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WHITE PAPER

Transforming chemical operations through technology

Part 1: Using digital to address internal and external challenges

Contents

03–04 **Executive summary**

05–12 **Challenges facing the chemicals industry**

External challenges

06 Volatile energy/raw material input prices
07 Regional dynamics
10 Growing importance of the circular economy
10 Continued strong demand over the long term

Internal challenges

11 Complex project management
11 Safety and security
11 Operational complexity
11 Disjointed communication and information silos
11 Insufficient supply chain collaboration
12 Mature markets: Retiring workforce
12 Emerging markets: Inexperienced workforce
12 Aging assets
12 Influence of energy volatility and regulations

13–16 **Digital solutions and technologies to address the challenges**

13 Collaborative Operations and Intelligent Projects™
14 Greenfield
15 Brownfield

17–18 **Optimizing chemical performance in practice**

17 **BASF:** Transforming rotating equipment into intelligent machinery to improve uptime and reliability
18 **Sadara:** Building and operating the world's largest petrochemical complex ever built in a single phase

19 **Conclusion**

19 **References**

Executive summary

Chemical companies in fast-growing emerging markets like China have done particularly well in recent years. Similarly, manufacturers in areas with access to abundant low-cost feedstock, such as the US which is the midst of a boom brought on by shale, have enjoyed considerable growth and profitability.

Looking ahead, however, conditions over the next decade are likely to become more challenging -even for the regionally blessed, let alone for more mature markets such as Europe and Japan where costs are comparatively high and demand growth is less.

There is considerable uncertainty and disparity of performance throughout the industry. The effects of low oil prices on chemical producers is not straightforward as some are benefiting more than others. Some regions, such as the Middle East, are even restructuring their economies to diversify beyond a dependence on fossil fuel extraction and actively pursuing increased local production of non-oil business and consumer goods which means more chemical manufacturing there. Demand growth, particularly from emerging markets is slowing down. And, with considerable capacity expansion over the last decade, margins are already eroded. Profitability could get squeezed further considering significantly more capacity is expected to come online in the next five years. There are also concerns that currently advantaged feedstocks might become less abundant in the medium to longer term.

And, if the above weren't enough to challenge even the most seasoned executives, by its nature the chemical industry is complicated on many levels making decision-making particularly difficult. Thousands of chemicals go into making an ever-increasing myriad of products, demand for which continues to remain high despite various global challenges. There are numerous manufacturing complexities, such volatile costs and prices, as well as products that can be made in different ways with various combinations of materials, across more than one plant at a given company, to achieve the same output. The number of variables to process for maximum performance are enormous. Challenges also vary by region. For example, emerging markets need to address a skillset gap whereas plants in mature markets need to address a growing exodus of seasoned talent due to retirement.

Digital can help, whatever the scenario happens to be for a given company, wherever in the world they are.

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"We are getting lots of data and lots of analytics. And we're drowning. And then we're getting everyone's opinion on everything. And we're drowning. What companies need is to know how to filter, how to put all of this information into a useful paradigm so it's not just information technology, but knowledge… So knowledge enterprise has to embrace digitization that results in increased knowledge to beat your competitors."

Dow CEO, Andrew N. Liveris speaking to McKinsey, May 2015, on "How Dow reinvented itself".[1]

Many chemical companies have spent years investing in automated operations, process controls, sensors and real-time data systems, albeit in a relatively scattered manner. Advances in digitalization are now enabling them to bring together the data they already have hidden in disparate systems to deliver greater value to their businesses than possible before, in a more agile and real-time manner.

Digitalization, done well, allows chemical companies to get a highly granular view of their

assets which, when viewed in conjunction with data from more traditional business systems, can generate quicker and better insights to drive competitive advantage.

Better information means companies are poised to take their performance and productivity to the next level of efficiency, safety and security. Increasingly cost-effective digital technology will facilitate improved monitoring, more collaborative and integrated operations and remote management to drive greater productivity at reduced costs and risk.

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"A lot of energy and momentum in the field of digital can be observed. Chemicals are catching up. It is not a question of if, but rather what and how it will be done."

Dr. Frithjof Netzer, Chief Digital Officer, BASF, contributing to a World Economic Forum White Paper on the "Digital Transformation Initiative."[2]

However, to benefit significantly from the potential offered, companies will need to embrace digitalization on a bigger, much more holistic scale encompassing end-to-end processes throughout plants across the supply chain – not just in isolated pockets of change.

Network-connected assets, when thoroughly integrated, can significantly improve risk, schedule and costs in new projects as well as brownfield sites.

Deploying the transformative power of digital, however, will not be easy. The scope of what is required is significant and technological solutions are evolving at a fast pace.

A dramatic, fourth industrial revolution is underway and, unless chemical companies embrace the Industrial Internet of Things (IIoT) throughout their organization, they not only risk delivering disappointing shareholder returns now but, longer term could put their companies in serious jeopardy.

While the chemicals sector is less cyclical than other part of the hydrocarbon chain, its leaders need to make the right investments today to set themselves up for long-term success.

This white paper considers the various internal and external challenges facing the industry and provides an overview of how companies can use digitalization to transform their operations in ways which reduce costs, minimize risks and drive sustained profitability. Its sequel will analyze the chemical industry's digital present and future in greater detail.

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"Significant competitive advantage will fall to chemical companies who are able to develop an end-to-end digitalized ecosystem which delivers timely, manageable data to optimize decision-making."

Guido Jouret, Chief Digital Officer, ABB

Challenges facing the chemicals industry

The chemicals and advanced materials industry has a significant impact on the world, contributing to approximately 2 percent of global gross domestic product (GDP). With over 100,000 chemicals in the world today, 10 million people employed in the industry and sales forecast to grow to $6.9 trillion by 2030, it is a complex, yet attractive market for many companies.[3]

According to Cefic, in 2016 world chemicals turnover was 3,360 billion euros (just over 4 trillion US dollars), 1.86 times its value in 2006.[4] However, growth has slowed with overall global chemical sales between 2015 to 2016 rising only by 0.4 percent. Indeed, apart from China, Japan and some Asian emerging market players, most countries having the largest chemical producers showed a decline between 2015 and 2016.[5]

The global petrochemical industry experienced a boom since the turn of the millennium, with annual ethylene production volume, for example, going from 100 million metric tons in 2000 to nearly 150 million metric tons in 2016.[6] And, continued solid demand from emerging markets in recent years, has meant that petrochemical companies have been able to hold onto higher margins resulting from the collapse in oil prices recently, rather than needing to pass on drops in feedstock costs through to customers which has more normally been the practice.[7]

