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Abbreviations

Acfm: Actual cubic feet per minute

API: American Petroleum Institute

ASME: American Society of Manufacturing Engineers

b: billions

barg: bar gauge

Bpd: barrels per day

Bbl: barrel of crude oil

BOG: Boil off gas

BTU: British Thermal Unit

Capex: capital expenditure

CCGT: Combined Cycle Gas Turbine

Cfm: cubic feet per minute

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

GPM: gallons per minute

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

PCP: Process Reciprocating Pump

Psi: pounds per square inch

Psig: pounds per square inch gauge

ROP: Rate of Penetration

Scfm: Standard cubic feet per minute

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

1 Scope

Process Compressors are used in the oil and gas industry to store, transport, or reduce the volume of gas, or to pressurize it for supply to refinery or combustion processes (e.g. hydrogen make-up, petrochemical, or fuel gas applications). The gas being compressed can range from raw natural gas, primarily composed of methane, ethane, and nitrogen, to sales gas, which is purified of contaminants such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), and liquids, to separated pure gases for petrochemical applications, e.g. ethane for ethylene production.

This study focuses on larger, engineered units for use in upstream and downstream oil production and refining (input power ranges from 2k MW to 40k MW). It examines the following equipment types:

- Process Centrifugal Compressors, focusing on those built to API 617 specifications
- Process Reciprocating Compressors, focusing on those built to API 618 specifications

The following types of Compressor are not included in the scope of this study:

- Axial
- Rotary Screw
- Rotary Vane
- Diaphragm

1.1 Process Centrifugal

Centrifugal compressors can be classified by *design characteristics, function, medium, application*, and *module*.

By *design characteristic*, centrifugal compressors can be classified by their casing, number of stages, and rotor design. Casings can be horizontally split, vertically split, or barrel type. Inside, they can be single stage, multi-stage, or integrally geared. Rotors can be characterized by impellers, lobes, or vanes. All designs are considered in this study, except the vane type (“axial compressor”), which is used mostly in downstream applications.

By *function*, similar equipment (all in the ‘turbomachinery’ family) can either compress, expand, or blow the gas. ‘Compressors’ compress, ‘turboexpanders’ expand, and ‘blowers’ accelerate flow rates. This study is focused on compressors, but excludes turboexpanders and blowers since they operate at significantly different temperature, pressure, and flow ranges than centrifugal gas compressors, and are frequently used in downstream applications.

By *medium*, centrifugal compressors can compress natural gas, air, or inert gases such as nitrogen (for example, for gas reinjection). This study focuses on natural gas compression. Air compression is much simpler and cheaper than gas compression, so comparisons would not be valid.

By *application*, this study focuses on natural gas gathering, transportation, and production, hence the name “Process Centrifugal” rather than simply “Centrifugal.” Upstream, this includes gas reinjection,

gas lift, gas processing, fuel gas boosting, and gas gathering. Midstream, it includes pipeline compressors, gas liquefaction, and gas compression for storage and transport.

By module, Centrifugal compressors can include the compressor itself, the driver, and other auxiliaries, as well as packaging and service. This report focuses on the compressor itself, and excludes (except where otherwise noted) other elements of the package, such as the driver (most commonly an electric motor or gas turbine); integration onto a skid, including piping; control and monitoring systems; generators and power systems; and installation, commissioning, and service.

The total market size figures include downstream applications such as ethylene production, refinery (cracking), gas to liquids (GTL), and air separation, but these applications are not included in price comparisons by virtue of the reference product specifications, which are oriented toward upstream and midstream applications. The scope also excludes centrifugal compressors for industrial use (such as mining), even though these applications may involve the compression of various gases.

1.2 Process Reciprocating

Process Reciprocating Compressors (a.k.a. piston compressors) use a rotating crankshaft to drive pistons through cylinders, compressing gas fed into the cylinders from a suction manifold. These units can be either single-acting (compressing only as the piston goes one direction) or double-acting (compressing on both the upstroke and the downstroke of the piston). Reciprocating compressors can also be integral, with the driver (a gas engine or an electric motor) and the compressor housed in the same crank casing, or separable, with a separate driver. Integral units are typically lower speed (less than 750 rpm), while separable compressors cover speed ranges from 750-1,800 rpm. Rated horsepower can range from a few hundred hp up to 12k hp for typical units (higher horsepowers exists, although those are classified as “hypercompressors,” generally used for petrochemical plants).

Drivers are not included in the scope of this study, to promote accurate comparisons. Most manufacturers do not make drivers, and many do not sell them together at all. Moreover, driver options can significantly alter the cost of the unit, independent of any compressor variable such as application.

API 618 (5th edition) defines the minimum requirements for reciprocating compressors used in the oil & gas industry. It covers performance requirements for the overall unit and for multiple subcomponents including lubrication systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment. It requires the unit to be built for a minimum service life of 20 years, with at least three years between major overhauls (this does not include ring and packing replacement, which are needed more frequently). The standard does not cover integral units driven by gas engines. ISO 13631 also defines requirements for packaged high-speed reciprocating compressors for oil and gas production service.

Reciprocating compressors are typically used in applications that require higher pressures at lower flow rates than centrifugal units. They are also used when variable flow rates are required, as the turndown ratio can be as high as 80%, compared to 20-30% for centrifugal compressors. Applications for reciprocating units include:

- Gas gathering in the field
- Gas processing and refining
- Gas storage
- LNG boil-off gas (BOG)
- Pipeline transportation
- Hydrogen supply for refinery processes such as hydrocracking and hydrotreating

2 Methodological Notes

1. References to equipment types as proper nouns (where capitalization is used, e.g., “Process Centrifugal Compressor”) are specific to the scope of equipment as outlined in the Scope section and further clarified by the Reference Product (see Reference Product Definitions and Scope). Continuing with the preceding example, “Process Centrifugal Compressor” would be more specific than “centrifugal compressor”).
2. Demand is nominal (not real, inflation-adjusted), and is based on Sales excluding backlog that has not yet been recognized as revenue.
3. 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.
4. 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.
5. 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%.
6. 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.
7. 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).

3 Vital Statistics

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

Metric	Time Horizon	Centrifugal Gas Compressors		Process Reciprocating Gas Compressors	
Demand ($M, per quarter)	Q2 2013		1,310		1,039
	Q2 2015	▲	1,397	▲	1,135
	Q2 2020	▲	1,733	▲	1,493
	'13-'15	▲	6.6%	▲	9.2%
	'13-'20	▲	32.4%	▲	43.7%
Order Lead Time (Weeks)	Q2 2013		53.9		29
	Q2 2015	▲	54.5	▲	31
	Q2 2020	▲	54.5	▲	31
	'13-'15	▲	1.2%	▲	3.8%
	'13-'20	≡	1.2%	≡	3.6%
Capacity Utilization (%)	Q2 2013		92%		88%
	Q2 2015	▼	91%	▲	91%
	Q2 2020	▼	91%	▲	93%
	'13-'15	▼	-0.8%	▲	2.4%
	'13-'20	▼	-0.6%	▲	4.0%
Prices (Index 2005Q1 =100)	Q2 2013		139.9		141
	Q2 2015	▲	145.8	▲	147
	Q2 2020	▲	162.2	▲	165
	'13-'15	▲	4.2%	▲	4.4%
	'13-'20	▲	15.9%	▲	18.5%

4 Centrifugal Gas Compressors

4.1 Market Overview

Table 2: Key Indicators for Centrifugal Gas Compressors

(Total Change over Each Period)

Key Indicators	Q1 2013 – Q1 2015		Q1 2013 – Q1 2020	
Demand Growth	▲	6.6%	▲	32.4%
Demand ($m)	▲	1,310-1,397	▲	1,310-1,733
Capacity Utilization	▼	-0.8%	▼	-0.6%
Prices	▲	4.2%	▲	16%

1. Demand

Demand for Process Centrifugal Compressors will grow steadily at a compound annual rate of approximately 3.2% through 2020, as investments in LNG, CCS, EOR, and gas pipelines surpass conventional oil exploration and production.

While overall demand for Process Centrifugal Compressors was rocked by the Great Recession (demand fell by about 25% from the peak in 2008 to the trough in 2009), a global shift from oil to gas promises a bright future in the long run. Gas demand is stimulating major projects in gas gathering and processing, liquefaction, and transport (pipelines). In addition, gas injection for CCS, EOR, and non-hydraulic fracturing are extending the range of applications for both Centrifugal and Reciprocating gas compressors. Finally, increasing demand for electricity worldwide has a number of power companies building up gas storage capacity to drive their turbines. The result is that while the demand for oil will rise by 0.9% on a compound annual growth rate through 2035, demand for gas will rise by 2.0% per year during the same period, according to the IEA's Global Energy Outlook's "current policies" scenario.

Gas gathering and processing has been driving demand for gas compressors worldwide.

- Saudi Aramco ordered centrifugal compressors (sized to handle 1.2m cfd of gas) to process rising production from its Shaybah gas field. Saudi Aramco is boosting the field's crude oil production by 33%, to about 1m bpd, up from the current 750k, increasing the amount of associated gas produced there to 2.4 mmscfd (originally contracted in 2011).
- Petrobras has ordered 80 compressor trains to be installed on eight FPSO units, totaling $700m (originally contracted in 2011 and currently underway as part of a massive program to build the FPSOs).

- Aker Solutions ordered four subsea process centrifugal compressors to produce natural gas from Statoil's Åsgard FPSO oilfield in the North Sea (originally contracted in 2011, final delivery is expected at the end of 2014).
- Nuevo Midstream upgraded the capacity of its Ramsey gas gathering system in Texas (US) (the project began in 2011 and concluded in 2013).
- The Abu Dhabi National Energy Company is building an underground gas storage facility in Alkmaar, the Netherlands, which uses six integrated motor-compressor systems.

More gas pipelines are being built worldwide, which require compression before and during gas transport. As pointed out in the Valves report, 30k miles are under construction worldwide, mostly in Russia, Eastern Europe, and South America.

- Most of the mileage is being built in India, China, and Australia – there are 14k miles of pipeline being constructed there and 20k more in the design phase. China's second West to East natural gas pipeline, which was recently completed, will carry 30 bcm per year from central Asia to the Yangtze and Pearl River Deltas. A third, fourth, and fifth version of this same pipeline are also in the planning phase. As part of the WEPP, China will build a 3k km pipeline to Kazakhstan to have an alternative to importing LNG by sea.
- The former Soviet Union countries have also ramped up pipeline construction to link them with Asia and Europe. For example, Nord Stream's twin 760-mile, 55 bcm/year pipeline began operation in June 2011 and November 2012. Also, the 916-mile Kazakhstan to China pipeline was completed in late 2012, and a 193-mile addition is planned for 2014-15 from Beineu–Bozoy to a compressor station in Karaozek.
- Latin American oil producers have several plans for constructing new pipelines, notably Petrobras's pipeline from Minas Gerais and Sao Paulo to Rio de Janeiro, and a plan in Colombia to export LNG from the La Creciente gas field to the Caribbean coast.
- In the Middle East, 9k miles of pipelines are being designed and around 2,700 miles are being built. The Iranian and Pakistani governments are building a 559-mile pipeline that will link the two countries' national gas grids together.
- Africa and Europe, suffering from economic and political malaise, plan to build only 7,617 and 2,172 miles of pipeline, respectively.
- American pipelines are numerous, but each one is relatively short, and while US gas pipeline spending spiked in 2008, 2009, and 2011, it slumped sharply in 2012. Three major projects (Appalachian Gateway, Sunrise, and Texas Eastern Appalachian to Markets expansion) totaled $1.1b in capex. Some pending pipelines could drive significant demand for gas pipeline compressors, such as the 'Sandhills' Pipeline from West Texas to East Texas, the Greencore CO_2 pipeline from Wyoming to Montana to support enhanced oil recovery pressure pumping, Kinder Morgan's Cochin Marcellus Lateral Pipeline, and a 1,717-mile pipeline from Alaska's North Slope to the Alaska/Canada border by ExxonMobil.

An increasing number of LNG investments is driving the need for more gas compression for liquefaction.

- In the Middle East, Qatargas and RasGas ordered six process centrifugal compressors to maintain pipeline and tank pressure at the port of Ras Laffan in order to reduce the amount of gas wasted during regasification. Also, Israel Natural Gas Lines will build a $140m offshore LNG terminal with 2.5b m3 annual processing capacity.
- In Europe, Shell is building an LNG receiving terminal at its Zeeland refinery in the Netherlands, due for commissioning in 2016 (as noted in the Reciprocating chapter).
- In Asia, rising Japanese LNG imports have fueled a number of LNG projects for increased regasification capacity, and China's Quangdong Dapeng is expanding its receiving capacity.
- In the US, 19 LNG export terminal projects have applied for approval from the federal government, with planned commissioning dates ranging from 2017 to 2021 (as noted in the Reciprocating chapter).
- In Australasia, eight liquefied natural gas facilities are scheduled to open before 2015. For example, ExxonMobil began construction of a new LNG export facility in Papua New Guinea. Shell began the construction of the world's first floating LNG liquefaction facility off the Australian Coast. The rig will be 480m long and weigh over 600k tonnes. Also, Australia Pacific LNG (APLNG), ordered 10 compression trains to develop coal seam gas fields. The units are for compressing low pressure coal seam gas for delivery via the main pipeline to an LNG facility being built on Curtis Island, Australia. Each train is designed to transport around 84m cubic feet of gas per day.

Although not a core focus of this report, refineries, petrochemical plants, and air separation units ordered centrifugal as well as axial and other gas compressors. For example, Gazprom ordered eight barrel compressors for a hydrogen recovery unit at the Omsk oil refinery, and Sonatrach ordered two refrigerant compressors for ethylene and propylene.

Overall, most of the growth in demand for Process Centrifugal Compressors has come from Asia and the Middle East. Europe and the US are essentially flat and will remain so. Asian demand has grown at 1.8% to 3% per quarter since 2011, while demand in Europe, the Middle East and Africa has grown at 1.4% to 2.6% per quarter and growth in the Americas has only squeaked out 0.3% to 0.8% per quarter.

Moving forward, demand will grow at 6.6% globally between now and 2015 Q2 (CAGR of 3.2%), and 32.4% globally between now and 2020 Q2 (CAGR of 5.8%).

Future demand will come mostly from Asia. From 2013 through 2020, Asian demand will grow at a compound rate of 7% per year, compared to EMEA growth of 3% and Americas growth at 1.5%. Asian demand will be particularly important for pipeline compressors, given the large number of pipeline underway there, including India, which will build three major pipelines totaling 2,500 miles:

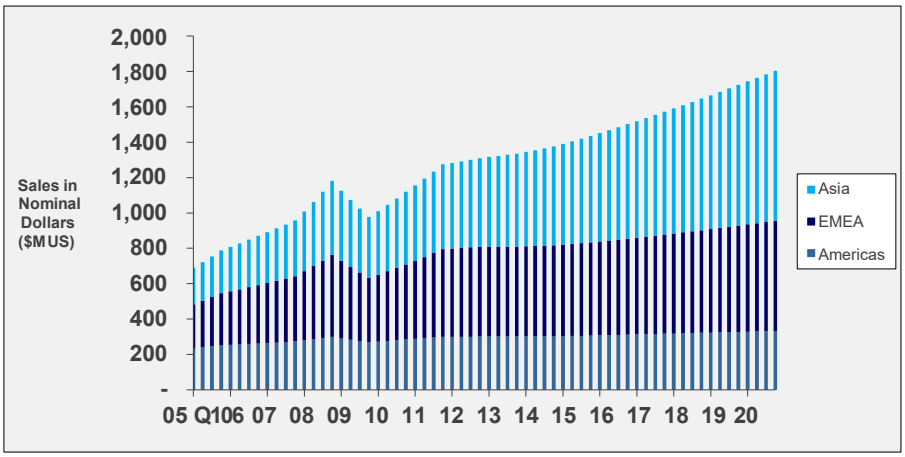
Papua New Guinea, which will build a 435-mile pipeline from Southern Highlands to Port Moresby, and many others that are currently in the planning stage; Australia, which will build a 261-mile gas pipeline from Gladstone to Curtis Island; and Thailand, which will build a 185-mile LNG pipeline.

Emerging compression applications such as gas injection for CCS, EOR, and non-hydraulic fracturing will extend the range of applications for both centrifugal and reciprocating gas compressors through 2020.

- Gas (usually nitrogen or carbon dioxide) injection can be used as an alternative to hydraulic fracturing to extract shale gas. The development of US LNG export facilities will stimulate production of shale gas, some of which will involve gas injection. In China, Sinopec and Petrochina are actively pursuing shale gas drilling programs In Eastern Europe, Chevron has a shale gas drilling program, and Ukraine is negotiating shale gas development agreements with Chevron, Shell, and ExxonMobil, and drilling there could begin as early as 2014 Q1.
- Carbon Capture and Sequestration (CCS) and Enhanced Oil Recovery (EOR) offer more potential growth areas for centrifugal gas compressors.
    - ADNOC (Abu Dhabi National Oil Company) successfully piloted a CO_2 injection project in Abu Dhabi in the United Arab Emirates with Praxair. Praxair supplied 60 tons per day of CO_2 to ADCO (Abu Dhabi Company for Onshore Oil Operations), and ADCO is pumping that into its offshore Umm Shaif and Lower Zakum oilfields. The effort has enhanced oil recovery by about 10%.
    - In Spain, Leni Gas & Oil PLC (LGO) partnered with Praxair to use nitrogen injection to stimulate production as nitrogen in well stimulation is effective and has relatively small environmental impact. Nitrogen, which is inert and does not corrode, can be used in conjunction with water or polymer flooding and can boost production by about a third.
    - GE launched its new integrated supercritical CO_2 compressor and pump system in February 2011 specifically for CO_2 re-injection.

