA
- ATB Riva Calzoni

Quarterly capacity is $390m as of 2013 Q1, with Capacity Margin of $120m. This leaves room for 5-6 reactor additional orders per quarter before lead times begin to extend, or approximately 20-25 reactors per year. To put this figure into perspective, a megaproject such as the Yanbu refinery in Saudi Arabia ordered eight reactors, meaning that it would take three project orders of this size (in

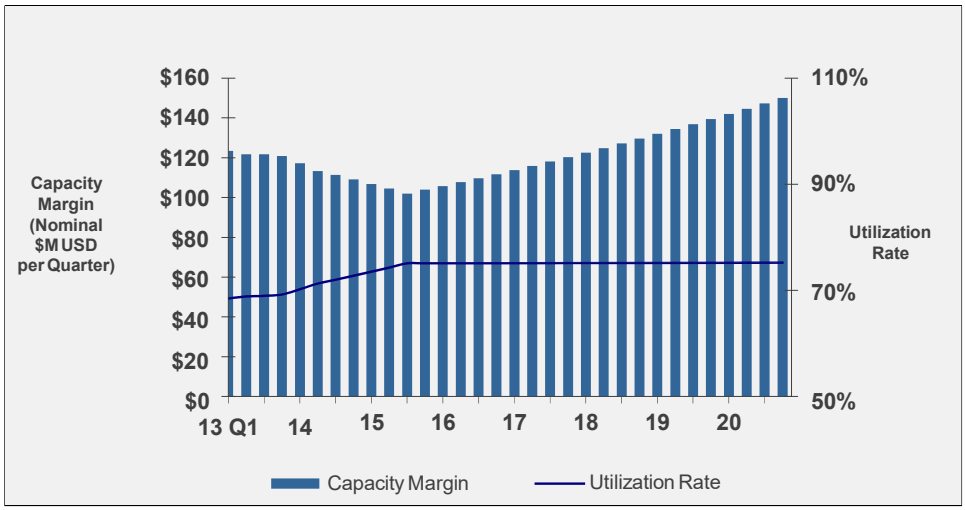
addition to those in queue) to cause a significant increase in industry lead times. Orders this large are exceedingly rare though, and there is little likelihood of three unexpected megaprojects unexpectedly ordering reactors.

Capacity levels are stable in 2013, after some expansions in 2011 and 2012, as suppliers refrain from adding new capacity due to slow demand growth. Sinopec Engineering, Larsen and Toubro, and JSW have added capacity since 2010, which has not entirely been absorbed by order growth. Recent capacity additions include:

- Sinopec added forge capacity in 2011, installing one 12.5k tonne forge press and one 15k tonne unit.
- Larsen and Toubro expanded twice, opening a new yard at Hazira in 2011 and an expansion in Oman in 2012. The investments added forging, bending, cutting, and welding capacity, and collectively gave Larsen and Toubro the ability to make an additional four reactors per year. The capacity also serves the nuclear market, so not all of it is available for hydrocracking reactors at any given time, but orders from the nuclear sector have been slow after the Fukushima meltdown.
- JSW also invested in new machinery at its plant Muroran plant in Japan, increasing bending and welding capacity, also primarily for the nuclear industry. Much of that capacity is idle now, however, and JSW is eager to use the forge presses.

Due to the above capacity additions, Sinopec Engineering and JSW are 60% utilized, while Larsen & Toubro is running at 70%. GE's Nuovo Pignone division is exiting the reactor business, which is removing some industry capacity. GE's move is motivated by lower margins than it makes in most of its other business units and the fact that GE does not own the technology (it is licensed from patent-holders such as Axens, UOP, Chevron and Shell). However, Carpenteria Corsi is replacing most of the capacity that GE is removing, hiring its engineers and adding more machinery to compensate, so the impact on industry capacity levels is minimal.

Figure 20: Capacity Margin - Hydrocracking Reactors



Due to the above glut of capacity and slow demand growth, most suppliers are not willing to invest in new capacity. Carpenteria Corsi is adding capacity this year, but it will largely just replace capacity that GE is removing from the market as it exits the reactor business (through its Nuovo Pignone unit). Carpenteria is actively hiring Nuovo Pignone's workers to support its expansion. As a result, the firm is only about 50% utilized.

In contrast with the above firms, Belgian G&G International is 80% utilized, on orders from Russia, while Cimtas' Turkish plant is also 80% utilized.

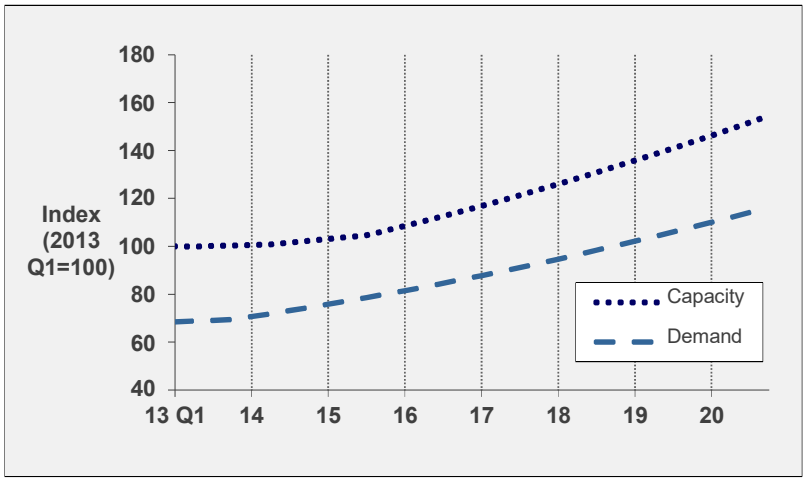
Industry utilization rates are approximately 68%, but this figure is deceptively low. Manufacturing a single reactor is a major project and lead times are 18-26 months, depending on the reactor size and the company's existing backlog. Each company needs a significant cushion of spare capacity to take more than a few orders, and utilization rates much above 75% mean that a company is at risk of losing a bid due to high lead times.

Table 13: Reported or Estimated Capacity Utilization Rates at Selected Hydrocracking Reactor Suppliers

Company	Country	Current Level	12-Month Forecast
Larsen & Toubro	India	70%	70%
Sinopec Engineering	China	65%	67%
JSW	Japan	60%	60%
Carpenteria Corsi	Italy	50%	50%
G&G International	Belgium	80%	80%
Cimtas	Turkey	80%	80%
Chicago Bridge & Iron	US	60%	60%

Industry utilization rates will increase progressively through 2014, and reach 75% in 2015. According to most manufacturers, utilization rates at this level are a trigger for adding more capacity, and manufacturers with already high utilization rates (such as G&G and L&T) are willing to expand. In the meantime, manufacturers with low utilization rates such as Carpenteria Corsi and JSW should be the most eager to court sales with discounts.

Figure 21: Demand vs. Capacity - Hydrocracking Reactors



9.1.3 New contracts

The largest contracts came from Saudi Aramco and IOCL. Leading Japanese manufacturers JSW and Kobe Steel won the orders for the largest reactors.

Saudi Aramco is by far the largest single buyer in the recent past, letting contracts for refineries at Jubail, Yanbu, and Jazan. The hydrocracking reactor portions of those contracts total more than $400m for 19 units.

- The Yanbu project will be the largest hydrocracker in Saudi Arabia, with eight reactors and 124k bpd in hydrocracking capacity. The reactors are collectively worth $168m, including a 10% volume discount from Doosan.
- The Jazan refinery had a higher per unit cost ($21.6m vs $21m), for a total cost of $129.6m for the reactors, despite using local supplier Zamil Steel, due in part to the remote nature of the project and suppliers' unwillingness to reduce prices given the logistical challenges.
- The Jubail Refinery (SATORP) had the highest unit cost, due to a combination of the unit size (24k bod per reactor), the lower number of units (5 compared to 6 and 8 for the other projects), and the choice of supplier (Japanese Kobe Steel).

OMZ benefitted from local content preferences, winning multiple orders from Rosneft in Russia:

- The first order, two reactors for $45.6m, is for the Achinsk refinery upgrade, with final delivery scheduled for the third quarter of 2013.
- Rosneft's Novo refinery ordered three reactors from OMZ. OMZ delivered one reactor in Q1 (installation has already begun), and expects to deliver the final unit in Q4.

The major Japanese suppliers, Kobe Steel and JSW, won the orders for the largest reactors, on a combination of reputation, forge press capacity, and low utilization rates. Both firms have a reputation for quality – for example, JSW is the only supplier qualified to make nuclear reactors to US standards. Both suppliers make their own steel, which contributes to a reputation for consistent quality. With multiple 15k tonne presses each, both firms can handle the largest practical reactor sizes (which cannot be said of all suppliers, as many of them have forge presses only up to 9-10k tonnes). JSW is also only 60% utilized, as expected orders for nuclear reactors have not materialized.

The outlook for new contracts is strong after 2013, with more than 2.35m bod in additional refining capacity planned in China, and at least another 2.3m bod planned for the rest of Asia.

Table 14: Summary of New Contracts and Estimated Values for Hydrocracking Reactors

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Saudi Aramco (Yanbu)	Saudi Arabia	Doosan	8 reactors: 124 bpd	$168.00	$21.0
Saudi Aramco (Jazan)	Saudi Arabia	Zamil	6 reactors: 110k bpd	$129.60	$21.6
IOCL (Paradip)	India	Essar	6 reactors	$122.00	$20.25
SATORP (Jubail)	Saudi Arabia	Kobe Steel	5 reactors: 120k bpd capacity	$112.50	$22.5
TAIF (Nizhnikamsk)	Russia	JSW	4 reactors: 86k bpd	$88.00	$22.0
Valero (St. Charles)	US	G&G	4 reactors: 60k bpd	$75.00	$18.85
Lukoil (Volgograd)	Russia	IDESA	3 reactors	$70.00	$23.3
Rosneft (Novo)	Russia	OMZ	3 reactors	$69.60	$23.2
National Refinery Limited - Pakistan	Pakistan	Carpenteria Corsi	3 reactors: 40k bpd	$52.50	$17.5
SK Energy (Inchon)	South Korea	Doosan	3 reactors: 40k bpd	$51.00	$17.0
Rosneft (Achinsk)	Russia	OMZ	2 reactors	$45.60	$22.8
Sinochem (Guanzhou)	China	Sinopec	2 reactors	$42.00	$21.0
Essar Oil (Stanlow)	UK	Essar	2 reactors: revamp project	$38.41	$19.2
Bashneft (Ufa)	Russia	Belleli	1 reactor	$24.00	$24.0
Total (Gonfreville)	France	Carpenteria Corsi	1 reactor: 15k bpd expansion	$16.00	$16.0

9.2 Analysis

9.2.1 Costs

Overall costs have been stable in 2013 Q1, but they will rise 1% for the year on rising wages, alloy prices, and machinery costs. Costs will rise a total of 11% by 2020 Q1.

Metals constitute 51% of the cost structure for Hydrocracking Reactors on average, approximately half of which is for chrome steel. That percentage can vary by up to 10% based on the exact metallurgy for the reactor, and the relative percentage of other costs, such as labor. Exotic metals make up a larger component of costs for reactors than for any other category, due to the temperature and pressure resistance requirements. Typical metallurgy for reactors ranges from 1 Cr-1/2 Mo w/ 3/8" 347 SS cladding at the low end of the pressure spectrum (1350 psig) to 2 1/4 Cr- 1 Mo w/ 3/8" 347 SS cladding, and, increasingly, vanadium alloys.

Machinery costs account for 21% of the cost structure, relatively high for refinery process equipment due to the extreme cost of the forge presses that are the critical machinery for producing these reactors.

Labor makes up 17% of the cost structure for Hydrocracking Reactors, the smallest percentage for any of the categories covered in this study. This is due to the high absolute cost of the above components, which gives them a higher weight.

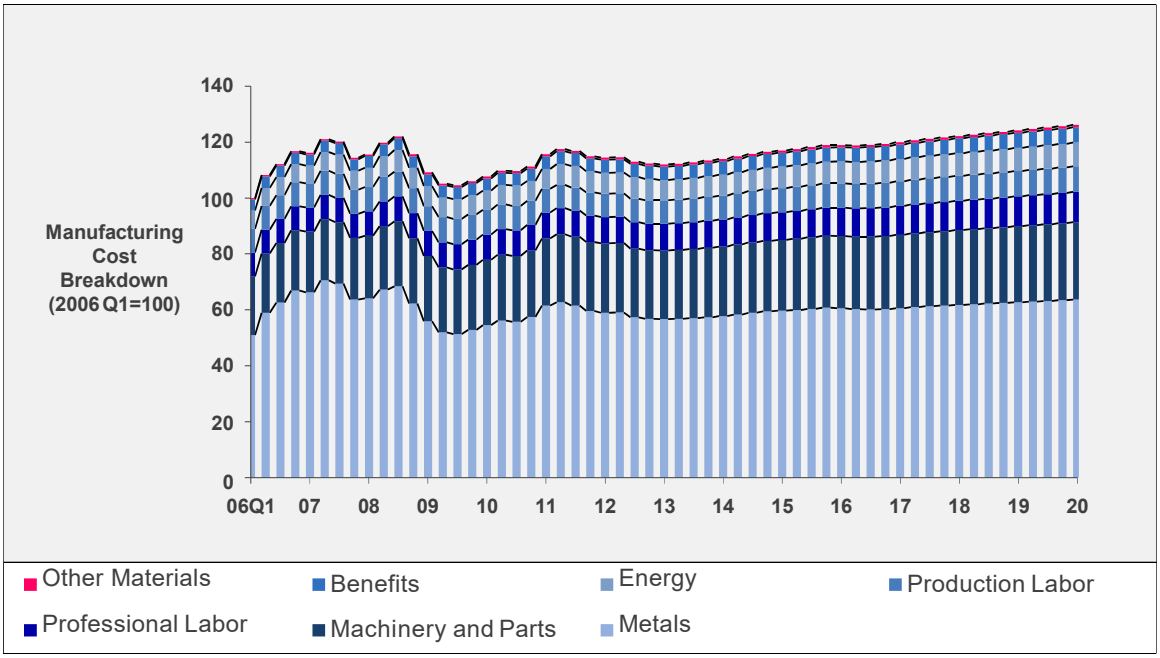
In Q1, chrome steel costs fell 2%, but labor and machinery costs rose 0.5-1% each, negating the drop in metal prices for stable average costs.

Over the rest of 2013, costs will rise only slightly – 1% – as chrome steel costs rebound and global labor costs increase. The labor cost growth will be most noticeable in Asia (4% vs. 2% in most of the rest of the world) where rising demand for skilled workers (e.g. welders, machinists, and forge operators) and professional workers (management and engineers) is rising faster than the other regions. Asian costs will rise slightly faster than the other regions as a result – 2% vs. 0.7%.

Costs will rise a total of 11% from 2013 Q1 to 2020 Q1. Alloy costs will drive much of the increase, rising 15% for the period. This includes metals such as molybdenum, vanadium, and titanium. Labor costs will be the other major driver of increase, especially in Asia. Asian labor costs will continue to

rise at about double the rate in other regions – 4% per year vs. 2%, which will drive Asian costs up 15% by 2020 Q1, compared to 8-10% in the other regions.

Figure 22: Cost Structure of Hydrocracking Reactors



Note: Prices are ex-works.

9.2.2 Profit Margins

Supplier margins average 4% for Hydrocracking Reactors and will only rise one percentage point by 2020, closely pegged to costs because buyers negotiate hardest for these high-value components. GE is exiting the business because this level of margin is too low.

Suppliers' net margins, at 4% on average, are tenable for Hydrocracking Reactors but not by themselves attractive. Buyers are tightly focused on these high-value components, and they negotiate prices aggressively. Manufacturers such as Larsen and Toubro, Doosan, KNM, and Sinopec Engineering all use their participation in this sector as a qualification to bid on large projects with other types of equipment in scope. In addition, alloy costs can fluctuate wildly (as much as several hundred percent over the course of a single year for nickel, molybdenum, and vanadium) and manufacturers are eager to protect themselves from these swings by keeping prices closely in line with costs. Together, these factors mean that prices are not far from cost levels, and that they will stay pegged.

GE has decided to exit the reactor business because the margins are too low. The overall firm earned net margin of 10% in 2012, primarily by focusing on businesses where it can add unique value. While qualified to manufacture reactors, GE's Nuovo Pignone division is only on an even footing with the other Italian suppliers (Carpenteria, ATB, Belleli), and arguably at a disadvantage compared to the Japanese firms JSW and Kobe Steel. GE has never been a major player in the other refinery process equipment categories in this study, and as such there is little opportunity for the firm to achieve economies of scope. As a result, GE has decided to exit the hydrocracking reactor business, and is in the process of making its last deliveries.

Many of the Asian suppliers' net margins are even lower than 4%. Sinopec Engineering's margin for reactors is only 1-2%. Doosan Heavy Engineering's net margin was -1.15% for the first half of 2012 (the latest reporting period available), because it under-bid to win orders – attempting to "buy" the market.

The main factors that affect margin are the ability to produce the steel that goes into the reactors, and the ability to make the largest units available – approximately 1,200 tons (which are more valuable to the refinery operator because they process feedstock more economically). Integrated steel production and reactor manufacturing allows the supplier to avoid the worst of the alloy price fluctuations, because these are driven to a large degree by global inventory levels that determine market prices for the alloys. As reactor size increases, the number of qualified manufacturers decreases, allowing those few to negotiate more aggressively. For example, JSW's operating margin for its energy division was 11% in 2012, significantly higher than the firm's overall operating margin of 5.7%. JSW both makes its own steel and can fabricate the largest reactors on the market. Saudi Arabian Zamil Steel, with its own metal-producing capability, earned 5.5% operating margin for its Industrial Division, higher than average profitability for this segment.

9.2.3 Prices

Reactor prices will remain in line with costs because they are the most heavily-negotiated component of the refinery system, rising 1.5% in 2013 and 12% by 2020 Q1.

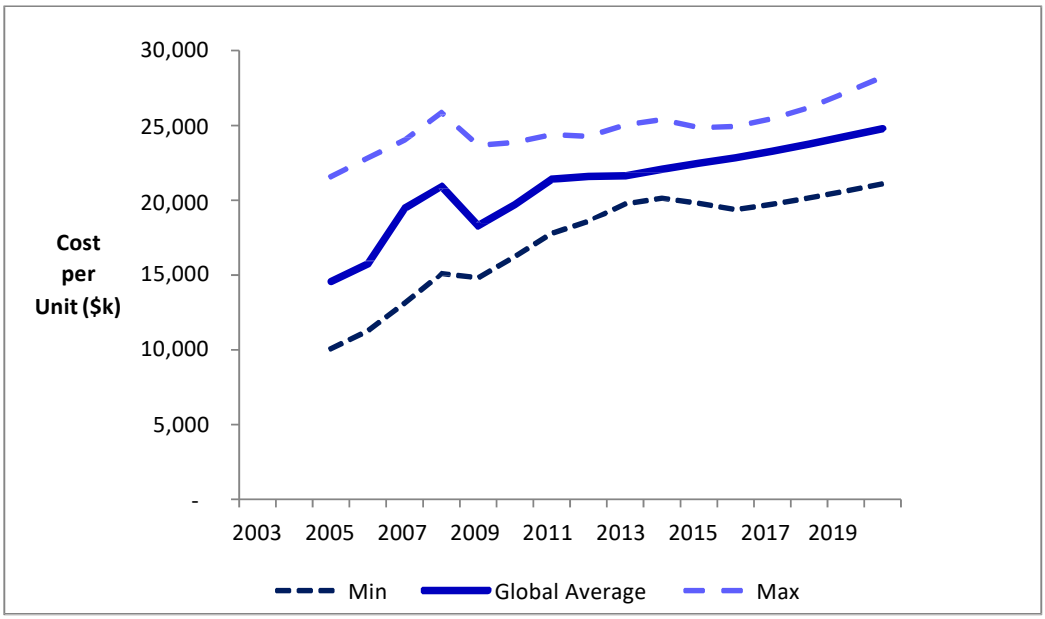
Hydrocracking Reactor prices are approximately 48% higher than in 2005 Q1, net of several fluctuations driven by economic conditions and metals prices.

As explained in section 9.2.2, prices move closely with costs, as buyers are tightly focused on getting the best price for these high-value, high-visibility pieces of equipment. The buyer is typically the EPC, which often awards packages of work based on its price negotiations for the major components, within an overall cost framework.

Prices were stable in Q1 as chrome steel costs fell 2%, but labor and machinery costs rose 0.5-1% each. Overall prices will increase 1.5% in 2013 and a total of 4% from 2013 Q1 through 2015 Q1, driven by 2-3% annual increases in electric power, and labor cost increases of 2% in the Americas and EMEA, and 4% in Asia. Carbon steel costs will contribute to the increase, rising 8% annually, although they make up only 5% of the overall costs for the category.

Global prices will rise 12% from 2013 Q1 to 2020 Q1, as costs for chrome steel increase 2% annually on average, and labor cost growth averages 3%. Wages for skilled machinists and welders in China and India, the main Asian markets for these reactors, will increase 4% on tighter supply of these workers than in the more mature economies. In contrast, labor costs will only increase 2% annually in the Americas and EMEA.

Figure 23: Overall Price Forecast for Hydrocracking Reactors



The reference unit is a 16'x120' hydrocracking reactor, rated for pressure up to 2,200 psig, using 2 1/4 Cr-1 Mo metallurgy with 3/8" 347 stainless steel cladding, at a US cost of $23m. Japan has the highest benchmark price levels at 109, followed by Europe at 103 and the US at 100. Despite comparatively high production costs in these regions, seven out of the top 10 global manufacturers of hydrocracking reactors produce them in Japan or Western Europe due to the more consistent availability of qualified labor, more stable power supply, and logistics infrastructure. These factors allow the manufacturers to maintain their reputations for high quality and on-time delivery.

- As with the other categories of Pressure Vessels, high power and labor costs drive the relatively high costs in Japan. The difference is lower than for many of the other categories however, partially because the major Japanese suppliers make their own steel, eliminating one stage in the value chain.
- Western Europe has slightly higher labor costs than the US for engineers and skilled machine operators, and higher power costs as well (by 54%). Although metals costs are slightly lower on average due to cheap imports from Russia, the region has a slightly higher cost of production than the US.
- High labor and materials costs compared to other regions leave the US at a cost disadvantage compared to other regions, up to 18% in the case of Southeast Asian countries like Thailand and Malaysia, as US costs for materials and labor are higher than in most global regions.

Asian cost levels are not at quite the same advantage for Reactors as they are for the other categories in this study. This is due to the higher proportion of material costs to labor costs and the advanced metallurgy required for the reactors. However, China, India, and "Other Asia," are still the

lowest cost regions, at index levels of 87, 86, and 82, respectively, due to lower labor costs, and frequently lower steel costs. For example, Spanish IDESA sold three reactors to Lukoil for its Volgograd expansion at an average cost of $23.3m per unit, while Indian Essar sold six units to Indian Oil Company Limited for its Paradip refinery in Orissa, India for $20.25m per unit, a per unit price difference of 17%.

