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dow chemical co.: big data in manufacturing

R. Chandrasekhar wrote this case under the supervision of Professors Mustapha Cheikh-Ammar, Nicole Haggerty and Darren Meister solely to provide material for class discussion. The authors do not intend to illustrate either effective or ineffective handling of a managerial situation. The authors may have disguised certain names and other identifying information to protect confidentiality.

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It was September 2012. At his office in Texas City in the United States, Lloyd Colegrove, data services director at the Dow Chemical Company (Dow), was reviewing the results of a pilot study initiated by his team in one of the company’s U.S. manufacturing plants. The six-month study consisted of testing a data analytics module being used at the plant’s research and development (R&D) lab for its applicability to the shop floor. Attached to a laboratory information management system (LIMS), the module collected and analyzed data, in real time, from instruments tracking the quality parameters of finished goods at the plant, and acted upon them to maintain high quality yields.

The objective of the pilot study was to test whether the basic structure of the LIMS could be supplemented and extended, plant-wide, into a larger system known in the bourgeoning analytics industry as enterprise manufacturing intelligence (EMI). EMI was both a management practice and a software tool for manufacturing. It contained more sophisticated analytics than the LIMS and provided easier and faster aggregation of different data types. It also incorporated visualization tools to summarize key insights and post them on different dashboards for plant engineers to monitor and act upon. The possibility existed to scale up EMI company-wide, in all 197 of Dow’s manufacturing plants across 36 countries.

However, Colegrove had several issues on his mind:

The pilot [study] shows that plant engineers are working for the data; the data is not working for them. There is clearly an opportunity to reverse the trend through EMI. But the opportunity has also opened at least three dilemmas for me. How do we access data at the points of origin, [in] real time? Can we gain user acceptance of the proposed EMI and, if so, how? What are the metrics with which we could measure the return on investment on EMI?

GLOBAL CHEMICAL INDUSTRY

The chemical industry often served as a forerunner of the state of an economy, since its products were consumed at early stages in the supply chains of user industries. Its business consisted of processing raw materials to produce chemicals used, in turn, as raw materials by other industries. The business was cyclical, relying on basic commodities such as oil and gas, and volatile. Of the 20 largest chemical companies operating 25 years ago, for example, only eight remained in operation in 2012. The rest did not survive for three reasons: they were not making incremental and necessary changes to stay competitive; they were not ensuring a regular pipeline of new products, and they were not investing in the regular generation of patents covering proprietary manufacturing processes.

The global chemical industry was witness to a churn in relation to business models. By 2012, three models were evident worldwide. The first was characterized by ownership of resources such as feedstock (as the raw materials serving as inputs for the chemical industry were known). The companies following this model focused on securing low-cost positions through economies of scale since they used a large asset base to process largely commodity-like chemical products such as petrochemicals. The second model was characterized by niche positioning. The companies following this model were leaders in specific technologies and sought to protect their intellectual property through quality, innovation, and strong relationships with customers that purchased their niche products. The companies following the third model, such as Dow, were characterized as solutions providers. They understood end-to-end value streams in different user industries, developed strategic partnerships with customers to drive innovation, and responded to market changes faster than their industry peers.[[1]](#footnote-1) This space was getting increasingly competitive as oil producers, for example, sought to generate new revenue streams by moving into the space that companies such as Dow traditionally held.

More recently, some American companies, including Dow, were creating new production capacities in the United States because of the availability of low-cost shale gas on which to run their plants. Together, these companies committed up to US$110 billion[[2]](#footnote-2) of direct investment in advanced manufacturing factories in the United States.[[3]](#footnote-3) The North American chemical industry was also witness to the phenomenon of reshoring, resulting from low energy costs in the United States. In a telling example of the cost advantage being offered in that country, Methanex Corporation, a Canadian company and the world’s largest producer of methanol, was planning to close a plant in Chile and relocate to Louisiana in 2012.[[4]](#footnote-4)

Process variations were a major characteristic of the chemical industry. The amount of output per unit of input, known as yield, also often varied for no immediately apparent reason. Both of these inconsistencies had effects on product profitability. To ensure both quality and yield, it was common for a chemical plant to use statistical process control systems. These systems collected data from sensors on equipment and measurement instruments, such as meters and gages embedded within the process, to regularly monitor the statistical performance—and variations from “normal”—of equipment, processes, and materials.