In addition, increasing electricity consumption will lead to the development of additional gas storage plants to meet future electricity demand. For example, Taqa Energy placed a multi-million dollar order for compressor trains for the Bergermeer gas storage project in the Netherlands, and Russian Verkhnechonskneftegaz placed orders for barrel compressors for an underground gas storage facility with 1b m^3 storage capacity.

Figure 1: Demand for Centrifugal Gas Compressors



2. Supply (Capacity)

The top suppliers of Centrifugal gas compressors are investing in new capacity in strategic oil and gas hot spots such as Australia, Russia, Saudi Arabia, and China.

The top gas processing compressor suppliers are:[1]

- GE (US)
- Siemens (Germany)
- MAN (including the former Sulzer Turbo product line) (Germany)
- MHI (Japan)
- Cameron (US)
- Rolls Royce (UK)
- Atlas Copco (Sweden)
- Dresser Rand (US)
- Howden (UK)
- IHI (Japan)

The top pipeline compressor suppliers are:

- MAN (including the former Sulzer Turbo product line)
- Dresser Rand

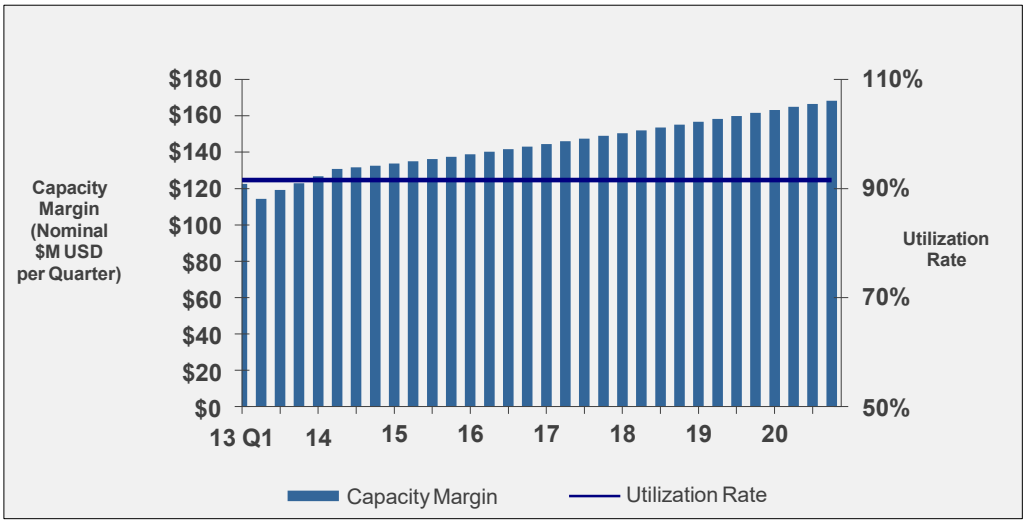
[1] Many companies could be added to this list, but are tangential to the focus of the study. For example, Samsung Techwin sells its own air and gas compressors (including API 617 units), and also distributes and packages Dresser Rand's DATUM® compressors. Samsung sold compressors worth about $140m in 2010, but most of them were air compressors and the gas compressors are for special applications such as steam compressors, blow-off gas compressors, and companders.

- GE
- Siemens
- Rolls Royce PLC
- Cameron
- Atlas Copco
- Solar (a division of Caterpillar) (US)
- Kawasaki (Japan)
- Ebara/Elliott (Japan)
- Howden
- IHI

Capacity additions tend to lag demand increases since suppliers are cautious about overinvesting and capacity overhang. The business operates in long cycles, and after each boom and bust cycle, OEMs are cautious and hesitant about adding new capacity. For instance, before the 2008 bubble burst, they were operating over 100% of capacity, running three shifts and 7-day per week operations in some cases. Then, between 2008 and 2012 there was abundant excess capacity. Now conditions are tight again, but suppliers are loathe to add capacity until they get firm orders first, lest they overbuild and have to absorb the cost of excess capacity for another cycle, which could last 5-10 years.

There is a relatively small amount of Capacity Margin available ($120m per quarter). Large projects could consume the available capacity of the top suppliers if orders come in large increments, or if they are skewed toward certain types of compressors, or if they are directed toward one or two of the top suppliers. However, the risks of that happening are mitigated by aggressive capacity expansions at most of the top suppliers, which makes a 'steady state' capacity utilization scenario realistic.

Figure 2: Capacity Margin - Centrifugal Gas Compressors



MAN Diesel & Turbo built an open air test bed at its Oberhausen, Germany, facility to test large compressor trains. The 17,200 sq.ft. test bed is adjacent to its indoor test building. The test bed's two sections are each capable of hosting a large compressor train. It is sized for compressors rated at up to up to 33,250 hp (25 MW). With this latest addition, the Oberhausen facility has 25 test stands. The plant is close to the canal harbor, in order to facilitate transport of large, fully-assembled compression systems. MAN is also continuing to ramp up production at its new Changzhou plant in China, increasing headcount by 15%.

GE is setting up a massive $100m training and service center in Australia to cater to the LNG needs of supermajors like Chevron, which operates its gargantuan Gorgon project there. The facility will serve as a compression center of excellence. GE also formed a 10-year licensing agreement in India with BHEL (Bharat Heavy Electricals Limited), under which BHEL will manufacture GE's centrifugal compressors in India and market them in South Asia. GE will also complete the construction of a new 4.6k m^2 multiproduct facility in India that will manufacture compressors and other products.

Dresser Rand set up a 10k m² assembly facility in Brazil (Santa Barbara d'Oeste) to assemble, package, test, and repair up to 80 DATUM compressor trains for eight FPSOs under its $700 million contract with TUPI B.V. (Petrobras 65%, BG Group 25%, Petrogal 10%) and GUARA B.V. (Petrobras 45%, BG Group 30%, Repsol-Sinopec 25%). In addition to assembling gas compressors, the plant will repair industrial gas turbines and package engines/generators and cogeneration systems for the oil & gas, industrial and marine sectors.

Siemens is expanding production capacity in Russia, Saudi Arabia, and India.

- Siemens expanded in Russia, through a JV with RusTurboMash LLC and Iskra-Avigaz. The JV entity built a new $79mm compressor manufacturing plant in Perm, Russia, which will initially make stator components and gradually increase its scope of production to make full compressors and employ 250 people.
- Siemens is building a manufacturing plant for gas turbines and compressors in Dammam, Saudi Arabia. The investment, in collaboration with a Saudi partner, is a commitment to the Kingdom and aims to increase jobs there as well as produce equipment.
- Siemens has also made a major commitment to building a center of competence and a manufacturing facility in Vadodara, India. The plant will make approximately 60 different types of products, including compressors.

Cameron built a 104k ft^2 gas compressor manufacturing, packaging, repair, and overhaul facility in Gaomi, China. The new facility is equipped with balancing machines, numeric-control machine tools and testing capabilities for machines up to 3500 hp. The plant also handles rotor repairs and balances MSG compressors, as well as air compressors under the old JOY brand (acquired by Cameron in 2011). The operation also includes an aftermarket parts warehouse for centrifugal and other products. Cameron views the Chinese market as critical to its global expansion plans.

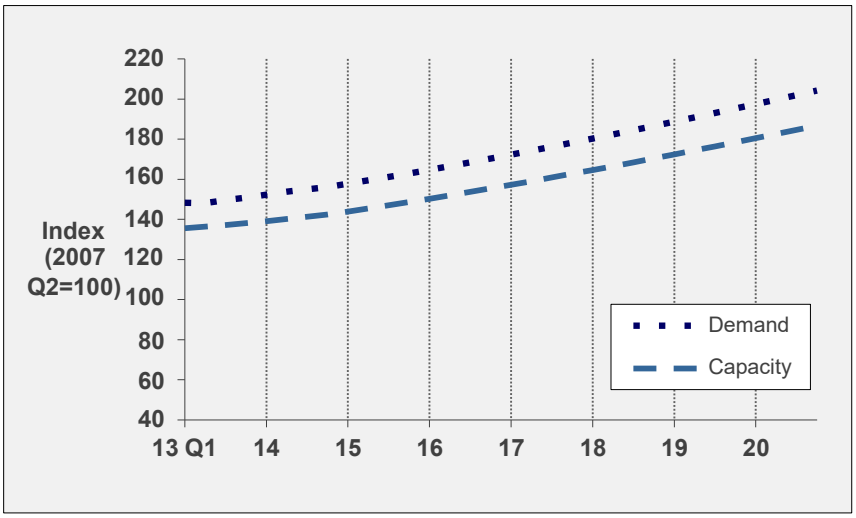
Ebara will increase production of natural gas compressors in anticipation of global demand growth. Ebara completed a $99m expansion of its main US plant located in Pennsylvania in 2012. The plant's production capacity will increase 50% to 110 units per year.

Other OEMs and packagers refocused their capacity or their strategy on the oil and gas markets, which amounts to a capacity addition of the relevant product range.

- For example, MCO (MHI) established a marketing company in Houston and appointed as its head a former chief engineer from ExxonMobil Chemical Company as a signal of its intent to focus on oil and gas industry applications.
- IHI concluded a sales alliance agreement with Atlas Copco, and its corporate parent issued about $150m in debt to fund facility expansion.
- Kobelco, a maker of mostly (but not entirely) screw compressors, made several capacity expansions, including building a new $20m plant in the US, acquiring 44% of Wuxi Compressor Co. in China, and expanding its Shanghai manufacturing plant.

In aggregate, Process Centrifugal Compressor suppliers are operating at 92% capacity utilization.

Figure 3: Demand vs. Capacity - Centrifugal Gas Compressors



Capacity for Process Centrifugal Compressors is very specific to certain product types and applications, and is therefore not fungible, as it would be in a commodity industry, so even though there is 8% available capacity in the industry as a whole, this does not mean that a buyer will readily find a supplier for a specific requirement, because suppliers carefully consider potential bids, and decline to bid if it is not in their 'sweet spot.' For example, MAN Turbo is not interested if the pressure ratio is not in the right range, and Elliott (Ebara) is not interested if the application is for standard pipeline compressors, an application in which it does not consider itself to be very competitive.

Furthermore, some suppliers are only interested in bidding on a compressor if they can win the contract for the driver, too. Rolls Royce and GE want the compressor in order to get the gas turbine sale. Sulzer (Man Turbo) wants the compressor in order to sell the steam turbine. Siemens wants the

compressor only if it can get the whole compressor train. Sundyne, which does not make units as large as the reference product, bundles all its compressors with electric motors as a solution. For example, the price of its BMC 341 pipeline compressor includes both the compressor and the motor.

Therefore, when trying to determine the adequacy of capacity, capacity utilization at individual suppliers will ultimately determine lead time and cost.

Table 3: Reported or Estimated Capacity Utilization Rates at Selected Centrifugal Gas Compressor Suppliers

Company	Country	Current Level	12-Month Forecast
Dresser Rand	USA	85%	85%
Elliott (Ebara)	Japan	90%	90%
Cameron	USA	100%	85%
Sundyne	USA	80%	80%
MAN Turbo	Germany	80%	80%
Rolls Royce	UK	85%	85%

Most of the top suppliers have more available capacity now than in the past 1-2 years, due to the aforementioned capacity additions. However, capacity at all of the majors is still at least 80-90% occupied.

- Elliott is operating at about 90% of capacity, and is turning down requests for proposal unless they fit the company's target products and applications, which are largely in petrochemicals. This is also an improvement from 2011, in which the company was operating at 95% at its Sodegaura, Japan, factory.
- Dresser Rand was recently about 90-95% utilized based on major orders in Brazil.
- MAN Turbo's capacity utilization is relaxed compared to 2011, when it had overbooked its yearly capacity as of August.
- Cameron is operating at 100% of capacity now, but claims it can still fulfill orders. The company did not add enough people last year, so has been operating at over 100% capacity until recently. They booked 80% of their goal for the year as of early May, but executives claim that the company's capacity investments will provide the resources it needs: their 18-24 month S&OP plan shows plenty of excess capacity into 2014.
- Mitsubishi Heavy Industries was recently at 95% of capacity in Asia, due to a rapid regional demand growth for 50MW input units, used primarily in gas pipelines.
- Asian suppliers, such as Hitachi, Kobelco, and Samsung, are less utilized than their Western counterparts, partly due to their focus on their domestic markets.

Lead times for both gas processing and pipeline compressors currently stand at 12-14 months. There is no material difference in lead times for gas processing, or pipeline, units.

- Cameron and Siemens both quote 52 weeks, which consists of 8-9 months for the centrifugal compressor, three months for the ends, and one month for shipping.
- Elliott quotes 48 weeks for gas processing and pipeline compressors.
- MAN Turbo quotes the longest lead time, at 74 weeks. The company's lead times are typically longer than other suppliers due to its focus on highly customized machines.
- GE has historically quoted 52-76 weeks for the reference products, and Rolls Royce 61 weeks.
- MHI has lead times close to the market average at 63-64 weeks.

Lead times are at some risk of extension due to delays in obtaining magnetic bearings. MAN Turbo is experiencing 6-month lead times for obtaining magnetic bearings, so it has forged an alliance with S2M, a subsidiary of SKF, to avoid a bottleneck in its overall delivery lead times. The company attempts to manage lead times and buyer expectations of lead times, by bringing potential customers to existing installations and planning for orders well before they transact, to manage customer expectations and keep its shop load smooth.

3. New contracts

There is a high level of activity among a relatively small number of leading players, due to strong industry concentration.

Most of the contracts are bundled packages involving numerous entire compressor trains with auxiliary equipment and ancillary services. The following observations on the contracts could be useful for a buyer:

- The largest all-in contracts are from Petrobras and operators in Australasia (Australia and Papua New Guinea, in the case of the contracts listed).
- Almost all contracts reflect sales of whole packages (a few by Rolls Royce and Atlas Copco are exceptions).
- GE had the largest awards, followed by Dresser Rand, MHI, and MAN Turbo (assuming that Hitachi does not max out its agreement with Saudi Aramco).
- Elliott's contract relates to air separation rather than upstream oil or gas.
- Many of the contracts in China and Africa (especially Nigeria) are at a steep discount to prices elsewhere.

The cost of the compressors are usually only part of the total contract value, since the requirements and the contracts are driven substantially by the price of the driver (especially if a gas turbine is used), and also by the cost of the associated services.

Because almost all of the deals were bundled, the contract values and per-unit prices in the table are estimates based on calculations that attempt to extricate (unbundle) the price of the compressors from the prices of the drivers, packaging, and auxiliary equipment and services. These inherently required a substantial number of assumptions, and they should therefore be interpreted or used with caution.

In addition to the contracts with quantified estimates or actual values in the table below, a number of other deals are worthy of note, including these;

- Sengkang LNG purchased four motor-driven trains with a capacity of 0.5 MTPA each, 2 SGT-1000F gas turbines, electrical transmission and distribution equipment, and communications systems from Siemens for installation in Indonesia.
- Petronas purchased one Cryogenic BOG turbo compressor and 1 single-casing LNG-refrigerant turbo compressor from Siemens for installation in Malaysia.
- Shell signed a six-year LNG compressor framework agreement with Mitsubishi, establishing MHI as a preferred supplier of refrigeration and process gas compressors for Shell's global LNG plants. Mitsubishi is one of the two designated vendors (along with GE) that Shell has selected to supply compression systems for its LNG plants.