However, even for petrochemicals, McKinsey estimates that the last decade's 3.6 percent growth rate for global petrochemicals may slow to 2 to 3 percent through 2030 as it will take some time before a new group of emerging markets such as India, Pakistan and parts of Africa, start contributing to demand growth in any significant way.[8]

World chemical sales: geographic breakdown

World chemical sales (€3.360 billion in 2016)

Source: Cefic Chemdata International as reported in Cefic Facts & Figures 2017 of the European Chemical Industry.
* Rest of Europe covers Switzerland, Norway, Turkey, Russia and Ukraine
** North American Free Trade Agreement
*** Asia excluding China, India, Japan and South Korea

Unless specified, chemical industry excludes pharmaceuticals
Unless specified, EU refers to EU 28

External challenges

A range of market disruptions have been affecting the chemical industry in recent years. These include the shale gas explosion in the US, over-capacity issues in China along and the oil price crash. There are also whispers of concern that the current surge in capacity creation within the US might lead to over-capacity issues on the mid- to long-term horizon. And, while demand has been growing generally, there is a noticeable reduction in the pace of growth, largely due to a slowdown in China. In the face of all these factors and the considerable uncertainty they introduce, companies would be wise to strengthen their commercial and operational capabilities via digitalization.

Before 2009, the chemical industry's boom and bust cycles averaged around 10 years; now it is closer to 2 to 5, indicating greater commoditization and an increased need to be operationally efficient and use capital wisely.[9]

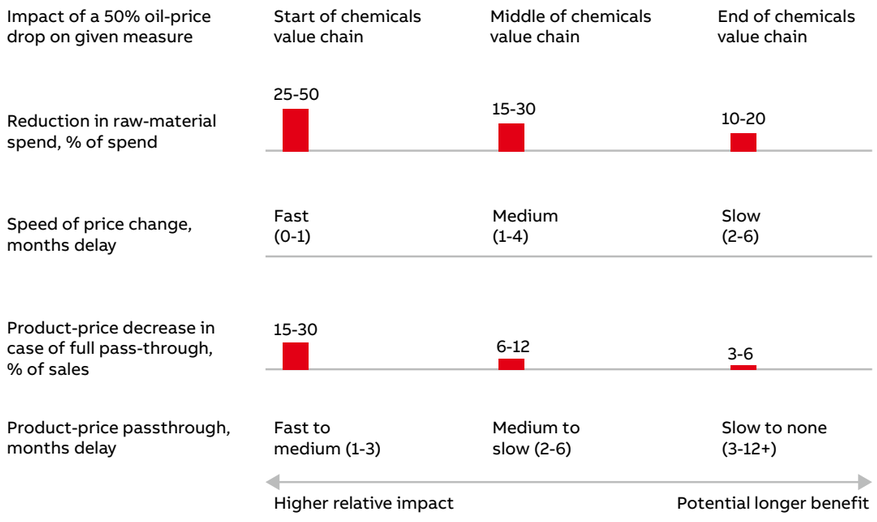
Volatile energy/raw material input prices
Securing the raw material inputs at the best price, quantity, quality and specification is essential for profitability within the industry. Purchasing can account for 20 to 60 percent of sales revenue for specialty chemical producers and 50 to 80 percent for commodity chemical makers, so getting it right is critical.[10]

Since 2000, the market for chemical raw materials has become even more global than before, giving companies a wider choice of price and grade for many inputs, along with some added complexity in terms of factoring in lead time and transportation costs to ensure they get the best deal.

The prices of some feedstock materials correlate directly to oil prices. Crude oil is a significant cost driver in the petrochemical industry as it is provides many of the key building blocks for chemicals (eg, ethylene and propylene). Plus, some chemicals like chlorine are made through very energy intensive processes meaning they are significantly impacted by oil price fluctuations.[11] Other by products of naphtha cracking, however, show no direct correlation (eg C4 and C5).[12]

Analyses by McKinsey[13] and Bain[14] show the effect of oil prices across the chemical industry:

The impact of the oil-price drop is differentiated along the chemicals value chain



Source: McKinsey & Company. "Oil price shocks and the chemical industry: Preparing for a volatile environment". May 2015.

Net effect of reduced oil price on economics for selected categories of chemical products

Oil feedstock commodity producer	➡	• Decrease in feedstock prices offset by decrease in oil-linked product prices • Potential upside from decrease in energy costs
Gas feedstock commodity producer	↘	• Price decreases and flat feedstock prices have reduced margins
Agrochemicals	↗	• Decrease in feedstock margins and limited price pressure • Could take up to a year to see benefits in some sub sectors further downstream from oil-based feedstocks, such as crop protection
Oil ond gas services	↘	• Decrease in exploration and drilling, leading to reduced revenues
Industrial gases	➡	• Decrease in energy costs (25% to 40% of costs of goods sold), offset by reduction in hydrogen sales for desulfurization
Coatings	↗	• Decrease in feedstock costs and limited price pressure
Packaging	↗	• Decrease in feedstock costs

Source: Bain & Company. "Responding to Oil Price Volatility in the Chemical Industry." May 29, 2015.

The return of raw material pricing volatility with the recent oil price crash may have eventually helped oil feedstock-based producers but being alert early to such signals in either direction will yield significant competitive advantage to any chemical manufacturer. Those companies who respond the quickest and most effectively to raw material price changes will enjoy greater margin improvements when such prices fall. And, in a rising input price environment, they can protect or improve margins by raising prices faster than their costs go up. This of course all relies on the right information being made available at the right time to facilitate the best decisions. Such opportunities do not last indefinitely as the difference between input costs and finished goods prices rising/falling eventually normalize once time lag effects catch up.

It is expected oil price volatility will continue for some years to come due to a range of factors including the rise in unconventionals (eg light tight oil in the US and oil sands in Canada), impact from politically sensitive countries such as Iran and Iraq, decisions taken by OPEC and the growth in biofuels, coal to liquids, and natural gas liquids.[15]

Regional dynamics
The chemical industry differs regionally based on how competitive the local supply chain is, the strength of local business and consumer demand, the level of raw material advantage and the ability to process value-added products.

