A study on Technology Transfer between industry and university. The case of NanoCarbonUp, a General Purpose Technology developed By Politecnico di Milano

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ABSTRACT

Our thesis aims to identify and analyze the markets where NanoCarbonUp, a technology proposed by Professor Maurizio Galimberti of Politecnico di Milano and his research group (ISCaMap), could be introduced. We highlight the most appropriate path to introduce this technology (and similar innovations) and find out which could be some of the application sectors and possible killer applications.

We organized the thesis in three chapters.

In the first chapter, we review the literature on the core concepts on which this thesis bases. Firstly, there is a deep dive on the concept of General Purposes Technologies (GPT), through which we explain what a GPT is and what are its main features. We also discuss a couple of examples of fundamental GPTs and their impact in the past. The subsequent part of the first chapter revolves around the notion of Technology Transfer from universities to the industry. We study all the possible transfer channels and the methodologies to evaluate the effectiveness of technology transfer processes. Moreover, we highlight the current legislation, the advantages and disadvantages of the most frequent options (licensing and spin off/start up) and some alternative solutions.

The second chapter presents the NanoCarbonUp technology developed by professor Galimberti and his research group, inspecting its potential application sectors. Then we describe processes, advantages, challenges and existing solutions for carbon allotropes functionalization. We also treat the topic of sustainability, the final aim the ISCaMap group.

In the third chapter, we develop a case study based on interviews to industrial and academic experts. The aim of the chapter is to apply the concepts of the first two chapters to real-world situation. The chapter has the following structure: in the first part, we report the case study methodology, in the second one, we expose the key findings emerging from the interviews, divided in four areas, basing on the interview guide.

In the final sections it is possible to find the conclusions to the research work, obtained summarizing the key elements emerged in case study, and the potential future developments of our thesis.

CHAPTER 1: LITERATURE REVIEW

1.1 INTRODUCTION

At the outset, we would like to present the methodology that drove our approach to the literature review. Initially, we had to collect relevant papers, to this end, we opted for the use an online platform, Scopus[1] that gave us the access to a huge amount of scientific papers and research documents. Scopus gave us the possibility to research the most interesting academic works for the purpose of the thesis by inserting research keywords and applying appropriate filters (such as the year of publication and the number of citations). In so doing, we can set effectively the boundaries of our research. Clearly, the access to a huge amount of material made it necessary selecting which papers to consider for the purpose of the thesis. We did it considering firstly the compatibility with our research keywords and topics of interest, secondly favoring the most recent articles with respect to the older ones and thirdly by considering the number of citations that the paper had (to include the most diffused and appreciated pieces of work).

Then, being the first chapter mostly based on two main themes, i.e., general purpose technologies (GPTs) and technology transfer (TT), we had to decide the order and the methodology through witch we should collect information. We opted to collect firstly all the required knowledge on the part of GPTs and, than to switch our attention to the TT themes. We made this choice to avoid as much as possible every possible element of confusion, working on two different topics at the same time.

Moving now to the content of the literature review, we followed a logical path along this research work. Starting from the General Purpose Technologies, we wanted to approach the study from a wider point of view. We started from the topical issue of the innovative direction of business models through the licensing technique, narrowing then to the concept of Market for Technology (MFT). Then we analyzed it in all its components (structure, supply, demand, characteristics and limitations) and finally getting to the specific GPT analysis, explaining them through a scientific model, two real-life examples and a deep dive on the three main characteristics that a GPT must possess.

With this logical direction, our objective was to investigate the broad ensemble moving gradually to the main subject of our study.

For what concerns the part of TT from universities to the industry, we presented the

topics as follows. Firstly, we define the concept of TT; secondly, we go deeper into the potential channels for technology transfer; and, finally, we study their effectiveness.

[1] https://www.scopus.com/home.uri

After this brief introduction to the topic of TT, we will dig deeper into the theme of the commercialization: a representation of the three-macro areas of commercialization of internally developed technologies (internal, quasi-internal and externalization approaches) and a further segmentation in all the specific alternatives.

Subsequently, we will highlight which are the factors specifically related to the university characteristics that can affect the positive or negative result of a TT process.

Once we set the general context, we will focus on the two main, most adopted and most relevant alternatives to commercialize a technology developed in a university, the licensing and spin-off options. We will pose a particular attention to the advantages and disadvantages of investing in the equity of a start up (that could be a spin-off of the university or an external start up that want to use a license of the university) and to the capabilities that a university must develop to generate a spin off.

After the analysis on licensing and spin offs, we present the most important regulation about patenting and TT actually in place: the Bay-Dole act, with some focuses on the European and Italian situation.

Finally, we illustrate an alternative to the traditional commercialization of a technology: the academic engagement, and in this last paragraph, we will compare the requirements, characteristics and outputs of academic engagement compared to the commercialization of technologies.

1.2 BUSINESS MODEL INNOVATION: TOWARDS GENERAL PURPOSE TECHNOLOGIES

Our research begins with a presentation of the business model innovation trends, proposed by Gambardella and McGahan (2010). Their study analyzes the diffusion of a business model, which is becoming more important day by day, and the development and diffusion downstream of GPTs.

Teece (2010) provided this definition of business model: "management's hypothesis about what customers want, how they want it, and how an enterprise can best meet those needs, and get paid for doing so". The main objective of a business model is to put the firm in the condition to generate profits, and the success depends on the ability in the collection of strategic resources. Business model innovation is the development of new concepts supporting an organization's financial viability and the processes for bringing those concepts to fruition.

1.2.1 A new business model based on intellectual capital

A rapidly spreading area concerns the MFT, where firms, individuals or academic institutions sell their intellectual property to other entities interested in using knowledge for their businesses. In the past, usually, companies issued licenses abroad, because they were not able or interested in entering in those markets directly. The model changed with the big licensing wave of 1980s when firms started to sell intellectual property also to companies operating in the same market and industries. An example is given by all those small software development firms that tried to develop killer applications but instead than commercializing them directly on the market, they sold them to other larger companies specialized in retail distribution, with marketing expertise, and with more developed distribution channels. There was a mechanism of specialization, the upstream vendors of semi-finished software focused on the technical aspects of the development, while the competitive advantage of downstream firms rely on their commercialization and marketing capabilities.

