Industry 4.0 and the chemicals industry

Catalyzing transformation through operations improvement and business growth

Deloitte University Press

The Chemicals and Specialty Materials group within Deloitte Consulting LLP's Supply Chain and Manufacturing Operations practice helps companies understand and apply Industry 4.0 technologies in pursuit of their business imperatives. Our insights into additive manufacturing, IoT, and advanced analytics enable us to help chemicals companies reassess their people, processes, and technologies, in light of advanced manufacturing practices that are evolving every day.

About the authors

Stefan Van Thienen is a partner and leader of the Chemicals and Specialty Materials sector at Deloitte Belgium. His focus is on advising European chemical clients on growth, innovation, and performance improvement, and on the application of advanced technology in business operations.

Andrew Clinton is a senior manager in the Supply Chain and Manufacturing Operations practice at Deloitte Consulting NA. He is responsible for the development of analytics-based solutions for operations strategy, and he has led the development of industry-leading data analytics and visualization tools and capabilities.

Monika Mahto is an assistant manager with Deloitte Services India Pvt. Ltd., affiliated with Deloitte's Center for Integrated Research. Over the last eight years, she has been involved in various strategic research assignments for clients in the consumer and industrial products industry.

Brenna Sniderman is a senior manager with Deloitte Services LP, affiliated with Deloitte's Center for Integrated Research. Her research focuses on issues related to the application of advanced technologies in manufacturing and the supply chain, and their impact on business growth.

Acknowledgements

The authors would like to thank **Negina Rood** and **Robert Libbey** (Deloitte Services LP) and **Subramanian Neelakantan** and **Vaibhav Khobragade** (Deloitte Services India Pvt. Ltd.) for their research contributions to this report.

Contents

Introduction

IN one way or another, the chemicals industry contributes to almost every manufactured product. The industry converts petroleum and natural gas into intermediate materials, which are ultimately converted into products we use daily. With more than 20 million people employed and annual sales of $5 trillion, the global chemicals industry serves as the backbone of many end-market industries such as agriculture, automotive, construction, and pharmaceuticals.[1] Changes in the chemicals industry are thus likely to have a ripple effect on a number of other industries.

The rise of the fourth industrial revolution, or Industry 4.0 (see the sidebar "An overview of Industry 4.0"), is likely to drive such changes. Industry 4.0 brings together a number of digital and physical advanced technologies to form a greater physical-to-digital-to-physical connection—and it can potentially transform the chemicals industry by promoting strategic growth and streamlining operations. The time is ripe for such a transformation: Advanced technologies relevant to the chemicals industry—such as the Internet of Things (IoT), advanced materials, additive manufacturing, advanced analytics, artificial intelligence, and robotics—together have reached a level of cost and performance that enables widespread applications.[2] More importantly, these technologies are now advanced enough that they can integrate with chemicals companies' core conversion and marketing processes to digitally transform operations and enable "smart" supply chains and factories as well as new business models.

For example, BASF is using Industry 4.0 applications in its deployment of connected systems and advanced analytics models for predictive asset management, process management and control, and virtual plant commissioning.[3] Beyond these traditional applications, the company completely automated the production of liquid soaps at its smart pilot plant in Kaiserslautern. Once a user places an order for a customized soap, the radio-frequency identification tags attached to the soap containers inform the equipment on the production line via wireless network connections about the desired composition of the soap and packaging—thus enabling mass customization without human involvement.[4]

Industry 4.0 brings together a number of digital and physical advanced technologies to form a greater physical-to-digital-to-physical connection—and it can potentially transform the chemicals industry by promoting strategic growth and streamlining operations.

This paper assesses key Industry 4.0 applications across different stages of the chemicals value chain. With the help of use cases, the paper analyzes the opportunities that Industry 4.0 applications present, and discusses ways in which Industry 4.0 technologies could help chemicals companies achieve strategic imperatives, specifically in the areas of business operations and business growth. Because data play a key role and act as a connecting link between information technology (IT) and operations technology (OT), a solutions layer architecture for data management and use can help executives plan and deploy advanced technologies and address challenges related to Industry 4.0 applications.

AN OVERVIEW OF INDUSTRY 4.0

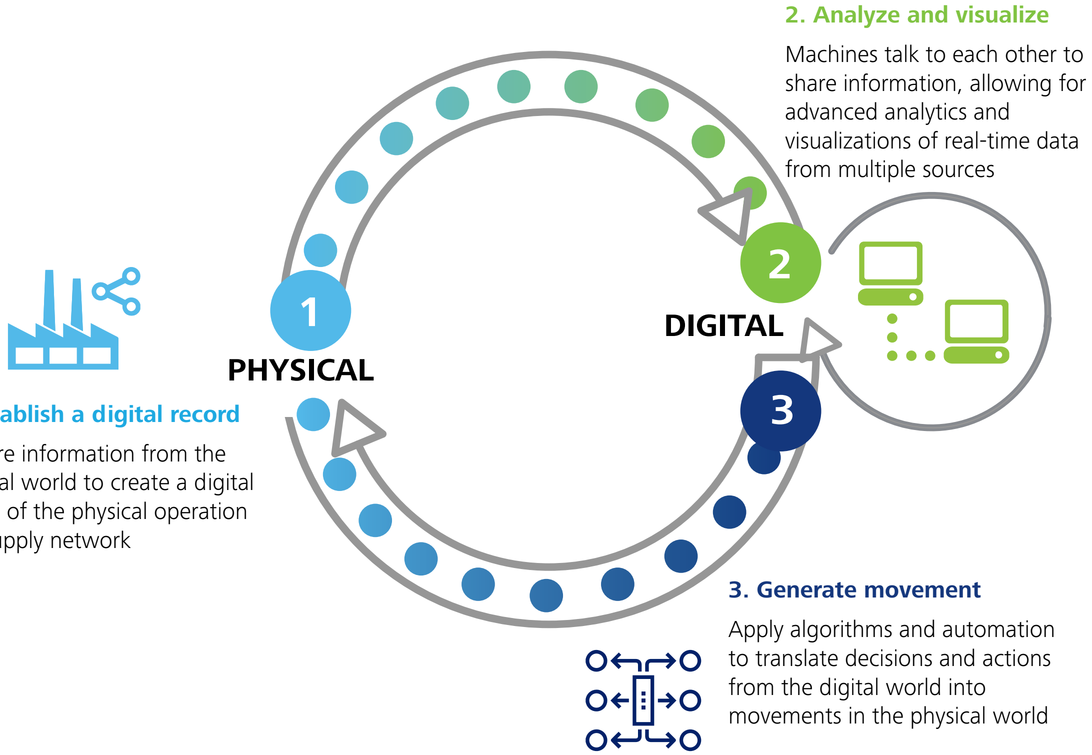
As we explore the ways in which information is used to create value, it is important to understand this from the perspective of the manufacturing value chain, where organizations create value from information via the movement from physical to digital, and back to physical. Industry 4.0 combines the connected technologies inherent in the Internet of Things (IoT) with relevant IT and OT, including analytics, additive manufacturing, robotics, high-performance computing, artificial intelligence, cognitive technologies, advanced materials, and augmented reality, to drive the physical act of manufacturing.

