Methods for innovation : the varying role of industrial research in DSM's nitrogen fertilizer business, 1925-1970

Citation for published version (APA):

Rooij, van, J. W. (2007). Methods for innovation : the varying role of industrial research in DSM's nitrogen fertilizer business, 1925-1970. *Technology and Culture*, 48(3), 550-574. <https://doi.org/10.1353/tech.2007.0139>

DOI:

[10.1353/tech.2007.0139](https://doi.org/10.1353/tech.2007.0139)

Document status and date:

Published: 01/01/2007

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Project
MUSE®
Scholarly journals online

Methods for Innovation

The Varying Role of Industrial Research in DSM's Nitrogen Fertilizer Business, 1925–1970

ARJAN VAN ROOIJ

DSM, one of the largest multinational companies in the Netherlands, produces a wide range of chemical products, from food additives and fertilizers to Dyneema polyethylene fiber.¹ On one of its production sites in Limburg in the Netherlands, one can find an old concrete structure startlingly out of place among its gleaming neighbors. This building represents an interesting technological moment in DSM's history because it is from this building that DSM stores and ships fertilizers, the product of its first venture into the chemical industry. DSM's roots go back to 1902, when the Dutch state established Staatsmijnen (State Mines) in Limburg to mine coal.² Using specialized engineering contractors to build the necessary plants, by 1919 the company was producing coke, and by 1930 it was producing fertilizers on a large scale—a high-technology business at the time. In subsequent years, DSM diversified further in the chemical indus-

Arjan van Rooij works as a researcher at the Technical University of Eindhoven in the Netherlands. His previous work focused on engineering contractors and their effects on the chemical industry. The author thanks Mila Davids, Harry Lintsen, and Frank Veraart for their comments on an earlier draft of this article. He also thanks John Staudenmaier and the anonymous referees for their commitment and their comments.

©2007 by the Society for the History of Technology. All rights reserved.
0040-165X/07/4803-0004\$8.00

1. For the top 100 largest Dutch companies, see E. S. A. Bloemen et al., “De Vermogensontwikkeling van Nederlands Grootste Industriële Ondernemingen, 1930–1950,” *NEHA Jaarboek* 10 (1993): 133–60.

2. DSM stood for Dutch State Mines, a more or less literal translation of Nederlandse Staatsmijnen that was only used internationally. The company took on the name DSM in 1969, after its incorporation in 1967, but the abbreviation lost its meaning when the company closed its last coal mine in 1973. The change of name from Staatsmijnen to DSM was intended to underscore the company's transformation from coal to chemicals. I use DSM throughout because this article is in English. For the name changes, see F. A. M. Messing, *Geschiedenis van de Mijnsluiterij in Limburg: Noodzaak en Lotgevallen van een Regionale Herstructurering, 1955–1975* (Leiden, 1988), 103–4, 365, 460.

try both by buying technology and through internal research and development (R&D).

DSM's innovation strategies varied, as did the structure of its innovation process. This article examines the methods of innovation employed at DSM, and it argues that even in a high-tech and competitive sector like the chemical industry, DSM made use not just of R&D, but of several distinct methods of innovation. Furthermore, the company used these methods simultaneously. This article therefore offers a framework to analyze different methods of innovation within a firm, using this to investigate the history of innovation within DSM from 1925 to 1970 and thus adding to our understanding of the structure of innovation within high-technology firms in the twentieth century.

To distinguish methods of innovation in my analysis, I use three key parameters: the *scope* (of the technological work undertaken), *localization* (who was involved in the firm), and *source* of technology (internal or external). A firm often chooses these methods of innovation under the influence of a broader innovation strategy, which, following Chris Freeman's categorization, can be *offensive*, *defensive*, or *imitative*. Companies that use an offensive strategy aim to create market and technological leadership by producing technological breakthroughs, while defensive companies will follow the leaders in some way. Imitative companies focus on low costs to capture and maintain their position. Freeman points out that different innovation strategies emphasize different technical functions of firms. For instance, an offensive strategy is highly R&D intensive, while imitative strategies stress engineering.³

Much of the literature in the history of innovation has focused on R&D, especially its foundation in the late nineteenth century. During this period, invention became an industrialized, collective, and concerted effort.⁴ Historians have explored the significance of R&D for its role in the diversification as well as the maintenance of businesses, arguing that the success of R&D-intensive firms pushed others in the same direction, making the R&D laboratory the dominant source of technology for firms.⁵ The pioneering

3. Chris Freeman, *The Economics of Industrial Innovation* (Harmondsworth, U.K., 1974), 254–82 (see especially table 37, p. 258). His analysis of innovation strategy did not change much in his second edition (London, 1982 [168–86]), nor in his third (with Luc Soete, London, 1997 [265–85]). Freeman distinguishes six types, but the *offensive*, *defensive*, and *imitative* are the most important for my purposes.

4. David F. Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism* (New York, 1977). Georg Meyer-Thurrow, "The Industrialization of Invention: A Case Study from the German Chemical Industry," *Isis* 73 (1982): 363–83.

5. See, for instance, the seminal study of DuPont by David A. Hounshell and John K. Smith, *Science and Corporate Strategy: DuPont R&D, 1902–1980* (Cambridge, 1988). See also Wolfgang Wimmer, "Wir haben fast immer was Neues": *Gesundheitswesen und Innovationen der Pharma-Industrie in Deutschland, 1880–1935* (Berlin, 1994), and Meyer-Thurrow.

phase of R&D between 1870 and 1920 has attracted the most attention, resulting in case studies of DuPont, General Electric, Bayer, and other companies from the German and U.S. chemical and electrical industries.⁶ These firms typically pursued an R&D-driven, often offensive, strategy.

Some important studies have addressed innovation outside the R&D laboratory. Hans-Liudger Dienel shows that the German refrigeration industry shied away from research performed in formal and centralized laboratories and instead innovated in close contact with, and at the site of, its clients. Traveling engineers involved in sales and supervision of construction drove this method. Only in exceptional and clearly formulated cases, and for only a limited period of time, were specific problems studied at testing stations.⁷ Even firms that had R&D laboratories did not always rely solely on these facilities to innovate. Samuel Hollander's detailed study of incremental improvements in a number of DuPont rayon plants shows the large cumulative impact of these small improvements and demonstrates that responsibility for them did not lie with the research department, but rather with technical-assistance groups, engineers, and chemists close to the production floor whose jobs entailed solving operational problems. Walter Vincenti calls this "production-centered innovation": innovative work done on the shop floor through empirical experimentation, without any industrial research.⁸

The literature on innovation shows that the R&D department, plant staff, and other units of a company may all pursue innovation, making it worthwhile to investigate all of the different methods of innovation that a given firm employs. Comparing the work of R&D departments with work on the shop floor suggests two parameters that can be used to analyze the character of innovation: the scope of the work that goes into the innova-

6. For instance, Leonard S. Reich, *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926* (Cambridge, 1985); George Wise, *Willis R. Whitney, General Electric, and the Origins of U.S. Industrial Research* (New York, 1985); Paul Erker, "Die Verwissenschaftlichung der Industrie: Zur Geschichte der Industrieforschungen in den europäischen und amerikanischen Elektrokonzernen," *Zeitschrift für Unternehmensgeschichte* 35 (1990): 73–94; Carsten Reinhardt, *Forschung in der chemischen Industrie: Die Entwicklung synthetische Farbstoffe bei BASF und Hoechst, 1863 bis 1914* (Freiburg, 1997); and F. Kees Boersma, *Inventing Structures for Industrial Research: A History of the Philips Nat. Lab., 1914–1946* (Amsterdam, 2002).