Depending on the product, over 200 measures and variances were being monitored during the chemical transformation process by sensors, devices, and instruments on the shop floor. For example, gas chromatography instruments measured the various chemical elements in a sample as it passed through a process. The chemical inputs or outputs from a process had to be within certain parts per million to conform to normal specifications. Temperature was another type of measure. To improve yields, chemical companies applied management concepts such as lean manufacturing and Six Sigma. These companies were always looking for granular approaches to diagnose and correct process flaws.

BIG DATA ANALYTICS

The term “big data analytics” referred to the analysis of data originating from different sources to identify patterns and trends, according to which managers could make informed, rather than intuitive, decisions. Consulting firm McKinsey & Company defined big data as “data sets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze.”[[5]](#footnote-5) Research company Gartner defined it as “high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making.”[[6]](#footnote-6)

Big data analytics differed from conventional analytical approaches such as data warehousing and business intelligence in four ways: volume, velocity, variety, and veracity. The *volume* of data processed in typical data warehousing and business intelligence installations was measured in petabytes (i.e., 1,000 terabytes), whereas big data analytics processes dealt with volumes up to geobytes.[[7]](#footnote-7) By way of comparison, one petabyte was the equivalent of text requiring a storage capacity of 20 million filing cabinets of the kind used in a typical office. The *velocity* of big data installations supported real-time, actionable processes. A retailer, for example, could use geolocation data from mobile phones to ascertain how many customers were in the store’s parking lot on a given day, making it feasible to estimate the sales for that day even before the retailer had recorded those sales. The *variety* of sources from which big data could be mined included both structured data, such as database tables, and unstructured data originating from diverse sources such as mobile phones, social networks, sensors, video archives, radio-frequency identification (RFID) chips, and global positioning systems. Finally, the *veracity* of data referred to the inherent discrepancies in the data collected, bringing the reliability and trustworthiness of the data itself into question.

Any data that could be captured in a digital form had the potential to be analyzed using big data tools. The key algorithm in big data was known as MapReduce. The algorithm was part of the back-end analytics platform developed by Google in 2000. Having by then indexed 20 billion web pages amounting to 400 terabytes, Google faced three major challenges: the data were largely unstructured, the volume of data was huge, and the overall size of the digital universe was doubling every two years.[[8]](#footnote-8) Google engineers rose to the challenge by designing an analytics platform consisting of a parallel cluster of low-cost commodity servers, each containing a central processing unit and a disk to hold a subset of data.

In using MapReduce at Dow, Colegrove noted,

The MapReduce algorithm performs four types of procedures: it reads data from the disk; it maps the data by applying a variety of filters; it reduces the data by summarizing it in some specified ways; and it writes results back to the disk. By mapping and reducing the data across a parallel array of servers, you can cut down its processing time dramatically, from six hours to less than 30 minutes per petabyte.

The Enterprise Manufacturing Intelligence Challenge

Chemical plants had been the pioneers of what later came to be called big data as it pertained to manufacturing. The arrival of data historians in the 1980s had enabled process engineers to collect and store data, both technical and non-technical, from manufacturing operations.[[9]](#footnote-9) The data historians (mostly in an R&D capacity) stored terabytes of structured data generated daily from sources such as sensors, monitors, and meters accompanying each piece of machinery on a shop floor.

However, up until recently, plants, including Dow’s, had been generally better at collecting and storing data than using it in a holistic fashion. Most success up to 2012 with using data was derived from dealing with a variance in a process locally—at the point of the variance, rather than within the context of the whole process—as in resetting temperature controls on a piece of equipment. R&D engineers worked on historical insights, whereas process engineers in a plant worked on mostly local issues. Neither saw the thread that connected the data to the things going on both within and outside of an enterprise. They were busy collecting data instead of contextualizing it. For example, they would troubleshoot based on a post-mortem of the data after a problem with product quality or yield had emerged, but then months or years later would find themselves in the same situation and having to do the post-mortem all over again. They would continue to measure a parameter for years as a matter of habit without ascertaining whether the data was relevant or could add value to decision making.

A large chemical plant would normally have between 1,500 and 3,000 measures ranging from, for example, tracking the viscosity of a liquid to monitoring the electrical impedance on a motor. Each measure was known as a tag, and each tag was a source of data in an EMI system. The question was how to turn tags into valuable insights, so that tags were not just a local variable in the vast chemical transformation process.