Industry 4.0 incorporates and extends these connected technologies to complete the physical-digital-physical cycle (figure 1).[5] The physical-to-digital and digital-to-physical leaps are unique to manufacturing processes; it is the leap from digital back to physical—from connected, digital technologies to the creation of a physical object or an improved process—that constitutes the essence of Industry 4.0.[6]

Broadly speaking, we identify two business imperatives for manufacturers: **operating the business** and **growing the business**. The focus on operations and growth can serve as a guide on which areas of the value chain merit greatest attention. Some areas can be readily addressed through Industry 4.0 applications. Deloitte terms these areas *transformational plays*: areas within the manufacturing value chain in which manufacturers can apply Industry 4.0 to achieve business imperatives.

For further information, see *Industry 4.0 and manufacturing ecosystems: Exploring the world of connected enterprises.*[7]

Figure 1. The physical-to-digital-to-physical leap of Industry 4.0



Sources: Center for Integrated Research

Graphic: Deloitte University Press | DUPress.com

What can Industry 4.0 do for chemicals?

OF the two imperatives of business operations and growth, organizations focused on the former can use Industry 4.0 technologies primarily to improve productivity and reduce risk, while those focused on growth can apply Industry 4.0 to build incremental revenue or generate wholly new income streams.

Table 1 illustrates the Industry 4.0 transformational plays (see the sidebar "An overview of Industry 4.0") for the chemicals industry. These strategic objectives can be pursued at different stages of the chemicals value chain, and in combination with each other.

Table 1. Industry 4.0 transformational plays for the chemicals industry

Product impact	Key objectives	Transformational plays
BUSINESS OPERATIONS	Improve productivity	• Smart manufacturing • Supply chain planning
	Reduce risk	
BUSINESS GROWTH	Add incremental revenue	• Research and development • Smart products and services
	Generate new revenue	

Source: Deloitte analysis.

Graphic: Deloitte University Press | DUPress.com

The initial momentum of Industry 4.0 in the chemicals industry is primarily at the level of business operations, mainly due to the abundance of historical sensor data collected by chemicals companies over the years.[8] The long-term potential for business growth applications promises to be equally, if not more, transformational, but those applications take time to develop.

Improving business operations: Productivity and risk

As table 1 shows, improving business operations manifests in two ways: improving productivity and reducing risk. The productivity of chemicals plants can be improved by various smart manufacturing techniques: predictive asset management, process control, and production simulations, among others. Reducing risk, though, involves managing supply chains and in-house operations to respond to changing customer needs and to improve safety and quality (table 2).

Smart manufacturing: Marrying IT and OT to improve productivity

Also known as "smart factory," smart manufacturing combines IT, such as the IoT, artificial intelligence, and advanced analytics, with

Table 2. Key objectives and transformational plays related to business operations

Key objectives	Transformational plays and description	
Improve productivity Reduce risk	**Smart manufacturing**	Predictive asset management: Maximize asset utilization and minimize unplanned downtime
		Process management and control: Minimize production variability and improve quality
		Energy management: Reduce energy costs and assess alternative energy sources
		Safety management: Monitor assets, processes, people, and products on a continuous and real-time basis
		Production simulation: Improve operator training, manufacturing planning, and timely plant commissioning
	Supply chain planning	Safety management: Monitor assets, processes, people, and products on a continuous and real-time basis
		Demand forecasting: Adjust production schedules in line with changing customer needs

Source: Deloitte analysis.

Graphic: Deloitte University Press | DUPress.com

The productivity of chemicals plants can be improved by various smart manufacturing techniques: predictive asset management, process control, and production simulations, among others.

OT, such as additive manufacturing, advanced materials, and robotics.[9] This process can benefit chemicals companies in several ways:

Predictive asset management

The chemicals industry is characterized by high asset intensity. As such, advanced IT/OT technologies can help companies optimize their maintenance spends and improve asset efficiency through predictive or digital maintenance. Using the continuous feed of data collected from sensors on critical equipment such as turbines, compressors, and extruders, advanced analytics tools can identify patterns to predict and diagnose possible breakdowns. In doing so, *smart equipment* can send messages to plant operators about any required maintenance, potential breakdowns, and parts ordering and delivery schedules. This can enable manufacturers to evolve from scheduled or reactive repairs to predictive maintenance. Also, data from similar equipment installed in different sites can be collected, compared, and used for predictive maintenance, performance optimization, and design of new facilities.

The simultaneous relay of machine performance information to both the chemicals company and the equipment manufacturer can also improve aftermarket performance: Equipment that performs according to performance contract earns agreed-upon payment, while the payment for equipment with failures or breakdowns early in the promised life cycle is lower. Such arrangements are especially critical for the chemicals industry, where equipment is sophisticated and expensive.

In one example, a global chemicals company repeatedly faced unplanned downtime due to an extruder that failed more than 90 times in one year—leading to losses in production, scrap, and overtime labor. Using real-time monitoring, the company gathered structured data from the extruder sensors as well as unstructured data from maintenance records, training records, and other sources, and developed failure prediction models. By evaluating cause-and-effect relationships, the prediction model generated alerts and recommendations on the extruder performance. Business results included an 80 percent reduction in unplanned downtime and operational expenditure savings of about $300,000 per asset. As part of a transformation of its operating model, the company is considering deploying similar asset management systems for other critical assets across plant locations.[10]

Process management and control

In earlier days, control rooms of petrochemicals companies used to have analog controllers along the walls; operators walked around the room, manually checking readings to ascertain plant operations and conditions. In modern control rooms, data are collected through connected systems and presented to operators digitally, obviating the need for manual reviews and saving operators' time and effort.[11] Digitization is only the first step, however. Industry 4.0 technologies such as real-time analytics and automated control actions bring together the digital and physical realms—supporting prediction, alerts, and prescriptive responses. This, in turn, enables greater control over batch consistency and quality.