7. Hans-Liudger Dienel, "Der Ort der Forschung und Entwicklung im deutschen Kältemaschinenbau," *Technikgeschichte* 62 (1995): 49–69.

8. Samuel Hollander, *The Sources of Increased Efficiency: A Study of DuPont Rayon Plants* (Cambridge, Mass., 1965); M. Gibbons et al., "Innovation and Technical Change: A Case Study of the U.K. Tractor Industry, 1957–1977," *Research Policy* 11 (1982): 289–310; and Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore, 1990), chap. 6, 170–99. See also Robert Fox and Anna Guagnini, "Life in the Slow Lane: Research and Electrical Engineering in Britain, France, and Italy, ca. 1900," in *Technological Development and Science in the Industrial Age*, ed. Peter A. Kroes and Martijn Bakker (Dordrecht, 1992), 138–39.

tion, and the localization, or site of innovation (for example, the R&D lab or the shop floor).⁹ A third important parameter is the source of technology, whether internal, as produced by an R&D laboratory, for example, or external. Like DSM, a firm might hire an engineering contractor to build a plant, cooperate with other firms on R&D projects, hire independent laboratories, or buy patents from a variety of sources, which then must be developed into a commercial product or industrial process.¹⁰

To analyze the different methods of innovation operating within a single firm, my framework adopts Freeman's model of innovation strategy and adds to it the three parameters that determine innovation methods: scope, localization, and source of technology. Research-driven innovation mainly relies on the work of the research department, while the scope of internal technological work varies. In this case, the innovation strategy will typically be offensive (breakthrough) or defensive (catch-up). On the other hand, production-centered innovation relies on the production-support function of firms, organized in work laboratories, plant staff, or otherwise. The scope of these innovations is usually narrow and limited to incremental changes to existing processes and products. Innovation strategy will typically be imitative because the firm emphasizes low costs in this approach. When firms buy external technology they engage in a third method of innovation, whereby the scope and localization will vary depending on the form this external technology takes. Buying plants, for example, requires a capability to evaluate available sources of technology and to supervise the work of the contractor—often a job for the engineering department or other members of the technical staff. Buying patents, on the other hand, requires a firm to develop them, which in turn requires the in-house capabilities to be able to do so.¹¹

9. This point has also been made in the field of economics. See, for instance, Keith Pavitt, "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory," *Research Policy* 13 (1984): 353.

10. Arjan van Rooij and Ernst Homburg, *Building the Plant: A History of Engineering Contracting in the Netherlands* (Eindhoven, 2002). On fertilizers, see Arjan van Rooij, "Engineering Contractors in the Chemical Industry: The Development of Ammonia Processes, 1910–1940," *History and Technology* 21 (2005): 345–66. On patents, see Naomi R. Lamoreaux and Kenneth L. Sokoloff, "Inventors, Firms, and the Market for Technology in the Late Nineteenth and Early Twentieth Century," in *Learning by Doing in Markets, Firms, and Countries*, ed. Naomi R. Lamoreaux, Daniel M. G. Raff, and Peter Temin (Chicago, 1999), 19–57. On private laboratories, see David C. Mowery, "The Relationship between Intrafirm and Contractual Forms of Industrial Research in American Manufacturing, 1900–1940," *Explorations in Economic History* 20 (1983): 351–71. On cooperative research, see John Hagedoorn, "Inter-Firm R&D Partnerships: An Overview of Major Trends and Patterns since 1960," *Research Policy* 31 (2002): 477–92. On cooperative research institutions, see P. S. Johnson, *Co-Operative Research in Industry: An Economic Study* (London, 1973); and Luitgard Marschall, *Im Schatten der chemischen Synthese: Industrielle Biotechnologie in Deutschland 1900–1970* (Frankfurt am Main, 2000), 26–35.

11. Arjan van Rooij, *Building Plants: Markets for Technology and Internal Capabilities*

In this article, I apply this framework to DSM's fertilizer business for the period between 1925 and 1970. Through fertilizers, DSM diversified from coal and coke into chemicals, building a foundation for its later diversifications and ultimately for its survival. Fertilizer production, in the period under study here, was a high-tech and highly competitive sector of the chemical industry. DSM's fertilizer business is therefore a good case study to illustrate the entire spectrum of innovation methods employed within the firm.

How a Coal Mining Company Entered the Chemical Industry and Built an R&D Laboratory

DSM started out not as a fertilizer or chemical company, but as a coal mining enterprise. In the late nineteenth century, private companies with Belgian and German capital and know-how got involved in coal mining in the province of Limburg, in the south of the Netherlands, triggering a parliamentary debate. Some officials feared that the region's coal, which was a national resource, was falling into foreign hands. In response, the Dutch government established DSM in 1902 to exploit the coalfields that had not yet been granted to private companies. Soon after starting production, DSM began to mine bituminous coal. This type of coal is particularly suited for the production of coke, an industrial fuel best known for its use in blast furnaces. By 1919 DSM had built its first coke plant using specialized engineering contractors, and ten years later it had built a second one.¹² DSM's swift action to take advantage of its access to bituminous coal reflected its management's freedom to maneuver. Although DSM was state owned, the government had instructed the company's top management in 1913 to run it like a private business because unlike other state-owned companies, it had no monopoly and therefore needed to operate in a competitive marketplace. This 1913 mandate would govern relations between owners and managers until the government of the Netherlands privatized DSM in the late 1980s.¹³

Just as the company made the leap from coal mining to coke production,

in *DSM's Fertilizer Business, 1925–1970* (Amsterdam, 2004), 97–108. Mowery also argues that contractual difficulties hinder the ability of firms to use independent laboratories; see Van Rooij, *Building Plants*, chap. 10.

12. For an overview of the history of DSM, see *Staatsmijnen in Limburg* (Heerlen, 1952); P. Tans, "Van Staatsmijnen tot DSM: Hoofdlijnen van de Ontwikkeling," *Het Land van Herle* 27 (1977): 87–103; Messing (n. 2 above); Harry Strijkers, "DSM, een Koninklijke Eeuwling: Kroniek van de Laatste 25 Jaar," *Het Land van Herle* 52 (2002, special issue).

