Journal of Business Chemistry

Vol. 7, Iss. 3

www.businesschemistry.org

09.2010

Published on Behalf of the Institute of Business Administration at the Department of Chemistry and Pharmacy, University of Münster, Germany

Vol.7, Iss. 3, September 2010 Journal of Business Chemistry

Contents

ISSN 1613-9615

Letter from the Editor

The chemical industry at the edge of change?

It's grumbling in the chemical industry. The "Deepwater Horizon" drilling rig explosion and the resulting oil spill in the Gulf of Mexico underscore the resource and energy related challenges of the 21st century. In addition to the inevitably existing technical complexity, the situation will be further exacerbated through growing public pressure and simmering mistrust, impeding the companies' intention to access the last oil deposits. This development might accelerate the replacement of crude oil. Among others that depend on crude oil as their main resource, chemical companies are forced to rethink their future strategy more than ever before. Although the development of scenarios that outline an oil-free world, the existing value chain of the status quo has to be considered. New business models, new resources or new technologies: the whole industry is at the edge of a revolutionary change. Accordingly, this issue of the Journal of Business Chemistry tries to shed light on some of the mentioned aspects.

In his commentary "Bio products from bio refineries - trends, challenges and opportunities", Bhima Vijayendran distinguishes between three waves for bioderived chemicals: bioproducts produced through (1) the thermo-chemical/ catalytic conversion of feedstocks, (2) biochemical conversion technologies and (3) genetically engineered plants with designed functionality. The author highlights recent developments in each of the three waves.

In their research article "Analyzing the Direct Methanol Fuel Cell technology in portable applications by a historical and bibliometric analysis" Arho Suominen and Aulis Tuominen evaluate the opportunities provided by the new fuel cell technology. Focusing on portable applications, the authors use patent und publication databases to assess the inherent potential of the emerging technology. Based on this analysis, they argue that although the research interest in the new fuel cell technology has risen since the beginning of the 1990s, a reasonable commercialization has not taken place yet.

In the second research article "Multidisciplinary collaborations in pharmaceutical innovation: a two case-study comparison", Irina Saur-Amaral and Alexander Kofinas highlight how intra-organizational collaboration can be achieved across varying disciplines. Since multidisciplinarity marks an important issue for both future research and innovation activities, the authors compare two pharmaceutical companies with different geographical strategies.

The practitioner contribution to this issue deals with a new research paradigm that may reshape the pharmaceutical industry. In their identically-named article "Pharma 3.0", Patrick Flochel and Frank Kumli introduce a new, health outcomes-oriented business model that incorporates the emerging need to deliver a sustainable value proposition. Besides contrasting prior business models with the new "Pharma 3.0" approach, the authors outline principal guidelines that may help pharmaceutical companies to adopt the new business model.

Moreover, we want to announce that Sebastian Kortmann will join our team as Executive Editor. He is one of our successors and will replace Irina and me in the near future. Now, please enjoy reading the third issue of the seventh volume of the JoBC. We would like to thank all authors and reviewers who have contributed to this new issue. If you have any comments or suggestions, please do not hesitate to

ISSN 1613-9615

send us an email at contact@businesschemistry.org.

David Große Kathöfer, Executive Editor
(dgk@businesschemistry.org)

Journal of Business Chemistry

Commentary

Bio products from bio refineries - trends, challenges and opportunities

Bhima Vijayendran*

* Battelle Science & Technology Malaysia, Sdn Bhd (809178-W) GTower, Suite 15.02 199 Jalan Tun Razak 50400 Kuala Lumpur, Malaysia vijayenb@battelle.org

A recent study estimates that, by 2025, over 15% of the three trillion dollar global chemical sales will be derived from bio-derived sources. Many of these bioproducts would be manufactured in bio-refineries by the deployment of rapidly emerging industrial biotechnology. It is expected that bioderived chemicals will come from three sources: direct production using conventional thermochemical and catalytic process, biorefining, and expression in plants. Direct production is already a reality, as evidenced by the production of propane diol and polylactic acid from corn-derived glucose and others. There has been recent commercialization of bio-derived plasticizers for polyvinyl chloride, polyester resins for coatings and inks, biopolyols for urethane foams and others based on vegetable oil and carbohydrate renewable sources. Chemical biorefineries, on the other hand, based on various platforms such as carbohydrate/ cellulose, oil, and glycerin, a co-product of biodiesel production, and algae are in the pilot stage. Chemicals expressed in genetically enhanced plants to accentuate target functionalities such as primary hydroxyls, oxirane and others are in the discovery phase and furthest from commercialization. This paper highlights some of the recent developments and trends in each of the three waves for bioderived chemicals. Further, it also covers some of the successes in the commercialization of bioproducts, lessons learned, and challenges ahead for the nascent chemical biorefineries.

Introduction

A recent report (C&News, 2009) estimates over $100 billion of the current global chemicals market, about 3%, are derived from either bio-based feedstock or fermentation or enzymatic conversion or combination of them. This report projected that the share of bio-derived chemicals would grow to about 15% of global chemical sales by 2025. There are several drivers for the interest and growth of bio products in the marketplace. A few that are worth mentioning include the availability of cost effective technologies including novel functional building blocks and improved processes, concerns about long term sustainability and price volatility of fossil-based feedstock, a more benign footprint on the environment, and consumer interest in green products and public policy. Many large and established chemical and biotechnology companies as well as numerous smaller startup and venture companies are actively involved in the development and commercialization of bioproducts from a variety of renewable biomass sources. These companies are trying to follow a bio-refinery model, similar to current petrochemical refineries, which co-produce large volume commodity fuels and high value chemicals.

This paper covers the following topics related to these emerging technologies:

- Various bio refinery models
- Conversion technologies
  - First wave of bioproducts by thermo chemical/catalytic conversion of bio-derived feedstock
  - Bio feedstock platforms
  - Second wave of bioproducts by bioche

mical conversion technologies
- Third wave of bioproducts from genetically engineered plants with designed functionality of bio-monomers/building blocks

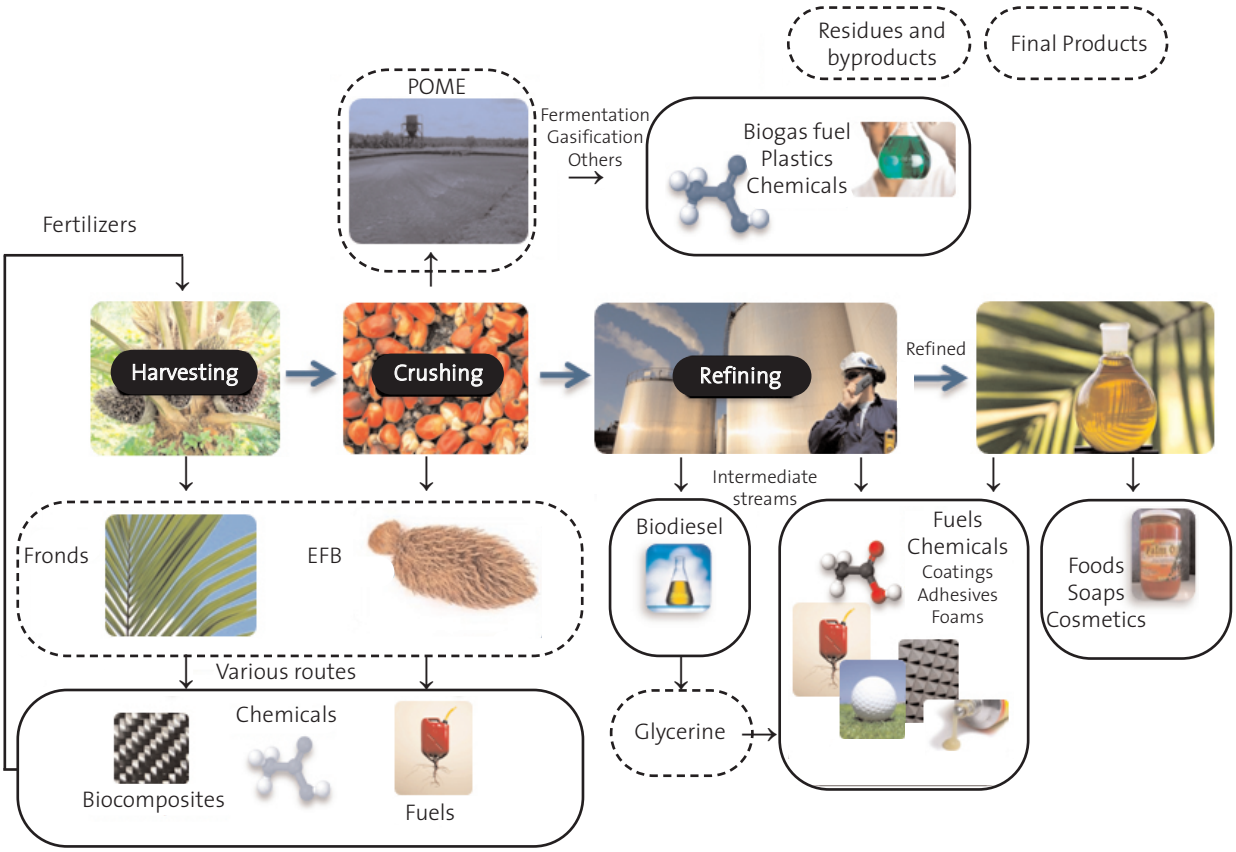
- Some challenges and opportunities for bio refineries

Various bio refinery models

There are various bio refinery models under development, most of which differ based on the biomass source. A palm plantation-based bio refinery is shown in Figure 1.

The concept of palm-based bio refinery (and others such as corn wet mill, sugar cane, and soybean) is quite simple and similar to the current petroleum refineries. Biomass is converted to fuels (biodiesel from palm oil and bioethanol from lignocellulosic contained in the feedstock, in this case empty fruit bunches, fronds, etc. that are residues from palm oil processing) and value added chemicals. In a typical palm plantation, besides the oil and lignocellulosic biomass sources, there is some activity to convert palm oil mill effluent (POME) to high value chemicals and biogas. In the case of corn wet mill and sugar cane plantations, biomass is converted to fuel (mostly bio ethanol) and chemicals such as polyols, acids, and others. One major difference between a bio refinery and petroleum refinery is that one of the main product from a bio refinery—at least for the first generation ones based on palm, corn, and sugar cane—is food for humans and animals. This is an important consideration and challenge and has created a serious debate as to the sustainability of first generation bio fuels in particular, and to a lesser extent for smaller volume bio products. Technologies are being developed to use co-products from the first generation bio refineries that are not targeted for food and feed. To address this problem more directly, the trend is to develop non-food energy crops such as jatropha, switch grass, and others as the biomass source for future bio refineries. The general consensus is that the bio refineries will initially focus

Figure 1 Emerging palm biorefinery concept



on large volume fuels followed by high value chemicals similar to the evolution of petrochemical refineries.

First wave bioproducts

Many first wave bioproducts are already in the marketplace and are finding applications in myriad end uses. These bioproducts are derived from thermochemical conversion of new bio monomers or building blocks. Products often fall in two categories, namely, the ones that are chemical replacement for petroleum-derived chemicals such as ethylene or lactic acid or functional equivalent of existing chemicals. The main driver for successful first wave bio products is the competitive cost of bio-derived feedstock compared to the current petroleum counterpart that is being replaced. This is very true for bio products such as bio ethylene derived from sugar cane or bio 1,3-propanediol that are targeted to replace corresponding petroleum derived products.

A few of the first wave bio product initiatives are captured in Figure 2.

It is worth noting that there are other projects such as the propylene glycol plant to be commissioned by Archer Daniel Midland (ADM) shortly and the polyvinyl chloride (PVC) by Solvay Indupa in Brazil from bio based feedstock (Martinz and Quadros, 2007).

Bio feedstock platforms

The bio feedstock platform for the production of bio products is mainly focused on the following chemical functionalities.

Vegetable oil/fatty acid esters of glycerol

Vegetable oils and fats provide useful chemical functionalities such as unsaturation and ester groups for further modifications using conventional schemes such as hydrogenation, selective oxidation, epoxidation , meta thesis reaction and others to introduce functionality of value in diverse applications such as plasticizers, coatings, adhesives, polymers, composites, etc. Several bio products such as bioplasticizers for PVC (Vijayendran, 2005), bio toners (Vijayendran, 2008), biopolyols (Benecke et al.; 2008) based on this approach have been commercialized recently.

Sugar-based platform

Platforms based on sugars (Werpy and Petersen, 2004) have been deployed to create acids such as succinic acid and convert the acid to high value chemicals such as 2- pyrrolidone, 1,4-butanediol, tetra hydrofuran and others.

More recently cellulosic feedstock (Zhang et al., 2009) has been converted to 5-hydroxymethyl furfural (HMF) using some novel catalysts and ionic liquids as platform chemical to make a variety a high value chemicals derived from petroleum sources, as shown in Figure 3.

Glycerine Platform

Figure 4 shows bio products derived from crude glycerine, a co-product of biodiesel production.

Figure 2 Summary of the first wave of bio-derived plastics

	DuPont Bio-PDO (Serona®)	Nature Works™ PLA	Braskem Bio Ethylene
Plant scale	45kTA	140kTA	200kTA
Fermented products	1,3- Propanediol	Lactic acid	Ethanol
Key processes	Fermentation, Cendensation, Polymerisation	Fermentation, Oligomerization, Ring-Closing & Ring Opening, Polymerizsation	Fermentation, Hydratation, Polymerization
Initial product	PDO/TPA Copolymer	Polylactic acid	Ethylene, Polyethylene, Copolymers
Flexibility	Moderate	Low	High

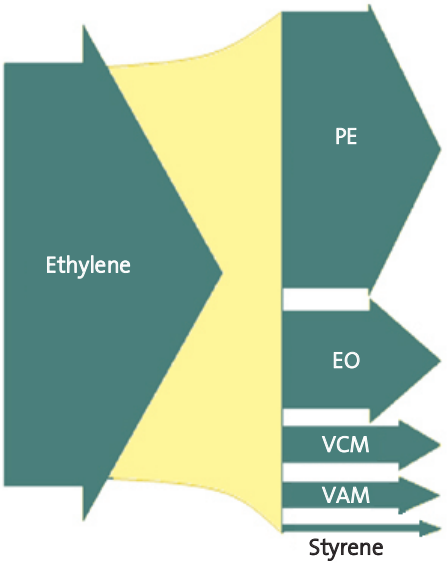


Figure 3 Derived from cellulosic biomass, 5-hydroxymethylfurfural (HMF) can be converted into many types of compounds now obtained from petroleum sources

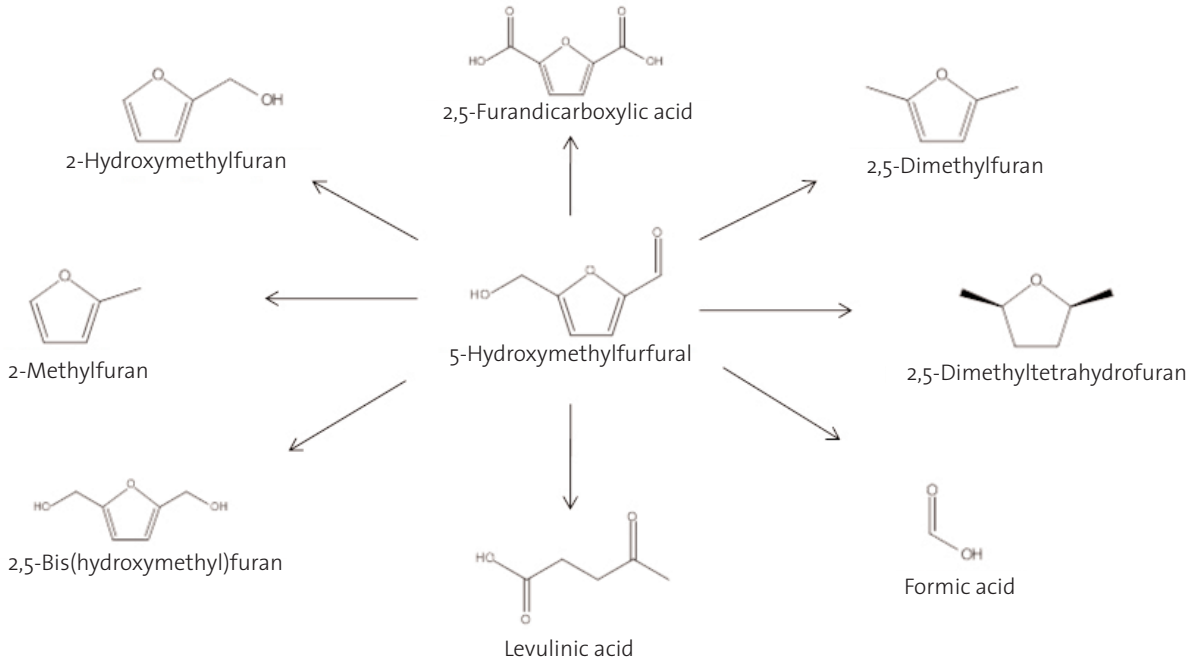
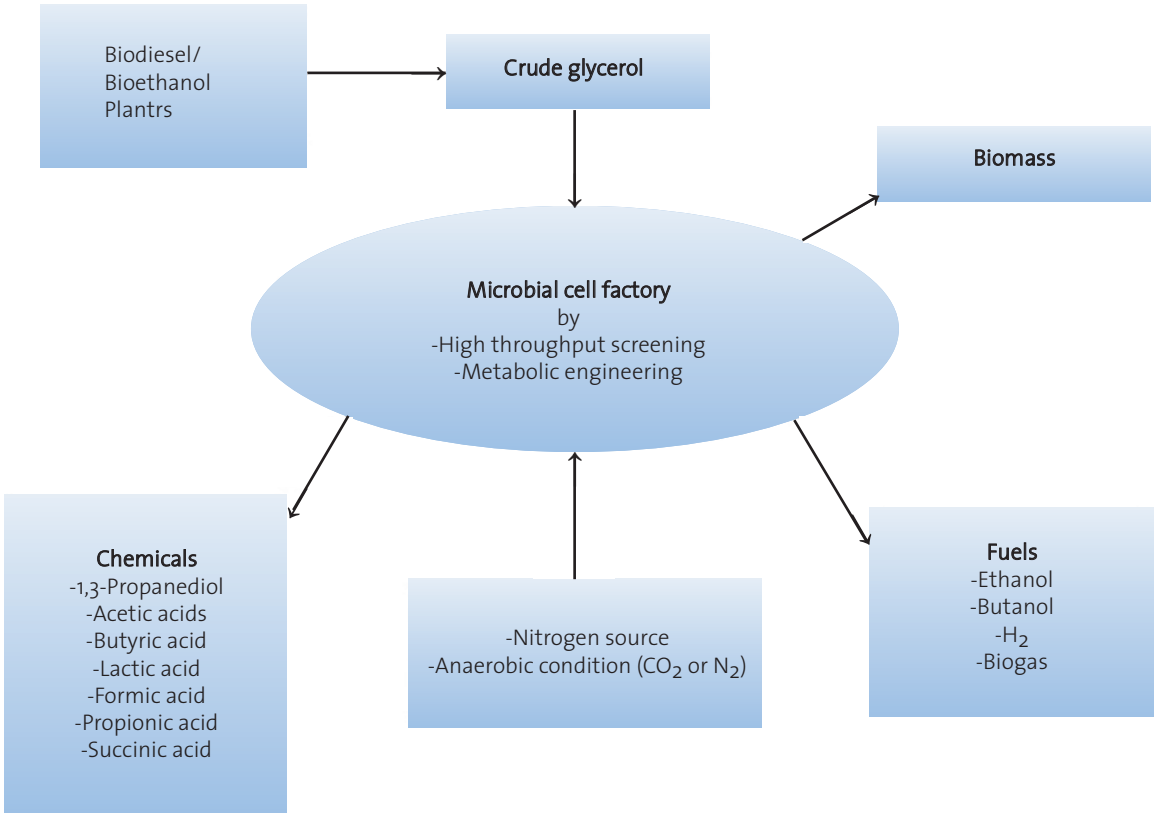


Figure 4 Example platform production of bio products derived from crude glycerine



There have been recent activities to convert abundant and low cost lignin to value added chemicals and fibers (Baker, 2009).

Recent commercialization efforts of first wave bioproducts have clearly shown that it is important that the technology is proven at the pilot scale and the economics are competitive with the petroleum products. In many cases, such as in bio plasticizers for PVC and biotoners for office copiers and printers, the bio product replacements have functional attributes that are of value and not available from current petroleum products. In the case of bio plasticizers, it is shown that one of the new bio plasticizers, reFlex™ 100, has significantly better thermal stability, lower plasticizer migration, and improved plasticization efficiency compared to industry standard (butyl benzyl phthalate [BBP]) and a petroleum-based phthalate replacement (DINCH from BASF), as shown in Figure 5.

Plasticization efficiency and thus lower use level with no known health concerns compared to the petroleum based phthalate plasticizers, besides being "green" and environmentally friendly. See Table 1 for some comparative data of reFlex™ 100 bioplasticizer from PolyOne and the industry control, butyl benzyl phthalate (BBP).

In the case of bio toners, the bioproduct replacement has lower fusion temperature and easier recycling of office waste paper (Vijayendran, 2008). The message that is becoming clear is that any new bio products that are targeted to replace existing petroleum-derived products should be able to compete on cost and performance. Just being "green" and bio-derived from a sustainable source are not enough to be accepted in the marketplace.

Second wave bio products

The second wave bio products involving the conversion of bioderived sugars, cellulosics and oils by biochemical routes are in the advanced R&D and early pilot scale phases. Biochemical processing using advances in metabolic engineering and separation technologies to produce high value chemicals have made great strides in the last few years. Bioprocessing tend to have the following attributes compared to conventional thermo chemical conversion technologies:

- Lower yields
- Fairly dilute solutions with lower concentrations of actives
- Most reactions are done at ambient temperature and pressure thus offering processes with potential lower capital and operating investments
- Microorganisms have several pathways to make the same products and rapid screening tools have helped to design metabolic pathways to achieve high yields of target molecules
- Most of the initiatives in the second wave bio products are in the advanced R&D or pilot scale. Major milestone is to demonstrate commercial viability of many of the technologies that have shown R&D feasibility in the laboratory scale.

Figure 5 Improved thermal stability of reFlex™ 100, a bio-derived green plasticizer, compared to butyl benzyl Phthalate (BBP) plasticizer, and diisononylcyclohexane-1,2 dicarboxylate (DINCH), a petroleum-based non-phthalate plasticizer. Test conducted on heat stability in a metastat oven set to 375 degrees for 5-to-60 minutes.

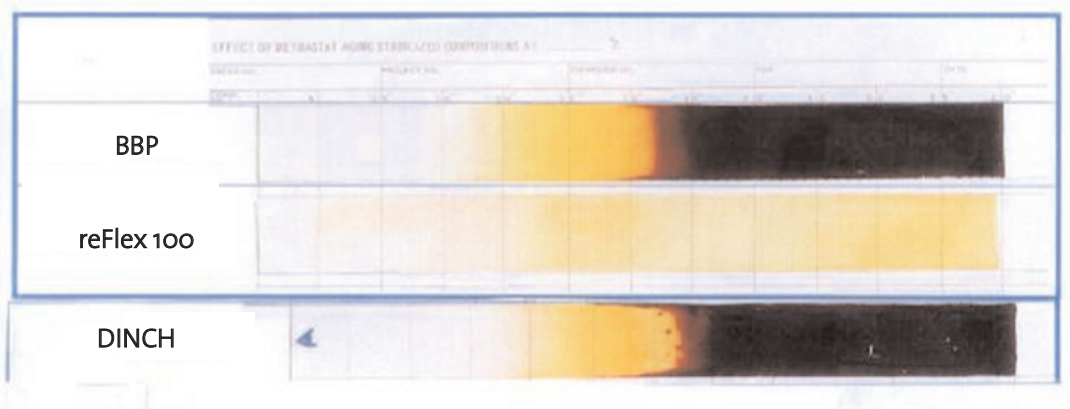


Table 1 Benefits of reFlex™ 100 in plastisol and flexible PVC applications

Feature	Benefit
Bio-derived	■ Allows the incorporation of high level of renewable content
Improved air release	■ Reduced evacuation time ■ Improved productivity ■ Reduced defect rate
Greater efficiency	■ Reduced usage level
Fast gelation and fusion	■ Fast processing ■ Low fusion temperatures possible
Lower paste viscosity	■ Easier material handling
Imparts excellent thermal stability	■ Reduction of heat stabilizers - lower cost ■ More robust performance

A few of the players that are active in the second wave bio product development and commercialization are shown in Table 2.