Process variability results from a variety of factors, starting from the quality of the raw materials to variations in internal processes such as raw material dosing, temperature control, residence times, system fouling, and aging catalysts.[12] Similar to predictive asset management, process management involves collecting structured and unstructured data via sensors from various sources such as the lab, alarms, and process equipment. Analytics models help to identify patterns and deviations in chemical processes before they occur, thus reducing production risks.

Energy management

Energy costs contribute significantly to a chemicals plant's production costs. A typical plant involves multiple activities and their interactions, and it is difficult for operators to select optimal operating conditions. One leading manufacturer, Borealis, uses data mining and modeling to develop dynamic target values for the energy consumption of a plant—accounting for factors such as the current conditions of the plant, outside temperatures, fouling of the systems, aging of the catalysts, etc.[13]

Digitization is only the first step, however. Industry 4.0 technologies such as real-time analytics and automated control actions bring together the digital and physical realms—supporting prediction, alerts, and prescriptive responses.

The chemicals industry has a high degree of automation, and most plants monitor standard variables such as temperature, flows, tank levels, and pressures to derive optimal plant working conditions. However, Industry 4.0 technologies such as soft or virtual software sensors can augment these data points with additional information and enable control of nonstandard process variables to improve energy efficiency. Soft sensors are neural-network–based inferential estimators that can process a number of variables collected through standard instrumentation, estimate new process and equipment parameters (not otherwise collected), and improve operator effectiveness and plant efficiency. Soft sensors can be helpful in cases where physical instrumentation is expensive or difficult to install.[14]

Safety management

Given the sensitive nature of their products, it is particularly critical that chemicals companies ensure the safety of their employees, supply chain partners, and customers throughout the product life cycle, from production to storage, transport, and end use.[15] While traditional safety methods involve monitoring and testing samples, connected technologies can help companies in continuously monitoring products, by-products, as well as any waste generated. For example, "smart" (piezoelectric composite) paints can sense mechanical vibrations or other changes such as corrosion or cracks in a chemical tank and inform the operators, reducing production risks.[16]

In another example, a specialty chemicals manufacturer uses unmanned aerial systems (drones) to inspect hard-to-reach or dangerous plant locations and equipment such as elevated pipelines, power lines, tanks, and flare stacks. Traditionally, the company used ropes, ladders, and bucket trucks for monitoring and inspecting elevated structures. Inspection of flare stacks is especially tricky because flare temperatures could exceed 2,000 degrees Celsius, requiring the plant to be temporarily shut down for a manual inspection.[17] In contrast, drones equipped with cameras can capture high-resolution images, while a variety of sensors can capture much more information than the human eye, thus improving the efficiency of maintenance engineers and safety of the plant and surrounding areas.

Production simulation

Chemicals companies are increasingly using 3D visualization and virtual reality for training operators and maintenance staff. Siemens' Immersive Training Simulator, for example, provides operators virtual experience of various on-site situations. Trainees can "walk" across a simulated plant, "work" with the equipment and instruments, and "handle" safety situations. They also can collaborate with their peers, and individual and collective performances can be monitored by instructors.[18] Operators can also access the real plant data created through the use of digital twins.[19]

In addition to operator training and prognostics, 3D virtualization also helps operators prepare before the plant operations begin. BASF is using a simulated environment to reduce the time required for plant commissioning at its site in Germany.[20] The company can validate automation configurations, while data inconsistencies and errors in the automation can be identified and corrected. In another example, Sinopec Engineering, a Chinese chemicals company, used SmartPlant 3D, an advanced plant design software, to plan the plant structure, machinery, and piping models for a 300,000-ton polyethylene project in Maoming and improve workflow.[21]

Supply chain planning: Predicting changes to reduce operational risk

Industry 4.0 helps chemicals companies plan their supply chains in two ways: First, sensors and connected systems can help to improve visibility into the supply chain, reducing risks. Second, advanced analytics tools can help chemicals companies predict demand patterns and accordingly align their supply chain and manufacturing operations.[22]

Supply chain visibility

Chemicals companies largely operate on a business-to-business model, selling products that are used by their customers to create another set of products. In some instances, customers may require that the products be delivered within a specific range of temperature or pressure so that they are suitable for subsequent production processes. To monitor chemicals during transit—a delicate time for monitoring and controlling conditions—many companies in the upstream and downstream value chain use connected tools such as Ovinto satellite monitoring devices on railcars. The device is fitted with a GPS to track the location of the railcar, while several sensors measure the physical properties of the chemicals as well as the condition of the railcar via data such as shock impacts. The data are collected through Low Earth Orbit satellites that ensure continuous connectivity. The system generates alerts when the railcar is near the customer location or is involved in an impact or collision, or when the physical properties of the chemicals being transported exceed the set ranges, thus triggering automated action or manual intervention.[23] The visibility provided by the direct, continuous interaction between the railcar and chemicals company can enable better supply chain planning while helping to ensure safe transport of dangerous chemicals.

The above example illustrates the opportunity for chemicals companies to build and operate in digital ecosystems that enable several players—the transport operator, sensor provider, satellite network operator, technology provider for data storage on the cloud, and analytics provider for data analysis and visualizations—to work in tandem toward a common business objective.

Demand forecasting

Chemicals companies can achieve capacity optimization through demand forecasting and responsive scheduling. In one example, BASF is deploying a predictive analytics approach by combining the company's historical data with economic data, enabling it to forecast demand. The forecasting model considers external factors such as seasonal effects, macroeconomic data for customer industries at national and regional levels, regulatory changes, and internal factors such as BASF's strategies—expansion, mergers and acquisitions, divestures, and other transactions. Using the forecasting model, BASF can plan and adapt its plant runs as demand changes.[24]

> Industry 4.0 helps chemicals companies plan their supply chains in two ways: first, by improving visibility into the supply chain; second, by predicting demand patterns.

Demand forecasting is relatively easier for companies in the downstream chemicals value chain, given their proximity to end customers. AkzoNobel, for instance, uses point-of-sale data from retail outlets to reduce operational risks associated with out-of-demand paints and holding costs associated with slow-moving inventories.[25] Demand forecasting can be extended beyond the point of sale to earlier stages of the value chain. Apart from working with their construction companies, chemicals companies can use sensing software to monitor construction-relevant discussions on social media and draw inferences about customer sentiments related to new construction as well as inclination toward home buying and renovation.[26] The collected data can be classified according to a number of criteria such as sites, geographies, and demographics to understand different buying behaviors. In order to validate the demand signals, the information collected from social media can be compared with information from other sources such as residential listings, search behaviors, and actual past data from the census and third parties.[27] Such forecasting efforts can help chemicals companies identify demand indicators, and expand or contract their production capacities accordingly.