Table 15: Regional Price Variations over Time for Hydrocracking Reactors

Region/Country	Today	2014	2015	2020
North America	1.00	1.01	0.99	1.06
Latin America	0.96	0.99	1.01	1.16
Europe	1.03	1.03	1.02	1.08
Middle East/North Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.88	1.02
Russia	0.89	0.94	0.95	1.13
China	0.87	0.88	0.86	0.92
Japan	1.09	1.11	1.08	1.09
Other Asia	0.82	0.83	0.82	0.86

9.2.4 Price Differences by Technology, Model, and Feature

Reactor prices vary primarily on size, especially diameter, metallurgy, and pressure rating. Using a 16'X120' reactor, rated for 2,200 psig, made of 2 1/4 Cr-1 Mo w/ 3/8" 347 SS cladding as the benchmark unit, significant variations include:

- On average, each additional pound per square inch of pressure rating adds $1,900 to the cost of the reactor.
- Downgrading in metallurgy from 2 1/4 Cr-1 Mo to 1 Cr- 1/2 Mo would save 20% of the cost, but in some field applications this has reduced the reactor's life by as much as 50%.
- Larger reactors cost less per barrel of processing capacity, on average approximately 5% less per barrel of capacity for every additional 2' of reactor diameter.

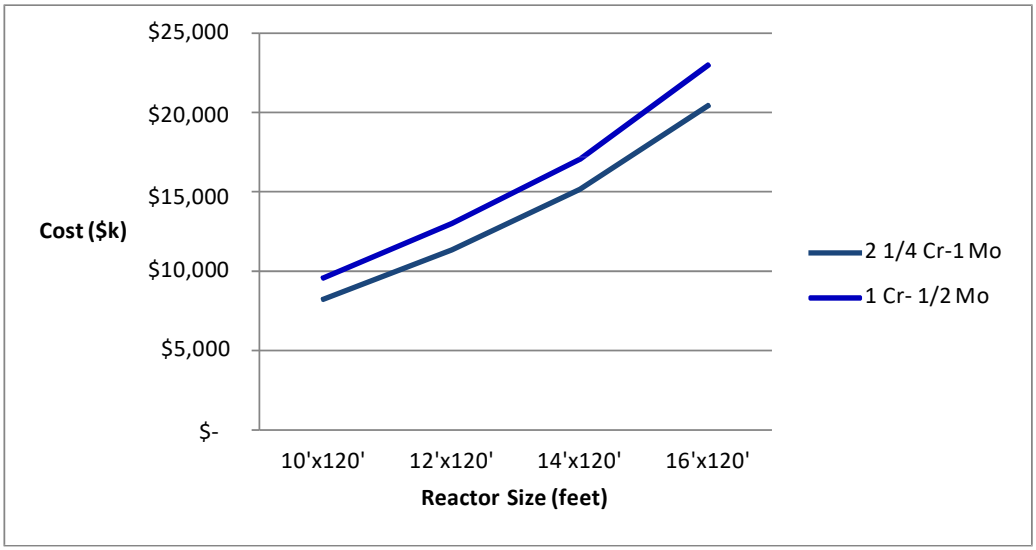
Table 16: Incremental Cost per Extra Parameter or Feature for Hydrocracking Reactors (Reference unit is 16'X120', 2,200 psig, made of 2 1/4 Cr-1 Mo w/ 3/8" 347 SS cladding)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Pressure Rating	psig (base 2,200)	$-3.5m to downgrade to 1740 psi	Cost per barrel of processing capacity falls as diameter increases
Metallurgy	2 1/4 Cr-1 Mo, 3/8" 347 SS cladding as reference point	$-2.5m to downgrade to 1 Cr- 1/2 Mo w/ 3/8" 347 SS cladding	Upgraded metallurgy lasts up to 50% longer
Processing Capacity	$/bpd (8,500 bpd capacity as reference point)	Decreasing the reactor size from 16' to 14' raises processing cost by $124.36 per barrel	Per barrel process cost falls a total of 13% for a 16' dia reactor vs. a 10' unit.

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

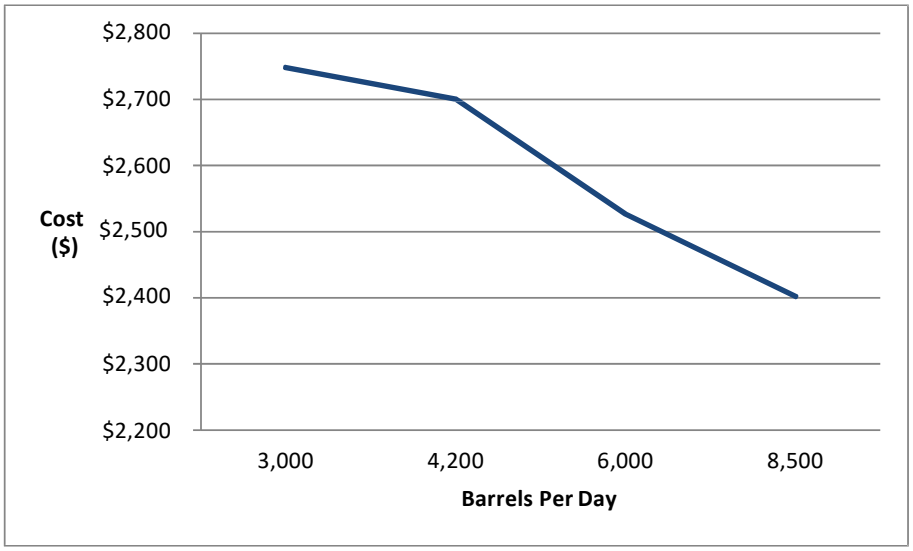
Cost increases accelerate with reactor diameter. For example, a 14'X120' reactor costs $4m (31%) more than a 12'X120' reactor, while a 16'X120' reactor costs $5.9m (35%) more than that.

Figure 24: Hydrocracking Reactor Size vs. Cost – by Diameter



With higher diameter comes an exponential increase in processing capacity, however, and cost per barrel of capacity falls from $2,750 per barrel for a 10'x120' reactor to $2,400 for a 16'x120' unit.

Figure 25: Cost of Hydrocracking Reactors per Barrel per Day of Output



Economies of scale are smaller for Hydrocracking Reactors than for most of the equipment types covered in this study, in large part because margins are already comparatively low for this subcategory. According to Chicago Bridge and Iron, KNM, and Carpenteria Corsi, buyers can expect up to a 5% per unit discount for an order of six reactors, vs. ordering 1-2.

Figure 26: Economies of Scale in Hydrocracking Reactors

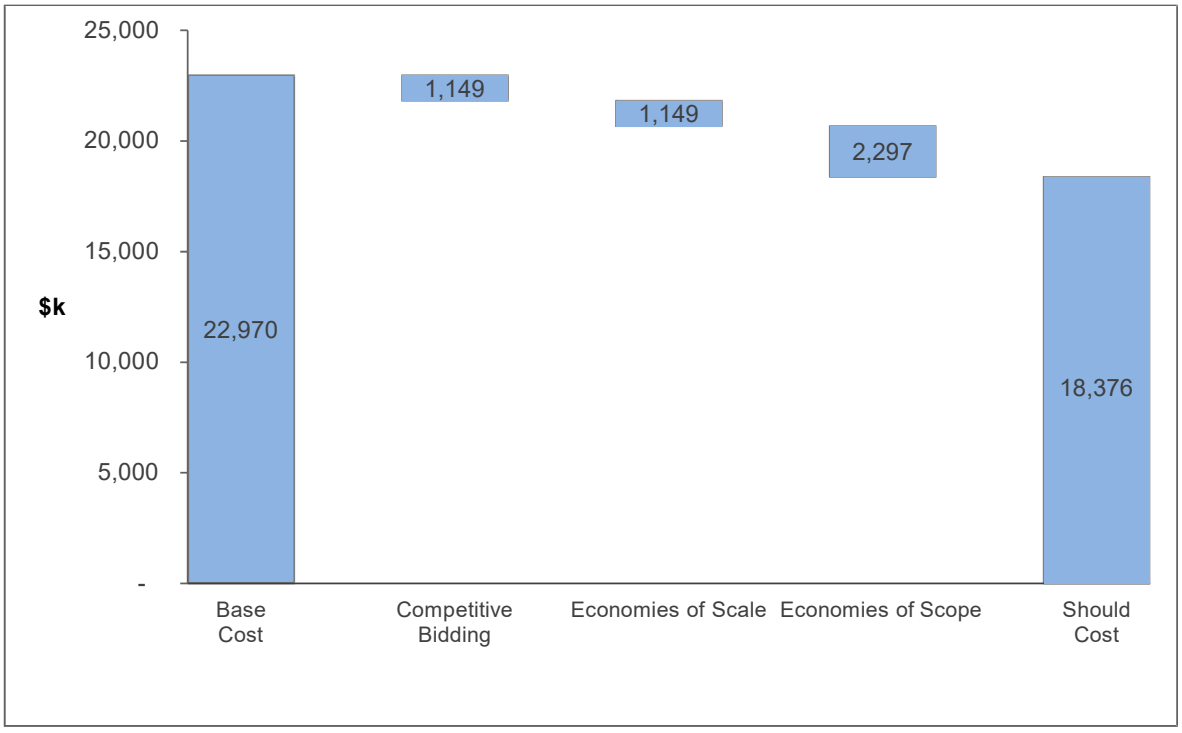


9.2.5 Should-Cost Analysis

Economies of scale and scope both represent opportunities for buyers to bring down the unit cost of reactors. As discussed above, manufacturers are willing to give discounts of up to 5% for additional order volume. The bigger lever on prices is project scope though, and this is what refiners and EPCs typically use to negotiate reactor prices down. Feedback from buyers and suppliers suggests that giving a manufacturer additional project scope can bring down reactor costs by up to 10%.

The Figure below illustrates the potential savings per unit for a large order of six reactors, assuming that the manufacturer also receives the contract for other pressure vessels, which could include hydrotreaters, heat exchangers, and vessels not within the scope of this study such as slug catchers and surge drums.

Figure 27**: Should-Cost for Hydrocracking Reactors**



9.3 Price Negotiation Strategies

1. Target suppliers with extremely low utilization rates for discounts. Carpenteria Corsi has added machinery and hired workers to fill the void left by Nuovo Pignone and is only 50% utilized. JSW added forge capacity in anticipation of nuclear reactor orders that have not materialized and it is 60% utilized.
2. Gain benefits from economies of scope by awarding orders for hydrocracking reactors along with other packages such as hydrotreaters and heat exchangers. Supplier feedback indicates that doing so can bring reactor cost down by up to 10%.

3. Approach steel mills directly to reserve capacity for advanced metallurgy requirements to avoid price spikes due to low inventory levels – which can cause price fluctuations of as much as 50-100% over the space of a year for chrome, nickel, and molybdenum alloys.

10 Hydrotreating Reactors

10.1 Market Overview

Table 17: Key Indicators for Hydrotreating Reactors

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	10.8%	▲	62.5%
Demand ($m)	▲	292-323	▲	292-474
Capacity Utilization	▲	3.5%	▲	5.5%
Prices	▲	5.2%	▲	16.8%

10.1.1 Demand

Demand will rise 2.5% in 2013 as refiners build hydrotreaters to produce cleaner fuels and increase liquid products yield, and 59% by 2020 Q1 on rapid investments in Russia, Asia, and Latin America.

Demand for Hydrotreating Reactors is growing faster than for any other category at 2.5% annually in 2013, which will accelerate to 7-8% annually through 2010. This comparatively rapid growth is driven by tightening global fuel emission standards, refiners' incentive to get the most liquid products out of their feedstocks while product prices are high, and the low capital cost of a hydrotreater compared to hydrocracking units.

As discussed in previous chapters, refiners are improving their global processing capabilities to reduce vehicle emissions. These moves are motivated in part by recent or pending fuel standards such as Euro 6, which govern sulfur and particulate emissions content. Instead of cracking the feedstock, hydrotreating primarily removes contaminants such as sulfur, nitrogen, and metals, as well as saturating carbon-heavy molecules with hydrogen, producing more liquid fuels with fewer contaminants.

Hydrotreating typically increases liquid fuel yield, such as diesel or kerosene, by 10-20%, allowing refiners to sell more product for the same amount of feedstock. At average US gasoline prices of $3.50 -3.70 per gallon in April (and $3.90 - 4.00 for diesel), and an average of $7 per gallon for diesel in 21 European Countries, refiners are eager to maximize fuel output.

Hydrotreating is an economical option to meet these goals in many cases, particularly as a desulfurization process, as hydrotreating units typically cost only tens of millions of dollars, compared to hundreds of millions for a hydrocracker, due to the lower process severity and scale. It

is essentially the same process as hydrocracking, but operated at lower temperature (800° F vs. 950° F) and pressure (up to 1,100 psig vs. up to 2,300 psig), in a smaller reactor. Due to the lower severity of the process, it usually converts only 10-20% of the feedstock from heavy fractions into lighter ones, compared to 50-100% for hydrocracking.

Demand is growing fastest in Asia, at an annual rate of 5% in 2013, where Chinese refiners CNPC, CNOOC, and CPC are moving to comply with the government's decree that they must comply with the current Euro 5 standards by 2017. Regional growth will accelerate to almost 15% in 2014, as Petronas and Cambodia Petrochemical Company order reactors for major projects. Projects include:

- Sinochem took delivery of hydrotreating reactors for a 4k bpd diesel hydrotreater its Quanzhou refinery in Q1.
- Sinopec's Zhanjiang refinery will include a 40k bpd diesel hydrotreater, and a 20k bpd kerosene hydrotreater.
- CNOOC is building three hydrotreaters at its Huizhou refinery with total processing capacity of nearly 100k bpd to treat diesel, gasoline, and FCC feedstock.
- Petronas' 300k bpd Melaka II expansion is in the contracting phase, with multiple hydrotreaters on the award list.
- Cambodia Petrochemical Company will incorporate 2-3 hydrotreaters at its Kampot refinery.

Projects in Russia, Qatar, and Saudi Arabia are contributing to a 4% increase in demand from EMEA this year, which will only slow slightly to 3% next year on a lull in the Saudi Arabian megaproject orders. Refiners are going ahead with multiple hydrotreater projects, as opposed to hydrocrackers, primarily because of the lower capital cost.

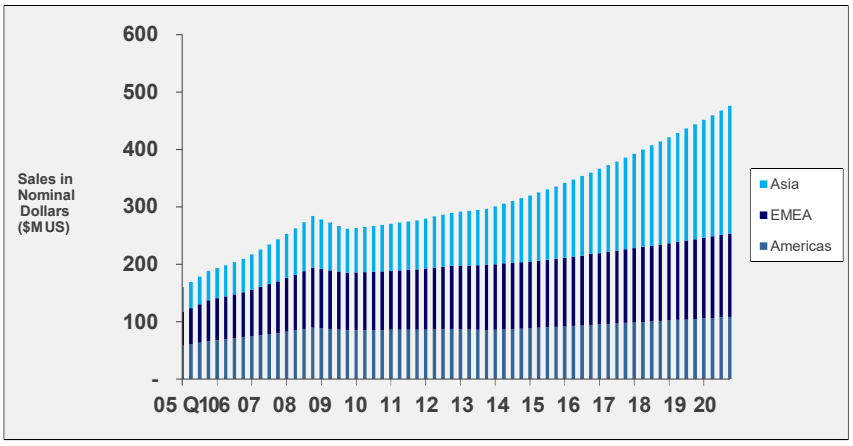
- Rosneft is building three hydrotreating units at its Syrzan, Achinsk, and Novo refineries. Gazprom is adding a 50k bpd diesel hydrotreater at its Moscow plant, and Neftegas is building a naptha hydrotreater at Afipsky.
- Qatargas ordered a 4-reactor, 54k bpd diesel hydrotreater for its Laffan refinery.
- Final progress payments for two hydrotreaters, diesel and naptha units with total capacity of 263k bpd, at Saudi Aramco's Yanbu refinery bolstered sales earlier this year.

Demand growth in the Americas will retreat 2% this year, slower than the decline for overall refinery capital spending on orders from Brazil and multiple small projects in the US. However, regional demand growth will surge to 3% for 2014 as reactors for Petrobras' Abreu e Lima refinery ship and Canadian Natural Resources takes delivery of new units. Projects include:

- Petrobras ordered reactors for a 38k bpd diesel hydrotreater at its Refap plant, which will arrive this year from Spain (Duro Felguera).

- Husky energy will complete work on a new 20k bpd diesel hydrotreater at its Lima, Ohio refinery in Q3 2013.
- Tesoro completed a small (22k bpd) hydrotreater at it Mandan refinery and will commission it in Q2.
- Dakota Oil Processing plans to build two hydrotreaters at its 20k bpd Trenton Diesel Refinery, currently under construction, one for diesel and one for kerosene.
- Petrobras ordered 10 hydrotreating reactors for its Abreu e Lima refinery, from Larsen and Toubro.
- Canadian Natural Resources ordered reactors for a gas oil hydrotreating unit, awarding the EPC package in September 2011. The project will not be complete until mid-2015, and the reactors will be delivered next year.

Figure 28: Demand for Hydrotreating Reactors



Global demand growth will accelerate to annual rates of 7-8% in 2015-2020, for a total increase of 62.5% from 2013 Q1 to 2020 Q1. Investments by national oil companies in Asia, the Middle East, and South America will drive the growth.

- Asian demand will increase by 125% as Chinese expansions at Nanhai, Zhenhai, and others add hydrotreating capacity, and major refining projects in Thailand, Vietnam, and India move forward.
- In EMEA, Saudi Aramco's Jazan refinery plans to build two diesel hydrotreating trains, each with 87.5k bpd in processing capacity. Iraq's planned Nassiriya refinery will include a 105k bpd diesel hydrotreater and a 24k bpd kerosene hydrotreater. Multiple refinery expansions in Russia will also contribute to a 40% increase in demand for the region.
- Most of the 25% growth in the Americas will be from South America, on projects at Petrobras and PDVSA, although Canadian Natural Resources' Athabasca expansion will contribute. In the US, both the preference for gasoline, which needs hydrotreating less

commonly, and the lighter production slate from shale plays will contribute to slower regional growth in hydrotreating investments.

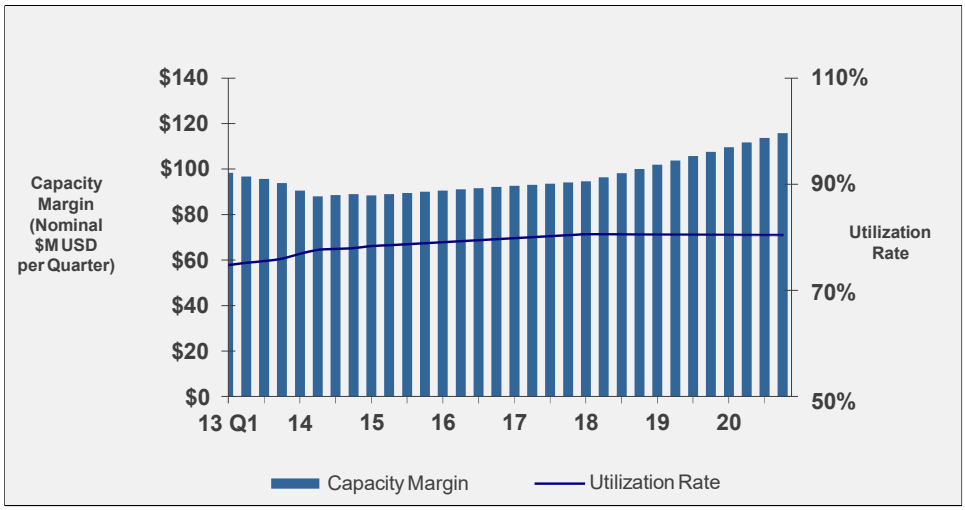
10.1.2 Supply (Capacity)

Industry capacity is more than sufficient, and utilization rates will rise gradually from 75% on average in 2013 Q1 to approximately 80% in 2018. Absolute Capacity Margin will continue to grow, so there is little risk of capacity shortages.

The major global Hydrotreating Reactor manufacturers include:

- Larsen and Toubro
- JSW
- Hitachi Zosen
- Technip
- Doosan
- Sinopec Engineering (Luoyang)
- IDESA
- KNM Group
- Belleli Energy
- Shanghai Boiler Works

Figure 29: Capacity Margin - Hydrotreating Reactors



Quarterly capacity is $390m as of 2013 Q1, leaving a Capacity Margin of $90m. It would take orders for 40-50 large reactors – 3-4 megaprojects' worth of capacity – in any given quarter to move lead times up significantly from their current level of 12-14 months.

Table 18: Reported or Estimated Capacity Utilization Rates at Selected Hydrotreating Reactor Suppliers

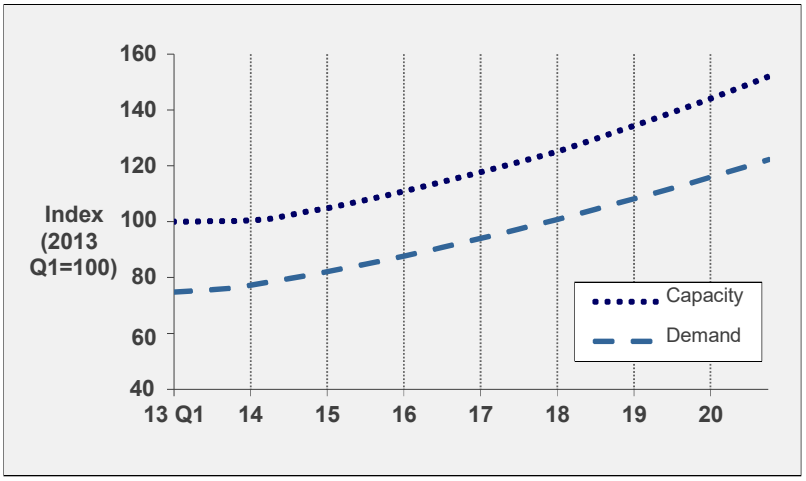
Company	Country	Current Level	12-Month Forecast
Larsen & Toubro	India	75%	75-80%
KNM Group	Malaysia	75%	75-80%
JSW	Japan	65%	65%
Shanghai Boiler Works	China	70%	75%
OMZ	Russia	80%	80%
Hitachi Zosen	Japan	70%	70%
Titan	US	65%	65%

Overall capacity levels are steady in 2013, with no significant plans to add roofline, workers, or machinery at the major manufacturers. As a result, utilization rates will rise steadily with demand, from 75% in 2013 Q1 to 77% in 2014 Q1.

- US-based Titan Metal Fabricators is 65% utilized, lower than most suppliers because it completed a new 80k square foot facility in 2012.
- JSW has also expanded recently, and is similarly 65% utilized.
- Larsen and Toubro also built new plants in 2011 and 2012, but its utilization rate is higher for hydrotreating reactors, at 75%, largely due to major orders from South America.
- OMZ, which is making most of the hydrotreaters for Russian projects, is 80% utilized, and preparing to add capacity in 2014 Q1 to keep up with more anticipated orders from Gazprom and Rosneft.

- Duro Felguera, which took the order for the 38k bpd Refap hydrotreater, is also 80% utilized.