Table 4: Summary of New Contracts and Estimated Values for Centrifugal Gas Compressors

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Petrobras	Brazil	GE Oil & Gas	32 compressors (Reciprocating and Centrifugal) driven by electric motors; 8 turbocompression trains driven by LM2500+ gas turbines; 8 PGT25+ gas turbines and electric generators; installation and commissioning support, dedicated local field service engineers; 9,600 man-hours of training; packaging, testing	$500	$5.6
Shell	Russia, Australia	MHI	Not available	$360	$90.0
Shenhua Ningxia Coal Industry Group Co.,Ltd. (via Linde and Hangyang)	China	Man Diesel & Turbo	11 turbomachinery trains, each consisting of a 6-stage MAX1 axial/centrifugal compressor type AR115/06M, a 6-stage integrally geared compressor type RG 56-6, and a condensing steam turbine DK080/250R, acting as the driver for both compressors	$163	$2.9
PNG LNG	Papua New Guinea	GE Oil & Gas	13 turbocompressor train stations of PGT25+G4 gas turbines and centrifugal compressors	$136	$2.6
Saudi Aramco	Saudi Arabia	Hitachi	10 compressors, to be determined during planning stages. This framework agreement does not specify exact equipment.	$125-$250m	$6-12
Petrobras	Brazil	Dresser Rand	14 centrifugal compressor trains comprised of 18 casings; 2 mechanical drive gas turbines; and 4 gas turbine generator sets	$120	$6.9
PetroChina	China	GE Oil & Gas	6 gas turbine-driven compressor trains and 9 electric motor–driven compressors	$100	5.7
Linde (via Samsung Engineering)	India	Elliott Group	An 88MD2, an 88M4 and a 60M4/4I driven by an Elliott 2SNV-10 65 MW steam turbine, a 70M8-6 compressor driven by an SNV-8 steam turbine, and a 46M9-8 compressor and a 56M6I compressor driven by an SNV-6 steam turbine. With lube oil and buffer gas systems.	$89	$7.9
PetroChina	China	Rolls Royce	6 RB211-driven pipeline compressors	$75	$12.5
Petronas	Malaysia	GE Oil & Gas	4 PGT25+G4 gas turbine generator systems, 2 PGT25+G4 gas turbine driven compressors, and 2 electric motor driven centrifugal compressors	$72	$2.9
WINGAS (Wintershall / OAO Gazprom)	Germany	Siemens	3 compressor trains, each comprising an STC-SV compressor driven by an SGT-700 gas turbine. With control units and auxiliary systems.	$52	$3.8
SBM Offshore (via Samsung Techwin)	Offshore Equatorial Guinea	Dresser Rand	DATUM(R) centrifugal compression trains driven by electric motors and 3 DR-61G (LM2500) gas turbine generator sets	$44	$2.5

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Asia Trans Gas	Uzbekistan	Rolls Royce	3 RB211 gas turbine driven pipeline compressor units	$40	$13.3
JKC Ichthys LNG Joint Venture (JKC JV) (JGC, KBR, Chiyoda)	Australia	MCO (MHI)[2]	9 compressors (of which 3 are cCentrifugals) and 7 motors	$33	$2.9
Total E&P Norge	Norway	GE Oil & Gas	4 complete, variable frequency drive high-speed electric motor and centrifugal compressor packages.	$27	$2.9
Tupi BV, via MODEC Offshore (Singapore) Pte Ltd.	Brazil	MCO (MHI)	6 compressor packages	$22	$2.9
RWE	Germany	Man Diesel & Turbo	2 multi-stage HOFIM radial compressors arranged in tandem around a central 14 MW motor driver. Output of 0.3 X 106 m3/hr in parallel, and peak pressure of over 160 bar in series operation.	$20	$7.8
Shell Petroleum Development Company (SPDC)	Nigeria	Siemens	2 x STC-SV (06-4-B); 2 x STC-SV (06-6-A); and 2 x STC-SV (08-8-B)r.	$18	$3.0
Pemex	Mexico (Abkatun-D)	Dresser Rand	2 single-lift compression trains, each containing 2 Datum compressors. With dedicated unit controls; process coolers, valves, instrumentation and interconnecting piping.	$13	$3.1
Shaanxi Zhongyuan Green Energy Natural Gas Company Ltd.	China	Siemens	SV(10-7-B) centrifugal compressor and an 11 megawatts fixed-speed electric motor, plus gearbox, lube oil system and unit control system	$10	$2.4
SEC (via Bemco and GS Eng'g, for PP-12)	Saudi Arabia	Atlas Copco	3 centrifugal gas compressors	$9	$2.9
Shell	Canada	Man Diesel & Turbo	RG-type RG90-8 frame size integrally-geared centrifugal compressor. 8 stages; discharge pressure of 130 bar. Handles 80,000 cubic meters of CO2 per hour.	$9	$9.2

[2] Mitsubishi Heavy Industries Compressor Corporation (MCO), a wholly-owned subsidiary of MHI.

2. Analysis

1. Costs

Professional labor and materials costs are the principal cost drivers; both types of cost are forecast to rise slowly and gradually.

Most of the cost of Process Centrifugal Compressors is in labor and machinery & parts. Wages, salaries and benefits comprise over 42% of the cost, with professional labor comprising 18%, Production labor comprising 18%, and Benefits summing to 6% of the total.

The rest (52%) is in machinery and parts, largely parts and components that are made of steel. This includes forgings, stampings, and castings, such as rotors, impellers, and fittings, whose costs are driven in large measure by the rate of economic growth and internal prices of China. It also includes the costs of:

- Power equipment
- Engine equipment and apparatus
- Valves
- Piping
- Fabricated parts

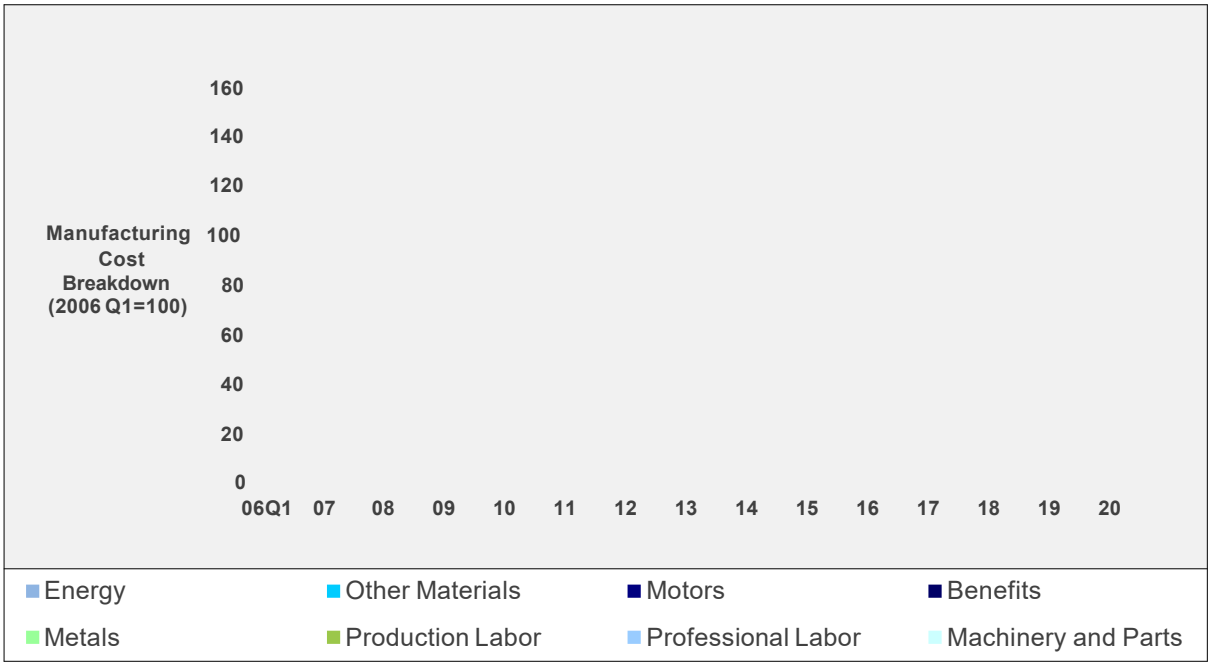
Most of the relevant costs are growing between 0.3% and 0.6% per quarter on a steady basis for the foreseeable future. Steel could be a wild card since it constitutes such a large portion of the machinery and parts, but the current outlook is for stable steel costs.

Suppliers' costs are affected by internal management practices well as externally purchased materials and services costs. Supply chain management can lower costs through outsourcing, modularization, and lean manufacturing.

- GE outsources to external partners where possible to manage cost and also to mitigate capacity constraints. For critical components such as casings, cast housings, and forged rotors and impellers, the firm has already outsourced production to partner suppliers to keep its lead times low. The firm still does most of its machining in house, but when machining becomes a bottleneck GE outsources it to a third party supplier. MAN has also used subcontractors to lower its breakeven point and keep capacity flexible both upward and downward.
- Rolls Royce modularized its compressor packaging to enable easier change out of parts and increase maintenance intervals, thereby reducing operating and maintenance costs for users. Rolls Royce also incorporated modularity in design, which makes internal components easier to remove for repair or replacement. Its RCB barrel compressor can have both stationary and rotating parts removed at the same time.
- Ebara quality improvements resulted in a year-on-year 50% drop in defective rates for compressors, which lowers the cost of manufacturing as well as warranty repairs. FMEA

(failure mode effects and criticality analysis) has been implemented in new product design, the individual production stages, and developed a work standard to prevent nonconformities. Ebara also introduced the PDCA cycle (plan-do-check-act), an iterative procedure for continuous process improvement.

Figure 4: Cost Structure for Centrifugal Gas Compressors



Note: Prices are ex-works.

As previously indicated, the cost of the compressor is only one part of the cost of the whole compressor train, which also includes a driver (most commonly an electric motor or gas turbine); integration onto a skid, including piping; control and monitoring systems; generators and power systems; and installation, commissioning, and service. Driver and power systems could cost $2-10m or more, and engineering, installation, and construction can cost 10-60% of the value of the compressor and driver, depending on site conditions. This includes the cost of control and monitoring systems, packaging, and commissioning.

2. Profit Margins

Suppliers earn 10-11% operating margins, consistent with Process Reciprocating Compressors.

Segment operating margin is 11.6%, on average. There is a wide range of profitability across suppliers. For example, the operating margin of the relevant segments of those companies include (in rank order by operating margin):

- Atlas Copco, 23.1%

- Solar Turbines, 16.3%
- GE, 12.6%
- Cameron 12.5%
- Dresser Rand, 12.3%
- Rolls Royce, 11.3%
- Siemens, 6.6%
- MAN, 6.1%
- Kawasaki, 4.4%

Pipeline Compressors are 2.5% more profitable than Gas Processing Compressors, given their higher price tag and higher engineering labor component. The gross margin on these units – before sales, general and administrative costs (a different metric than used in the preceding paragraph) – is14.4%, compared to 11.9% for Gas Processing compressors.

Gross margin increases slightly with the size of the unit, due to the same reason – a higher price tag and more engineering labor inputs. For example:

- The gross margin on a 10 MW Gas Processing compressor with input and output pressure of 8 and 40 bar, respectively, is 11.3%, whereas the gross margin on a 15 MW unit with input and output pressure of 8 and 40 bar, respectively, is 12.9%.
- The gross margin on a 20 MW Pipeline Compressor is 14.1%, whereas the gross margin on a 37.3 MW unit is 14.4%.

3. Prices

Prices are growing steadily, which allows both buyers and suppliers to plan for capital projects with some degree of certainty.

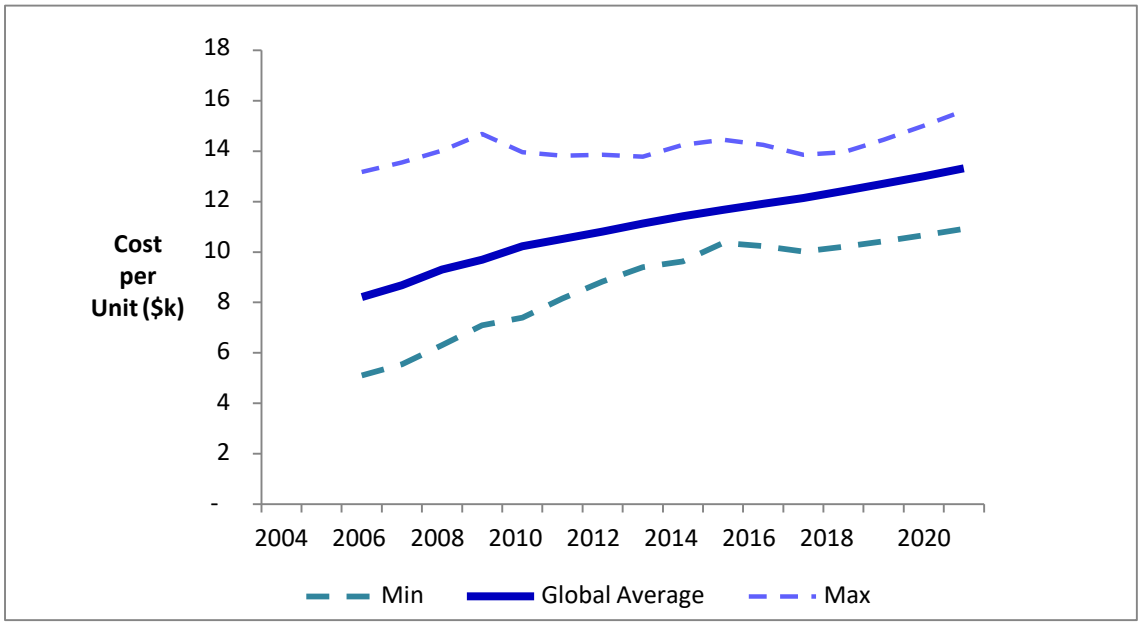
At benchmark US price levels, the average Process Centrifugal Compressor unit costs an average of $5.6 million, based on a representative pipeline compressor with a price of $8.3m, and a representative gas processing compressor with a reference price of $2.9m. There are based on the following specifications:

- Gas processing compressor
  - 12 MW input power (16k hp)
  - 6 bar (87 psig) inlet pressure
  - 30 bar (435 psi) discharge pressure
  - 16k acfm inlet flow rate (27k m3/hour)
  - Driven by an electric motor
  - API 617

- Processing gas that is 82% methane, 7% ethane, 6% CO2, and 3% propane (the rest is 'other'), with molecular weight of 21, temperature of 131 F, and H2S content of 10ppm.
- Operating at 500m in ambient temperature of 80 F

- Pipeline compressor
  - 30 MW input power
  - 23 bar (333 psig) inlet pressure
  - 115 bar (1668 psi) discharge pressure
  - 11k acfm inlet flow rate (19k m3/hour)
  - Driven by a gas turbine
  - API 617
  - Processing gas that is 82% methane, 7% ethane, 6% CO2, and 3% propane (the rest is 'other'), with molecular weight of 21, temperature of 131 F, and H2S content of 10ppm.
  - Operating at 500m in ambient temperature of 80 F

Figure 5: Overall Price Forecast for Centrifugal Gas Compressors



Japan is the most expensive market for Process Centrifugal Compressors, followed by the US, Latin America, and Europe.

- Japan's high cost of labor and power, as well as its relatively insular domestic economy, contribute to a high cost of manufacturing.
- The US and Europe's high cost of labor drives up costs based on a high cost of engineering (recall that nearly half of the cost structure is labor-related).

- Prices in Latin America, although there are no identified manufacturers, are driven up by Petrobras' large requirements and the cost burden of local content rules to foreign manufacturers.

India, Russia, and China benefit from regionally lower prices. Although suppliers typically claim that they use one price worldwide, our analysis of the contract data indicates otherwise. Suppliers seem to discount prices to these emerging markets due to demand inelasticity. The deals will only transact at certain prices, so they compete for the projects at whatever price levels they need to win the jobs, and this results in lower prices for these countries. GE's sales to PetroChina and MAN Turbo's sales to Shenhua Ningxia Coal Industry Group, and Siemens' sales to Nigeria came in lower than calculations would suggest is the market rate, even after taking into account local cost differentials, implying that they are aggressively pricing in these markets to gain market share.

Globally, nearly all these manufacturers are engaged in a long-term process of cultivating suppliers in emerging economies, especially China and Russia, to build more and more engineered and precision parts and components so that eventually they will be capable of producing the full compressors.

Table 5: Regional Price Variations over Time for Centrifugal Gas Compressors

Region/Country	Today	2014	2015	2020
North America	1.00	1.00	0.98	1.05
Latin America*	0.95	0.98	1.00	1.13
Europe	0.97	0.97	0.97	1.02
Africa*	0.75	0.76	0.75	0.84
India	N/A	N/A	N/A	N/A
Russia	0.81	0.85	0.85	1.00
China*	0.81	0.81	0.80	0.85
Japan	1.11	1.13	1.11	1.12
Other Asia	0.84	0.84	0.83	0.88

Notes:
"N/A" means no local manufacturers and no known sales.
"*" means supplied by foreign manufacturers only

Globally, prices will rise by 4.2% in the next 24 months, and 16% over the next 7 years, for a steady rise of about 2% per year. Prices in Asia will rise slightly faster (0.2%/quarter) than in EMEA or Americas, due to regulation and fast-rising labor costs.

4.3.1 Price Differences by Technology, Model, and Feature

Higher power (hp or MW) levels increase the price of centrifugal gas compressors, while higher flow rates and pressure levels generally decrease the price.

The power range of the unit determines the design of the unit, which is why it is an important economic variable. For instance, the power range (MW or hp) and pressure (bar or psig) determine whether the unit needs to be vertically vs. horizontally split. A vertically split design is needed for higher pressures and for gases like hydrogen.

The gas makeup determines important configuration specs, such as the seals, the speed, and the number of gears or stages. Dry gas, which has low or no H_2S, obviates the need for highly engineered seals, which can cost about 20% more than a standard unit. In addition, dry gas does not require a 'support system' of knock-out pots (suction drums).

The flow rate and discharge pressure drive 'step change' cost increases that depend on the manufacturer, compressor type, and application. For example:

- For a gas processing compressor (based on Siemens):
    - Increasing the flow from 40 to 70k cfm would require two rotors instead of one
- For a pipeline compressor (based on Cameron):
    - Increasing above 20MW would require two compressors, thereby doubling the cost.
    - Increasing the pressure from 1900 to 2200 psi, and/or the flow rate from 40k cfm to 70k cfm, would require more stages and a gas cooling system, thereby adding about 25% to the cost.

The table below shows the incremental impact of changes in power of the driver, discharge pressure, and flow rate on the prices of Pipeline compressors and Gas Processing compressors. The fundamental relationships are similar.