Operators in areas with access to abundant low-cost gas feedstock, for example, have enjoyed considerable growth and profitability. This has been the case particularly for companies relying on gas-based feedstock as in the Middle East and, more recently, the US. Their advantage here was greatest during the period of high crude oil prices that ended in 2014.

In areas more reliant on oil-based feedstocks, such as Europe and Japan, times have been tough for quite some time. Not only do they not have the buoyant consumer demand of emerging markets to drive growth but also until the oil-price crash, their feedstock costs were particularly high. And, while this has been alleviated somewhat by the market correction, they are still at a disadvantage versus companies using gas feedstocks.

Looking ahead over the next decade, however, conditions are likely to become more challenging even for those regionally blessed with abundant feedstocks. McKinsey predicts that by 2020, most of the world's advantaged feedstock projects will have come online, and from 2020 to 2025, they expect fewer truly advantaged investments.[16]

Indeed, a 2017 analysis by McKinsey says that margin erosion, caused by increased commoditization throughout much of the industry has already been happening, but has been masked by low-priced feedstocks in the US and the Middle East as well as by strong growth in emerging markets.[17]

China
China now holds the top position in terms of sales followed by the EU and US. Indeed, China's sales are higher than the next nine countries combined.[18]

Over the last decade strong GDP growth in China led to a rise in demand for a wide range of goods requiring chemical inputs. As a result, there was considerable CAPEX-led growth with many new chemical manufacturing facilities being set up. Growth now appears to be stagnating as many Chinese consumers seem to have, by and large, caught up with the rest of the world in terms of material purchases. There is a limit to the number of fridges and cars one needs, for example. Also, the construction sector is struggling with many new homes lying vacant.[19]

Current GDP growth in China is 6.6 percent, and while this is significantly less than a high of 10.6 percent in 2010, it still higher than many other countries, making it an excellent opportunity for chemical companies there.[20] That said, companies in China will need to sweat their existing assets more than they have needed to in the past. After the recent chemical capital expansion boom there are now concerns about overcapacity and an increased interest improving margins, especially in light of slowing demand growth. In particular, they are now more concerned about operational excellence in the form of increased yields and throughput along with decreased energy usage.

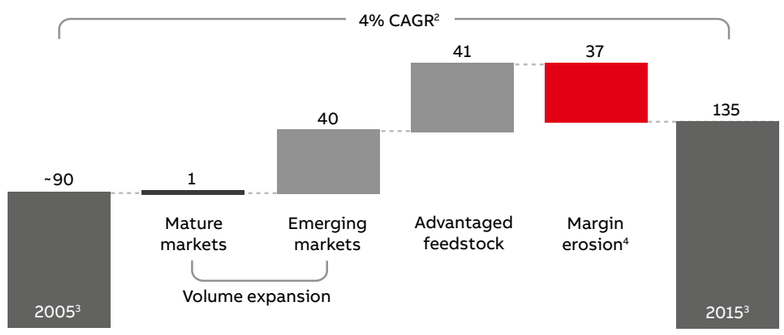
Dependent on imports for oil and gas, the country is developing coal as a raw material for a range of materials given that it has large reserves of suitable coal. However, coal is an environmentally sensitive raw material for chemicals, just as it is for electric power, and China faces calls to lessen its use.[21]

Europe
According to Cefic, over the last 20 years EU chemical sales increased by more than 50 percent and yet its world market share has halved. It now ranks second to China, with the US a close third behind it. Petrochemicals and specialty chemicals account for roughly half of its sales. Production has reached its highest level in eight years, and in fact grew 3.1 percent in the first half of 2017 compared to the same period in 2016, but it is still below its pre-financial crisis levels. Capacity utilization has reached its long-term average.

Europe faces many issues such as comparatively high feedstock, labor and energy costs as well as considerable regulatory and tax burdens. Ethylene is the biggest volume building block in the chemical industry and is a key ingredient in many plastics, detergents and coatings, for example. Making ethylene in Europe was three times more expensive than the US and Middle East in 2013 and, while the recent oil price crash has helped shrink the gap versus other markets like the US and the Middle East, European costs are still nearly double.[22]

Margin erosion has dampened gains from volume growth and attractive feedstock prices

Chemical-industry value pool, EBITDA,[1] $ billion



[1] Value pool covers 90 products; EBITDA = earnings before interest, taxes, depreciation, and amortization.
[2] Compound annual growth rate.
[3] 3-year trailing average.
[4] Primarily margin erosion through product commoditization (especially Asia); netted for >$4 billion margin improvement in Western Europe.

Source: McKinsey Quarterly. "Fighting commoditization in chemicals with a better commercial model." August 2017.

In terms of regulatory costs, these have nearly doubled in Europe between 2004 to 2014 with a number of key pieces of legislation being introduced such as REACH and the Classification, Labelling and Packaging (CLP).[23]

Energy prices in the EU are also comparatively expensive versus other key markets. For example, in 2015, its electricity costs were 1.7 times greater and its gas 2.5 times dearer than the US.[24] While the region has managed to use technology and other measures to drive its fuel and power consumption down by 26 percent since 1990, it still remains significant factor.[25]

Labor costs per employee in the European chemicals industry have also increased 47% since 2003.

North America
Abundant and inexpensive gas supplies have recently turned the US from a high-cost producer to one of the lowest and companies from around the globe are investing heavily there in shale gas projects. As of April 2018, the American Chemistry Council says that 325 projects have started, been completed or planned. This represents $195 billion in new capital investment, 468,000 direct and indirect jobs by 2025 (with an extra 378,000 further jobs generated by household spending) and $337 billion in new economic output.[26]

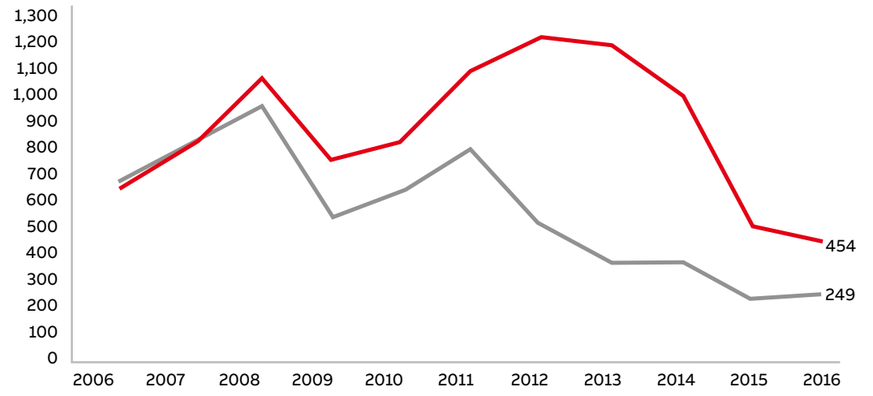
CAPEX costs are now rising due to a variety of factors including tighter construction market conditions, higher costs related to areas where the new plants are being build and the fact the industry is reaching the limits of feasible cost reductions from building large-scale, mega-projects.[27]