The advent of supply chain connectivity in the 1990s established a loop that soon became seamless. Although engineers had access to technologies that helped them “listen” to business processes in the same way that marketers listened to customers, they were struggling with incorporating those technologies into a mix that could extract actionable insights from the data. One of the reasons for their struggle was that the plant and machinery infrastructure in many manufacturing companies was old. In sum, the challenge lay not in generating data, since data historians, statistical process control software, and long-term quality management practices were already well established; rather, the challenge for an EMI initiative lay in making the data actionable. Colegrove saw this as an opportunity and a means to enhance company performance in the long run.

In anticipating a move from data collection and storage to an integrated EMI system, Colegrove thought,

The EMI system will have three characteristics in its final form. It will encompass, in a single platform, the sampling, collation, and analysis of both structured and unstructured data from various sources in the manufacturing value chain including the company’s vendors. It will do so in real time. It will focus on finding value in existing data rather than on adding new measures to generate more and more data.

DOW CHEMICAL OVERVIEW

Founded in 1943 in Midland, Michigan in the United States, Dow had manufacturing sites in 197 locations in 36 countries. In 2011, it was the fourth-largest chemical company in the world by revenue, at $59.98 billion. The company employed about 52,000 people and had five business divisions (see Exhibit 1). Dow was the world’s largest producer of ethylene, which was a feedstock for many industries. Its ethylene capacity was Dow’s single largest competitive advantage and, with a commitment in 2012 to a $4 billion investment in plant capacity for ethylene, it provided the foundation for growth into the future. The 5,000 products in Dow’s portfolio were used as raw materials by businesses involved in providing, for example, clean water, affordable housing, healthy foods, and renewable energy.

Originally making inorganic chemicals, Dow had expanded into organic chemicals, petrochemicals, and then plastics. In recent years, it had moved beyond those singular sectors into operating at their intersections.[[10]](#footnote-10) Dow was redefining its core capabilities from being the best in one area to working at the intersection of multiple areas for the greatest good. It had identified several areas where it could achieve world-class breakthroughs aimed at finding solutions to global challenges.

Food was an example of Dow moving beyond singular sectors; the company had deployed its skills in chemistry to genetically modify canola seeds, yielding a type of canola oil with maximum omega-9 fatty acids for use by fast foods companies. Thus, Dow had taken 1.5 billion pounds (about 680 million kilograms) of fat out of the American diet. Another example was Dow’s BETAMATE, an adhesive that eliminated the need to weld metal to metal and then metal to plastic. Its use by car manufacturers had taken 30–40 pounds (roughly 13.5 to 18 kilograms) off the weight of every car, leading to a reduction in gasoline consumption in general.

For many years, the average age of Dow employees was 51. It had since dropped significantly to 41.[[11]](#footnote-11) The company had an average employee retention rate of 14 years. This was largely owing to the launch of a reinvention program during the early 2000s by Dow’s Chief Executive Officer Andrew Liveris.

Colegrove said,

There are three overarching challenges facing the global chemical industry: imminent large scale retirement of older employees; shortages of core engineering skills among the new generation of job seekers; and the general unpopularity of the chemical industry as an employer of choice. Millennials have little recognition of the relevance of the chemical industry to society, drawn as they are to IT [information technology] and financial services as career options.

As part of establishing a new foundation for innovation, Dow had been hiring statisticians, data scientists, and big data experts across the organization since 2005. The average time from the discovery of a product to its launch had since decreased from seven years to 14 months, and products were being customized rather than made for stock.

Colegrove explained,

Dow has a unique engineering culture. Its engineers are known to design the solution around the process, not the process around the solution. They value their professional autonomy. For example, Dow’s process automation series, known internally as Manufacturing Operating Discipline, was designed not by process automation engineers as in many chemical companies, but by chemical engineers familiar with the intricacies of the process.

Extracting Value from Big Data: Developing EMI at Dow

Dow plants had access to a lot of data; each facility had a statistical process control system, as was common in the industry, to collect measurements related to process instruments on the shop floor. Data was stored in any plant at four sources: instrument software; the LIMS; process historians, which created local copies of data; and enterprise systems such as SAP. Extracting data from the existing systems carried a time lag. Dow engineers had to use a locally written code to extract the data, transfer it to a spreadsheet (such as an Excel spreadsheet), and route it to a statistical tool (such as JMP statistical software from SAS) where a surveyor analyzed it. This practice was prone to both human and machine errors, as well as significant time delays. Getting the data into the spreadsheet alone could take a week. No data would come up for analysis unless there was a compelling reason, such as a problem requiring urgent resolution. Most of the analysis pertained to examining problems after they had occurred rather than troubleshooting in real time or anticipating them beforehand to prevent them from occurring. Until 2011, Dow was mostly using its R&D lab and R&D engineers to track tags and data and to collect measurements in the LIMS—mostly related to product quality.