13. Messing, 99. For the Dutch postal, telegraph, and telephone services, see Mila Davids, *De Weg naar Zelfstandigheid: De Voorgeschiedenis van de Verzelfstandiging van de PTT in 1989* (Hilversum, 1999).

so also did it diversify by exploiting the opportunities presented by coke. Frits van Iterson was the main force behind this diversification. As a member of top management, he was responsible for the company's operations above-ground, including coal classification and processing as well as the production of coke. Van Iterson wanted DSM to benefit from coal as much as possible, which meant diversifying the company and thereby making it less dependent on the coal market.¹⁴ Production of coke presented several options to diversify through the by-product coke oven gas—a type of gas that resembled coal-based town gas sold for lighting, heating, and industrial purposes. Coke oven gas contained a number of commercially interesting compounds, such as benzene and toluene, that DSM extracted and sold to other companies. The gas also contained hydrogen, one of the feedstocks for the synthesis of ammonia.¹⁵ While the German chemical company BASF developed the first ammonia-synthesis process during the 1910s, several engineering contractors followed with processes of their own during the 1920s. Other contractors developed techniques to extract hydrogen from coke oven gas. Because these contractors made the technology readily available, DSM was able to begin large-scale manufacture of nitrogen fertilizers. The company hired the Belgian engineering contractor ASED (Ammoniaque Synthétique et Dérivés) to engineer and construct the necessary installations. The fertilizer works was started in 1930 and called SBB (an abbreviation of Stikstofbindingsbedrijf, Dutch for Nitrogen Fixation Works).¹⁶

The first laboratories associated with DSM were works laboratories that conducted routine quality controls for the production of both coke and fertilizers. In 1935, however, Gé Berkhoff and Honoré Pieters, the heads of these laboratories, proposed a formal, centralized research laboratory. In 1938, after plans for a new laboratory building had been developed and after Berkhoff had written an outline of a research program, top management agreed to establish an R&D organization and construct a new laboratory building. The new department was called Central Laboratory (Centraal Laboratorium in Dutch).¹⁷ The outbreak of World War II hindered the growth of the organization, but after the war, Central Laboratory started to conduct research on a significant scale. Research expenditures increased from 3.9 percent of chemical turnover in 1949 to 6.8 percent twenty years later. The number of researchers similarly grew, from 421 in 1950 to

14. See J. Laugs, *Stikstof van de Staatsmijnen, 1930–1940* (Nijmegen, 1988).

15. For an overview of coke and chemical by-product operations, see Walter Bushmann, ed., *Koks, Gas, Kohlechemie: Geschichte und gegenständliche Überlieferung der Kohleveredlung* (Essen, 1993).

16. Van Rooij, *Building Plants* (n. 11 above), 66–83.

17. E. van Royen, “Steenkolenveredeling en Industriële Research bij Staatsmijnen,” in *Research Tussen Vetkool en Zoetstof: Zestig Jaar DSM Research 1940–2000*, ed. H. Lintsen (Eindhoven, 2000), 23–24; Ernst Homburg, *Speuren op de Tast: Een Historische Kijk op Industriële en Universitaire Research* (Maastricht, 2003), 22–23.

1,220 two decades later. Central Laboratory became one of the largest industrial research laboratories in the Netherlands.¹⁸

The growing importance of Central Laboratory can also be measured by its position within the organization. Until 1949 it had been part of the chemical production unit with the coke ovens and the fertilizer plants. In that year, however, the laboratory was placed directly under top management and became a corporate entity, getting its budget directly from corporate funds and charging production units only for service research and troubleshooting.¹⁹ This expansion of Central Laboratory and its new position within the company reflected the strong faith management placed in research. Jan van Aken, who was appointed to DSM's top management in 1949 and held responsibility for managing DSM's chemical businesses, voiced a widely held opinion at DSM when he said in a 1959 lecture that research was a "vital organ," necessary to match the research efforts of the competition and to enable the company to diversify. Van Aken viewed research as a tool to keep up with the competition and to boost the development of the company.²⁰ Central Laboratory proved to be an effective tool for accomplishing this: between 1930 and 1970 it initiated 63 percent of DSM's diversification projects.

Research without a Dedicated Research Organization

Despite the later importance of Central Laboratory, DSM entered the chemical industry and the manufacturing of fertilizers before having a dedicated research organization. To operate the fertilizer plants DSM acquired in the late 1920s, the company drew on its coal and coke operations and hired new operating personnel. Van Iterson needed engineers and chemists who had the ability to understand the processes used in the plants, especially the ammonia plant, where a smooth operation was essential. To oversee production he hired Berkhoff for the air- and gas-separation sections of the ammonia plant. Berkhoff was an academically trained chemist who had worked in the cryogenic laboratories of Leiden University and at ASED's

18. Central Laboratory annual reports, 1948–1970. Turnover figures are from "Bedrijfs-economisch Verslag," 1950–1956, State Archives (Maastricht), company archives DSM (hereafter RAL), 17.26/18B inv. no. 83, and from DSM annual reports, 1957–1970. Chemical turnover excludes turnover from coal, coke, coke oven gas, electricity, and other nonchemical activities (author's calculations).

19. "Bekendmaking van de mutaties bij de Chemische Bedrijven," Centraal Laboratorium, 17 January 1948, RAL, 17.26/36A inv. no. 1; minutes, top management meeting, 2 November 1949, DSM (Heerlen, the Netherlands), corporate archives department (hereafter CADH).

20. J. S. A. J. M. van Aken, "Management's View on Research in Chemical Industry," *TVF* 31 (1960): 57–64, quote on 62.

own ammonia plant in Belgium before being assigned to DSM's fertilizer works, SBB.²¹ Van Iterson also hired Van Aken and two other chemical engineers who had worked for the Dutch synthetic-fiber company ENKA. The ammonia plant soon was operating without problems and Van Aken was reassigned to SBB's staff, while the other two engineers moved to the works laboratory. Berkhoff became head of the works laboratory in the early 1930s.

This group provided the expertise that was vital when DSM's fertilizer business was threatened during the early 1930s. At that time, markets for fertilizers were oversupplied and prices were falling because many operators of coke oven plants had diversified into the large-scale manufacture of ammonium-sulfate fertilizer. One response of BASF, the leader in the fertilizer industry, was to address the common problems of caking and dust in ammonium sulfate. Fertilizers are hygroscopic: they attract water and then form a solid mass, or "cake." In addition, the size of fertilizer particles often varies, and smaller particles ("dust") hinder farmers during application and act to worsen the caking problem. BASF had improved the quality of its ammonium sulfate by increasing the size of its particles, which reduced dust and caking and which consequently increased the already fierce competition in oversupplied markets. Therefore SBB faced strong competition in the Dutch and several export markets.²²

In the early 1930s, SBB responded to the competition by introducing a package of methods to improve the quality of its ammonium sulfate. In 1931, Berkhoff started research with this aim in mind. By reacting ammonia and sulfuric acid in saturators—vessels made of a material that could withstand the acid—ammonium sulfate crystallized (fig. 1). Berkhoff tried to understand the crystallization process theoretically and how it worked in the saturators used in the plant. He found that the ammonia and sulfuric acid should be injected carefully and mixed thoroughly to make larger crystals. To achieve this, Berkhoff suggested changes to the operating procedures and to the design of the plant. In addition, he investigated the influence of sulfuric acid on crystal size and found that certain impurities led to small crystals, developing a method that bound impurities and rendered them harmless by injecting some phosphate into the saturators. In September 1933, SBB's staff implemented these changes in the plant while production continued; moreover, they introduced a gas-oil coating. Coating was a common procedure in which the fertilizer particles were covered with a particular substance to reduce caking.²³

21. Letter, top management of DSM to Mijnraad, 7 March 1930, RAL, 17.26/06A inv. no. 17.

22. For an overview, see H. Grossmann and P. Weicksel, *Die Stickstoffindustrie der Welt* (Berlin, 1930), 91–199.

23. G. Berkhoff, "De Bereiding van Grofkristallijn Ammoniumsulfat," *Chemisch*

JULY

2007

VOL. 48

FIG. 1 Saturators in the ammonium sulfate plant, 1930s. Improving the crystallization process was the SBB's first innovation, and it was also the first technology that it licensed to other firms. This picture was published in an article in *Chemical and Metallurgical Engineering* that was written by Gé Berkhoff to advertise the process. (Courtesy of the DSM Corporate Archives, Heerlen.)