It will be interesting to watch over the next several years how successful the second wave products from these companies are going to be in the marketplace.

It is worth mentioning here that there are several algae-based initiatives to make biofuels and high value chemicals such as acids, alcohols, esters etc (Solix Biofuels.com). It should also be mentioned that there is a joint venture between ADM and Metabolix to produce poly hydroxyl alkanoates, a polyester biopolymer with some interesting properties (Chen, 2010).

Third wave bio products

Third wave bio products derived from plant expression through genetic engineering to produce chemicals with designed functionality are still in the early discovery stage and furthest from commercialization. The work on high oleic acid oils is perhaps furthest along in terms of commercialization. There are several patents describing the use of such high oleic acid oils in several industrial applications such as inks, lubricants, etc. (Knowlton, 1999). Some early work has shown the feasibility of introducing primary hydroxyl functionality in vegetable oils such as canola. About 12% riconelic acid has been expressed in conventional canola seed (Grushcow, 2007). Primary hydroxyl functionality from such modified oils has several useful functionalities and attributes of interest in lubricant, coating and polymer applications. Recent work at CSIRO, Australia (Green et al., 2009) has shown the feasibility of expressing high levels of epoxy functionality in some native oil seeds. A crop producing epoxy oil would be an interesting replacement for epoxidized oils produced by the convention per acid route. The same group has also expressed acetylinic functionality in plant oils with the potential provide useful reactivity and functionality of value in several high value chemical applications.

Summary

Use of bio products is growing with the first wave products derived from thermochemical conversion of bio-derived building block taking the lead in commercialization. Second wave bio products produced by metabolic engineering and bioprocessing technologies are in the pilot scale. Third wave bio products based on plant expression are in the discovery phase. Bio refineries based on a variety of biomass feedstock are still in the nascent stage and will require some time to fully develop. Continued R&D investment to improve the technologies to provide cost effective solutions is very much needed. Also, establish-

Table 2 Second wave bio products other than ethanol and biodiesel

Company	Product	Contact
Gevo	Isobutanol	www.gevo.com
Verdezyne	Adipic acis	verdezyne&Schwartz-pr.com
Myriant Technologies	Succinic acid	www.myriant.com
Opexbio	Acrylic acid	www.opxbio.com
SyntheZyme	w-hydroxyfatty acids	rgross@synthezyme.com
Virent	BioForming process for various chemicals	www.virent.com
Zeachem	Ethyl acetate/ ethanol	www.zeachem.com
LS 9, Inc	Hydrocarbon/ fuel	www.LS9.com
Genecor/ Good Year	Isoprene	www.genecor.com
Genomatica	1,4 butanediol	www.genomatica.com

ment of supply chain of feedstock as well as compatibility with existing infrastructure of the well established petrochemical industry is expected to facilitate commercialization of bioproducts. It is expected that bio products from bio refiners will continue to grow and compliment the petrochemical refineries to serve the global chemicals markets.

References

Baker,F.S., Low Cost Carbon Fiber from Renewable Resource., EERE, U.S. Dept of Energy Project ID # lm_03_baker

Benecke, H., Vijayendran, B.R., Garbark, D. and Mitchell, K. (2008): Low Cost Highly Reactive Biobased Polyol—A Co-Product of Emerging Bio Refinery Economy., *Clean Journal*, **36** (8), p. 694.

C&News, July 2009, p. 26-28.

C&News, Bio Refineries, Oct 12, 2009, p. 28-29.

Chen, G.Q., Industrial Production of PHA., Plastics from Bacteria., *Microbiology Series* Vol. **14**, 121-132,

Choi, W.J. (2008): Glycerol Based Bio refinery for Fuels and Chemicals, *Recent Advances on Biotechnology*, **2** (3), p. 174.

Gray, J. (2009): Personal communication from PolyOne, Cleveland, OH.

Green, A., O'Shea, M., Lawrence, L. and Begley, C. (2009): Beyond Biodiesel., *Inform*, **20** (6), p. 345.

Grushcow, J. (2007): New Opportunities in Oil Seed Engineering., available at http://www.linnaeus.net, accessed, 2009

Knowlton, S. (1999): U.S. Pat 5981781, Du Pont Company.

Martinz, D. and Quadros, J. (2007): Presentation at Brighton Conference, Brighton, U.K.

Vijayendran, B.R. (2005): Emerging Opportunities and Challenges for Soybean oil –derived Industrial Products., *Inform*, **16** (10), p. 659.

Vijayendran, B.R. (2008): Presidential Green Chemistry Award Invited Lecture, Washington, June 2008.

Werpy, T. and Petersen G. (2004): USDOE's Top Sugar Derived Building Blocks, available at http://www.nrel.gov/docs/fy04osti/35523.pdf, accessed 2009.

Zhang, Z.C. (2009): Single Step Conversion of Cellulose to 5-Hydroxyl Methyl Furfural (HMF) - a versatile Platform Chemical., *Applied Catalysis*. A **36**, p. 117

Journal of Business Chemistry

Research Paper

Analyzing the Direct Methanol Fuel Cell technology in portable applications by a historical and bibliometric analysis

Arho Suominen* and Aulis Tuominen**

* Department of Information Technology, University of Turku, 20014 University of Turku, Finland, arho.suominen@utu.fi

** Department of Information Technology, University of Turku, 20014 University of Turku, Finland, aulis.tuominen@utu.fi

The development of direct methanol fuel cell (DMFC) technology through an analysis of research, patenting and commercial adoption is studied in this paper. The analysis uses a dataset gathered from both publication and patent databases. This data is complemented with a review on commercial efforts on portable fuel cells. Bibliometric methods are used to identify research networks and research trends. The Fisher-Pry growth model is used to estimate future research activity. The patent landscape is also analyzed by exploring patenting activity. The bibliometric and patent database analysis results were then reflected against a review on commercial adoption. The research indicated increased research activity from the early 90's and expectations of significant growth in the future. Strong emphasis is seen in Asian organizations producing research results and gathering Immaterial Property Rights. However the early expectations on rapid commercialization of the technology have not been met. The commercially viable application of the technology is still lacking.

1. Introduction

The growing environmental awareness has made new energy solutions, such as solar, wind, and fuel cells promising alternatives for existing technologies. In the search for an environmentally friendly and efficient energy source Fuel Cell (FC) technology is one promising choice. FC is an electrochemical device that produces electricity through a reaction between a fuel and an oxidant.

The most significant difference to existing electricity production methods is the possibility to produce electricity without moving parts in a single process (Barbir, 2005). The principle of FCs was invented already in 1838 by German scientist Schönbein and proven by Sir William Robert Grove one year later (Kurzveil, 2009). Since then the technology had for decades been only of mediocre interest, only to increase in interest due to the space programs in the 1950s.

Only in the last twenty years has FC technology taken leaps forward in technology maturity. Due to their versatility, FCs can be adopted to a variety of applications from large stationary solutions to small milliwatt scale systems (Cropper, et al., 2004). The possibilities of using FCs in portable devices have been driven by the high power and lifetime requirements of portable devices. These requirements are proving hard to meet with conventional rechargeable battery systems, due to their limited specific energy and operational lifespan. (Broussely and Archdale, 2004; Eckfeld et al., 2003; Dillon et al., 2004). To meet this market need FCs and specifically Direct Methanol Fuel Cells (DMFCs) are seen as a viable option.

The development of FC technology has taken several leaps forward since the technology was first applied. In the 1970s the deve-

lopment focused on large solutions. Partly due to the oil crisis, possible future energy sources received a significant amount of attention. Only more recently, since the 1990s, has the focus turned towards smaller solutions (Cropper et al., 2004). In the 2000s there has been an increased amount of attention to FCs as a whole. This development can be awarded to several companies which have put significant effort into the development of portable fuel cells (Kamarudin et al., 2009).

In addition to being used in different applications ranging from large stationary power plants to micro watt solutions, FC technology can be divided into several sub-groups such as Solid Oxide (SOFC), Molten Carbonate (MCFC), Alkaline (AFC), Phosphoric Acid Fuel Cell (PAFC) and Polymer Electrolyte Membrane (PEM) Fuel Cells. DMFC is a sub-category of PEM fuel cells. It uses methanol as a fuel in a direct process. DMFC is seen as an energy storage and production device for portable applications (Goodenough et al., 1990), although higher output transport and stationary solutions have also been suggested. DMFCs can be seen as one of the most prominent fuel cell technology to be used in small portable application, this largely due its high energy storage density fuel, fast refueling and capability to refuel during operation. DMFC can also be viewed as a "comparatively simple system" (Cremers et al., 2005).

The paper focuses on the application of DMFC technology in portable applications. A portable application, in the scope of the study, is seen as movable fuel cells with the purpose of producing usable energy. These applications range from power systems in consumer electronics to larger back-up power systems. DMFCs, in portable devices, are entering a highly matured market of providing an energy service. DMFC based power systems are restricted by similar expectations of reliability, cost, noise, efficiency and regulations as conventional systems. Even though the requirements for new electronic devices have increased, the power consumption a specific application has decreased. Nevertheless systems, such as mobile phones, offer several other services than the primary function. This has increased the demands for an energy source. Battery technology has been able to follow the increased requirements of new portable devices. As an example, the newest mobile phones even with cameras and other services have an operational time that exceeds that of the first mobile phones produced. As Agnolucci (2007) has noted, battery manufacturers see that secondary batteries are not facing an urgent crisis.

Despite this, in several geographical areas, governments, research organizations and industry are putting increased effort into developing FC systems. As an example the European Union's 7th framework program has allocated significant resources on the development of fuel cell and hydrogen technology (Fuel Cells Bulletin, 2008 a). Similar efforts can be found in the USA and Japan (Fuel Cells Bulletin, 2008 b). Although these programs focus on FCs widely, there is a significant portion of the effort put to the development of portable devices. In the industry sector we can also see increased efforts as we have seen a steady increase in units shipped in the portable FC sector for several years. In 2008 approximately 9,000 portable units were shipped (Butler, 2009).

By analyzing the developments of research and patent landscapes, while reviewing this data against commercial adoption, scholars and practitioners can gain insight to emerging possibilities. DMFC technology has been developed for decades, often with a clear expectation of commercial possibilities. The research questions set for the study strived to 1) identify research trends, 2) identify significant research organizations, and 3) identify the patent landscape, while reflecting these against commercial adoption. This is done by a bibliometric and historical analysis on research trends and patent landscape.

The paper is structured as follows. The following chapter will explain the characteristics of portable fuel cell technology. It will also review the background on technology lifecycle analysis. The third chapter will describe the methodology and dataset. Fourth chapter will give the results of the study. These are later discussed in the final chapter.

2. Background

2.1 Characteristics of commercializing Portable Direct Methanol Fuel Cell Technology

The challenges of portable DMFC technology can be divided into several barriers, most significantly to lifetime, cost and commercialization. Technological barriers still have a significant effect on portable FCs being seen as a viable option for existing power sources. Technological barriers are analyzed in detail by Kamarudin et al. (2009). Cost as a factor is

also analyzed by several authors. In the work of Wee (2007) DMFC based fuel cells were seen as more expensive than conventional lithium-ion batteries in both manufacturing cost and operational cost. Dyer (2002) however found contradictory results. However, the low application rate of FCs would argue against Dyer's results. For detailed analysis on the lifetime and cost barriers refer to e.g. Kamarudin et al. (2009) and Wee (2007).

In analyzing commercialization, Smith (1996) has studied how emerging technologies, such as FCs, can substitute existing technological solutions. Smith described the methods as relating to functionality, and product or asset substitution. Hellman and van den Hoed (2007) have used Smith's work in the context of FCs and presented several significant factors seen as relating to the technological characteristics of FCs. These are 1) immaturity, 2) application diversity, 3) replacement technology, 4) subsystem product and 5) complexity.

1) FC technology immaturity is seen most easily in the rapid technological progress seen in several measurable attributes such as power densities. Significant development has happened in a short timeframe, which has enabled several demonstrations of portable FCs. 2) Application diversity is derived from FCs being energy sources. The abundance of devices requiring a power source has grown significantly. In this the distinctive aspects of portable devices are even more significant. Even thought scholars might disagree on the applicability of fuel cells in mobile phones, we are able to demonstrate the overall increase in of portable devices needing an energy source. The number of mobile phones has from its invention in the 1980's risen to over 4 billion. A similar trend can be found from several different types of portable devices from PDAs to laptops. These all require a power source to which FC is one possibility among others.

3) It is however important to point out, as Hellman and van den Hoed (2007) have done, that FCs are a replacement technology. Competing technologies, some of which are extremely mature, are seen as setting the bar in the customer's expectation on cost and performance. If we for example analyze the cost structure of a mobile phone, we see end-user products being offered to the customer with ever lower prices. This will drive the price of components ever lower, and if we see FCs as a viable solution for portable solutions we are faced with a strong need for price reductions and technological development. We can even question if the assumptions, made by Dyer (2002), that the allowable cost of fuel cells in portable devices is in the range of $3-5/W would be sufficient in the future?

In comparison to cost, FC and DMFC technology has a clear advantage in system energy densities. Currently the portable electronics industry mainly uses lithium based battery technology. This technology enables energy densities of 475 Wh/l and 220 Wh/kg-1 with the expected growth path of 5 to 10 percents yearly (Ryynänen and Tasa, 2005, cited in van der Voorta and Flipsena, 2006). This development phase is however expected to diminish due to the physical constraints related to the technology (Broussely and Archdale, 2006). The theoretical energy density of FCs is near 5000 Wh/l from which the practical energy density with current technology is in the range of 250 – 1000 Wh/l (Dyer, 2002; Flipsen, 2005).

4) The characteristics of FCs also include the notion that FCs are subsystems of product. Although different structures of fuel cells have been researched (Qian, et al., 2006), FCs will most likely have some BoP (Balance of Plant). In the current demonstrational status we see FCs being integrated as such to existing products. These products, for examples mobile phones, are designed to use batteries as a power source. Through a high degree of interdependence current devices are optimized to work with existing power sources. FCs that are integrated to a product are also heavily interdependent on the application and as such will set design constraints.

5) FC is a system which is constructed from the actual FC as well as from the BoP connected to the FC. This structure is in no way a simple one. We can see it requiring specific knowledge on several aspects from materials science, chemistry, electronics to mechanics. Complexity and the sub-system nature of FCs have a significant effect on the convenience and perceived safety of FC based systems. Concerns on the storage of fuel, such as methanol, and the technical limitations of materials can reduce the practical advantages of using DMFC in portable applications (Dyer, 2002).

2.2 Emerging Technology lifecycle indicators

Pavitt (2006) describes innovation into three overlapping processes: 1) The production of scientific and technological knowledge, 2) responding to and influencing market demand,

and 3) the translation of knowledge into working artifacts. Pavitt sees the production of scientific and technological knowledge as a major trend. Pushed by the industrial revolution, the increased production of highly focused scientific and technological knowledge will be seen as offering opportunities for commercial exploitation.

There have been several notable scholarly presentations on the process of Research and Development (R&D) diffusing to the market. Abernathy and Utterback (1978) have presented the model of innovation which presents the dynamic process of industry over time. The model shows innovation going through three specific phases in its lifetime: fluid, transitional and a steady state. The fluid stage is characterized as the uncertainty phase where technological and market related uncertainties prevail. In the transitional phase producers are becoming more aware of true customer needs as technological application. This is seen also as an increased need for standardization. This stage can be presented as a "dominant design", which can be seen as a standardized product design with little or no variation between applications. In the steady state the focus moves from differentiation through product design to cost and performance enhancements.

The evolution of technology and its market applications is also presented by Balachandra et al., (2004). They see the evolution as a co-evolution with three specific stages: exploratory, transitional, and technology variation and refinement. The model is coherent with the work of Abernathy and Utterback (1978) as it sees the first phase as an exploratory phase lacking the knowledge of widespread application. The first stage is seen as evolving to a transitional stage where the industry is more aware on the external inputs from the market. The last phase focuses on variation and refinement.

An S-curve is often used to demonstrate the evolution of a technology. Presented in the work Diffusion of Innovation, Rogers (1962) presents the diffusion of innovation through a social system as an S-shape curve. Rogers presents the rate of adoption, which is defined as the relative speed in which the members of a social system adopt a specific innovation. This work divided adopters to specific categories such as innovators, early adopters and majority. With this categorization a technology can be seen as diffusing into the social system.

While the work of Abernathy and Utterback, and Rogers present the model of which a specific technology can diffuse to the market, Watts and Porter (1997) have presented methods to understand the evolutionary status of a technology. In their work Watts and Porter elaborate on the possibilities of bibliometric methods in assessing the lifecycle status of a technology. Borgman and Furner (2002) define bibliometrics as methods of analyzing text databases quantitatively. Daim et al. (2006) elaborate that bibliometric methods enable the analysis of large databases in order to understand the underlying structures in technological development. These structures can then be modeled through analysis to understand the evolution of a technology. One of the most known concepts in analyzing a specific technology is the Technology Life Cycle (TLC) indicators presented by Porter et al. (1991). Watts and Porter argue that technological development has five stages which could be identified by bibliometric methods. The stages, basic research, applied research, development, application, and social impact, can be identified for example by the number of instances counted in a stage specific databases. The stages should, in an ideal situation, form a continuum where each stage reaches its most active phase after the previous stage has started to diminish in activity. This linear model of development has however been criticized (Rosenberg, 1994). It however gives a simplified representation of technological life-cycle (Balconi, Brusoni and Orsenigo, 2010).

Bibliometric methods are seen as giving a direction, but one should avoid making too straightforward assumptions on the specifics. As mentioned by Watts and Porter, bibliometrics are limited by the secrecy related to R&D as well as it is limited on the queries made to databases. Databases also include a significant portion of mistaken information which confuses the data analysis. Technological forecasting can however give an understanding on the direction and rate of development of a specific technology.

3. Methodology and dataset

There are several studies on the bibliometrics and patents analysis on a specific technology (Chao, Yang and Jen, 2007; Kajikawa et al., 2008; Kajikawa and Takeda, 2009; Huang et al. 2010). These are used to analyze the future trends, research co-operation, and Immaterial Property Rights (IPR) owners. The study

presented in this paper uses bibliometric methods to assess the developments of portable DMFC technology.

In this paper a time series analysis is done by applying an S-shaped growth curve to research and patent trend analysis. Several different growth models have been used to forecast technological development, such as the exponential growth model. The S-shaped growth curve has been, however, seen as fitting well to the modeling of technological growth processes. Scholars are seen as using two distinct S-shaped growth models, the Fisher-Pry model or the Gompertz model to forecast growth (Porter et al., 1991; Watts & Porter 1997; Bengisu & Nekhili 2005; Huang et al. 2010). In this paper the Fisher-Pry model is used to forecast the trend of DMFC related articles. The Fisher-Pry model, named after Fisher and Pry, was described by its authors as "a substitution model of technological change". Fisher and Pry (1971) explained that the model would be powerful in for example forecasting technological opportunities. The basis for the Fisher-Pry Curve is described by Porter et al. (1991). The Fisher-Pry curve is defined as $f = 1 / (1 + c \exp(-bt))$.

In the equation, the analysis is constricted by the analyst being able to determine the values of b and c which fit the data used. This is done by assessing the upper bound for the growth. For detailed analysis refer to Porter et al. (1991) and Chung and Park (2009). Analyzing the Fisher-Pry curve is however seen as giving the trend for future research efforts.

In addition to the Fisher-Pry trend extrapolation the publishing organizations were identified by the regions, countries and research organizations. The ten most frequent countries and research organization publishing research results were identified to form a picture of the research landscape.

Patent landscape has also been analyzed by several authors. A wide view on the feasibility of patent analysis has been given by Bretizman and Mogee (2002). They see patent analysis been used from IPR management to stock market evaluation. A policy view on the use of patent analysis is given Hicks et al. (2001). Strategic analysis is also seen as one of the applications of patent analysis (Liu and Shyu, 1997). Combining bibliometric analysis and patent analysis has been presented for example by Daim et al. (2006). By studying both research and patent data, the authors hope to describe the transformation of knowledge to industry. The patent data was analyzed by the trend of development (frequency) and a forecast with the Fisher-Pry growth model. Patent data was also categorized by applicants to gain insight on the companies developing the technology. The International Patent Classification (IPC) was used to find possible underlying structures in the applications. Applicants and IPC classes with a high frequency were then structured to a bar chart by the co-occurrences that applicants and IPC classes have. This was seen as showing the focus of patenting within the most frequent patent applicants.

The data for the study is based on evaluation of bibliometric and historical data gathered from several sources. The main section of data, the journal data, is based on data gathered from the Science Citation Index (SCI) database. Patent data has been analyzed from the European Patent Office (EPO) Espacenet database, which is openly available. In regard to the query design, there were no studies published which could of explain the keywords needed to cover all of the bibliographical and patent data related to Direct Methanol Fuel Cells. By a trial and error-phase the authors found a suitable search algorithm. The analysis was done by a query of "fuel cell" AND ("Direct Methanol Fuel Cell" OR "DMFC") being mentioned in the title or topic in the SCI database and by using the same query for the Espacenet database "Keyword(s) in title or abstract" field. With industry development, the data refers to PriceWaterhouseCoopers (PWC) series of FC industry surveys as well as to the Fuel Cell Bulletin journal for textual analysis on industry development.

4. Results

4.1 Development trends

Fuel cell technology has been an extensively researched topic in recent years. The last 20 years seems to be a period of increased activity in research publications as a whole. In figure 1, the historical trend of portable fuel cell research is depicted. An increase of publications can be seen yearly from 1990's, this is also the starting point for DMFC related articles.

As significant notion is that among the various FC technologies DMFCs are a relatively young technology. Although similar to other FC technologies, DMFCs have their own challenges.