Colegrove had three decades of experience in both research and manufacturing. Holding a PhD in chemical physics from Texas A&M University, he had begun his career at Dow in 1990 at its Polymers R&D and was involved in improving analytical methodology in various plant labs. He soon moved into manufacturing, where he went on to set up the applied statistics group, the first of its kind at Dow.

In his early days in manufacturing in the 1990s, Colegrove was surprised to notice that Dow deployed data analysis practices developed in the early 1970s, characterized by the most basic spreadsheet tools. The situation was, however, typical of the chemical industry, which was over a century old. He also noticed that he could extract value out of the existing data streams at Dow manufacturing by using advanced tools and more powerful computing capability, which had become available by then. By 2005, Colegrove had started collaborating with external “data scientists” (the term had not yet gained currency) and inviting them to work with Dow engineers on piecemeal projects. However, to his dismay, he soon discovered that Dow chemical and process engineers—who were among the best and the brightest in chemical engineering and recruited from premier universities around the world—considered the computational techniques to be the purview of the “privileged few” and something that people in R&D would find more valuable. This was mainly because process engineers had neither an educational background nor on-the-job experience in data analysis, which for them had a certain mystique around it. This continued to be an issue, and Colegrove wanted to bridge the prevailing gap between core engineering skills on the shop floor and data management capabilities, which were quickly becoming a necessary skill set on the shop floor.

The launch of an EMI pilot project in early 2012 in the polymer division of the Midland plant was a step toward bridging that gap. At that time, Dow was moving progressively into the manufacturing of customized products. Increasing levels of customization had resulted in a multi-product environment requiring complex changeovers of both equipment and processes. Monitoring these changeovers and producing data on product quality and utilization of inputs had become critical in the polymer division.

Dow had an R&D lab in each individual division of its manufacturing locations, which, in addition to allowing for research into new products and processes of the division, provided production support to the division. At its core, each lab was in the information business—storing, managing, and processing both current and historical information on a variety of process parameters—in which the LIMS was a key component. At the Midland plant pilot site, the EMI software that Colegrove was testing was integrated with the LIMS to allow engineers in the R&D lab to respond to the needs of customization in the polymer division; it delivered test results in real time to production engineers. Thus, the R&D lab had become the site of all innovation and exploration; however, the downside was that these individuals had no control over the real-time processes in the plant. Colegrove felt it would be better if the production engineers were engaged directly in EMI activities.

The pilot test provided other insights. First, the pilot test team observed that production engineers were better at collecting and storing data than interpreting it. The engineers were not familiar with contextualizing the data, nor with recognizing the difference between valuable data and not-so-valuable data. Second, some process metrics had been in place at the plant for 30–40 years. Plant engineers had become so accustomed to the existing process metrics that even when Colegrove’s team demonstrated that the metrics had nothing to do with efficiency, the engineers had a hard time letting go. Since the best value would be created by these plant engineers and not just by R&D staff sitting in the lab, Colegrove wondered how he would get their buy-in for EMI.

Several possibilities existed for the application of EMI. For example, EMI would enable Dow engineers to ascertain which of the multiple build-to-order configurations for a new chemical compound would have the least impact on manufacturing costs. Fine-grained data from EMI could also provide insights on developing substitutes for and variants of existing products. Real-time data could enable plant operators to be proactive rather than reactive, potentially eliminating their use of non-valuable data in situations where data collection had become a habit.

Another potential benefit of EMI was maintaining consistency in practices when dealing with issues. Plant supervisors at Dow factories around the world often interpreted similar data differently owing to different experiences, educational backgrounds, and even personal beliefs, which often bordered on biases. With the adoption of well-developed algorithms to process data and a common dashboard to display the results, EMI could ensure that plant supervisors would reach identical conclusions on witnessing identical process behaviours.