Figure 30: Demand vs. Capacity - Hydrotreating Reactors



Manufacturers with currently high utilization rates, including OMZ above, are prepared to add capacity once demand growth picks up, and expansions after 2013 will keep utilization rates from getting much above 80%. In the meantime, Titan in the US is eager for business, and may be willing to give discounts in exchange for volume. JSW's utilization rate is low enough that the manufacturer is furloughing workers to avoid losing money, and it is also likely to be willing to trade volume for discounts.

10.1.3 New contracts

Saudi Aramco awarded some of the largest contracts in history; Technip was the major global winner while OMZ snapped up Russian contracts.

Saudi Aramco awarded hydrotreater contracts for three major projects, Ras Tanura, Yanbu, and Jazan, dominating recent tenders with more than $23m in spending on 18 reactors.

- The Jazan refinery ordered 10 reactors, for two separate diesel hydrotreater trains with capacity of 87.5k bpd each, at a reactor cost of $13.5m.
- The Yanbu project ordered five reactors for $6.29m, three for a 117k bpd diesel hydrotreater and two for an 85k bpd naptha unit.
- Ras Tanura ordered three reactors for a diesel hydrotreater at a cost of approximately $3.4m, giving the contract to local supplier Zamil Steel. The project allowed Saudi Aramco to meet government requirements to produce diesel with 10 ppm or less of sulfur emissions.

Also in the Middle East, QatarGas awarded the contract for a major project, 4 hydrotreating reactors for its Laffan refinery. The 54k bpd diesel hydrotreater will allow Qatargas to produce low-sulfur diesel for export, compared to the high-sulfur diesel it currently produces.

Technip has won three major projects since 2010, a total reactor value of approximately $8.2m. The firm won the Yanbu order from Saudi Aramco, a large order by itself. It also won contracts from Hindustan Petroleum Company Limited for its Visakh refinery expansion, completed in 2013 Q1. It also closed a smaller order from Husky Energy in the US, for a 20k bpd diesel hydrotreater.

OMZ bagged orders from Rosneft in Russia for units at Syrzan and Novo (Novokuybishevskiy), the latter was bundled with hydrocracking reactors:

- Rosneft ordered a diesel hydrotreating reactor for its Novo project ($1.5m), which it claims to have received at a discount by bundling the order with three hydrocracking reactors.
- Rosenft's Syrzan refinery ordered another 50k bpd diesel hydrotreater.

With annual demand growth rates projected to accelerate to 7-8%, the outlook for new contracts is strong, especially given the stated goal of refiners in South America and Asia to build new refineries or units to meet new fuel emissions requirements. One major refining project in the Middle East is currently in the contracting phase, Iraq's Nassiriya oilfield and refinery. The Iraqi Ministry for Oil currently plans to auction off the rights to develop the oilfield and build the refinery in December 2013, with more than 50 bidders currently qualified.

Table 19: Summary of New Contracts and Estimated Values for Hydrotreating Reactors

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Saudi Aramco - Jazan	Saudi Arabia	IDESA	10 reactors, two 87.5k bpd diesel hydrotreater trains	$13.50	$ 1.35
Saudi Aramco - Yanbu	Saudi Arabia	Technip	5 reactors, 117k bpd diesel, 85k bpd naptha hydrotreater	$6.29	$ 1.28
QatarGas - Laffan	Qatar	Samsung	4 reactors	$6.14	$ 1.54
Petrobras - Abreu e Lima	Brazil	Larsen & Toubro	10 reactors, 166k bpd diesel hydrotreater	$5.07	$ 0.51
Saudi Aramco - Riyadh	Saudi Arabia	Zamil	3 reactors, diesel hydrotreater	$3.38	$ 1.13
PetroChina - Lanzhou	China	Luoyang (Sinopec)	2 reactors	$3.00	$ 1.50
Rosneft - Syzran refinery	Russia	OMZ	1 reactor, 50k bpd diesel hydrotreater	$1.62	$ 1.62
Holly Corp - Tulsa	Brazil	Titan	1 reactor	$1.51	$ 1.51
Rosneft - Novo	Russia	OMZ	1 reactor	$1.50	$ 1.50
Petrobras - Refap	Brazil	Duro Felguera	1 reactor, 38k bpd hydrotreater	$1.47	$ 1.47
HPCL - Visakh	India	Technip	1 reactor, diesel hydrotreater	$1.25	$ 1.25
GS Caltex - Yeosu	South Korea	Doosan	1 reactor, 24k bpd hydrotreater	$0.90	$ 0.90
Husky Energy	US	Technip	1 reactor, 20k bpd hydrotreater	$0.69	$ 0.69
Dakota Oil Processing	US	NRG	1 reactor	$0.47	$ 0.47

10.2 Analysis

10.2.1 Costs

Cost levels were flat in 2013 Q1, but they will rise 1.5% for the year on rising costs for labor, and carbon steel. Costs will rise a total of 14% by 2020 Q1.

Metals make up 54% of the cost to make Hydrotreating Reactors, slightly higher than the percentage for Hydrocracking Reactors because machinery costs are lower for the smaller, less heavily specified units. The manufacturer of hydrotreating reactors does not require the same heavy-duty (8k-15k tonne) forge presses, or the same specification of welding, as manufacturers are able to use the cheaper, faster submerged arc welding process to a larger degree instead of the more expensive GTAW (gas tungsten arc welding) process. Common metallurgies for hydrotreating reactors are simple carbon steel for lower pressure applications (400 psig). Chrome steel is used in higher proportion for high-sulfur applications, such as hydrodesulphurization. Once pressure ratings reach 600 psig and above, 1 Cr-1/2 Mo is common, and nickel-vanadium alloys are sometimes included.

Labor and benefits account for 23% of the overall cost structure, although that percentage is lower in regions with lower labor costs.

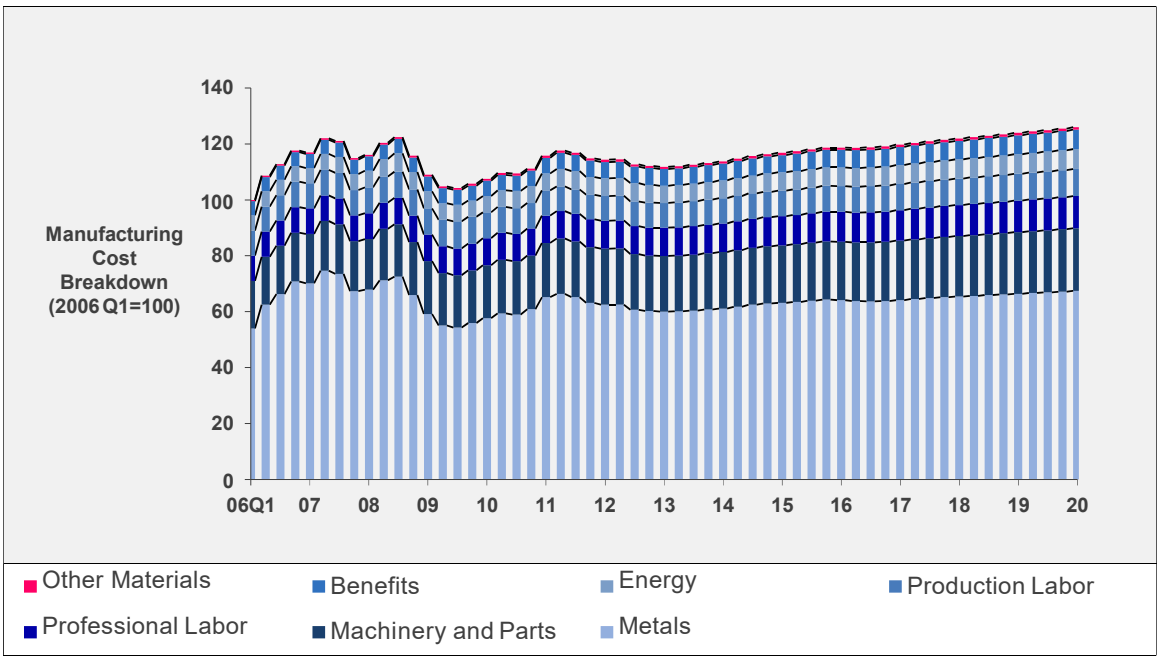
Machinery costs make up 17% of the total cost structure, which includes cutting, bending, beveling, lifting, welding, and painting equipment.

Global cost movements balanced each other out in Q1. Although average costs fell 1% in the Americas for the quarter, due to a drop in carbon steel and power costs, they rose approximately half a percent in the other two regions on labor cost growth. Carbon steel costs fell 12% in 2012 due to slow demand and global overstocking, which kept 2012 price growth to just 1%, and the inventory overhang has persisted longer in the US.

Costs will rise approximately a half a percent per quarter globally for the rest of 2013, accelerating slightly to just over 1% per quarter in 2014. Carbon steel, chrome steel, labor, and machinery costs will climb slowly but steadily over the period, forcing overall cost levels up.

Average costs will rise a total of 12% from 2013 Q1 to 2020 Q1. Carbon steel cost growth will be a driving factor. While volatile in both directions, costs for this staple material will increase 17% by 2020 Q1. Asian labor cost increases will be the other main driver, growing almost twice as fast as labor costs in the more mature Western economies (1% per quarter vs. about 0.5%). As a result, costs will rise about 16% in Asia, vs. 12.5% in the Americas and 11% in EMEA.

Figure 31: Cost Structure of Hydrotreating Reactors



Note: Prices are ex-works.

10.2.2 Profit Margins

Margins for Hydrotreating Reactors are consistent with overall company profits, averaging 5-6%. Rapid demand growth will allow suppliers to raise margins by 2-3% points by 2020.

Average supplier margins for Hydrotreating Reactors are 5-6%. According to Doosan, its net margin on Hydrotreater projects is consistent with profits for the company as a whole, or 7.6% in 2012. Sinopec Engineering and Larsen & Toubro earned similar profit levels, citing healthy reactor shipments and backlogs. Belleli's margin levels were somewhat lower last year at 4%, due in large part to low utilization rates that allowed overhead to devour most of its profits. Hitachi's Zosen division, the unit that makes pressure vessels, only earned 3%, after bidding low on several projects in Southeast Asia to win against low-cost competitors.

Margins for Hydrotreating Reactors are more difficult to isolate than for most pressure vessel projects, because the reactor cost is such a small portion of the total, 2-5% depending on the size, pressure, catalyst loading, separator arrangement, number and type of pumps and compressors, number of reactors in the unit, and other factors.

Supplier margins correlate heavily with utilization rate, due to the capital-intensive nature of the manufacturing process. For example, Titan Metal Fabricators, which is only 65% utilized, had margins of only 3%. Belleli cited low utilization rates as the reason for its own low margin. In contrast, Larsen and Toubro and Sinopec Engineering are both 75-80% utilized, with 7-8% profit margins.

10.2.3 Prices

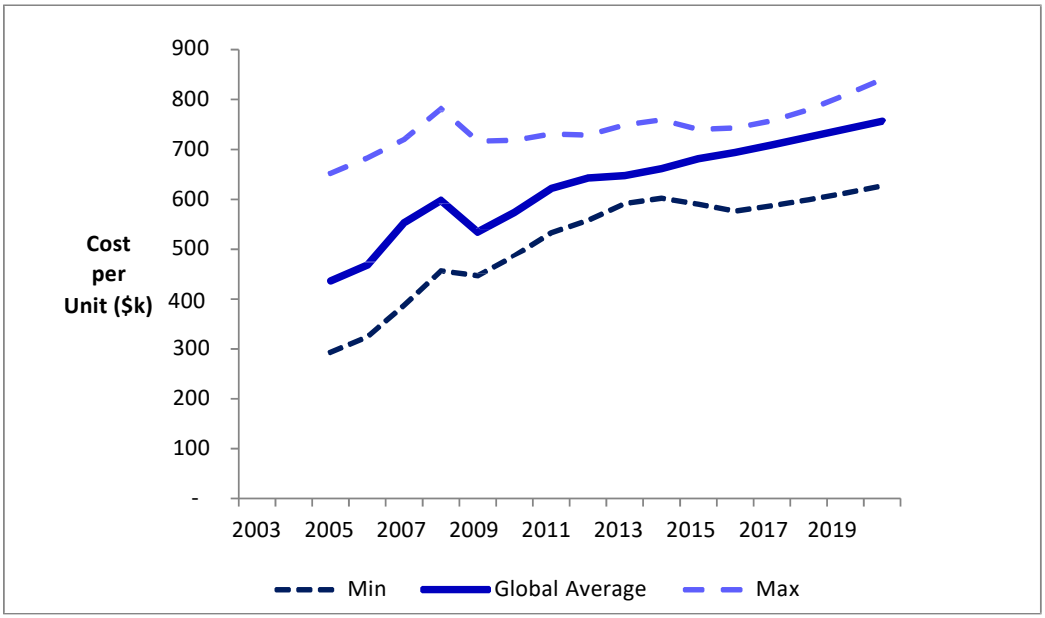
Prices will rise 1.5% in 2013, consistent with cost increases, before accelerating faster than costs beginning in 2015 based on rapid demand growth and higher utilization rates (17% vs. 14% by 2020 Q1).

Average prices for Hydrotreating Reactors are 48% higher than they were in 2005 Q1, net of a rapid ramp up during the so-called “golden age or refining,” which lasted from 2004 to 2008, a subsequent crash during the 2008-2009 recession and then another, slower ramp up as refinery spending began to recover in 2010 and 2011.

Prices remained steady in Q1, as falling carbon steel costs canceled out increases for machinery and labor. Reactor prices will increase 1.5% in 2013 and a total of 5% over the next two years, driven by 8% annual increases in costs for carbon steel, 2-3% annual increases in electric power, and labor cost increases of 2% in the Americas and EMEA, and 4% in Asia.

Hydrotreating Reactor prices will increase by a total of approximately 17% by 2020 Q1, although costs will only increase 14%. The differential growth rate for prices is explained by rapid demand growth, as well as “value-based” pricing on the part of manufacturers as buyers scramble to comply with tightening fuel quality standards in order to maintain access to markets where the standards apply. If refiners lose access to those markets, their own earnings potential will fall, and hydrotreating units will be critical in allowing refiners to make fuels to the right specifications.

Figure 32: Overall Price Forecast for Hydrotreating Reactors



The reference unit for Hydrotreating Reactors is a 20k bpd vessel, made of 1 Cr-1/2 Mo steel, designed to operate at 800 psi and 800° F. At benchmark cost levels (US) this reactor would cost $687k.

Consistent with the other subcategories of Pressure Vessels Japan has the highest benchmark price levels, although somewhat lower than most at 105. The difference is due to a lower proportion of electric power and labor in the cost structure, the cost components that put Japan at a cost disadvantage. At this cost level, the benchmark unit would cost $715k. Europe is follows Japan closely at 102, mostly due to higher labor costs, and the reference unit would cost $700k.

Cost levels are lowest in Southeast Asia, where labor and power costs are both low. At Index levels of 82, the reference unit would cost $570k. Reference cost levels are 86 in India and 87 China and Russia. These cost levels are roughly borne out by reactor costs on the following projects:

- Larsen and Toubro sold 10 reactors to Petrobras for its Abreu e Lima project at an average cost of $510k per reactor for 17k bod reactors. At US cost levels, factoring in a 10% volume discount, these units would have cost approximately $570k each – or 10.5% more.
- Technip sold a 20k bpd diesel hydrotreating reactor to Husky Energy, manufactured at its plant in Lousiana, US, for $690k, on par with benchmark cost levels. It sold a 44k bpd diesel hydrotreating unit to HPCL in India, which it manufactured in New Delhi, for $1.35m, approximately 10% below benchmark cost levels for the corresponding unit.

Table 20: Regional Price Variations over Time for Hydrotreating Reactors

Region/Country	Today	2014	2015	2020
North America	1.00	1.01	0.99	1.05
Latin America	0.96	0.98	1.01	1.14
Europe	1.03	1.03	1.02	1.07
Middle East/North Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.88	1.02
Russia	0.89	0.94	0.94	1.12
China	0.87	0.88	0.86	0.91
Japan	1.09	1.10	1.08	1.08
Other Asia	0.82	0.83	0.81	0.85

4. Price Differences by Technology, Model, and Feature

Prices for Hydrotreating Reactors vary primarily on reactor pressure rating, metallurgy, and capacity. Using the reference unit as a benchmark, significant variations include:

- On average, each additional pound per square inch of pressure rating adds $750 to the cost of the reactor.
- Downgrading in metallurgy from 1 Cr- 1/2 Mo to 1 1/4 Cr or simply carbon steel would reduce unit cost by 25% and 36%, respectively.

Table 21: Incremental Cost per Extra Parameter or Feature for Hydrotreating Reactors

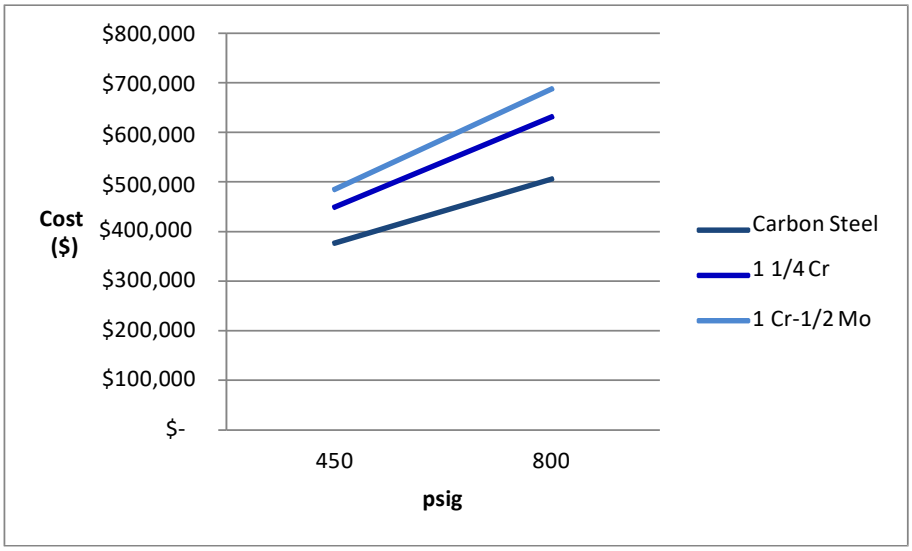
(Reference unit is 7'x23', 800 psig, 1 Cr-1/2 Mo)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Pressure Rating	Psig (reference is 800)	Reducing pressure requirements to 450 psig cuts reactor cost by $202k	Decreasing pressure reduces conversion rate
Metallurgy	1 Cr-1/2 Mo as reference point	Downgrading to 1 1/4 Cr saves $56.4k, and to carbon steel saves $181.5k	More advanced metallurgy is required for corrosive applications
Processing Capacity	$/bpd (reference is 20k bpd)	-26% to per barrel cost when increasing from 10k to 20k bpd	Cost reductions plateau or increase after 20k bpd

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

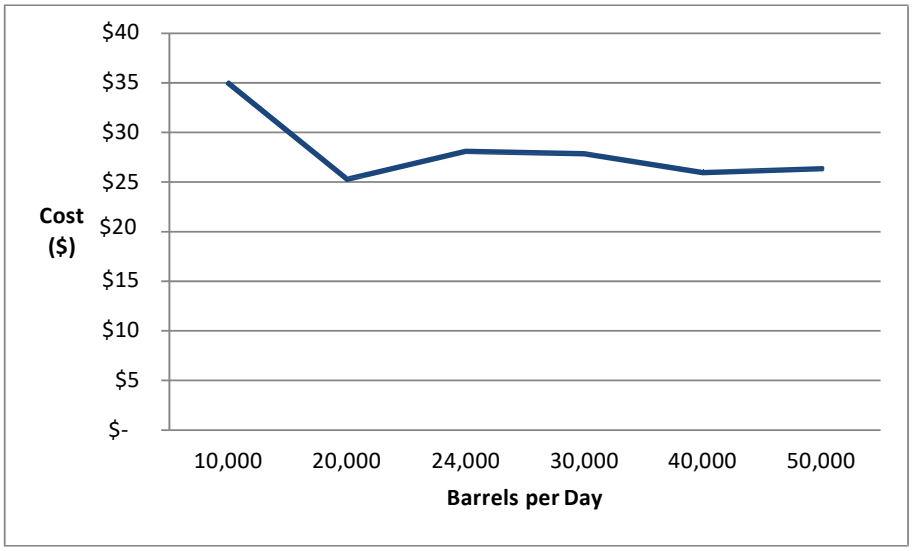
On average, increasing the pressure rating from 450 psi to 800 psi increases cost by 37%, although the ratio varies from 18% to 42% depending on size and metallurgy.

Figure 33: Hydrotreating Reactor Pressure Rating vs. Cost – by Metallurgy



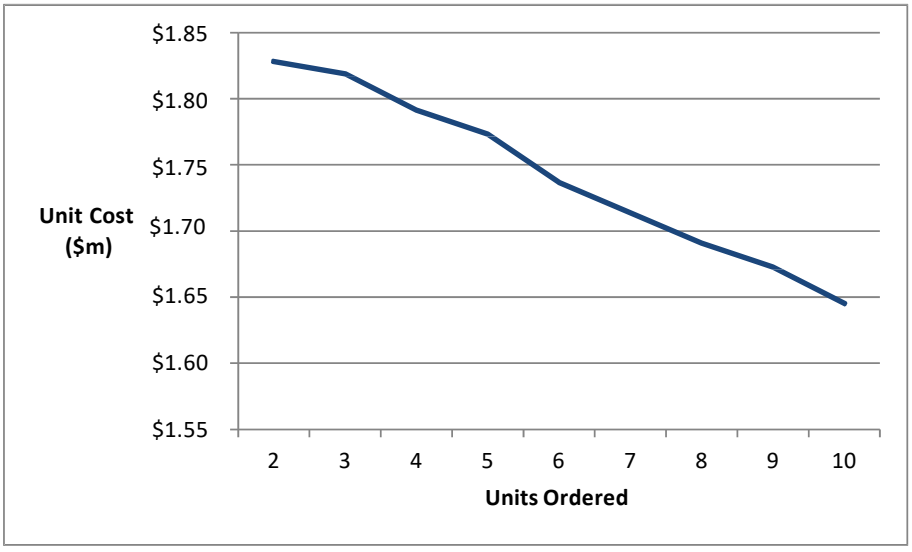
Processing costs fall rapidly from a 10k bpd unit to a 20k bpd reactor, then plateau at approximately $26 per barrel of installed capacity.

Figure 34: Cost per Barrel of Capacity for Hydrotreating Reactors



Supplier feedback and reactor cost levels indicate that economies of scale of up to 10% are available, at reactor quantities of 10 or more. For example, Larsen & Toubro gave Petrobras a discount of approximately 10% on reactors for its Abreu e Lima refinery.