Table 6: Incremental Cost per Parameter or Feature for a Centrifugal Gas Compressor

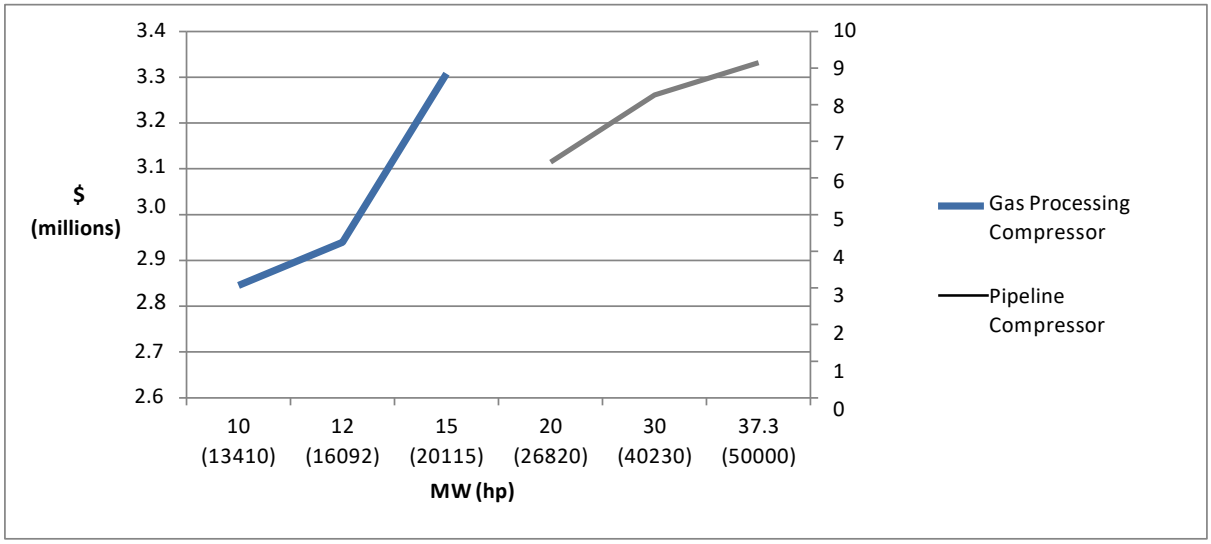
(based on the reference unit specified above)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
MW (hp)	**MW (hp)**	For Gas Processing compressors, increasing power from 12 to 15 MW, while holding the compression ratio constant, increases the price by $0.368m (12.5%). For Pipeline compressors, increasing power from 30 to 37 MW, while holding the compression ratio constant, increases the price by $0.882m (10.7%).	For a given power increment, price rises faster for Gas Processing compressors than for Pipeline compressors
Pressure	**Barg (psi)**	For Gas Processing compressors, increasing the inlet/discharge pressure from 6/30 bar to 8/40 bar, while holding the compression ratio constant, increases the price by $28k (1.0%). For Pipeline compressors, increasing the inlet/discharge pressure from 23/115 bar to 26/130 bar, while holding the compression ratio constant, decreases the price by $614k (-7.4%). However, other increments, such as to 20/100 to 23/115 bar, yield an increase rather than a decrease.	While pressure is one of the key technical parameters of centrifugal gas compressors, changes in pressure are not directly correlated with higher compressor cost.
Flow Rate	**ACFM (m3/hour)**	For Gas Processing compressors, increasing the flow rate from 13k acfm to 19k acfm, while holding power and pressure constant, decreases cost by $35k (1.2%). [Increasing the flow rate from 16k acfm (the flow rate of the reference product) to 20k acfm, while holding power and pressure constant, decreases cost by $1.5m (50%); however, this is random noise since there is no correlation at other increments, and most changes in flow rate yield less than 1% change in compressor cost, holding power and pressure constant.] For Pipeline compressors, increasing the flow rate from 11k acfm (the flow rate of the standard product) to 13k acfm, while holding power and pressure constant, decreases cost by $19k (0.2%).	While flow rate is one of the key technical parameters of centrifugal gas compressors, changes in flow rate are not directly correlated with compressor cost.

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

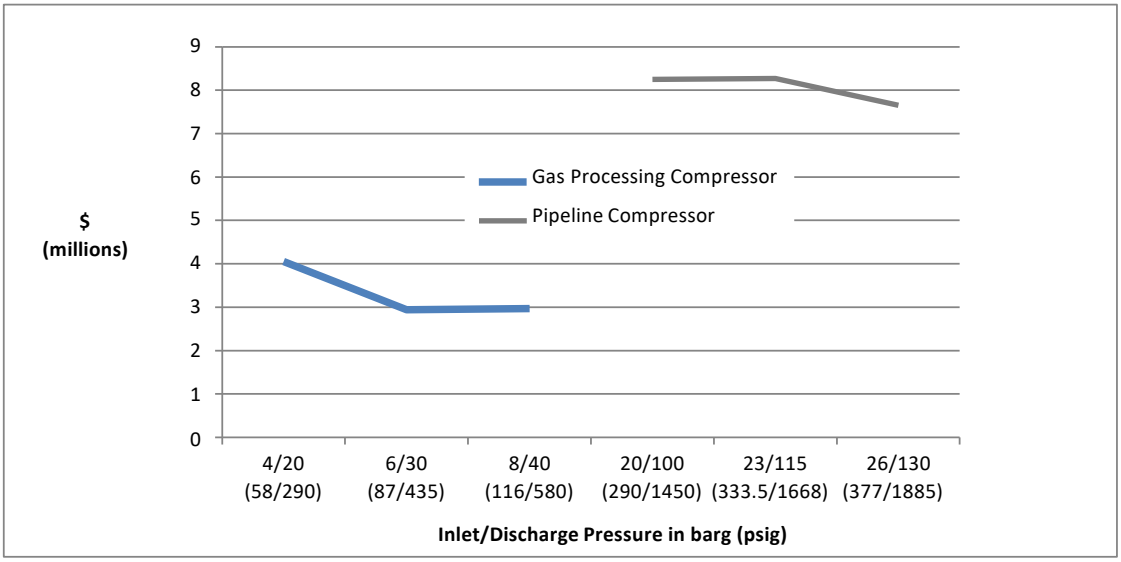
Increasing the power of the driver (either a gas turbine, typically measured in MW, or an electric motor, typically measured in kW or hp) raises the price of a centrifugal compressor rapidly, even more than a broad array of pressure and flow design permutations. This is true of both Gas Processing compressors and Pipeline compressors. The rate of increase of price of a Gas Processing compressor decreases as power increases because the integral gearing design allows for higher speed for relatively little cost, once the basic design is chosen. In contrast, the price of Pipeline compressors increases at an increasing rate with power output as they reach the edge (asymptote) of the standard ranges.

Figure 6: Centrifugal Gas Compressor – Input Power Impact on Price



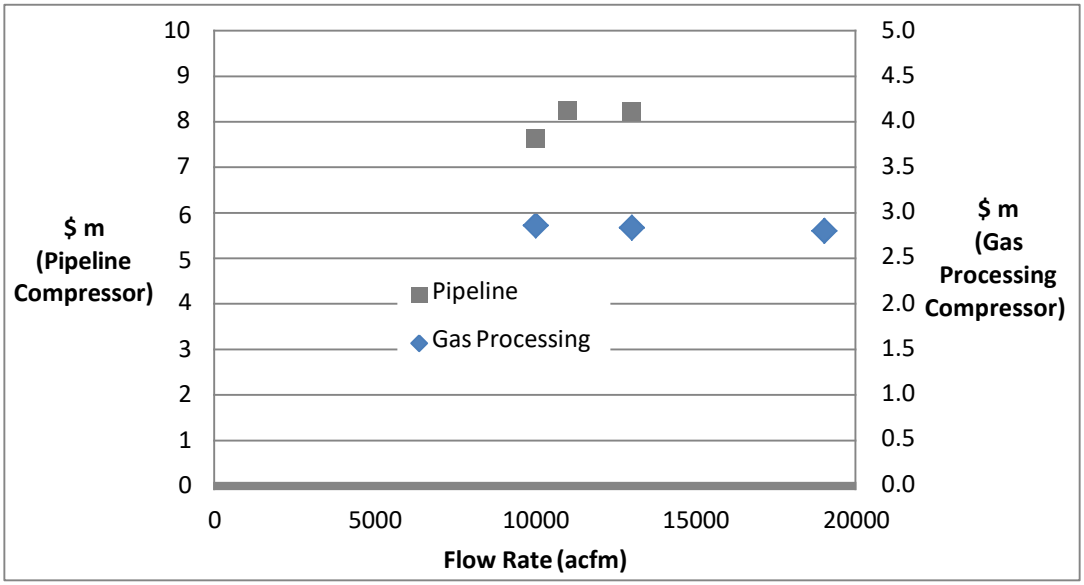
Increasing the inlet and discharge pressure do not result in a predictable impact on the price of the compressor. For both the Gas Processing Compressor and the Pipeline Compressor, the price decreased over one range and increased over another, with very small percent changes and without a trend. This is true while holding the compression ratio constant, and also while allowing the compression ratio to vary over the ranges concerned (changing the flow rates).

Figure 7: Centrifugal Gas Compressor – Input and Discharge Pressure Impact on Price



To test the impact of the flow rate on cost in a realistic way, a series of scenarios was developed in which the flow rate increased and decreased while the driver power and the compression ratio were held constant. The results indicated that changes to flow, in the absence of the other variables, had less than a 1% impact on the price of the compressor (with the exception of the Pipeline Compressor moving from 10k to 11k acfm, which bumped the price up by 8%).

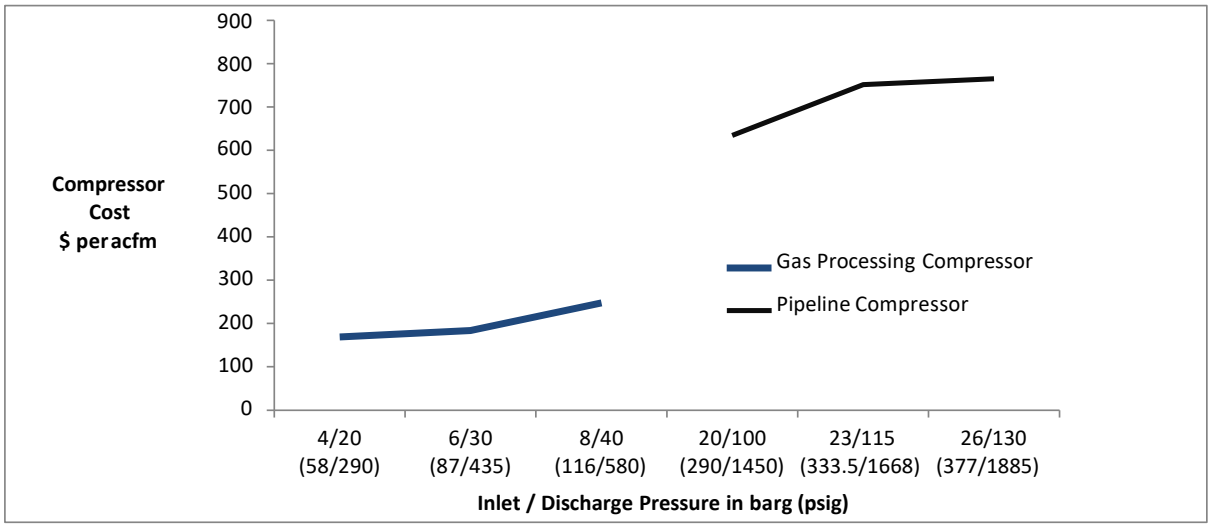
Figure 8: Centrifugal Gas Compressor – Flow Rate Impact on Price



The cost per unit of flow achieved (cost per acfm) increases as the cost and power of the units increase. The effect is exacerbated when considering the cost of the driver (typically a gas turbine

or electric motor). Therefore, careful engineering is required to avoid overspecifying the unit and thereby incurring excess cost (of the unit, the driver, and the packaging, including control systems and piping)..

Figure 9: Cost per Unit of Output – Centrifugal Gas Compressors



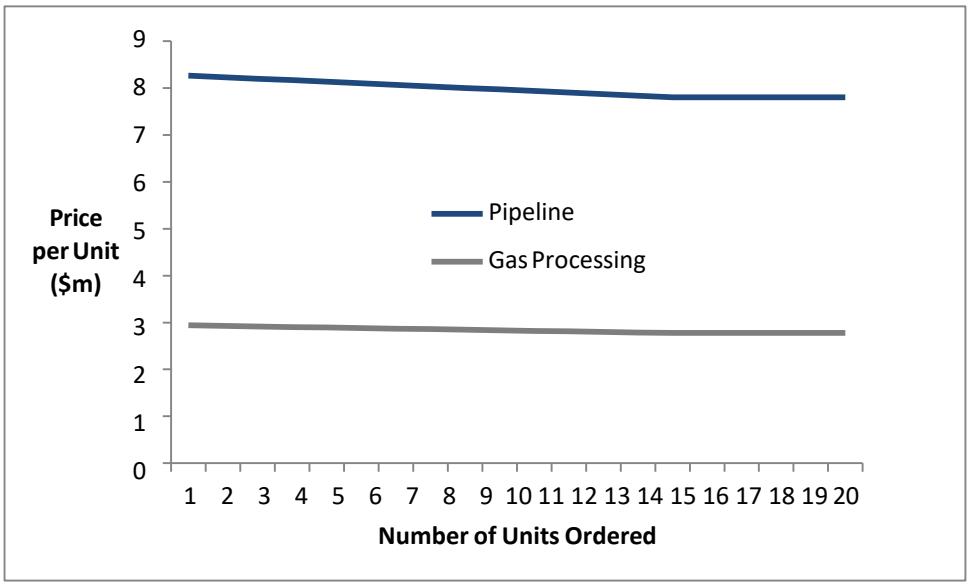
OEMs realize economies of scale for large orders of both Pipeline and Gas Processing compressors. Manufacturers suggest figures of up to 5-10% for orders more than 10 units. However, this includes bundling discounts (discounts for ordering the compressor and the driver together, or with ancillary equipment, systems and services). Separating these effects out, the economies of scale seem to settle at 2-6%. For example:

- GE sold 15 compressors to PetroChina (in 2011). The package of six gas turbine-driven compressor trains and nine electric motor–driven compressors sold for about $100m. Based on average prices for compressors, gas turbines, and electric motors, the bundle could be worth $145m at 2013 prices. Deducting 20% for country-specific price discounts would yield $116m. Assuming the difference is split between economies of scale and bundling discounts, the economies of scale would be 5.6% of the simple additive price.
- GE sold 13 turbocompressor trains of PGT25+G4 gas turbines and centrifugal compressors to PNG LNG (in 2010). Based on average prices, as above, the contract would have been worth $174m. After allowing for 15% regional price discount, there is still an 8.2% discount, which we may split between economies of scale and bundling, at 4.2% each.
- Dresser Rand sold 18 compressors to Petrobras (in 2010). Based on average prices for compressors, gas turbines, and electric motors, the bundle was worth $134m (at 2013 prices), but was contracted for $120m. After accounting for a 5% lower price due to Latin American competitive conditions, this left a 6% price discount, which could be assumed to be split between 3% for bundling and 3% for economies of scale.

- MAN Diesel & Turbo sold 11 compressors to Shenhua Ningxia Coal Industry Group Co., Ltd. (via Linde and Hangyang) in 2013. The calculated value of this contract is $213m, versus a published value of $163m. After allowing for 19% regional pricing differences and splitting the difference between economies of scale and 'bundling' savings, the economies of scale and bundling savings each appear to be about 3%.

Many contracts indicate smaller economies of scale, and in most cases economies of scale are simply reaped by the supplier rather than the customer. Below is a curve showing economies of scale capping at 5.6% at the 15th unit.

Figure 10: Economies of Scale for Centrifugal Gas Compressors



4.3.2 Should-Cost Analysis

As with any rotating equipment, the focus of cost management for Process Centrifugal Compressors should be on lifecycle cost, which first and foremost requires specifying the optimal equipment for the job. The potential savings from lifecycle cost management typically exceed the savings on the initial purchase cost.

Value Engineering is almost impossible since each unit is already customized. Furthermore, supply chain integration, in the form of collaborative logistical and inventory planning, is tiny compared to the equipment costs.

Assuming lifecycle cost drivers have been properly specified, procurement officers may pursue three high-leverage actions to reduce initial purchase cost by a maximum cumulative amount of 21%.

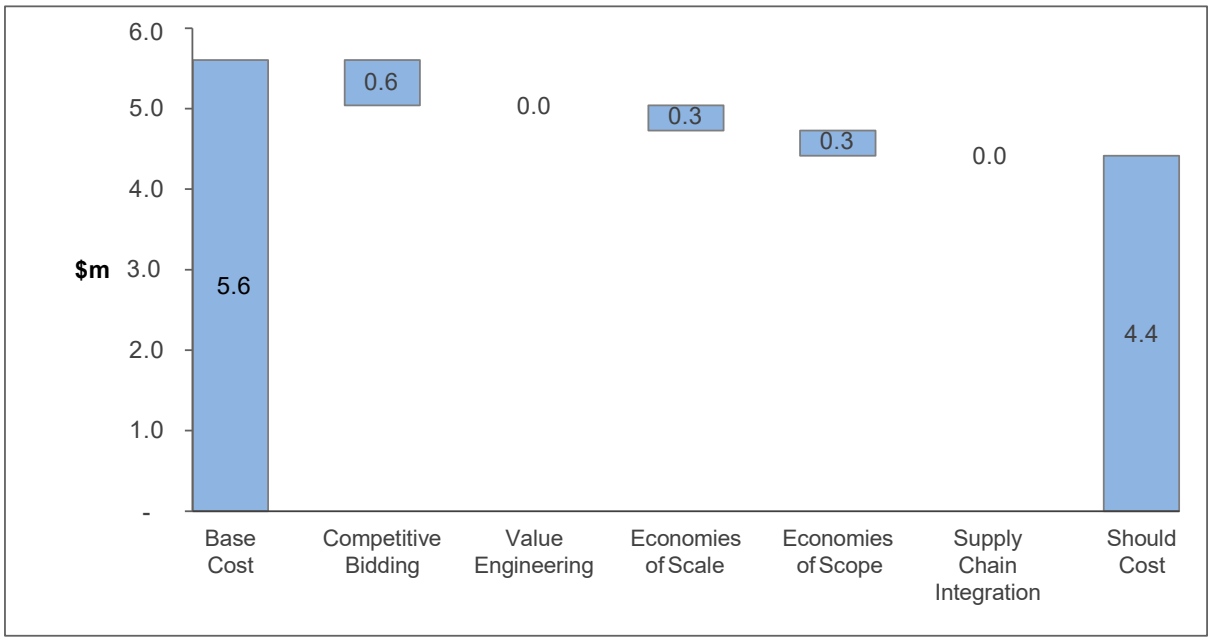
- Bundling with other products and ancillary services, including the total compressor train(s), to allow suppliers to realize economies of scope (to reduce their sales and overhead cost, and the risk of not selling the other equipment to other buyers during the same time window). This strategy is particularly effective because the suppliers themselves are focused on achieving

this benefit, so the interests of the buyers and suppliers are aligned. Some suppliers are highly motivated by achieving bundling synergies.