Improving the quality of ammonium sulfate was SBB's first innovation, which it produced only a few years after DSM had entered the chemical industry. It was a crucial defensive innovation for maintaining SBB's position in an oversaturated market. It was also a research-driven innovation, though one narrow in scope, as suited SBB's laboratory. This blurred distinction between routine production control and research indicates that the company could perform the latter without a formal research organization.²⁴

Weekblad 32 (1935): 186–97; G. Berkhoff, "Ammonium Sulphate Crystallization Benefits from Simple Inexpensive Process," *Chemical and Metallurgical Engineering* 44 (1937): 366–67; G. Berkhoff, "Het Kristalliseren van Technische Producten en van Ammonium-sulfaat in het Bijzonder," *Chemisch Weekblad* 35 (1938), 868–72; and H. J. Merx, "Chronologisch Overzicht van de Geschiedenis van het Stikstofbindingsbedrijf, 1925–1952" (typescript, DSM corporate archives department, 1955), 13, 14–15, 17.

24. Compare with Sally Horrocks, "Technology and Chocolate: Research in the British Food Industry before 1940," in *Innovations in the European Economy between the Wars*, ed. François Caron, Paul Erker, and Wolfram Fischer (Berlin, 1995), 131–49.

Production-Centered Innovation in Ammonia

DSM's efforts to improve product quality were not the only ways it sought to become more competitive. The company also aimed to expand and diversify its fertilizer operations. In August 1931, DSM hired the German engineering contractor Uhde—a company with extensive interests in fertilizer technologies—to engineer and construct plants for nitric acid, an intermediate component in fertilizer manufacture, and calcium ammonium nitrate, a marketable fertilizer.²⁵ DSM chose to focus on expanding its capacity and lowering the costs of producing ammonia because of ammonia's importance in the production of nitrogen fertilizers. Ammonia was the key intermediate in nitrogen-fertilizer production.

Ammonia production consisted of three steps: producing a synthesis gas of hydrogen and nitrogen, the elements of ammonia; compressing this gas; and feeding it into converters that created the ammonia. These steps were separate but interrelated. Expansion in one step usually had to be followed by expansion in the other steps to use the plant to maximum capacity. Removing bottlenecks could also increase production at relatively little cost. ASED, for instance, built the ammonia plant with five synthesis units, but the gas- and air-separation units were not large enough to fully utilize synthesis capacity. SBB's staff therefore extended this section of the ammonia plant by ordering the necessary equipment and installing it in the plant. Staff engineers began the extensions in 1932 and soon boosted capacity above the designed level; by 1933 the cost of ammonia production had been cut by 55 percent through a process of learning and expanding capacity.²⁶

After World War II DSM continued expanding its ammonia capacity. In 1945, the company established Chemiebouw, a department intended to oversee the work of engineering contractors and also to engineer and construct plants with its own in-house expertise. Chemiebouw engineered and constructed several synthesis units during the 1950s. Synthesis units 6 and 7 commenced in 1949, unit 8 in 1956, and unit 9 in 1962, with Chemiebouw engineering these at increasingly larger capacities. Units 6 and 7 had a capacity of 90 tons of nitrogen daily, unit 8 of 100 tons, and unit 9 of 125 tons. This last unit was more than six times larger than its predecessors from the 1930s. Chemiebouw closely followed ASED's design of the original units, thereby making the process of scale-up relatively straightforward. The scope and localization of the work were tightly connected.²⁷

25. Merx, 11–12, 14.

26. Letter, DSM to Minister of Transport and Public Works (Waterstaat), 14 March 1931, RAL, 17.26/03A inv. no. 2478; R. Lachmann-Mosse, *Die Stickstoffindustrie und ihre internationale Kartellierung* (Zürich, 1940), 55–59.

27. J. O. Oosterling, interview by Ernst Homburg and the author, 8 January 2001; “Korte notitie met betrekking tot de plannen inzake de capaciteitsverhoging van de ure-

JULY

2007

VOL. 48

Besides the expansion of synthesis capacity, the compressors and air- and gas-separation units of the ammonia plant were also frequently extended. After World War II, compressors for ammonia synthesis were more-or-less standard pieces of equipment available from several engineering works. The staff of the ammonia plant designed new units for air and gas separation that produced hydrogen and nitrogen. SBB's in-house workshop built these machines.

The staff's main task was to continuously measure the performance of the ammonia plant, solve operational problems, and implement small modifications or remove bottlenecks. Such measures increased production and reduced costs. For example, while *Chemiebouw* engineered synthesis unit 8 with a capacity of 100 tons of nitrogen per day, it followed a typical practice in the chemical industry and designed installations with a safety margin for capacity. Additionally, engineers sometimes solved design problems by making equipment a little larger, as they considered this a better option than ending up with equipment that was too small. Consequently, unit 8 produced more than its design capacity soon after it started, even though it was not yet in regular production. The plant's staff started analyzing the plant once it was operational to find out its maximum capacity and remove bottlenecks. "De-bottlenecking" usually required only small investments of money, but could boost production and reduce costs. A production of 130 to 140 tons of nitrogen per day was expected, with peaks of 160 to 180 tons.²⁸

Production-centered innovation by the plant's staff was crucial for maintaining competitiveness. The localization of this work reflects its narrow scope. Complemented by the engineering work of *Chemiebouw* on extension projects, DSM possessed an organization capable of providing its production of ammonia with the technology and knowledge it needed. Focused on low production costs, which derived from the importance of ammonia in the production of nitrogen fertilizers, DSM's innovation strategy in ammonia was imitative.

As the key intermediate component in fertilizer production and an almost ideal bulk commodity, ammonia was sold based on its chemical composition and was capable of being manufactured in large-scale installations. Low cost was decisive in this type of chemical product; there were few other means to differentiate one competitor from another. In ammonium sulfate and other fertilizer end-products, product quality also played a role. Here, again, low cost was decisive because these products are mainly sold

umfabriek," *Staf Chemische Bedrijven*, 12 August 1957, RAL, 17.26/19B inv. no. 217; Merx, 42, 49, 54; and "In ammoniaksynthese kwam 9e groep gereed," *Nieuws van de Staatsmijnen* 11 (1962): 4.

28. "Korte notitie," 12 August 1957.

based on their chemical composition (their nitrogen content). These product characteristics led to a focus on technology in which markets and contacts with customers played only a small role.²⁹

Ammonia Technology Markets

Historical studies of R&D have argued that companies use external sources of technology only when their own research laboratories are in a build-up phase, which eventually results in internal R&D becoming the dominant source of technology.³⁰ Chemiebouw and the ammonia plant's staff continued to expand ammonia production and innovate, however, while Central Laboratory grew. DSM continued to utilize external sources of technology.