From figure 1 we can easily argue that FC technology research has grown significantly

Figure 1 Cumulative journal and conference publications in fuel cell and direct methanol fuel fell technology

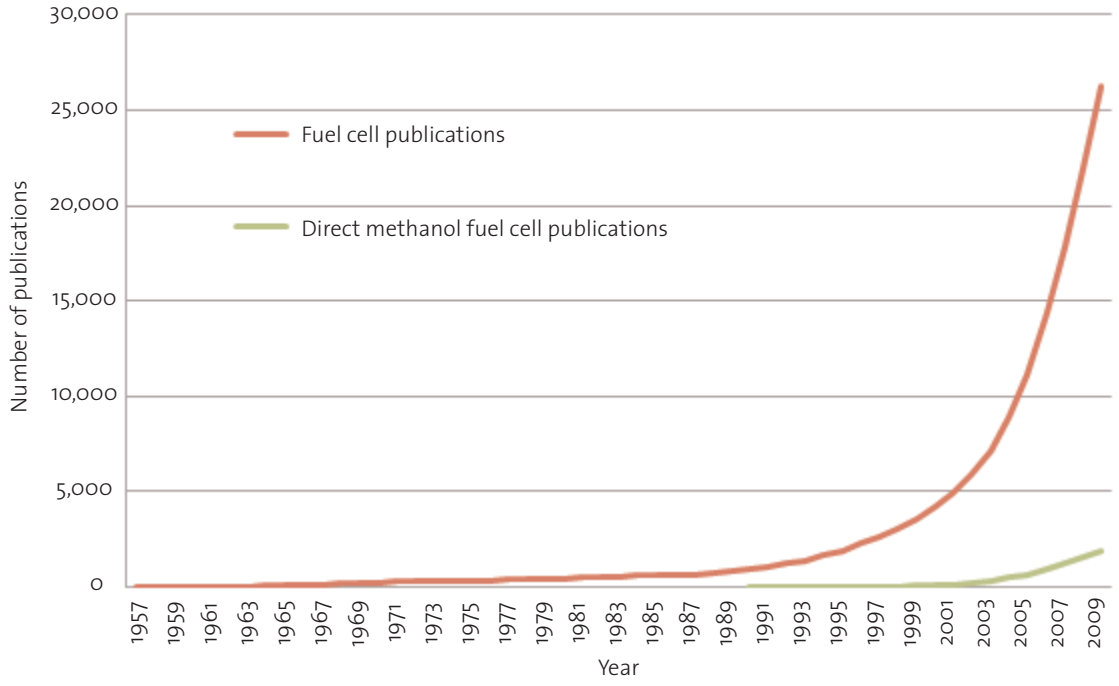
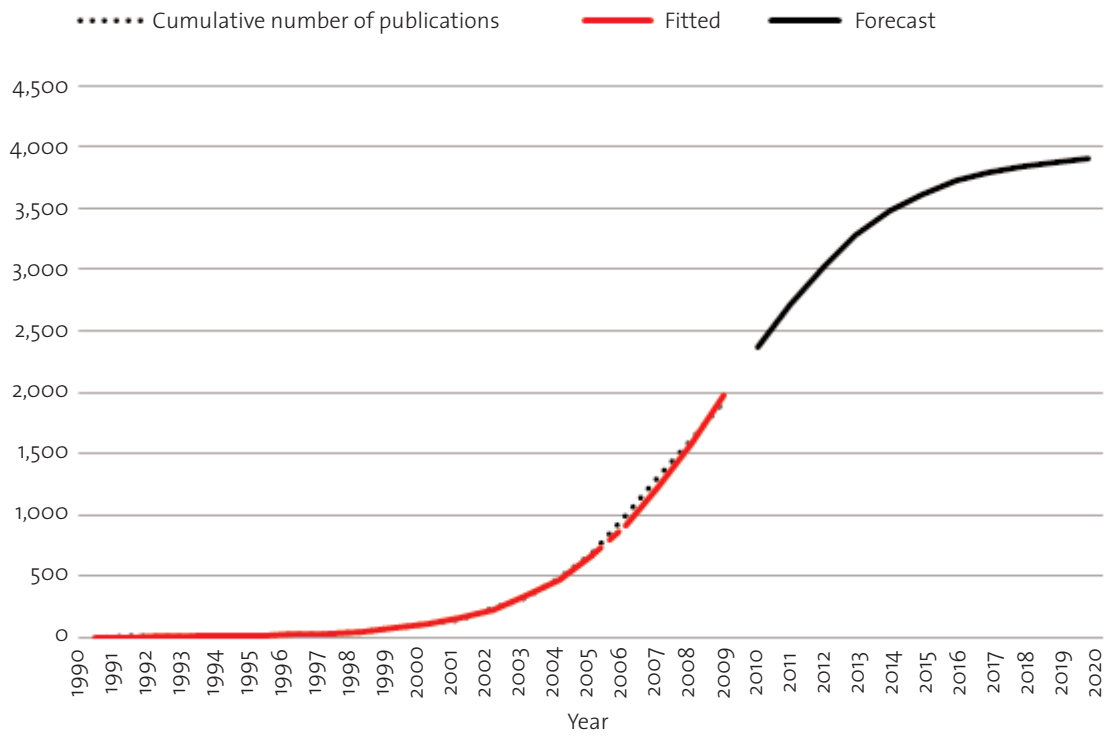


Figure 2 Cumulative journal and conference publications and trend extrapolation of Direct Methanol Fuel Cell technology



in the recent years. DMFC technology has however had a significantly shorter research period. To gain perspective on the technology life cycle of DMFCs, we extrapolate the research trend of DMFCs. In figure 2 the trend analysis of journal and conference publications in the Science Citation Index (SCI). The bibliometric data was modeled using the Fisher-Pry model that fits the data with a high R^2 coefficient of 0,99.

The growth model suggest that the growth period of basic research would continue for a few years, but by 2014 we would see the phase of rapid growth as ending. This would suggest

Table 1 The document frequency of the ten most frequent Countries and Organizations of DMFC research. Percentages are counted from the overall number of records 2128. [Based on the SCI database]

Region	Country	Organization	Document Frequency	Percentage (in %)
Asia			1411	66.3
	China		491	23.1
		The Chinese Academy of Science	123	5.8
		The Hong Kong Ubniversity of Science and Technology	60	2.8
		Tsinghua University	46	2.2
		The Harbin Institute Technology	45	2.1
	South Korea		346	16.3
		KAIST	57	2.7
		Seoul National University	57	2.7
		Korea Institute of Science and Technology	42	2.0
		Hanyang University	34	1.6
	Japan		213	10.0
	Taiwan		161	7.6
	India		80	3.8
Europe			566	26.6
	England		81	3.8
		Newcastle University	63	3.0
	Germany		201	9.4
		Forschungszentrum Jülich	41	1.9
	Italy		89	4.2
North America			381	17.9
	USA		340	16.0
	Canada		60	2.8
South America			58	2.7
Australia			12	0.6
Africa			6	0.3

that within the following year's research would move more towards application and not towards basic research. Current status would indicate that the research is at a half-way point. Several technological barriers, such as analyzed by Kamarudin et al. (2009), are unanswered but within the following few years we should expect significant advancements in DMFCs

The gathered database entries were analyzed by the research organization and region of research. From the dataset 876 individual terms that refer to an organization were indentified. The terms were checked for possible duplicate organizations caused by misspelling of names. Organizations were only analyzed at the university, research organization or company level. Possible sub-organizations, such as research labs, were not identified. In addition to organizations, the text mining tool was used to identify nationalities of the research organizations. Regions of research were identified as continents and countries of research and shown by their document frequency. Document frequency being defined as the number of record in which a country or research organization appears.

As seen from table 1 a significant portion of DMFC research is done in Asia, China and South Korea being the most significant research countries when counted by the pure number of publications. It is significant to note that in addition to Asian organizations being involved in 66,3 percent of the research, there are several focused research organizations in the region which contribute significantly to the number of papers being published. The effort done in Europe and North America shouldn't however be forgotten.

The increase in patent data can be seen in the Figure 3. The increase in patents has had a similar trend in comparison to the research journals plotted in Figure 2. Modeled with the Fisher-Pry equation, the patent trend has a lower R^2 value of 0,94. It is however visible that patent data has had a simultaneous increase with the increase of research trend frequency. When looking at the forecasts in Figure 2 and Figure 3 the trend extrapolation seems similar to both datasets.

It is significant to note that the patent applications have increased in numbers simultaneously with the increase of basic research results. The forecast suggested that basic research would reach the end of the growth phase by 2014, this is the half-way point for patent data. This suggests a lag between basic research and patents, which is coherent with the linear model of TLC indicators. By the end of the decade we would see the patenting frequency in DMFCs slowing significantly.

When clustering the patents by applicants, we see a strong emphasis on a few companies in gathering immaterial property rights rela-

Figure 3 Cumulative patent applications and trend extrapolation of Direct Methanol Fuel Cell technology

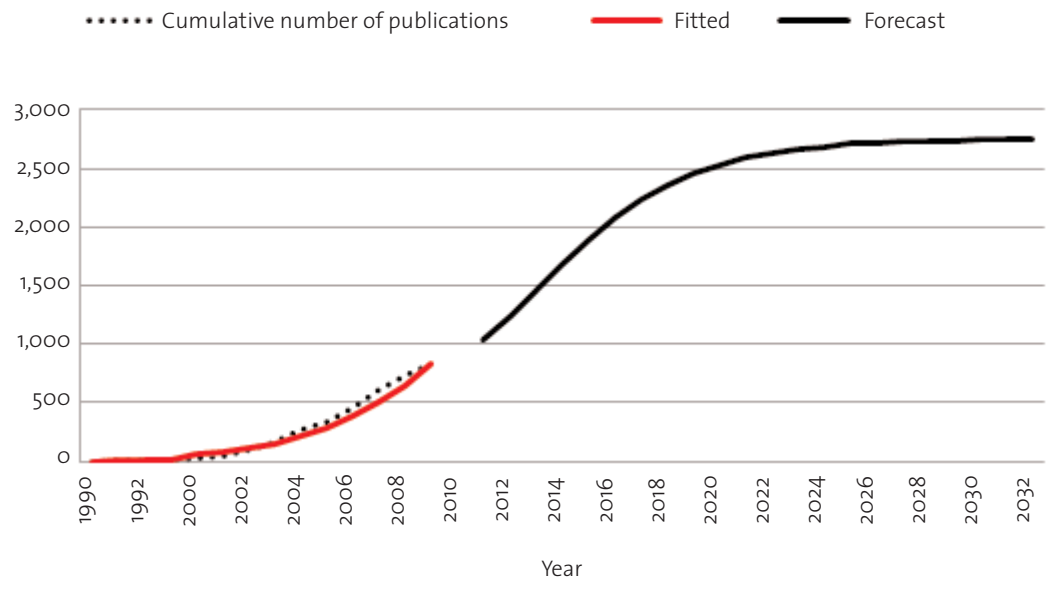
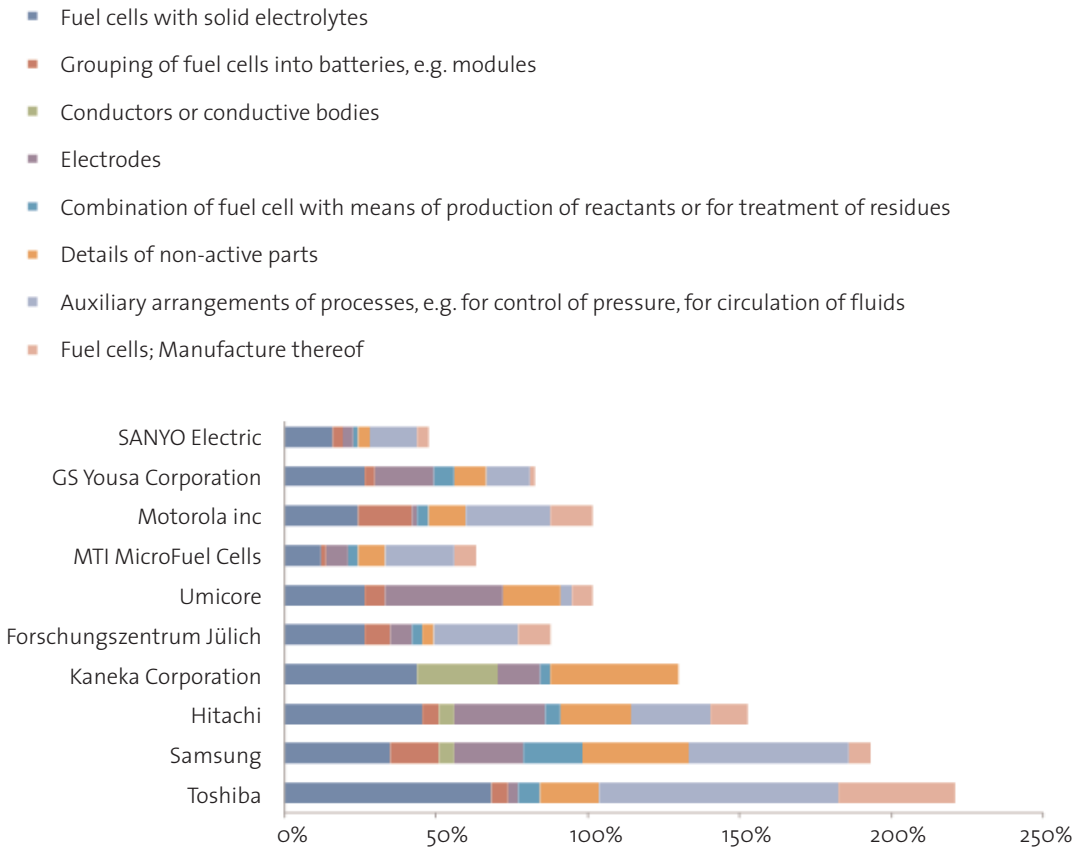


Table 2 Ten most frequent Direct Methanol Fuel Cell patent applicants. (Based on the Espacenet database)

	Applicant	Count	Percentage
1	Toshiba	57	6,9%
2	Samsung	52	6,3%
3	Hitachi	31	3,8%
4	Kaneka Corporation	25	3,0%
5	Forschungszentrum Jülich	21	2,5%
6	Umicore	20	2,4%
7	MTI MicroFuel Cells	16	1,9%
8	Motorola inc	16	1,9%
9	GC Yuasa corp	15	1,8%
10	SANYO Electric	13	1,6%

Figure 4 The patents of the ten most frequent applicants by the IPC classes of the patents. Figure contains the eight classification most frequently used in DMFC patents.



ted to DMFCs. As seen in Table 2, only 10 companies sum up to 32,2 percent of the patents applied. This shows a high concentration of patents, which is argued by Ayers (1987) to be one of the indicators of an infant technology.

The applicants were clustered by the IPC classes the patents have been classified. In Figure 4 the ten most frequent patent applicants seen in Table 2 have been classified by the IPC classification. Classification "Electrodes" is a collection of sub-categories under the Electrodes category. All other categories consist of a single classification. Patents can and often are classified to several classifications. As seen from the Figure 4 all of the companies with the exception of Kaneka Corporation and Umicore have a similar profile in patents. What can be seen as significant is the strong emphasis on patents relating auxiliary systems seen in the patent portfolios of several companies. These could indicate a focus on concrete fuel cell systems. This would support the finding made by Verspagen (2007). Verspagen found that the patent development in FCs development trend in patents have moved from components to systems. As the patents taken into this study are from the last 20 years, we see the focus turning to "Auxiliary Systems" and "Grouping of fuel cells into batteries".

4.2 Commercial adoption

As seen from the article and patent data analysis, portable FC development efforts are focused to a few companies focusing on this emerging technology. PWC (2008) has divided the worldwide FC industry to five market focus areas: stationary, portable, fuelling infrastructure, vehicle drive and auxiliary power units for vehicles. PWC data elaborates that 20 percent of the industry is focused on the portable market, geographically dividing most significantly to organizations in the EU, US, Japan or Canada. Over 50 percent of the companies with a market scope on portable fuel cells are in the US, and if North America is seen as an entity, we see that over 70 percent of companies with focus on portable are based in the US or also Canada. The PWC analysis is however based on surveying public companies with the primary goal of fuel cell production, integration or related fueling infrastructure. The survey does not take into consideration subsidiaries and private companies. This leaves out a significant portion of the industry.

The survey can however give an overview on the commercial development the industry. The growth indicators for the industry are presented in consequent years by PWC (2005; 2006; 2007). We have seen during the period of 2003 to 2006 a growth of 14 percent to the whole industry. This, while R&D expenditures have risen by 26 percent and employment numbers by the industry have risen by 36 percent, can be seen as challenging. By this we see the increased usage of corporate research funding by large corporations and venture capital funding by new ventures. The increased corporate R&D expenditure and employment cost can be seen as draining the resources of the industry.

In the portable FC industry we see a near four time increase in portable units shipped from 2005 to 2008. This however, still amounts to only little over 9,000 units shipped worldwide. These units are mostly used for toys and other demonstration by Chinese and Taiwanese companies. European and USA based companies focus mainly on military solutions (Butler, 2009.)

Similarly to the increase of journal and patent data, industry activity can be seen as increasing in the 2000s. Companies such as MTI Micro Fuel Cell (MTI), seen also in Table 2, have started FC technology development in the early 2000 (Fuel Cells Bulletin, 2001). MTI is an example of technology transfer as MTIs work is based significantly on the technology of Los Alamos National Lab (Fuel Cells Bulletin, 2002a), MTI has been a significant developer of small portable solutions. Development has been partly driven by large military contract with US Marines and Army, which have focused on the development of handheld power devices based on FC technology (Fuel Cells Bulletin, 2004a; Fuel Cells Bulletin, 2004b). MTI has since gone to develop its own FC based systems as well as manufacturing prototypes for Samsung (Fuel Cells Bulletin, 2007a). MTI has also demonstrated a GPS system with a FC system integrated to the product. This has resulted up to 60 hours of continuous operation (Fuel Cells Bulletin, 2008c).

In larger portable systems, early enthusiasm on finding the suitable application to take advantage of the technology can be seen for example in the Japanese based Yuasa Corporation, which published its FC technology based power production system in 2002 (Fuel Cells Bulletin, 2002b). Yuasa also had the ambitious goal of commercializing its technology by 2003. At the same time a US based Lynntech delivered a self contained FC power production system to the US Army (Fuel Cells Bulletin, 2002c). Presenting a similar prototype as Yuasa demonstrated in Japan. Both of these systems were designed for larger applications, Yuasa's system weighing from 25 to 60 kg. The applications were clearly targeted to independent power production in a small scale. In this

application range the German based Smart Fuel Cell (SFC) has been able to commercially manufacture its EFOY system. Offering products to a small market, SFC has been able to market its product successfully. SFC manufactures a portable energy source for military systems and recreational vehicles (Fuel Cells Bulletin, 2003a; Fuel Cells Bulletin, 2007b). SFC has been successful in a specific market attending to a large consumer base in recreational vehicles (Fuel Cells Bulletin, 2007c; Fuel Cells Bulletin, 2008d).

Early R&D has also been done at Samsung, which has carried out research in both applied as well as the fundamental technology. (Fuel Cells Bulletin, 2002a). Similarly to Samsung, Japanese industry has also focused on small FCs and consumer electronics applications. NEC co-operated with Japanese research organizations in 2001 in the development of micro fuel cells. (Fuel Cells Bulletin, 2002a) Similarly to NEC and Samsung several other large companies have focused on FCs at an early stage. This has resulted in several consumer electronics demonstrators, such as FCs in laptop computers. The competitive advantage seen in the laptop application was the extended operating time a fuel cell system could offer. For example Samsung demonstrated a laptop working with a FC power system with the operational time of 10 hours (Fuel Cells Bulletin, 2004c). Similar demonstrations have been made by companies such as Fujitsu, IBM, LG, Motorola, NTT, Sanyo, Sony, Casio, Polyfuel and Toshiba, which have all presented a FC powered laptop prototypes (Wee, 2006, Fuel Cells Bulletin, 2002a, Fuel Cells Bulletin, 2003b).

Many of the companies also, similarly to Yuasa, had high expectations on commercialization. Companies such as Toshiba, suggested that it would commercialize FC systems in 2005 (Fuel Cells Bulletin, 2003c). Samsung claimed to be ready for commercialization with a laptop docking station by the end of 2007 (Fuel Cells Bulletin, 2007d). These efforts did not deliver wanted results even though several scholars (Rashidi, et al., 2009; Wee, 2006) have analyzed the cost of using a fuel cell powered device in comparison to battery based systems, and found that a FC power source would be more cost-efficient after one year. However as Agnolucci (2007) has pointed out that consumers are more interested in the physical size and weight of the system than its cost-efficiency. Subsequently the market is still waiting for the competitive portable FC application.

Mobile phones, and several other small portable devices (Flipsen, 2005; van der Voorta and Flipsena, 2006), have been suggested to be the competitive application. This possibility has been presented for example by Toshiba and at an early stage by start-ups such as Manhattan Scientifics. (Fuel Cells Bulletin, 2004d; Fuel Cells Bulletin, 2002a) Similar to laptops the cost-efficiency of FC systems isn't a problem (Rashidi et al., 2009). More significantly, the development of the FC products in mobile devices is dictated by the development of lithium batteries and innovations making devices more energy efficient, smaller in size and weight, and the ease of use of the systems (Agnolucci, 2007). Subsequently integrated commercial FC systems have not been available.

It seems more likely that a portable device charger would be the application enabling sustainable growth. As a product, this would be similar to the larger scale products presented by e.g. SFC, which have all been based on independent power production. Several companies have demonstrated future portable FC products in this product range. Sony has been for several years developing its system. Trying to meet the growing power need of a mobile phone, Sony claims that its system enables a state-of-the-art cell phone to be used for watching a TV broadcast for 14 hours with only 10 ml of methanol. (Fuel Cells Bulletin, 2008e). However, also in this niche market, high expectations have led to several promised market launches, such as Hitachi's small FC system. Hitachi was expected to commercialize a small FC by the end of 2007 with the manufacturing capability 2,000-3,000 units yearly (Fuel Cells Bulletin, 2007e). However, Toshiba was the first to present a commercial FC based mobile charger (Fuel Cells Bulletin, 2009).

5. Discussion

To gain an insight on the future possibilities of the portable FC technology, a historical and bibliometric analysis was performed. The study revealed the increase of journal publications since the early 90s as well as the increase in patenting frequency. The growth models suggested that the rapid development phase in both research and patents would continue for the next few years. In this the patent trend was seen as lagging, which would be coherent with the "linear model of change" (Porter et al., 1991).

The identification of research regions, countries and organizations brought forward the leading DMFC research areas. Complementing this with patent data has shown the significant effort made in Asia to develop DMFC technology. It could be argued that the research and development of DMFC is concentrated to a group of organizations. The argument made by Ayers (1987) that this would suggest an infant technology could be

argued to be accurate in the case of DMFCs. However, as in the findings of Verspagen (2007), the patent classifications would suggest that the patent applicants would be focusing towards FC systems in addition to basic research. This could be seen as encouraging to the industry hoping to take advantage of this emerging technology. In addition the several years of widespread technological demonstrations by several large corporations has laid the ground work for actual DMFC products being offered to customers.

The authors would however argue that DMFC technology is having a hard time in integrating to the mature energy production market. The existing extremely mature technologies are still offering more value to most existing solutions. As Agnolucci (2007) has pointed out, consumers will not adopt DMFC technology only to use new technology. Cost, convenience, and physical size are more significant factors impacting consumers. R&D managers should also notice the increased public funding towards FC technology. Programs such as the 7th framework program in the European Union (Fuel Cells Bulletin, 2008a), while funding R&D efforts, can be seen as building up a hype towards the technology. In addition the high expectations of commercialization promoted by several companies can be building excitement towards the technology.

As a conclusion, DMFC technology is in a fluid phase, where technological and market related uncertainties prevail. Consumers have not adopted DMFC technology in a large scale. This can be seen from the fact the number of DMFC systems delivered, although there has been significant increase, is small. DMFC technology is still looking for the application that would enable sustainable growth. It can be argued that the development efforts are still highly subsidized governmental projects and this, while creating a market, disrupts the "natural creation" of a demand based market. Viable market applications, such as the one created by SFC, have been unable to show that a DMFC solution would be viable outside the niche that it occupies. However, as the power demand of small portable devices continues to increase in the future, existing systems can be unable to meet the demand. This situation would arguably create the needed competitive edge for portable DMFC systems.

Acknowledgements

The research was funded by the Finnish Funding Agency for Technology and Innovation

References

Abernathy, W. and Utterback, J., (1978): Patterns of Industrial Innovation. *Technology Review*, **80**(7), p. 40-47.

Agnolucci, P. (2007): Economics and market prospects of portable fuel cells. *International Journal of Hydrogen Energy*, **32**(17), p. 4319-4328.

Ayres, R.U. (1987): *The industry-technology life cycle: an integrating meta-model?*

Balachandra, R., Goldschmitt, M. and Friar, J. (2004): The evolution of technology generations and associated markets: A double helix model. *IEEE transactions on engineering management*, **51**(1), p. 3-12.

Balconi, M., Brusoni, S. and Orsenigo, L. (2009): In defence of the linear model: An essay. *Research Policy*.

Barbir, F. (2005): PEM Fuel Cells: Theory and Practice 1st ed., *Academic Press*.

Bengisu, M. and Nekhili, R. (2006): Forecasting emerging technologies with the aid of science and technology databases. *Technological Forecasting and Social Change*, **73**(7), p. 835-844.