- Buying multiple units at once, to allow the suppliers to purchase common materials and to schedule engineering and production activities concurrently to benefit from repetition. The actual volume discount offered by suppliers will vary, depending on the supplier's shop load and whether or not there are common components.
- Competitive bidding, realized by structuring bids to ensure competitive alternatives, and also through initiating the bid and contracting process from an international procurement office (IPO) in a developing country such as China or Nigeria, to facilitate price leverage, since prices for equipment sold into China and Africa are demonstrably lower than Western prices. GE's deal with PetroChina, PNG LNG, and Petronas fell 4-12% below the regionally adjusted benchmark price levels. MAN Turbo's deal with Shenhua Ningxia Coal Industry Group fell 6% below the regionally adjusted benchmark price levels.

The graph below assumes that multinational customers may obtain half of the maximum regional price differential by conducting bids from these countries and leveraging local and regional competition as credible threats.

Figure 11: Should-Cost for Centrifugal Gas Compressors



4.4 Price Negotiation Strategies

1. Shop globally through International Procurement Offices in low-cost countries, to tap into the suppliers' propensity to offer price discounts to customers in less developed markets. Target MAN Turbo and GE with this strategy since they seem to price lower into developing markets in order to build market share.

2. Bundle the driver, packaging, and other components together to get economies of scope. This means structuring the bid package to ensure competitive alternatives even during the technical qualification, which could be long before the commercial evaluation. Target bundling savings especially at GE, which offers significantly better pricing for bundled solutions.
3. Order as many units together as possible to get economies of scale, and develop a well-reasoned case for helping the supplier achieve economies of scale and standardization of materials, components, and engineering activities.

5 Process Reciprocating

5.1 Market Overview

Table 7: Key Indicators for Process Reciprocating Compressors

(Total Change over Each Period)

Key Indicators	Q2 2013 – Q2 2015		Q2 2013 – Q2 2020	
Demand Growth	▲	9.2%	▲	43.7%
Demand ($m)	▲	1,039-1,135	▲	1,039-1,493
Capacity Utilization	▲	2.4%	▲	4.0%
Prices	▲	4.4%	▲	18.5%

1. Demand

Demand growth will accelerate from 4% annually in 2013 and 2014 to 5-6% per year through 2020, driven primarily by global projects to liquefy, transport, and regasify LNG, as well as shale gas developments in the US and Asia.

Demand for Process Reciprocating Compressors is driven primarily by upstream gas gathering and processing investments, midstream LNG spending, and downstream refinery and petrochemical projects that use the reciprocating units for hydrogen supply or process gas compression. Reciprocating units are also used in pipelines, primarily in applications with low or variable flow rates, but their use in pipelines is dwarfed by centrifugal compressors.

Global demand grew slightly less than 1% in 2013 Q1. Growth was fastest in Asia where a 2% increase in combined oil & gas and chemical industry capital spending drove a similar increase in compressor purchases. Demand grew 0.5% in EMEA, on Russian refinery investments and Middle Eastern gas field projects. In the Americas, low natural gas prices restrained investments, for growth of just 0.2% last quarter.

In the up and midstream markets, oil & gas producers built infrastructure to supply gas to markets where prices are high, notably China, Western Europe, and Japan where gas prices were $10-11, $12-13, and $16-17 per thousand cubic feet, respectively in Q1. Gas field developments and LNG projects, many of them in or off the coast of Australia, ordered compressors to meet this demand. For example:

- Abu Dhabi's Tubul gas field made progress payments on $10.8m worth of compressors from Ariel due for delivery in Q2.
- The Icthys LNG project in Australia ordered a total of nine compressors from MHI in March 2012, scheduled for delivery beginning in August 2013. Three of the units will be reciprocating compressors for boil-off gas, worth a total of just over $9m.

- Shell's Prelude FLNG project also ordered three reciprocating compressors on the same scale from MHI.
- Korean Gas Corporation (KOGAS) ordered two 3.75k hp reciprocating units worth a total of $6m for its Samcheok LNG terminal, currently under construction.

In contrast to Western Europe and Asia, US wellhead natural gas prices hovered around $3-4 per thousand cubic feet, restraining regional growth in upstream spending to approximately 0.2% in Q1. Nonetheless, continuing investments in shale gas production and processing infrastructure, as well as early payments for LNG facilities that will allow US gas producers to cater to foreign markets, drove some growth, including:

- Energy Transfer Partners began taking delivery of a total of 17 reciprocating units from Ariel, nine 5k hp units and eight rated at 1.75k hp. Final delivery of the equipment was completed in Q2, with a total compressor value of $39m.
- Williams Partners ordered three gas processing plants from Exterran to process 600m cfd of gas in the Marcellus Shale in 2012 Q3, including compressors worth a total of approximately $15m. The first of the units will be commissioned in 2013 Q4, and the remaining two in early 2014.
- Cheniere Energy's Sabine Pass LNG export terminal ordered five 1.5k hp reciprocating units for boil-off gas, collectively worth approximately $5.25m, from GE in 2012 Q4.

Ongoing FPSO orders from Petrobras also contributed to demand growth in the Americas, and will continue to do so for the rest of the year. GE won orders for four reciprocating compressors (as well as multiple, larger centrifugal units), for FPSOs destined for Petrobras' Santos Basin. MHI also won an order for two reciprocating units for an FPSO that will operate in the Tupi field, MHI is scheduled to deliver the compressors in 2013 Q3.

In the downstream market, petrochemical producers in Asia and the Middle East and European refiners, mostly in Russia, placed orders or made progress payments. These projects include:

- LG Chem made final payment for a 10.5k hp unit from Burckhardt in Q1, a $12m compressor for its new polyethylene plant in Daesan, Korea.
- Sipchem took delivery of a 25k hp unit from Burckhardt for its 200k tpy petrochemical plant in Jubail, Saudi Arabia.
- Shell made progress payments on a 9.4k hp compressor from Burckhardt, which will be installed at its Zeeland refinery upon delivery in 2013 Q3, to supply hydrogen for a hydrotreating unit.
- EPC firm Toyo engineering ordered three 20k hp reciprocating compressors from Howden Thomassen in Q1, for TAIF's Nizhnekamsk refinery's hydrocracker upgrade project.
- The Antipsky refinery ordered two smaller units from Howden Thomassen (2.4k hp each) to supply hydrogen for a hydrodesulfurization unit.

Demand growth will accelerate slightly in 2013 Q2, for full-year growth of just over 4%. Asia will continue to drive most of the growth, at an annual rate of 7.5%. Chinese demand for natural gas will rise approximately 10% this year, as the nation's government emphasizes gas-fired power generation over coal due to lower emission rates. In Japan, natural gas-driven power generation is replacing nuclear plants shut down due to safety concerns. In EMEA, high European natural gas prices will remain in effect due to Russia's near monopoly on gas imports, but negligible electricity demand growth in Western Europe and delays in shale gas drilling programs in Poland and the Czech Republic will slow regional demand growth to 2% for the year.

In the Americas, low US natural gas prices ($4 per thousand cubic feet), will restrain demand growth to 1% for the year. Petrobras' FPSO investments will contribute to this growth, along with LNG export facilities in the US. US natural gas production rates have plateaued at 2012 levels, restricting new investments in upstream natural gas production and processing investments. As a result, the key driver of North American LNG growth will be the Sabine Pass LNG export facility currently under construction, and the Quintana Island facility that recently received government approval.

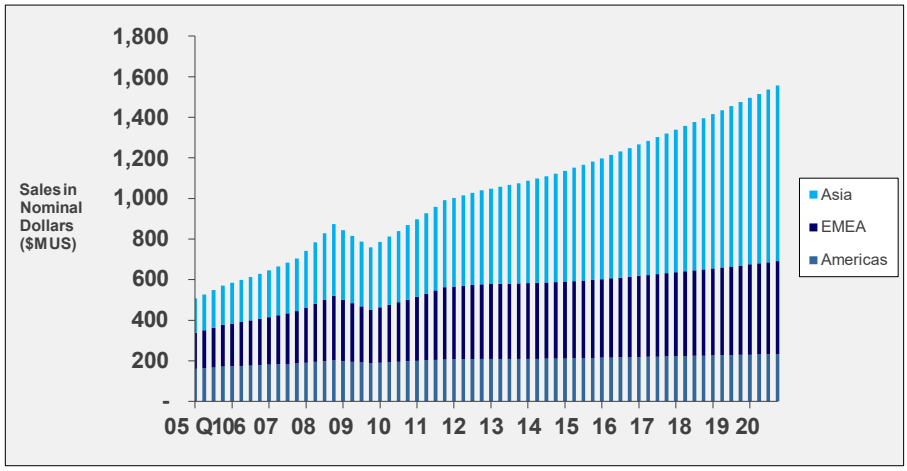
Global demand growth will hold steady at just over 4% in 2014, before accelerating to 5-6% annually through 2020, driven largely by LNG projects and shale gas developments in the US and Asia.

In addition to the abovementioned LNG investments, Shell is building an LNG receiving terminal at its Zeeland refinery in the Netherlands, due for commissioning in 2016. China's Quangdong Dapeng is also expanding its receiving capacity. In the US, 19 LNG export terminal projects have applied for approval from the federal government, with planned commissioning dates ranging from 2017 to 2021. Each approved project is likely to order $10-20m in reciprocating compressor units, which will contribute strongly to increases in global demand.

Shale gas projects will continue to drive global growth as well. In the US, developments in the Barnett, Bakken, Marcellus, Utica, Niobrara, and Eagle Ford shales have been temporarily deprioritized as natural gas prices feel from highs of $12 in the US to lows of $2-3 per thousand cubic feet (and they have only rebounded to $4 as of June). However, as the LNG export facilities currently under construction, and at least some of the 19 other such facilities currently in the approval process, begin exporting natural gas, they will put upward pressure on US natural gas prices, at least to the $5-6 range, stimulating further upstream investments. In China, Sinopec and PetroChina are actively pursuing shale gas drilling programs that will add order volume throughout the forecast period. Regulatory issues and disappointing drilling results in Poland and the Czech Republic have left Chevron as the only major shale gas developer in Eastern Europe as of 2013. This near-monopoly for Chevron, combined with regional gas prices of $12 per thousand cubic feet, virtually guarantee that the firm will continue its drilling program in the region, adding further shale gas volume to the global total. The Ukraine, which has an estimated 1.5 trillion cubic meters of gas

reserves in the Olesska shale alone, is also negotiating shale gas development agreements with Chevron, Shell, and ExxonMobil, and drilling there could begin as early as 2014 Q1.

Figure 12: Demand for Process Reciprocating Compressors



2. Supply (Capacity)

IHI, Kobelco, GE, Exterran, and Dresser Rand added capacity in 2011 and 2012. Cameron and Atlas Copco are adding more in 2013, but demand growth has outpaced capacity increases. Utilization rates rose 1% in 2012, to 88%, and will reach 93% in 2018 as capacity additions continue to lag demand growth.

The top Process Reciprocating Compressor manufacturers are:

- Burckhardt (Germany)
- MHI (Japan)
- Dresser-Rand (US)
- Ariel (US)
- Cameron (US, France)
- Exterran (US)
- Neumann & Esser (Germany)
- GE (US)
- IHI (Japan)
- Howden Thomassen (Netherlands/UK)

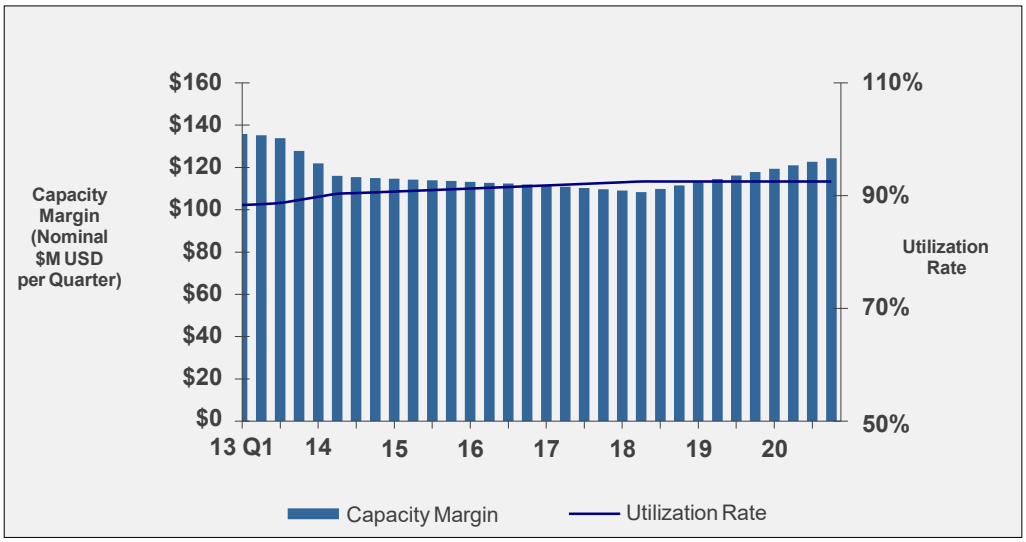
Major capacity additions by Japanese manufacturers IHI and Kobelco in 2011 were more than absorbed by demand growth of 10% in 2011.

- Kobelco added capacity in China and the US in 2011, but the margin created by these facilities has already been absorbed by new orders. The firm invested $20m to double US capacity for reciprocating and rotary screw compressors from $50m to $100m in equipment value, opening a new plant near Los Angeles, California in April 2011. The new capacity

was more than 90% utilized as soon as it opened, however, as Kobelco had been importing units from Japan to keep up with orders from rapidly expanding US shale plays. Kobelco opened a new manufacturing line in Shanghai, China in July 2011, a $12m expansion that increased the plant's capacity by 60%. The Beijing plant makes finished compressors for the Chinese market, as well as components used in Kobelco's other plants in Japan and the US.

- IHI commissioned a $3.6m plant in Jiangsu, China in 2011 Q3, but rapid order growth in the meantime has nearly fully occupied the new factory.

Figure 13: Capacity Margin - Process Reciprocating Compressors



Exterran, Dresser-Rand, and GE added more capacity in 2012, in the US and Latin America, but the additions failed to keep up with demand growth. Industry utilization rates rose to from 87% to 88%, as global demand grew almost 7%, outpacing these and other minor capacity additions.

- Exterran opened a new 65k square foot factory in Youngstown, Ohio, in 2012 Q4. The plant will primarily support the firm's customers in the Marcellus and Utica shale plays, both manufacturing compressors and fabricating packages and processing facility modules.
- Dresser-Rand opened a $25m machining and assembly facility in Brazil, also in 2012 Q4. The plant will primarily package compressor units, both reciprocating and centrifugal, made in the US or France, but it does have the ability to conduct final machining on critical parts.
- GE hired 115 workers to support compressor and driver production at its plant in Wisconsin, US, in 2012 Q3. The move supports GE orders for LNG plants and FPSOs.

Table 8: Reported or Estimated Capacity Utilization Rates at Selected Process Reciprocating Compressor Suppliers

Company	Country	Current Level	12-Month Forecast
Burckhardt	Germany	100%	100%
Cameron	US	100%	90%
Cameron	China	75%	80%
IHI	Japan	90%	90-95%
Neumann & Esser	Germany	100%	100%
Ariel	US	85-90%	90%
GE	Italy	85%	85%
Dresser-Rand	US (Painted Post)	85-90%	90%
Dresser-Rand	France (Le Havre)	90%	90%
Dresser-Rand	India (Ahmedabad)	80-85%	85%
Mitsubishi	Japan	95%	95%

The increase in capacity utilization drove lead times up slightly in 2012. Lead times for the smaller reference unit (4.5k hp) averaged 20-28 weeks as of 2013 Q1, depending on the manufacturer, while lead times for the larger reference unit (9k hp), averaged 42-54 weeks.

- Neumann & Esser pointed to average lead time increases of one month for units rated at driver horsepower of 3k hp or greater.
- Burckhardt, which took orders for several 9-12k hp units last year, listed lead time increases of six weeks for units in this range, compared to only 1-2 week increases for units rated at less than 5k hp.
- Ariel's lead time rose by two weeks on average, lower than for most manufacturers due to its modular design approach, and a high percentage of repeat orders (for units similar to ones already shipped) from US shale gas developers.

Atlas Copco and Cameron are both adding capacity this year. Atlas Copco, a small player in the Process Reciprocating segment despite its dominant position in the market for Air Compressors, opened a 60k square foot plant in Pune, India, in March. The factory will make parts for both air and process compressors, contributing lower-cost parts for process compressor assembly plants in China, France, and the US. Cameron is increasing compressor manufacturing capacity in China. The new plant, near Shanghai, will open in Q3 and reduce Cameron's overall reciprocating compressor utilization rate from 100% to 90%.