DSM's main method of innovation in ammonia was to buy technology and then use its own internal expertise to improve and better understand what it had bought. In 1946, DSM hired the British engineering contractor Powergas to build a water-gas plant because there would not be enough synthesis gas available to start synthesis units 6 and 7. A water-gas plant produced a gas mixture rich in hydrogen by passing steam over hot coke (the so-called gasification of coke). The municipal gas industry pioneered water-gas production during the second half of the nineteenth century, and BASF adapted it to the manufacture of ammonia during the 1910s. Water-gas technology was widely available and proven and, although new to the company, an attractive acquisition option. Many contractors worked in this field and Powergas had vast experience. DSM's own engineers made this acquisition more beneficial by boosting production above designed capacity, and Chemiebouw engineered a major extension of the installation in 1956.³¹

At the same time that it was focusing on buying new technology, DSM's Central Laboratory also pursued internal research on a related topic, catalysis. Ammonia synthesis proceeds in the presence of a catalyst; in general, catalysts improve the yield and speed of chemical reactions without taking part in the reaction itself. Improving catalysts meant improving the economics of chemical processes. SBB's laboratory had conducted catalysis research and in the late 1940s developed an improved catalyst, but its studies gradually lost significance for DSM as a whole as its Central Laboratory expanded during the 1950s and researched other catalytic reactions in addi-

29. Charles H. Kline, "Maximising Profits in Chemicals," *Chemtech* 6 (1976): 110–17.

30. Meyer-Thurrow (n. 4 above) and Wimmer (n. 5 above).

31. Merx (n. 23 above), 41, 60; "Roestvrijstalen reuzentorens op het Stikstofbindingsbedrijf," *Nieuws van de Staatsmijnen* 6 (1957): 2. For an overview of water-gas and related technology, see E. A. Thau, "Grosswassergaserzeugung für chemische Synthesen," *Öl und Kohle* 38 (1942): 589–601, 617–25, 685–91, 721–27, 749–65.

JULY

2007

VOL. 48

tion to ammonia synthesis. Central Laboratory mainly aimed at understanding how catalysis worked; it could not produce a next-generation ammonia-production process because it did not pursue research on it nor on the necessary equipment.³²

Following its work on ammonia catalysis, in 1948 Chemiebouw asked Central Laboratory to commence research on a catalyst for the removal of carbon dioxide from raw water-gas. Though Chemiebouw considered the Powergas catalyst to be good and, moreover, though it could have selected another catalyst supplier, it asked Central Laboratory because it wanted to become independent of these suppliers. Central Laboratory developed a catalyst, but, for reasons that are not clear, it was not used in the plant. What this does indicate is DSM's increasing confidence in its research. There was no immediate problem and no immediate need to develop a catalyst, but this type of research was part of the laboratory's scope.³³

As Chemiebouw expanded its ammonia plant with additional synthesis units during the 1950s, the demand for synthesis gas increased further. DSM expanded its external distribution network for coke oven gas. Around 1960, however, the company's coal mining activities faced a sharp downturn in the market: production of coal fell, and consequently the production of coke and coke oven gas fell. At about the same time, natural gas was discovered in the northern Netherlands and became available for industrial uses. By 1960 natural gas was a well-established feedstock for ammonia synthesis, and several engineering contractors and chemical companies offered this technology. Engineering contractors had also been active in scaling up the capacity of ammonia-synthesis units, achieving sizes much larger than Chemiebouw's designs.³⁴

The internal demand for feedstock and the availability of state-of-the-art technologies led DSM to acquire many plants in its expansion during the 1960s (table 1). The company began its switch from coke oven gas to natural gas with the acquisition of methane-cracker 3 from Powergas. This "reformer" processed natural gas with steam into a gas mixture rich in hydrogen, and it subsequently purified this mixture to make it ready for ammonia synthesis. ICI, the leading British chemical company and at that time the leader in reformer technology, had licensed the technology to Powergas

32. Central Laboratory annual reports, 1948–1970; J. W. Geus and R. van Hardeveld, "Catalysis at DSM Research: A Review of Fifty Years of Work, 1944 till 1994," in *A Short History of the Dutch School of Catalysis*, ed. J. J. F. Scholten (The Hague, 1994), 180–209; and Homburg, *Speuren op de Tast* (n. 17 above), 34–35.

33. Central Laboratory annual reports, 1951 and 1956; G. Berkhoff, "Bespreking over de CO-conversie-proefapparatuur," Centraal Laboratorium, 20 October 1949, RAL, 17.26/36A inv. no. 98.

34. See Messing (n. 2 above); J. P. Smits and B. P. A. Gales, "Olie en Gas," in *Techniek in Nederland in de Twintigste Eeuw*, ed. J. W. Schot et al. (Eindhoven, 2000), 2:67–89; and Van Rooij, *Building Plants* (n. 11 above), 197–99, 217–21.

TABLE 1
DSM'S TECHNOLOGY ACQUISITIONS IN RELATION TO AMMONIA, 1959–1971

<i>Plant</i>	<i>Type</i>	<i>Feedstock</i>	<i>Contractor</i>	<i>Process</i>
methane cracker 1	synthesis gas plant	coke to oven gas (methane), con- verted to natural gas	Gegi	ONIA partial oxidation process
methane cracker 2	synthesis gas plant	coke to oven gas (methane), con- verted to natural gas	Chemiebouw	ONIA partial oxidation process
methane cracker 3	synthesis gas plant	natural gas	Powergas	ICI reformer
methane cracker 4	synthesis gas plant	natural gas	Chemiebouw	ICI reformer
methane cracker 5	synthesis gas plant	natural gas	Selas of America	ICI reformer
synthesis unit 10	ammonia synthesis unit	natural gas	Topsøe	Topsøe converter
synthesis unit 11	ammonia synthesis unit	natural gas	Chemiebouw	Topsøe converter
Texaco cracker	synthesis gas plant	natural gas	Foster Wheeler Française	Texaco Develop- ment Corporation
ammonia plant 2	ammonia plant	natural gas	Bechtel	Foster Wheeler reformer and Topsøe converter

Source: Company newsletters.

and six other engineering contractors. DSM's production staff chose this technology simply because it offered the lowest possible production costs.³⁵

Chemiebouw oversaw the work of Powergas, but the new installation suffered from several problems. Chemiebouw's production staff soon concluded that the Powergas design had flaws and quickly corrected the problems on its own. In the purification section, the removal of carbon dioxide functioned improperly and Central Laboratory acted as a troubleshooter. Additionally, Chemiebouw itself built a duplicate of the acquired installation, using Powergas's drawings and specifications to engineer the plant (after paying an extra licensing fee).³⁶ Chemiebouw built other duplicates in the same way (table 1), with research playing no role in these projects.

35. "Bouw van een derde kraakinstallatie voor waterstofbereiding op het SBB," Staf Chemische Bedrijven, 7 March 1963, CADH, D. V. 1963/87; N. R. Gard, "Thirty Years of Steam Reforming: A Review of ICI Developments and Experience," *Nitrogen* (1966): 25–29.