Growing the business: Incremental and new revenue

The transformational plays Industry 4.0 offers related to business growth lie on two ends of the value chain. On one end, companies can develop new offerings or improve existing ones through research and development (R&D) of advanced materials and specialty products. On the other end, digital technologies enable chemicals companies to integrate with customers' operations and customize products, extend their products with information and services in a way that allows them to charge premiums, and, at times, develop new business models (table 3).

The transformational plays Industry 4.0 offers related to business growth lie on two ends of the value chain.

Research and development: Developing new products to expand revenue

R&D is perhaps the most critical stage in the value chain: It shapes not only how the products will be manufactured but also informs subsequent improvements.[28] Because R&D demands heavy investment, chemicals companies are looking at big data and other tools to predict the outcome of an investment. In the field of material genomics, for example, advanced analytics helps researchers use the available data to understand the chemical properties of available materials, and consider possible combinations in order to develop new materials with desired properties for specific customers.

Additive manufacturing for testing or developing new products

Additive manufacturing (also known as 3D printing) uses information from the digital realm to create a physical product, encapsulating the IT/OT transition, potentially helping chemicals companies save costs during the R&D process. It allows designers to custom-build a reactor with specific geometrical configurations to control the chemical process within, as well as with the specific reaction kinetics or residence time of the chemical reaction.[29] For example, researchers at the University of Glasgow developed 3D-printed polypropylene reactors that could serve as cost-effective alternatives to stainless steel reactors. These plastic reactors—built at lab scale or bigger—perform just as well as traditional reactors at 150 degrees Celsius, potentially reducing operating costs of chemicals labs and aiding additional experimentation that might lead to the discovery of new chemical compounds.[30]

Furthermore, additive manufacturing can help chemicals companies develop and build advanced materials, creating new revenue opportunities. A leading manufacturer of specialty chemicals recently developed stretchable

Table 3. Industry 4.0 key objectives and transformational plays related to business growth

Key objectives	Transformational plays and description	
Add incremental revenue Bring in new revenue	Research and development	Additive manufacturing for testing or developing new products
		Advanced analytics for selecting materials
		4D printing for developing advanced materials
	Smart products and services	Developing smart products for chemicals applications
		Offering data services to augment existing revenues
		Building new revenue models by forward-integrating into customers' operations

Source: Deloitte analysis.

Graphic: Deloitte University Press | DUPress.com

> Advanced analytics can help chemicals companies use digital information to create new "physical" materials.

and screen-printable electronic inks for use in smart clothing. Manufacturers can use the printable ink to embed sensors such as electrocardiogram, temperature, and motion sensors along with a battery onto a small, coin-sized disk on conventional fabrics to collect data via a smartphone app.[31]

Advanced analytics for selecting materials

Advanced analytics can help chemicals companies use digital information to create new "physical" materials. Researchers at the University of Illinois, Urbana-Champaign, recently developed a molecule-synthesis machine that develops new drugs and agricultural chemicals; it works by breaking down complex molecules into their basic building blocks, which can then be recombined to create new compounds.[32] Developments such as lower data-storage cost, high-performance computing (HPC), and advanced analytics help build databases that store information on available materials and their properties, as well as present new material combinations with desired properties—leading to advances in material genomics.[33] Chemicals companies could also shift from trial and error to modeled outcomes to digitize the material-selection process.[34]

The Deloitte report *Driving growth: Advanced materials systems* discusses a reverse approach in which companies could start with the function they would like the materials to perform in a solution or system. Then, through "reverse engineering," companies can determine what the chemical and physical properties of the constituent materials should be and develop materials accordingly.[35] As their customers start to use this approach, chemicals companies may be pushed into a pure-play (contract) manufacturing role, thus disrupting their traditional business models of just selling liquids and solids. The next transformational play on smart products and services discusses how chemicals companies can develop differentiated value-based propositions for their customers and grow their revenue streams.

4D printing for developing advanced materials

Among many developments in advanced materials, one noteworthy example is that of programmable materials, also known as 4D printing. Developed at the MIT's Department of Architecture lab, programmable materials can self-assemble and change shape and form with time—the fourth dimension. External stimuli such as light, heat, and water trigger expansion and contraction at different places in the material.[36] As commercial developments materialize, the chemicals industry can use programmable materials to create new products for customers in the aerospace, automotive, construction, and health care industries, benefitting from new revenue streams.[37]

Smart products and services: Making products intelligent and creating new data services

Advanced technologies such as the IoT could allow chemicals companies to add intelligence to their existing products and deliver better customer service. In addition, chemicals companies could complement their traditional pay-by-the-ton revenue model by offering value-added data services. By forward-integrating into their customers' operations, chemicals companies can deliver value propositions and even build new business models.[38]

Smart products for chemicals applications

Beyond offering traditional products, chemicals companies can provide technical recommendations via an app or software to help customers determine the right choice and application of chemical products. In this way, the combination of chemicals and technology becomes a "smart solution," or a larger product and service offering. Eastman Chemical, for example, offers an online "solvent comparison tool" and a web-based "resin calculator" for its coatings customers. The solvent comparison tool helps companies compare and choose resins and solvents based on their properties. The resin calculator generates resin solubility charts for various resins sold by Eastman as well as other chemicals manufacturers, and helps customers understand the stoichiometry for resin polymerization in coatings and adhesives applications. Once the user enters a selection of raw materials and resin parameters, the model uses a series of calculations to propose a resin product that meets the desired parameters. Both the tools provide formulators with the technical intelligence to develop coatings that meet various performance requirements within cost constraints.[39]

Data services to augment existing revenues

Information and connected systems can help chemicals companies create data services that complement their existing product revenues. For instance, Monsanto offers a "Climate Basic" app that provides farmers with real-time information collected from satellites on temperature, weather, and soil conditions and forecasts for the next few days, along with recommendations on optimal water levels and fertilizers based on the information collected from the field.[40]

Likewise, there are software tools that help farmers detect and diagnose plant diseases. The farmer can click a picture of the diseased plant and feed the image into an analytical model. The model works by comparing the leaf's diseased part with images of diseased plants stored on a connected database. Once the model identifies a match, it provides recommendations for treatment. For validation of computerized recommendations, the image could also be sent to a laboratory and reviewed by pathologists. Additionally, alerts could be sent to farmers in nearby areas—identified via GPS—about the possible spread of that disease and suggestions for preventive measures.[41]