Figure 35: Economies of Scale in Hydrotreating Reactors

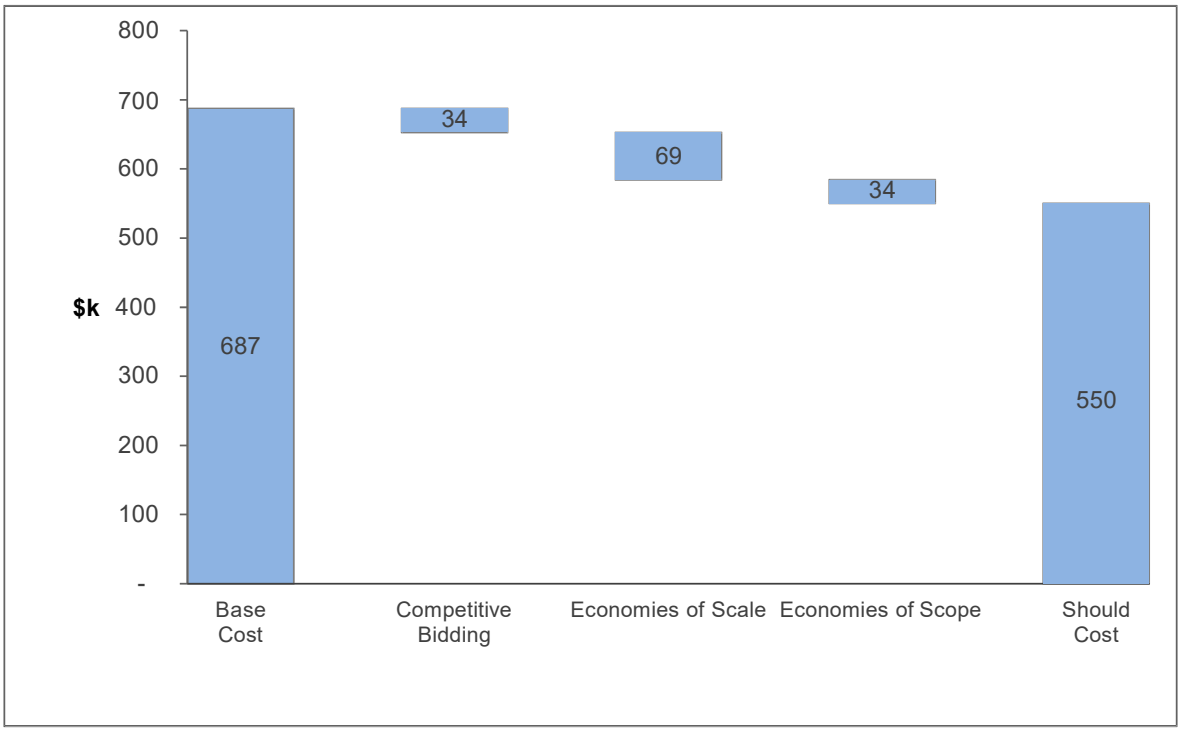


10.2.5 Should-Cost Analysis

Aside from generally yielding to the pressures of competitive bidding, manufacturers are willing to give discounts both for an increase in the number of units ordered, and for a larger scope of work (awarding the hydrotreaters in conjunction with other processing units such as hydrocrackers).

OMZ exhibited both of these tendencies when supplying units for Rosneft's Novo refinery, giving a small discount (5%) for the three hydrocracking reactors, and knocking about 5% off of the price of the single hydrotreating reactor it supplied for the project.

Figure 36: Should-Cost for Hydrotreating Reactors



10.3 Price Negotiation Strategies

1. Consider Titan Metal Fabricators and JSW as ripe targets for discounts in exchange for large orders. Both suppliers are only 65% utilized, and are eager to cover overhead costs by winning orders.
2. Focus on costs for the entire hydrotreating unit, rather than the reactor, as the actual reactor vessels can cost as little as 2-5% of the unit's cost (less than the cost of the unit's compressors in some cases). Instead of negotiating hard for a 5% discount on a $687k unit ($34.35k), negotiate with the EPC on the entire unit cost – a 5% reduction on a hydrotreating unit cost of $70-200m could amount to $3.5-10m.

11 Coke Drums

11.1 Market Overview

Table 22: Key Indicators for Coke Drums

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	9.8%	▲	54%
Demand ($m)	▲	200-219	▲	200-308
Capacity Utilization	▲	0.7%	▲	2.7%
Prices	▲	5.2%	▲	16.8%

11.1.1 Demand

Demand growth will rise 54% by 2020 Q1 despite being restrained by the growth of hydrocracking capacity (which leaves little to no residuum for a coker to process).

Coking, either delayed or fluid, thermally cracks residual hydrocarbons left from distillation or cracking processes to recover the last liquid fractions, leaving solid carbon (coke) as a byproduct. Delayed coking, by far the more common process, uses two or more drums so that at least one drum is still operating while one is emptied and the coke removed. Fluid coking keeps the coke in fluidized form and cycles it into a burner so that the drum does not have to be shut down to be cleaned. Drums can range in diameter from 20' to 32', depending on the throughput capacity required of the unit and the number of drums.

Demand for Coke Drums is heavily dependent on overall refinery capital spending, although growth is somewhat slower in this category than for overall refinery spending because hydrocracking, an alternative to coking that leaves little to no residuum for a coker to process, has gained in popularity. Global Coke Drum demand is growing at 1.8% annually in 2013, as refinery capital spending grows 4-5% in Asia and EMEA, but contracts by 4% in the Americas.

Asian projects driving this growth include:

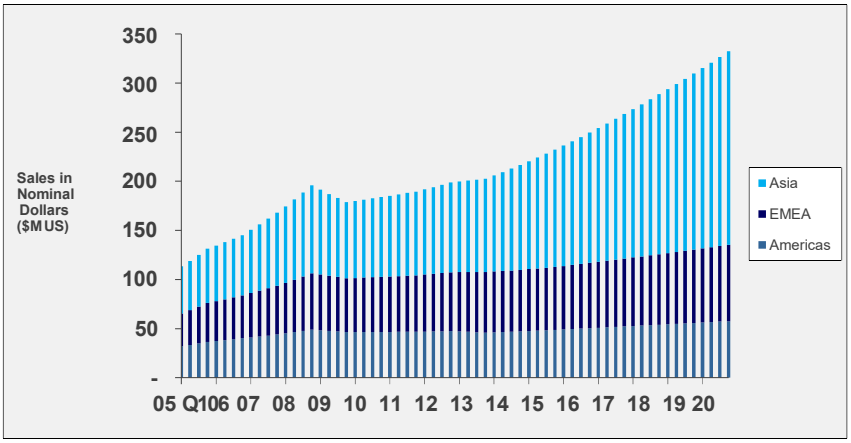
- China National Petroleum Corporation's 400k bpd Nanhai refinery, being built to process Orinoco crude, will include a coking unit.
- Indian Chennai Petroleum Corporation Limited is building a 45k bpd coking unit as part of its Manali expansion.
- Malaysia's Melaka II project includes a delayed coker unit that will produce fuel-grade coke.

In EMEA, Lukoil's Perm refinery, which ordered four coke drums from CB&I in late 2011, will take delivery of the units this year. Saudi Aramco is likely to order coke drums for its Jazan project this year as well.

Contrary to the global trend, Coke drum demand will shrink 3% this year in the Americas, particularly in North America. Major coking units recently completed have increased US coking capacity by 6.5% since 2010, including Motiva's Port Arthur complex and BP's 102k bpd Whiting unit (currently the second largest DCU in the world). In the meantime, the US crude oil production slate has grown lighter on light, sweet crude from shale plays, requiring less coking capacity. Motiva's expansion plans to use heavy Arabian crude, but less of the crude will be available in the US once Saudi Arabia's Yanbu and Jazan projects are commissioned to process the oil domestically. Canadian Suncor has already canceled its Voyageur upgrading project, a joint venture with Total, due to what is shaping up to be an excess of heavy crude processing capacity in North America. Instead of using cokers, ExxonMobil opted to use paraffinic froth treatment for its Kearl oil sands project, a partial upgrading process that will allow the bitumen to be exported via pipeline and processed with existing coking capacity.

Coke Drum demand growth will accelerate rapidly beginning in 2014, to approximately 7% per year, as global refinery capital spending increases at 8% annually. While demand growth will be slower than for the other categories, the cumulative increase of 54% will still be aggressive.

Figure 37: Demand for Coke Drums



Demand from Asia, where refinery spending will grow at 12-15% per year, will increase fastest, at annual rates of 7-8%. China will account for about half of this growth by itself, but expansions in India, Malaysia, Vietnam, and Cambodia will contribute. Major Asian projects that will place orders in this timeframe include:

- CNPC's 400k bpd Nanhai refinery, which may order its coke drums by the end of the year, will receive the drums in this period and make several progress payments.
- The Cuddalore refinery in India will include a 50k bpd delayed coking unit.
- Sinopec's 100k bpd Hainan refinery expansion will include a 20-30k bpd delayed coker.
- Vietnam's Nghi Son and Dung Quat refineries will both include cokers when they are completed in 2017, for a total of 50k bpd in coking capacity.
- Petronas' Johor refinery will include a coker, although the unit's size is not decided.

Demand growth rates in the Americas and EMEA will be more subdued through 2020, at 3-4% annually. In the Americas, most of the growth will come from Latin America, as North American coking capacity is already abundant (see above). In EMEA, Russia and Iraq will place major orders, while Saudi Arabia's Jazan project will receive coke drums for its 117k bpd DCU. Specific projects include:

- Petrobras' Premium II and Comperj II refineries will both order coke drums. The Premium II order will likely be on the same scale as Premium I – four drums (from Larsen and Toubro).
- Gazprom's Moscow refinery expansion, scheduled to start in 2016, will include a coking unit.
- Iraq's Nassiriya refinery will include a coking unit.

11.1.2 Supply (Capacity)

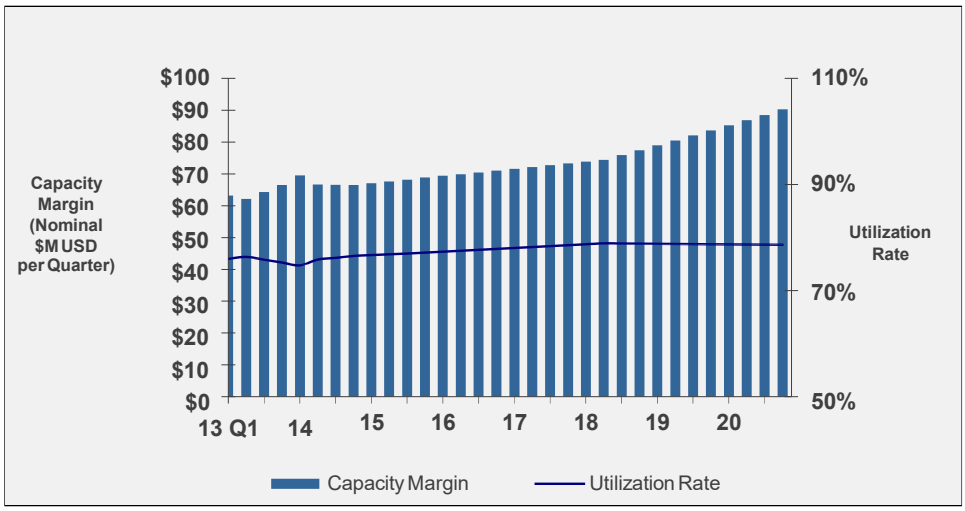
CB&I is opening plant expansions this year, and other manufacturers such as Sinopec Engineering and Mangiarotti will add enough capacity to keep utilization rates from rising significantly.

The major global Coke Drum manufacturers include:

- Larsen & Toubro
- Chicago Bridge and Iron
- Sumitomo Heavy Industries
- Sinopec Engineering
- Sungjin (Posco)
- IDESA
- Duro Felguera
- Hitachi Zosen
- CPTDC
- G&G International

Manufacturing capacity for Coke Drums is approximately $263m worth of equipment per quarter. At average capacity utilization rates of 76%, this leaves approximately $65m worth of capacity, or 8-10 large drums per quarter. This can equate to as little as one major order, such as KNPC's Clean Fuels project (a two-refinery upgrade) – which bought 10 drums from Larsen & Toubro that shipped over the course of six months in 2011. However, orders of that size are infrequent and rarely are there four or more of them in a year. In summary, there seems to be plenty of capacity available to satisfy the projected demand.

Figure 38: Capacity Margin – Coke Drums



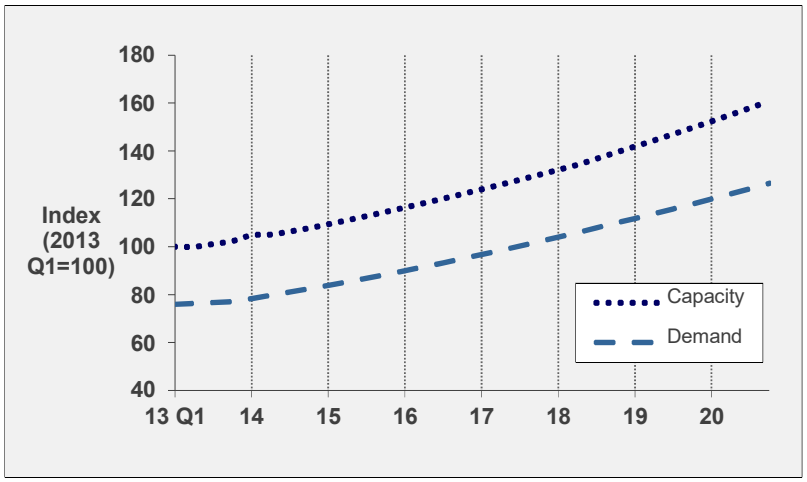
Larsen and Toubro has the lowest utilization rate of the major manufacturers currently, at 50%, after expanding two facilities in 2012 and recently shipping major orders for Petrobras, IOCL (in India), and Petron (in the Philippines). The firm expects that new orders will fill this gap soon, and that its utilization rate will return to 75-80% within a year.

Table 23: Reported or Estimated Capacity Utilization Rates at Selected Coke Drums Suppliers

Company	Country	Current Level	12-Month Forecast
CB&I	USA	80%	60%
CB&I	Thailand	80%	85%
Sumitomo Heavy Industries	Japan	70%	75%
Sungjin (POSCO)	Korea	80%	80%
Duro Felguera	Spain	75%	75%
Isgec	India	70%	75%
Mangiarotti	Italy	90%	90%
Larsen & Toubro	India	50%	80%

Italian newcomer Mangiarotti (it entered the coke drum market a decade ago, but is still a relatively new company in this business) is 90% utilized, in part because of its small size. The company can only manufacture 6-8 drums at one time and, with several orders currently in production, cannot start producing more than one more drum immediately. The firm is expanding, and expects to increase its capacity by 50% within a year.

Figure 39: Demand vs. Capacity – Coke Drums



Chicago Bridge and Iron is also adding capacity at yards in the US and Thailand. The former will open in 2013 Q4 and the latter in 2014 Q1. The new cutting, bending, and welding machines in both locations will increase CB&I's drum capacity by 6-8 units per year, creating a noticeable bump in industry Capacity Margin and helping to reduce average utilization rates to 74% briefly next year.

Sinopec Engineering is also planning to add capacity within the next two years. Its machinery for large, heavy wall vessels such as Coke Drums is 80% utilized, and the firm intends to add capacity once that level reaches 85%.

11.1.3 New contracts

Larsen & Toubro is the major contract winner since 2010, followed by Sumitomo. US buyers favor Japanese and European manufacturers.

Larsen and Toubro has emerged as the biggest contract winner in the last several years (since 2008), winning high-profile orders from Petrobras, IOCL, and KNPC.

- Petrobras ordered a total of 28 drums from Larsen & Toubro from 2008-2011 worth approximately $155m, for its delayed Premium I and Abreu e Lima refineries.
- IOCL ordered six drums for its Paradip refinery at a cost of $43m, which comes online this year.
- KNPC ordered 10 smaller drums, worth $34.5m, for its Clean Fuels Project. The number of drums required multiple lifts, and deliveries stretched over six months, ending in June 2011.

Sumitomo Heavy Industries won contracts from Saudi Arabia and the US, leveraging its reputation for quality and reliability. Multiple buyers cite Sumitomo as the only manufacturer that routinely performs stress relief welds on all of its coke drums, which goes beyond ASME U stamp requirements. According to operators, this can make the difference between a drum that lasts for the designed 30 years and one that fails (cracks or bulges) in 10 years or less.

- Saudi Aramco ordered 18 drums, collectively worth $149m, for its joint venture refineries in Jubail and Yanbu.
- CHS tapped Sumitomo for two smaller drums, together worth $9m, to replace aging drums at its McPherson refinery in the US.

Three out of three US contracts in Table 24 went to Japanese or European suppliers, Sumitomo, Kobe Steel, and IDESA, respectively. This is largely due to the perception of these suppliers as higher quality.

Pending contracts include more units for Petrobras, for its Premium II and Comperj II refineries, which are likely to be on the same scale as its recent orders, meaning 20-28 drums. Refineries in Moscow (Russia) and Nassiriya (Iraq) will also order units. In Asia, China has approximately 1.85m bpd in distillation capacity scheduled for construction by 2020 that have not tendered contracts yet – which could mean up to 500k bpd in coking capacity. Also in Asia, Indian IOCL currently has two more tenders out for coke drums, one for replacement drums and one for an entire coking unit.

Table 24: Summary of New Contracts and Estimated Values for Coke Drums

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
SATORP - Jubail	Saudi Arabia	Sumitomo	12 drums, 200k bpd	$98.88	$8.24
Petrobras - Premium I	Brazil	Larsen & Toubro	200k bpd	$78.34	$4.90
Petrobras - Abreu e Lima	Brazil	Larsen & Toubro	12 drums	$77.11	$6.43
Saudi Aramco - Yanbu	Saudi Arabia	Sumitomo	6 drums, 117k bpd	$50.27	$8.38
BP-Whiting	US	Foster Wheeler (EPC)	6 drums, 102k bpd	$43.06	$7.18
IOCL - Paradip	India	Larsen & Toubro	6 drums	$42.75	$7.13
KNPC - Clean Fuels Project	Kuwait	Larsen & Toubro	10 drums	$34.43	$3.44
Gazpromneft - Omsk	Russia	OMZ	4 drums	$30.00	$7.50
Chevron - El Segundo	US	IDESA	6 drums	$26.93	$4.49
Sinochem - Guanzhou	China	Sinopec	50k bpd	$20.12	$6.71
Lukoil - Perm	Russia	CB&I	4 drums, 44.7k bpd	$18.42	$4.61
Petron - Bataang	Philippines	Foster Wheeler (EPC)	2 drums, 37.5k bpd	$16.40	$8.20
CPCL - Manali	India	Isgec	4 drums, 45k bpd	$15.18	$3.80
ENAP - Concón	Chile	Duro Felguera	2 drums	$9.45	$4.73
CHS - McPherson	US	Sumitomo	2 drums	$9.00	$4.50
ConocoPhillips - Billings	US	Kobe Steel	2 drums	$9.00	$4.50

11.2 Analysis

11.2.1 Costs

Steel, nickel, and Asian labor costs will push overall cost levels up 11% by 2020 Q1. Differing metallurgy and transportation costs for individual projects make costs highly variable for each unit.

Metals account for 48% of the cost to make Coke Drums, less than for reactors due to the lower pressure tolerance requirements (and thus thinner walls – 1-2" vs up to a nearly 12"). Metallurgy varies widely, from 1 Cr-1/2 Mo to 2 1/4 Cr-1 Mo, often with 410 stainless steel cladding. Upgrading from the relatively simple 1 Cr-1/2 Mo to 2 1/4 Cr-1 Mo w/ 410SS cladding typically adds 40-55% to the drum's overall cost.

Machinery costs make up 21% of the overall cost structure. Machinery includes cutting, bending, beveling, lifting, welding, and painting equipment. Coke drum manufacturing is especially welding-intensive especially if stress relief welds are made.

Labor accounts for another 17% of the overall structure, including wages for welders, machinists, and shop hands, and salaries for management and engineers.

Manufacturing to specifications above ASME section VIII division II codes also adds cost, time, labor, energy, and some materials. According to operators, coke drums can fail by bulging or cracking after as little as 4-7 years, even if they are manufactured to ASME specifications. Advanced metallurgy, the current preference is 2 1/4 Cr-1 Mo, often with stainless steel cladding, and stress relief welds are the major approaches to extending drum life, beyond ASME requirements.

Transportation costs are frequently a major factor – much more so if overland transportation is required. According to ExxonMobil and ConocoPhillips, costs including feasibility studies, direct hauling (marine and truck), licenses, and road upgrades can add millions of dollars in cost. The least costly option is typically to prefabricate the entire unit and send it by ship directly to a refinery with access from the ocean.

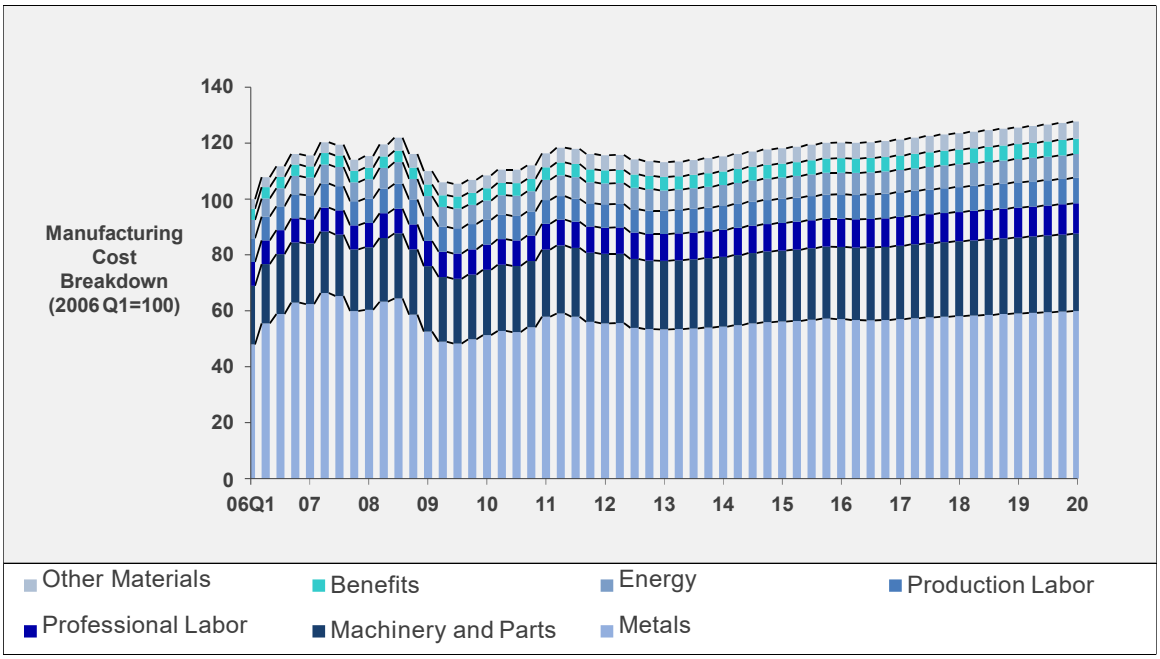
Overall costs crept up slightly in Q1, driving by a 0.5% increase in average costs in Asia. Labor and machinery costs drove the increase. Sinopec Engineering completed a major capacity expansion

shortly after Larsen and Toubro did the same, and Sinopec claimed that prices for the machinery it bought from manufacturers including Ajax, Erie, and Anyang, were inflated after L&T had just placed similar orders. Cost levels were stable in the other two regions, and global cost levels increased almost imperceptibly.