Breitzman, A. and Mogee, M. (2002): The many applications of patent analysis. *Journal of Information Science*, **28**(3), p. 187-205.

Borgman, C.L. and Furner, J. (2002): Scholarly communication and bibliometrics. *Annual Review of Information Science and Technology*, **36**, p. 3–72.

Broussely, M. and Archdale, G. (2004): Li-ion batteries and portable power source prospects for the next 5–10 years. *Journal of Power Sources*, **136**(2), p. 386-394.

Butler, J. (2009): *Portable Fuel Cell Survey 2009*. Available at: http://www.fuelcelltoday.com/media /pdf/surveys/2009-portable-free.pdf [Accessed November 15, 2009].

Chao, C., Yang, J. and Jen, W. (2007): Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005. *Technovation*, **27**(5), p. 268-279.

Chung, W.S. and Park, C.Y. (2009): Forecasting the Number of Publications of papers on Entrepreneurship in Academic Journals. *Research in Higher Education*, **4**.

Cremers, C. et al. (2007): Developments for improved direct methanol fuel cell stacks for portable power. *FUEL CELLS*, **7**(1), p. 21-31.

Cropper, M.A., Geiger, S. and Jollie, D.M. (2004): Fuel cells: a survey of current developments. *Journal of Power Sources*, **131**(1-2), p. 57–61.

Daim, T.U. et al. (2006): Forecasting emerging technologies: Use of bibliometrics and patent analysis. T*echnological Forecasting & Social Change*,

73(8), p. 981–1012.
Dillon, R. et al. (2004): International activities in DMFC R&D: status of technologies and potential applications. *Journal of Power Sources*, **127**(1-2), p. 112–126.
Dyer, C. (2002): Fuel cells for portable applications. *Journal of Power Sources*, **106**(1-2), p. 31-34.
Eckfeld, S., Manders, J. and Stevenson, M. (2003): The Asian battery market - a decade of change. *Journal of Power Sources*, **116**(1-2), p. 32-39.
Fisher, J. and Pry, R. (1971): A simple substitution model of technological change. *Technological Forecasting and Social Change*, **3**, p. 75-88.
Flipsen, B. (2005): *Power sources compared: the ultimate truth?* In International Power Sources Symposium 2005. Brighton (Great Britain).
Fuel Cells Bulletin (2001): Regional focus on fuel cells R&D: Northeastern US. *Fuel Cells Bulletin*, **4**(36), p. 8-14.
Fuel Cells Bulletin (2002a): Portable fuel cell systems. *Fuel Cells Bulletin*, **2002 c**(7), p. 8-12.
Fuel Cells Bulletin, (2002b): Yuasa builds DMFC system prototypes. *Fuel Cells Bulletin*, **2002 a**(2), p. 6.
Fuel Cells Bulletin (2002c): Lynntech DMFCs for US Army. *Fuel Cells Bulletin*, **2002 b**(2), p. 3.
Fuel Cells Bulletin (2003a): SFC products commercially available to end-users. *Fuel Cells Bulletin*, **2003 b**(10), p. 1.
Fuel Cells Bulletin (2003b): PolyFuel unveils DMFC prototype at Intel forum. *Fuel Cells Bulletin*, **2003 a**(4), p. 5.
Fuel Cells Bulletin (2003c): Latest DMFC prototypes from Toshiba, Hitachi. *Fuel Cells Bulletin*, **2003 b**(12), p. 2.
Fuel Cells Bulletin (2004a): US Army lab awards MTI Micro DMFC contract. *Fuel Cells Bulletin*, **2004 a**(6), p. 9-10.
Fuel Cells Bulletin (2004b): MTI Micro wins Marines, Army DMFC contracts. *Fuel Cells Bulletin*, **2004 b**(12), p. 4.
Fuel Cells Bulletin (2004c): Samsung demos 10 h DMFC notebook. *Fuel Cells Bulletin*, **2004**(6), p. 6.
Fuel Cells Bulletin (2004d): Toshiba reveals thumb-sized 100 mWe DMFC prototype. *Fuel Cells Bulletin*, **2004 b**(8), p. 2-3.
Fuel Cells Bulletin (2007a): MTI taking orders for Mobion30, prototypes for Samsung. *Fuel Cells Bulletin*, **2007**(1), p. 9-10.
Fuel Cells Bulletin (2007b): SFC delivers portable military fuel cell systems. *Fuel Cells Bulletin*, **2007**(1), p. 7-8.
Fuel Cells Bulletin(2007c): SFC, Webasto to put DMFCs in leisure vehicles. *Fuel Cells Bulletin*, **2007**(11), p. 4.
Fuel Cells Bulletin (2007d): Samsung shows smallest fuel cell yet for mobile charger, laptop station. *Fuel Cells Bulletin*, **2007**(2), p. 3.
Fuel Cells Bulletin (2007e): Hitachi to sell DMFCs for PCs, phones in 2007. *Fuel Cells Bulletin*, **2007**(2), p. 3, 5, 7, 9.
Fuel Cells Bulletin (2008a): EU agrees to set up [euro]1 billion fuel cells, hydrogen initiative. *Fuel Cells Bulletin*, **2008**(7), p. 8-9.
Fuel Cells Bulletin (2008b): DOE commits $130m to accelerate hydrogen fuel cell development. *Fuel Cells Bulletin*, **2008**(7), p. 8.
Fuel Cells Bulletin (2008c): MTI Micro debuts embedded DMFC GPS prototype. *Fuel Cells Bulletin,* **2008**(5), p. 1.
Fuel Cells Bulletin (2008d): SFC sees EFOY fuel cell sales continue to grow. *Fuel Cells Bulletin*, **2008**(10), p. 7.
Fuel Cells Bulletin (2008e): Sony brings hybridization to micro DMFCs. *Fuel Cells Bulletin*, **2008**(7), p. 5, 7, 11.
Fuel Cells Bulletin, (2009): Toshiba launches Dynario power source for mobile devices, but only in Japan. *Fuel Cells Bulletin*, **2009**(12), p. 6.
Goodenough, J. et al. (1990): Porous carbon anodes for the direct methanol fuel cell, The role of the reduction method for carbon supported platinum-electrodes. *Electrochemica Acta*, **35**(1), p. 199-207.
Hellman, H. and van den Hoed, R. (2007): Characterising fuel cell technology: Challenges of the commercialisation process. *International Journal of Hydrogen Energy*, **32**(3), p. 305-315.
Hicks, D. et al. (2001): The changing composition of innovative activity in the US -- a portrait based on patent analysis. *Research Policy*, **30**(4), p. 681-703.
Huang, L., Guo, Y. and Porter, A.L. (2010): Identifying Emerging Roles of Nanoparticles in Biosensors. *Journal of Business Chemistry*, (1).
Kajikawa, Y. & Takeda, Y. (2009): Citation network analysis of organic LEDs. *Technological Forecasting and Social Change*, **76**(8), p. 1115-1123.
Kajikawa, Y. et al. (2008): Tracking emerging technologies in energy research: Toward a roadmap for sustainable energy. *Technological Forecasting and Social Change*, **75**(6), p. 771-782.
Kamarudin, S., Achmad, F. & Daud, W., 2009. Overview on the application of direct methanol fuel cell (DMFC) for portable electronic devices. *International Journal of Hydrogen Energy*, **34**(16), p. 6902-6916.
Kurzweil, P. (2009): HISTORY | Fuel Cells. In *Encyclopedia of Electrochemical Power Sources.* Amsterdam: Elsevier, p. 579-595.
Liu, S.J. and Shyu, J. (1997): Strategic planning for technology development with patent analysis. *International Journal of Technology Manage-*

ment, **13**(5), p. 661–680.
Pavitt, K. (2006): Innovation Processes. In *The Oxford Handbook of Innovation*. Oxford University Press, USA.
Porter, A.L. et al. (1991). *Forecasting and management of technology*, Wiley-Interscience.
PWC, P. (2005): *2005 Fuel Cell Industry Survey*. Available at: http://www.pwc.com/en_CA/ca/technology-industry/publications/fuel-cell-industry-survey-2005-en.pdf.
PWC, P. (2006): *2006 Fuel Cell Industry Survey*. Available at: http://www.pwc.com/en_CA/ca/technology-industry/publications/fuel-cell-industry-survey-2006-en.pdf.
PWC, P. (2007): *2007 Fuel Cell Industry Survey*. Available at: http://www.pwc.com/ca/en/technology-industry/fuel-cell-survey-2007.jhtml.
Qian, W. et al. (2006): Architecture for portable direct liquid fuel cells. *Journal of Power Sources*, **154**(1), p. 202-213.
Rashidi, R. et al. (2009): Performance evaluation of direct methanol fuel cells for portable applications. *Journal of Power Sources*, **187**(2), p. 509-516.
Rogers, E.M. (1962): Diffusion of innovations, *Free Press of Glencoe*.
Rosenberg, N. (1994): Exploring the black box: Technology, economics, and history, *Cambridge Univ Pr.*
Smith, C.G. (1996): Design competition in young industries: an integrative perspective. *Journal of High Technology Management Research*, **7**(2), p. 227–243.
van der Voorta, E.J. and Flipsena, S.F.J.: Research by design: *Feasibility of a DMFC powered PDA*.
Watts, R.J. & Porter, A.L. (1997): Innovation forecasting. *Technological Forecasting and Social Change,* **56**(1), p. 25-47.
Wee, J. (2006): Which type of fuel cell is more competitive for portable application: Direct methanol fuel cells or direct borohydride fuel cells? *Journal of Power Sources*, **161**(1), p. 1-10.
Verspagen, B. (2007): Mapping technological trajectories as patent citation networks: A study on the history of fuel cell research. *Advances in Complex Systems*, **10**(1), p. 93.

Journal of Business Chemistry

Research Paper

Multidisciplinary collaborations in pharmaceutical innovation: a two case-study comparison

Irina Saur-Amaral*,** and Alexander Kofinas***

* University of Aveiro, GOVCOPP, Department of Economics, Management and Industrial Engineering, Campus Universitario de Santiago, 3810 – 093 Aveiro, Portugal, isaur@ua.pt
** Portuguese Institute of Business and Marketing (IPAM), Rua das Cardadeiras, Esgueira, 3800-125 Aveiro, Portugal, irina.amaral@ipam.pt
*** Business Information Technology & Enterprise, School of Engineering, University of Greenwich, Medway Campus, Central Avenue, Chatham, Maritime, Kent ME44TB, a.k.kofinas@gre.ac.uk

Multidisciplinary collaborations are increasingly predominant in innovative industries facing complex challenges. Yet, too frequently managers fail to identify the appropriate situations in which collaborations can be efficient, as their dynamics are not fully investigated. We examine multidisciplinary collaborations, their pertinent agents and complementary network capabilities in the context of the pharmaceutical industry. We focus on three research issues: a) how do multidisciplinary partnerships operate in the pharmaceutical industry? b) at what level are they most relevant (e.g. for knowledge external to the company, or internal)? c) what are the main challenges and benefits of multidisciplinary collaborations?
We analysed empirical data from two different innovative pharmaceutical firms: a global top-ten corporation based in UK and an international firm located in a small/medium European economy. Our research is using a comparative case study design, drawing strongly from the literature. This research design provides a strong empirical grounding for a rich, in-depth, understanding of multidisciplinary collaborations in the pharmaceutical R&D process, with strong focus on the nature of internal and external partnerships and their impact in the organisation.
The findings indicate that innovation management is increasingly reliant on multidisciplinary organisational arrangements; attention to complementary network- and agent-related externalities has become vital for the success of the pharmaceutical company. Good managerial practice for multidisciplinary practice is more complex and nuanced than the literature may indicate and relies on flexible, adaptive and contextual processes.

1 Introduction

No man, no society, no institution is an island, existing in solitude from other human beings, societies or institutions. Collaborations among human beings have been the main means of facing everyday challenges and difficulties since the beginnings of our civilization. Corporations are no exception. When facing a challenge an organisation will put together employees in a collaborative team to solve the issue. It is often tempting though to see all challenges as similar in nature, They are not. When the organisation faces a simple problem that is typical for a particular discipline then they will use methods and approaches that are agreeable within that particular community of practice. The approach is often the best one as the experts know how to handle such an issue and the results of such

efforts are often seen as "incremental" (Caruso and Rhoten, 2001; Romm, 1997; Saur-Amaral, 2005).

However, as technology advances and corporations face novel organisational challenges, to resolve these emergent challenges may require diverse human resources that can move across technologies and disciplines. Thus, increasingly, organisations adopt multidisciplinary approaches in their collaborations (hereinafter MDCs), especially in industries where the innovation context is complex and challenging. Managers responsible for such collaborations should duly consider how multidisciplinary collaborations can be utilised effectively and comprehend the strengths and weaknesses of the MDC approach in order to pre-empt any negative side effects (Caruso & Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999).

Some weaknesses of multidisciplinary approaches are: a) take more time than disciplinary approaches, especially in the beginning b) have a higher probability of team conflicts and c) are often characterized by communication problems (Caruso and Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999).

However, MDCs can be more efficient in response to complex challenges that cross several disciplines and need testing and original, idiosyncratic methods to solve emerging issues. MDCs may lead, in principle, to innovation, and thus higher profit margins. Furthermore, are often associated with "radical" innovation and knowledge creation (Caruso and Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999; Saur-Amaral, 2005; Saur, 2005).

Our paper examines MDCs in a complex, innovative industry: pharmaceuticals. The choice of this industry is pragmatic, as the preliminary systematic literature review and the subsequent RefViz analysis on multidisciplinarity (detailed in section 4) indicated that more than half of all records identified in ISI Current Contents and Proquest databases on MDCs are related to the pharmaceutical industry.

This was a sensible result as pharmaceutical industry is a knowledge-intensive multidisciplinary industry, with a large proportion of sales spent on research and development (R&D). R&D is vital in conferring the key competitive factor for the big pharmaceutical innovators: the development of novel drugs as fast as possible, leading to a patent that provides a legal monopoly for the corporation. Drug development is performed with external and internal collaborations, within a multidisciplinary context (Attridge, 2007; Atun and Sheridan, 2007; Kofinas and Saur-Amaral, 2008; Saur-Amaral, 2009; Saur-Amaral and Borges Gouveia, 2007).

We thus aim to understand:

a) how do multidisciplinary partnerships operate within the pharmaceutical industry?

b) at what organisational levels are they most relevant (for example: absorbing knowledge external to the company, or sharing knowledge internal to the company)?

c) what are the main challenges and benefits of multidisciplinary collaborations?

The paper is organised as follows. After this introduction, we present the methodology used to perform our research.

In the third section we present key insights from the literature review: The concept of multidisciplinarity (and how it differs from disciplinarity/ interdisciplinarity) and the concept of MDCs (which led us to the concept of network capability).

In the fourth section we examine the results obtained from the empirical study, we utilise a multiple (two) holistic case-study (Yin, 2003) that analyses in depth the role of multidisciplinary partnerships and network capabilities in pharmaceutical innovation.

In the fifth section, we discuss the findings and show how cases validate and enrich the patterns discussed in the existing literature. The fact that they are significantly distinct in research routines, in size, internal organisation, R&D structure, yet reveal similarities in the way they manage MDCs indicates validity and partial universality to our findings.

In the sixth section, we look at the nature and operations of MDCs in the pharmaceutical industry and consider some good managerial practices that might be applicable in other pharmaceutical companies or other innovative industrial sectors. We end with conclusions.

2 Methodology

In order to analyse multidisciplinary partnerships in pharmaceutical innovation, we adopted a twofold strategy.

First, we performed a thorough review of existing papers published between 1998 and 2007 on this topic that were included in ISI

and Proquest databases. Our search looked at papers referring to MDCs (alliances, partnerships or networks). The most relevant papers were selected and thoroughly analysed to inform our literature review, clarify the basic concepts, and build the coding taxonomy used for the empirical sections. We used as a methodological tool the bibliographic analysis software RefViz, which enabled us to increase comprehension of key topics related to MDCs theory. The results of this process are presented in section 3 of this paper.

Second, we did two in-depth holistic case studies (Gomm, Hammersley, and Foster, 2004a, 2004b; Yin, 2003). We used the literature review to inform and build a predefined coding structure (Tashakkori and Teddlie, 1998). The coding structure was embedded in an NVivo 7.0 file and each author performed a qualitative analysis on the data to draw the the case reports.

We focused on two cases:

- A bioinformatics department of a global top-ten pharmaceutical multinational based in UK (PharmaCo), and
- An international firm located in a small-medium European economy, top-20 pharmaceutical firm in its national pharmaceutical market (PharmaEU).

The choice of these two cases was motivated by the proximity and access to the sites, as well as by the distinct contributions they would make to this research agenda (Gomm, et al., 2004a). We were aiming for a wide range of possible insights, originating from the high degree of difference between the in-depth holistic case studies chosen. The fact that they are significantly distinct in research routines, in size, internal organization, R&D structure, any similarities and insights identified would increase the validity and replicability of our findings and thus attribute a validity and partial universality to our insights in MDC management. Results of this process are presented in section 4 and section 5 of this paper.

3 Multidisciplinarity, multidisciplinary partnerships and network capabilities

3.1 Multidisciplinarity concepts

The concepts of disciplinarity, multidisciplinarity (MD) and interdisciplinarity (ID) have been used frequently in the; literature but they are often nebulous defined. To avoid misinterpretations we aim in Table 1 to summarize the differences between the two approaches.

From our point of view, disciplinarity involves a well-specified knowledge domain, with fairly well defined boundaries, within which specialists share cultural and conceptual frameworks (Roper and Brookes, 1999; Saur-Amaral, 2005; Saur, 2005). These specialists use common methods and instruments and they play by the rules established within the respective community of practice (Caruso and Rhoten, 2001; Pellmar and Eisenberg, 2000; Roper and Brookes, 1999; Saur-Amaral, 2005). Disciplinary collaborations seem to be more efficient when based on diagnosis and application of agreed instruments and problem-solving techniques. However, scholars have argued that disciplinary collaborations may be less creative (Caruso and Rhoten, 2001; Romm, 1997; Saur-Amaral, 2005).

Multidisciplinarity implies there are specialists from two or more disciplines that work

Table 1 Disciplinarity and multidisciplinarity: characteristics and comparison

	Well defined approach known instruments	Complex approach unknown instruments	Efficiency	Conflict	Creativity	Impact on disciplinary knowledge
Disciplinarity	Appropriate	Less appropriate	High	Less probable	Limited to knowledge domain	Limited, relatively to the existing paths
Multi-disciplinarity	Less appropriate	Appropriate	Low	Very probable	High, goes beyond knowledge domains	High possible impact, challenging existing paths

together for a specific objective. Usually the objective is more complex and challenging, in the sense that it is located on the boundaries of a specific discipline, or even beyond such boundaries. In such cases there are no agreed conventions and instruments applicable to solve the challenge, and there is a need for creative solutions and experimentation, which can be detrimental to efficiency (Nissani, 1999; Romm, 1997; Saur-Amaral, 2005; Saur, 2005). In addition, MDCs often have to overcome communication hurdles and have to deal with frequent conflicts, management and coordination problems (Caruso and Rhoten, 2001; Chiesa and Toletti, 2004; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999). In the literature the term Interdisciplinarity (transdiciplinarity) is often used as a synonym to multidisciplinarity are often used in the literature, while select authors present them as separate concepts (e.g. Bruce, Lyall, Tait, and Williams, 2004). Interdisciplinarity falls at the crossing of various disciplines, and interdisciplinary enterprises are in that sense similar to multidisciplinary ones. However, an interdisciplinary enterprise evolves and changes the original disciplines it originated from and leads to new methods, instruments, and work practices. The final outcome is a new discipline formed to cover a prior gap, and may lead to other disciplinary – multidisciplinary – interdisciplinary cycles of knowledge evolution. An example of interdisciplinary research would be human robotics, where scientists from biology and mechanics, just to name two disciplines, work together to achieve common goals (Saur-Amaral, 2005; Saur, 2005).

Thus, an enterprise that creates a new discipline can be seen as a multidisciplinary enterprise that evolves into an interdisciplinary enterprise (Bruce, et al., 2004; Saur-Amaral, 2005). In our study, we focus on multidisciplinary collaborations, in the sense defined in the above paragraphs.

3.2 Multidisciplinary partnerships and network capabilities

On October 26, 2007, we performed a systematic search on the topic of papers included in ISI Current Contents and Proquest, between

Figure 1 Distribution of papers related to multidisciplinary partnerships using RefViz (based on conceptual proximity)

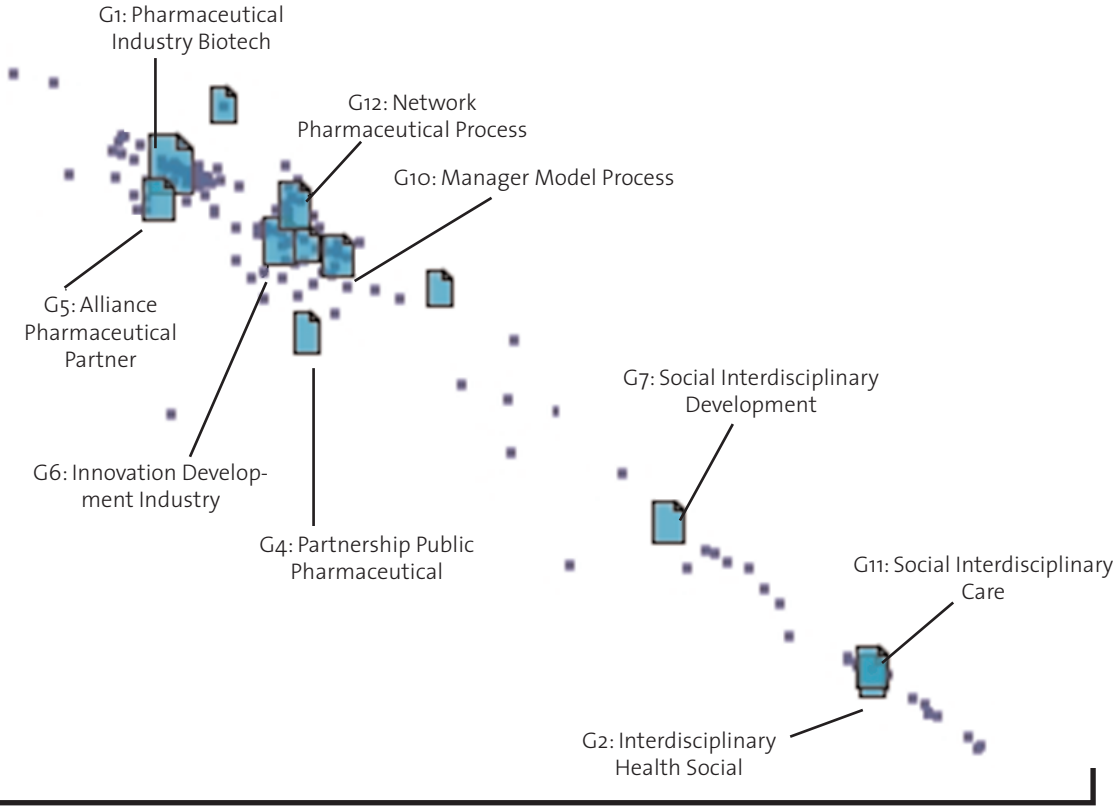
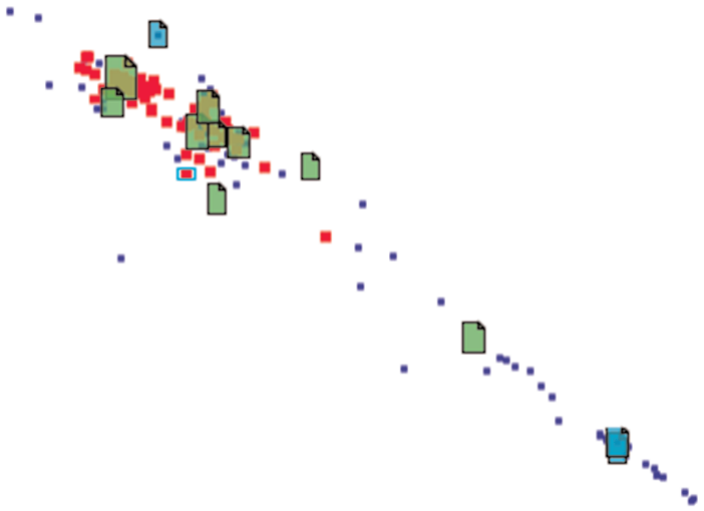


Figure 2 References related with pharmaceuticals (represented in larger squares)



1998 and 2007. We limited our search to Social Sciences and used the following keywords: interdisciplinary multidisciplinary alliance* collaboration* partnership*.