And, while chemical capacity in the US shows little sign of abatement, there are whispers of concern that too much capacity might come online. In fact, in North America, the feedstock advantage is expected to slowly disappear over the next 10 years as new ethylene cracking capacity and export opportunities increase demand for ethane and propane, which could drive prices up.[28]

Middle East
The petrochemical industry in the Gulf exceeded the global average growth of 2.2 percent by expanding by 3.7 percent in 2016 and reaching 150 million tons of capacity, of which Saudi Arabia accounted for 66 percent. While this less than the Gulf's rate of five percent the preceding year, it is still a healthy level of growth. Much of the fall was attributed global economic uncertainty and feedstock supply constraints.[29]

Investment still remains high in the region with projects announced in 2016 worth $13 billion due to come onstream between 2020-2024, adding eight million tons of capacity and creating 4000 new jobs.[30]

Average ethylene cash costs in the EU versus North America (US$/ton)



Sources: ICIS and Cefic analysis as reported in Cefic Facts & Figures 2017 of the European Chemical Industry
Unless specified, chemical industry excludes pharmaceuticals
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That said, the Middle East is in a period of restructuring. The recent oil price shock has encouraged petroleum companies there to diversify their economies beyond pure fossil fuel extraction and export. In fact, the Saudi Vision 2030 aims to increase the Kingdom's non-oil exports from around 16 percent today to 50 percent.[31] While encouraging increased local production of more business and consumer goods represents an excellent opportunity for chemical manufacturers in the region, the skillset and experience of the local labor force to cope remains a challenge.

Growing importance of the circular economy
Making products from finite natural resources and sending them to landfill is a decreasingly acceptable practice. This is particularly true of plastics which are made primarily from petrochemical building blocks and which are typically thrown away after initial use.

There is now a greater interest in what is called the circular economy whereby finite resources are more effectively managed and recycled to recirculate items in various forms over time instead of being thrown away forever. Governments and consumers alike are increasingly interested, with headlines across the world announcing the intention to ban or minimize the use of various forms of plastic.

More recycling and reuse means demand for "virgin materials" will decrease.

Continued strong demand over the long term
A majority of products being used today contain chemicals of some form or another. In fact, despite a growing global shift away from fossil fuels towards renewables, petrochemicals will still experience strong demand as renewables cannot replace hydrocarbon's use in a range of plastic products and various types of clothing. Demand for such products is projected to continue rising particularly as consumers in developing countries begin to exhibit similar spending patterns to their peers in the developed world.

The outlook for manufacturing, and the associated chemicals required, continues to look promising. Indeed, while demand for such items may have slowed compared to previous highs, such as in China, emerging market demand still remains large. And, other mature economies are showing reasonable levels of growth. Automotive and construction industries, which are particularly important to the chemicals industry, have been picking up, beginning to approach pre-crisis levels.[32] Low oil prices at the moment are helping to encourage or sustain demand on a more global basis.

Internal business challenges
The industry is being driven by a plethora of business hurdles including, but not limited to:
- Complex project management
- Fragmented communication
- Lack of collaboration between various departments and across the supply chain
- Difference between sites in mature versus emerging market locations
- Maximizing aging capital assets
- An aging workforce
- Improving safety
- Energy volatility
- Cybersecurity challenges

The careful integration of technology can help overcome these challenges by increasing visibility, improving communication and eliminating duplication -all of which has a positive impact on the bottom line as well as employee safety and morale.

Internal challenges

Challenges	Issues	Benefits through digital approach

Delivering large scale projects on-time, on-budget, on-schedule and with minimized risk	• Diverse contracting forms: electrical, automation, instrumentation etc.
	• Many new projects, particularly in the US with $194 billion in new capital investment due to shale gas expected, with over 325 projects planned, started or completed as of April 2018[33]
	• 64 percent of projects today face cost overruns and 73 percent also report schedule delays
	  • Leading to a significant impact on profitability in terms of actual costs incurred and foregone revenues from projects delivered late
	• Cost overruns of 20-30 percent range are common
	• As many as 30 percent of loops fail on commissioning due to errors in the engineering process
	  • Primarily in the data from EPCs
		• Helps streamline labor intensive activities, reducing opportunity for human error and speeding up schedules
		• Automated data management, standardization and cloud-based workbenches, for example, can:
		  • Consolidate new project execution activities
		  • Simplify documentation requirements
		  • Reduce engineering man hours
		  • Pave the way for virtual commissioning resulting in fewer on-site changes
		  • Streamline equipment and shrink required footprint
		• Configurable I/O reduces marshalling and hardwiring significantly, generating large time and cost savings

Improving safety and security through better prevention and quicker ability to address problems effectively	• Dangerous conditions for workers, contractors and visitors • Possible accidents with machinery • Potential explosions • Particularly dangerous areas of activity include flare stack inspections where temperatures can exceed 2000 ^{0}C, requiring processes to be shut down for manual inspections • Unstable, dangerous political environments	• Cuts downtime, insurance costs and litigation, while improving employee retention, recruitment and morale by reducing injuries and fatalities • In collaboration with Accenture, the World Economic Forum estimate digitalization may save 20-30 lives and avoid 2,000-3,000 in the chemistry and advanced materials industry between 2016-2025[34] • Drones equipped with cameras and sensors can be sent into particularly dangerous areas • Alarm and safety systems can identify hazardous situations and help prioritize response • Capturing information from many sources: Test reports, online measurement, shutdown reports, alarms, work permits etc. to see how well and how safe the plant is operating, ensuring critical safety barriers are maintained • Automated identity and security management programs that centrally track employees' access rights, location, duration, training, safety certification, permissions and compliance to tighten security • Cybersecurity systems and services to ensure asset integrity and performance
Overseeing highly complex operations	• Plants in many locations across the world • Information overload • Insufficient visibility of key information • Only 1 percent of information collected is being made available to the key decision-makers[35] • Engineers spend 70 percent of their time looking for and manipulating data	• Visibility possible onsite and from distant, centralized control rooms (at plants and company headquarters etc) • With everyone viewing the same real-time data to enable effective decision-making • Dumb data is turned into analytic intelligence with the right information being channeled to the right person at the right time in a prioritized manner • Enabling employees to focus on the issues that matter, allowing the smart equipment to take care of the rest