36. "Agreement series B no. 3,628 between Hoofddirectie van de Staatsmijnen in Limburg, Heerlen, the Netherlands, and the Powergas Corporation Limited, Stockton-on-Tees, England, relating to 'Technical Advice, Service, and License for a Synthesis Gas Plant,'" undated, RAL, 17.26/34 inv. no. 777; Central Laboratory annual reports, 1966

JULY
2007
VOL. 48

The acquired plants and later duplicates were to some extent conventional technologies. During the 1960s, however, the approach to ammonia production changed radically when American engineering contractors combined reformers, compressors, and very large synthesis units in one plant design—the “single-train ammonia plant.” This design offered several advantages: the opportunity to further increase scale, to economize on energy use, and to cut production costs. The single-train plant design quickly diffused across the fertilizer industry. Neither Chemiebouw nor Central Laboratory had anticipated this development, nor did they attempt to follow it. DSM simply bought a plant from Bechtel.³⁷

These case studies of innovation demonstrate DSM’s complex relationships with internal and external sources of technology. Although DSM was willing to purchase external technology, it also mobilized its internal capabilities when it did not want to rely solely on contractors or to wait for external experts to solve its production problems. Regarding ammonia, DSM aimed at cutting costs and expanding production; its innovation strategy was imitative. Buying external technology and production-centered innovation practices fit with this strategy. The tasks involved suited both the plant’s staff, which increased capacity and cut costs in small increments, and Chemiebouw, which engineered expansions or oversaw the work of contractors. Fundamental research on catalysis—a broad-scope subject—suited Central Laboratory and reflected the company’s policy of studying and improving what it bought. The results of catalysis research were incremental improvements to the catalyst used in ammonia production, and a generic body of knowledge that could be applied to other products as well.

Most importantly, DSM did not use external technology only in the build-up phase of Central Laboratory, but continued to do so after it was well established. The availability of proven, low-production-cost technologies from engineering contractors led DSM to acquire them. The increasing capabilities of Chemiebouw enabled the company to work with contractors in more partnering ways than they had during the 1930s, as DSM could now buy processes and build duplicates. The emphasis on low costs offered opportunities for engineering contractors, as it paid them to optimize their designs, improve processes, and thereby make their services attractive for companies like DSM. This mechanism was not unique to fertilizers and operated in other bulk-commodity sectors of the chemical

and 1967; and J. Schneider, “Verslag van bespreking met fa. Power Gas Corp. te Geleen op 11, 12, 13 januari 1966 betreffende moeilijkheden met Meka III en IV,” Chemiebouw, 25 January 1966, RAL, 17.26/34 inv. no. 778. Compare Van Rooij, *Building Plants*, 22–26.

37. “Verslag van de bespreking van de Hoofddirectie met diverse functionarissen op 10 juni 1968 betreffende Chemische Bedrijven,” RAL, 17.26/19C inv. no. 40; “Ammoniak-productie wordt vernieuwd en uitgebreid,” *Staatsmijnen Nieuws* 17 (1968): 1, 2; and Robert H. Multhaupt and Gunther P. Eschenbrenner, *Technology’s Harvest: Feeding a Growing World Population* (Houston, 1996).

industry as well. However, in some other sectors, engineering contractors played a smaller role.³⁸

DSM's Entry in Urea

The previous sections have shown that the works laboratory, plant staff, and engineering department played important roles in innovation processes. The improvement of the ammonium-sulfate process was a small, incremental innovation. DSM did not innovate in ammonia at all, but instead purchased state-of-the-art technology. The case of urea is different. Here, DSM *did* innovate and *did* obtain a position of technological leadership in the field. During its first years of work in this field, the focus of the innovation process was in engineering and production and in the work of Chemiebouw, while R&D from Central Laboratory played only a supporting role.

Urea could be used for the production of urea-formaldehyde resins. Introduced during the 1920s, these resins could be produced in many colors and were used to manufacture products such as tableware. Urea also had a relatively high nitrogen content and hence was useful as a fertilizer, proving to be particularly suited for tropical climates. Calculated on the basis of the benefit provided by plant nutrients, the costs of transporting it to tropical areas were low.³⁹

In 1922, BASF started the first urea-synthesis plant in the world. Urea was produced in two steps: ammonia and carbon dioxide reacted to form ammonium carbamate; this compound then decomposed into urea and water. Carbamate was highly corrosive, leading to major problems in the design and operation of plants. Moreover, not all the ammonia and carbon dioxide reacted and not all the carbamate decomposed, leading to substantial amounts of off-gases. BASF recycled these off-gases, but this involved

38. On ethylene crackers, see E. Homburg, A. van Selm, and P. Vincken, "Industrialisatie en Industriecomplexen: De Chemische Industrie Tussen Overheid, Technologie, en Markt," in *Techniek in Nederland in de Twintigste Eeuw*, 384–85; see also B. Schott and W. Müller, "Process Innovation and Improvements as a Determinant of the Competitive Position in the International Plastics Market," *Research Policy* 4 (1975): 88–105, esp. 104. On the role of engineering contractors, see Ashish Arora and Alfonso Gambardella, "Evolution of Industry Structure in the Chemical Industry," in *Chemicals and Long-Term Economic Growth: Insights from the Chemical Industry*, ed. Ashish Arora, Ralph Landau, and Nathan Rosenberg (New York, 1998), 394–95. Arora and Gambardella's report results from a study of a database of plant construction in the chemical industry between 1980 and 1990. For the example of the Dutch specialty-chemical firm Noury & Van der Lande, see Jasper Faber, *Kennisverwerving in de Nederlandse Industrie 1870–1970* (Amsterdam, 2001), 193–250.

39. F. W. R. Röthig, "Het Ureumproject van de Staatsmijnen in Limburg: Archiefdocumentatie 1940–1960" (typescript, DSM corporate archives department, 1960), 2–3; Jeffrey L. Meikle, *American Plastic: A Cultural History* (New Brunswick, N.J., 1995), 76–78.

JULY
2007
VOL. 48

FIG. 2 Simplified structure of (a) “once through”; (b) “partial recycle”; and (c) “full recycle” urea processes. (Illustration by author.)

elaborate equipment and was hindered by corrosion. The company therefore usually operated its plant as a so-called once-through unit, processing all off-gases of urea synthesis into by-product fertilizers (fig. 2a). Partial recycling was also possible, where some of the off-gases were recycled and the remainder processed into by-products (fig. 2b).⁴⁰

40. *Ullmanns Encyklopädie der technischen Chemie*, 3rd ed., vol. 8 (München, 1957), 380–93; Van Rooij, *Building Plants* (n. 11 above), 139–41.

In the 1930s, several companies followed BASF's lead (table 2). DSM drafted some tentative plans and in 1946 began serious planning when Chemiebouw took up the study of urea manufacture. Chemiebouw's head, Jef van Waes, had worked on urea during the 1930s while he was at Compagnie Néerlandaise de l'Azote (CNA), another Dutch manufacturer of fertilizers owned by the Italian chemical company Montecatini and others.⁴¹ DSM also sought contact with ASED, a company that was closely related to CNA through common shareholders and at that time one of the few companies that would license urea technology. DSM wanted ASED to engineer and construct a plant for it, but ASED declined, saying it had not finished its work. When DSM proposed that the two companies work together, ASED agreed, and they signed a contract in April 1947.⁴² Under the contract, CNA shipped its pilot plant to DSM in May 1947, and the installation was put into operation in January of the following year.