Both the examples illustrate how real-time farm information, combined with chemicals companies' historical databases built through years of field trials, could help farmers move from intuitive to analytical decision making around what seed to plant, when to plant it, and what inputs to provide: water, fertilizers, chemical treatments, and others.[42]

New revenue models by forward-integrating into customers' operations

Chemicals companies have the opportunity to use their years of collaborative knowledge to integrate within their customers' operations. Traditional manufacturers, in addition to selling water-treatment chemicals, provided water-treatment recommendations to their customers based on site visits and their understanding of materials and assets. With Industry 4.0 connectivity, monitoring, and analytics, chemicals companies can have direct visibility into and interaction with their customers' operations, and can provide real-time recommendations to optimize the operations and improve the design of water-treatment facilities; this, in turn, helps them create a new business model for themselves. One case in point is Ecolab, which provides water treatment as a service. In addition to supplying water-treatment chemicals, the company uses real-time monitoring of customers' operations and assets with advanced analytics to provide recommendations on water use, reuse, and recycling.[43]

Throughout each of the application areas discussed above, the collection, management, and use of data remain the most critical element of Industry 4.0; thus issues associated with data security, ownership, and interoperability are pertinent for executives planning Industry 4.0 deployments. A *solutions layer architecture*, discussed in the next section, allows executives to link data implementation to business-level decisions and build a digital DNA within their organizations.

The solutions layer architecture

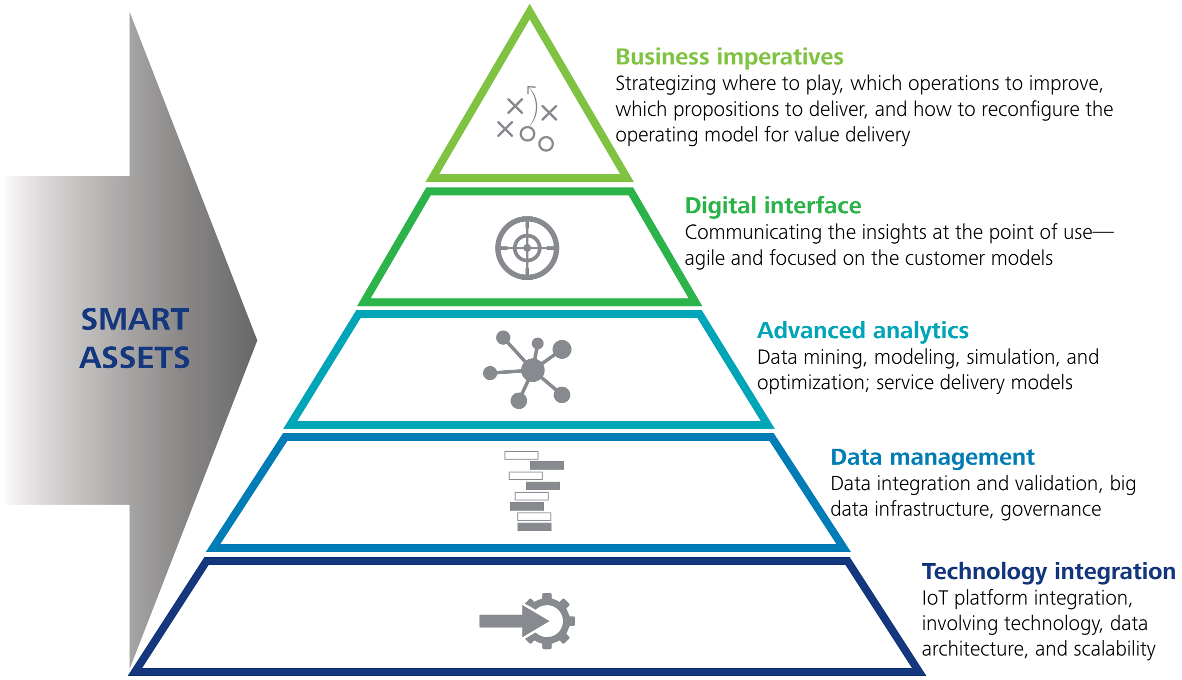
Enabling Industry 4.0 technologies and capabilities

IN Industry 4.0, data play a key role in connecting IT and OT. Data management, analytics, and automation, combined with domain knowledge in manufacturing and supply chain along with leadership support, are critical factors to enabling a company's Industry 4.0 journey.

These factors, however, can present challenges; it is difficult for organizations to know where to focus and what to prioritize, or even what capabilities should be put in place, to achieve their specific objectives. A structured series of capabilities, or a *solutions layer architecture*, can help executives plan and implement Industry 4.0 technologies. The goal of this architecture is to enable the company to build a *digital DNA*—the underlying sequence that brings together capabilities in different domains—required for a digital transformation.[44] The layers in this structure begin with technology integration, data management, and advanced analytics, which in the physical realm are manifested in the form of digital interfaces that are used to drive digital capabilities and, finally, the strategic imperative of the business.

The architecture draws on data from smart assets created via connected technologies used in product design, manufacturing and supply chain operations, and customer engagement. Figure 2 describes the multiple layers of Industry 4.0–driven capabilities that chemicals organizations must have as they seek to use information to drive productivity, reduce risk,

Figure 2. Solutions layer architecture and its key dimensions for Industry 4.0



Sources: Deloitte Services, LP.

Graphic: Deloitte University Press | DUPress.com

and grow revenue. Also, as Industry 4.0 facilitates increased connectivity between chemicals manufacturers and upstream and downstream partners along with their products, services, equipment, and information databases, managing cyber risk is a critical component.

Technology integration

The most fundamental layer of the Industry 4.0–driven approach for chemicals, technology integration encapsulates all of the technology elements that facilitate the physical-to-digital transition. The layer connects specific hardware components, supporting systems, and applications, facilitating the integration of different parts of chemical equipment, different equipment in a plant, and different chemicals plants across locations to share best practices on the use of data management and advanced analytics.

Data management

Data management includes all the activities associated with the collection, aggregation, storage, and processing of data. Chemicals companies are wrestling with the fact that their data are stored in different systems: Financial, sales, and marketing data are stored in one system; operations, production, and manufacturing in a different system; and R&D and engineering in another.[45] In order to truly realize the value of Industry 4.0, these data must be combined for a holistic view of the organization. The "data lake," a component of the data management layer, combines all the data from multiple sources, both internal and external, on cloud-based warehouses and deploys real-time analytics to provide meaningful insights to chemicals manufacturers.[46] The amount of data generated may necessitate tools such as HPC and other Industry 4.0 technologies.