EMI was also necessary from the point of view of Dow’s customers, who were large and small businesses in a variety of industries. For example, a customer making personal care products expected its raw material vendors to provide historical evidence about the sources of its chemical ingredients, and EMI facilitated compliance with regulations around product safety, which was crucial in the personal care products industry. It also enabled its customers in the pharmaceuticals industry to comply with pharmacopeia rules on plant monitoring as part of drug regulatory requirements.

THE CHALLENGE AHEAD

As part of planning for the Midland plant EMI pilot project, Colegrove had put together a three-member team to examine the possibility of launching a full-fledged analytics system at a plant. Over a luncheon meeting, they drew out the possibilities for EMI beyond the pilot site (see Exhibit 2). They envisioned an opportunity to track the tags across the entire operation of a plant, and then across the organization. Colegrove wanted his team to play the role of enabler. He was keen that plant engineers should do the analysis themselves, rather than seek the help of organizational resources such as the information technology department or have the R&D engineers at each plant do the analysis for them. Being on the shop floor, they were better equipped, in his view, to listen and respond to the signals that the machines were sending out.

Colegrove identified several challenges of scaling the EMI pilot project:

We collect a lot of data at a Dow plant. But, as it happens in a large organization, much of that data does not get looked at. Data does not become information until it is analyzed. Without analysis, the data will not have value. That is why I am keen that data should not only be accessed at the point of origin but also be analyzed at the point of origin. Data silos add to the complexity of production lines. I want to keep it simple. We also do not want to make investments in replacing current databases and building new ones. EMI should not add substantially to our costs.

The first challenge was around the data—accessing it at the source equipment/process and accessing it in real time. Accessing data at the point of origin meant eliminating the need to move it to a parallel data space, which would mean a time lag in downloading data from multiple sources in the plant and getting it into spreadsheets for analysis. The parallel space detracted from direct interactions on the go among plant engineers, which were integral to sharing best practices. The redundancy inherent in parallel space would also contribute to data islands (data stores with non-existent or limited external connectivity), which would in turn forestall operational efficiency.

However, the concept of real time was not the same across Dow plants. It varied with whether it pertained to batch processing or continuous processing in the production line. In batch processing, the machine run often took a break, depending on internal issues such as the need for remedial intervention or on external issues such as a shortfall in sales orders. In continuous processing, there was no provision for a break. If the machine parameters were not on par, they would drain resources without a break, without the knowledge of plant engineers. Real-time tracking of data was thus more important in continuous processing.

Colegrove said,

Both collection and analysis of data need to be real time. The analytics platform should incorporate metrics which are mission-critical to enable continuous monitoring of process health. The metrics should be relevant to different levels of shop floor management. The platform should have graphical dashboards so that users see only those charts and graphs that are relevant to their specific areas and take remedial action on events as they happen. For instance, operations staff would use a visual dashboard for inventory accuracy reports, quality achievement metrics, and equipment downtime graphs. The dispatch staff might use a dashboard to track on-time shipping completion percentages and premium freight costs reports.

A second major challenge was adopting big data innovation at Dow. EMI practices and software were new to plant engineers. The diffusion of this innovation required their buy-in and was crucial to scaling it company-wide. Among other things, addressing two issues—simplification and integration—was important to gaining the buy-in of plant engineers.

Colegrove explained,

A common reaction from process engineers while the pilot [study] was under way was: “Your system, your suite with all those functions . . . is too complex.” They saw it as complex because they were required to not only read the data but interact with it, and they were to do it real time. It is therefore important to simplify the module before scaling it up. An option I am looking at is to make the suite modular.

This option meant cutting the suite into specific modules. Energy, for example, could be a module. Energy was a major cost element at Dow, as in all chemical plants. Dow had set specific targets through an energy intensity reduction program, which was tracked at the C-suite. Plant engineers had been regularly implementing measures such as putting better insulation around reactors and revising the inputs in favour of materials with lower energy requirements. A plant-wide EMI initiative could add valuable real-time information to the energy reduction effort and assist in making decisions leading to reduced energy consumption more quickly. Other examples of possible modules were waste recovery—waste was a major cost element in a typical chemical plant—and recycling, in view of the growing importance of environmental sustainability.

As part of simplification, it was important for Dow to ensure that the modules would be easy to install on individual workstations. Operators could be given a package that was pre-programmed so that they could install it with no more than a few easy clicks. The package could also have default dashboards. The dashboard could offer multiple possibilities of data extraction—pie charts, bar charts, and colour codes—enabling flexibility to move the pieces around to comply with reporting needs at different levels. Work would have to be done to ensure that EMI technology would meet this need for simplicity.