In particular, many firms whose competitive advantage is in technology tried to strengthen a strategy based on the investment in technologies with more general applicability. Even Adam Smith (1776) in The Wealth of Nations, had a clear understanding of the possibility that a given technology could be applied to different sectors when he argued that philosophers are "...capable of combining together the powers of the most distant and dissimilar objects". Stigler (1951) spoke about "general specialties." Rosenberg (1976) analyzed the evolution of the US machine tool sector and those of firearms, sewing machines, bicycles, and automobiles during the period 1840–1910, and observed "[...] the growing volume of manufacturing output […] was accompanied by the technological convergence of larger groups of industries". More recently, Bresnahan and Trajtenberg (1995) formalized the concept of a "general specialty" or GPT, characterizing it not only with a wide range of uses, but also with a technological cumulativeness and dynamism, and complementarity innovations, "[...] in the sense that technical advances in the GPT make it more profitable for its users to innovate and improve their own technologies".

Giving a rundown, the evolution of the development of technology licensing is evocative of a wider phenomenon comprehending business-model innovation based on intellectual capital. The incentives associated with the sale of intellectual property through market mechanisms drives innovators toward generalized technologies

All these arguments highlight a particular area of the market for technologies, which is the one of General Purpose Technologies (GPTs).

1.3 WHAT IS A MARKET FOR TECHNOLOGY

Before going into a deeper analysis of what GPTs, are and what are their characteristics, we decided to go through a study of market for technologies, in order to start analyzing the topic from a wider point of view, narrowing progressively and eventually getting to the specific.

A market for technology makes technology available broadly, to a large set of firms. The starting point for Arora and Gambardella (2010) is considering technology as an economic commodity. This is due to the possibility to separate technology from physical product and trade it. The ability to protect intellectual properties is one of the enabling factors.

1.3.1 World and US Markets for Technology analysis

In particular, we think it is crucial to point out the current situation of US and world Markets for Technology (MFT). Indeed, both markets have grown in the last years, corroborating the thesis of the shifting towards a business model whose strength is in licensing. Looking at specific numbers, not considering payments for packaged software, trademarks, and copyrights (as Athreye and Cantwell did in 2007) the size of the US MFT in the 1990s was about $25-35 billion, and about $35-50 billion globally (Arora et al. 2001a). These numbers include those transactions among affiliated entities, which may be an offsetting effect. However, cross-border flows of technology between unaffiliated parties has grown steadily (Arora and Gambardella, 2010). From 1980 to 2003, disembodied technology royalty payments and receipts have increased by an average annual factor of 10.7%, substantially higher than the growth of the world GDP in the same period (OECD, 2006).

Even at firm level, a 2003 OECD survey recorded an increased inward and outward licensing during the 1990s, covering 105, mostly large, firms. Other evidences show how licensing activity has increased also between 2003 and 2006 (Arora and Gambardella, 2010).

It is useful to discuss what we know about both the supply and the demand for technology.

1.3.2 The supply for external technologies: determinants of technology licensing

As far as the supply is concerned, there are two factors affecting it: (i) the appropriability regime and (ii) the control of downstream assets. Concerning the appropriability regime, intellectual property rights (IPR) allow to reduce transaction costs because the seller is less worried about the potential loss of property rights on the innovation (Arora and Gambardella, 2010). As regards the second factor, firms will produce technologies that fit the type of downstream assets and vice versa. In addition, licensing creates competitors. Thus, firms have to compare revenues from licensing with the rent dissipation effect that is the inefficient system in which the effort expended chasing value wipes out the value chased. Licensing is discouraged if:

- Large downstream operations – the larger the number of activities that have to be done downstream, the higher the dissipation effect.
- More differentiated downstream market – a greater number of direct competitors in the same product market causes a higher dissipation of money.
- Weak IPR – reduced revenues from licensing.

On the other side, licensing is encouraged when a product market is fragmented, and the technology is more general. The first aspect is necessary to avoid that the potential licensor exploit all the possible applications of the technology by itself. At the same time, a licensor operating in a homogeneous market could potentially sold its technology only to direct competitors, thus the technology cannot be used by distant licensees, far from the licensor business.

1.3.3 The demand for external technology

Literature treated the demand for technology less carefully than the supply (Arora and Gambardella, 2010). Firstly, Arora and Gambardella discussed the “Not Invented Here” (NIH) syndrome, when analyzing the demand side. External technologies put at risk synergies that arise within an organization, indeed many companies prefer to inefficiently develop technologies internally. However, competition from external innovations could stimulate internal R&D departments to greater effort.

Absorptive capacity is another determinant. It is the measure of the rate at which an organization can learn and use scientific, technological or other knowledge that exists outside of the organization itself. It is a measure of a firm’s ability to learn. Firms with a “good ability to utilize” will be more likely to be licensees, while firms with higher “ability to evaluate” will demand less, but the expected value of technologies will be higher.

1.3.4 Considerations about the Market for Technology: characteristics and limitations

We can consider Markets for Technology as social welfare enhancers (Thoma, 2008). First, the duplication of R&D among firms using similar production processes is avoided. Second, public R&D outcomes can be potentially internalized, when specialized firms license their technology, making it available to the whole market. Moreover, MFT allow a greater entry of firms in the downstream product markets, thanks to the relaxing of technological constraints; and they allow a larger product diversification for incumbent firms as well. Finally, MFT incentivize specialized suppliers to increase the modularity of their technologies, creating standard modules that a broader set of firms could embody.

We did other considerations regarding those factors limiting the growth of MFT. The most important aspect is that uncertainty is a barrier to MFT. Arora and Gambardella (2010) distinguished three types of uncertainty:

- About property rights: The licensing period is more likely around the date of grant of patent, because before then the licensor has no property right to sell. However, the trade may occur earlier in time, at a discounted price for the buyer, basing on the probability that the patent will be granted and/or the expected scope of the protection conferred. The problem is that the supplier wants to conclude the deal after the date of grant, to avoid this premium in form of discount that the buyer may request.

  Furthermore, licensing is more likely to occur between geographically close parties, because the exchange of information reduce the information asymmetries by definition. Therefore, the parties will have the same expectations about whether the patent office will grant the patent or not.
- About the value of technology: it is gradually revealed, so the MFT is more competitive in the early stages, because after a while a dominant design should emerge. This reduces the value of alternative technologies.
- About the transaction process: buyers fear the "winner's curse" and they will place valuations substantially below their idea of what the technology is worth. Uncertainty here derives from the private nature of bids. An interesting fact is that the opening bid would often anchor subsequent negotiations. Moreover, uncertainty in transactions is due to the willingness of the parties to gain bargaining power.