However, the above capacity increases will be small compared to 2011 and 2012 and industry utilization rates will rise another 1% in 2013, to 89%. Manufacturers are reluctant to overbuild capacity, as the boom-bust cycles of the oil & gas industry can turn too little capacity into too much in as little as a year. In 2008, the industry was nearly fully utilized, 95% on average. This rate plummeted to less than 80% in 2009 as buyers canceled or postponed orders due to the global recession and falling oil & gas prices. As a result, manufacturers are willing to let backlog build, giving them some security against another market correction. To some extent, this attitude depends on a similar situation at most competitors. All of the major manufacturers are at least 85% utilized, which prevents suppliers from gaining significant lead time advantage over one another.

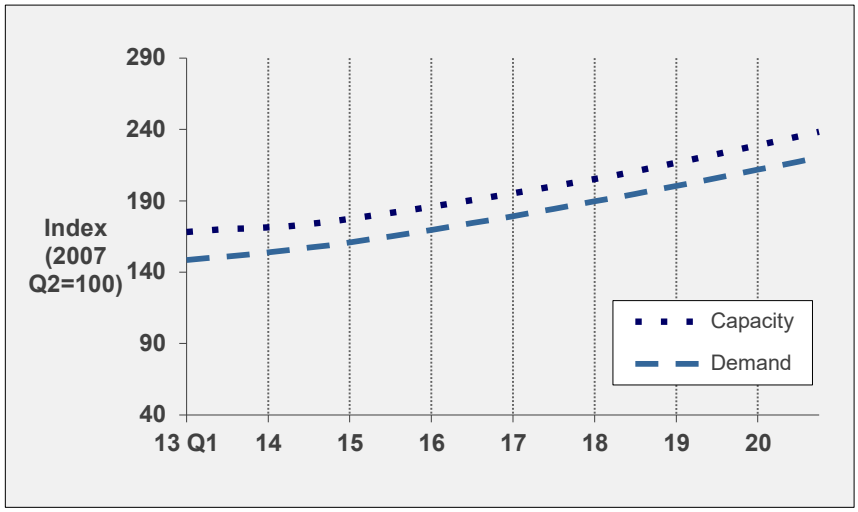
- Buckhardt and Neumann & Esser are 100% utilized, on orders predominantly from refinery and petrochemical plants and upstream gas gathering and processing respectively. Both manufacturers manufacturer compressors in Germany, then package them at local facilities in major markets such as the US, Middle East (Dubai), and China.
- Mitsubishi recently booked multiple LNG and FPSO orders, pushing its utilization rate up from 90% last year to 95% as of 2013 Q2. The firm manufactures compressors in Japan and the US.
- Ariel is only 85% utilized. The firm nearly doubled capacity (in Mount Vernon, Ohio, US) in 2008 in response to a major increase in backlog, and did not reduce capacity during the downturn, giving it one of the lowest utilization rates in the industry today.
- GE is 85% utilized at its compressor plant in Massa, Italy. The same plant makes multiple types of compressors and pumps, as well as turbine components, allowing GE to maintain roughly this utilization rate by flexing machinery and workers between functions and production lines.
- Dresser-Rand's utilization rate varies substantially by location. It is 88% utilized at its US plant in Painted Post, US, where it recently hired workers to cope with an increase in orders. Its factory in Le Havre, France, is 90% utilized because it has not added machines or head count there for several years due to the stagnant European economy. Its plant in Ahmedabad, India, where it built plenty of capacity in 2008 because of the low capital cost per foot of roofline, is only 80% utilized. This plant mostly makes components for assembly in other facilities, though, and as such does not give the firm a noticeable lead time advantage.

By region, utilization rates are slightly lower in China and India than for the rest of the world (80% vs 90% in other regions for Dresser Rand, and 85% vs 90-100% for Kobelco). This is because manufacturers have expanded there more recently, and because the low regional labor costs give firm less incentive to maximize utilization rates at the expense of flexibility.

Industry capacity margin is $138m in 2013 Q2, enough for 20-30 large reciprocating units, depending on the application. This capacity could be absorbed by as few as 3-5 major orders, representing a substantial risk that lead times will rise quickly, and that a buyer's bargaining

leverage with a given supplier could evaporate without warning. For example, Dresser-Rand offered an oil & gas industry buyer a 12 month lead time on a major order in in 2007, but the buyer waited too long to give notice-to-proceed, and another order was queued for Dresser-Rand's last available production slot. This added four months to the unit lead time.

Figure 14: Demand vs. Capacity - Process Reciprocating Compressors



Due to manufacturers' cautious approach to capacity mentioned above, industry utilization rates will rise steadily to 93% in 2018, near peak levels in 2008. Industry capacity utilization will top 90% in Q3 2014, giving suppliers additional pricing leverage. At this level, lead times will vary highly by manufacturer, depending on which ones are completely utilized. At full utilization levels, lead times have historically peaked at two years for 9-10k hp units, and one year for units rated at 4.5-5k hp. As with previous capacity crunches, suppliers that have capacity available (and quote lead times substantially less than their competitors) will be more flexible on pricing.

5.1.3 New contracts

ExxonMobil, Saudi Aramco, ConocoPhillips, and Repsol signed partnership agreements with Dresser-Rand to ensure capacity availability and to bring down unit costs. Ariel and Exterran dominated upstream orders in 2012 and early 2013, while GE and MHI booked major deals for LNG and FPSO projects.

The cyclical capacity crunches endemic to the process compressor industry make capacity reservation arrangements and even partnership agreements attractive mechanisms for buyers with large, recurring requirements to secure access to capacity. Partnership agreements also promise cost synergies from working closely with a preferred supplier, although many buyers fail to achieve all of the expected cost reductions.

Dresser-Rand is the strongest proponent of this approach of the major suppliers, boasting partnership agreements with Saudi Aramco, ExxonMobil, ConocoPhillips, and Repsol. Among the benefits that buyers and suppliers typically hope to share are faster project lifecycles, the

elimination of an EPC as an intermediary, and lower unit cost for machinery by eliminating redundant engineering and supplier manufacturing configurations. According to Dresser-Rand, buyers can typically expect 2-5% minimum cost reductions under these agreements, and as much as 10%. The engineering labor savings alone can amount to as much as $300k per machine for a framework agreement covering at least 10 units.

Oil & gas companies including Shell, ExxonMobil, and Motiva caution that these benefits are difficult to achieve in practice, however, and that buyers must institute careful controls. In many instances, price benefits disappear after the supplier feels comfortable that the buyer will not request proposals from other manufacturers. As a result, buyer experiences suggest that an end-user should not commit all of its compressor volume to one manufacturer, and that the people responsible for administering the agreements must be rotated out periodically, to avoid building comfortable relationships with supplier representatives.

Another major dimension of many contracts is the aftermarket service agreement, which can be bundled with the equipment purchase or awarded separately. GE is the clear leader in OEM service agreements, recently bagging approximately $1b in expected aftermarket revenue to maintain gas compressors and drives for the Gorgon project (a 22-year agreement), and the Soyo LNG project in Angola. Howden Thomassen signed a five-year agreement with Dutch gas producer NAM in March, with a five-year extension clause, to maintain its own compressors in NAM's network. OEM service providers typically argue that they are the best choice to maintain their own equipment, and that they can deliver higher uptime than third party service companies. This argument is not completely proven in practice, however, and third party service agreements generally cost about half as much as a service plan from the OEM.

MHI and GE won the bulk of the recent orders in the LNG market. Most of these orders were for boil-off gas compressors, bundled with centrifugal units.

- Shell's Prelude FLNG project ordered compressors from MHI in January 2012, including three BOG units rated at 4.5k hp, worth a total of $10.5m.
- Inpex's Icthys project (through EPC consortium JKC) ordered $9m in reciprocating compressors from MHI in March 2012, three units rated for 3.5k hp each.
- Shell signed an agreement with MHI in May 2011 covering compressors for an LNG receiving terminal in the Netherlands in May 2011. The agreement includes significant design engineering work, and final delivery of the compressors will not take place until 2016. The final number of reciprocating compressors has not been determined, but the final value is likely to be between $5-7m.
- GE sold six motor-driven reciprocating units to Qatargas in Q2 2012, to collect gas that is currently being flared as it reaches its vapor point at the Ras Laffan LNG plant.
- GE also got the order for the four approved liquefaction trains at Cheniere Energy's Sabine pass in Q4 2012. The reciprocating compressors under this order consist of five units rated

for 1.5k hp each. Cheniere may order compressors for up to two more trains at the same facility, with the final investment decision scheduled for this year.

GE and MHI also won the major orders for compressors on three FPSOs under construction for Petrobras. GE will manufacture four of the six reciprocating compressors, and MHI will make the remaining two. The GE units, bundled with centrifugal compressors and gas turbines, are a mix of units rated for 4k and 3.5k hp, worth a total of $12m. NHI's two 4k hp units are worth $7m.

In the upstream market, Ariel and Exterran won major orders for gas gathering and processing, while Burckhardt and GE sold units for gas reinjection into aging fields.

- Ariel sold a 5k hp unit to MarkWest Energy Partners for gas gathering at its Majorsville processing facility in Dallas, West Virginia in December 2012.
- Energy Transfer Technologies installed 17 reciprocating compressors from Ariel in April 2013 at its Jackson County processing facility in Texas. Nine of the compressors are rated at 5k hp, and eight at 1,750 hp.
- Ariel sold compressors worth approximately $11m to EPC firm Enerflex, delivered in 2013 Q2, for installation in Oman's Abu Tubul gas development. The units will 90m cfd of natural gas when the plant is commissioned in Q3.
- Packaging firm Valerus sold two 5k hp Ariel units to Petrofac in Q2 2013, for installation at the Magallanes and Santuario fields, for Pemex.
- Williams Partners ordered three gas processing plants from Exterran to process 600m cfd of gas in the Marcellus Shale in 2012 Q3. The largest single order for Exterran from this region to date, it will bring Exterran's total installed base in the Marcellus and Utica Shales to more than 2b cfd in processing capacity. The first of the units will be commissioned in Q4 2013, and the remaining two in early 2014.
- Petrobras awarded Exterran a $5m contract for another gas processing plant, this one with capacity for 200m cfm, for a project in Itau, Bolivia in January 2012. Under the contract, Exterran will deliver a finished plant, through startup and commissioning.
- Boardwalk Pipeline Partners contracted Exterran to provide a 150m cfm gas processing plant in the Eagle Ford Shale, in Texas. The $3.7m deal was signed in February 2012, and the plant was completed in March 2013.
- SemGas ordered a 60m CFM plant from Exterran in 2011 Q4, for installation in Oklahoma's Mississippi shale play.
- TNK-BP ordered three reciprocating compressors worth nearly $11m from GE, to capture gas that is currently being flared at the Verkhnechonsk field in Siberia and inject it into a cavern for storage and future use. Placed in 2012 Q4, the order is comprised of three reciprocating units and a gas turbine to power the electric motors that drive them.
- Burckhardt booked a $3.7m order from Petroleum Development Oman (PDO) for an API 618, 500 bar compressor to reinject gas at the oil producer's Al-Noor production station.

The unit, ordered in Q3 2011, was delivered in Q3 2012. Worley Parsons was the EPC for the project.

Burckhardt and Howden Thomassen dominated the list of new contracts in the downstream sector.

- Burckhardt booked an order from Shell in July 2012 for a 9.4k hp unit for hydrogen make-up at a diesel hydrotreating unit at the Zeeland Refinery.
- Burckhardt also won orders from Lanxess in Germany (August 2012) for a $11m unit for a petrochemical plant, LG Chem in Korea (December 2011) for a $12m compressor, and Sinopec Wuhan Petrochemical (May 2011) for six units worth $20m.
- Howden Thomassen received an order for three hydrogen make-up compressors from Toyo Engineering, for the TAIF-NK Nizhnekamsk refinery hydrocracker upgrade project. The 20k hp C-85.6 models are scheduled for delivery by the end of 2013.
- Howden also won an order for two smaller refinery units in Russia in 2013 Q1, 2.4k hp C-35.2 units for the 7.5m tpy Antipinsky Refinery's hydrodesulfurization unit upgrade.
- Another Russian refiner ordered three units from Howden for hydrogen make-up and recycle for a hydrocracker upgrade in 2013 Q3. The main make-up unit will be rated at 23k hp, and it will be the largest of its kind when it is installed in 2014. The two recycling units are smaller, at 2.5-3.5k hp.

Table 9: Summary of New Contracts and Estimated Values for Process Reciprocating Compressors

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Toyo Eng.	Japan	Howden	3 units, 14.9k hp	$ 41	$ 13.6
Energy Transfer	US	Ariel	9 5k hp units, 7 1.75k hp units	$ 40	$ 3.1
International Polymers	Saudi Arabia	Burckhardt	1 unit, 24.8k hp	$ 23	$ 22.9
SINOPEC Wuhan	China	Burckhardt	6 units, 3k hp	$ 20	$ 3.3
Pemex	Mexico	Exterran	44 units, 500 hp	$ 16	$ 0.4
Williams Partners	US	Exterran	38 units, 500 hp	$ 15	$ 0.4
LG Chem	Korea	Burckhardt	1 unit, 10.5k hp	$ 12	$ 12
Braskem Idesa	Mexico	MCO	2 units, 4.5k hp	$ 12	$ 5.9
TNK-BP	Russia	GE	3 units, 4.5k hp	$ 11	$ 3.6
OOCEP (Oman Oil Company Exploration and Production)	Oman	Ariel	3 units, 4k hp	$ 11	$ 3.6
Lanxess	Germany	Burckhardt	1 unit, 9.7k hp	$ 11	$ 10.7
Technip	Australia	MCO	3 units, 4k hp	$ 10.5	$ 3.5
MAN	Switzerland	Burckhardt	2 units, 5.5k hp	$ 10.5	$ 5.2
Zeeland Refinery	Netherlands	Burckhardt	1 unit, 9.4k hp	$ 10	$ 10.3
Petrofac	Mexico	Ariel Corp	2 units, 5k hp	$ 9	$ 4.6
JKC Ichthys LNG	Australia	MCO	3 units, 3.5k hp	$ 9	$ 3.0
TNK-BP	Russia	GE	3 uits, 4.5k hp	$ 9	$ 2.8
Guangdong Dapeng LNG	China	IHI	3 units, 3.5k hp	$ 7	$ 2.3
Petrobras	Brazil	MCO	2 units, 4k hp	$ 7	$ 3.2
Petrobras	Brazil	GE	2 units, 4k hp	$ 6	$ 3.2
Fluor Transworld	Qatar	GE	6 units, 1.5k hp	$ 6	$ 1.1
KOGAS	South Korea	Howden	2 units, 3.75k hp	$ 6	$ 3.0

Buyer	Country of Installation	Supplier	Product	Estimated Value ($m)	Estimated Cost/Unit ($m)
Petrobras	Brazil	GE	2 units. 3.5k hp	$ 6	$ 2.8
Cheniere Energy	US	GE	5 units, 1.5k hp	$ 5	$ 1.1
Petrobras	Bolivia	Exterran	12 units, 500 hp	$ 5	$ 0.4
MarkWest Energy	USA	Ariel Corp	1 unit, 5k hp	$ 5	$ 4.6
Antipinsky Ref	Russia	Howden	2 units, 2.4k hp	$ 4	$ 1.9
Boardwalk Pipeline	US	Exterran	9 units, 500 hp	$ 4	$ 0.4
Worley Parsons	Oman	Burckhardt	1 unit, 4k hp	$ 4	$ 3.7
SemGroup	US	Exterran	3 units, 500 hp	$ 1	$ 0.5

5.2 Analysis

5.2.1 Costs

Global cost levels will rise 2% in 2013, and a total of 16% from 2013 Q2 to 2020 Q2, driven by increasing Asian labor costs and global price inflation for major components such as casings, cylinder blocks, and crankshafts.

Labor and benefits make up 39% of the cost structure for Process Reciprocating compressors, the largest single cost category. Costs for production labor, such as machinists, welders, and assembly workers, account for 20 percentage points. Engineering and management salaries make up another 13%. This is slightly lower than for Process Centrifugal Compressors due to the lower percentage of engineering labor required to make these more standardized units. Benefits such as training, bonuses, pension plans, and health care round out the total for labor, at approximately 6% of the overall cost.

Machinery and parts is the next largest cost category for reciprocating compressors, at 33% of the total. Manufacturers typically buy many semi-finished components and machine them to final specification before assembly, rather than making them in-house. The largest single component in a reciprocating compressor is the crankshaft casing (block), followed by the cylinder casings and distance pieces. Compressor manufacturers buy these components from a foundry and then machine them, specifically the cylinder bores and the mounting points for all three components. After the major castings, the forged crankshaft is the biggest, most expensive piece for the compressor, followed by piston rods, connecting rods, and crossheads. This category also includes capital costs for the CNC, cutting, grinding, milling, and lifting machines used to finish and assemble the compressors.

Compressor manufacturers typically have little leverage over costs for the major components above (casings, cylinder housings, and crankshafts). The same forges and foundries supply most of the major compressor makers, and they change prices in near-unison. The typical model for these component suppliers is to offer firm pricing for 30-45 days, and then change prices by similar increments. They have little incentive to try and undercut their competitors because they nearly always have a backlog, and keeping prices low would do little more than build more backlog of low-margin orders (which would extend lead time). Even customers looking for a price break would eventually go to another, higher-priced, supplier for lower lead times.