Costs will rise approximately half a percent per quarter globally for the rest of 2013, accelerating slightly to just over 1% per quarter in 2014. Steel, labor, and machinery costs will climb slowly but steadily over the period, forcing overall cost levels up.

Cost levels will rise 11% on average from 2013 Q1 to 2020 Q1. Carbon steel will drive much of the increase, as costs for the input rise 17%. More exotic metals will fuel the increase as well, nickel costs (a major component of stainless steel used for cladding) will increase 9.5% by 2017. Slow labor cost growth in the US and Europe (approximately 1.5% per year, or a cumulative increase of 9%) will restrain global cost growth. Asian costs will rise fastest by a slight margin, 12% vs. 10% in the Americas and EMEA, as with the other categories primarily on faster increases in labor costs (twice as fast as labor cost growth in the other regions).

Figure 40: Cost Structure of Coke Drums



Note: Prices are ex-works.

11.2.2 Profit Margins

Supplier net margins average 6%, except for Korean manufacturers, and they are unlikely to increase as buyers pay close attention to project costs.

Net margins for the relevant divisions at most manufacturers average 6%.

Sumitomo and Larsen and Toubro were well above these levels in 2012, still buoyed by major orders from Saudi Arabia and South America, respectively. Sumitomo Heavy Industries' plants and facilities division earned an operating margin of 13.7% last year. It attributes this in large part to the immensely profitable orders it recently completed for Saudi Aramco. Larsen and Toubro enjoyed an 8% margin, again on the back of major orders that kept utilization rates high, spreading overhead costs over more revenue.

Chicago Bridge and Iron earned only 4% in its project engineering and construction division, due in part to a lull in business after completing much of its work on the Reficar refinery in Colombia. Its business has picked up in 2013, however, and it predicts that segment operating margin will be higher for this year.

Sungjin (POSCO) lost money last year. This is due in large part to low bids to win projects in Asia and the Middle East that cost more than expected, and Sungjin had to eat the cost difference. High margin levels and continued successes on the part of the other major Asian suppliers indicate that, in Sungjin and other Korean manufacturers are attempting to buy the market, they are not succeeding. This is due in part to the importance of reputation for coke drum manufacturers, and low bids actually tend to undermine that reputation.

Margins are likely stuck at this average level, however, because buyers keep a close eye on prices in relation to costs for coke drums. They are the largest single cost component of the overall coking unit, and the contract for the coking unit is often awarded by itself, instead of in a package with the other process units. As a result, buyers are in a better position to oversee project costs and ensure that prices stay in line. Despite this attention to cost levels and their impact on prices, suppliers earn higher margins for Coke Drums than for most other types of Pressure Vessels because there are fewer alternative suppliers and because the cost of cutting corners to boost margins (if the project has been bid too low) can be quite high – replacing the unit in five years instead of 30.

11.2.3 Prices

Prices will rise 1.5% in 2013, consistent with cost increases, before accelerating faster than costs beginning in 2015 based on rapid demand growth and higher utilization rates (17% vs. 14% by 2020 Q1).

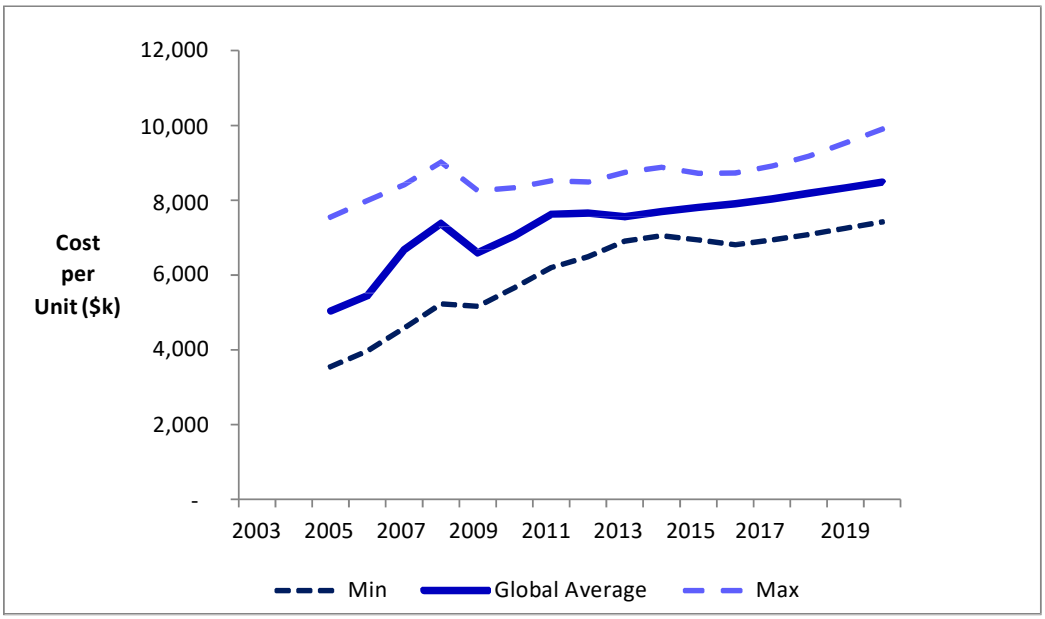
Prices for Coke Drums followed a similar pattern to the other Pressure Vessel Categories, spiking from 2005 to 2008, falling in 2008-2009, and then rising again until 2013, now about 50% higher than in 2005 Q1.

Prices are tightly linked to costs, as explained above, because buyers pay close attention to cost levels vs. prices. As a result, price movements will track cost growth closely.

Global price levels remained stable in Q1, as stable costs in the Americas and EMEA roughly balanced out a small increase in Asia.

Prices will rise 1.5% annually in 2013 and 2014, spurred by slow average increases for metals, labor, and machinery costs, and a total of 12% by 2012 Q1. This will outpace cost growth by only 1%, indicating that aggressive demand growth and rising capacity utilization will give suppliers a tiny bit of leverage to raise prices relative to costs.

Figure 41: Overall Price Forecast for Coke Drums



The reference unit for Coke Drums is a 30'x110' drum, made of 2 1/4 Cr-1 Mo steel with 410 stainless cladding, with approximate processing capacity of 20k bpd. This represents close to the largest diameter available. Diameters over 32' are currently infeasible due to the increase in pressure at the base of the drum and the resulting increasein failure rate. At benchmark, US cost levels, this unit costs $8.4m, on average.

Japan remains the highest-cost country to produce coke drums in, at an index level of 109, driven by Japan's high electric power rates (about 50% higher than benchmark US levels). Labor costs are also a somewhat higher proportion of the total, contributing to the cost. As a result, we calculate the reference unit cost at $9.2m, not considering volume discounts or the impacts of competitive negotiation.

China and India enjoy the lowest cost levels, 13-14% lower than benchmark levels in the US, due to lower power, labor, and somewhat lower machinery costs. These lower costs indicate that the reference unit should cost approximately $7.2m if manufactured in either of these countries and slightly less in other South Asia Countries, such as Thailand. In the case of Chicago Bridge and Iron, the manufacturer acknowledges that a drum made at its yard in Thailand would cost about 15% less than one made at its Louisiana (US) plant. In terms of actual units sold, the 12 drums Sumitomo sold for the SATORP project cost approximately $8.25m per drum compared to $6.43m per drum for the 12 units Larsen & Toubro sold to Petrobras' Abreu e Lima project. This works out to a difference of 28%, only slightly high than the implied 24% cost difference, partially due to the fact that the drums for SATORP were slightly larger.

Table 25: Regional Price Variations over Time for Coke Drums

Region/Country	Today	2014	2015	2020
North America	1.00	1.01	0.99	1.07
Latin America	0.96	0.99	1.01	1.17
Europe	1.03	1.03	1.02	1.08
Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.89	1.03
Russia	0.89	0.94	0.95	1.14
China	0.87	0.88	0.86	0.92
Japan	1.09	1.11	1.09	1.09
Other Asia	0.82	0.83	0.82	0.87

11.2.4 Price Differences by Technology, Model, and Feature

Material costs for Coke Drums are mainly sensitive to the size of the drum and the metallurgy.

Table 26: Incremental Cost per Extra Parameter or Feature for Coke Drums

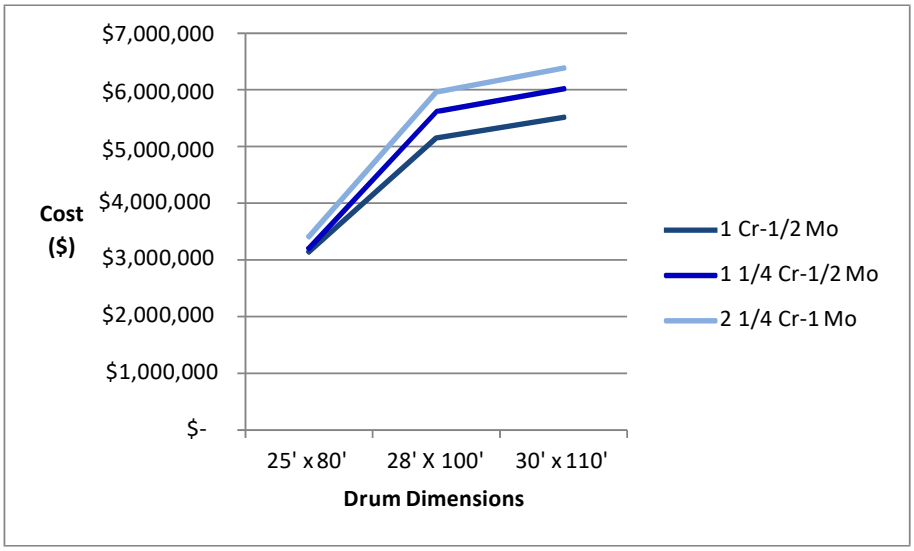
(Reference unit is 30'X110', 2 1/4 Cr-1 Mo w/ 410SS cladding, 20k bpd in throughput capacity)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Size	30' x 110' as reference point	Cutting diameter by 2' and length by 10' reduces cost by $560k	Diameters over 32' technically infeasible
Metallurgy	2 1/4 Cr-1 Mo w/ 410SS cladding as reference point	Downgrading to 1 1/4 Cr-1/2 Mo costs $300k less	Cost increases 9% to upgrade from 1 Cr-1/2 Mo to 1 1/4 Cr-1/2 Mo, then 6% for 2 1/4 Cr-1 Mo
Processing Capacity	$/bpd (reference is 20k bpd)	Cost per barrel of capacity is $26k higher for a 10k bpd drum than it is for a 20k bpd unit	Per barrel cost decreases flatten after 90k bpd

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

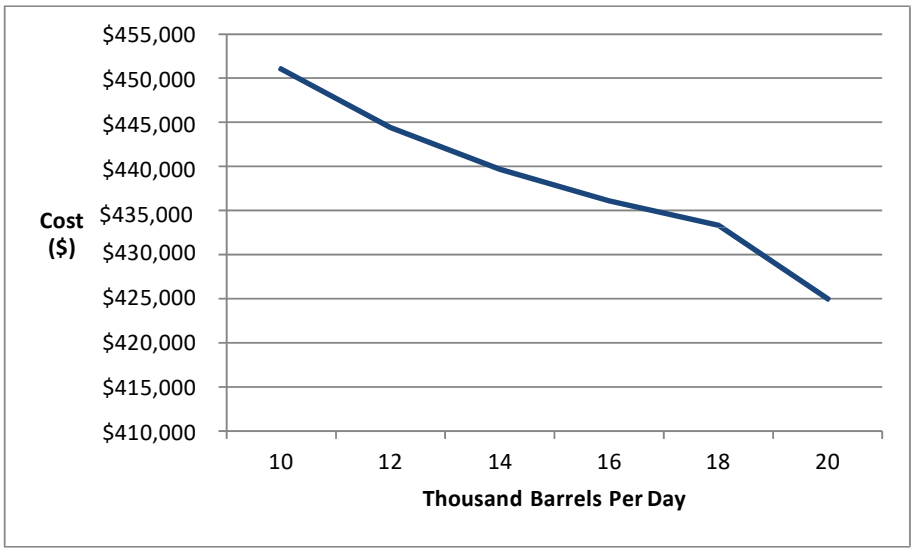
Increasing or decreasing the diameter of the unit changes the cost by approximately $775k per foot, on average, between 25' and 30', using 2 1/4 Cr-1 Mo w/ 410SS cladding as the baseline. A 30' unit costs approximately $8.4m, compared to $4.5m for a 25' unit. Upgrading metallurgy increases cost by approximately 50%, going from 1 Cr-1/2 Mo to the reference metallurgy.

Figure 42: Coke Drum Size vs. Cost – by Metallurgy



The cost per barrel of processing capacity decreases at an increasing rate with the size of the drum. For example, the 12 drums that Sumitomo Heavy Industries sold to the Jubail refinery cost $490k per barrel of capacity, compared to $430k per barrel of capacity for the 6 larger drums it sold to the Yanbu refinery.

Figure 43: Cost per Barrel of Capacity for Coke Drums



Manufacturers are willing to give discounts of up to 5% on projects with eight or more drums, and up to 10% if there are 12 or more. Adjusting for the size of the reactors, Larsen and Toubro charged 7% less for the reactors it sold to Petrobras Abreu e Lima refinery (12), than for the six units it sold to IOCL for the Paradip project.

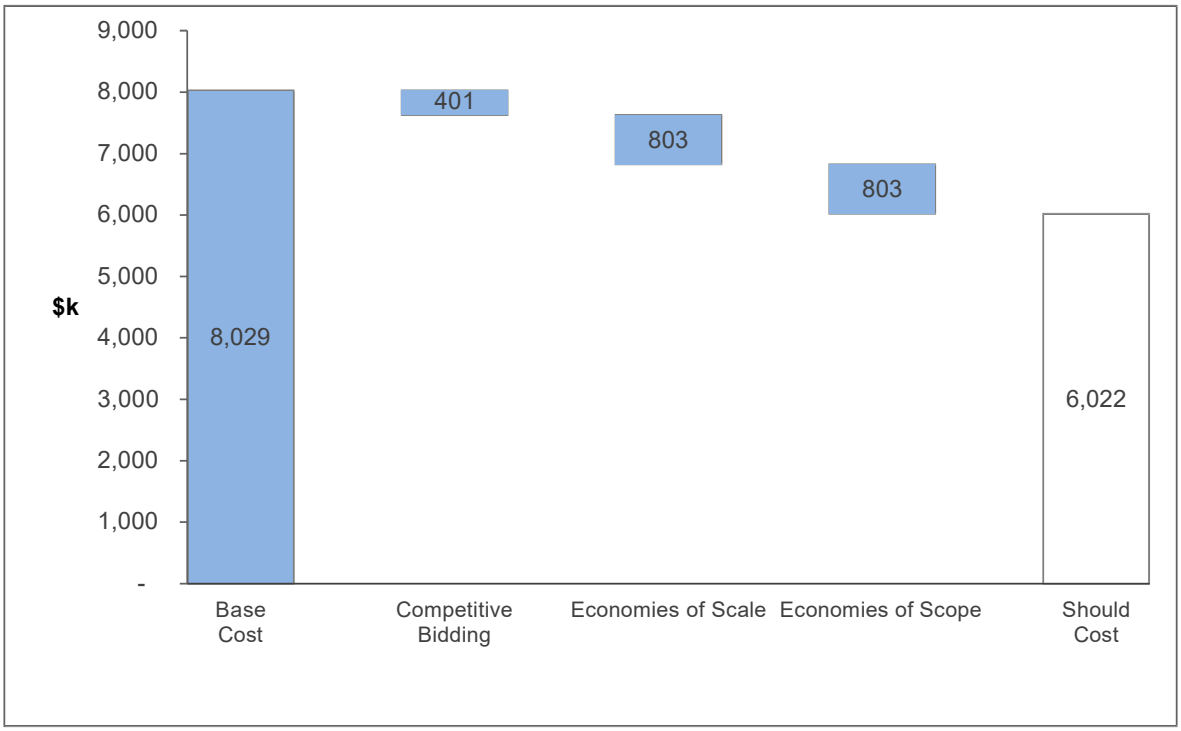
Figure 44: Economies of Scale in Coke Drums



11.2.5 Should-Cost Analysis

Manufacturers are willing to give discounts both for an increase in the number of units ordered, and for a larger scope of work (awarding the coke drums in conjunction with other processing units such as reactors or columns). Competitive bidding, a common industry practice, also nets discounts, as illustrated in figure 45.

Figure 45: Should-Cost for Coke Drums



11.3 Price Negotiation Strategies

1. Buy or reserve capacity for steel when prices are low (now, for any orders planned for tendering within the next two years).
2. Determine if Mangiarotti is carrying out plans to add capacity and, if so, consider placing an order at a discounted rate. A guaranteed order before new facilities are complete would be valuable to the company, despite its currently high level of utilization.

12 Spherical LPG Tanks

12.1 Market Overview

Table 27: Key Indicators for Spherical LPG Tanks

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	9.6%	▲	53%
Demand ($m)	▲	147-161	▲	147-224
Capacity Utilization	▼	-0.8%	▼	-0.4%
Prices	▲	4.7%	▲	15.4%

12.1.1 Demand

Refining, petrochemical, and shale gas projects will drive demand growth of 2% in 2013, and 7% annually through 2020.

LPG (propane or butane) is produced at gas processing plants and refineries and either used as a feedstock for propylene-based petrochemicals or as fuel for heating or transportation, along the same distribution chain as many other refinery products. As a result, LPG production, and storage demand, track overall refinery capital investments closely.

After rising 4% in 2012, matching global refinery capital spending, demand for LPG Spheres will rise 2% annually in 2013, slightly faster than the 1% increase in global refinery spending as orders placed last year are delivered and the final payments made.

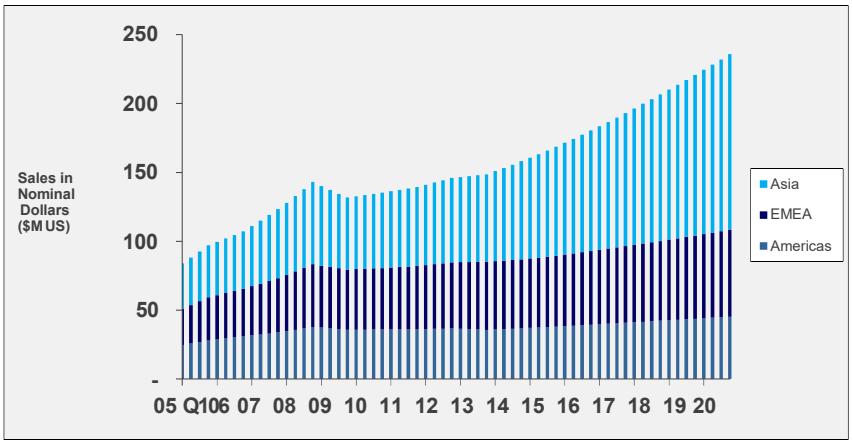
Growth will be fastest in Asia, at 4%, again in line with refinery capital spending in the region. Sphere deliveries in Asia this year include these examples:

- Henan Petrochemical received two spheres in Q1 at its chemical plant in Henan, China, and will receive another two before the end of Q2, completing a total order of approximately $8.5m.
- China National Petroleum Corporation's Zhejiang refinery will receive two spheres in Q3, both 50' in diameter.
- Indian Oil Company Limited ordered two large spheres (50'-60' in diameter) from Sharp Tanks and Structurals. These are scheduled for delivery in Q3.

In EMEA, refinery capital expenditures will only grow 3% this year, driving a corresponding increase in LPG Sphere sales.

Demand will retreat slightly in the Americas this year, falling 2% on a 5% contraction in refinery capital expenditures. Sphere sales will not fall as fast as refinery spending due to the growing need for shale gas storage, as a result of the major shale gas boom in the US. For example, Kinder Morgan ordered a 50' sphere from CB&I for its Galena Park NGL plant in Texas, being built to handle shale gas, in 2012 Q3, and added another unit to the order in 2013 Q1.

Figure 46: Demand for Spherical LPG Tanks



Demand growth will accelerate to 6% in 2014 and 7% annually beginning in 2015, primarily due to rapid increases in Asian spending. Asian refinery capital purchases will surge at rates of 12-15% annually on rapid fuel and chemical demand increases. Asian refiners are planning to add a total of nearly 10m bpd in refinery distillation capacity by the end of 2020. Chinese projects alone will equal approximately half of the total, combined with planned expansions in India, Thailand, Vietnam, Cambodia, and even Japan (although Japanese capacity additions will largely replace outdated refineries).

LPG Sphere demand will only grow 3-4% per year in the Americas and EMEA. In the Americas, planned projects (mostly on the part of Latin American refiners Petrobras and PDVSA) will add approximately 2m bpd in refining capacity. In EMEA, the completion of Saudi Aramco's megaprojects, Russian expansions on the part of Gazprom and Rosneft, and Iraq's Nassiriya development will contribute to new refining capacity of approximately 2.5m bpd.

12.1.2 Supply (Capacity)

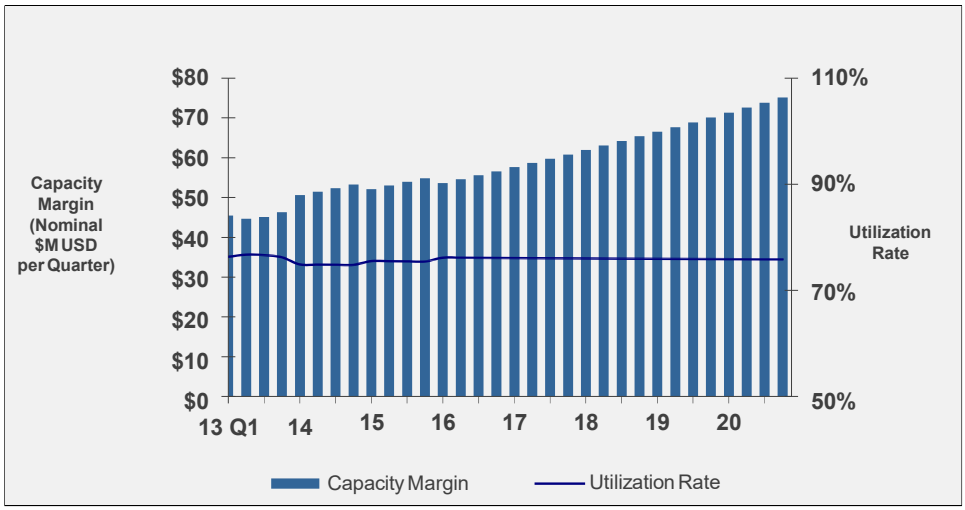
Expansions in Thailand, Denmark, and Malaysia by CB&I, Fabricom, and KNM will reduce capacity utilization from 77% in Q1 to 75% in 2014.