Overcoming disjointed communication and information silos	• Many independent pieces of equipment and systems, each with its own data and interfaces
	• Hard to share information and expensive to upgrade
	• Data needed to make effective decisions comes from a wide range of legacy system whose data needs to be cleansed and properly aggregated so that it can deliver the insight needed to improve performance
	  • Data retrieval and management can take up to half an employee's time and requires significant skill if done manually
	• Duplicated activities and costs (eg. procurement)
	• Difficulty making timely, effective decisions to manage disturbances due to lack of common visualization within and across plants as well as headquarter locations
	• Technology has grown in a diverse and chaotic way resulting in fragmented automation where:
	  • Operators and control room staff see different screens and view separate pieces of information
	  • Managers feel they are drowning in data but are unable to find the answers they need
	• Insufficient real-time information
	• Over-reliance on operator skill
		• Digital technologies can clean, aggregate and share data in minutes rather than days
		• Easier information sharing to facilitate better business decisions
		• Collaborative operations leveraging open standards can help futureproof investments through easier upgrades
		• Changes how employees view and interact with their operations and markets
		• Allows greater visibility by integrating information technology with that of operational technology
		• For example, information from sensors on equipment can empower technicians to optimize decisions by quickly working through robust scenario planning factoring in the different crudes or other raw materials available along with pricing, availability, delivery and inventory information
		• Throughput maximized given operators can now use technology to juggle many more variables than before
		• More strategic and better integrated procurement programs
		• Enables companies to be more responsive and flexible
		• Enhances delivery performance
		• As a result manufacturers can benefit from:
		  • Increased production and revenue
		  • Reduced operations cost and improved margins
		  • Better return on capital employed

Leveraging collaboration across the entire supply chain	• Elements of the supply chain are isolated • Suppliers, customers and partners rarely interact • Teams in different locations hardly ever talk to each other • Missed opportunities to develop novel approaches • Insufficient best practice sharing: Reinventing the wheel	• Enhances productivity and performance • Helps resolve common issues more quickly and effectively • Shared knowledge can result in more accurate plans (eg, forecasting) • Potentially builds customer loyalty and may identify new revenue streams • Due to technology, innovation and R&D being shared more easily and frequently throughout the company and with partners, suppliers and customers

Challenges	Issues	Benefits through digital approach

Mature markets: Dealing with an aging, difficult-to-replace, workforce	• According to an analysis by Accenture and the WEF on US Bureau of Labor Statistics:
	  • 33 percent of chemical workers, 42 percent of chemical engineers and 48 percent of chemical and material scientists are over 45 years old[36]
	• Transferring knowledge and experience to the new generation is a challenge
	• Industry is not seen as a particularly attractive sector
	• And, according research conducted by Accenture for the American Chemistry Council:
	  • Of the total graduates in key chemical fields, only 30 percent are working in the sector[37]
	  • A survey of 505 North American chemical workers, including 100 C-suite employees, found that 87 percent agreed the sector needed to change its image to attract talent with 76 percent feeling the industry is "not cool enough"[38]
	  • They also expressed concerns that younger, millennial workers tended to be less likely to stay
		• Technology can pick up the slack of having fewer experienced workers available
		• Automated processes mean you need fewer workers on-site and these employees can be supported by experts at headquarter or supplier locations if needed
		• Knowledge is captured and delivered to the right workers at the right time thereby expediting execution to generate higher productivity and improve margins
		• Optimizes expertise of global workforces through virtualization, training simulators and remote support
		• Promotes an optimized management setup with centralized organization and reduced cost structure via efficient and rapid decision-making
		• Makes chemicals appear an attractive, less alienating career option for high-tech graduates: a digitalized plant has fewer knobs and buttons than before, instead bringing technology they are already familiar with, such as touch screens and check and point options, into the control room; some elements can even be operated by a smart phone

Emerging markets: Working with a relatively inexperienced workforce	• There is typically mismatch between the demand for skilled project engineers and the supply available within the local market	• Process becomes less dependent on operator knowledge and intervention • And, where required, technology can help guides operator actions to ensure safe and efficient performance • Helps upskill the local workforce through digital training and simulators

Managing aging assets to minimize downtime risk and its impact on profitability and workforce safety	• Across the world key assets are already beyond their expected life span
	• According to an Economic Intelligence Unit report (conducted for Oracle) of global process industry executives, three quarters of which were from the oil gas and chemicals industry, 77 percent stated that aging infrastructure impacted operations in terms of time and cost[39]
	• Average age of ethylene crackers[40]
	  • Western Europe: 38 years
	  • North America: 32 years
	  • Middle East: 12 years
	• The operational cost of downtime at a major cracker in the US can be more than be up to $1 million per day[41]
	• The reputational damage of major incidents such as explosions, can be significant, and have a dramatic effect on the bottom line
	• Reactive and time-based maintenance are dominating maintenance strategies
	  • As a result of a fragmented, often manual, approach to asset management
	• Lack of data acquisition systems and real-time data complicates more proactive strategies
	• Isolated from other business planning functions
		• Reduces time, expense and downtime through real-time condition and health monitoring
		• Assets are instrumented, interconnected and intelligent, reporting their location, status and other key metrics remotely and automatically
		• Facilitates preemptive condition monitoring using systems with predictive data modeling to trigger maintenance orders and prevent breakdowns before they happen
		  • Predictive maintenance can reduce equipment downtime by 30-50 percent and increase longevity by 20 to 40 percent.[42]
		• Helps determine the optimal way for these assets to behave and interact with each other by providing a view of the entire asset management life cycle
		• Asset management is integrated with other business functions and systems, such as enterprise resource planning and documentation, thereby enabling better control over costs