Chemiebouw's work intensified after the pilot plant arrived. At the end of 1948 DSM decided to build its own plant having the production capacity of 15 tons of urea per day. Although Central Laboratory investigated the possibilities of recycling the off-gases, SBB's staff chose to use the once-through process. Because of the daily capacity of 15 tons, the quantity of by-products would be low, and a recycle process required a larger investment. Chemiebouw began engineering and the pilot plant stopped operation in October 1949. About a year later construction commenced. When the plant became operational in 1952, several problems emerged that Central Laboratory helped to solve. In this case, the research department performed the role of production support.⁴³

DSM entered the urea field through the work of Chemiebouw and not Central Laboratory; engineering, not research, was key. The tasks involved suited Chemiebouw, even though they were unproven processes. DSM became involved with urea to catch up with leading companies in the field, and thus, its innovation strategy was defensive.

From Engineering to Research in Urea

After conducting market research in 1953, DSM dropped its plans to manufacture resins and concentrated instead on the fertilizer market. The company considered urea a long-term replacement for ammonium sulfate, a product it mainly exported after calcium ammonium nitrate replaced it in the Dutch market. This choice proved fortuitous because export fertil-

41. J. P. M. van Waes, interview by Ernst Homburg and the author, 4 April and 17 May 2000; Van Rooij, *Building Plants*, 142.

42. "Samenwerking ASED/Staatsmijnen op het gebied van de bereiding van ureum," signed by ASED on 1 April 1947 and by DSM on 23 April 1947, RAL, 17.26/19B inv. no. 370.

43. Central Laboratory annual reports, 1949 and 1951; Röthig, 8–11.

TABLE 2
IMPORTANT UREA PROCESSES, CIRCA 1950

<i>Company</i>	<i>Process</i>	<i>R&D phase</i>	<i>First plant</i>	<i>Licenses available?</i>	<i>Initial license availability</i>	<i>Contractor(s)?</i>
BASF	once-through, recycle	1913–1922	1922	no		
DuPont	once-through	1920–1933	1933	no		
ICI	once-through	1927–1935	1935	no		
Montecatini	once-through	1931–1939	1939	yes	after World War II	no
DuPont	recycle	1933–1936	1936	no		
Pechiney	recycle	1934–1938	1938	yes	1951	Foster Wheeler
Toyo-Koatsu	once-through	1937–1948	1948	yes	1954	Fluor, Girdler (1961), Toyo Engineering (1961)
Montecatini	recycle	1944–1953	1953	yes	1953	Kellogg
DSM	once-through	1946–1952	1952	yes		
Toyo-Koatsu	recycle	1948–1950	1950	yes	1954	Fluor, Girdler (1961), Toyo Engineering (1961)
Allied Chemical	recycle	1940–1949	1949	no		
Inventa	recycle	1945–1949	1949	yes	1952	Vulcan
Lonza	recycle	1946	1946	yes	early 1960s	Lummus
Chemico	recycle	1952	1952	yes	1952	
DSM	recycle	1953–1956	1957	yes	1957*	

*The first license was sold in this year.
Source: Arjan van Rooij, *Building Plants: Markets for Technology and Internal Capabilities in DSM's Fertilizer Business, 1925–1970* (Amsterdam, 2004), 140.

izer markets grew rapidly during these years. The Asian market became particularly important, as China and India became major users of fertilizers. In both countries, powerful central-government offices bought much of this fertilizer in large quantities, forcing prices down. For fertilizer producers, this meant that low production costs remained crucial even though demand grew.⁴⁴

DSM started planning for a second urea plant in 1953, only a year after the first unit had commenced operation. This time, at a capacity of 100 tons per day, the amount of off-gases would become too large to process into by-products. Several companies had developed recycling technology by the early 1950s, and acquiring the process from Montecatini, the leading Italian chemical company, was a serious alternative to developing it in-house. In August 1953, Van Aken and Van Waes went to Italy to talk to Giacomo Fauser, Montecatini's chief engineer, and to tour the urea plant at Novara. Van Aken had been appointed to top management and assigned responsibility for chemicals in 1949; in the same year, Van Waes had been promoted to head of production. Van Aken and Van Waes thought that buying recycling technology from Montecatini could minimize the risks of in-house R&D.⁴⁵

In September 1953, DSM management decided to build a large urea plant. There were two options for building it: acquire the technology from Montecatini, or develop it in-house. In this case, the company opted to go it alone.⁴⁶ Several reasons were behind this decision. First, DSM wanted to show its independence, choosing to build on its experience in urea production. It also believed it might later be able to license its own technology elsewhere. Although development would be expensive, recycling technology could be developed alongside production, as the plant could operate as a once-through unit until the recycling technology was ready. The plant could also be extended without major financial expenditures. DSM's push toward urea production intensified as it chose an offensive strategy for innovation.⁴⁷

In 1952, both Chemiebouw and Central Laboratory began work on the recycling processes. Chemiebouw started by evaluating existing processes, focusing on the so-called partial-recycle processes whereby only some of the off-gases were brought back to urea synthesis and the remainder was processed into by-products. Central Laboratory also started working on the

44. Minutes, top management meeting, 25 June 1953, CADH; Röthig, 15. For an overview of the fertilizer market during the 1950s, see Ursula Ewald, *Recent Developments of the World Fertilizer Market: A Statistical Analysis* (Kiel, 1957).

45. "Samenvatting van de bespreking met de heer Borelli (ASED) inzake ureum (12 mei 1953 te Den Haag)," 18 May 1953, second version dated 20 June 1953, RAL, 17.26/35A inv. no. 193; Röthig (n. 39 above), 13–16.

46. It isn't clear from the archival sources who in management made this decision.

47. Minutes, top management meeting, 29 September 1953, CADH; letter, top management to Minister of Economic Affairs, 29 December 1953, RAL, 17.26/19B inv. no. 217; Röthig, 16–17.

JULY

2007

VOL. 48

recycling problem, developing a process of its own by January 1956. The design of its synthesis reactor was changed from a spiral to a more conventional autoclave. In a "carbamate decomposer," pressure and temperature were reduced to break up ammonium carbamate into ammonia and carbon dioxide, which was the established practice at the time (fig. 2b). The breakup was not complete, so that by-products still resulted from urea manufacture. After the second urea plant started as a once-through unit in September 1956, DSM installed a partial-recycle pilot plant in December of that year. The production plant was converted soon thereafter.⁴⁸

In 1957, DSM decided to extend urea production further because synthesis unit 8 produced more ammonia than expected. Central Laboratory continued to work on recycling the off-gases as well. In 1958, Chemiebouw proposed to change the partial-recycle process to full recycle, but again closely followed the established practice by adding another decomposer to reduce pressure and temperature further and disintegrate more of the carbamate (fig. 2c).⁴⁹ DSM eventually succeeded in developing partial- and full-recycle processes on its own, though it took more time than its competitors (table 2). In the development of the recycle processes, the engineering that had enabled the company's entry into the field was complemented by research. CNA and ASED established the configuration of the once-through process, but DSM investigated recycle processes in-house. The scope of internal technological development increased to incorporate research.