The major global LPG Sphere manufacturers include:

- Chicago Bridge and Iron
- Duro Felguera
- Fabricom
- KNM Group
- G&G International
- Bharat Tanks and Vessels
- China First Metallurgical Construction Corporation (CFMCC)
- Taishan Group
- Emaco Group
- Mercon

Capacity for Spherical LPG Tanks is approximately $192m worth of equipment per quarter. At average capacity utilization rates of 77%, quarterly Capacity Margin is $45m. This equates to approximately 30 units at 40' diameter, or 10-12 units at 60' diameter. Given that the average order size is approximately four units, with only a few new orders per quarter, there is little risk that a surge in orders will increase lead times drastically or give manufacturers a considerably stronger bargaining position. Capacity utilization can be higher for spheres than for large reactors without causing lead time increases because the plates used to construct them can be made in batches, then fabricated at a later date. As a result, the bending machines (rollers) do not have to be used continuously on the same project, allowing manufacturers to level capacity utilization between projects more effectively than they can when one work piece must occupy a machine for as long as weeks at a time.

Figure 47: Capacity Margin – Spherical LPG Tanks



Chicago Bridge and Iron is expanding in Thailand and the US. It will commission new machinery at a plant in Newcastle, Delaware (US) in late 2013, and the expanded yard in Thailand in 2014 Q1. CB&I's plate bending capacity is 90% utilized in the US, driving the decision to add new bending machines to fill orders stemming from US shale projects. Its fabrication capacity is only 80% utilized in the US. The new US capacity will bring local utilization rates down to 80% for both types. In Thailand, the yard expansion will reduce the plant's utilization rates from 80% to 75%.

Fabricom is adding bending machines and a fabrication bay in Denmark to lower utilization rates from their current level of 85% to 80% early next year when the new units open.

Table 28: Reported or Estimated Capacity Utilization Rates at Selected Spherical LPG Tanks Suppliers

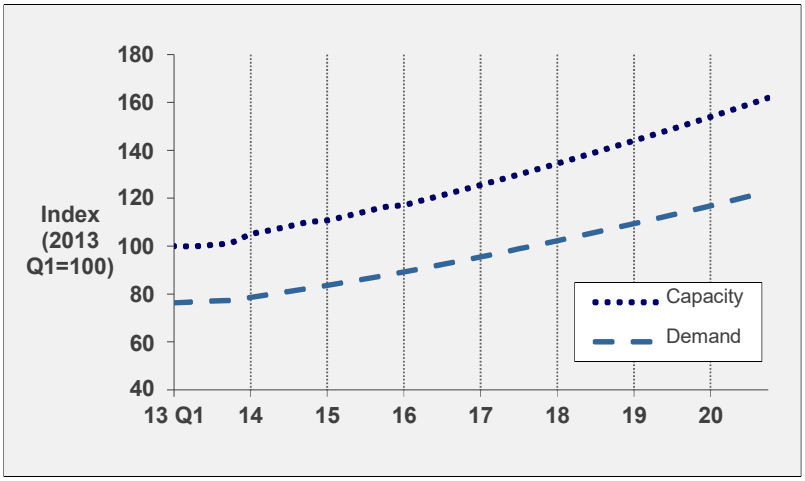
Company	Country	Current Level	12-Month Forecast
CB&I	USA	90%	80%
CB&I	Thailand	80%	75%
KNM	Malaysia	80%	75%
Sungjin (POSCO)	Korea	80%	80%
Duro Felguera	Spain	75%	75%
Isgec	India	70%	75%
Mangiarotti	Italy	90%	90%
Larsen & Toubro	India	50%	80%

KNM is expanding in Malaysia, adding bending machines and fabrication bays, which are scheduled to open in 2013 Q4. Similar to CB&I, the expansion will reduce local capacity utilization from 80% now to 75%.

Many suppliers are only 70% utilized, however, including Mercon, Cimtas, and Bharat Tanks and Vesels, so there is plenty of capacity available in the market as a whole.

Capacity will remain available on a global basis, although periods of high utilization may develop for specific regions with large orders, through 2020. Capacity utilization will be steady at 76%, and absolute Capacity Margin will increase slowly to $75m per quarter.

Figure 48: Demand vs. Capacity – Spherical LPG Tanks



12.1.3 New contracts

CB&I has dominated contract awards, wining orders from South America, Asia, Europe, and the US, leveraging the cost-competitiveness of its Thai manufacturing plant. Domestic suppliers Taishan, CFMCC, and Sharp won orders in China and India.

Chicago Bridge and Iron has booked an impressive list of orders since 2010: Combined with orders from Dong Energy in Denmark and Kinder Morgan in the US,

CB&I has booked more than $52m in Sphere revenues since 2010.

- Its biggest win in recent years has been as the EPC for the Reficar refinery in Cartagena, Colombia, with seven spheres worth $20m.
- CB&I won two other orders from South America, from the Brazilian Suape Petrochemical Complex and ANCAP's La Tablada refinery in Uruguay, for $6.2m (three spheres) and $2.5m (one sphere), respectively.

- It also booked contracts in Saudi Arabia from SABIC (10 small spheres for $10m) – which it completed in 2012 – and the Rabigh refinery (one 60' sphere for butene) – due for completion in 2015.

In China and India, domestic suppliers have an advantage on bids, as well as a tendency to win orders for field-erected units, which spheres often are, because of the need for a local labor base. For example, Chinese Taishan won the five-sphere order, worth almost $11m, from Sinochem's Guanzhou refinery. China First Metallurgical Construction Corporation won two orders, totaling $12.7m, from Henan Petrochemical and the Zhejiang refinery. These orders reflect a local content preference on the part of government-run companies, as CB&I and KNM are more cost-competitive at their respective facilities in Thailand and Malaysia.

Refinery orders are supporting a string list of pending contracts for award or completion 2013 and 2014. Examples include:

- Two spheres for Bangladesh's Eastern Oil Refinery in Chittagong, bidders include KNM and Fabricom.
- Oman Oil Refineries and Petroleum Industries Company (ORPIC) is building a new storage terminal in Muscat that will order 4-5 large spheres. As of April 2013, the project is in planning and ORPIC expects to start construction of the terminal in 2014.
- The Aegis group began building a new terminal at the port of Pipavav in Gujurat, India. The facility will have capacity for 120k m^3 of liquids, including LPG, and 2.7k tonnes of gas.
- Indian Oil Corporation contracted Sharp Tanks and Structurals to expand its LPG bottling plant in Belgaum. The project includes two storage spheres for $3m each. Construction has already begun and completion is scheduled for August 2013.

Table 29: Summary of New Contracts and Estimated Values for Spherical LPG Tanks

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Reficar - Cartagena	Colombia	CB&I	7 units, 55' dia	$ 20.20	$ 2.24
Simon Storage - Seal Sands	UK	Mercon	9 units, 50' dia	$ 13.80	$ 6.90
SNDP (National Oil Distribution Company)	Tunisia	VINCI	2 units, 70' dia	$ 10.90	$ 1.82
Sinochem - Guanzhou Refinery	China	Sinopec	6 units	$ 10.83	$ 2.17
SABIC	Saudi Arabia	CB&I	5 units, 50' dia	$ 10.00	$ 1.00
Litro Gas	Sri Lanka	Fabricom	10 units, 35' dia	$ 10.00	$ 2.50
Gas Filling Company	Iraq	HEESCO	4 units, 50' dia	$ 9.70	$ 4.85
Sonangol - Luanda	Angola	Perini	2 units	$ 9.10	$ 4.55
Henan Petrochemical Company	China	CFMCC	2 units, 60' dia	$ 8.43	$ 2.11
Lyondell	Switzerland	Mercon	4 units, 50' dia	$ 8.00	$ 2.67
Shell	Australia	Vijay Tanks	3 units, 50' dia	$ 7.44	$ 3.72
Map Ta Phut Olefins Co., Ltd	Thailand	Thai Rotary Engineering	2 units, 60' dia	$ 6.42	$ 2.14
Suape Petrochemical Complex	Brazil	CB&I	3 units, 50' dia	$ 6.23	$ 1.25
IOCL	India	Sharp Tanks and Structurals	5 units, 40' dia	$ 6.00	$ 3.00
Dong Energy	Denmark	CB&I	2 units, 55' dia	$ 5.37	$ 2.69
Kinder Morgan - Galena Park NGL processing plant	US	CB&I	2 units, 50' dia	$ 5.16	$ 2.58
Rayong (Thailand)	Thailand	Fluor	2 units, 50' dia	$ 4.83	$ 1.21
Zhejiang	China	CFMCC	4 units, 40' dia	$ 4.30	$ 2.15
Rabigh II (Saudi Aramco/Sumitomo Chemicals)	Saudi Arabia	CB&I	2 units	$ 3.00	$ 3.00
ANCAP - La Tablada	Uruguay	CB&I	1 unit, 60' dia	$ 2.52	$ 1.26
RECOPE (Refinadora Costarricense de Petróleo S. A.)	Costa Rica	Duro Felguera	2 units, 40' dia	$ 1.54	$ 1.54

12.2 Analysis

12.2.1 Costs

Cost growth for carbon steel and labor will push overall cost levels up 15% by 2020 Q1, faster in Asia due to a shrinking pool of qualified new welders.

Metal makes up 45% of the cost structure for Spherical LPG Tanks. This is lower than for most other categories in this study, not because the tanks use proportionately less metal, but the because they do not require the advanced chrome, molybdenum, nickel, and vanadium alloys commonly used in reactors or coke drums, instead using carbon steel.

Machinery costs are 24% of the total, the highest of any category, because the plates require so much time of bending machines and because each plate is small compared to the overall surface area of the sphere, which results in more weld seams.

Labor costs account for 20% of the cost structure, slightly higher than for reactors, due to in part to the additional welding time required. Out of a total 18-20 months of lead time for an order of five, 50' spheres, engineering typically takes 1-2 months, while procurement and planning takes 6-7 months due to the long lead time for the carbon steel. During this time, most of the costs incurred are for engineering and administrative labor, rather than manufacturing.

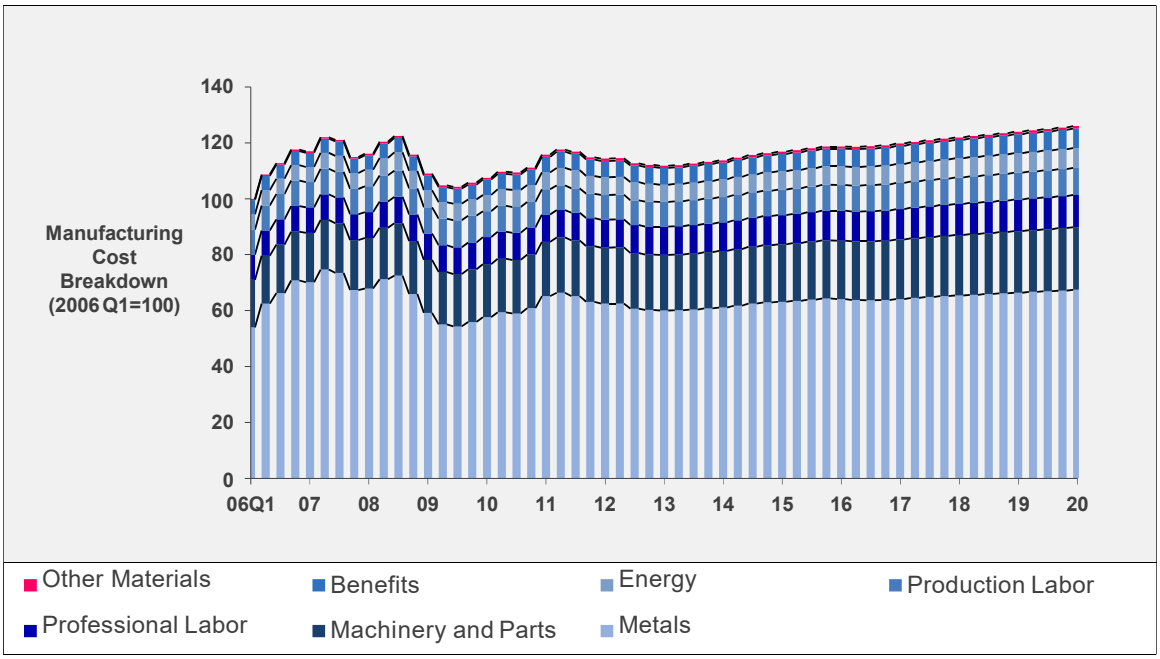
Spheres can either be prefabricated and shipped as a unit (if the destination can be accessed by a ship), or shipped in plate sections and fabricated in the field. The first option typically increases labor costs because shop labor is often expensive than field crews, especially if the units are being manufactured in a high-cost environment. However, shop fabrication allows for more control over the welding processes, post weld heat treat and non-destructive testing (NDT), allowing for more consistent welds and eliminating the potential impact of inclement weather on the project schedule. For this reason, many buyers prefer shop fabrication despite the often slightly higher cost. On the other hand, if the units need to be delivered first by ship, then by truck, field fabrication becomes the more economical choice in many cases. Shipping overland is extremely expensive and, in some cases, completely infeasible, making field-fabrication the only choice.

Increases in Asian machinery and labor costs pushed global manufacturing costs for LPG Spheres up by 0.5% in Q1. With multiple manufacturers expanding in Asia – particularly in Thailand and Malaysia – and ordering similar bending, rolling, cutting, and welding machinery, the machinery manufacturers raised prices slightly on the surge in orders. In addition, labor costs rose due to a scarcity of qualified welders. According to Korean Wonil, "nobody wants to weld anymore," creating a smaller pool of labor and pushing up average wages. As a result, costs rose 1% in Asia, vs. 0.5%

in EMEA (where labor costs also rose), and stable average costs in the Americas (where a drop in carbon steel costs canceled out slight increases for labor and machinery).

Global cost levels will rise a total of 4.7% by 2015 Q1, and 15% by 2020 Q1, on global cost increases for carbon steel, and continued wage inflation in Asia. Carbon steel costs will rise 17% over the period. Wage and salary levels will rise approximately 1.5% annually in the in the Americas and EMEA, holding cost growth in these regions to a cumulative 11-12%. Asian cost levels will increase nearly 20% over the same period, as labor rates rise twice as fast as in the other regions.

Figure 49: Cost Structure of Spherical LPG Tanks



Note: Prices are ex-works.

12.2.2 Profit Margins

Competition from smaller, local competitors will keep global suppliers from overbidding and maintain average margins at 5%.

Operating margin levels are approximately 5% for Spherical LPG Tanks, a consistent level for most manufacturers.

- Chicago Bridge and Iron's Engineering and Execution division earned an operating margin of 4% last year. The division traded margin percentage for revenue volume, according to a source at the company, to win orders in Saudi Arabia and Indonesia.
- GDF Suez' Energy Services division, which consists largely of sphere manufacturer Cofely-Fabricom, had an operating margin of 4.6%. The firm bid low on its recently completed sphere project in Sri Lanka, and it is likely to do the same on an upcoming project in Bangladesh.
- Belgian manufacturer G&G International nets approximately 5% on sphere projects.
- Duro Felguera's manufacturing division's operating margin was 6.3%, somewhat higher as most of the projects it worked on were in Europe, where it did not have to compete with low-cost local suppliers.

Margins are influenced by region of operation, as indicated by the slightly higher margin levels for the more regional European suppliers above, Duro Felguera and G&G with average operating margin of 5.7%, compared to 4.3% on average for the global leaders C&I and Fabricom, which regularly compete in "low-cost" regions.

This level of margin is protected by the level of capital intensity required to make large spheres, the bending and fabrication process requires large machinery and production facilities that represent a barrier to entry. However, local competitors exist in most markets (CFMCC and Taishan in China, Bharat and Sharp in India, Mercon in Northern Europe, Cimtas in the Middle East, to name a few), providing a credible threat to the global firms' success on bids and allowing competition to contain margin levels. This competition serves to keep margin level fairly constant, and they are unlikely to rise substantially by 2020.

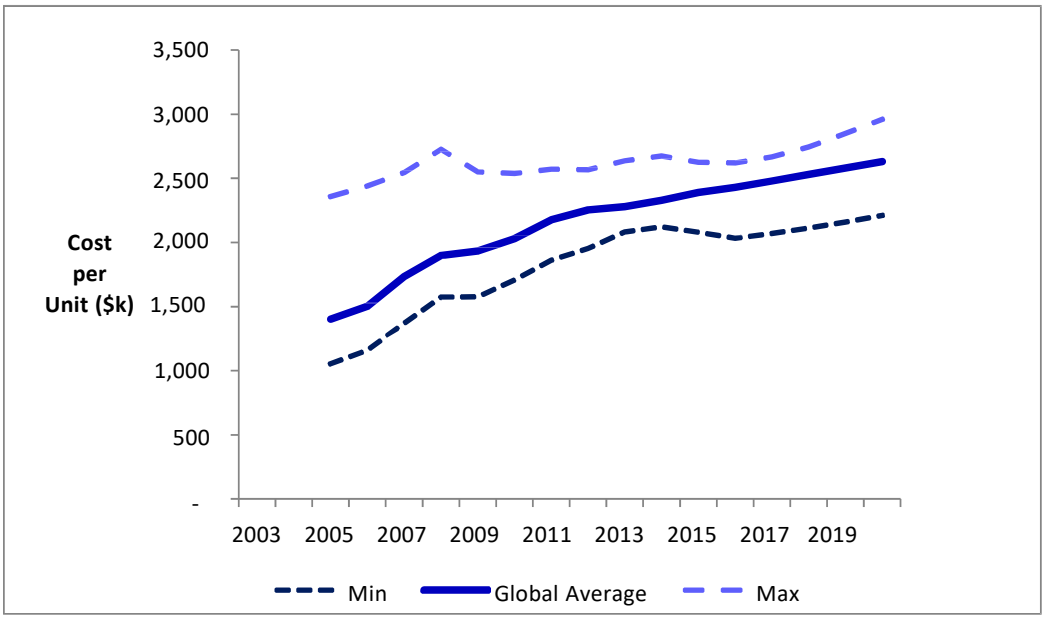
12.2.3 Prices

Price growth, closely linked to costs, will accumulate to 15.5% by 2020 Q1.

Spherical LPG Tank prices rose incrementally, approximately half a percent, in Q1, pushed up primarily by rising Asian wages for welders.

Price growth will track costs closely from now through 2020, rising 5% from 2013 Q1 to 2015 Q1 and 15.5% from 2013 Q1 to 2020 Q1. Cost drivers and margin factors are discussed above.

Figure 50: Overall Price Forecast for Spherical LPG Tanks



The reference unit for Spherical LPG Tanks is a carbon steel sphere 50' in internal diameter, with a wall thickness of 2.36", built to withstand pressure of up to 200 psig. At benchmark, US cost levels, this unit costs approximately $2.6m.

Southeast Asia is the lowest-cost region to produce LPG spheres, by a substantial margin. Recent contract wins by Chicago Bridge and Iron and KNM Group, based to some extent on their cost-competitiveness at yards in Thailand and Malaysia, respectively, indicate lower production costs in this region, as well as good access to marine transport for inbound shipments. In contrast, poor internal infrastructure and wage inflation have driven costs in China and India up slightly, although production costs there are still low compared to the rest of the world. "Other Asia" is at a 17% cost

advantage to the US, compared to 15% and 14%, respectively, for India and China. The difference is even greater compared to costs in Europe at an additional differential of approximately 5%. For example, Thai Rotary Engineering sold three 50' spheres to Map Ta Phut Olefins for $2.15 per unit, compared to $2.67 per unit for three 50' spheres that Mercon is building for LyondellBasell in Switzerland. The per unit price difference between these orders is 25%, which includes a slight increase in unit cost for the European spheres due to the need for overland transportation.

Table 30: Regional Price Variations over Time for Spherical LPG Tanks

Region/Country	Today	2014	2015	2020
North America	1.00	1.01	0.99	1.07
Latin America	0.99	1.03	1.05	1.27
Europe	1.05	1.06	1.04	1.11
Africa	0.93	0.94	0.93	1.03
India	0.85	0.87	0.88	1.02
Russia	0.91	0.95	0.96	1.15
China	0.86	0.87	0.86	0.91
Japan	1.09	1.10	1.08	1.09
Other Asia	0.83	0.83	0.82	0.87

12.2.4 Price Differences by Technology, Model, and Feature

The major factors that influence sphere cost are size and pressure rating. Typical sphere sizes range from 30' to 70', although some are as big as 150'. Our reference unit is 50', which would hold approximately 11,657 barrels of LPG. Sphere pressure ratings range from as low as 30 psi to as much as 300. Pressure rating requirements are governed by the vapor pressure of the LPG. Propane has a higher vapor pressure than butane, and spheres designed to hold higher mixtures of propane therefore have higher pressure ratings (wall thicknesses). At 100° F, propane has a vapor pressure of 177 psi, and most LPG tanks that may hold pure propane are designed to withstand up to 200 psi, and potentially up to 300 psi if the ambient temperature is high. The reference unit is rated for 200 psi. Based on US cost levels, the reference unit costs about $2.58m.