1.3.5 The structure of the Market for Technology

We did few other considerations about how Markets for Technologies are structured. First, the general purpose of a MFT reduces entry barriers, making the product markets more competitive. In addition, the competition is raised by the fact that firms in these markets will focus more on their competitive advantages, so being more efficient, thanks to the fact that they can use technologies better developed by others.

Second, MFT shift the value of an industry chain, because the innovation of the outsiders increases the market value of the dominant firm of the downstream market, which owns the assets and license the technology.

Third, Bresnahan and Gambardella (1998) defined two components to determine the size of a MFT: N, the number of different applications of a certain technology, and S, the average size of each application. It is demonstrated how the increase of N implies a clear vertical division of labor; while the increase in S entails the willingness of downstream firms to integrate backward. This happens because a more fragmented market, with smaller companies, is less likely to allow an upstream integration by incumbents.

It appears clear how with a high N a specialized technology supplier can reach economies of scale at the industrial level and enhance the production of general technologies. On the other hand, high S encourages the exploitation of economies of scale at the firm level, justifying investments by the downstream firm in a dedicated technology.

Thus, a fragmented downstream market (high N) is the consequence, and not the cause, of MFT. This is because MFT enhances the competition in product markets and this encourages the producers to escape competition by differentiating. The differentiation of the downstream market is the only resource that licensors can control, since their technology is now diffused and is no more the key to beat competition.

Arora and Fosfuri (2003) showed the dynamic structure of the industry, finding out that the licensing by one firm increases the incentives of other technology holders to license as well. We can consider this as a reinforcing mechanism of the MFT.

On the other hand, the industry has some dynamic limitations. The main question is whether technology specialists could survive in the long run just by selling the technology, or they would be forced to integrate forward. Technology suppliers have problems to maintain the ownership on their main asset, since by licensing, by definition, they diffuse their technology. Although patented, it becomes known and others can build upon it. But then, the owners of the technology cannot profit from the selling if they keep it secret, and they can only integrate forward to be profitable.

This is the contradiction of the licensing model. A chance to survive could be to continue to produce new technologies unceasingly. Nevertheless, it is complex and the probability that a second technology is successful is small.

Another way is to provide services associated with the technology. However, significant resources are required in this case as well, and it may not even guarantee a competitive advantage, also because of the so-called "servitization" trend with which firms are offering more and more complementary services and the competition is increasing even on this aspect. Furthermore, the forward integration requires significant investments and it is a difficult process for any startup that begin as a technology supplier.

As a result, peers or large firms acquire the greater part of technology suppliers (Arora and Gambardella, 2010). However, this discussion over the licensing model limitations has a firm-level perspective. The model can be profitable at the industry-level: while the single technology supplier may drop after some time, there will be new entrants.

1.4 GENERAL PURPOSE TECHNOLOGIES: DEFINITION AND CHARACTERISTICS

Once presented the direction of business model innovation, we could proceed to a more detailed analysis of the GPTs.

Those technologies, classified as general in purpose, transform both household life and how firms conduct business (Jovanovic and Rousseau, 2005). However, a GPT does not increase productivity immediately upon arrival. For example, the introduction of IT in 1971 with the invention of the "4004" micro-processor did not change the productivity declining trend. Only after 2000, we have seen an inversion in it.

Bresnahan and Trajtenberg (1995) presented the three "fundamental" characteristics of GPTs:

- Pervasiveness: spread to most sectors, a technology or its principle is used in large number of products throughout an economy and in various applications
- Improvement: get better over time, lowering costs of its users. A sort of technological dynamism, these technologies have to experience significant improvement in their efficiency and effectiveness along their lifetime
- Innovation spawning: make it easier to innovate and invent. These abovementioned improvements induce innovations in application sectors of this technology

These characteristics, however, are just a starting point for evaluating GPTs, since most technologies possess them to some degree. In Chapter 1.5, we will present in detail the introduction and evolution of two selected GPTs, Electricity and IT, studying them under all of the abovementioned characteristics.

It is important to underline also the concept of "innovational complementarities" (Bresnahan and Trajtenberg, 1995), common to all GPTs. This concept entails the fact that the productivity of downstream R&D increases consequently to an innovation in the GPT. GPTs also play the role of "enabling technologies", creating opportunities rather than proper final products.

1.4.1 The diffusion of General Purpose Tecnologies

As regards the diffusion of GPTs, it starts from Hall's (2005) classification of the factors affecting technological diffusion. According to Hall, there are four main groups of factors:

- *Benefits received from the new technology:* these benefits are mostly concerning the amount of improvement offered by the new technology over the previous ones. The point is: if existing technologies are close substitutes of the new one, then the adoption process will be slower. Even the "learning by doing" process is relevant: the greater is the ease of use of the technology the lesser will be the switching cost to adopt it.
- *Costs of adoption*: apart from acquisition costs, they may arise from diverse sources. For example, complementary investments for use, management, maintenance and discarding the technology.

  GPTs' adoption costs are strictly related to the technological and organizational learning processes of the use of the technology. Difficulties in these processes explain the diffusion rate of a GPT: of course, difficulties in the adoption and learning of how to use a specific technology will cause higher costs.
- *Network effects*: the volume of the customer base increases the direct attractiveness of the new technology, by the presence of other goods enabling customers to communicate with others using the same technology. It is relevant to consider as well the role of indirect effects from network externalities in adoption.
- *Information and uncertainty:* the role of information and uncertainty may be significantly relevant in the diffusion of a GPT. This is because of the potential coordination failures between technological investment decisions by users and those concerning the general characteristics of the GPT by the producer.

However, alongside the opportunities brought by advances in GPTs, such as the rapid technical progress and economic growth, there are some concerns. For example, the dispersion throughout the economy of the downstream activities makes very hard to coordinate and provide adequate incentives to the GPT (Bresnahan and Trajtenberg, 1995). Other considerations are done: first, according to Bresnahan and Gambardella (1998), smaller sized application sectors are more likely to adopt a general technology, compared to larger ones. Second, users' absorptive capacity turned out to be very important: again, the ability to assimilate and apply new knowledge for the benefit of the business performance are key to a firm's ability to innovate. The new competences required by the technology could be absorbed if an internal propensity to R&D already existed.