Our search yielded 153 results, out of which more than half referred to the pharmaceutical industry (see Figure 2). This allowed us to assume that, in the analyzed papers, the role of pharmaceutical multidisciplinary collaborations has been intensively studied. MDCs in the papers were linked with intense processes of learning, internal, external or mixed learning, and were based on internal capabilities, external networks and agents. We imported these 153 results into RefViz, and during these process, three papers were identified as outliers and removed from the sample. We were then left with 150 records. RefViz identified 12 main groups, as shown in Figure 1 and explained in Appendix 1.

Several of these groups referred specifically to the pharmaceutical industry and we performed a text search to identify all those records. Our search yielded 82 results, which are distributed among the 12 groups as indicated in Figure 2. These 82 results were subsequently analysed in depth using NVivo 7 software to identify key themes and concepts in a more reliable manner.

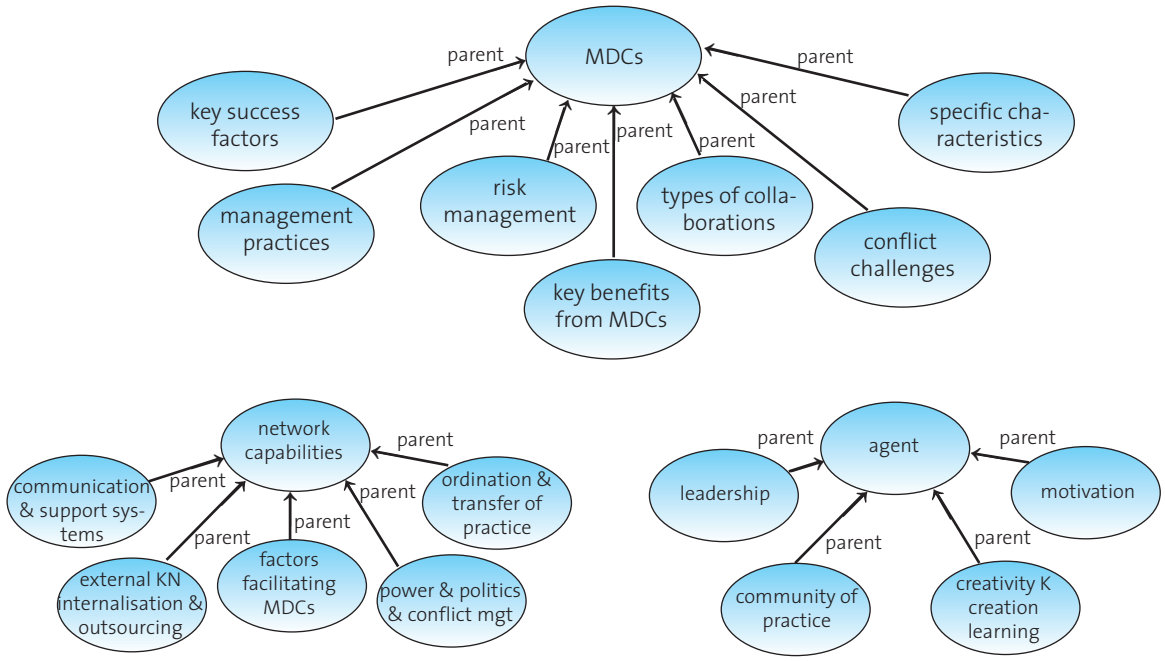
There was a strong suggestion that the pharmaceutical industry has frequently relied upon multidisciplinary partnerships, with internal and/or external organisations. For instance, Rothaermel (2001a, 2001b, 2002) refers to the preference for partnerships/alliances that leverage complementary assets in external collaborations, and a concern for appropriability regimes (de Leeuw, de Wolf and van den Bosch, 2003).

There is also a strong focus on external learning through partnerships and external knowledge sourcing (de Leeuw et al., 2003; Santos, 2003), raised by the specific characteristics of the pharmaceutical industry, i.e. low success rates, efficiency hurdles, large amount of information/knowledge sources to tackle).

Another interesting topic, mentioned by Mendez (2003) and previously addressed by Zeller (2002), brings out the importance of a project view in multidisciplinary collaborations, i.e. focusing on specific challenges and supporting coordination activities with "standardization of results and work procedures". And as we have teams working on the projects, trust building and management of the optimal level of expectations (Adobor, 2005) emerge as important elements to help reducing the high percentage of alliances/ partnerships that fail due to non-technical reasons (Laroia and Krishnan, 2005).

Ultimately, multidisciplinary partnerships are presented in the analysed papers as a way to enhance learning processes and knowledge sharing (Powell, 1998). Prior experience of collaboration or share of similar knowledge sources (Kim, Beldona and Contractor, 2007), as well as previous external relationships, are given high importance/are seen as critical to facilitate the absorption, share and dissemination of new knowledge created in multidis-

Figure 3 Key components of the coding structure



ciplinary settings (Powell, 1998).

This would be a relevant factor to develop the absorptive capacity (Cohen and Levinthal, 1990) of the firm, and also to develop network capabilities, i.e. capabilities linked to the firm's ability to choose the right partners for the challenge at hand, to facilitate formation of new partnerships (Hagedoorn, Roijakkers, and Van Kranenburg, 2006; Roijakkers and Hagedoorn, 2006; Roijakkers, Hagedoorn, and van Kranenburg, 2005), as well as to coordinate resources, and manage relationships/partnerships.

At the end of our analysis, the final analytical model derived contained three inter-related key topics: MDCs, Network Capabilities and Agent, as shown in detail in Figure 3.

These elements relate to the old issue of structure agency here reframed and subtly altered in the dialectics of network capabilities and the agent. The network is not structure alone but it also includes the dynamics of work to form the structure. Work is performed by the agents. We considered both components as well as the specific issue of MDCs. Definitions of the concepts for each major component of the taxonomy can be found in Appendix 2.

4 Insights from pharmaceutical industry: two case study comparison

The two case studies considered are in-depth descriptive, holistic, and retrospective, aiming for theory building (De Vaus, 2001).

One case focuses on a global top-ten pharmaceutical multinational based in UK, and on the evolution of their bio-informatics group and the focus is on their projects related to the Human Genome Project (HGP), deemed vital for the new IS-based research paradigm that emerged in the industry since the mid-90s.

The other case focuses on an international firm located in a small-medium European economy, which produces, sells and does research in the pharmaceutical area and is part of the top-20 pharmaceutical firms in its national market, and on the multidisciplinary practices used in the drug development process.

The comparison is achieved by using the same analytical framework based on our eclectic understanding of the in-depth literature review performed in the first part of the empirical research. The main elements of the coding structure were presented in Figure 3. The data collected in the empirical study was analysed in NVivo 7.0, using that analytical coding model.

4.1 PharmaCo case

In PharmaCo, 12 interviews with 9 employees were performed between February 2005 and January 2006 and the case material covered the six years of the creation of a bioinformatics tool from 1999 to 2005. The specific project was designed to handle the information from the Human Genome Project (hereinafter HGP) and to provide the necessary bio-informatics tools to capture such data as they were generated.

Five of these interviewees were intimately involved with the project, including project managers and technical leaders (BI1-5). Three individuals were among the main stakeholders and clients of the bio-informatics group (SC1-3) while the remaining two participants were a high-level corporate information systems (CI1 and CI2) manager. The interviewees thus encompassed the three major communities involved in the project.

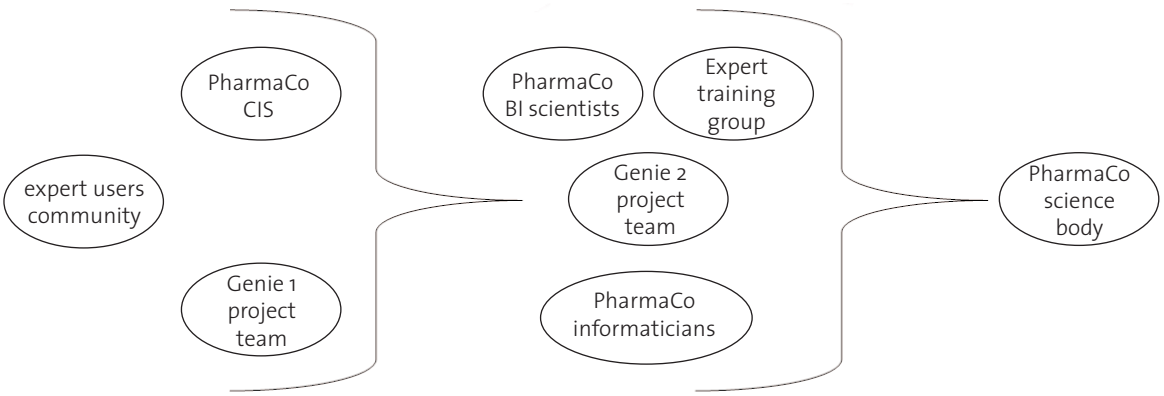
PharmaCo, the result of a major merger in the 1990s, responded early to the main challenges of the last decade posed by biotechnology and IT. They hired a number of people who were versed in IT and in science and together with pre-existing employees they formed a small group of bio-informaticians (BI) that was to handle the new technologies and data that were emerging. The newly formed multidisciplinary department managed a number of key external relations with novel organisational actors. Their products not only had to be proprietary IT, as there was no commercial software available, but also needed to be bio-science informed. The task of the BI group was formidable. This case study focuses on a major effort of the BI group to absorb the emerging HGP data.

The BI group run two major projects for the HGP; Genie 1 and Genie 2. Both were multidisciplinary projects, involving a variety of actors. Genie 1 had four project members from different disciplines and sub-disciplines of bio-science and bio-informatics. It was based on a publicly available database called Genie which involved a public institute (PI) and its related open source group (OSG) that was supporting that PI's goals. 2 years later Genie 1 was absorbed into Genie 2, a project that designed a proprietary tool to bring data from HGP to the internal scientific community. Genie 2 had a very elaborate stakeholder base and structure as illustrated in Fig. 4.

However it was quite a different multidisciplinary beast from Genie 1, with a more complex network of communities involved involved. According to its leader, from the beginning Genie 2 was built to be a showcase of a bio-informatics project and aimed for achieving PharmaCo's independence from the public software that Genie 1 was using.

It involved, from the design stage, expert users, scientists with informatics experience who resided within the PharmaCo research

Figure 4 Communities involved in the management of Genie 1



body, and the corporate IS. It also enrolled from the beginning the project team of Genie 1. By involving the various disciplines and communities from the beginning, Genie 2 managed a harmonisation of goals and avoided many of the conflicts and risks that the Genie 1 team faced.

4.1.1 Agent

Over the period of six years there was a certain degree of stability among the communities of practice. The three main communities involved, persisted throughout that period and were perceived as quite well defined and distinct even though they collaborated within the same projects. For example SI1 claims:

"I feel we have missed opportunities to leverage the various cultures to our benefit. Within BI there is intrapreneurial spirit but also there is much conflict."

The distinction between the three main communities is reciprocated by members of the other two communities. For example SC1 notes that:

"Research Area scientists are rampaging around finding technology and information. BI should get more involved, they should rampage around technologies, fast moving. It is difficult for BI. In Research projects a multi-skilled team. In CI staff often gets de-skilled (software becomes obsolete etc...)."

Nevertheless when it came to project management the project work became a priority and the various communities were acting in a complementary manner adding to each other's strengths. Explains SC2 with regards to Genie 2:

"It was particularly useful to work with the scientists for BI people. Genie team got surprised with how much we valued the literature part rather than the Bio-informatics part of Genie [...]. It meant removing ambiguity even though we all knew that it meant sometimes that Genie could be wrong."

Concerning leadership there were two types exhibited according to the participants. The first was the entrepreneurial, informal kind of leadership, which was the hallmark of Genie 1. In that project BI3 was the formal project manager but he explains with mild amusement that:

"BI1 would still go his own way. It did become his baby and he was personally convinced that it was the only way forward. Overall it was difficult to manage BI1. He would go on developing something and then come back in the sessions with his results. He found it hard to delegate and would not ask for help while BI3 spent much time persuading him to do exactly that. On the other hand BI1 has been very good at presentations. BI1 has been an unrecognised gem in that department".

Thus, BI1 was informally the project manager of Genie 1 as he was the creative force behind it. In contrast, in Genie 2 the formal leadership was also representative of the actual situation in the project as the project manager was particularly keen to make GC an exemplar in project management and was hands on from the beginning.

"They did very well in getting the user requirements. (Genie 2 project manager) had a clear, strong vision."

The creativity inherent in the BI group and the formal/informal leadership mix are both hallmarks of an innovative organisation where new knowledge creation is paramount. In the case of PharmaCo there was a lot of creativity and learning present during the creation of the Genie tools. As BI1 observed of the science community during the development of Genie 1:

"They were interested in functionality data. Sometimes they would tell us something was completely wrong and we would feed that back to the Ensemble who then feed that back to the genome sequencing community. So they were using us as a filter for trying to improve the assembly or the annotation of the genome. They were telling us things they wanted to see and things they wanted to be able to do in the Ensemble. So we could also produce new functionality based on their feedback. So they were a big driver."

Clearly Genie 1 was creating new knowledge as the scientists were intimately involved from the early start with the creation of the tool. Genie 2 incorporated them formally and explicitly in the structure of the project. It seemed however that each community of practice had a slightly different way of managing multidisciplinary projects. In Genie 1 there was also a lot of learning involved in engaging an external community such as the open source people:

"It produced a cultural change within informatics as well. It was so great and we did so many things to it, it had to drive us towards better practice. So it has led to programming practices which we didn't have before." (BI1)

4.1.2 Multidisciplinary collaborations

In the level of the project, we observed that the identification of the agents to the corresponding communities of practice can be the seed of much potential conflict. For example:

"The BI guys divide into targets leads etc., for us is more of a blur and we think in rather different terms." (SC3)

"BI is not good at recognising local developments and applying them globally. Cost-benefit analysis changes throughout the years. [...] Scientists are not committed to anything other than developing drugs." (SC1)

CI notes that there is even some antagonism between science and CIS:

"Within the science community, if you are not a scientist you don't know. Definitely [there are] personality elements in this. Thus there is a lack of trust in Discovery."

"The pharmaceutical industry has low recognition of the IS function, a fact that is represented by the line of report that we have. The pharma[ceutical people] have not mined the value of informatics and IS and have not utilised the information available."

Bio-informatics has been by definition a multidisciplinary discipline and that was corroborated in the findings of this study. All five BI members had a mixed background of science and information systems. However, that often alienated them from both the CI and the science people. Yet within the projects the actualised benefits from the collaboration in creating Genie tools implementation cannot be overstated. Such benefits far outweighed the difficulties of communication:

"It was particularly useful to work with the SC for BI people. Genie team got surprised with how much we valued the literature search part rather than the bio-informatics part of Genie. We wanted Genie to provide Soft Bioinformatics. It scared them because it meant asking them to make decisions over science results. It also meant removing ambiguity even though we all knew that it meant sometimes that Genie could be wrong." (SC 2)

"The resulting efficiency savings were enormous, for each ISB maybe 50% of their time was saved as GC now was doing automatically that part of their work." (SC 2)

Such mutual understanding achieved through the MDC alleviated conflict and it was a key success factor in the Genie story. Such collaborations were based on informal relationships that would become formalised when the team would be forming. SC2 explains how the connection with BI group and the mini-Genies he created led the BI group to seriously commit resources for Genie 2 as it was clear that Genie 1 was not covering the needs of the science community:

"I talked to (Genie Project manager) about mini-Genies, some time back. (Genie Project manager) and some other BI members saw a disconnect between the BI group and their user base. They were also embarrassed of mini-Genies, as it was built by people with limited technical knowledge (expert users within the science community) but it satisfied what they saw as the client base had much conflict over there with issues of user involvement."

Another key success factor was represented by the two artefacts and their continuous exposure to the various communities. The tools were instrumental in pivoting the evolution of the Genie project. In Genie 1, the continuous demonstration of its potential was actually crucial to keep the cohesiveness of the support coalition. Such engagement with the artefact seem necessary as Genie 1 involved a lot of dependency on public actors, something that BI and CI management in particular were not keen upon. The head of BI notes that:

"Ensemble was more a protective thing, to protect investment and time; there was much dissent from CI. However Ensembl gained external respect in pharma companies and the BI community for competence."

Another important success factor was the commitment of actors in the Genie project. Each project had a champion who was there for the majority of the project's running time and who cultivated a certain project mentality that persisted throughout macro-structural changes and team consistency changes. As BI 2 notes:

"A project develops its own culture. It is important and it works but the team should not lose sight of the customer. After awhile the project culture tends to take over and the goals, stakeholder committee aims etc. become engraved in stone/sacrosanct. However when the customer will say that what you deliver does not do for the business you can not say is the customer's fault."

In the case of Genie 1 the success was moderate as the customer was not as involved. However in Genie 2 the customer was actually part of the project team and made a tool that was relevant to the science base.

4.1.3 Network capabilities

We can already discern from the previous analyses that the network itself was rather important in the running of the multi-disciplinary project. For example we notice how the consideration of the underlying network shapes Genie 2. So in this section we will examine the network alluded to in the previous two sections and its interaction with project structure and the agent.

The issues of co-ordination and knowledge transfer are explicit throughout the interviewing process. Lack of co-ordination hinders knowledge transfer acknowledges CI 1:

"We spend 4 billion dollars on managing and changing the organisation! The fragmentation of IS has a very high cost. The weakest IS area is that of information sharing and management. There are many reasons for that. First of all, IS is fragmented and there is a silo mentality. The default of information management was to be that information is available unless it needs to be protected while in reality information is not available unless it is given specifically to me. It is our own stupidity when we can not co-ordinate ourselves. It also gives leeway to innovation. There is a need for balance."

That issue is not limited to IS. In BI there are similar difficulties:

"Science is embodied in real people. One of the downsides of a global organization is that anything new is difficult to diffuse across various sites." (BI 4)

However for certain actors within the BI and the science communities such efforts in co-ordination were viewed as covert efforts of control:

"If process helps the work that has to be done is fine but if it becomes everything... The Matrix structure has broken it down, when you have to ask for permission seven people is much harder to achieve anything. Those little pockets of innovation need some lack of transparency at times. Not always a need for transparency." (BI2)

The issue of control and politics appeared again and again during the interviews with the main focus on the ambivalent understanding of the bio-informatics function. That may have something to do with the culture of the group as explicated by a top level manager in the BI group:

"There is one simple trick I have been using. You tell people the trick, you explain how it works and still people do not believe you. Basically when somebody tells you to do something, you reply to them: «This does not apply to me and my team because what we are doing something different»..."

When it came to transfer of knowledge in this particular group the IT systems, the main artefacts of the BI group, were instrumental. Both in internalising external knowledge as with the case of Genie 1, and in discoursing project parameters:

"Genie 2 was not from the beginning beautiful architecture. The focus was to get front end right and then work out the architecture. That was in contrast to the IS culture where the focus is first on the architecture and then the architecture becomes the constraint with regards to the front end usability and interface of the application." (SC2)

Other tools facilitated internal knowledge transfer by improving upon communication means. Genie 2 team for example used WIKI and the intranet:

"WIKI was quite helpful. The Genie 2 team had provided access to all ISBs on the meeting notes and other information. The priority was on usability." (SC2)

And both projects took advantage of training resources from the expert training group:

"Organizationally that's where courses would be so that was all handed over to TAU. Same place for other courses such as the website, putting everything up on." (BI1)

4.2 PharmaEU case

Between March and April 2008, we interviewed four employees of PharmaEU, located in key positions related to the R&D process, ranging from people in R&D department and in business development, or general management functions. We used as complementary information sources: internal documents (not confidential), public documents, archival records, researcher's diary and site observation. We triangulated the opinions, using cross-checking between interviewees and post-interview clarifications.

Our study centred on multidisciplinary teams in PharmaEU and network capabilities, with focus on both internal and external partnerships. We followed the coding structure derived from the literature review, presented in Figure 3 and Appendix 2, to construct our personalized interview scripts. We uncover issues related to: internal multidisciplinary teams for R&D, both formal and informal, partnerships with external agents, outsourced or

licensees.

We next present key insights from the data collection and analysis, following the key components of the before-mentioned coding structure.

4.2.1 Agent

The "communities of practice" in PharmaEU, as indicated by all interviewees, are well defined and functionally represented. All people participating into R&D tasks have their responsibility quite perfunctorily defined, especially if we are speaking of multidisciplinary collaboration for R&D. Note that there is a concern for complementarity when a multidisciplinary team is created:

"The idea is that all these people come to the meeting to represent their own functions"

"We have to have complementarity and less redundancy [...], we need to have a wide pool of competencies and opinions."

In terms of creativity and learning, several issues are worth of mentioning.

First, we got a grasp of some of the pharmaceutical industry serendipity linked to a very systematically defined R&D process, which can be useful, nonetheless:

"There are things that need not inventing, fortunately there is nothing here to discover. People know what they are doing, they know the steps they need to make. Of course, there is a creative aspect that is not in the books, and we need to have people to have ideas for new products."

Then, we see the advantages in terms of creativity and better decision-making associated to a multidisciplinary team:

"The very concept of discussion is associated to evolution. When we are discussing something, this is due to different opinions and several possibilities emerge: either we have an opinion clearly better than the other, and we've won already, either is it not obvious and maybe the combination of two or several ends up as a major advantage for the next step. From this perspective, the discussion is fundamental."

At last, there is a learning experience associated to the duration of a multidisciplinary team, both in terms of knowledge creation for R&D:

"Because many people have been involved since the beginning, we have been part of a learning experience."

and in terms of relating with one another:

"Entropy reduces as we work together, no doubt about it, our experience shows it. In the beginning, there was more entropy in terms of e.g. information fluidness and of how we talked to each other. There were issues to clarify and as time passed, the entropy has been reducing."

Leadership seems a multifaceted issue, and is perceived differently according to the type of internal multidisciplinary team. When speaking of informal, ad-hoc teams, created so as to respond to specific, usually technical issues, leadership is not perceived as an individual, but more with a coordinating role, with one coordinator in each function present in the team.

When speaking of formal teams, in our case one specific team created so as to coordinate and align objectives and actions between the various functions involved in the R&D projects, opinions on leadership are divided.

Part of the interviewees indicated the official coordinator of the team, in charge with the agenda and meeting logistics, to be the leader. His role is mainly ensuring that all "voices" are heard and that participants speak openly:

"My role is to facilitate the meeting, to do the agenda, to run the meeting essentially [...]. I am in charge of the logistics and make sure everything happens...that minutes go out and that people are done what they are supposed to do."

Part of the interviewees referred another member of the team as the leader, mostly in an informal sort of way. Regarding the leadership role, opinions diverge.

In terms of external partnerships, leadership belongs to the Sponsor, and there is coordination between Project Managers on both sides, which then create the necessary linkages inside their own organizations.

4.2.2 Multidisciplinary collaborations

Multidisciplinary teams were perceived as having several insightful characteristics, presented next.

The diversity of expertise brought up by multidisciplinary experiences is seen as a very positive element.

"In the company, we end up having several competencies that we can have around the same table, specialists in various areas that complement each other in the interpretation of the information we receive."