Table 31: Incremental Cost per Extra Parameter or Feature for Spherical LPG Tanks

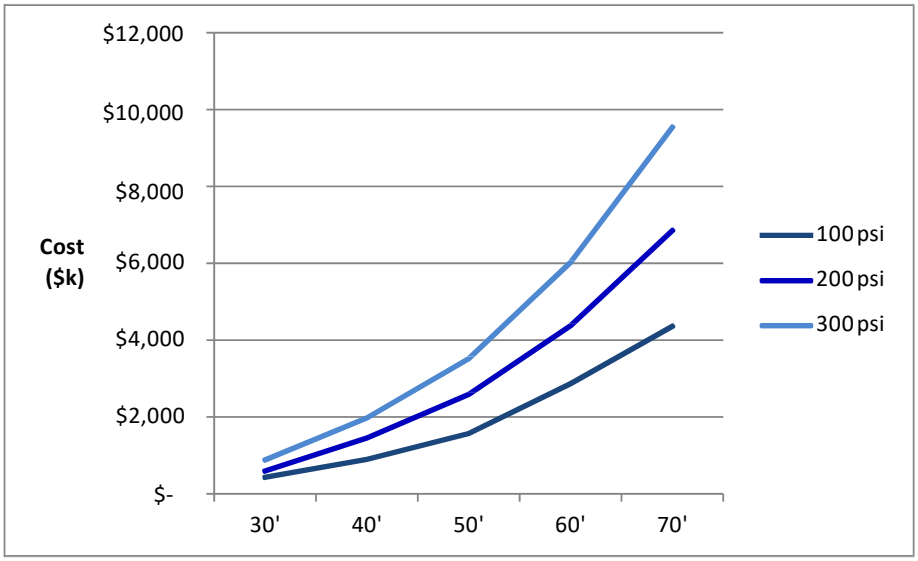
(Reference unit is 50' in diameter, carbon steel, with a pressure rating of 200 psi)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Size	50' diameter as reference point	+10' adds $1.8m, +20' adds $4.26m	Cost increases exponentially along with surface area
Pressure Rating	200 psi as reference point	Cutting psi rating to 100 saves $1m, increasing to 300 costs $930k	Cost increases are linear with psi
Tank Capacity	$/barrel (50' diameter sphere holds 11,650 barrels)	Cost per barrel falls from $246 at 50' to $238 at 70'	Per barrel cost decreases flatten starting at 50'

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

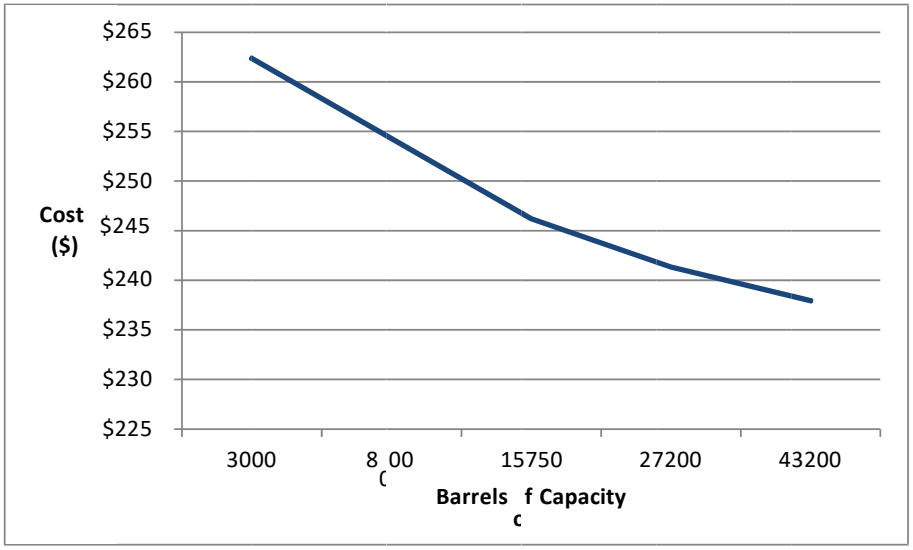
Costs increase rapidly with diameter. Increasing the size of the sphere from 50' to 60' (at 200 psi), increases the unit cost by $1.8m, or 69%. Increasing the diameter to 70' would raise the cost by $4.26m (165%), for a total cost of $6.85m.

Figure 51: Spherical Tank Diameter vs. Cost by Pressure Rating



Cost per barrel of holding capacity decreases from approximately $262 per barrel at 30' feet of diameter, to $246 per barrel at 50'. After that point, the rate of decrease slows slightly only falling to $248 per barrel for a 70' sphere.

Figure 52: Cost per Barrel of Holding Capacity for Spherical LPG Tanks



Discounts to the unit cost on spheres are highly linear, according to manufacturers, at up to 10% for a major order of 20 spheres. The discount arises from shared engineering costs, which become negligible on a per sphere basis if the order quantity rises to 20. For example CB&I gave Reficar in Colombia a 5% discount for 9 spheres. Due to the volume of the order, the 50' spheres were manufactured in both the US and Thailand, for an average cost, with discount, of $2.24m.

Figure 53: Economies of Scale for Spherical LPG Tanks

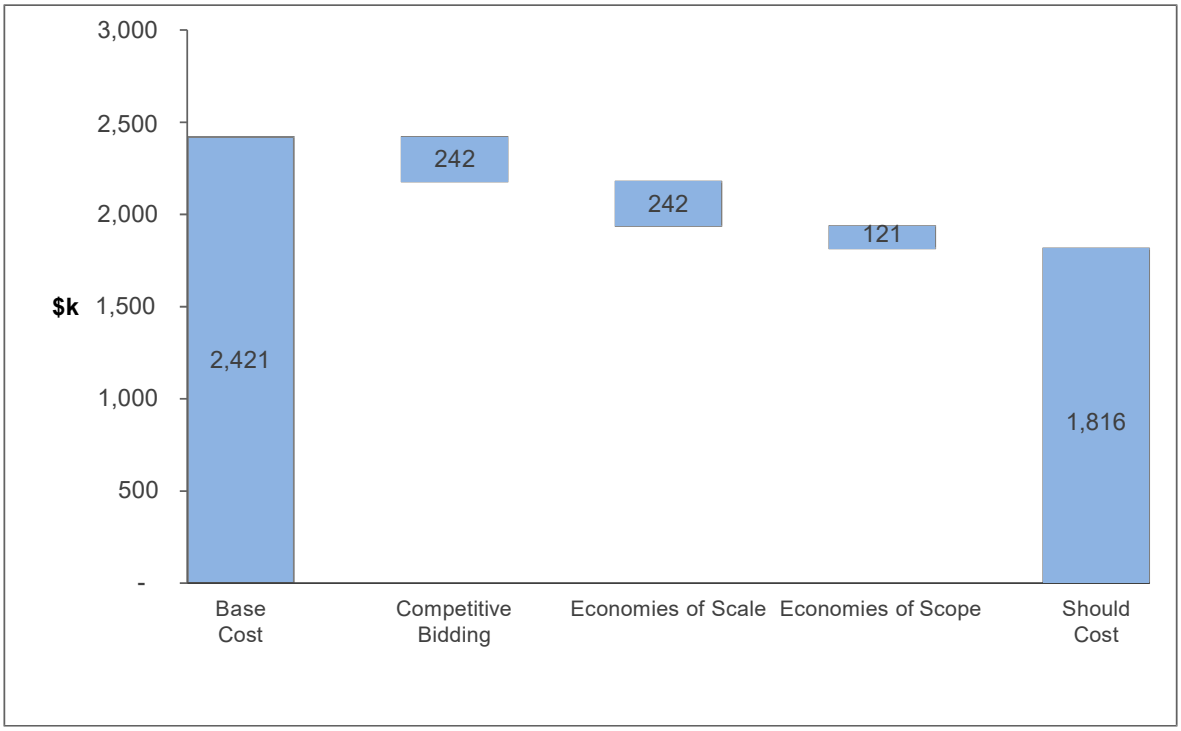


12.2.5 Should-Cost Analysis

Competitive bidding, an increase in the number of spheres ordered, and a larger project scope (more work at the same refinery), will all incent suppliers to reduce unit prices, sharpening their

pencil" to win the bid. Feedback from major manufacturers indicates that they are willing to reduce unit prices by up to 25% if all three of these factors are fully leveraged.

Figure 54: Should-Cost for Spherical LPG Tanks



12.3 Price Negotiation Strategies

1. Leverage falling capacity utilization (expansions at CB&I, Fabricom, and KNM will reduce industry utilization from 77% to 75% over the next year) to push for discounts. All three manufacturers will be eager to keep their new facilities busy and may be willing to give up margin to do so.
2. Make sure that bidder lists are balanced between major global suppliers and smaller, more local competitors. This will keep the global majors from padding their bids.
3. Buy or reserve capacity for steel when prices are low (now, for any orders planned for tendering within the next two years).

13 Heat Exchangers

13.1 Market Overview

Table 32: Key Indicators for Heat Exchangers

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	8.9%	▲	47.5%
Demand ($m)	▲	4,168-4,539	▲	4,168-6,146
Capacity Utilization	▲	3.9%	▲	7.3%
Prices	▲	5.3%	▲	15.7%

13.1.1 Demand

Demand will grow 3% in 2013, advancing to annual growth of 5% in 2014, then 6% through 2020, overwhelmingly driven by orders from the Asian power and refining sectors.

Demand for Heat Exchangers rose nearly 6% in 2012, led by 11.5% growth in Asia on strong growth from the chemicals, refining, and LNG sectors. Many of these orders are long-term contracts that will continue to drive demand growth in 2013. For example:

- In 2012 Q2, Inpex ordered heat exchangers for the Ichthys LNG project in Darwin, Australia.
- Also in 2012 Q2, a South Korean refinery ordered $17.1m worth of heat exchangers, scheduled for delivery in 2013. The units will be used in to recover and recycle heat from xylene production.
- In 2012 Q4, Indian Oil Corporation placed a $10m order for air cooled heat exchangers for its refinery in Orissa.

EMEA demand grew more slowly, at 4%, as Western European (where manufacturing industry orders grew by only 2%) demand idled but projects in the Middle East and Africa placed orders. The Wasit gas processing plant in Saudi Arabia placed one major order, while a Saudi fertilizer plant accounted for another. Also in the fertilizer industry, Morrocan OCP ordered new units. As with the Asian orders above, payments and deliveries for these orders have carried over into 2013.

- The Wasit gas processing operation ordered $11.9m in heat exchangers, scheduled for delivery this year.
- In 2012 Q3, Saipem ordered 17 heat exchangers for the SAFCO-V project in Saudi Arabia.
- Moroccan fertilizer producer OCP ordered $11m in plate heat exchangers to cool process fluids. Deliveries started in 2012 and will continue into 2014.

Americas demand growth was even slower than in EMEA, at 2.5% in 2012, as power industry and manufacturing orders rose only 1-2%, while refinery capital spending grew 3.2%. Included in the refining sector, Motiva's Port Arthur refinery took delivery, and installed the last, the 541 heat exchangers in ordered over the prior four years.

Global demand growth will slow to 3% in 2013, as demand growth cools from 11% to 7% in Asia, from 4% to 2% in EMEA, and from 2.5% to -0.5% in the Americas.

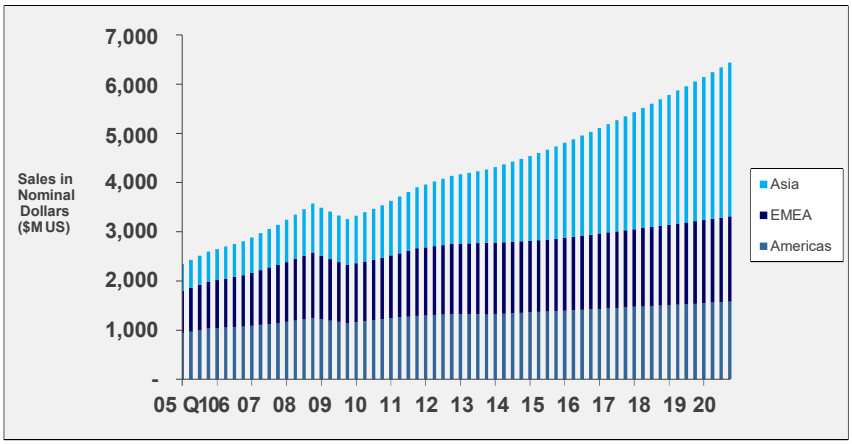
In Asia, demand growth of 8-10% from the power generation, chemicals, and manufacturing sectors will drive the increase, slowed slightly by growth of only 5% from the refining industry. Orders listed above will help fuel the demand growth, but new projects include:

- A large order from Petronas for heat exchangers, among other equipment, for its Bintulu LNG complex in Sarawak, East Malaysia
- An order from Lubrizol for its plant in Navi Mumbai, India.
- Replacement of heat exchangers for the crude distillation unit and FCC unit at the Mangalore refinery in Karnataka, India

EMEA growth will be driven by 3% increases in capital spending from the Power Generation and Chemicals industries, despite growth of only 1% from the manufacturing sector.

In the Americas, weak refinery spending (down 2% from 2012) will cause a 0.5% decline. One contributing factor is Suncor's cancellation of its Voyageur upgrader project. On the upside, ExxonMobil's Kearl oil sands project has ordered $9.2m in heat exchangers this year, although most of the payments will spill over into 2014.

Figure 55: Demand for Heat Exchangers



Global demand will grow 5% in 2014, and a cumulative 47.5% by 2020 Q1. Asia will once again drive most of the growth, where Heat Exchanger sales will increase 10-11% annually on strong growth (8-15%) in the refining, chemicals, utilities, and manufacturing sectors. Demand will grow about 3.5% annually in EMEA on more subdued refining and chemical industry growth, most of which will come from Eastern Europe and the Middle East. In the Americas, Latin America will drive the growth (2.5% annually), as the North American manufacturing sector grows very slowly.

13.1.2 Supply (Capacity)

Alfa Laval and Larsen and Toubro, among others, expanded rapidly in 2012, driving industry utilization rates down to 73%. Capacity utilization rates will rise only gradually, from 73% to 80% by the end of 2012 as demand growth outpaces capacity additions slightly.

The major global Heat Exchanger manufacturers include:

- GEA
- Alfa Laval
- SPX
- GE
- Larsen & Toubro
- Doosan
- Morimatsu
- Shanghai Boiler Works
- Hitachi Zosen
- CPTDC

The above manufacturers account for about half of global sales (highly concentrated among the top five), but thousands of manufacturers make up the remaining 50%, including recently founded companies in Eastern Europe and Asia, started to take advantage of cheaper production costs in those regions. These manufacturers include Uton (Romania), Uzuc (Romania), Kunshan (China), Praj (India), and Dolphin (UAE). Many of these smaller suppliers specialize in equipment for the oil & gas industry, and will provide a "relief valve" for both capacity and prices for the foreseeable future.

Heat Exchanger manufacturing capacity is approximately $5,700m worth of equipment as of 2013 Q1, on a quarterly basis. Industry utilization rates are 73%, leaving approximately $1,500m in capacity margin. Given recent major order sizes of less than $20m, even for megaprojects such as Icthys, or $45-50m for the Port Arthur Refinery expansion, the industry so much spare capacity that buyers have a negotiating advantage and suppliers will be eager to book orders, even at low margins, just to keep their fabrication shops utilized.

The current glut of capacity is mostly due to major expansions at Alfa Laval, Larsen and Toubro, Cimtas, and Titan Metal Fabricators in 2012.

Alfa Laval has made a string of capacity additions in China, Russia, and India from 2010 through 2012. Some of the capacity has been for refrigeration-oriented heat exchangers, but about half of the capacity added will support process applications in refining, chemicals, and power generation. The plants are part of a localization strategy to allow the firm both to cut production and transportation costs and to adapt more quickly to changes in demand from the local markets.

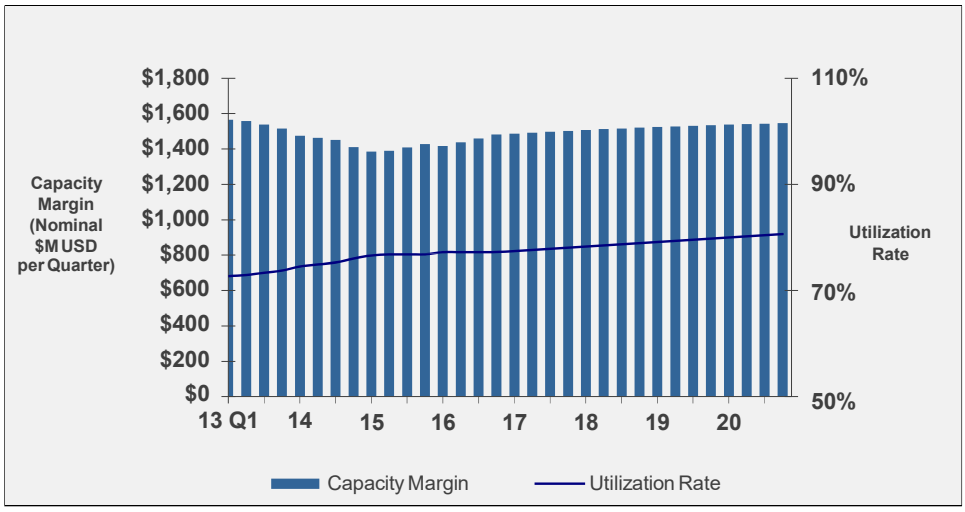
- In 2010, it opened a new plant in Sarole, India.
- In 2011, another one in Potok, Russia.
- In 2012 Q1, the firm opened a plant in Brazil.
- In 2012 Q2, it opened a plant in Kunshan, China (after doubling heat exchanger capacity in China already four years previously).

Larsen and Toubro expanded in 2012, opening a new yard in Hazira, India, and expanding its fabrication facility in Oman to keep up with rapid demand growth from domestic refiners including Indian Oil Company and Hindustan Petroleum Company, as well as orders from customers in Qatar and Kuwait.

Titan Metal Fabricators expanded in the US and China in late 2012. It added 30k feet of manufacturing space in Camarillo, US, in 2012 Q3 as part of a move to a new, consolidated

manufacturing plant. Prior to the move, the firm had several different manufacturing locations, all of which were space-constrained. In 2012 Q4, the firm opened a new fabricating facility in Wuxi, China, both to reduce its overall cost base and to be closer to major Asian customers.

Figure 56: Capacity Margin – Heat Exchangers



Industry capacity utilization is 73% on average, indicating that there is plenty of spare capacity for even the largest orders. At individual companies, utilization rates at manufacturers range from 50% to 90%.

- Market leader GEA's Heat Exchanger division is 85% utilized, one of the highest utilization rates in the industry. Despite a backlog of $1.2b at the end of 2012, the unit reduced headcount by almost 400, leaving it with little spare capacity compared to its main competitor, Alfa Laval.
- Alfa Laval is 70% utilized, following its 2012 expansion program.
- After expanding dramatically in 2012, Titan is only 60% utilized. While that rate will increase with demand, the firm will have plenty of spare capacity for at least two years.
- Olayan Descon in Pakistan and Dwell Company, in China are both only 50% utilized, having recently expanded.
- Chinese manufacturer CPTDC is 90% utilized after booking several major domestic orders. The firm expects to have progressively more capacity available as it ships units out, and its utilization rate will fall to 80-85% by 2014.

In 2013, capacity additions will virtually stop, although Air Products will open a new facility. It began building a new plant for coil-wound heat exchangers used in the LNG industry in 2012 Q3. The 300k square foot plant will house 250 employees when it is commissioned in 2013 Q4. Air Products decided to build the plant for two reasons: 1) with multiple LNG projects in the pipeline it needs

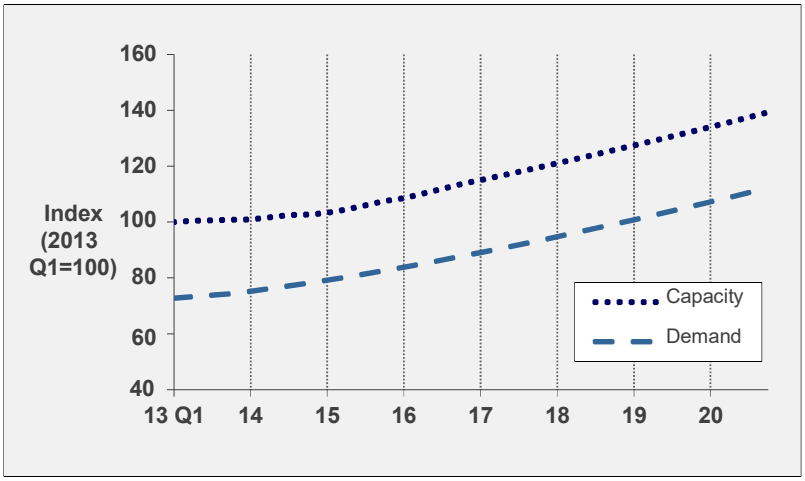
more capacity; and 2) the new plant at the Port of Tampa in Florida will be much more accessible to marine transport than Air Products' existing plant in Wilkes-Barre, Pennsylvania. The new plant will make coil-wound units up to 16.5 feet (5.0 meters) in diameter, 180 feet (55 meters) long, and 500 tons in weight.

Table 33: Reported or Estimated Capacity Utilization Rates at Selected Heat Exchangers Suppliers

Company	Country	Current Level	12-Month Forecast
Alfa Laval	Global	70%	75%
GEA	Global	85%	85%
Titan Metal Fabricators	US	60%	65%
Morimatsu	China	80%	85%
Cimtas	Turkey	80%	80%
Cimtas	China	70%	75%
Dolphin Group	UAE	65%	70%
China Oil HBP	China	80%	85%
Shaanxi Xinlong Petroleum Equipment	China	70%	75%
Sungjin	South Korea	70%	80%

Due to the current glut of capacity, and the negotiating disadvantage it gives manufacturers, most suppliers are not planning further major expansions. As a result, Industry capacity utilization will rise gradually with demand, reaching 75% in 2015 and 80% in 2020.

Figure 57: Demand vs. Capacity – Heat Exchangers



13.1.3 New contracts

GEA, Alfa Laval, and Doosan won the preponderance of oil & gas and power contracts. Air Products scored big wins in LNG.

GEA scored big with refineries, winning orders collectively worth $150m from SOCAR (Turkey), Pemex (Mexico), Petrobras, and QatarGas.

Doosan won a larger single order for 400 units from Saudi Aramco. The order, for the Yanbu refinery project, is worth a total of $230m.

Alfa Laval won two smaller orders from Saudi Aramco, as well as projects from Korean S-Oil and Rosneft. The orders are worth a total of $53.5.

Air Products won three major contracts, collectively worth approximately $25m, from LNG plants, all for cryogenic coil-wound units. The largest was for Shell's Prelude LNG project, followed by INPEX's Icthys development and Petronas' LNG complex in Sarawak, East Malaysia.

Going forward, the outlook for new contracts is strong on refinery projects alone, with more than 3.5m bpd in Asian refinery capacity alone being planned.

Table 34: Summary of New Contracts and Estimated Values for Heat Exchangers

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($k)
Saudi Aramco	Saudi Arabia	Doosan	400+ units, including shell and tube, box, and plate	$230.00	$575
China Southern Power	China	GEA	200+ units; shell & tube, plate, air coolers	$67.96	$316
SOCAR	Turkey	GEA	Shell & tube, box, plate, air coolers	$41.42	$237
Samsung Engineering	Mexico	GEA	200 units; shell & tube, plate, air coolers	$36.25	$181
Petrobas	Brazil	GEA	120 units; mostly shell & tube, air coolers	$36.21	$302
QatarGas - Laffan	Qatar	GEA	Shell & tube, air coolers	$33.62	$224
S-Oil	South Korea	Alfa Laval	60 units; shell & tube, plate	$17.00	$283
Saudi Aramco - Wasit	Saudi Arabia	Alfa Laval	24 units; shell & tube, air coolers	$13.77	$574
Saudi Aramco	Saudi Arabia	Alfa Laval	Shell & tube, plate	$12.00	$300
OCP Fertilizer	Morocco	Alfa Laval	45 plate units	$11.00	$244
Rosneft	Russia	Alfa Laval	Shell & tube	$10.70	$238
BASF	Germany	Alfa Laval	Shell & tube for petrochem plant	$10.70	$268
IOCL-Paradip	India	GEI Industrial Systems	Shell & tube, air coolers	$10.00	$222
ExxonMobil - Kearl	Canada	Alfa Laval	Shell & tube	$9.20	$368
Saudi Aramco-ExxonMobil (SAMREF)	Saudi Arabia	Zamil	Shell & tube, air coolers	$8.30	$415
Shell	Australia	Alfa Laval	18 plate units	$7.50	$417
Petronas	Malaysia	Air Products	8 plate units	$2.80	$350

13.2 Analysis

13.2.1 Costs

Global costs will rise 5% in the next two years and a total of 15% by 2020 Q1, driven by costs for machinery, metals (primarily carbon steel), and wages for welders.