1.4.2 Timing of General Purpose Technologies

Another relevant factor affecting the commercial exploitation of GPTs is timing (Bresnahan, 2010). Technologies can be invented at a point in time and diffuse only in later on (close or far in time, diffused). Especially in GPT context, a distinction exists between the invention of the technology and the further innovation needed to create value. However, why often we observe a slow diffusion in the early stage followed by more rapid diffusion? Many explanations exist. A first possible answer is a naturally S-shaped diffusion curve (already demonstrated with the Electricity and IT cases). For instance, there could be supply constraints, so value can be created only after cost is reduced under a certain threshold. Alternative, demand constraints can be in place, users are heterogeneous and attribute to the technology a lower value in the initial stages, adopting the technology later. In addition, adjustment costs related to learning may arise.

There is a double effect causing the slow diffusion at the initial phase of the technology life-cycle: first, there is the slow diffusion of the GPT across the different AS of an economy. Second, once a complementary innovation has been made within a particular AS, there is the slow diffusion of that innovation across firms. Only after both sources of slow diffusion have been overcome is possible to see the acceleration.

1.5 BRESNAHAN-TRAJTENBERG MODEL FOR GENERAL PURPOSE TECHNOLOGIES

To better understand the relation between GPTs and their downstream markets, or application sectors (AS), we briefly present the model by Bresnahan and Trajtenberg (1995).

The model is of a set of related industries with highly decentralized technical progress, centered around the GPT.

The following formulas can describe the model:

$$Max_{w,z}\ \pi^g(z,T,w) - C^g(z)$$

$$Max_{T_a}\ \pi^a(w,z,T_a) - C^a(T_a)$$

z: Quality of the GPT

w: Market price of the GPT

c: Marginal cost of the GPT

T_a: Technological level of AS_a

π^g, π^a: Gross rent of the ith sector, i: GPT, AS_a

C^i: R&D cost of the ith sector, i: GPT, AS_a

The model shows how each application sector determines the level of its own technology, $T_a \geq 0$, and its demand for the GPT, X^a. It is evident from the model that the marginal value of enhancing the AS's own technology increases with the quality of the GPT, so technological improvements in the GPT cause complementary innovations in the AS. Moreover, the return to the GPT producer from investing in quality upgrades is ensured to be increasing with T_a. Another relevant, but clear, finding of the model is that A(*w,z*), or the set of sectors that find profitable to use the GPT, will include more sectors the larger *z* is, and fewer sectors the higher *w* is.

The model explains a dual inducement mechanism: improving T_a of any AS increases the incentives for the GPT users to upgrade their technology, just as a higher *z* enhances the AS to invest in higher T_a.

Considering the best decentralized Nash equilibrium, that is the one exhibiting the largest A, which will be associated with the largest *z* and $\bar{T}$; the model finds a divergence between the social optimum and this Nash equilibrium.

1.5.1 Two positive externalities

Moreover, Bresnahan and Trajtenberg identify two distinct externalities: the "vertical" externality between the GPT and each application sector, and the "horizontal" one across application sectors.

The vertical externality coincides to a bilateral moral hazard problem. Firms in both AS and GPT industries have linked payoffs, so the upstream firm would innovate if it can appropriate some social returns ($w > c$). The problem here is that, for any $w > c$, the private incentive for the downstream firm to innovate is too low. So, neither upstream side nor downstream will have sufficient incentive to innovate. Some government policies (IP protection, limits on foreign competition, relaxation of antitrust standards) aim to increase the incentive to innovate in the GPT sector.

The horizontal externality comes from the generality of purpose of these technologies. The increase in the set A would enhance the level on investment in the GPT, on the supplier side; but on the buyers' side, this increase in the willingness to pay for the GPT by any AS would make all others AS better off. It is clear that *z* acts like a public good. This virtuous circle, in many sectors such as microelectronics and transportation generated very large external effects, prompting a process of technical change and growth.

Clearly, these externalities offer strong reasons to increase the degree of cooperation and explicit contracting between the parties, and between the application sectors themselves. In each case, payoff will be larger for the GPT sector and for all the application sectors that are not in the contract as well.

To give an example from the real world, over time, dominant firms such as IBM and AT&T are no longer coordinator between GPT-related sectors and their application sectors, but few innovators that influence the advance in GPT sectors took over. Strategic alliances, consortia, software missionaries and other mechanisms emerged for coordinating and directing technical progress.

Bresnahan and Trajtenberg conclude highlighting how the releasing of a GPT leads to increasing returns-to-scale, and this is crucial in defining the rate of technical advance in the set of A. On the other hand, this makes it difficult for a decentralized economy to fully exploit the growth opportunities provided by an unfolding GPT. First, it is difficult to make precise forecasts about the technological development and this may decrease the technical advance growth of all sectors. Second, arm-length market, if present, will cause "too little, too late" innovation in both GPT and AS sectors.

1.6 TWO PROMINENT GENERAL PURPOSE TECHNOLOGIES: ELECTRICITY AND IT

As already stated, the three "fundamental" characteristics of a GPT are its pervasiveness, its continuous improvement, and innovation spawning ability.

In this paragraph, we would like to expose two real world cases: Electricity and IT, basing on the previous studies by Jovanovic (2005).

These GPTs characterized their eras, and it is possible to highlight some similarities between these two historical periods. In particular, in both eras, growth rates of the economy were below those attained in the decades immediately preceding the GPT's arrival; indicators of invention were higher; and private consumption mounted gradually.

On the other hand, there are some differences alike. Among others, the productivity slowdown was stronger in the IT era, IT diffused more slowly than did electrification, and innovation measures were increasing in a faster way for IT.

The most important fact, however, seems to be that GPTs have lower growth in the beginning and a growing one subsequently. Summarizing the findings, electricity was more pervasive, while IT clearly leads in terms of improvement and innovation spawning. The two candidate GPTs are then studied under each one of the abovementioned characteristics.

1.6.1 Pervasiveness

Firstly, we analyzed technology pervasiveness by looking at aggregates and then considering industrial sectors in more detail.

Pervasiveness in the aggregate: the period from 1869 to 1954 covers the decline in usage of water wheels, the rise and decline of steam engines, and then the sharp rise in the use of electric motors. The rapidity of the whole steam cycle suggests that Electricity, which replaced it, was relevant enough to force a rapid transition among manufacturers.

Computers, instead, have arrived at the first inflection point in their "S-curve" later in time, compared to Electrification in its early years, but, while the spreading of Electricity had decelerated by 1930, computer and software selling keeps their fast rise.

Pervasiveness among sectors: evidences show how sectors such as primary metals, rubber, stone, clay, glass and non-electric machinery saw a rapid increase in electricity use, indeed, they were heavy users of steam and they withdrew from steam most rapidly, according to Jovanovic.