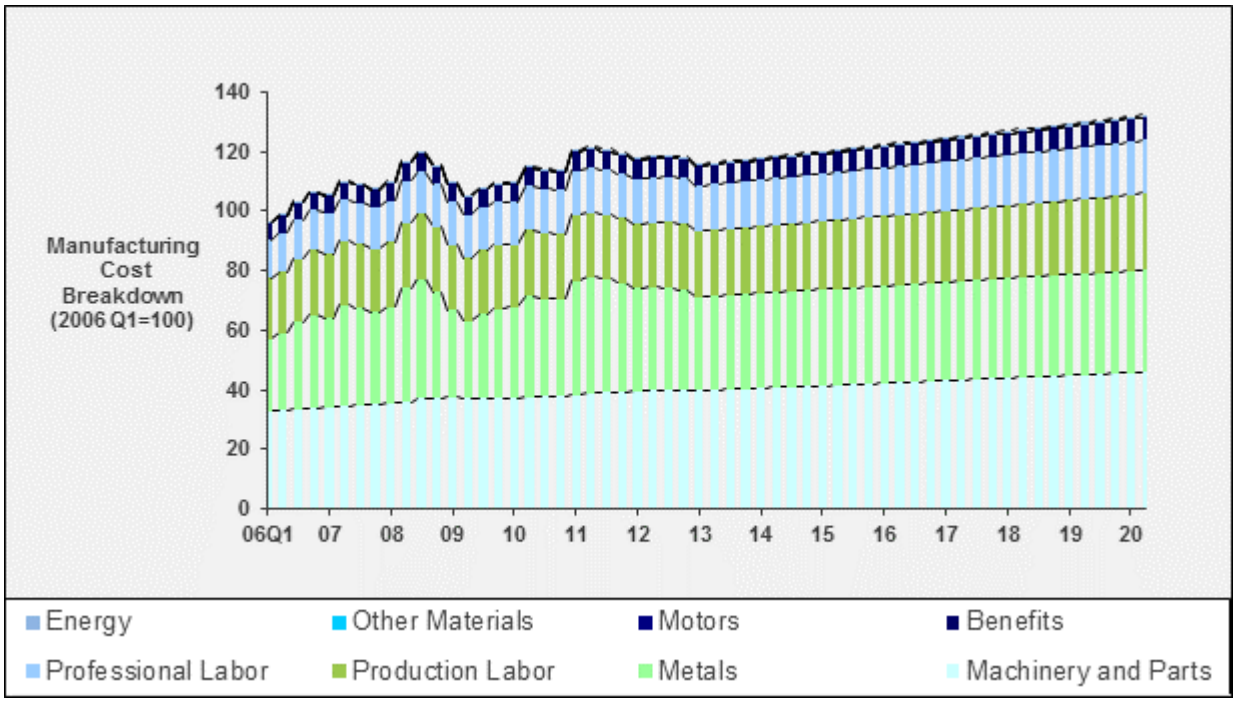
Metals make up most of the remaining costs for compressor manufacturers, 24% of the overall cost structure. Metals commonly used in reciprocating compressors range from gray iron, ductile iron, carbon steel, alloy steel, and stainless steel, and even aluminum on occasion for pistons and piston covers.

Overall costs rose 0.5% in Q1, driven up by increasing costs for labor and transportation in Asia. In major Asian manufacturing centers such as Beijing, Tianjin, and Shanghai, urban areas with access to transportation infrastructure, costs of living are rising rapidly. Combined with cost of living increases, aggressive hiring in the region on the part of multiple manufacturing sectors that require skilled workers is driving Asian labor costs up more than twice as fast as in other regions. In Q1, professional labor costs rose 2% in Asia, compared to less than 0.5% in EMEA and the Americas. Asian production labor costs rose about 1%, contributing to overall Asian cost growth of almost 1% for the quarter.

Transportation costs also rose rapidly in Asia last quarter, as the Chinese government allowed nearly a 20% increase in natural gas prices and a 10% increase in retail fuel prices (both of which are regulated in China). This pushed up costs for raw materials and semi-finished components that potentially require shipment multiple times before they reach the plant where they are assembled.

In contrast with Asia, costs rose only 0.2-0.3% in the Americas and EMEA. In North America and Western Europe, the largest economies in these regions, labor costs stagnated due to high unemployment slow overall economic activity. Materials costs likewise rose only 0.25-0.5%, leading to slow overall cost growth.

Figure 15: Cost Structure for Process Reciprocating Compressors



Note: Prices are ex-works.

Global manufacturing cost levels will rise another 0.5% in Q2, driven by the factors described above, as well as a slight increase in labor costs in North America. The pace of hiring in the US has picked up in Q2, and engineering salary levels will grow 0.7% this quarter.

Overall cost levels will rise just over 2% in 2013, and another 2% in 2014. Asian labor costs will continue to drive much of the growth, rising 4-5% annually, twice as fast as labor costs in the other two regions. Slower increases in metals costs, 0.5-1% annually in 2013 and 2014 due to oversupply and sluggish demand growth, will offset labor cost growth.

Global manufacturing costs for Reciprocating Compressors will increase 2-2.5% annually, for a total of 16.5% from 2013 Q2 to 2020 Q2, driven by costs for major cast components in the Americas and EMEA and continued labor cost inflation in Asia. Global costs for raw cast components will rise 2-3% annually, driven up by 2% annual cost increases for carbon steel, the most common material used in these components, as well as upward pricing pressure from demand growth. Global energy costs will also rise 1.5-2% annually, contributing to the increase in overall costs. Asian cost levels will rise fastest, a total of 17.5%, as regional labor costs rise 4-6% annually, and materials and component costs increase at similar rates as in the rest of the world. Labor cost growth will remain more subdued at 2% annually in the Americas and 1% in EMEA, leaving component cost growth to drive regional cost levels up 13% and 11%, respectively.

2. Profit Margins

Average operating margins for Reciprocating Compressor makers are 10.5%. Japanese firms take much lower operating margins, 4.5%, to offset higher manufacturing costs. Hypercompressor makers Burckhardt and Howden, average 18% operating margin.

Manufacturers of Reciprocating Compressors made operating margins of 10.5% on average in 2012, and net margins of 7%. These figures are deceptively low for most firms though, as the average includes multiple outliers, namely a number of Japanese manufacturers, and Exterran.

Japanese manufacturers MHI, IHI, Kobelco, and Hitachi accept lower margins than their competitors to offset their higher cost of manufacturing (discussed in the Prices section) and still win bids against competitors with a lower cost base.

- IHI had the highest operating margin of the Japanese suppliers in 2012, at 6.3% operating margin (1.9% net margin). The firm credited its strong presence in the LNG BOG compressor market with the success. With Japan's nuclear power generation capacity idled, LNG imports have made up much of the shortfall, driving new orders for compressors at receiving terminals. Terminals including Senboku, Himeji, and Kagoshima took delivery of compressors from IHI in 2012, helping drive the firm's comparative profitability.
- Hitachi's Industrial Systems division made the highest net margin last year, at 3.5%, with operating margin of 4.3%.
- MHI's compressor-manufacturing subsidiary, MCO, posted operating margin of only 4% in 2012, and net margin of 0.87%. This is the second-lowest of any of the major Japanese suppliers, although partly due to the timing of billing cycles for projects including Icthys and the FPSO Petrobras ordered for its Tupi offshore development. Adjusting for this book-to-bill offset, the relevant ratios are 6% operating margin and 1.75% net margin for the business unit.
- Kobelco's Machinery business unit actually booked a net loss of 0.8% in 2012, and operating margin of just 3%, but the loss was mostly due to underbidding on construction equipment. For compressors, the relevant operating margin is 5%, and all of its compressor orders were profitable last year, according to a source within the company.

Exterran Holdings suffered a net loss in 2012, but the loss was largely due to its full acquisition of Exterran Partners, a subsidiary that shared ownership with an investment consortium as a holdover from the merger of Hannover and Universal (the predecessors of Exterran's compressor manufacturing arm). Its operating margin was 6.3% for the year, still lower than many competitors because Exterran focuses on smaller, low-margin units (its highest-selling compressor unit is rated at 500 hp).

Excluding the above outliers, average operating margin for the rest of the reciprocating compressor manufacturers was 14.8% (in rank order).

- Burckhardt: 19.7%

- Howden Thomassen: 16.7%
- GE: 12.6%
- Cameron: 12.5%
- Dresser-Rand: 12.3%
- Siemens: 6.6%

Manufacturers with dominant market share in specific segments make higher margins than their direct competitors. For example, IHI, which has a 60% share in the LNG BOG compressor market, has the highest margins of any Japanese reciprocating compressor manufacturer. Burckhardt and Howden Thomassen, the dominant suppliers of hypercompressors (units for petrochemical processes that require pressures up to 7k psi) made operating margins of 19.7% and 16.7%, respectively, in 2012. Neumann & Esser poses a competitive threat to these firms, as it began making hypercompressors in 2011, but its market share is still small.

Suppliers' individual capacity utilization at a given time, based primarily on order volume and its utilization rate, also impacts the margin that they will accept at any given point in time. This is more the case for Process Reciprocating Compressors than for most equipment markets due to the low number of units and high value of the equipment typical in this industry. When manufacturers are busy, they give less away in negotiations. Neumann & Esser, for example, admitted to giving up 5-8 percentage points of operating margin on compressor projects in 2009, when orders were slow and its utilization rate was 75-80%. In contrast, its operating margin was 15-16% in 2007 and early 2008. It also trades margin for volume. "Only one-off buyers pay list price," said one company executive, and operating margin for individual projects can fall as low as 3-5%, depending on the customer and its own utilization rate.

Due to the above impact of utilization rates on prices, suppliers will gain pricing leverage as utilization rates increase from 88% in 2013 Q1 to 93% in 2018. This is likely to add 1-2 percentage points to cost growth by 2020 Q2, or an average 10-20% increase in operating margins.

3. Prices

Prices will rise 2.5% this year on rising costs for labor in China and India, where suppliers make or source many components. Increasing capacity utilization will allow suppliers to raise prices slightly faster than costs increase, for price growth of 18.5% by 2020 Q2.

At benchmark cost levels based on US assembly, units for gas field compression would cost $3.3m and units for refinery hydrogen circulation and product compression would cost $6.5m.

The reference units for Process Reciprocating Compressors (API 618) are:

- Gas field compression:
  - 4,500 hp
  - 20 bar max discharge pressure
  - 18k cfm inlet flow rate

- Refinery hydrogen circulation, product compression:
    - Double-acting
    - 9,000 hp
    - 150 bar max discharge pressure
    - 21k cfm inlet flow rate

Prices increased 0.7% in 2013 Q1, slightly faster than cost increases of 0.5% (see Cost section above) due to rising capacity utilization and strong demand growth. Total price growth for 2013 will amount to 2.5%, again slightly higher than the underlying cost growth as manufacturers reduce discounts off of "list" prices because they feel less pressure to win orders.

Cameron expects that price increases in the range of 2-5%, depending on the product line. Prices paid for larger units will rise faster, according to Cameron, as its production bays for units with horsepower from 7-9k hp are more heavily backlogged than the manufacturing cells for smaller units.

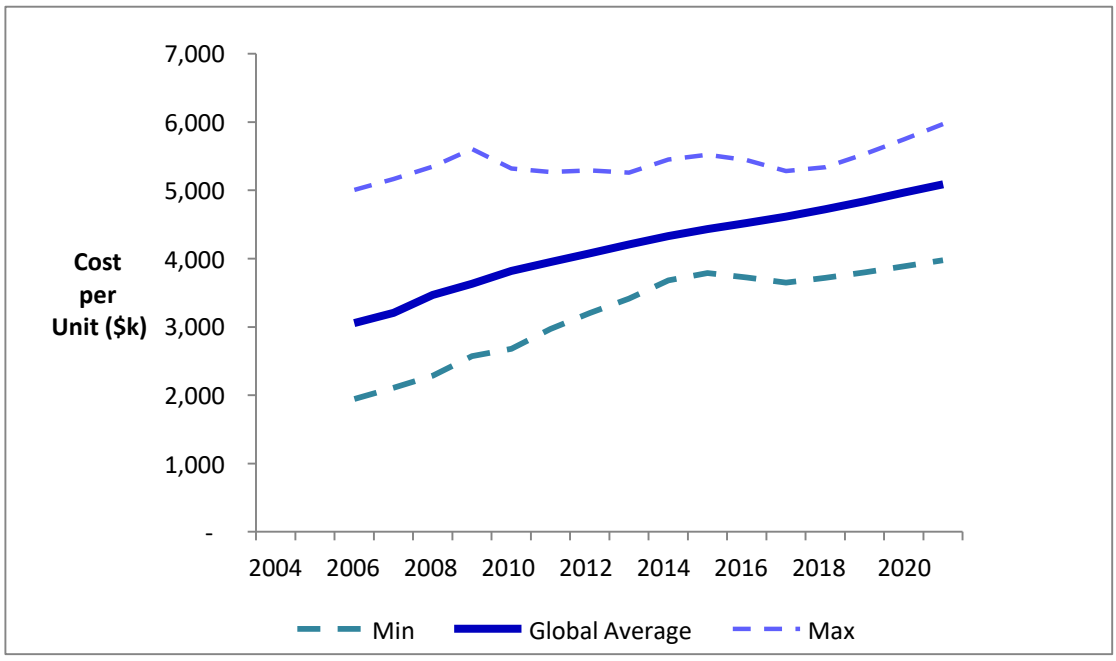
Ariel plans to raise prices 3% in 2013, the same level as it price increases last year. During "normal" economic times, the firm targets annual price increases of 5% per year, although it has not had a year it considered normal since 2006.

Burckhardt, which is currently backlogged and only likely to become more so within the next several years, is planning to raise prices for new orders by 5% this year, although the impact of the price increase will be delayed until later years to a large extent, since buyers typically only pay 20-30% of the purchase price when placing the order.

MHI and IHI are not planning to increase prices this year. This is partially an issue of public perception, as many of their orders are still for domestic emergency gas receiving or transportation applications after the Fukushima disaster. Raising prices for domestic orders would be seen as "profiteering."

Rising capacity utilization rates will continue to give suppliers leverage to raise prices faster than costs through 2018, and prices will increase a total of 18.5% from 2013 Q2 to 2020 Q2. This is in contrast with cost growth of 16.5%, indicating that manufacturers will raise operating margins to an average of 17% for non-Japanese firms.

Figure 16: Overall Price Forecast for Process Reciprocating Compressors



However, differing equipment standards, model choices, and pricing expectations contribute to substantial pricing differences by region.

For example, Beijing Jerrywon in China packages Cameron's units and Evolution in India does the same with Dresser Rand's products, often with cheaper ancillary systems (such as skid materials, piping, engines, and exhaust treatment). They are essentially value-engineering the units from the global manufacturers. This can result in a compressor package up to 30% cheaper than one made to US standards, although the cost of the compressor itself rarely varies more than 10-15%. Most of the reduction in actual compressor costs comes from the major manufacturers using a higher percentage of locally-sourced components, and often older, less expensive (and less efficient) piston and piston-ring technology for units sold in low cost markets.

Regional pricing dynamics have become more homogenous over the past 15-20 years in that most manufacturers are now sourcing or making many components in "low-cost countries" such as China and India. LCCS is commonly conducted by most major suppliers at the component level, although not for critical components such as cylinders, piston heads, piston rods, or shafts. This distributes the benefit of lower labor costs in these regions to countries with traditionally higher cost bases.

"Country pricing" also contributes to regional differences. Suppliers acknowledge that a buyer in the US is willing to pay more for a compressor than a buyer in Asia, and they price accordingly. To some extent, they are able to offset the differences in margin by making more or less of the components low-cost manufacturing locations, but suppliers frequently accept lower margins in some regions to meet the lower price expectations.

Prices are lowest in India at index levels of 79, followed closely by Russia and China at 81 due to a combination of lower labor and materials costs and an expectation on the part of regional buyers of lower prices.

- Average labor costs in these countries are approximately 25-30% lower than in the US, even factoring in the lower labor productivity in these regions. Labor cost levels are lowest in India, lower even than in China due to more rapid urbanization and cost of living increases in China.
- Steel plate costs in China and India are $600 per ton, compared to $700 in Germany and just under $800 in the US.

Despite their willingness to accept lower margins, Japanese suppliers charge the highest prices for reciprocating compressors. They compete on strong reputations for quality to offset this initial price difference, arguing on lifecycle cost benefits. Japanese price are 11% higher than benchmark prices in the US due to higher costs for labor, power, and steel.

- Average salary levels in the Japanese manufacturing sector, including benefits such as training, bonuses, and paid leave, are approximately $157k per year. In comparison, US workers total compensation averages $125k per year.
- Steel costs are also slightly higher in Japan – $570 per tonne for hot rolled steel vs. $540 in the US and $490 in China.

Examples of regional price differences include:

- IHI sold three boil-off gas compressors to Guangdong Dapeng LNG in 2012 Q4. The firm made the units, except for the crankshafts and casings, in China, and sold them for $2.3m each. This is 15% lower than benchmark price levels for a comparable unit in the US, despite making the largest components in Japan, a high-cost environment.
- Burckhardt makes reciprocating compressors for the Indian market domestically, and confirms that these units sell for approximately 20% less than the units it sells in Europe and the US.
- GE sold three 4.5k hp units to TNK-BP in 2012 Q4 for field gas compression, at a unit price of $2.8m, 18-20% less than prices for comparable units in the US.

Table 10: Regional Price Variations over Time for Process Reciprocating Compressors

Region/Country	Today	2014	2015	2020
North America	1.00	1.00	0.99	1.06
Latin America	0.95	0.98	1.00	1.14
Europe	0.97	0.97	0.97	1.02
Africa	N/A	N/A	N/A	N/A
India	0.79*	0.81*	0.82*	0.95*
Russia	0.81	0.85	0.85	0.99
China	0.81*	0.81*	0.80*	0.86*
Japan	1.11	1.13	1.11	1.12
Other Asia	0.84*	0.84*	0.83*	0.88*

Notes:

"N/A" means no local manufacturers and no known sales.