Advanced analytics

Once all the data are aggregated, advanced analytics makes sense of the information to drive action in the physical realm. Data about chemicals processes, asset performance, energy use, and supply chain operations—even if not in a perfect and clean state—can be used to draw meaningful insights that can guide informed decision making. Talent is an important issue here: Industry 4.0–driven advanced analytics requires not just software programmers but also analysts who can marry chemicals domain knowledge with software capabilities.

Digital interface

This layer describes how the insights generated by analytics are conveyed to the business user, with a focus on customizations for the applications and end users. Insights are conveyed in a meaningful and useful way to the user at the point of use (for example, on the factory floor or during a face-to-face interaction with the customer) so that users can either determine next steps or understand the impetus behind actions that have automatically been taken by intelligent systems and machinery. The digital layer is critical in facilitating this delivery.

Business imperatives

At this layer, company leaders can use the data to determine actions they may want to take based on their current strategic position and where they want to go. What is important to note here is that, via Industry 4.0 technologies such as advanced analytics, HPC, and cognitive computing, chemicals companies have far wider and deeper insight than ever before, enabling more informed strategy decisions. At the same time, however, strategic decisions must include a willingness to make investments in Industry 4.0 technologies in the first place, and this can present a significant hurdle. Financial implications associated with the cost of purchasing smart equipment, retrofitting old equipment with sensors, and meeting connectivity and energy requirements must be addressed. In addition to the financial factors, behavioral factors associated with leadership's hesitation to deploy new technologies present an altogether-different set of challenges to Industry 4.0 implementations.[47]

Climbing the pyramid: Where to start

Chemical companies need to build capabilities on each of the layers to achieve some combination of business operations and growth. As chemicals organizations seek to build an Industry 4.0 solutions architecture, the following actions might help them:[48]

- **Start with what you know or do best**. A good starting point could be the areas where chemicals companies have a strong foundation: Use organizational agility to absorb changes in mature chemicals processes, traditional products, and supply chain operations where there is good visibility, then move onto relatively newer, more complex applications. This approach should work well because chemicals companies are likely to have historical data related to mature products and processes that they can leverage to uncover new insights and identify new sources of operations improvements or revenue growth.

- **Enable a cross-functional Industry 4.0 team**. The competencies required in the architecture sit in different business functions, and hence it is important that chemicals executives create a cross-functional team to focus on Industry 4.0 opportunities. It is worthwhile to reiterate that Industry 4.0 applications extend across different stages of the value chain, making it even more relevant for chemicals companies to bring together competencies from different departments—such as R&D, sourcing, manufacturing, and commercial operations—in pursuit of a common imperative related to business operations or growth.

- **Build and be a part of a pervasive ecosystem**. Companies need to build diverse capabilities in big data infrastructure, management, integration, validation, and analytics to be able to deploy Industry 4.0 applications. This requires chemicals companies to partner with technology vendors, analytics providers, and universities, among others, to manage operations at each layer. Chemicals companies have access to customers' data related to their assets, manufacturing activities, and buying attitudes; however, often, those data are underutilized. Chemicals companies can collaborate with partners and utilize those data brownfields to draw insights on developing smart chemicals products and service-based value propositions, and devising new revenue models.

- **Manage your cyber risk**. With greater interaction with ecosystem partners, chemicals manufacturers should focus on a risk management policy and technologies. These can help them manage the risks associated with retrofitting and loosely coupled assets as well as those associated with scalable automated systems that eliminate human involvement.[49]

Conclusion

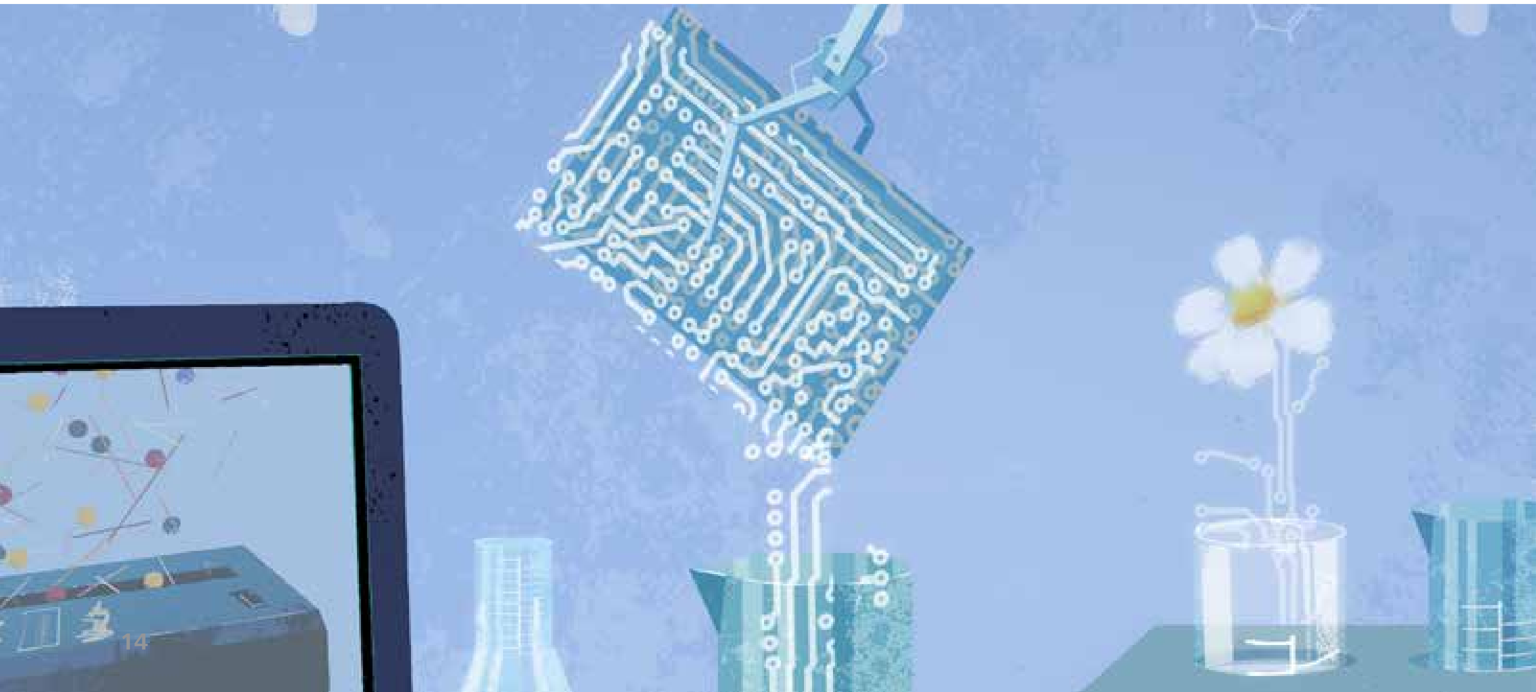
INDUSTRY 4.0 will likely impact the way chemicals companies operate and grow their businesses, as they shift away from the pay-by-the-ton revenue model to provide value-added products and services to their customers. How fast and well companies perform will depend on the decisions they take today and the initiatives they commit to for the coming years.