IT spread rapidly as well, and its diffusion has not yet slowed down, as Electrification did after 1929. On the other hand, IT is not as widespread as Electricity.

Adoption by households: data from "General Purpose Technologies" by Jovanovic discloses that families and companies embraced electricity as rapidly as they are accepting the PC.

Of course, there are different reasons causing a slowdown in the diffusion for both the GPTs. For example, it was difficult to touch the rural areas for Electricity, not for PC, where its main problematic is the learning cost. The spreading of the PC should have been much quicker than that of Electricity, since its price is decreasing more rapidly than the price of Electricity had done.

1.6.2 Improvement

Improvement in efficiency could show up through a decline in prices, an increase in quality, or both. Evidences show how the equipment prices declined most sharply after the arrival of both GPTs.
We could classify electricity, motor vehicles and computers as GPTs, all of them. Computers, however, are undoubtedly the most revolutionary, also because the sharpest decline in prices, thousand times faster than the general prices (price indexes calculated on the same logarithmic scale).

1.6.3 Ability to spawn innovation

Electricity and IT both spawned innovation, but IT seems to do it more and better, it has seen an unprecedented increase in inventive activity. There are two factors that may go with the ability to spawn innovation: patenting and investment by new firms vs. investments by incumbents (Jovanovic and Rousseau, 2005).
Patenting: it is clear that patenting should be more intense after a GPT introduction. Indeed, between 1900 and 1930, and after 1970, sharp increases in the activity have been registered.
Does the intensification in patenting return in an enlargement in the amount of inventions, or was the rise prompted by modifications in the policies that augmented the propensity to patent? Kortum and Lerner (1998) concluded that technology was the cause for the surge, because it was worldwide and not connected to country-specific policy changes.
The surge in trademarks registered gives further support to this conclusion, because they are easier to obtain and not governed by legal developments.

Investment by new firms vs. investments by incumbents: new firms do not have sunk costs in old technologies and they are more flexible than existing firms are. Helpman and Trajtenbergs' expectation of a surge in the number of entries (1998) is met and confirmed by the surge in IPOs between 1895 and 1929, and after 1977, which again matches the dating of the two GPTs. The greater number of stock market launches in which shares of companies are sold to institutional and individual investors is symptomatic of the raise of the number of entries.

While during Electrification the investments by stock market newcomers accounted for a bigger portion of stock market value than the overall new investments (in the US economy), and this denotes that Electricity favored new entrants; this has not happened in the IT-era. The investments level by stock market entrants has been low for a long time, but it has rapidly increased in last years. This is due to the difficulties and adjustment costs of IT adoption for both entrants and incumbents in the early years, until the cost of equipment falls enough to generate a wave of new adoptions by new firms.

1.6.4 How to recognize a General Purpose Technology: other factors

With the introduction of a GPT on the market, there are some other “symptoms” on the economy that are marked as common:

a. Productivity should initially slow down: the innovation can even be not user-friendly at the beginning, and returns may stay low for a period while the economy adjusts itself.
b. The competence premium should rise: if the GPT is not user-friendly at first, the demand of skilled people will be important when the new technology appears, and the remunerations should increase compared to those of the unskilled workers
c. Entry, exit and mergers should rise: new crucial technologies are the basis for the reassessment of assets.
d. The prices of stock should fall at first: the utility of previous capital should decrease. How quickly it falls count on the approach that the market uses to get in touch to the GPT’s arrival.
e. Minor and relatively new companies should perform better: new firms will often bring to the market the products based on the GPT. The market value and share of early born companies should, therefore, increase compared to older firms.

Electricity and IT can be considered as the most important GPTs to date. For sure, the two GPTs differs, but the similarities between the two GPT-eras are certainly significant as well.

1.7 PATENTING: EVIDENCES OF GENERAL PURPOSE TECHNOLOGIES IN PATENT DATA

As we already argued, patenting may go along with the ability of a technology to spawn innovation. This research wants to report some of the investigations, which tried to find out evidences of GPTs in patent data. In particular, we focused on the study conducted by Hall and Trajtenberg (2004): they examined three million US patents granted between 1967 and 1999, and their citations in other patents between 1975 and 2003. This would be useful to identify GPTs in their early stages and, also, to provide a more detailed analysis of the direction and rate of technical change.

The goal of such an investigation is to specify measures, using patents and citations, which quantify the three characteristics, which define GPTs: pervasiveness, continuous improvement, and innovation spawning.

Of course, there are some limitations in the Hall and Trajtenbergs' research:

- Patent data do not guarantee total coverage of innovative environment, not all innovations are patented or patentable.
- It relies on the US Patent Office classification system for technology, so it is more adapt for a US measurement than for a global one.
- Availability of patent citation data in computerized form only from 1975, and citation lag by around 1995 shortened the period of study, forcing to emphasize the 1980s and 1990s.

Patent citations are extremely relevant since they delimit the scope of the property rights awarded by the patent. Moreover, citations received may be telling of the relevance of the cited patent.

Patent citations provide a link between past and present inventions and this is a further relevant aspect. They can explain us both whether they are made to patents in the same or in different technological areas. This helps to define the *breadth* of applications, which is the extent of reachable applications.

1.7.1 Measures of General Purpose Technologies

According to Trajtenberg and Hall definition, patents associated with GPTs innovations, have the following characteristics:

- Many citations from outside their specific technology area: this indicates the potentiality of the technology to reach different fields
- Many citations within their technology area, setting a "technology trajectory".
- It causes a sort of "epidemic" innovative activity, as complementary goods are developed.
- Citation lags may be longer than average, because of the long time needed for a GPT to spread through the whole economy.

The study focused mainly on highly cited patents and studied some measures of GPTs: the generality, the growth in patenting, and the citation lags.

Generality

Talking about Generality, we can start from the Trajtenberg, Jaffe, and Henderson (1997) measure, similar to the suggestion deriving from observation (1):

$$G_i = 1 - \Sigma_j^{n_i} s_{ij}^2$$

with s_{ij} denoting the percentage of citations collected by patent *i* that is a member of patent class *j*, out of n_i patent classes. Therefore, if a patent is cited by following patents that are part of a wide range of fields (low $\Sigma_j^{n_i} s_{ij}^2$), the generality will be important; whereas if the greatest part of citations are clustered around a small number of fields (high $\Sigma_j^{n_i} s_{ij}^2$), it will be low (close to zero). Even if Generality is relatively high, the absolute number of citations should also be high, implying that there may still be many citations in the patent's own technology class.