"We make a phone conference and on one side, we have specialists from the various area,

whilst on the other side we also have these specialists, and instead of Project Managers speaking with one another, we can have a more technical discussion between the various specialists."

Task and responsibility definition is perfunctory, as mentioned before, based on functional expertise, on "silos of skills".

"An R&D project involves different areas, and due to that, for key tasks in the R&D process, there is a direct or indirect linkage to specific teams. It is not difficult to know which are the teams holding responsibility in that area."

Communication between the members of the multidisciplinary teams, and in partnerships with external actors, was a widely discussed topic, frequently mentioned by interviewees.

In internal teams, communication is fluid, using both formal and informal circuits, yet following hierarchical flows, clearly defined, if a formal decision-making is involved.

"Formally, when the communication is not defined, the rule I use for me and my team is common sense, is that in case of doubt, we use the hierarchy."

With external partners, communication is technical, and ruled by confidentiality agreements before any type of sensitive information being exchanged.

"Before any type of information is exchanged, we put in place a specific confidentiality agreement. This is necessary not only for us, but also for them, because they also give us information which is confidential from their point of view."

"As far as I know, there has been no leakage of confidential information. No breach of rights or copying. We only work with top companies, they are credible. It's like a loyal, they cannot reveal data, they work based on a clear policy of information control."

In terms of instruments supporting communication, either internal or external, there is generalized use of phone, phone conferences and email, which complement face-to-face encounters. Phone is used in case of doubt, to clarify issues.

"Today, people tend to believe that e-mail solves everything. It doesn't. Normally, when the situation requires it, we have a face-to-face meeting. [...] Sometimes we do phone conferences [...] and like that the information shared by e-mail was contextualized, there is less chance to be misinterpreted."

There is a common concern to minute the key decisions of any verbal meeting, and result is sent by e-mail to all participants.

"Every time we have a meeting, call conference, whatever, we try to put everything down in written, in minutes, so as to be able to consolidate there what we have decided... ."

"...communication is not difficult, but has to be very vigilant, exactly because we want to work in the same context, do the things we want to do in the way we want it to be done, and because the information needs to be shared the way we want it to be shared."

And multidisciplinary teams are seen as an open communication channel:

"It seems to me they create discussion channels so open that they ease not only the information flows, but also sharing specific issues regarding possible changes in plan, future development paths etc."

In terms of other positive aspects associated by interviewees to multidisciplinary team experience, we mention:

"Coordination, sharing, communicating knowledge, being aware of where we are, planning..."

"Opens our horizons, disseminates information and allows receiving more information..."

"Allows having a more aligned decision-making process..."

As of the success factors and management practices, we mention:

- small team dimension and unchanging team composition

"It helps being quite small [...]. We're able to communicate easily with each other, there are no twenty decision layers. We've got the same people, we formed a relationship in many years [...]. We have deep understanding of where we are."

- knowing your external partner, and monitoring closely project evolution

"You need to know, to see, who the clients of that partner are, with whom they work, where they are, what their philosophy is!"

- knowing how to deal with entropic communication, that cannot be dissociated from multidisciplinary experiences

"Either somebody says: ok, let us start again and explain the context so that we can all understand where we are, or the specialist says: hey guys, believe me, I am the expert! Not as an imposition, but as a way to move forward..."

However, the multidisciplinary teams are not seen as efficient experiences:

"I think efficiency could be better for all of

us..."

"That team is basically inefficient!"

"I would say results are more positive than if we wouldn't have the team..."

They are also situations (both internally and externally) where conflict exists, more in the sense of misunderstanding and disagreement.

"The conflict is not verbalized, is part of our culture..., yet sometimes things can only advance if there is conflict."

"There are always conflicts. Big conflicts, I wouldn't say. Basically minor. [...] but we have to resolve all of these things."

Several challenges were mentioned:

- growing organization hurdles: structure needs to be reorganized, and teams and relationships will evolve;
- communication difficulties when dealing with hierarchically superior figures in multidisciplinary teams;
- being too smaller team, which leads to compromises;
- being politically correct all the time when project is seen as going on the bad path.

Another complex issue is drawing the line and choosing between performing one task internally or doing it with external partners, in multidisciplinary and interorganizational collaborations.

"It's complicated. We have this philosophy of wanting to maintain the maximum of issues under our direct control. It doesn't mean we have no control over the outsourced partner, but it's not direct."

Several factors motivate the choice of performing tasks internally, prioritarily:

"First, because we create and maintain our know-how. Second, because we end up maintaining the project, which is confidential by default, even more confidential. Third, because we end up having a tighter control over the project."

When there is the possibility to do something with external partners, there is a duly analysis of its reasons:

"Insufficient know-how, capacity, or time! And we evaluate these reasons to see if there is a reasonable advantage performing that task outside the company. The decision balances in-between giving up the 100% control we have now, and trying to create internally the conditions, in a short timeframe, to do the task. And then, these conditions can serve other projects."

The logic is:

"When we can do it in-house, we do it. When we have to outsource it, and if we can outsource only partially, we do it. Why? Maintaining know-how internally, creating conditions for future projects, and fundamentally controlling the project."

And ultimately, disadvantages were pointed by interviewees.

"I cannot see any disadvantage except for the fact that in order to work within such a team, people have to know everything in their functions and think globally of the project as an entirety. If people are not able to come at the meeting and to think about the effect on other people's functions, then it does not work. People have to be able to think outside their day-to-day stuff."

"It can get a bit entropic! [...] As one does not understand a specific question related to our field, maybe because there is a certain technical distance between the different areas, you can get highly entropic discussions. And never-ending storied where one says A and the other understands B and they keep on and you don't get out of that."

"In complementary areas, people may think: well, if I am doing this, they probably do that! And if they do not talk and just assume, we can have serious surprises!"

4.2.3 Network capabilities

Conflict management is something present in all interviewees' discourse, casted though under a positive light.

"We have disagreements, but generally we have to find a solution and a way forward."

Coordination is a key issue, well debated between the informants. A multidisciplinary team is seen, by itself, as a coordination mechanism.

"We opted to create a transversal, multifaceted organization not so much to facilitate information flows, because this is easy, but to allow discussion of products and problems, to discuss why things are changes and why that was done."

Coordination is also seen as different, according to the partners involved:

"Interaction depends on who we collaborate with and with the nature of the issue we're dealing with. Some areas are highly complex, because we're speaking of long-term interactions and millionaire contracts. [...] In some cases we're in a top position, in others, in a low one and we need to adapt to the rules."

Coordination is performed applying good project management techniques and close monitoring of task execution and quality. Is never seen as easy.

"It's manageable. Sometimes, it can get quite hectic."

"It's not difficult, but it's not easy. Because there are ways of working which are different from our own. And when we have an external partner involved, we also need to coordinate the internal linkages! [...] Know-how is distributed and we need to integrate it! [...] Sometimes we need to manage everything: the project and the environment, so as to see and help things getting on the track when that happens."

Information technologies more widely used in other companies, e.g. Intranet, discussion forums, instant messaging, are not used in PharmaEU. Internally, teams function with shared drives, regulated by access permissions, and outside, information is shared via e-mail or, in more sensitive alliances, in specific highly protected data-sharing facilities.

"I don't miss IT tools from big companies, not really, because at the end of the day you need to have a personal interaction with people, it's always the best way. We're lucky, One of our strengths is we are small [...] if we need to talk, we stand up and walk there."

The very usage of multidisciplinary approaches to analyse and tackle information helps internalizing knowledge coming from outside the company or outside the functional/disciplinary area.

"Report drafts are reviewed by many people of different expertise, so as we can reduce the inherent risk of not knowing everything. We need to be multidisciplinary and precautious."

"In the company we have different competencies, different specialists that we can put at a round table and they can complement each other in interpreting the information we receive."

Yet, there is a draw of attention on language misinterpretation:

"One might think, hey this is easy, it's all international. That's wrong. The fact that we need to use in our contacts with the exterior a language which is not ours, is complex. We are fluent in English, we have to be, but sometimes the way things are said or written may lead to misinterpretation."

The internal transfer of knowledge or information is done hierarchically, punctually using the shared drive, using a careful information management approach.

"All the team working within that project receives all the information. The others do not because the information management says that, for a reason of efficiency, when I am reading something I do not need, I am wasting time."

"The information is essential to that person for two reasons: because I need feedback or because is essential for his/her work to continue. If this is not the case, the person does not receive the information. [...] and then we have the regular meetings to share other issues within the team."

Ultimately in this topic, interviewees referred linkages with external partners, service providers, to be slightly different in terms of coordination and management.

"Outsourcing means you will have to deal with delays, some budget variations, and with all those small things you cannot control [...] There are various ways we can deal with this: the more control over the projects, the better...we do it by doing audits, meetings, minutes and results (i.e. reports, timelines, and budget)."

5 Discussion

5.1 Comparative sum-up of the two case studies

Table 2 emphasizes the main differences and similarities between the two cases. As shown in this table, some key issues differentiate PharmaCo (BI department) and PharmaEU in what respect MDC partnerships.

A first key difference is a different focus on exploration/exploitation in pharmaceutical R&D.

In PharmaCo, analysed projects are exploratory in nature, more aligned and focused on radical innovation, yet there has been an evolution towards more exploitation approaches.

In PharmaEU, focus is essentially on exploitation, on more incremental approach in R&D, focused on me-too chemical drug development. This difference has effects onto learning, and increased coordination and control reflect in the focus on practices instead of content.

Another difference is paramount in organizational cultures and hierarchical structures in the two cases. If PharmaEU is hierarchical and vertical, with clear role definition, and strict information management policy, PharmaCo shows some vagueness and fuzziness

Table 2 emphasizes the main differences and similarities between the two cases. As shown in this table, some key issues differentiate PharmaCo (BI department) and PharmaEU in what respect MDC partnerships.

Category	PharmaCo Findings	PharmaEU Findings
Agent	■ Fuzzy definition of functions and communities of practice. Management of impressions becomes paramount ■ Perfunctory R&D task and responsibility definition ■ Complementarity in MDC ■ Serendipity complemented with good, creative HR ■ Better decision-making in MDC settings ■ Learning experience in MDC in terms of knowledge creation and relationships within team members ■ Leadership and hierarchy seen in non-aligned ways ■ A non-hierarchical culture and communication flows for decision-making ■ Responsibility for external collaborations taken by the project group	■ Clear definition of functions and communities of practice ■ Perfunctory R&D task and responsibility definition ■ Complementarity in MDC ■ Serendipity complemented with good, creative HR ■ Better decision-making in MDC settings ■ Learning experience in MDC in terms of knowledge creation and relationships within team members ■ Leadership and hierarchy seen in non-aligned ways ■ Hierarchical culture and communication flows for decision-making ■ Responsibility for external collaborations always of the sponsor
MDC collaborations	■ Diversity of expertise highly valued ■ Communication is complex issue, using formal and informal channels ■ Appropriability concern sometimes was neglected as communication was ad hoc, prior to info exchange ■ Communication instruments: e-mail, phone, phone conference, face-to-face meetings, shared drives, TWIKI, Intranet ■ Preference to put in written any info resulting from verbal understandings ■ MDC teams are seen as a communication channel ■ Success factors: small teams, dealing effectively with entropic communication, speedy delivery, good internal partners, fast delivery and continuous re-iteration with clients, successful translation of artefacts created across boundaries ■ Weaknesses: low efficiency, conflicts, entropic communication, people with holistic overview and technical knowledge, non-verbalized assumptions, silo mentality ■ Challenges: structural stretch-up, communication with people in higher hierarchical positions, choosing between internal and external performance of a task, involvement of a critical mass of stakeholders	■ Diversity of expertise highly valued ■ Communication is complex issue, using formal and informal channels ■ Appropriability concern reflected in confidentiality agreements with partners, prior to info exchange ■ Communication instruments: e-mail, phone, phone conference, face-to-face meetings, shared drives ■ Preference to put in written any info resulting from verbal understandings ■ MDC teams are seen as a communication channel ■ Success factors: small teams, fixed composition, dealing effectively with entropic communication, knowing external partners and monitoring closely project evolution ■ Weaknesses: low efficiency, conflicts, entropic communication, people with holistic overview and technical knowledge, non-verbalized assumptions ■ Challenges: structural stretch-up, communication with people in higher hierarchical positions, choosing between internal and external performance of a task

Category	PharmaCo Findings	PharmaEU Findings
Network capabilities	■ Coordination a key issue: via MDC teams, good project management techniques and politically appropriate approaches to overcome inertia and issues of creativity and control ■ A variety of IT tools are used, with focus on efficiency and clarifications in synchronous discussions and continuous transfer of information and developments ■ Language is used as a means to differentiate the different communities. For example IS talked about process and bio-science about content and result. Communication has to be sensitive to such community boundaries.	■ Coordination a key issue: via MDC teams, good project management techniques and politically appropriate approaches ■ Simple IT tools are used, with focus on efficiency and clarifications in synchronous discussions ■ Watch-out language misinterpretation: careful communication! Especially with external partners.

at this level, a more horizontal and flexible hierarchy, focused on projects, which creates specific management challenges, e.g. management of impressions.

Surprisingly to some extent, the two cases are not as different as we might have thought at the beginning.

We were comparing the department of a Big Pharma (i.e. multinational with a good presence in top twenty companies worldwide and reasonable part of world market share), multidisciplinary by nature, yet still only one function, with a medium-sized pharmaceutical firm, international, with recent drug development activities.

Furthermore we examined a department specialising in the discovery side of pharmaceutical R&D, traditionally the most creative department of the company, full of maverick scientists and new exciting technologies with the whole R&D function of a European mid-sized company.

The dramatic differences in the context of our two case studies make the points of conjunction even more important.

5.2 Limitations

One limitation is related to the research method. Our research was based on two case studies. Notwithstanding the methodological care, case studies have their inherent limitations, and only allow abstract generalization, i.e. to the theory (Yin, 2003). Whilst the findings can be used as inspiration for managers to identify hurdles or best practices and develop specific solutions for their own situation, the researchers cannot state that the findings will most probably apply in a specific situation.

The other limitation is related to the data collection. In spite of using a research protocol to orientate data collection and analysis, and maintaining close contact during all that phase, which increases internal validity (Kofinas & Saur-Amaral, 2008; Yin, 2003), interviews and secondary sources were collected by two different researchers (i.e. the two authors), in different geographical and language contexts and distinct companies. Due to confidentiality concerns, there was no possibility to cross-check the way data was coded by the other researcher, and subjective interpretation might affect the quality of our findings due to different Weltanschauungen.

The implications for theory and practice that hereby follow should be seen in the light of the before-mentioned limitations.

5.3 Implications for theory and practice

5.3.1 Agent

Communities of practice were proven not only important and present as the theory pointed out (Caruso and Rhoten, 2001; Pellmar and Eisenberg, 2000; Roper and Brookes, 1999; Saur-Amaral, 2005), but very clearly defined, which is a novel insight.

On one hand, they were stable and cooperating in most cases, however they needed to function in a context where roles and respon-

sibilities were perfunctorily defined, and this may be important for project leaders or facilitators as role diffusion or redundancy may prove to be a barrier to goal achievement and may increase conflict and communication entropy.

But on the other hand, empirical data in PhamaCo pointed out that the stability among those communities might limit learning and spillovers from MDC learning to the functions involved, which was not coined in the literature (e.g. Nissani, 1999; Romm, 1997; Saur-Amaral, 2005, 2009). However, in PharmaEU this aspect was less relevant, as the creation of good communication channels was a priority to diffuse knowledge among functions, using essentially the organizational hierarchical.

This may signify that the efficacy of communities of practice depends upon the specific context and communication channels, and the creation of a cumulative organizational learning experience based on team learning depends on culture and management practices. The well developed theory on organizational learning and learning organizations (knowledge management and strategic management scientific fields) (see Burgoyne, Pedler and Boydell, 2009; Dierkes, Antal, Child and Nonaka, 2003; Dodgson, 1993; Garvin, Edmondson and Gino, 2008; King, 2009; Senge, 1993; Senge, 2000; Skerlavaj, Stemberger, Skrinjar and Dimovski, 2007; Vera, 2009; Vera and Crossan, 2004, among others) will provide more insight into these areas and it should be used as starting point for further studies or for the development of good management practices.

When speaking of creativity, knowledge creation and learning, theory emphasized that MDCs were linked to intense learning, internal, external or mixed (Caruso and Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Powell, 1998; Romm, 1997; Roper and Brookes, 1999; Saur-Amaral, 2005; Saur, 2005), while the empirical study complemented this scientific knowledge with insights on the differences existing between the various communities of practice, importance of an innovative organization to stimulate communication and knowledge share, as well as the positive effect of stability of team members onto the reduction of communication entropy.

This has a direct implication for management, as it is common practice in pharmaceutical industry to change multidisciplinary team members along a project (Attridge, 2007; Atun and Sheridan, 2007; Saur-Amaral, 2009), which goes against our findings, where it is seen as a factor to increase entropy. And also points that there is little sense to make an effort to create a creative multidisciplinary team if members come from organizations which are not endowed with innovative cultures.

Note though that this intense learning process was not pain free. Whilst some of the participants in MDCs would appreciate the learning that came from a discussion and debate, which was seen as a way to evolve, others would complain about entropy, low efficacy and somehow arrogant attitudes of other participants. Conflict, as mentioned later in this section, is emergent, as theory also predicted (Caruso and Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Saur-Amaral, 2005) and managers should be sensitive to this aspect and look to coordinate and focus people on the project's success, a good practice pointed by our findings and predicted also by some authors (Mendez, 2003; Zeller, 2002).

Another aspect related to learning and creativity: external MDCs are led in different way, at least in one of the companies we studied. There is more technical and procedural learning and communication is well-defined and controlled. This may signify that internal and external MDCs should be studied separately, as they have different characteristics, and also that they should be managed differently. Current studies (e.g. Attridge, 2007; Atun & Sheridan, 2007; Kofinas and Saur-Amaral, 2008; Saur-Amaral and Borges Gouveia, 2007) did not make this separation, and this is a novel insight in the field.

Theory indicated that leadership was important for MDCs (Adobor, 2005; e.g. Caruso and Rhoten, 2001; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999; Saur-Amaral, 2005; Saur, 2005). Our empirical study showed that informal and formal leadership work effectively and complement each other in such collaborations, and also that there must be somebody to ensure that everybody is heard, when relevant, and that the presence of hierarchical superiors in multidisciplinary teams may prove ineffective, as it limits creativity, free communication and knowledge share. Managers should thus avoid putting in the same project team people from various hierarchical levels.

Our findings also suggest that in MDCs, two types of leaders/managers should co-exist, being formally appointed or not: the inspirational leader and the project manager. Each one has different roles. The inspirational leader motivates and makes participants believe

in the project, being the "creative thinker/visionary" character; he/she stimulates discussion and creativity and ensures commitment is high. The project manager makes sure coordination is done, and that the project is going in the right direction, having a more to the earth approach. Both future studies and managers should take into account this aspect.

5.3.2 MDCs

Some conflict and challenges were associated in the literature to MDCs (Caruso and Rhoten, 2001; Laroia and Krishnan, 2005; Nissani, 1999; Pellmar and Eisenberg, 2000; Saur-Amaral, 2005). In addition, our empirical study registered differences in formulating problems that created confusion and difficulties, antagonism and differences in the way communication flew between members. Also, the creation of efficient communication channels was seen as a good practice to reduce the impact of this aspect.

As a good practice to overcome challenges and conflicts, managers may want to discuss, confront, and monitor task execution instead of assuming that the other communities and team members will do anything. As communication is entropic and imperfect, assumptions are highly counterproductive. Using the project as a motivational tool can be useful, as this was a good practice identified in our findings which could help overcoming difficulties.

In contrast to what literature had suggested (Nissani, 1999; Romm, 1997; Saur-Amaral, 2005; Saur, 2005), MDCs were seen as a way to obtain efficiency and time savings at project levels and to remove ambiguity.

In both cases, internal MDCs were matrix structures on top of a vertical hierarchical structure, they were seen as an open communication channel. Thus, future studies should validate again the efficiency issue and better contextualize it.

Managers should continue to promote such initiatives if only for allowing communication to flow between the various communities represented in the organization, but also regulating the type of information that flows, in order to avoid conflicts and misunderstandings due to conceptual confusions.

Our empirical study pointed out some new key success factors for MDCs:

- mutual understanding;
- informal relationships;
- commitment of actors to project;
- presence of a champion in each project;
- good coordination mechanisms, as long as not seen as control;
- clear task and responsibility definition;
- small team dimension;
- good communication channels, mediated by technology or not;
- stable team composition.

These success factors should be validated in future studies and managers should inspire to create conditions for these elements to be present in multidisciplinary projects. Good practices may also serve to better draw network capabilities.

5.3.3 Network capabilities

Regarding coordination and transfer of practice, an issue raised in the literature as a key way to share and disseminate knowledge in MDCs (Caruso and Rhoten, 2001; Chiesa and Toletti, 2004; Nissani, 1999; Pellmar and Eisenberg, 2000; Romm, 1997; Roper and Brookes, 1999), we had the confirmation that the presence of the right coordination may facilitate MDCs and its absence may hinder it.

In large organizations like PharmaCo, structural barriers may hinder communication and coordination, and information technologies can play an important role as a platform to share and disseminate knowledge.

In medium-sized organizations like PharmaEU, coordination may be seen as a key issue, and good project management techniques and close monitoring of task execution and quality may be seen as fundamental for project success.

When internal knowledge transfer is hierarchical (formal), informal contacts interfere and allow knowledge share. Managers should not let aside the coordination and good project management techniques even when stimulating the team to cooperate and share knowledge. Entropy, lack of clear goal-setting and difficult communication may have a direct negative effect on goal achievement.

Regarding external knowledge internalisation and outsourcing, our empirical study only confirmed that there was a concern for group diversity in internal settings or in situations where light must be shed over external knowledge, however in external MDCs it depended on the on motivation of partner-

ship: lack of knowledge or lack of capacity.

In the first case, there is a concern for complementarity and diversity, as the literature suggested (de Leeuw, et al., 2003; Santos, 2003), in the second one, only for efficiency and given proofs.

There was no specific reference to the experience effect which enhanced network capabilities, as literature predicted (Hagedoorn et al., 2006; Powell, 1998; Roijakkers and Hagedoorn, 2006; Roijakkers et al., 2005), but there was reference to the fact that choice between internal and external partnerships was far from easy, in spite of the usage of MDC approaches could help understanding and internalizing knowledge.

Contact with external partners was seen to involve different types of coordination, as politics and control were working in a different way than they did internally.

A final note on knowledge transfer and the role of information technologies, pointed by the literature as facilitators (Arora, Gambardella, Hall and Rosenberg, 2010; Bailey and Zanders, 2008; Barnes, et al., 2009; Gassmann, Reepmeyer and von Zedtwitz, 2008; Hohman, et al., 2009; Hughes and Wareham, 2010; Williams, 2008).

Our empirical study showed that technologies can facilitate (PharmaCo), but communication it can work just as nicely without it (PharmaEU). This would lead to the possible conclusion that in smaller organizational settings, communication is better done with few technologies, whilst in bigger organizational settings is seen as a necessary tool to allow communication. So it may all depend on the context and dimension of the organization.

Knowledge transfer resulting from MDC needs to occur, independently of the technological or not technological tool that makes it possible, so it will depend on the efficacy of current communication channels.

Future studies should probably best focus on the efficacy of those channels instead of information technologies, which represent more a mean than an end per si. Managers should also think twice before implementing information technologies to improve communication, as more often than not in certain types of organizations it works the other way around.

6 Final considerations

The two cases uncovered two different stories, providing relevant information for managers working in pharmaceutical industry or other practitioners linked to drug development, so as to better understand its dynamic, Multidisciplinary partnerships were widely present in these cases. They appeared to be part of the industry way of thinking and best practices to deal with complexity, which made them a good object of study to understand the way they work and delineate strategies for other industries where they are less frequent.