Integration, which meant assembling data from processes, equipment, and legacy systems, was also crucial to securing mass acceptance by Dow plant engineers and the company in general. This would be less complicated in a plant that Dow had built from the ground up than in plants that Dow had acquired worldwide, but integration would still be complex. Complexity could arise because the proposed EMI was to be positioned between two layers—SAP and automation—both of which were global, when EMI was meant to be local.

Colegrove said,

EMI would be owned and managed at each factory by plant engineers from within that factory. The user group itself should create dashboards by generally playing around. Pull factors, rather than push factors, would come into play in deploying EMI. It is the only way of ensuring that data would stay at its point of origin. It also means that the role of my team will be limited to providing users with tools to mine their own data.

A final challenge for Colegrove pertained to measuring the impact of the EMI initiative. Return on investment would be linked closely to the key performance indicators of each plant. Operational reliability was a major key performance indicator, and it varied not only with each plant but with each process. Return on investment could be calculated based on the number of shutdowns avoided and the lowered turnarounds for maintenance.

Colegrove explained,

Currently, a few engineers in each plant would go every Friday to a database to upload specific pieces of data. It typically takes all afternoon for them. With EMI capability, we would eliminate that work altogether. It amounts to giving, say, five hours of work back to each engineer in a plant. If you look at it over a 52-week time frame, that is a lot of manpower/womanpower brought back into the plant for other things. I need to identify deliverables metrics like that to make a compelling case for EMI at Dow. What would those tangible evidences be?

Colegrove and his team had gained enough insight during the pilot project to know that Dow could benefit from an EMI initiative. But they also understood that the success of an EMI initiative would depend on many factors. Colegrove wondered how he should proceed. Should his team continue the pilot project and gather further insight into the specific metrics that mattered? Should the team modularize the EMI initiative, or roll it out on a broader scale to let the engineers play around with it and learn on their own? Was this the right time to be making such demands of plant engineers, or would it be better, for a start, to keep it in R&D? Or, with no immediate problems to fix, should Colegrove wait until there was a problem to be solved, in case EMI was just the latest fad within the big data phenomenon?

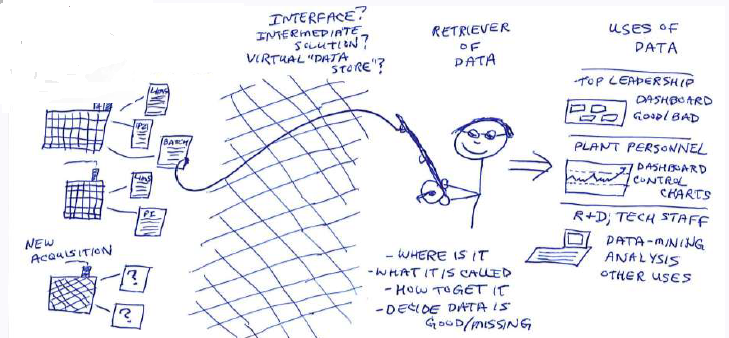
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Exhibit 1: the DOW CHEMICAL company BUSINESS PORTFOLIO, 2011

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Business Segment | Product Categories | Some Examples of Products | Applications | Revenue  (US$ million) |
| Electronic & Functional Materials | Electronic materials | Aurolectroless, Cyclotene, Intervia, Optograde, Enlight, Solderon, Visionpad | Electronic displays, Food processing, Home care ingredients, Printed circuit boards, Hygiene and infection control | 4,599 |
| Functional materials | Acusol, Glutex, Primene, Venpure, Ethocel, Duolite, Primene, Kathon |
| Coatings & Infrastructure Solutions | Building & construction | Aquaset, Cellosize, InstaStik, Tile bond, Primal, Rhoplex, Methocel, Weathermate | Building industry, Insulation, Tile adhesives, Concrete, Plasters, Cement modifiers, Traffic paints, Pipeline coatings, Corrosion protection, Water purification | 7,200 |
| Coating materials | Ropaque, Primal, Maincote, Fastrack, Orotan, Evoque, Ecosurf, Tamol |
| Water solutions | Amberjet, Dowex, Optipore |
| Agricultural Sciences | Crop protection | Clincher, Delegate, Dithane, Fortress, Widestrike, Starane, Telone, Vikane | Pest management in farming, industrial, and commercial activities; Plant breeding; Farming cultivation | 5,665 |
| Seeds | Agromen, Brodbeck, Mycogen, Renze |
| Performance Materials | Auto systems | Aerify, Betafoam, Voraforce, Robond | Automotive interiors and exteriors; Detergents, cleaners, and fabric softeners | 14,647 |
| Plastic additives | Advalube, Surecel, Tyrin, Paraloid |
| Others | Ecosoft, Cellosolve |
| Performance Plastics | Elastomers | Affinity, Engage, Infuse, Nordel, Versify | Consumer durables, Beverages, Industrial bottles, Leather, Textile, Graphic arts, Oil tanks | 16,257 |
| Telecom | Endurance, Ecolibrium, Unigard |
| Packaging | Adcote, Saranex, Tybrite, Trycite |
| Feedstock and Energy | Chlor-alkali | Caustic soda; Chlorine | Power, steam, and utilities; Captive power supply; Derivatives; Crude oil-based raw materials | 11,302 |
| Ethylene glycol | Polyethylene terephthalate |
| Hydrocarbons | Benzene; Butadiene; Butylene; Cumene |
| Others |  |  |  | 325 |
| Total Revenue | | | | 59,985 |