Then, there is the Hall's (2002) unbiased Generality computation:

$$\tilde{G} = \frac{N_i}{N_i - 1} G_i$$

where N_i is the number of citations observed. It appears how the twenty highly cited patents also have the highest generality: they mostly are in chemicals.

Patent classes that are fast growing in patenting are dealt. These classes are, primarily, information and data processing and multicellular biotechnology. It is evident that these rapidly growing classes include technologies that have characteristics of a GPT.

Growth in patenting

Another way of looking at the growth in patenting following the introduction of a GPT is to look at the growth of the patent classes that cite such a technology. This stems from the hypothesis that innovations coming from a GPT-like innovation will spawn new innovations.

Finally, the average citation lag to GPT patents might be longer. The twenty highly cited patents with long lags are mostly in older technologies, none in chemicals or electrical industries, and just five in computing.

Citation lags

We can say that highly cited patents have higher citation lags, on average; they have higher generality and are in patent classes that are growing faster than average. Furthermore, they take more time to be issued, they have more claims, and they are more likely to come from US and to have multiple assignees. More than the half of them are in computing hardware and software, and drugs and medical instruments classes. They are indeed the classes where modern GPTs were more likely to be found.

In conclusion, we demonstrated the potential validity of patent-based measures of GPTs.

1.8 GENERAL PURPOSE TECHNOLOGIES: A SYNTHESIS

The Tables 1, 2 and 3 show which are the main characteristics of GPTs (Table 1) and which are the main opportunities (Table 2) and the main threats coming from these technologies (Table 3)

Characteristic	Description
Pervasiveness	Spreading throughout industries
Improvement	Over time improvements
Innovation spawning	Making it easier to invent and innovate,
Complementarities in innovation	Increasing of downstream R&D productivity
Productivity slowdown	GPT may initially cause a fall of the output
Rise of the skill premium	GPT may initially cause a raise of the demand for skilled people
Redistribution of the assets	Rising of entries, exits, and mergers
Potential for entrepreneurship and creation of new firms	According to evidences, GPT innovations come from new firms, not by incumbents

Table 1: Main characteristics of GPTs

Opportunities	Description
Pervasiveness	Failing in one specific industries, does not mean failing totally, thanks to the large number of potential applications, the probability to find *jackpot applications* is higher.
Increase of social welfare	From a societal view point, the introduction of a GPT may cause an increase in the employment level, alongside the increase in innovation/invention and in patenting, and in the establishment of new firms
Economies of scale	A fragmented downstream market, that has a high number of application sectors, leads to economies of scale at the industry-level and boost the production of the GPT
Network effects	The volume of the customer base and the presence of other goods enabling customers to communicate with others using the same technology may increase the attractiveness of some specific cases of technology

Table 2: main opportunities from GPTs

Threats	Description
Perceived as a public good	The generality of purpose of GPTs may lead to lower investments from third parties, since others may take advantage of the GPTs without any development effort. This might result in an under-investment.
Productivity slowdown	It may be difficult to overcome the “dead phase”, that is the initial stage with no or negative incomes, as for any new startup
Dispersion	The dispersion of the technology through the economy may lead to coordination problems among the different field of applications and make hard to provide the adequate incentives

Table 3: threats of GPTs

1.9 WHAT IS TECHNOLOGY TRANSFER?

Technology Transfer (TT) indicates the set of channels/mechanisms through which distribute a technology from its creators or developers to a wider set of users in different industries, business areas, and geographical locations (Hargadon, 2003). It occurs through different channels: among universities, from universities to firms, from large firms to small ones (or from small firms to large ones), from governments to firms. Moreover, TT may occur formally and informally, where formal TT requires a legal contract on a patent or on collaborative research activities, while informal is based on personal contacts and, so, to the tacit dimension of knowledge transfer.

The final objective of TT mechanisms is to enable individuals and organizations to take advantage of new technologies and to expand the diffusion of such technologies, in order to generate new products, processes, applications, materials, or services.

It is possible to identify two diffusion channels, the *horizontal one* or the *vertical one*. The former one happens between an entity in a specific industry and/or business area to another entity in a diverse socio-economical context, for example, when a technology developed for an industrial field such as mining is adopted in a totally diverse field as agriculture. The vertical one consists in the passage from basic to applied research and finally to production for commercialization, practicing a specialization path.

The individuals with the ability and the mandate to bridge different areas and application fields are called "*technology brokers"* (Andrew Hargadon), they apply the so called "technology valorization", that means finding new applications for scientific and technological concepts or processes. The first case is in the late 1876 when Thomas Edison, in six years, produced more than 400 patents in his Menlo park laboratory.

In the rest of the analysis, we will focus mostly on university-industry relationships, keeping by side all the others possible alternatives of TT.

In a paper written in 2013, Bozeman, Rimes and Youtie attempted to explain the evolving state of the art in TT research, making a review of the literature on this topic of the previous 15 years, updating a previous review (2000) of Bozeman.

According to the authors, the main trends in the literature were three:

1. Studies on government laboratories and research centers, especially located in European countries;
2. Many articles focus on the transfer from university settings or from multi-organizational research centers;

3. A deep analysis on the non-linear technology transfer mechanisms that can be divided in four types:
   3.1. Relationships between university-industry-government;
   3.2. Multiversity approach, which means that diverse sub-units of the university can interact with the firms in different manners;
   3.3. Open innovation, where the university both acquire and distribute unused intellectual property
   3.4. Open source approaches with transfer through standards creation and tacit knowledge sharing.