By 1955 Central Laboratory was more heavily involved in systematic, fundamental research in urea. The full and partial processes recycled the off-gases by reducing pressure and temperature below that of the synthesis pressure. Ammonia and carbon dioxide then had to be compressed again before being fed back into the synthesis reactor. Energy efficiency was therefore low. In addition, elaborate equipment was needed to recycle the off-gases. In an attempt to improve the full-recycle process, fundamental research aimed at a theoretical understanding of urea synthesis. In 1960, this research resulted in an important breakthrough: the stripping process, which used one of the reactants, carbon dioxide, to drive off the off-gases in a bundle of tall tubes called the "stripper" (fig. 3). This significantly improved energy efficiency and cut production costs. It also simplified the mechanical design and reduced investments.⁵⁰

48. Central Laboratory annual reports, 1953–1956; Röthig, 12–13, 34–35, 38; and "Dutch Urea Process Stresses Prill Quality," *Chemical Engineering* 66 (1959): 54, 56.

49. Central Laboratory annual reports, 1953–1959; "Korte notitie," 12 August 1957 (n. 27 above); Röthig, 38; "Stripper Replaces Decomposer for Urea," *Chemical and Engineering News*, 18 October 1965, 46–47.

50. Central Laboratory annual reports, 1955–1960; "Stripper Replaces Decomposer for Urea"; "Tien jaar geleden zette DSM de eerste ureumstripfabriek ter wereld in bedrijf," *DSM Magazine* (July 1977): 18–22; and Ernst Homburg, with contributions by Arjan van Rooij, *Groeien door Kunstmest: DSM Agro 1929–2004* (Hilversum, 2004), 168–70.

FIG. 3 Simplified structure of DSM's stripping process. (Illustration by author, based on "Stripper Replaces Decomposer for Urea," *Chemical and Engineering News*, 18 October 1965, 46–47.)

In 1962, DSM built a pilot stripping unit, and three years later commenced construction on an industrial plant, which became operational in June 1967 (fig. 4). DSM also sold many licenses for its stripping process, the popularity of which underlined the efficient solution the company had found for recycling the off-gases. Research had played a decisive role in this innovation. In the course of the development of recycle technology DSM's innovation strategy went from catching up to overtaking, and finally to a full-blown offensive strategy. Research became much more important because DSM could not rely on technology markets, nor could it follow the lead of other companies.⁵¹ The critical step in this switch from a defensive to an offensive strategy was the decision not to acquire technology from Montecatini. Increased self-confidence played an important role in this decision. DSM believed it could develop recycle technology while operating new plants and extensions as once-through units until its technology was ready. In this process, increasing self-confidence meant more research.

At the juncture of defensive and offensive strategies, the complexity of the tasks before DSM also increased. The development of recycle processes had required some research, but the development of the most efficient full-recycle process required much more. The stripping process built on knowledge of the chemistry involved and on the ability to translate this knowledge into an industrial process. The scope of internal technological development increased further when DSM took a more offensive course. This, in turn, established Central Laboratory as the crucial link in innovation.

51. A. M. A. Heunks, "Voorstel voor het overnemen van de productiecapaciteit van de proefureumfabriek door de ureumfabriek SBB," *Stamicarbon*, 5 September 1962, RAL, 17.26/34 inv. no. 878; H. A. Bunge, "Voorstellen aangaande enkele uitbreidings- en rationalisatieplannen op het Stikstofbindingsbedrijf," *Staf Chemische Bedrijven*, 22 April 1965, CADH, D. V. 1965/108; and "Ureum-stripfabriek op SBB in juni in bedrijf genomen," *Staatsmijnen Nieuws* 16 (1967): 7.

JULY

2007

VOL. 48

FIG. 4 The pilot stripper in 1966. (Courtesy of the DSM Corporate Archives, Heerlen.)

Conclusion

The history of innovation at DSM shows that even though Central Laboratory grew into a key position in the firm, research-driven innovation processes were not the only methods DSM used to innovate in its fertilizer business. The example of DSM illustrates how companies can use several methods of innovation simultaneously, and how companies continued to do so well into the twentieth century. External sources of technology and production-centered innovation were just as crucial as R&D, even for companies in high-technology and strongly competitive environments.

Using Freeman's concept of innovation strategy as my basis, I have analyzed innovation processes within the parameters of scope, localization, and source of technology. The case study of DSM indicates the tight relationships among these three parameters and the innovation strategy the company pursued in a particular product line. The example of ammonium sulfate showed that research could be performed at a works laboratory. This

research had a narrow scope, which suited this facility. Research at the works laboratory continued even after the establishment of Central Laboratory with the investigation of catalysis in relation to ammonia synthesis. While SBB's works laboratory improved the catalyst used in production, the broad scope of catalysis research, including the mechanisms of catalysis, eventually shifted focus to Central Laboratory, which was more suited to this kind of research. The scope of technological work therefore affected its localization within the company.

Although Central Laboratory conducted state-of-the-art research in catalysis, DSM's overall innovation strategy in ammonia was imitative—the company focused on lowering production costs. This affected its scope, as cutting costs mainly required incremental improvements rather than radical changes to installations. The ammonia plant's staff corrected the bottlenecks in the installation, while Chemiebouw built expansions at increasingly large scales. Production-centered innovation was crucial to maintaining DSM's competitive position. Innovation strategy also affected the source of technology, as it did during the 1960s when DSM bought ammonia technology to catch up with its competitors. As the company focused on low production costs, its strategy was to buy technology for new, low-cost processes for synthesis gas production and ammonia synthesis that engineering contractors had developed. Thus an imitative innovation strategy led the company to acquire technology as a means of innovating.

In the case of urea, the importance of external sources of technology declined as DSM's innovation strategy evolved from a defensive to an offensive approach. As DSM gradually aimed for a breakthrough, its scope of tasks increased, from the engineering needed to develop a once-through process, to extensive process research to develop a partial-recycle process, and then further to fundamental research to develop a state-of-the-art full-recycle process. Only Central Laboratory was equipped to undertake this increasing complexity of tasks. Scope and localization combined with innovation strategy to create a research-driven innovation process in urea.

Central Laboratory's key role in urea production reflects a broader trend in the practice of R&D. DSM, like many other companies, invested heavily in its R&D department after World War II. Management supported Central Laboratory, and the laboratory's successes, such as the urea stripping process, further cultivated this support. This example of urea illustrates the company's self-confidence, which increased during the 1950s. DSM decided to choose internal development mainly because management was convinced of the company's ability to develop such technology. In this way, self-confidence pushed the company further toward research-driven innovation.

Yet even in the expanding urea market, low production costs were vital. In fertilizers, as in other bulk-commodity sectors of the chemical industry, price was of overriding importance in the market. This led to a focus on

JULY

2007

VOL. 48

low production costs, and consequently on process technology. In other industrial sectors this orientation seems less pronounced. Many possibilities existed to source technology externally, and DSM's pattern of innovation in fertilizers leaned heavily toward acquiring technology externally rather than developing it internally. Therefore technology rather than markets played the crucial role in shaping innovation in this context.

Structural and historical trends led to a pattern inside DSM whereby several methods were used to innovate simultaneously. Scope, localization, and sources of technology varied and combined in different methods for innovation. The increasing confidence in R&D added an extra emphasis on research-driven innovation. However, the case of DSM's fertilizer business indicates that focusing solely on R&D provides a one-sided view of innovation.