Source: Company documents.

Exhibit 2: FIRST SKETCH OF EMI AT DOW (AS OUTLINED ON A NAPKIN)



Source: Company documents.

1. Deloitte, *The Talent Imperative in the Global Chemical Industry*, September 2015, accessed June 1, 2016 https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-mfg-talent-imperative-global-chemicals-industry.pdf. [↑](#footnote-ref-1)
2. All currency amounts in the case are in U.S. dollars unless otherwise specified. [↑](#footnote-ref-2)
3. Andrew N. Liveris, “Keynote – A Revolution by Design: Building an Advanced Manufacturing Economy,” MIT Industrial Liaison Program, September 20, 2013, accessed December 1, 2016, <http://ilp.mit.edu/videodetail.jsp?confid=77&id=901>. [↑](#footnote-ref-3)
4. Danielle Levy, “Is it Time to Play the ‘Nearshoring’ Boom?,” CityWire, August 21, 2013, accessed December 1, 2016, http://citywire.co.uk/wealth-manager/news/is-it-time-to-play-the-nearshoring-boom/a697719. [↑](#footnote-ref-4)
5. James Manyika, Michael Chui, Brad Brown, Jacques Bughin, Richard Dobbs, Charles Roxburgh, and Angela Hung, *Big Data: The Next Frontier of Innovation, Competition, and Productivity*, McKinsey Global Institute, May 2011, accessed October 15, 2016, www.mckinsey.com/business-functions/digital-mckinsey/our-insights/big-data-the-next-frontier-for-innovation. [↑](#footnote-ref-5)
6. “Organizing for Big Data through Better Process and Governance,” Gartner, accessed December 1, 2016. [↑](#footnote-ref-6)
7. The multiples included petabytes (1,000 terabytes), exabytes (1,000 petabytes), zettabytes (1,000 exabytes), yottabytes (1,000 zettabytes), brontobytes (1,000 yottabytes), and geobytes (1,000 yottabytes). [↑](#footnote-ref-7)
8. EMC Digital Research and International Data Corporation, *Discover the Digital Universe of Opportunities: Rich Data and the Increasing Value of the Internet of Things*, DELL EMC, April 2014, accessed September 10, 2016, www.emc.com/leadership/digital-universe/index.htm. [↑](#footnote-ref-8)
9. A data historian was a software platform where all chronological data of a plant relating to production, performance monitoring, and product tracking was stored. It was a data depository that enabled access through either a dedicated standard development kit (SDK) or an application programming interface (API). [↑](#footnote-ref-9)
10. Andrew N. Liveris, interview by Rik Kirkland, “How Dow Reinvented Itself,” McKinsey & Company, May 2015, accessed September 26, 2016, [www.mckinsey.com/global-themes/leadership/how-dow-reinvented-itself.](http://www.mckinsey.com/global-themes/leadership/how-dow-reinvented-itself.) [↑](#footnote-ref-10)
11. Leena Rao, “Dow Chief: We’re Not a Chemical Company, We’re a Science Company,” *Fortune*, July 15, 2015, accessed November 25, 2015, <http://fortune.com/2015/07/15/dow-chief-chemical-science/>. [↑](#footnote-ref-11)