This research aimed to answer three questions, which we satisfactorily have addressed, based on theoretical review complemented with strong empirical base. We managed to draw more light over MDC partnerships in pharmaceutical industry. We indicated that MDC collaborations are useful in both internal and external settings, as long as applied to the right challenges. We also indicated some challenges and benefits from MDC collaborations, as well as some good practice.

The two cases gave surprisingly similar results despite the different business context, the main differences centred around networks, arising from the exploration-exploitation focus and different organizational cultures. We might thus conclude that activity's nature changes the network and affects agents' behaviour. Our findings allowed seeing how differences in some categories of our coding taxonomies may affect agent behaviour.

We could also see that there was a confirmation of standardization of results and work procedures in pharmaceutical companies working in chemical R&D, complemented with the importance of creativity either by good human resources, or by more flexible, horizontal culture. This might signify that in pharmaceutical firms, at least in those somewhat linked to chemical R&D and blockbuster/me-too strategies, there is a high probability to find similar behaviour regarding, at least, MDC partnerships and network capabilities. It might have been a coincidence that two cases so different were so similar, yet this finding is a strong indicator that MDC issues may apply to other similar companies, too, acting in the pharmaceutical industry.

Complementarity concern in MDC partnerships, both internal and external (aspect not reflected in our literature review), was present and was considered good practice. Standardization of results and work procedures was con-

firmed, but complemented with the importance of creativity (in people or organisational structures) to overcome reliance on serendipity.

Redundancy was not seen as a useful tool to promote creativity. Our findings further highlighted the importance of careful choice of partners and functions, both in internal and external collaborations to minimize knowledge duplication and to maximize learning.

Prior experience of collaboration was seen as positive, in the sense it helped overcoming communication hurdles, yet a point is essential: in external partnerships, this should not reflect in easing the monitoring of the process and intermediate results, as effects were perceived as negative on project success.

We also saw that innovation management in pharmaceutical industry is reliant on multidisciplinary organisational arrangements. Attention to complementary network- and agent-related issues seems vital for the success of the innovative enterprise, in pharmaceutical industry or outside it.

Good managerial practices for multi-disciplinary practice are complex and nuanced and rely on flexible, adaptive and contextual processes and managerial understandings. Therefore, further studies should take into account this personalized culture context so as to understand better the respective practices and further their validity in different settings.

7 Acknowledgements

Authors kindly thank management and interviewees from the two pharmaceutical firms for their availability and collaboration during empirical research. We also acknowledge the comments of conference participants at R&D Management Conference 2008, which took place in Ottawa, Canada, and JBC's Executive Editor, David Grosse Kathoefer, and two anonymous reviewers. Without their relevant opinions, critics and suggestions, our paper would not have reached this level of scientific communication.

References

Adobor, H. (2005). Trust as sensemaking: the microdynamics of trust in interfirm alliances. *Journal of Business Research*, **58**(3), pp. 330-337.

Arora, A., Gambardella, A., Hall, B., and Rosenberg, N. (2010). The market for technology. *Handbook of Economics of Innovation*—Hall BH, Rosenberg N, eds.

Attridge, J. (2007). Innovation Models in the Biopharmaceutical Sector. *International Journal of Innovation Management*, **11**(2), pp. 215-243.

Atun, R. A., and Sheridan, D. (2007). Innovation in Health Care: The Engine of Technological Advances. *International Journal of Innovation Management*, **11**(2), v-x.

Bailey, D., and Zanders, E. (2008). Drug discovery in the era of Facebook--new tools for scientific networking. *Drug discovery today*, **13**(19-20), pp. 863-868.

Barnes, M., Harland, L., Foord, S., Hall, M., Dix, I., Thomas, S., (2009). Lowering industry firewalls: pre-competitive informatics initiatives in drug discovery. *Nature Reviews Drug Discovery*, **8**(9), pp. 701-708.

Bruce, A., Lyall, C., Tait, J., and Williams, R. (2004). Interdisciplinary integration in Europe: the case of the Fifth Framework programme. *Futures*, **36**(4), 457.

Burgoyne, J., Pedler, M., and Boydell, T. (2009). *Towards the learning company: concepts and practices:* National Centre for Vocational Education Research (NCVER).

Caruso, D. and Rhoten, D. (2001). *Lead, follow, get out of the way: sidestepping the barriers to effective practice of interdisciplinarity:* Hybrid Vigor Institute.

Chiesa, V. and Toletti, G. (2004). Network of Collaborations for Innovation: The Case of Biotechnology. *Technology Analysis and Strategic Management*, **16**(1), pp. 73-96.

Cohen, W. M. and Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, **37**(1), pp. 128-152.

de Leeuw, B. J., de Wolf, P. and van den Bosch, F. A. J. (2003). The changing role of technology suppliers in the pharmaceutical industry: the case of drug delivery companies. *International Journal of Technology Management*, **25**(3-4), pp. 350-362.

De Vaus, D. A. (2001). *Research design in social research*. London: SAGE.

Dierkes, M., Antal, A., Child, J., and Nonaka, I. (2003). Handbook of organizational learning and knowledge: *Oxford University Press*, USA.

Dodgson, M. (1993). Organizational learning: a review of some literatures. *Organization studies*, **14**(3), 375.

Garvin, D., Edmondson, A. and Gino, F. (2008). Is yours a learning organization? *Harvard Business Review*, **86**(3), 109.

Gassmann, O., Reepmeyer, G. and von Zedtwitz, M. (2008). *Leading pharmaceutical innovation: trends and drivers for growth in the pharmaceutical industry*: Springer Verlag.

Gomm, R., Hammersley, M. and Foster, P. (2004a). Case Study and Generalization. In R. Gomm, M. Hammersley and P. Foster (Eds.), *Case study method: key issues, key texts*. London Sage Publications.

Gomm, R., Hammersley, M. and Foster, P. (2004b). Case Study and Theory. In R. Gomm, M. Hammersley & P. Foster (Eds.), *Case study method: key issues, key texts.* London Sage Publications.

Hagedoorn, J., Roijakkers, N. and Van Kranenburg, H. (2006). Inter-firm R&D networks: The importance of strategic network capabilities for high-tech partnership formation. *British Journal of Management*, **17**(1), pp. 39-53.

Hohman, M., Gregory, K., Chibale, K., Smith, P., Ekins, S. and Bunin, B. (2009). Novel web-based tools combining chemistry informatics, biology and social networks for drug discovery. *Drug discovery today*, **14**(5-6), pp. 261-270.

Hughes, B. and Wareham, J. (2010). Knowledge arbitrage in global pharma: a synthetic view of absorptive capacity and open innovation. *R&D Management*, **40**(3), pp. 324-343.

Kim, C., Beldona, S. and Contractor, F. J. (2007). Alliance and technology networks: an empirical study on technology learning. *International Journal of Technology Management*, **38**(1-2), pp. 29-44.

King, W. (2009). Knowledge management and organizational learning. *Knowledge Management and Organizational Learning*, 3-13.

Kofinas, A. and Saur-Amaral, I. (2008). 25 years of knowledge creation processes in pharmaceutical industry: contemporary trends. *Comportamento Organizacional e Gestão*, **14**(2), pp. 257-280.

Laroia, G. and Krishnan, S. (2005). Managing drug discovery alliances for success. *Research-Technology Management*, **48**(5), pp. 42-50.

Mendez, A. (2003). The coordination of globalized R&D activities through project teams organization: an exploratory empirical study. *Journal of World Business*, **38**(2), pp. 96-109.

Nissani, M. (1999). Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research. *The Social Science Journal*, **34**(2), 201-216.

Pellmar, T. and Eisenberg, L. (2000). *Bridging disciplines in the brain, behavioural and clinical sciences.* Washington D.C.: National Academy Press.

Powell, W. W. (1998). Learning from collaboration: Knowledge and networks in the biotechnology and pharmaceutical industries. *California Management Review*, **40**(3), 228.

Roijakkers, N. and Hagedoorn, J. (2006). Inter-firm R&D partnering in pharmaceutical biotechnology since 1975: Trends, patterns, and networks. *Research Policy*, **35**(3), pp. 431-446.

Roijakkers, N., Hagedoorn, J., and van Kranenburg, H. (2005). Dual market structures and the likelihood of repeated ties - evidence from pharmaceutical biotechnology. *Research Policy*, **34**(2), pp. 235-245.

Romm, N. (1997). Interdisciplinary practice as reflexivity. *Systemic Practice and Action Research*, **11**(1).

Roper, A. and Brookes, M. (1999). Theory and reality of interdisciplinary research. *International Journal of Contemporary Hospitality Management*, **11**(4), pp. 174-179.

Rothaermel, F. T. (2001a). Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry. *Research Policy*, **30**(8), pp. 1235-1251.

Rothaermel, F. T. (2001b). Incumbent's advantage through exploiting complementary assets via interfirm cooperation. *Strategic Management Journal*, **22**(6-7), pp. 687-699.

Rothaermel, F. T. (2002). Technological discontinuities and interfirm cooperation: What determines a start-up's attractiveness as alliance partner? *IEEE Transactions on Engineering Management*, **49**(4), pp. 388-397.

Santos, F. M. (2003). The coevolution of firms and their knowledge environment: Insights from the pharmaceutical industry. *Technological Forecasting and Social Change*, **70**(7), pp. 687-715.

Saur-Amaral, I. (2005). Knowledge Management in Multidisciplinary Environments *International Journal of Knowledge, Culture and Change Management*, **5** (5), pp. 9-18.

Saur-Amaral, I. (2009). International R&D: Perspectives from the Pharmaceutical Industry. PhD Thesis in Industrial Management, University of Aveiro, Aveiro.

Saur-Amaral, I. and Borges Gouveia, J. J. (2007). Uncertainty in drug development: insights from a Portuguese firm. *International Journal of Technology Intelligence and Planning*, **3**(4), pp. 355–375.

Saur, I. A. (2005). *Knowledge and Information Management: case of a multidisciplinary innovation/R&D initiative.* MSc Thesis in Information Management, University of Aveiro, Aveiro.

Senge, P. (1993). The Fifth Discipline: The Art and Practice of the Learning Organization: Book review. *Consulting Psychology Journal: Practice and Research*, **45**(4), pp. 31-32.

Senge, P. (2000). Classic work: The leader's new work: Building learning organizations. *Knowledge Management: Classics and Contemporary Works*.

Skerlavaj, M., Stemberger, M., Skrinjar, R. and Dimovski, V. (2007). Organizational learning culture--the missing link between business process change and organizational performance. *International Journal of Production Economics*, **106**(2), pp. 346-367.

Tashakkori, A. and Teddlie, C. (1998). *Mixed methodology: Combining Qualitative and Quantitative Approaches* (1st ed. Vol. 46). Thousand Oaks: SAGE Publications.

Vera, D. (2009). On building bridges, facilitating dialogue, and delineating priorities: a tribute to Mark Easterby-Smith and his contribution to organizational learning. *Management Learning*, **40**(5), 499.

Vera, D. and Crossan, M. (2004). Strategic leadership and organizational learning. *The Academy of Management Review*, **29**(2), pp. 222-240.

Williams, A. (2008). Internet-based tools for communication and collaboration in chemistry. *Drug discovery today*, **13**(11-12), pp. 502-506.

Yin, R. K. (2003). *Case study research: design and methods* (3rd ed.). Thousand Oaks: Sage.

Zeller, C. (2002). Project teams as means of restructuring research and development in the pharmaceutical industry. *Regional Studies*, **36**(3), pp. 275-289.

Appendix

Appendix 1 RefViz group keywords and record distribution

Top	Top 3 Keywords	N.° of refs included	% from total	RefViz group number
1	Pharmaceutical Industry Biotech	47	31.33%	1
2	Network Pharmaceutical Process	20	13.33%	12
3	Innovation Development Industry	16	10.67%	6
4	Manager Model Process	14	9.33%	10
5	Social Interdisciplinary Development	11	7.33%	7
5	Alliance Pharmaceutical Partner	11	7.33%	5
7	Social Interdisciplinary Care	10	6.67%	11
8	Partnership Public Pharmaceutical	9	6.00%	4
9	Interdisciplinary Health Social	7	4.67%	2
10	Practice Change Structure	2	1.33%	3
10	Structure Organizational Model	2	1.33%	9
12	Strategic Network	1	0.67%	8
	Total:	**150**	**100.00%**	

Appendix

Appendix 2 Definitions of Terms in the Extended NVivo Taxonomy

Main Concept	Sub-components	Definitions
Agent		**Issues related to the MDC actors (employees, consultants, managers etc.)**
	Community of Practice	A group of people from the same discipline or sharing the same goal
	Creativity Knowledge creation Learning	How creativity contributes and managed within project teams and mention with regards to MDC and DC differences; Knowledge creation/innovation as an outcome of creativity or a separate concept
	Leadership	Indications of leadership and its need in MDCs / DCs. What makes a good leader in projects?
	Motivation	Motivation of individual actors within the MDC and how that affects the project of the group.
MDCs		**Core issues in assembling teams of individuals from different disciplines. Issues ideas and espoused theories of MDCs and other structural props and processes that facilitate it**
	Conflict Challenges	Factors hampering the progress of the MDC; Issues that were seen as challenging or difficult.
	Key benefits from MDCs	What were the benefits from engaging in an MDC
	Key Success Factors	What made the MDC successful according to the actors involved
	Management Practices	What makes an MDC work; sort of prescriptive advice; managerial routines.
	Risk management	How to manage uncertainty and risk in MDC, issues with risk and how to minimise exposure.
	Specific Characteristics	Time / Relevant experience / Communication between partners / Individual absorptive capacity / number of disciplines / types of projects / internal vs. external / preferences in partnerships / efficiency of MDs
	Types of collaborations	Instances and types of multidisciplinarity and collaboration.
Network capabilities		**Issues, ideas and espoused theories of Project Management. Also structural props and processes that facilitate Project Management.**
	Co-ordination & Transfer of Practice	Internal flow of information among partners / lead individuals / practice transfer and dissemination
	External Knowledge Internalisation & Outsourcing	Issues of absorptive capacity examined here. Group diversity, challenge of boundary crossing/spanning. Weak/strong external ties and internal ties/ Outsourcing
	Factors facilitating MDCs	Partners choice / complementarity / previous experience in MDCs
	IT & Communication & Support Systems	Role of IT in managing projects of MDC and DC nature, role of IT in boundary formations. How communication is facilitated, its import and influence.
	Power & Politics & Conflict Mgt	How organisational power issues affect the PM of an MDC. Also relates to gatekeeping phenomena.

Journal of Business Chemistry

Practitioner's Section

Pharma 3.0: delivering on health outcomes

Patrick Flochel* and Frank Kumli**

* Ernst & Young Ltd, Bleicherweg 21, Zurich, CH-8002, Switzerland, Patrick.Flochel@ch.ey.com
** Ernst & Young Ltd, Aeschengraben 9, Basel, CH-4002, Switzerland, Frank.Kumli@ch.ey.com

Health care spending continues to surge at rates that are, for most governments, unsustainable. As a result, a growing priority for governments today is increasing the effectiveness of their health care systems. Many countries, from the US to Europe and Japan to the emerging markets, have made health care reform a top priority.

In efforts to cut costs, pharmaceutical spending, has been a highly visible target for cost containment. This impact has been most evident in the price-cutting plans that have spread across Europe in recent months, accelerated by the sovereign debt crisis.

Yet a common ground of these reform efforts is to make these systems sustainable on the long-term by reshaping their "currency." To accelerate change, policymakers need to move away from costs or budget considerations and turn to changes in patient or population health status, or health outcomes, as their main focus.

Beyond the short-term cost-cutting initiatives that the pharmaceutical industry is navigating with diversification strategies, the opportunity is clear for the industry to become more visible in demonstrating the value it brings to the health care system.

Pharma 2.0

The fundamentals of the pharmaceutical industry are strong. A steadily growing and aging world population is expanding the potential patient base, and rising incomes in emerging countries are contributing to boost the global demand for higher-quality health care.

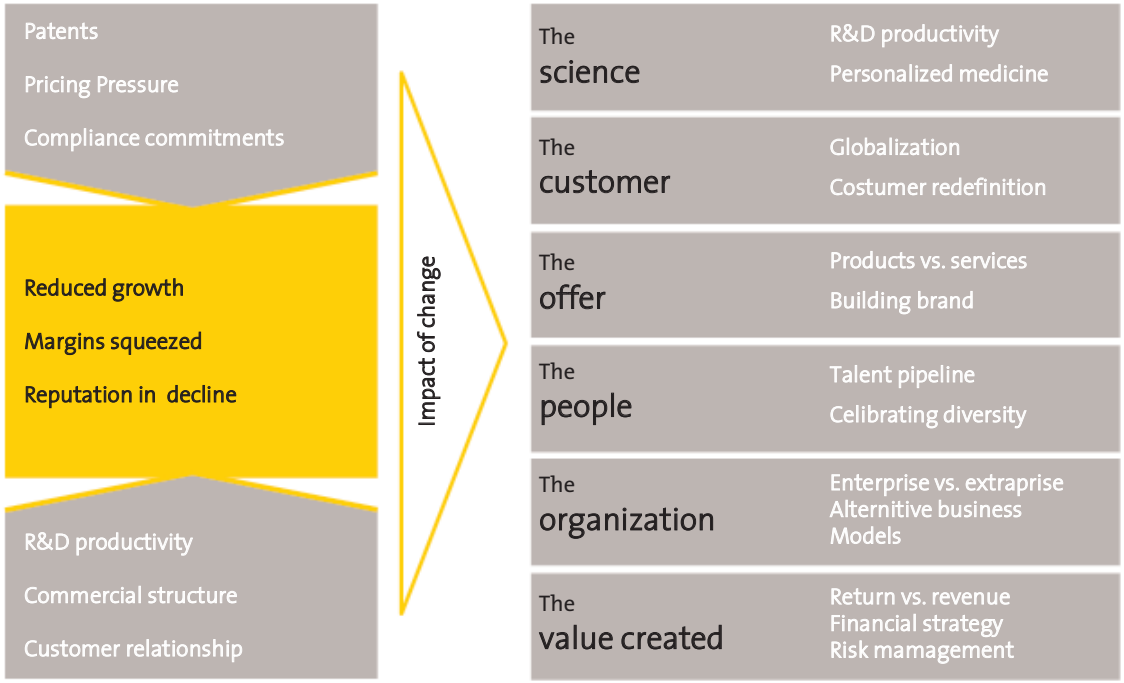
However, industry players concur that they are facing a number of pressure points — changing market realities such as pricing and regulatory pressures, thinning drug pipelines, efficacy issues, shifting demographics, globalization and more. Such macro changes have forced pharma companies to move away from their monolithic blockbuster business model, dubbed "Pharma 1.0", to become more innovative, collaborative, diversified, global and value-driven, – the model we call "Pharma 2.0".

Today, most pharmaceutical companies are in the midst of their transformation to 2.0. The strategic choices underlying this transformation have been built on the individual companies' view of the changing business environment, their core competencies and their potential competitive advantages.

The science – With more than $70 billion USD worth of drugs set to lose patent protection over the next five years, the need to reinvigorate pipelines is more pressing than ever. Pharmaceutical companies are taking a strategic approach to "the science" — therapeutic categories, organizational realignment, biotechnology and personalized medicine. They have recognized the need for new approaches to increase the quality and effectiveness of their portfolios. Efforts are made to prioritize therapeutic and disease categories, break down silos and increase collaborations with start-up companies and academia. As scientists advance to understand diseases at the molecular level, they are becoming increasingly empowered to develop treatments more specific and efficient, matched to patients' genetic profiles with the potential of a greatly diminished risk of adverse reactions.

The customer – Customer segments in mature markets have been expanding beyond the traditional base of physicians to include a broad range of additional customers, such as governments, insurance companies, public agencies, pharmacists, hospitals and patients. To adapt to these evolving customer profiles, pharma companies are transforming their approach to brand, marketing and sales management. At the same time, they are moving from a transactional model of interaction with customers to a more systematic, customer-facing model where all levels of the

Figure 1 Business model transformation: Pharma 1.0 to Pharma 2.0



organization, not just the sales force, are focused on the customer. Most companies are dismantling their large sales forces in the field, traditionally focused on physicians, and instead developing sales approaches and more specialized sales teams tailored to new customers and products.

In many cases, the industry is counting on emerging markets to extend the life of mature products as well as to develop new markets for their prescription drugs. It is targeting developing countries' growing ranks of the middle class — a strategy that has obvious benefits in the near and long term. Here, the industry, while it is dismantling its sales infrastructure in mature markets, is rapidly building up a sales force needed for growth in what are highly physician-driven markets. Yet, an emerging markets strategy represents an enormous challenge for an industry that has focused so much of its past efforts on selling to the top of the income pyramid. International expansion demands a certain degree of finesse and a more holistic view that takes into account the dynamic environment in emerging markets. There is also a growing urgency to create a more satisfying and sustainable approach to the patients at the base of the income pyramid in the developing world.

The offer – Services represent an area where pharmaceutical companies — with 99% of revenues tied up in products — are notably absent today. Interestingly, the evolution of nearly all product-based industries shows us that the best way to create loyal, long-term relationships and critical feedback loops with customers is through services and improvements in the customer experience. And pharmaceutical companies are in an ideal position to participate in the entire value proposition for better health as we will see later in this article.

The people – The pharmaceutical industry is constantly fine-tuning its approach and dedicating a wealth of resources – in money and time – to the discovery, development and lifecycle management of products. But the industry is still in its infancy when it comes to applying the same level of strategic focus to the discovery, development and lifecycle management of people. While all recognize that innovation comes from innovative people, not products, companies have not yet fully executed on the potential to transform themselves by transforming the way they recruit, train, mentor and advance the staggeringly diverse workforce of the 21st century.

The organization – The focus on the customer is driving decisions around "the organization." After years of building complex busi-

nesses with large bureaucracies, the industry strives to build and manage businesses nimble enough to meet global demands. The debate about centralizing versus decentralizing certain business functions has been joined by a parallel discussion on aggregating versus disaggregating company assets and business units. On both fronts, speed, nimbleness and agility are winning out. Industry leaders once known for consolidating assets to form large divisions are now carving out smaller business units to serve each market. This is enabling them to make decisions faster, a key attribute of a successful global business.

The value created – The industry is increasingly realizing the need to focus on "financial strategy" as a means of creating value and managing for risk-adjusted return, not just revenue. One area of progress is in the realm of cost management. For years, many companies relied on instant cost-cutting campaigns that paid little attention to, and in some cases jeopardized, long-term growth plans. Today's finance directors are taking a more strategic and sustainable approach by aiming to create a long-lasting cost advantage within the industry. Outsourcing and shared services are becoming the norm, and they are generating significant cost savings. While most directors admit that they have a long way to go to "grow lean," this new emphasis on efficiency initiatives that contribute to long-term profit growth represents a notable shift in thinking. The focus is now turning to building the systems, tools, metrics, processes and reports that can provide a more sophisticated approach to capital allocation.

Pharma 3.0

As the industry is in the midst of this Pharma 2.0 journey, new and sweeping trends have emerged that are again transforming the business environment. Changing incentives are reshaping the health care ecosystem with an emerging need to deliver a sustainable value proposition centered on health outcomes. This shift will require the industry to revisit its business model with a move towards Pharma 3.0 -- business models focused on health outcomes. Pharma 1.0 and Pharma 2.0 were focused on developing and marketing drugs; Pharma 3.0 is a reconfiguration of the model with a focus on health outcomes where the traditional product – a drug – is only one part of pharma's value proposition.