A clear understanding of their strategic imperatives can enable chemicals companies to plan their Industry 4.0 journey and help them identify how to integrate their digital and physical assets across different stages of the value chain. The use cases discussed earlier in the paper illustrate how chemicals companies can use Industry 4.0 technologies to enhance business operations via asset optimization, process and energy management, and safety processes, while also thinking about ways to grow their business through advanced material discoveries, smart chemical products, and new service-driven value propositions.

Note that the applications presented in this paper are not meant to be exhaustive but instead should provide ways for chemical executives to think through the opportunities that Industry 4.0 offers: evaluate their current strategic position; deploy advanced technologies in select applications to develop a proof of concept; and reconfigure operating models and, potentially, business models based on the outcomes.

As companies face various challenges in their journey to Industry 4.0, it is critical that they prepare their technology and data landscape to support the evolving changes in their products, services, and, at times, new business models to create a competitive advantage for themselves in the long run. The solutions layer architecture provides a simple way to approach the competencies required to deploy Industry 4.0 technologies. Beyond technology, however, the agility of people and organizations in adapting to change determines how effectively they adopt Industry 4.0.

As changes in chemicals affect related industries, time is of the essence: Industry 4.0 is no longer a topic of the future.



Endnotes

1. International Labor Organization, "ILO meeting: Decent work in the chemical industry," November 25, 2013, http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_230469/lang--en/index.htm; Paul Mulvaney, "Chemistry has a bright future for us and our economy," Phys.org, February 19, 2016, http://phys.org/news/2016-02-chemistry-bright-future-economy.html.
2. For detailed analyses on each of these technology domains, visit Deloitte University Press's Internet of Things collection at http://dupress.com/collection/internet-of-things/; additive manufacturing collection at http://dupress.com/collection/3d-opportunity/; and analytics collection at http://dupress.com/collection/analytics-strategic-advantage/.
3. BASF, "BASF cooperates with partners to introduce online control of complex batch processes," March 25, 2015, https://www.basf.com/en/company/news-and-media/news-releases/2015/03/p-15-172.html; Siemens, *Industry journal: Topics, trends, and technologies for decision makers in manufacturing*, January 2014, https://www.industry.siemens.com/topics/global/en/magazines/industry-journal/Documents/industry-journal-1-2014-en.pdf.
4. Germany Trade & Invest, *Industrie 4.0: Smart manufacturing for the future*, July 2014, http://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Brochures/Industries/industrie4.0-smart-manufacturing-for-the-future-en.pdf; Christopher Alessi, "Germany develops 'smart factories' to keep an edge," *Market Watch,* October 27, 2014, http://www.marketwatch.com/story/germany-develops-smart-factories-to-keep-an-edge-2014-10-27.
5. For detailed analyses on each of these technology domains, visit Deloitte University Press's Internet of Things collection at http://dupress.com/collection/internet-of-things/; additive manufacturing collection at http://dupress.com/collection/3d-opportunity/; and analytics collection at http://dupress.com/collection/analytics-strategic-advantage/.
6. Germany Trade & Invest, *Industrie 4.0*; National Academy of Science and Engineering, "Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative Industry 4.0," April 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf, accessed May 24, 2016.
7. Brenna Sniderman, Monika Mahto, and Mark J. Cotteleer, *Industry 4.0 and manufacturing ecosystems: Exploring the world of connected enterprises*, Deloitte University Press, February 22, 2016, http://dupress.com/articles/industry-4-0-manufacturing-ecosystems-exploring-world-connected-enterprises/.
8. Based on our discussions with internal chemicals industry practitioners.
9. The "smart manufacturing" transformational play maps to the "smart factory" transformational play, as described in Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.
10. Based on client work in our Supply Chain and Manufacturing Operations practice.
11. Based on our discussions with internal chemicals industry practitioners.
12. Based on our discussions with internal chemicals industry practitioners. "Residence time" refers to the time a material stays in a chemical reactor, while "system fouling" refers to the accumulation of unwanted material with a detrimental effect on the function provided by the system.
13. Based on client work.
14. Hiromasa Kaneko and Kimito Funatsu, "Database monitoring index for adaptive soft sensors and the application to industrial process," *AIChE Journal* 60, no. 1 (2014): pp. 160–69, DOI:10.1002/aic.14260.
15. Based on our discussions with chemicals executives and internal chemicals industry practitioners.
16. Y. Al-Saffar, O. Aldraihem, and A. Baz, "Smart paint sensor for monitoring structural vibrations," *Smart Materials and Structures* 21, no. 4 (2012), DOI:10.1088/0964-1726/21/4/045004.
17. Sarah Everts and Matt Davenport, "Drones detect threats such as chemical weapons, volcanic eruptions," *Chemical & Engineering News* 94, no. 9 (2016): pp. 36–37; Federal

Aviation Administration, "The Dow Chemical Company—exemption no. 11259," April 3, 2015, https://www.faa.gov/uas/legislative_programs/section_333/333_authorizations/media/The_Dow_Chemical_Company_11259.pdf.

18. Siemens, "Simulation and virtual reality: Training in the virtual world," October 1, 2014, http://www.siemens.com/innovation/en/home/pictures-of-the-future/digitalization-and-software/simulation-and-virtual-reality-immersive-training-in-virtual-worlds.html.

19. "Digital twins" are digital companions of physical assets built using data collected from sensors placed on equipment; digital twins can be used to model virtual plant operations. For further information, see Mark J. Cotteleer, Stuart Trouton, and Ed Dobner, *3D opportunity and the digital thread: Additive manufacturing ties it all together*, Deloitte University Press, March 3, 2016, http://dupress.com/articles/3d-printing-digital-thread-in-manufacturing/.

20. Siemens, *Industry journal: Topics, trends, and technologies for decision makers in manufacturing*.

21. Intergraph, "Case study: Sinopec Engineering Inc.," 2012, https://www.intergraph.com/assets/pdf/Sinopec_Case_Study.pdf.