"*" means supplied by foreign manufacturers only

5.3.1 Price Differences by Technology, Model, and Feature

Compressor horsepower rating increases with the physical size of the unit, making it the main determinant of unit pricing. At the same horsepower, units with a higher pressure rating are smaller, making giving psi rating an inverse relationship with price.

Manufacturers typically quote reciprocating compressor prices on a per-horsepower basis for units of a given application within a given range of horsepower and pressure ratings. Ranges for the reference units covered in this study are approximately $720-$840 for the gas field compression unit (3.5-4.5k hp), and $650-$720 for the refinery-scale unit (7-9k hp). Within these ranges, cost per horsepower increases slightly as horsepower rises. For example, a 3.5k hp unit with discharge pressure of 290 psig costs approximately $720 per hp (for a total of $2.5m). A higher-horsepower unit with the same pressure rating would cost approximately $736 per hp ($3.3m total). A unit in the higher horsepower and pressure range (2200 psi) would cost $654 per hp at 7k hp, and $719 per hp at 9k hp.

Table 11: Incremental Cost per Extra Parameter or Feature for a Process Reciprocating Compressor for Field Compression Applications

(Driver horsepower of 4.5k, discharge pressure of 290 psig, and flow rate of 18k cfm)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Input Power	4.5k hp as reference point	Reducing driver hp by 500 cuts unit cost from $3.3m to $2.9m	Cost increases accelerate slightly with higher horsepower due to higher engineering requirements and more expensive mechanical power transmission components.
Discharge Pressure	290 psig as reference point	Reducing psi from 290 to 220 increases compressor cost from $3.3m to $3.65m	Compressor cost and psi are inversely related at constant hp because psi falls as the size of the compressor increases.
Flow rate	2200 psig as reference point	Cost per cfm falls from $180/cfm at 4.5k hp (18k cfm) to $180/cfm at 3.5k hp (14k cfm)	Flow rate increases as psi falls due to the corresponding increase in unit size

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

The driver itself is not included in these prices, due to the wide range of driver choices available (gas engines vs. motors, and multiple options such as fuel or electricity source for each), and the resulting inability to make accurate comparisons between compressor units. As a general guideline, the driver and associated power transmission equipment and engineering typically add 25-35% to the cost of the compressor.

Table 12: Incremental Cost per Extra Parameter or Feature for a Process Reciprocating Compressor for Refinery Applications (e.g. hydrogen circulation)

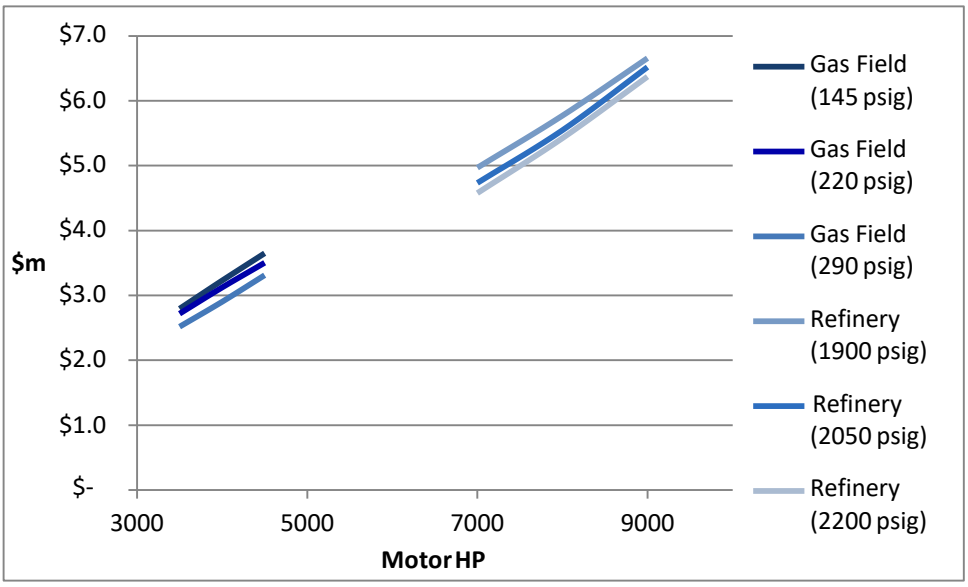
(Driver horsepower of 9k, discharge pressure of 2200 psig, and flow rate of 21k cfm)

Parameter or Feature	Unit of Measure	Indicative Cost Impact	Notes / Comments
Input Power	9k hp as reference point	Reducing driver hp by 1k cuts unit cost from $7m to $6m	Cost increases accelerate slightly with higher horsepower due to higher engineering requirements and more expensive mechanical power transmission components.
Discharge Pressure	2200 psig as reference point	Reducing psi from 2200 to 2000 increases compressor cost from $7m to $7.25m	Compressor cost and psi are inversely related at constant hp because psi falls as the size of the compressor increases.
Flow rate	2200 psig as reference point	Cost per cfm falls from $308/cfm at 9k hp (21k cfm) to $270/cfm at 7k hp (17k cfm)	Flow rate increases as psi falls due to the corresponding increase in unit size

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

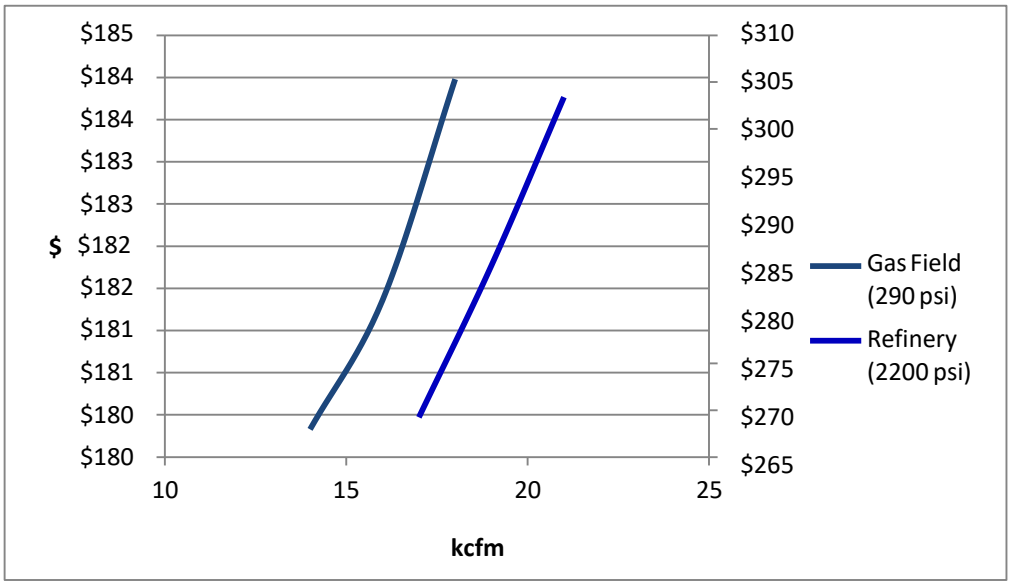
Compressor pressure rating is inversely related to unit cost at constant horsepower. For example, a 4.5k unit designed for 290 psig costs $3.3m, while a unit designed for 145 psig is larger, and costs $3.65m. At the refinery scale, a 9k hp unit rated for 2200 psig would cost $6.5m, compared to an 1885 psig unit at $6.7m.

Figure 17: Process Reciprocating Compressor (290 and 2200 psig) Motor HP vs. Cost - By Application



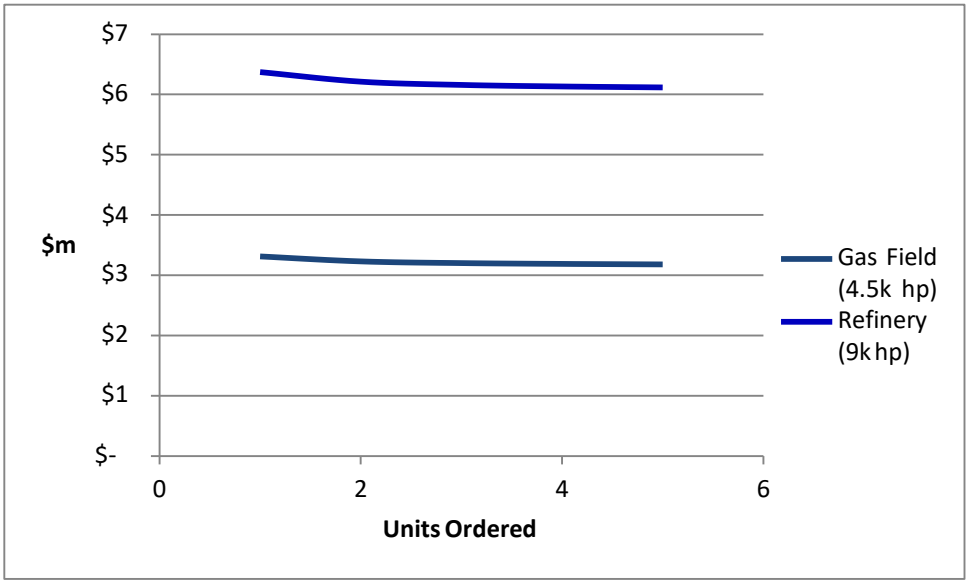
Cost per cfm of gas flow falls slightly as horsepower decreases, for each of the reference unit ranges; 1.4% from 18k cfm (4.5k hp) to 16k cfm (4k hp) for gas field processing applications (at 290 psig) and 6.3% 21k cfm (9k hp) to 19k cfm (8k hp) for refinery applications (at 2200 psig). For the gas field compressor, cost per cfm falls from $184 at 4.5k hp to $180 per cfm at 3.5k hp. Likewise, for the refinery unit, cost per cfm falls from $308 at 9k hp to $269 at 7k hp. As a result, buyers have a strong incentive to keep each compressor sized appropriately for the application, to avoid paying a disproportionately higher cost per cubic foot of gas processed.

Figure 18: Cost per CFM of Gas Flow by Application



Economies of scale when manufacturing multiple, similar units in the same order arise from eliminating redundant engineering and taking advantage of longer production runs without additional machine setups. Engineering costs cannot be completely shared, however, as each unit will be unique in some ways unless it will be used in exactly the same location on exactly the same gas stream. As a result, amortizing engineering over multiple units can reduce engineering costs by 30-50% on the successive units according to Cameron, Dresser-Rand, and Neumann & Esser, reducing the unit cost of each successive compressor by approximately 4%, on average. Streamlining the manufacturing process for similar units would cut off another percentage point of cost for each unit after the first. For an order of five units, this would reduce overall costs by approximately 4%.

Figure 19: Economies of Scale in Process Reciprocating Compressors



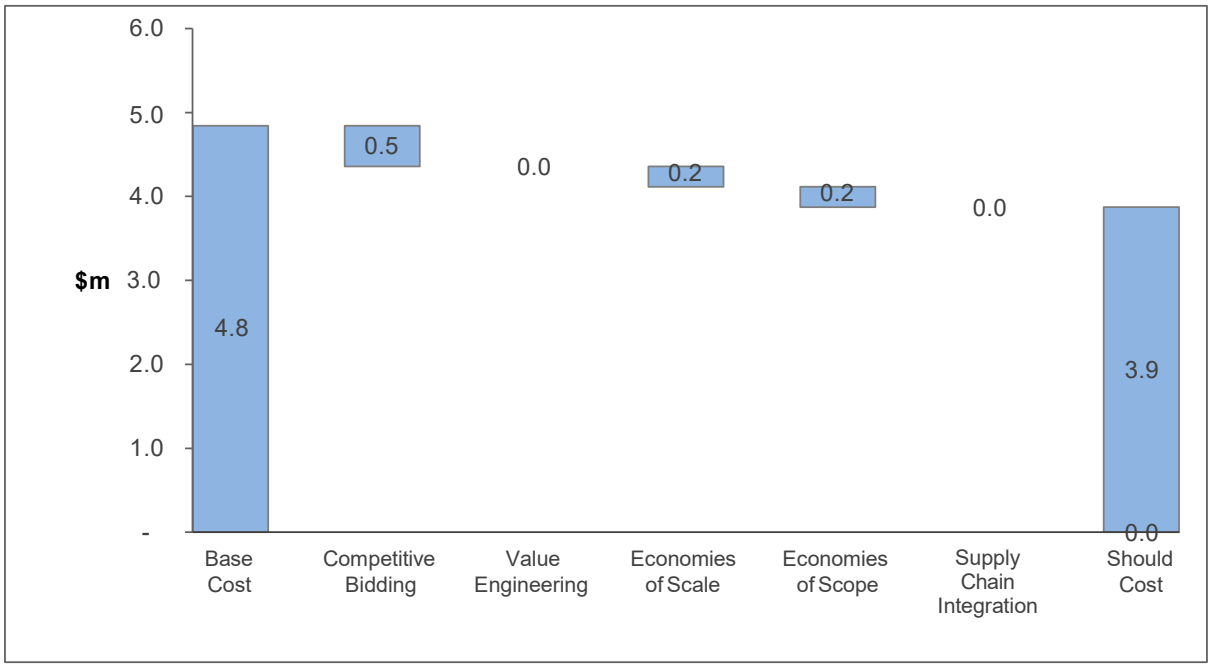
5.3.2 Should-Cost Analysis

Economies of scale and scope are the biggest lever buyers have on prices. Multiple manufacturers are willing to cut unit prices by as much as 5% each for economies of scale and scope. "Economies of scale" in this instance means ordering more of the same type of compressor, which has the benefit if reducing manufacturing costs. "Economies of scope" in this context means bundling the reciprocating units with other types of compressors or, a popular option for most manufacturers, a service plan. Japanese suppliers, with already thin margins, cannot afford to be this accommodating, however, and Kobelco, for example, is only willing to cut prices by a total of 5%.

Competitive bidding is common practice when ordering equipment of this size, and is already factored in to supplier margins. On average, the practice reduces unit prices by approximately 10% off list.

Value engineering is not an effective tool in most instances, as each unit is already custom-designed for the application. Large buyers with multi-year, program requirements (especially those that are willing to commit to an OEM service plan) can realize supply chain integration benefits such as vendor-managed spares inventory, but this category of savings applies primarily to operations, rather than initial cost.

Figure 20: Should-Cost for Process Reciprocating Compressors



5.4 Price Negotiation Strategies

1. Collect lead time quotes before negotiating prices. Suppliers with lower lead times and backlogs will be more willing to negotiate on price. For example, Burckhardt and Neumann & Esser will be less flexible on pricing. Both firms are fully utilized at present, and neither is building substantial capacity to work through backlog. Cameron has space available at its recently-enlarged plant in China, which is 75% utilized as of early Q2. GE, Dresser Rand and Ariel have lower utilization rates at major facilities (less than 90%). These firms will be much more receptive to negotiating tactics based on competitive bidding and economies of scale.
2. Place orders or reserve capacity now for compressor requirements sooner than 7 months for the 4.5k reference product, and 13 months for the 9k hp unit, to avoid losing bargaining power vs. increasingly busy suppliers, and incurring costly project delays or expediting fees. Accelerating demand growth will sap available production resources at the abovementioned companies in 2014, making cost savings harder to negotiate and increasing lead times.
3. Establish strict contract administration controls, such as rotating personnel in key positions of responsibility on an annual basis, for long-term procurement or service relationships. Other buyers caution that contract administrators often prioritize relationship maintenance over contract compliance, compromising performance vs. pre-negotiated savings targets.
4. Include Neumann & Esser on the bid list for any planned purchases of hypercompressors, especially units for petrochemical applications with drive power of up to 15k hp and pressure ratings up to 50k psig, The firm began manufacturing these units in 2012, but still has next to no market share compared to the established manufacturers in the segment, Burckhardt and

Howden Thomassen. Therefore, it may be willing to give steep discounts on these units, despite tight capacity, to gain market share.

6 Reference product definitions and scope

1. Process Centrifugal

- Reference Unit 1: Gas processing compressor
  - 12 MW input power (16k hp)
  - 6 bar (87 psig) inlet pressure
  - 30 bar (435 psi) discharge pressure
  - 16k acfm inlet flow rate (27k m3/hour)
  - Driven by an electric motor
  - API 617
  - Processing gas that is 82% methane, 7% ethane, 6% CO2, and 3% propane (the rest is 'other'), with molecular weight of 21, temperature of 131 F, and H2S content of 10ppm.
  - Operating at 500m in ambient temperature of 80 F
- Reference Unit 2: Pipeline compressor
  - 30 MW input power
  - 23 bar (333 psig) inlet pressure
  - 115 bar (1668 psi) discharge pressure
  - 11k acfm inlet flow rate (19k m3/hour)
  - Driven by a gas turbine
  - API 617
  - Processing gas that is 82% methane, 7% ethane, 6% CO2, and 3% propane (the rest is 'other'), with molecular weight of 21, temperature of 131 F, and H2S content of 10ppm.
  - Operating at 500m in ambient temperature of 80 F

2. Process Reciprocating

- Reference Unit 1: Field Compression Applications
  - API 618
  - 4,500 hp
  - 290 psig max discharge pressure
  - 18k cfm inlet flow rate
- Reference Unit 2: Refinery Applications (e.g. hydrogen circulation or product compression)
  - API 618
  - Double-acting
  - 9,000 hp
  - 2200 psig max discharge pressure
  - 21k cfm inlet flow rate

7 Notes

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

- Ariel
- Atlas Copco
- Burckhardt
- Cameron
- Dresser-Rand
- Elliott
- Exterran Holdings
- GE
- Ishikawajima-Harima Heavy Industries (IHI)
- MAN Turbo
- Mitsubishi Heavy Industries
- Neumann & Esser
- Rolls Royce
- Siemens
- Sundyne
- Valerus