Health outcomes

The primary agents of change are the payor- and the government-led reform initiatives underway in most major markets, from the US and Europe to emerging markets. A common theme throughout these initiatives is creating

Figure 2Evolving pharma business models

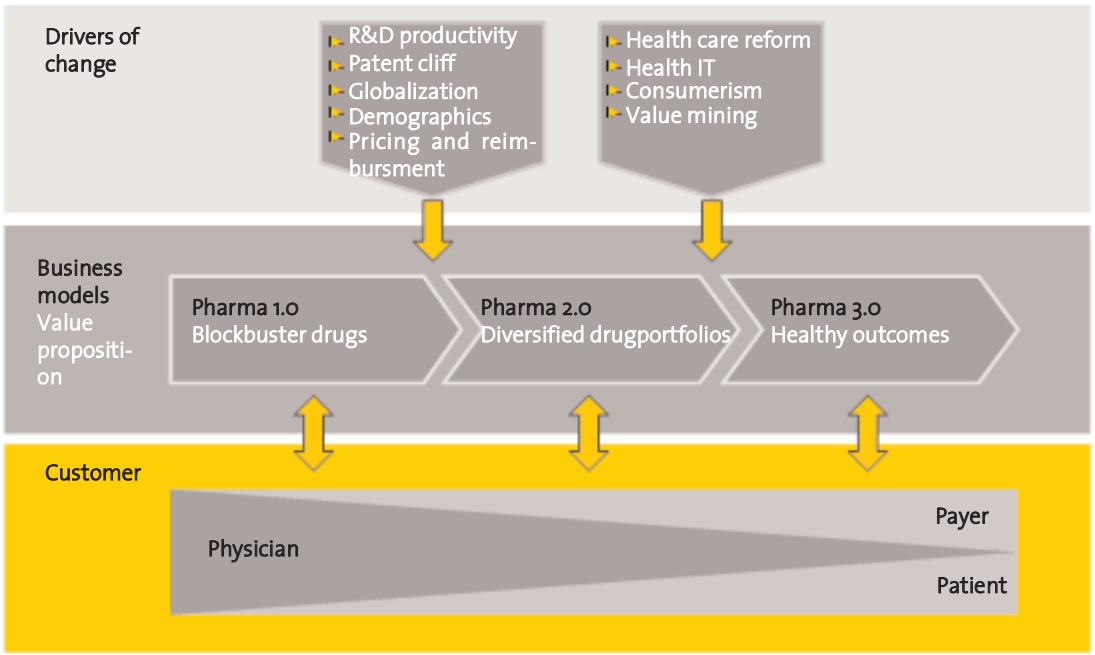
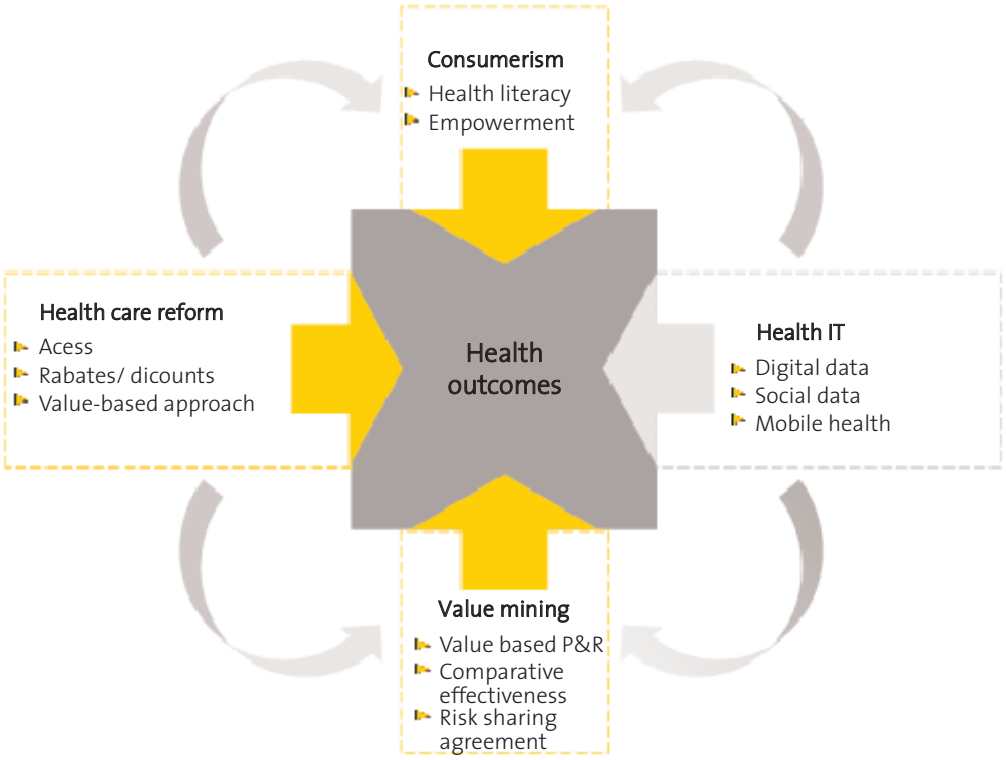


Figure 3 Drivers towards a health outcomes based health care ecosytem



more efficient systems by focusing on health outcomes. In this context, systems will reward stakeholders for the perceived value delivered to the system, with price cuts and rebates applied on most existing treatments and value-based approaches for innovative drugs.

Health information technology is further enabling and accelerating an outcomes-driven industry. The digitalization of health data, electronic health records and associated eHealth platforms offers the promise of enhancing efficiency, increasing safety and reducing costs. Mobile health technologies provide live and real-time access to digital health information, supporting diagnosis and monitoring, as well as driving compliance in medication. Social media platforms are enabling patients to share health information. The convergence of social media and health information provides the benefit of empowering patients in health literacy. People are empowered to improve their health as they can access and understand information that in the past was available only to their healthcare providers.

This tremendous expansion of availability of health data will empower payors to make better decisions as reform initiatives drive value-based choices and outcomes-based pricing and reimbursement.

The same transformation is happening on the patient's side. Traditional patients are becoming "superconsumers," capable of making real, value-based decisions based on their health outcomes.

Non-traditional players

This emerging ecosystem is attracting many new, non-traditional players, from e-health and mobile health firms to consumer electronics companies, large retailers to medical technology firms and information aggregators. These companies are rushing in to fill the gaps and capitalize on the potential returns of an outcomes-centered world.

In Ernst & Young's latest Progressions report, we surveyed business development and innovation leaders and found overwhelming agreement that these new entrants will play an increasingly important role in the health outcomes ecosystem. Looking at total responses across all categories of potential entrants, 92% of the respondents said it was likely that new entrants will enter the ecosystem. Analyzing the categories, the most likely entrants (as well as the most potentially highly disrup-

tive) are e-health/m-health and new medical technologies companies.

Delivering on health outcomes

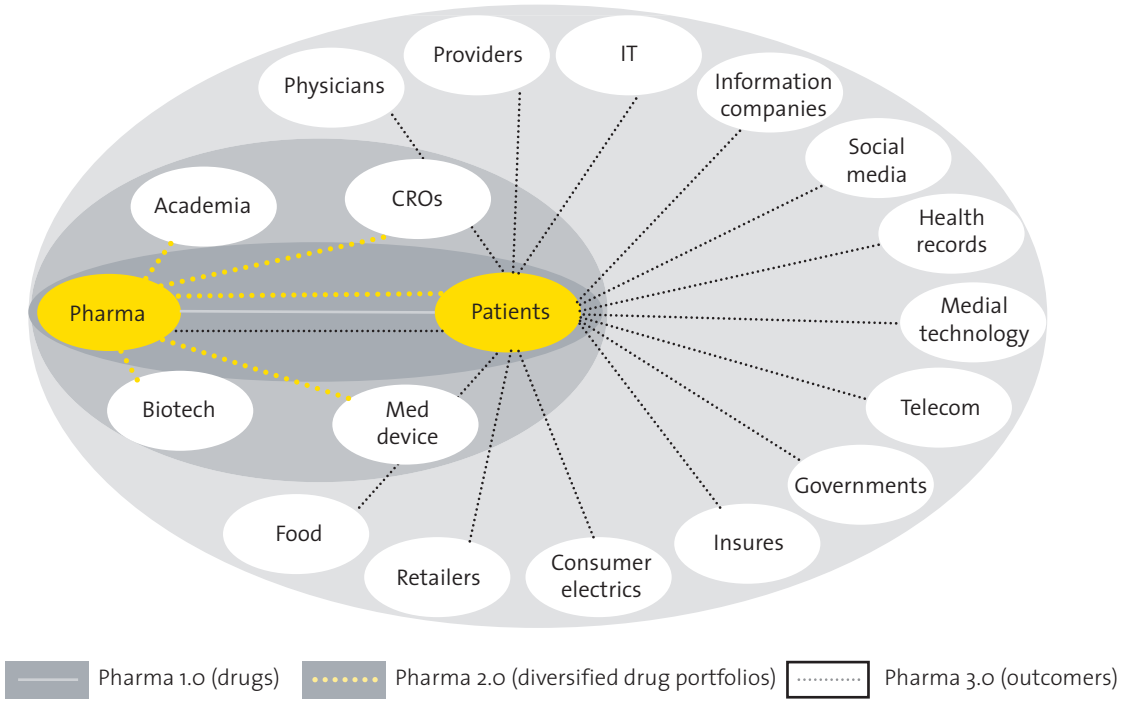
Delivering on health outcomes will require the pharma industry to engage in the cycle of care around the patient, from predisposition testing, prevention, diagnosis and therapy to patient monitoring. The industry's 2.0 business model is not equipped to deliver on such a value proposition. To do so, the pharmaceutical industry will need to collaborate with non-traditional players, bundling business models in symbiotic interaction. It will require also co-creating value for key stakeholders, from patients, payors and governments to business partners.

In the Pharma 3.0 business model, pharma companies seeking to deliver health status improvements need to reach new patients by tackling underserved markets, meet unmet medical needs and do a better job of serving existing patients by managing patient outcomes. As such, companies planning to develop new business models for Pharma 3.0 will need to build their models around some combination of three core value propositions:

1. Managing patient outcomes. Outcomes management could include, for example, fostering compliance through patient engagement, engaging in health care delivery either directly or by enabling a more targeted delivery through patient population stratification. Leading-edge examples include the partnership between Novartis and Proteus Biomedical, a Californian start-up, for developing a "smart-pill" technology. When one of these pills is taken, it sends wireless signals through the body to another chip worn as a skin patch. That, in turn, can upload data to a smart-phone or send it to a doctor through the internet. It ensures that the patient is taking their medication at the right time, a critical factor in successful treatments.

In another approach, Bayer Diabetes Care introduced DIDGET, a blood glucose meter for children with diabetes that connects directly to Nintendo gaming systems. The DIDGET meter is designed to help young patients manage their diabetes by rewarding them for building consistent blood glucose testing habits and meeting personalized glucose target ranges. Bayer's DIDGET meter reinforces consistent testing by awarding points that kids can use to unlock new game levels.

Figure 4 Business model transformation and partnering with non-traditional players



2. Expanding access to health care in underserved markets, in developing countries and in more mature markets for uninsured patient populations. Examples of collaborations to expand access include partnerships between pharmaceutical companies, governments and/or non-profit organization. For example, Roche joined forces with Novo Nordisk and the World Diabetes Foundation (WDF) in a program called "Changing Diabetes in Children" for humanitarian activities in emerging economies.

In their "SMS for Life" initiative, Novartis, IBM, Vodafone and the Roll Back Malaria Partnership have developed a combination of mobile phones, short messaging service technologies and intuitive websites to track and manage the supply of anti-malaria drugs in remote areas of Tanzania.

3. Meeting unmet medical needs, in complex indications such as oncology or immunology as well as in underserved therapeutic fields such as malaria, dengue fever and orphan diseases. A leading-edge example demonstrates that these initiatives are not reserved to big pharma. MondoBiotech, a Swiss-based innovative company focusing on neglected diseases, has entered a partnership with 23andme, a personal genetics company invested in by Google, Inc. and others, to advance genetic research for patients with rare diseases. MondoBiotech is sponsoring the enrollment of patients with rare diseases to the platform, in exchange for access to the genetic data for research.

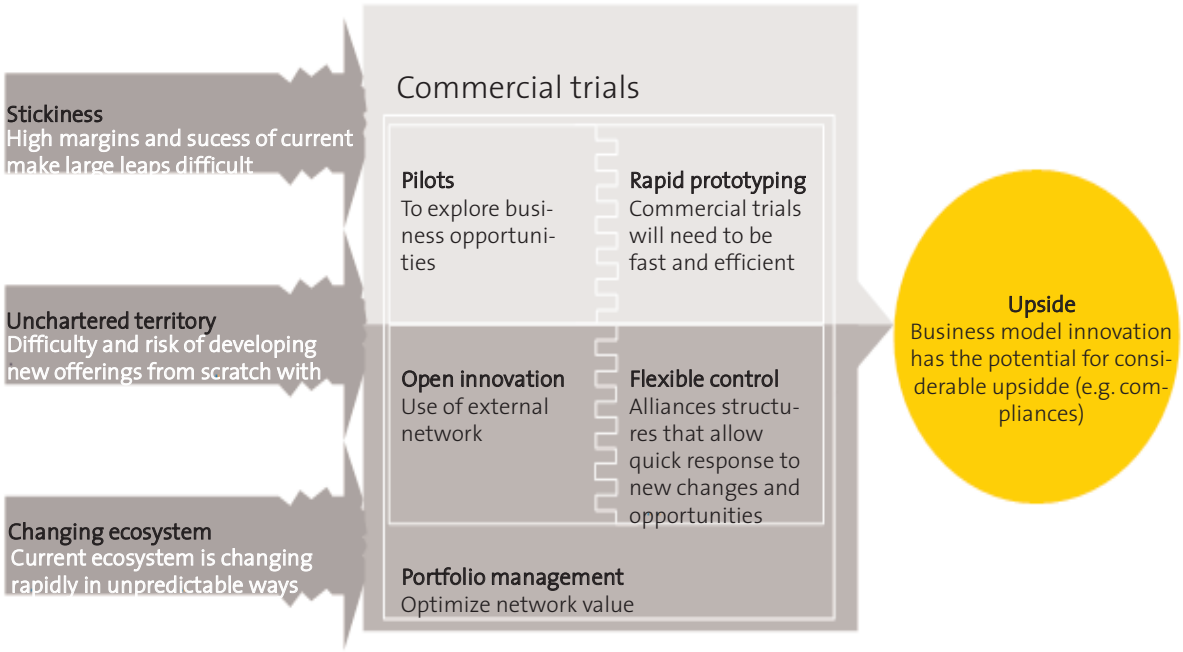
The industry is witnessing a surge of initiatives between the private and public sectors aimed at meeting unmet medical needs in the field of neglected diseases. The Medicines for Malaria Venture brings together multiple public and private partners, with the aim of discovering, developing and delivering new affordable anti-malaria drugs.

The pharmaceutical industry is also increasingly collaborating with peers, in "pre-competitive partnerships" such as Enlight Biosciences, which includes several pharma multinationals, focusing on developing transformational enabling technologies with an impact on the drug discovery process. Also, in the Innovative Medicines Initiative, Roche and Novartis are collaborating to develop solutions for overcoming the research bottlenecks in the drug development process.

Business model innovation

In our discussions with pharmaceutical exe-

Figure 5 Business model innovation: barriers and commercial trials



cutives about evolving business models, we find that they understand and embrace the promise of Pharma 3.0 , yet change continues to be difficult.

Three main challenges have emerged in our conversations:

1. The current business model is working. It is still delivering high margins and solid growth in its current configuration and is forecasted to continue to do so in the short or mid-term.

2. The industry will need to explore uncharted territories to develop business models around health outcomes. Companies will need to develop partnerships with players from other industries, which are beyond their current "comfort zone." Developing a partnership with a technology player, for example, holds the potential for deal-breaking clashes over different goals, operating principles and cultures.

3. Pharma companies will need to adapt to the pace of a swiftly changing ecosystem. The industry's product development lifecycle is notoriously long. In the new ecosystem, the business environment is rapidly evolving, as new technologies appear almost daily.

We believe that business model innovation should be supported by commercial trials, with the five following principles:

1. Pilots. Once a company has identified a strategic area in which it wants to focus, the next step is to identify different ways in which it can play in that space and to test those in early pilot versions.

2. Rapid prototyping. Succeeding in the future will require more than seizing opportunities; it will mean ending failing experiments and leveraging lessons learned through rapid prototyping. This will require new cultural mindsets and a different "tone at the top" — one that provides incentives for speed, flexibility and experimentation.

3. Open innovation. Delivering new outcome-based products and services in the Pharma 3.0 ecosystem will require combinations of competencies that no individual firm possesses. Companies will need to bring an outside-in, open approach.

4. Flexible control. Alliance structures will need to be sufficiently well defined to maintain the focus of the collaboration but flexible enough to allow for quick response to new challenges and opportunities.

5. Portfolio management. Companies will need to look across their alliance portfolios so that partners can learn from each other, identify synergies and increase the overall value they deliver.

Execution

It is far from clear which players will thrive and which will fail to capitalize on the new health outcomes ecosystem. But much of the answer will lie in the ability to execute and manage creative collaborations and transactions. To succeed, companies will need to assemble capabilities they don't currently have to build products and services that don't yet exist. In some cases, this might be done through acquiring companies or assets, but in most situations, we expect firms to enter alliances in which they will join assets and capabilities to co-develop new offerings.

Pharma 3.0 represents a significant shift from Pharma 2.0's "contractual" collaborative approach, where pharma companies have been in the driver's seat in managing collaborations with business partners and controlling and commercializing most of the value creation. In Pharma 3.0, companies will need to do a better job of fitting into the changing business models of other key players in the ecosystem. They will need to step outside the familiar and relinquish control – seamlessly combining capabilities, resources, channels and customer relationships with those of their business partners.

The life sciences industry has become quite proficient at executing traditional research and development collaborations with peers or biotechs. Partnering with non-traditional players from other industries - including technology, insurance, internet services, food and retailing – may require assimilating a host of differences in operations and cultures.

Inter-industry collaborations will face challenges at every stage of the process. Our survey of business development leaders at major pharmaceutical companies and non-traditional entrants canvassed the opinion of the key executives most likely to be at the forefront of these changes. Their self-assessments reveal surprisingly wide-spread capability gaps in areas that will become increasingly important for the Pharma 3.0 ecosystem.

The scatter plot below summarizes the responses to two questions: "what will be more challenging?" and "how well are you prepared?

Along the left axis we graph the portion of respondents who believe each execution element will be more challenging for non-traditional collaborations. Across all deal-related functions, an average of 50% of respondents

expects deals to become more challenging.

The tasks expected to be especially challenging reflect the unique nature of the journey ahead. Since it is fundamentally about developing new business models, it is not surprising that corporate and deal strategy as well as offer and market positioning are near the top of the list (with 75% and 64%, respectively, of respondents saying these functions will become more challenging).

Most expect the same of due diligence and valuation and modeling (75% each). Reflecting the critical roles of data security and intellectual property, 62% of respondents, for each category, expect challenges to increase. The same is true for change management and talent.

The bottom axis in the scatter plot provides the responses to the second question, which asked executives to rate how prepared they were to address each challenge. The greatest gap between the level of challenge and the degrees of preparedness is in valuation and modeling, where 75% of respondents think the issue will become more challenging. Other issues with large preparedness gaps have a high degree of overlap with the list of most challenging issues. These include talent, offer and market positioning, reputation, due diligence, change management and data security and privacy.

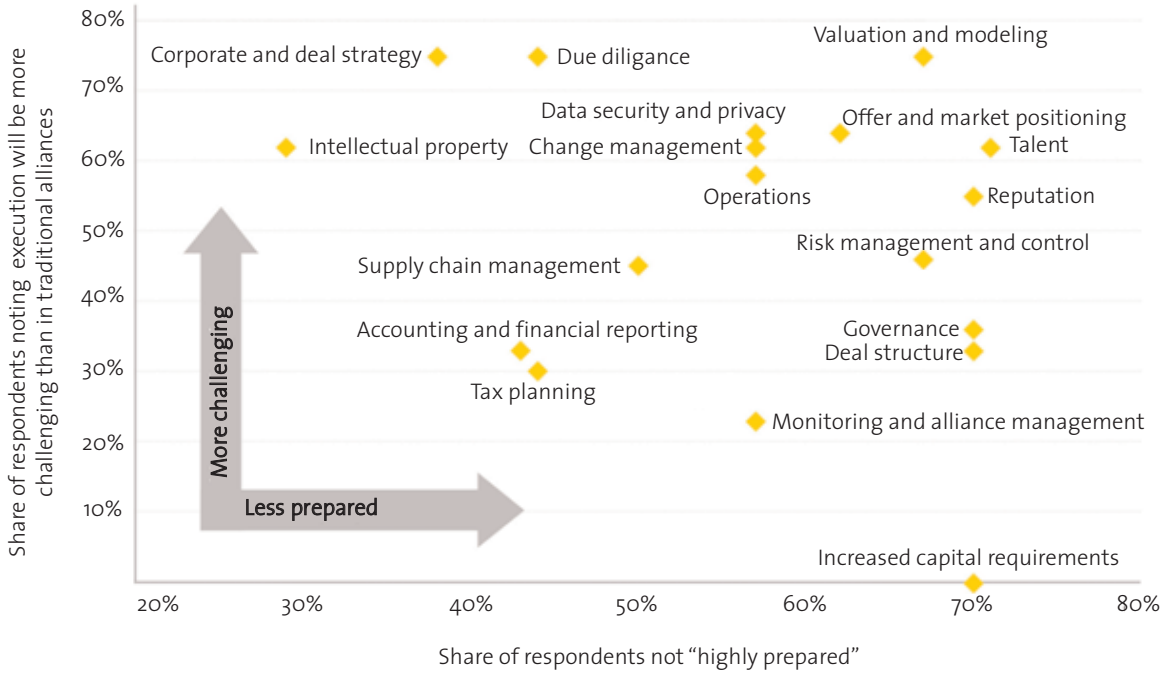
Guiding principles for Pharma 3.0

Regardless of which strategic alternative is chosen, the ultimate competitive advantage will come through a company's ability to execute its plan for delivering health outcomes.

Transformation is an evolutionary process. Each business model fuels the next, and subsequent models draw from the strengths of their predecessors. Pharma 1.0 has been and is still today a highly successful model that has driven the industry's growth, producing margins unmatched by other sectors. Pharma 2.0 has helped the industry change its approach to customers, alleviating some of today's pressures and laying the ground for Pharma 3.0 and a collaborative, outcomes-centered perspective.

Depending on each company's strategy, these models may co-exist at different times. A company may continue to be rooted in innovation around its product and market growth

Figure 6 Challenges and readiness for executing nontraditional alliances



Source: Ernest & Young Progressions survey, 2009

while morphing gradually into new way of doing business.

As companies begin to embrace the changing ecosystem with strategies to derive new growth, we propose four guiding principles to successfully capture the Pharma 3.0 opportunity.

1. Define your Pharma 3.0 brand.

The ecosystem is becoming more complex, incentives are changing, and nontraditional players are entering the market. To define your brand in the new environment, ask yourself these questions:

- Are your front-line executives focused on these trends?
- How will these changes impact your business?
- What is your strategic focus, and what will be your competitive advantage in this more complex reality?

2. Co-create value with partners and patients.

More than ever, firms will need to combine unique assets and attributes to build relevant offerings for the healthy outcomes ecosystem.

- How open is your (business model) innovation?
- Are you focused on being a partner of choice for nontraditional players?
- What is your network strategy to become a critical player by intentionally co-creating value for partners and patients?

3. Experiment. Think small. Fail fast.

There is no single right answer. Companies will develop solutions by experimenting with large numbers of "commercial trials" — and culling those that don't work.

- How well does your organization encourage experimentation and "outside-in" learning (and accept failure as an inevitable by-product?)
- How much are you investing in business model innovation (versus product innovation?)
- How rigorous is your pipeline of commercial trials for business model innovation?

4. Prepare for success.

Our survey and interviews indicate that pharma companies aren't fully prepared for the challenges that these creative new alliances will bring.

- What gaps do you have in your skill sets and capabilities, and what are you doing to fill them?
- How are you monitoring and addressing the new and heightened risks in Pharma 3.0 deals?
- Have you identified and empowered a leader for business model innovation?

Note: this article contains excerpts from the Ernst & Young Global Pharmaceutical Reports, Executing for success: powering new business models and Pharma 3.0