Coping with energy volatility, increased legislation and growing importance of the circular economy	• Energy volatility means volatile raw material costs for chemical companies
	  • Raw material purchasing can be 20-60 percent of sales revenue for specialty chemical companies and 50 to 60 percent for commodity producers[43]
	• Increased government regulations globally:
	  • Paris Agreement
	  • Australian Emission Trading Scheme
	  • European Union Emission Trading Scheme
	  • Kyoto Protocol
	  • Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation
	• Imminent and proposed bans /limits placed on various types of plastics
	• Manual management of carbon, water, energy and waste with currently little automation or integration
	• Perception chemicals industry is environmentally unfriendly
	• Little or no integration between the processing and power parts
		• Analyzes many purchasing variables to determine where and what raw materials to buy to make the best combination of products to maximize profit and yield
		  • Reducing overall expenditure by 6 to 10 percent can deliver a 3 to 5 percent point gain in EBIT[44]
		• Optimizes the use of finite planetary resources through more efficient raw material consumption and energy use
		• Helps reduce energy expenditure and regulatory costs
		• Tracks and monitors carbon, water and fuel from end to end and extends to footprint management, waste management, ecosystem risk management, plant closure and rehabilitation
		• Processes, information and analytical tools are used proactively to manage environmental and energy consumables, such as modeling carbon trade-offs, carbon trading, water management, fuel optimization and waste control
		• Tighter compliance with regulations and reduced costs of meeting/monitoring regulations
		• Analysis by Accenture and the World Economic Forum estimates that digitalization has the potential to cut CO_2 emissions by 60-100 million tons in the next decade[45]

Digital solutions and technologies to address the challenges

For over five decades ABB has been at the forefront of equipping companies across the hydrocarbon chain with a wide range of technologies to support some of the world's largest and most challenging chemical projects.

For example, ABB spearheaded the automation and instrumentation for the world's largest chemical complex ever built in a single phase with 26 integrated world-scale manufacturing plants – the Dow and Saudi Aramco Sadara project. It also supplied power and automation for the world's largest chemical cellulose plant, Sappi Saiccor.

With an installed base of more than 70 million connected devices and more than 70,000 digital control systems across a range of industries, and its deep understanding of the oil, gas and chemicals industry in particular, ABB makes it possible to understand and optimize industrial processes like never before.

ABB is an expert in developing and enhancing process control systems, communications solutions, sensors and software for the industrial IoT, helping chemical companies to exploit fully the promise of the fourth industrial revolution. Only when things, services and people are in sync will real change occur – all three matter and ABB has a proven track record of bringing these elements together seamlessly.

ABB's proven approach and technological capabilities help chemical customers analyze data more intelligently, optimize their operations, boost productivity and enhance profitability while reducing risks to schedule and safety across their entire operations.

And, knowing just how critical it is for the right people to have the right information at the right time, ABB has gone a step further for customers by partnering with Microsoft to develop one of the world's largest industrial cloud platforms. This partnership will give customers new insights to empower faster, more astute decision making.

Likewise, ABB has partnered with Hewlett Packard Enterprise (HPE) to combine ABB's deep domain expertise in operations technologies (OT) with HPE's leadership in information technologies (IT). ABB and HPE are delivering joint industry solutions that merge OT and IT to turn industrial data into insights and automatic action. They are combining cloud platforms like Microsoft Azure with IT systems running in corporate data centers and OT systems at the edge of the network closest to where the raw data is being collected. By helping customers employ the right mix of IT platforms and serve their OT data more effectively into those IT systems, ABB is helping customers accelerate data processing and enabling effective control of industrial processes across multiple locations.

Collaborative operations: A proven four-angled approach to cut costs, reduce schedules and minimize risk through properly integrated digitalization

ABB's collaborative operations approach addresses the need to use big data and data analytics to realize the potential of the industrial internet of things. We consolidate data to manageable levels whereby people can take decisions, helping to improve coordination between functional silos by providing greater visibility and real-time system integration. Collaborative operations is an operating mode which facilitates effective business transformation.

Collaborative operations is made up of four key elements and has been proven to work across many industries, including chemicals:

- **Intelligent engineering:** An integrated approach which covers the processes, tools and standards that take project execution from a traditional multi-vendor approach to one which streamlines the equipment to reduce human error, risks, labor and CAPEX costs. It also provides single-source accountability for extra peace of mind and shortens completion time. This project delivery model goes beyond traditional approaches to deliver extra value in large projects.
- **Intelligent infrastructure:** Having an intelligent infrastructure which seamlessly integrates process control, safety, power, automation, telecoms and electrification systems into one collaborative system is the backbone of many

operations. By optimizing how machines, applications and people communicate ABB, when used a single-source supplier, has proven that companies can significantly reduce CAPEX and OPEX expenditures while simultaneously improving production.

- **Intelligent applications:** Are software and system components that help improve efficiencies and optimize performance across the enterprise. They ensure the intelligent infrastructure reaches its full potential to deliver sustainable profitability. To that end ABB offers a suite of applications designed to enhance day-to-day equipment efficiency, promote safe and secure production and make it easy to access expert guidance whenever and wherever required.
- **Intelligent services:** Minimize downtime and improve employee effectiveness through a combination of human intervention and technological solutions which enable companies to move from costly reactive or unnecessary time-based maintenance to planned and predictive interventions based on actual equipment needs to ensure a cost-efficient and extended equipment lifecycle.

The first two elements provide the foundation on which performance improvement and cost containment rely while the other elements ensure that initial engineering and infrastructure investments continue.

Our approach is scalable such that companies can join in where it makes sense –though full benefits will only accrue to those opting for the totally integrated solution.

Greenfield

From a greenfield point of view, companies benefit from combining intelligent engineering with intelligent infrastructure, the first two elements of ABB's collaborative operations framework. The former simplifies and accelerates project execution while the latter helps to further reduce initial CAPEX expenditures by streamlining the equipment required and reducing required footprints. We call this Intelligent Projects™ and the approach can cut costs 20-30 percent and shorten schedule completion by a quarter. It should be noted, however, that the benefit goes beyond the initial design and build phase; an intelligent CAPEX investment here enables higher OPEX savings once the project is up and running.

Intelligent Projects are delivered using engineering in the cloud, standardized processes, automated data management, smart I/O systems and soft marshalling to decouple the hardware and software engineering activities in greenfield projects.