1.9.1 The model of technology transfer effectiveness

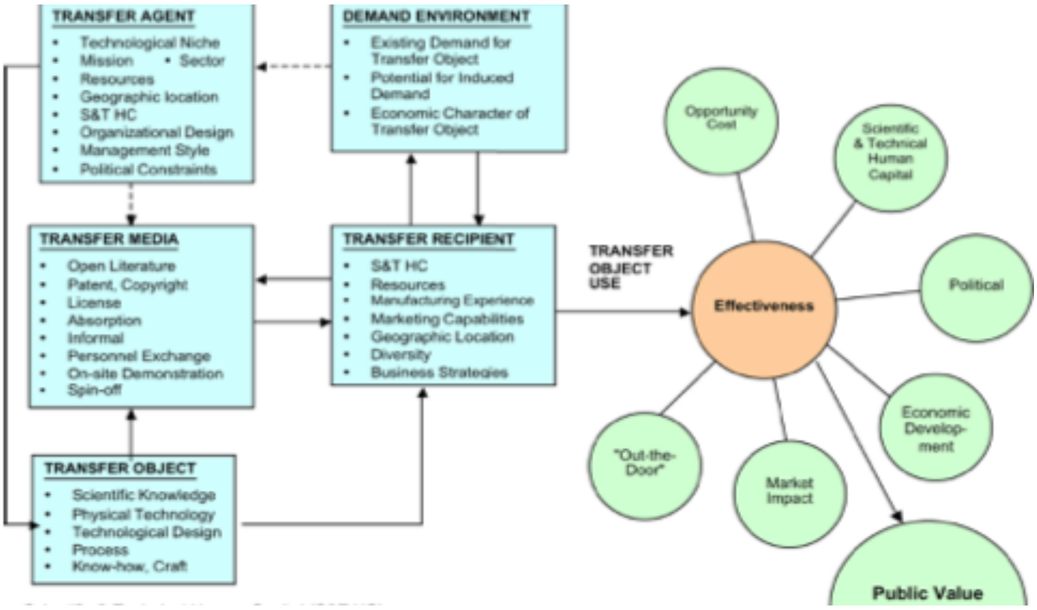

Figure 1: "revised contingent effectiveness technology transfer model"

In Figure 1 is represented the Bozeman's "revised contingent effectiveness technology transfer model"

In the model, there are five elements that characterize TT, on the left, the impacts of TT can be understood in terms of who, how and what is doing the transfer/being transferred and to whom. On the right side, instead, the Figure represents another relevant aspect, which we will analyze in detail in the next paragraph: the effectiveness of the TT. The great innovation with respect to the Bozeman (2000) previous version of the model is the introduction of the *public value*, which is crucial because many individuals work for public organizations, so their interest is in maximizing also societal wellbeing.

The concept of public value has some connections to the notion of responsible innovation. We may consider public value as a counterbalance value with respect to the economic impact, so it helps to take in consideration all those aspects not considered in the study of the economic impact of an innovation. A relevant consideration is that the economic impact is not always the best way to measure the value of an innovation on well-being of people, for instance, the economic return of a factory can be superior with respect to the one of a public park, but the social impact of the second one can be superior. Public value has a great importance for three reasons. First, it emphasizes outcomes that are important for the great majority of people. Second, the money collected from the taxes of contributors finance public science, so the objective should be oriented to maximize their benefits. Third, using other approaches it is easy to exclude these aspects of social utility, since you are not forced to take them in consideration.

1.10 METHODS TO STUDY THE EFFECTIVENESS OF TECHNOLOGY TRANSFER

This section still bases on the model proposed by Bozeman et al. (2013) and zooms in the methodologies to determine the success or failure of a TT action along diverse measures.

Out the door criterion: neither the uses nor the motive of the intellectual property handovers is considered, the only goal is to get the intellectual property (IP) out the door. There are three levels: pure out of the door (no information at all, except for its transfer), Out-the-Door with Transfer Agent Impacts (data also on the impact on the original holder of the technology), and Out- the-Door with Transfer Partner Impacts (taking in consideration the financial result on the part acquiring the technology). Often researchers adopt this methodology to determine the volume of patenting of a university. Powers (2003) analyzed more than 100 universities to find out that the number of licenses produced is connected to the technology transfer offices' age and to a higher level of R&D funding; while Caldera and Debande (2010) discovered that the dimension of TTOs in 52 Spanish universities is linked with superior spinoffs, R&D income and patenting activity. These two are just some examples of studies that applied this technique.

Out the door criterion does not offer direct knowledge on the success obtained by a TT activity in terms of economic and social impact. Despite this serious limitation, it is the most used approach, because of impartiality in measurement, but it still does not present information on downstream effects.

Market impact criterion: it aims on the commercial outcome of the transferred technology, examining effects on regional and national economic growth. It is the gold standard to estimate effectiveness of TT. It does not concentrate only on the monetary effectiveness, but it is clear that, in most cases, one of the variables of the greatest importance in a TT process is to obtain a significant economic return.
A potential issue concerns the ineffectiveness in the attribution of positive results and incapacity to understand the causes of failure. If there is a failure, it could be because the transfer of knowledge is not fruitful, but also for other motives, for example for problems in areas of marketing or strategy. There have been several applications of this criterion in the last 15 years, especially for the university-developed technologies. For instance, Roessner et al. (2013) used the AUTM (Association of university technology managers) annual surveys from 1996 to 2010 and economic input-output models to study, which were the consequences of university licensing in the U.S. economy in that period. Results indicate an excess of $162.1 billion and the quantity of job created over the same period raised from 7000 to 23,000 per year.

Political reward criterion: it is a method which has received quite little attention, it consists of three alternatives: 1) transfer agent is compensated because the technology has an extensive national socio-economic impact. It is rare because quite few technologies have such an impact. 2) the industry reports to the policymaker that transfer agents are reliable industrial partners, so the policymaker compensate them. 3) the most common case happens when the reward for the transfer agent depends on the appearance of dynamic and proactive seeking of technology transfer and economic success, it is similar to out the door.
We may see technology transfer activities as a channel to make a favor or reinforce political support rather than as a tool ensuring relevant economic and social benefit. In this sense, it is a means not an end (Rogers et al., 2001; Guston, 2007).

Opportunity cost criterion: it is a criterion rarely adopted; it considers the technology transfer activity as a non-fundamental function, a secondary activity to other more urgent tasks to be managed. Its effect is assessed considering the influence that technology transfer has on the primary objectives of the organizations, which can be firms, universities or laboratories.

The papers on university TT based on this criterion are especially connected to the eventual influence on individual researchers' agendas (Bercovitz and Feldman, 2008), and on teaching responsibilities (Mendoza, 2007).

Scientific and technical human capital criterion: with this criterion, the attention is on forming and strengthening technical and human capabilities, even without achieving particular objectives.
Some specialists of technology transfer management, especially in government organizations (Bozeman and Rogers, 2001; Rogers and Bozeman, 1997), think that, even without an immediate effect from discrete projects, technology transfer facilitates the development of capabilities within a geographic area, a scientific and technical field or an institution.