Metals account for 50% of the cost structure for Heat Exchangers. The largest component of that is carbon steel (on average, 30% of the total cost), the basic material for most shells, and frequently the tubes as well. Less frequently, exotic materials such as stainless steel, duplex steel, chrome steel, or even titanium are used for added strength or corrosion resistance.

Labor makes up 20% of the cost structure, including engineers, management, welders, and machinists.

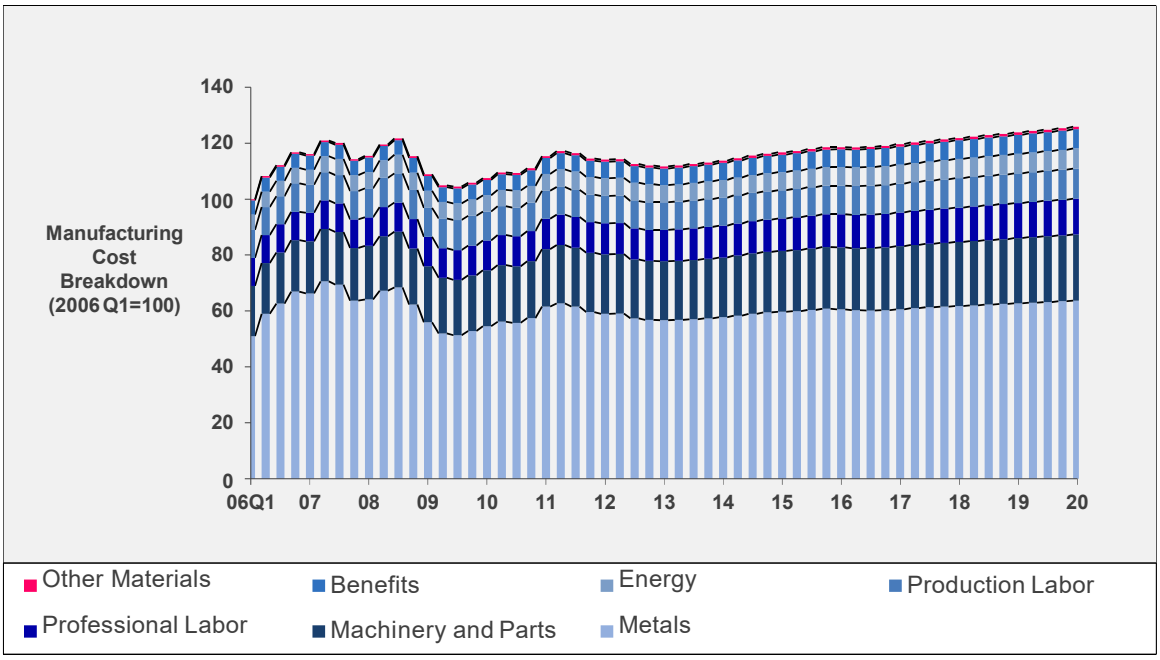
Machinery costs comprise another 18% of the overall cost, primarily for cutting, beveling, grinding, and welding machinery. This is lower for than for most categories, due to the lower weight and metal thickness of most heat exchangers. Reactors can weigh up to 1,200 tonnes, compared to figures in the low double-digits (frequently less than one tonne) for heat exchangers. They can also have wall thicknesses approaching 12", vs. about 1" in many heat exchanger applications.

Overall costs were steady in Q1, as a 3% decline in carbon steel costs balanced out increases in costs for machinery and Asian labor. Costs actually fell marginally (less than half a percent) in the Americas, where high US inventories of carbon steel allowed material costs to fall more rapidly.

Costs will increase 1.5% in 2013, and a total of 5% by 2015 Q1. Carbon steel costs will rebound a total of 8% by the end of next year, driving much of the increase. Labor costs will also continue to increase, fastest in Asia, where there is a shortage of qualified welders.

By 2020 Q1, costs will rise a total of 15%, driven by increases for all three major cost components, metals, labor, and machinery. Carbon steel prices will rise 17% and overall machinery costs will increase 16%. Labor cost growth will slow the average growth in the Americas and EMEA (increasing about 2% annually), but speed it along in Asia (with 4% annual growth). As a result, costs 20% in Asia, vs. 12-13% in the other two regions.

Figure 58: Cost Structure of Heat Exchangers



Note: Prices are ex-works.

13.2.2 Profit Margins

Supplier margins average 6.5%, but the range is wide depending on the type of heat exchanger and the industry.

Margins are healthy for most Heat Exchanger manufacturers, averaging 6.5%, although the division is sharp between suppliers that make highly engineered units for the oil & gas and power industries and those that make units for the chemical and manufacturing sectors.

Manufacturers that primarily serve the oil & gas and power industries average 9% net margin for the relevant business unit. This is primarily due to the more specialized (pressure and corrosion-resistant) nature of the units, as well as the "value" associated with them – meaning that their reliable operation has a high value to the end-user. Margins are also higher for this equipment than for many other pressure vessels sold to the oil & gas industry because the manufacturer frequently owns the technology associated with the unit. In contrast, reactor and coke drum manufacturers license the technology from a list of 8-12 licensors, limiting the value that the manufacturer provides.

- GE Oil & Gas makes air-cooled heat exchangers for the energy industry. The oil & gas unit earned 13.7% margin last year, in part due to GE's dominant position in this segment (air-cooled heat exchangers for the oil & gas industry), and also due to GE's ability to cloak

prices and margins for individual units in large bids for multiple types of refinery process equipment.

- Alfa Laval earned 8% net margin, which is somewhat diluted by mixing units for general industry with units for the oil & gas and power sectors.
- Doosan, flush with oil & gas orders from Saudi Arabia, booked a 7.6% net margin.
- Sinopec Engineering, which exclusively serves the oil & gas industry, earned 7%.

In contrast, manufacturers serving general industrial applications such as manufacturing or bulk chemical plants make less of a return, as these products are viewed as commodities that can be sourced interchangeably.

- SPC made only 3.4% margin for its heat transfer division.
- Hitachi Zosen, which also bid low to win contracts away from Asian competitors, made only 3% last year.

The factors above that allow manufacturers that serve the oil & gas industry to make higher margins also give them leverage to increase those margins during periods of aggressive demand growth. The forecast rapid demand growth from 2015 through 2020 will give suppliers more negotiating power, and the potential to increase profitability slightly.

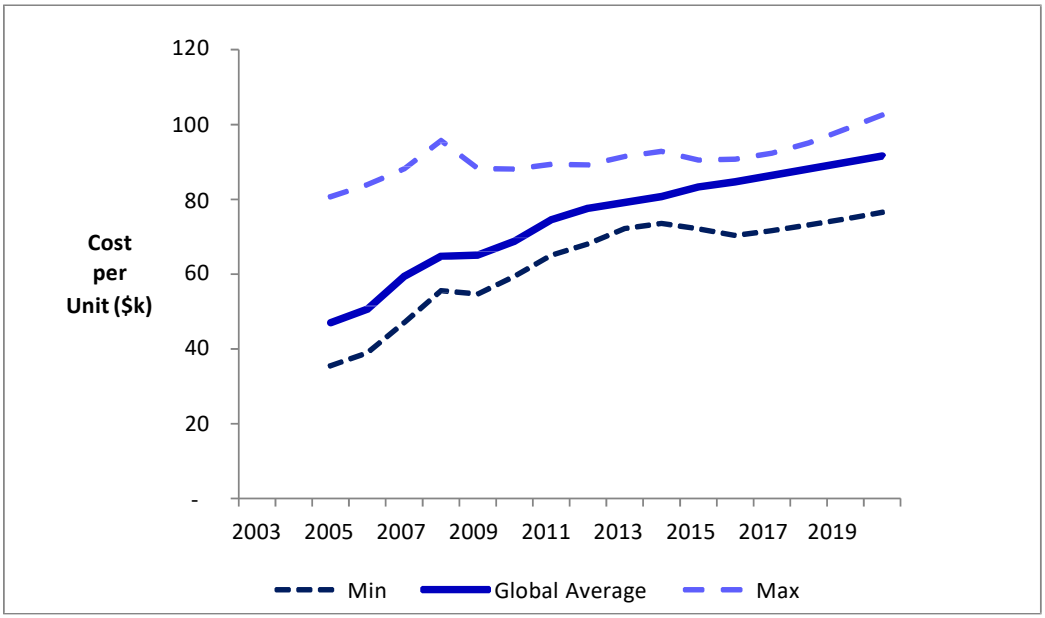
13.2.3 Prices

Prices will rise 5% by 2015 Q1 and 15.7% by 2020 Q1, pushed up by costs for steel, labor, and machinery, and inflated slightly by higher margins for complex units sold to the oil & gas and power sectors.

Prices were stable in Q1, as a drop in carbon steel costs balanced on an increase in wage levels for skilled labor, such as machinists and welders, in Asia.

Global prices will rise 5% by 2015 Q1, pacing cost growth closely. However, as demand growth accelerates in 2015, manufacturers will gain a limited amount of bargaining leverage. Costs will rise 15% by 2020 Q1, while prices will rise slightly faster, 15.7%. Suppliers that already have a dominant market position and proprietary technology, such as GEA, Alfa Laval, and GE, stand to benefit the most from the inflationary environment.

Figure 59: Overall Price Forecast for Heat Exchangers



The reference unit for Heat Exchangers is a 1-pass, shell and tube, u-tube unit, made of carbon steel, with carbon steel tubes, 3'x20', rated for pressures up to 400 psi. At benchmark, US cost levels, this unit's cost is approximately $84k.

Consistent with the other categories of Pressure Vessels, Southeast Asian countries such as Malaysia and Thailand have the lowest production costs for Heat Exchangers, followed closely by India and China. Low labor costs (although they are growing more rapidly there), and somewhat lower material costs are the main cost advantages in these countries. Production costs in these countries indicate that the reference unit, manufactured there should cost $70-73k. Russia also enjoys a significant cost advantage at present, due largely to an abundance of cheap steel. This advantage will erode, however, as electricity, steel, and labor costs rise rapidly.

Overall production costs are highest in Japan and Europe, although cost levels will be relatively stable in these countries. Due to higher costs for labor in both regions, and electricity in Japan, the reference price is approximately $92k in Japan and $88k in Europe.

The importance of these regional distinctions are blurry for the major manufacturers, as all of them have multiple manufacturing locations in multiple regions, and many of them perform most or all of the manufacturing in the low-cost regions and little to none in the higher-cost labor markets.

Table 35: Regional Price Variations over Time for Heat Exchangers

Region/Country	Today	2014	2015	2020

North America	1.00	1.01	0.99	1.06
Latin America	0.96	0.98	1.01	1.14
Europe	1.03	1.03	1.02	1.08
Africa	0.95	0.97	0.95	1.06
India	0.86	0.88	0.89	1.03
Russia	0.89	0.94	0.95	1.13
China	0.87	0.88	0.86	0.92
Japan	1.09	1.11	1.08	1.09
Other Asia	0.82	0.83	0.82	0.86

13.2.4 Price Differences by Technology, Model, and Feature

Multiple factors impact the cost of a heat exchanger – primarily size, material, and pressure rating, although the number of tube passes (for a shell and tube unit) or plates can increase the cost disproportionately to the overall size of the unit if they are of a more expensive material than the shell.

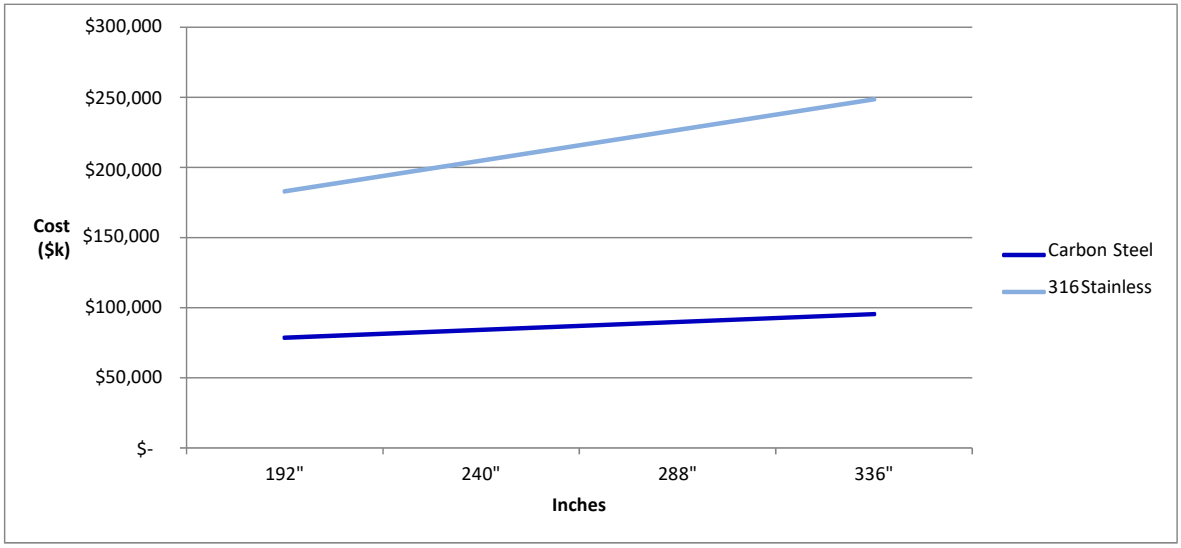
Table 36: Incremental Cost per Extra Parameter or Feature for Heat Exchangers (Reference unit is 3'x20', carbon steel, single-pass shell and u-tube, rated for 400 psi)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Tube Length	Inches (240" as the reference point)	+$471/inch when increasing tube length from 240" to 336"	Cost per inch increases are linear
Shell Diameter	Inches (3' as the reference point)	Increasing diameter to 4' costs $61.3k, and to 5' costs $140.5k	Cost increases by $50 per additional inch of diameter
Heat Transfer Surface Area	Sq. ft (3,240 as reference point)	Cost falls by $4 per square foot at constant diameter (3')	Maximizing unit length to diameter keeps unit costs low

Note: Changing one parameter usually involves changing others, and the cost impact may not be additive or linear.

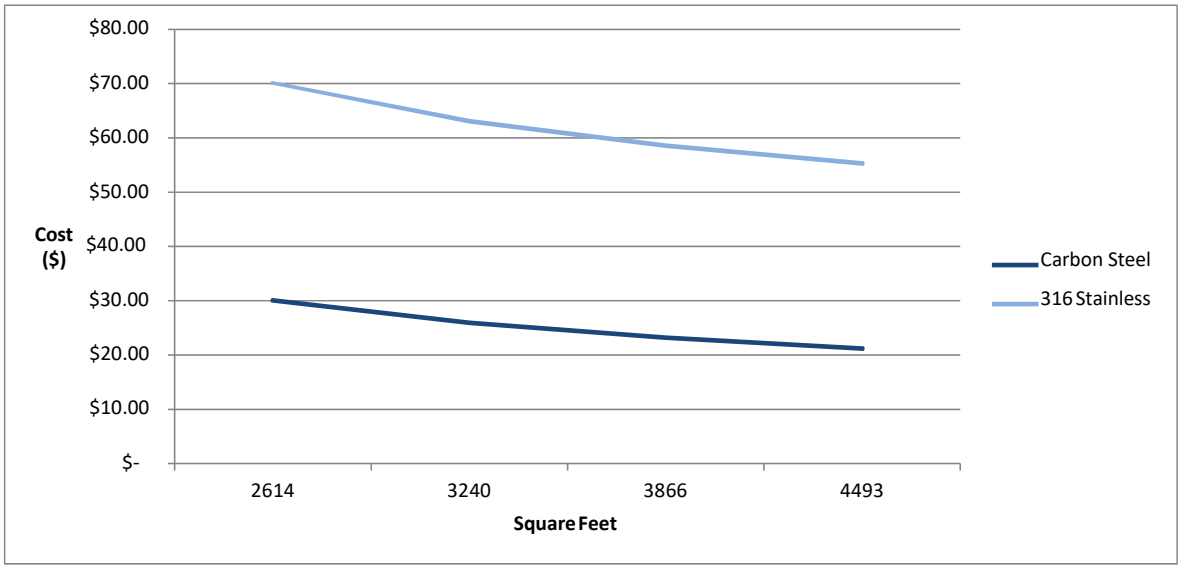
Unit cost increases are linear with tube length, adding 0.6% per inch ($471) to the cost of the unit going from 240" to 288".increasing tube length to 336" adds cost at the same rate ($471/inch). Upgrading from carbon steel to stainless steel for the reference unit increases cost from $84k to $160k.

Figure 60: Tube Length vs. Cost - by Material for 36" Shell Diameter



Cost per square foot of heat transfer surface area falls from $25.92 for the reference unit to $23.18 for 288” tubes and to $21.21 for 336” tubes. For a stainless steel unit, the corresponding numbers are $63.05, $58.54, and $55.29.

Figure 61: Heat Transfer Surface Area vs. Cost - by Material



Manufacturing economies of scale can amount to up to 20% if the order of on the scale of a full refinery, according to suppliers. Initially, the price reductions for an increase in units ordered is step-wise, with about a 5% discount going from 20 to 30 units, then another 2-3% on an increase from 40 to 50 units. Economies of scale are linear thereafter, up to a maximum of about 20%.

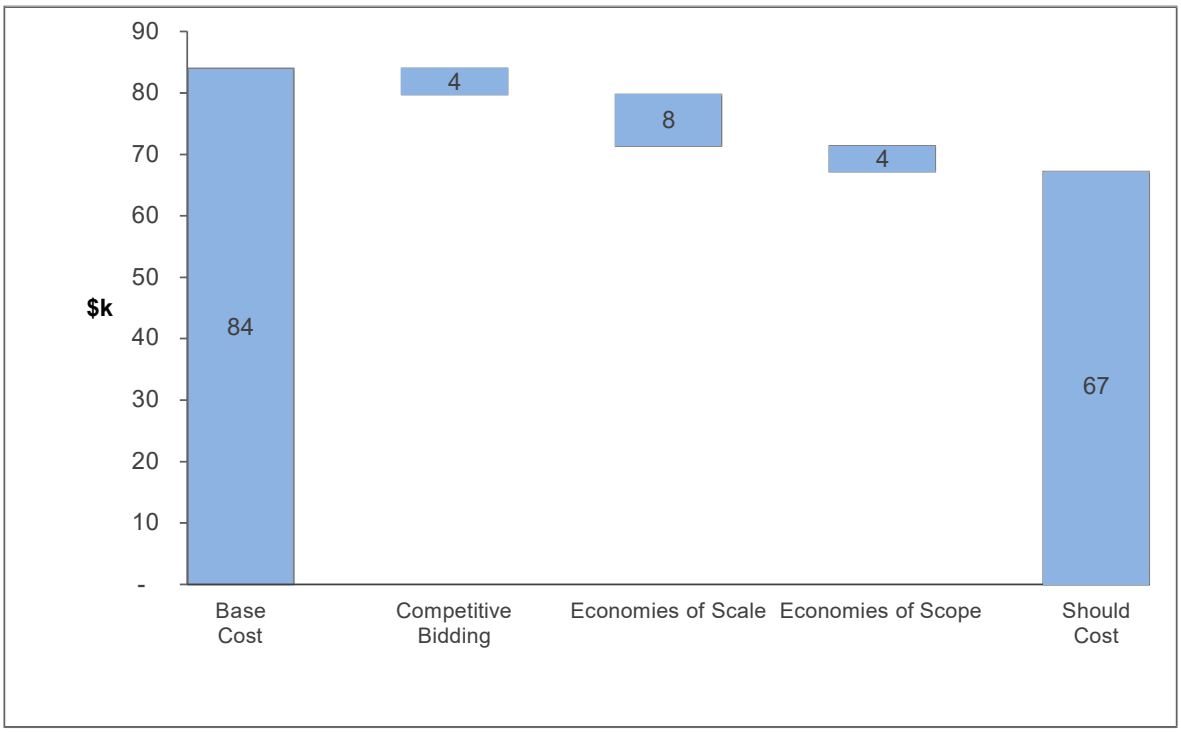
Figure 62: Economies of Scale in Heat Exchangers



13.2.5 Should-Cost Analysis

Procurement departments for oil & gas companies routinely use competitive bidding to bring down project costs, and these efforts demonstrate both economies of scale and economies of scope. Economies of scale are the richer target, at discounts of up to 20%. Economies of scope are not as productive, and could be counterproductive if a buyer is not paying attention, because the supplier can bury the price of the heat exchangers in the overall project cost. If the heat exchanger price is broken down in the bid, economies of scope of up to 5% are likely if the supplier is also awarded contracts for other process units or different types of heat exchangers.

Figure 63: Should-Cost for Heat Exchangers



13.3 Price Negotiation Strategies

1. Be cautious of lead time inflation from GEA. Despite having a $1,200m backlog for its Heat Exchanger division at the end of 2012, it reduced headcount by 400 for the business unit.
2. If GE is a bidder, require that it break out pricing by product. The firm makes the highest margin in the industry on its air-cooled heat exchangers, in large part because the prices and margins for individual units can be disguised in large bids for refinery and power plant equipment.

14 Reference product definitions and scope

1. **Distillation Columns**
   - 100’ long
   - 10’ diameter
   - Valve trays
   - Carbon Steel
   - Continuous distillation
   - Max temperature 720° F
2. **Component Removal and Reforming Towers (Towers)**
   - Stripper Tower
   - Carbon steel
   - 4’ diameter
   - 40’ length
   - 4100 lbs
   - Valve trays
   - Operating temperature 530° F
1. **Catalytic Hydrocracking Reactors**
   - 50k bpd capacity
   - 2 1/4 Cr-1 Mo w/ 3/8" 347 SS cladding
   - 16’ diameter
   - 120’ length
   - 1100 tons
   - 2200 psig
   - Max temperature 930° F
2. **Hydrotreating Reactors**
   - 20k bpd kerosene hydrotreating reactor
   - 1Cr-.5 Mo with 410 stainless cladding
   - 23’ tangent to tangent (length)
   - 7’ diameter
   - Max temperature 750° F
   - Max pressure: 1675 psig
3. **Hydrotreating Reactors**
   - 1Cr-.5 Mo with 410 stainless cladding
   - 30’ diameter
   - 120’ length
   - Max temperature: 950° F
   - Max pressure: 80 psig
4. **Spherical LPG Tanks**
   - Diameter: 50’
   - Pressure: 7 bar
   - Wall thickness: 2.36”
   - Carbon steel
   - Temp Range:-4 to +130° F
5. **Heat Exchangers**
   - AEU-type (Shell and tube,1-pass shell, U-tube bundle)
   - Max pressure: 25 bar
   - 20’ length
   - 3’ diameter
   - Carbon steel

15 Notes

The suppliers who were contacted directly for this study include, but are not limited to:

- Larsen & Toubro
- Doosan
- KNM Group
- Hitachi Zosen
- CPTDC
- Sinopec Engineering
- IDESA
- Sungjin
- Chicago Bridge & Iron
- Fabricom (GDF Suez)
- G&G International
- Petrofac
- Bellelli Energy
- Essar
- GE
- Chevron Lummus
- GEA
- Alfa Laval
- Air Products
- Bharat Tanks and Vessels
- Cimtas
- Morimatsu
- Mercon
- Titan