22. The "supply chain planning" transformational play maps to the "planning" transformational play, as described in Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.

23. "Monitoring tank wagons via satellite," *Railway Gazette*, October 28, 2015, http://www.railwaygazette.com/news/freight/single-view/view/monitoring-tank-wagons-via-satellite.html; Ovinto, *Monitoring of hazardous goods in unpowered transport units*, www.ovinto.com/assets/ovintosatatex-brochure.pdf, accessed March 8, 2016.

24. Robert Blackburn et al., "A predictive analytics approach for demand forecasting in the process industry," *International Transactions in Operational Research* 22, no. 3 (2015): pp. 407–28, DOI:10.1111/itor.12122.

25. Terra Technology, "AkzoNobel selects Terra Technology's multi-enterprise demand sensing to further reduce inventory," November 12, 2013, https://www.terratechnology.com/akzonobel-selects-terra-technology-s-multi-enterprise-demand-sensing-to-further-reduce-inventory/.

26. Based on pilot work for a client proposal.

27. Ibid.

28. The "research and development" transformational play maps to the "engineering" transformational play, as described in Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.

29. To learn more about additive manufacturing, see Deloitte University Press's *3D Opportunity* collection at http://dupress.com/collection/3d-opportunity/.

30. Royal Society of Chemistry, "3D printed reactionware hots up," August 6, 2014, http://www.rsc.org/chemistryworld/2014/08/3d-printed-reaction-vessels-hot-temperature.

31. Mary Catherine O'Connor, "Powered with printable electronics and sensors, smart apparel is reaching for stretch goals," *IoT Journal*, November 25, 2014, http://www.iotjournal.com/articles/view?12454.

32. Robert F. Service, "The synthesis machine," *Science* 347, no. 6227 (2015), pp. 1190–93, DOI:10.1126/science.347.6227.1190.

33. Ibid.

34. Council on Competitiveness, *Case study: Procter & Gamble's story of suds, soaps, simulations, and supercomputers*, July 28, 2009, http://science.energy.gov/~/media/ascr/pdf/benefits/Hpc_pg_072809_a.pdf.

35. For more information on the use of advanced technologies for the development of improved or new materials, see Duane Dickson, Tom Aldred, and Jeff Carbeck, *Driving growth: Advanced Materials Systems*, Deloitte University Press, March 28, 2013, http://dupress.com/articles/advanced-materials-systems/.

36. Dan Headrick, "4D printing transforms product design," *Research Technology Management* 58, no. 2 (2015): pp. 7–8.

37. Based on our discussions with chemicals executives and internal chemicals industry practitioners.

38. The "smart products and services" transformational play maps to the "smart products" transformational play, as described in Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems.*

39. Eastman Chemical, "Online tools," http://www.eastman.com/Products/Pages/Chemical_Wizards.aspx, accessed April 5, 2016.

40. Monsanto, "Finding the perfect planting window: The evolution of weather forecast," http://www.monsanto.com/improvingagriculture/pages/the-evolution-of-weather-forecast.aspx, accessed April 28, 2016.

41. Suporn Pongnumkul, Pimwadee Chaovalit, and Navaporn Surasvadiet, "Applications of smartphone-based sensors in agriculture: A systematic review of research," *Journal of Sensors* 2015 (2015): p. 4, DOI:10.1155/2015/195308, accessed April 12, 2016.
42. Manfred Kern, Digital agriculture, ISPSW, 2015, p. 3, http://www.isn.ethz.ch/Digital-Library/Publications/Detail/?id=189104; Tim McDonnell, "Farming in the face of climate change? Monsanto has an app for that," *Grist*, November 20, 2014, http://grist.org/climate-energy/farming-with-monsanto-seeds-theres-an-app-for-that/.
43. Ecolab, "Water management technologies," http://www.ecolab.com/innovation/core-technologies/water-management-technologies/, accessed May 12, 2016.
44. The Deloitte LLP research report *Building your digital DNA: Lessons from digital leaders* (2014) presents insights from a series of interviews and discussion groups with digital executives across industries and Deloitte consultants from the Deloitte Digital and Human Capital practices. The report, together with an interactive Digital Leadership Hub (http://www.deloitte.co.uk/digitalleadershub/index.htm#/), provides a toolkit to help organizations assess their digital maturity levels and navigate the leadership, organizational, and talent aspects of their digital transformation journey. View the complete report at http://www2.deloitte.com/uk/en/pages/technology/articles/building-your-digital-dna.html.
45. Based on our discussions with chemicals executives and internal chemicals industry practitioners.
46. For detailed analysis on data architectures, refer to Rajeev Ronanki et al., *Industrialized analytics: Data is the new oil. Where are the refineries?* Deloitte University Press, February 24, 2016, http://dupress.com/articles/data-assets-and-analytics/.
47. For detailed analysis, refer to James Guszcza and Mark J. Cotteleer "Editorial: Behavioral insights—putting Humans in the loop," *Deloitte Review* 18, Deloitte University Press, January 25, 2016, http://dupress.com/articles/behavioral-insights-leader-column/.
48. Based on our discussions with internal chemicals industry practitioners.
49. For a detailed discussion and insights on this topic, see Deloitte Cyber Risk services at http://www2.deloitte.com/us/en/pages/risk/solutions/cyber-risk-services.html.

Contacts

Duane Dickson
Global and US Chemicals sector leader
Principal
Deloitte Consulting LLP
+1 203 905 2633
rdickson@deloitte.com

Andrew Clinton
Specialist leader, Strategy and Operations
Senior manager
Deloitte Consulting LLP
+1 347 406 1272
aclinton@deloitte.com

Stefan Van Thienen
Belgium Chemicals and Specialty
Materials sector leader
Partner
Deloitte Belgium
+3 227 495 731
svanthienen@deloitte.com

Mark J. Cotteleer
Director, Center for Integrated Research
Managing director
Deloitte Services LP
+1 414 977 2359
mcotteleer@deloitte.com

Follow @DU_Press

Sign up for Deloitte University Press updates at DUPress.com.

About Deloitte University Press
Deloitte University Press publishes original articles, reports and periodicals that provide insights for businesses, the public sector and NGOs. Our goal is to draw upon research and experience from throughout our professional services organization, and that of coauthors in academia and business, to advance the conversation on a broad spectrum of topics of interest to executives and government leaders.

Deloitte University Press is an imprint of Deloitte Development LLC.

Cover art by Eva Vasquez