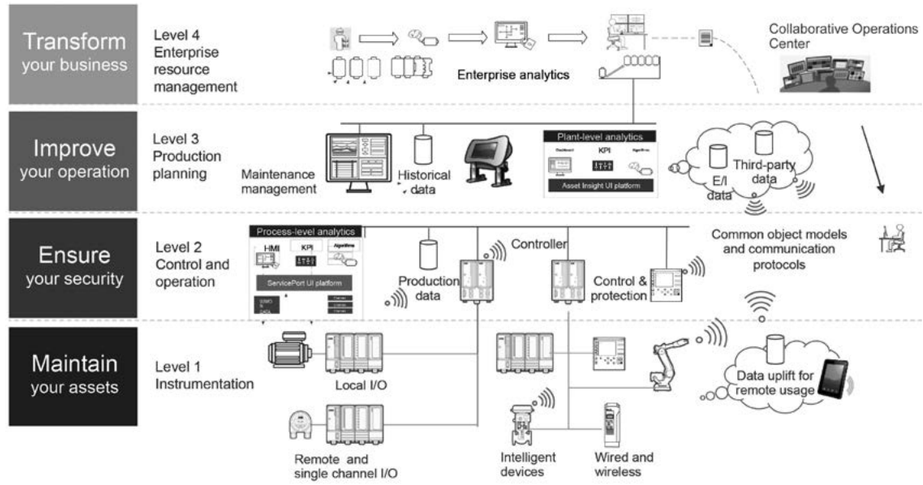
For example, standardized hardware designs and smart I/O products significantly reduce the need for upfront planning. Virtualization, emulation and simulation are technologies that can be used to enable application software testing to be conducted in a cloud environment without requiring the hardware. This allows hardware to be shipped to site much sooner leading to an earlier completion of installation and field loop verification.

This approach eliminates the need for project-specific junction boxes, armoured multi-core field cables and marshalling cabinets. Standard junction boxes containing smart configurable I/O become smart junction boxes. These can be procured from stock and installed in any convenient location. Field devices are simply cabled to the nearest smart junction box. The I/O loops are quickly and efficiently tested and verified by taking advantage of digital communication technologies. All this is achieved in parallel with the software engineering in the cloud. When the application software is downloaded into the hardware, the I/O system is soft marshalled and connected to the application software using a simple signal names (tag) matching process.

Cloud computing thus paves the way for "virtual commissioning" using process models which can be used to significantly boost the value of functional testing by providing a more realistic feedback. This approach results in far fewer changes and modifications being required on-site during commissioning.

ABB's cloud computing approach is further used to make designs, workflows, methodologies, support tools and lessons learned accessible to all project execution groups. This automated data management facilitates a common approach to automation engineering even when multiple EPC contractors across different countries are involved.

ABB's workflow manager tool, for example, ensures that the right people in the engineering process are quickly informed of any changes and assists in quicker turnaround times by determining the impact that the change requests have on cost and schedule.



Brownfield

For existing operations, companies may prefer to start their digitalization journey at an asset level which is fine so long as they do so with the end goal of enterprise-wide digitalization in mind. If they do not take such a long- term view, they risk continuing to develop islands of intelligence of an insufficient scale to deliver significant value and they will increasingly find themselves at a disadvantage to other players who create a larger digital ecosystem.

Ultimately they should be striving to close the communication loop more fully by having onsite operators liaise more closely with headquarter locations and suppliers such as ABB who can work remotely or in close proximity with local employees to make operations and services more efficiently.

In fact, at various ABB Oil, Gas and Chemicals Collaborative Operations Centers located throughout the world we have created digital hubs that allow IT and OT experts to work very closely together to solve customer issues in real-time. These centers gather data drawn from assets across the customer's production sites and translate this into intelligence, before transferring it back to each plant's operations center on-site and to management at headquarters.

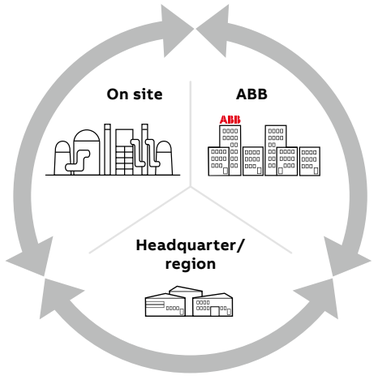
Using the ABB Ability™ platform , based on Microsoft's Azure, data from instrumentation, switchgear, motors, drives and other smart sensors, for example, are channeled through analytics which undertake condition monitoring, remote diagnostics, performance monitoring, cybersecurity and condition-based maintenance. Depending on customer requirements, a full suite of experts can man the center 24/7 meaning that project teams to address crisis situations can be quickly assembled. There are even high security Armor rooms for working directly on customers' own networks meaning that issues can be addressed particularly quickly and effectively.

Also, ABB Ability™ EdgeInsight, a new service offering which runs on HPE Edgeline hardware, is being piloted at a number of oil, gas and chemical customers. The new software collects data from field devices / gateways / PLCs in OT systems, converts the various field protocols into one common protocol and serves the standardized output to the IT infrastructure while simultaneously guaranteeing no access to the field network. Data can thus be shared efficiently beyond individual sites while protecting site assets from potential outside interference. Data is merged close to field level ensuring the same timestamp and context across vendors and protocols. By unifying complex industrial languages at the edge, it saves up to 75 percent of the data normally sent through control system databases and avoids data gaps due to control system updates, downtime or faults. Analyses which used to take days are now being done in minutes.

Across a range of oil, gas and chemical projects, ABB has proven it is possible to cut OPEX in existing operations by up to 30 percent while improving uptime by 20 percent and extending facility lifetimes by 20 years.

Collaborative Operations: In Summary
ABB's Collaborative Operations approach is a way of properly harnessing digitalization to increase the speed and quality of decision-making along the full hydrocarbon chain, changing how people interact with others in their organizations, fast-tracking innovation and creating new business models. This can be at an asset level or enterprise-wide, onsite or remotely, with as much expert guidance as required, up to and including the real-time assistance from ABB at a distance.

ABB's extensive cross-industry experience with digitalization underpins its ability to deliver effective solutions for chemicals customers at whatever level is required.



Closing the communication loop:
Fully collaborative operations.

ABB Ability™ cloud platform and services:
Remote monitoring solutions

Range of cloud-based services and advanced analytics

ABB Ability™ plant and enterprise solutions:
Power generation solutions, network management systems, substations

>6,000 solutions installed

ABB Ability™ automation and control systems:
DCS systems: 800xA, Symphony+, substation automation systems

>70,000 systems intalled

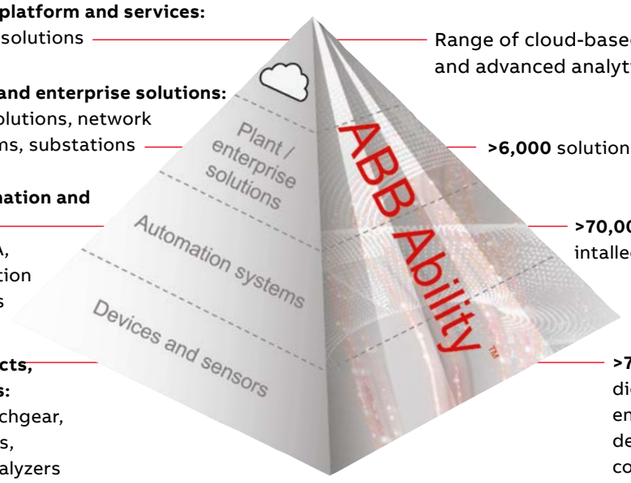


ABB Ability™ products, devices and sensors:
Motors, drives, switchgear, transformers, robots, instrumentation, analyzers

>70,000,000 digitally-enabled devices connected

Analytics and support from ABB experts help companies turn data into insights which are then visualized into a dashboard which facilitates chemical company decision-making.

Smart Wells	Production Performance Solutions and Services	Energy Management	Asset Management and Condition Monitoring	Digital Project Execution	Operations, Safety & Security Management
Flow Assurance Production Optimization		Process Power Energy Analytics			

Collaborative Operation Centers

ABB Ability™, IT Topology and Infrastructure, Cyber Security

Optimizing chemical performance in practice

BASF: Transforming rotating equipment into intelligent machinery to improve uptime and reliability

Challenges addressed
BASF has a large number of non-critical low voltage motors and pumps that are inspected manually during routine maintenance. However, this does not provide sufficient online information about the current state of degradation or about potential failures.

Fleet management for rotating machines has been identified by BASF as a co-creation initiative which will help to further enhance overall plant availability, reliability and efficiency.

How
ABB is providing a rotating machine digital service to BASF's Ludwigshafen site. More specifically, ABB is working on providing an end-to-end solution that goes from wireless sensors up to advanced analytics and an enterprise dashboard for a fleet of rotating assets. The solution aims to run complex fleet diagnostic algorithms to improve the overall fleet operation.

BASF has implemented ABB's wireless sensors at assets of pumps and motors. By this, it can easily gauge the status of each component in the plant using analytic algorithms running on ABB Ability™ platforms. This in turn gives BASF enough information to monitor the equipment and to identify upcoming problems in the machine. This supports BASF operations to improve maintenance by detecting fault before failure, thereby offering an alternative solution to improve predictive maintenance.

Background
Headquartered in Germany, BASF is one of the world's largest chemical producers. It operates in over 80 countries with hundreds of production sites across the globe. Its portfolio of products ranges from solvents and plasticizers to high-volume monomers and glues as well as raw materials for detergents, plastics, textile fibers, paints and coatings, crop protection and medicines.

Photo credit: BASF SE

Sadara: Building and operating the world's largest petrochemical complex ever built in a single phase

Challenges addressed
The sheer scale of the project was immense. In a very short time-frame, 26 manufacturing plants needed to be built as part of this $20 billion project. There were 19 key stakeholders and 15 different EPCs (Engineering, Procurement and Construction) involved from 8 different countries. And, once up and running in 2017, the mega-site need to operate efficiently from day one and for the decades to come.

Building by numbers	
Control systems	18
Input/Output (I/O) devices	150000
Redundant controllers	260
Servers	450
Workstations	210
Operator consoles across 5 control operator buildings	70

How
The complete automation and safety system for Sadara was very complex and central to the success of the whole facility. ABB's strengths in these areas led it being Main Automation Contractor (MAC). With its unique combination of domain and digital expertise, ABB facilitated excellent economies of scale, while delivering cutting-edge optimization that helped keep costs in line. Over 275 employees from ABB, including 180 on the site itself, worked on the project.

By deploying the Intelligent Projects approach described earlier, the project was delivered with reduced CAPEX and engineering costs. "Digital twin", high fidelity simulation systems were used in the project's initial phases as well as to train operators even before start-up and commissioning.

In addition to being the MAC, ABB also oversaw systems for continuous emissions monitoring, operations management, instrumentation and terminal management. ABB also supplied, but did not integrate, a range of electrical products.

A single operator is able to take on a range of complex, interlinked tasks that are central to the efficient operation of the facility. Additionally, digital twin capabilities are being used to guide day-to-day decision-making.

Furthermore, its deliberately scalable design allows Sadara to meet its evolving needs and integrate new technologies in a digital environment.

Background
Sadara represents a unique alliance between Saudi Aramco and The Dow Chemical Company who came together through shared values and a dedicated vision to develop and serve the Middle East market with chemical products that had never before been produced in the region. The project aims to enable Kingdom of Saudi Arabia to become self-sufficient and cut down on imports and boost exports within GCC (Gulf Cooperation Council) and wider Gulf region.

Sadara will support Saudi Arabia's industrial and social diversification by extending key value chains downstream and generating thousands of employment opportunities, both through the complex and through the adjoining PlasChem Park. Sadara's unique product portfolio, employing state-of-the art technologies, will add downstream value chains to expand and transform the Kingdom's existing chemicals landscape. Sadara will introduce many new products to the Kingdom, e.g., the first isocyanates and polyols (polyurethane) plants, enabling many industries that either do not currently exist in the Kingdom or only exist through imports of raw materials. Now operational, the site's annual output is 3 million metric tons of plastic and high value-added Park. Sadara's unique product portfolio, employing state-of-the art technologies, will add downstream value chains to expand and transform the Kingdom's existing chemicals landscape. Sadara will introduce many new products to the Kingdom, e.g., the first isocyanates and polyols (polyurethane) plants, enabling many industries that either do not currently exist in the Kingdom or only exist through imports of raw materials.

Now operational, the site's annual output is 3 million metric tons of plastic and high value-added chemicals.

Conclusion

In an uncertain macroeconomic environment and an industry with significant production and geography-related complexity, chemical manufacturers would be wise to invest in digital technologies and advanced analytics to help them harness their data for maximum performance so that they are in a position to thrive whatever challenges they face.

Leaders must also move quickly or risk being surpassed by competitors who embrace the full potential of digitalization to transform operations at a device, process, plant and enterprise level.

As Klaus Schwab, executive chairman of the World Economic Forum, put it: "In the new world, it is not the big fish which eats the small fish, it's the fast fish which eats the slow fish."[46]

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*Note: numbered references earlier in the document are digital links to the source material.