Public value criterion: Bozeman (2007) gave this definition of public values: "A society's public values are those providing normative consensus about (1) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled; (2) the obligations of citizens to society, the state and one another; (3) and the principles on which governments and policies should be based."
The empirical adoption of public value criterion is quite limited, because of the difficulties in terms of evaluation. An example deals with the concept of "academic capitalism": in few words, the process of commercialization of universities that start missing their core task, education of students. Harvard University president Derek Bok warns: "Even the appearance of hiring professors for commercial reasons will lower the morale of the faculty and diminish the reputations of the university". The results of studies on this topic give divergent results, sometimes commercialization of universities debilitate educational function but in other cases, it empowers the main mission.
The same problem emerges also in federal laboratories of research that can threaten national security, for instance.
Valdivia (2011) does an interesting application of this criterion. He utilizes the Public Value model in connection with university technology transfer. Specifically, he evaluates the Bayh-Dole Act adopting public value failure theory and its attendant analytical approach, Public Value Mapping (PVM). Once labelled the values, it is possible to attest whether a policy has failed to reach them by studying the corresponding social outcome indicators.

1.11 RESEARCH AND TECHNOLOGY COMMERCIALIZATION

There are many important sectors in the economic systems that take advantage from the research and innovations coming from universities, such as electronics, pharma and robotics (Markman 2012). The paradigm of open innovation tells us that the organizations no longer rely solely on internal R&D, there are no more firms that have enough human and technological capital inside their boundaries, so they augment R&D capabilities cooperating with external third parties and sourcing-in (co-develop, purchase, license) knowledge, inventions and innovation. The ecosystem comprehends licensing contracts with academic institutions, strategic alliances, research parks, joint ventures or spin-offs. Therefore, in the last decades the economy dealt with the advent of new organizational structures to favor the spread of new technologies, such as: science parks, industry-university research centers, incubators and TTO (technology transfer offices) (Berkovitz, Feldman, Feller and Burton, 2011). Alongside with this trend, there is a larger and larger involvement of universities in commercialization of technologies, encouraged by changes in legislation, which close the gap between academic and market environments (Bayh-Dole act in the US and OECD regulation in EU).

According to "Research and Technology Commercialization" (Markman, Siegel, and Wright, 2008) there are three possible ways through which a technology or a research can be commercialized: 1) internal approaches, 2) quasi-internal approaches, 3) externalization approaches.

1.11.1 Internal approaches

In this section are represented the solutions that are developed adopting only internal resources of the university, without external entities. Universities typically face problems in solving conflicting requests coming from governmental bodies, stakeholders, scientists, and firms (Siegel et Al., 2003). The agent who has to manage the relationship between the parties involved in the TT is the manager of the Technology Transfer Office (TTO), who must be a bridge between customers (firms/entrepreneurs) and suppliers (academic world). In to the boundary-spanning capacity, the organizational structure within which TTO managers work is also relevant to the commercialization efficacy (Markman et Al, 2008). For example, Bercovitz et al. (2001) identified four different potential structures in universities: "the functional or unitary form (U-form), the multidivisional (M-form), the holding company (H-form), and the matrix form (MX-form)".

A further area of interest is associated to the ambidexterity theory applied to universities. The formation of a dual structure with diverse evolution in their careers for employees participating in technology commercialization and for those involved in the traditional teaching and researching branch (Ambos et Al., 2008).

1.11.2 Quasi-internal approaches

Another option to do the TT is the business incubator: “a property-based organization focused on accelerating the growth and success of entrepreneurial firms through the provision of business support, resources, and services” (Markman et al. An incubator has four main objectives: economic development (job creation), technology commercialization, real estate development, entrepreneurship.

Phan and Siegel (2006) showed that incubators are more prolific when operating in an innovative environment, composed by other incubators, science parks, business angel networks, surrogate and academic contractors.

Clarysse et al. (2005) classified three different methodologies of incubation approaches. In the first case, the attention is totally dedicated to few but potentially projects aiming to become market leaders in the sector. In the second case the target is identified in businesses that already are producing a stable revenue stream (it is a sort of traditional but safe channel), whereas the third approach concentrates on a bigger amount of “light” service and consultancy businesses creating local employment.

Another quasi-internal approach is to outsource the commercialization stage to experts. This may happen through:

- The subscription of long-term contracts with hybrid public-private firms that commercialize their intellectual property.
- The identification of the intellectual property that can be more interesting for a commercialization path,
- The provision of the financial resources at the beginning of the commercialization stage,
- The selection strategic partners (for instance the IP group in the UK and the UTEK in the USA). It could be an appropriate solution for those academic institutions with a TTO relatively young and with limited capabilities developed (Wright and Filatochev, 2008).

1.11.3 Externalization approaches

With these approaches, the TT process is totally based on solutions that relies on structures outside from the university boundaries and the personnel working for the university does not manage directly.

University research parks: physical districts "whose ambition is venture acceleration through knowledge agglomeration and resource sharing" (Phan, Siegel and Wright, 2005). They are not devoted to start-ups or early-stage firms, while they are shaped for large projects that comprehend the involvement of corporate units and government laboratories. However, "open innovation platforms, virtual networks, and online marketplaces reduce search and collaboration costs, so collectively, they may substitute at least some of the network benefits of science parks and incubators". An example of research park in Italy is Kilometro Rosso, but it is not of a university.

Regional clusters: it bases on the concept of agglomeration of the resources of an area where there are not big cities or universities in order to compete with the big poles of innovation. It is a way to close the distance between major metropolitan areas and all those mid-range universities that do not have the resources to be major players in the field of research. It is a chance to make good use of economies of scale. They are not efficient as metropolitan ones, but still foster collaboration and strengthens relationships between universities and firms (Wright et al., 2004).

Academic spin-offs and start-ups: a strict definition of a spin-off could be: "new ventures initiated within a university setting and based on technology derived from university research" (Markman et Al., 2008). We will expose a deeper analysis of this methodology in the next paragraph.

Licensing: this kind of agreements defines the terms under which one party can take advantage of intellectual property in possession of another entity (Siegel, 2007). Goals of universities can be diverse, for example, public universities have less freedom than private ones, due to political pressures to license to smaller and local firms to foster the regional development, while private ones are free to license to anyone.

Contract research and consultancy: the literature on consultancy is enormous, but in the field of technology transfer is limited, compared to other topics connected with consultancy. As in other methodologies of commercialization, it is not easy to understand the effective impact of consultancy and research contracts on the advancement of the innovation at issue. Furthermore, usually, universities have rules that are rigid with consultancy, so the incentive to take this channel of commercialization is relatively low.

Joint venture spin-offs, alliances and collaborations: “new ventures in which technology is assigned to a company that is jointly owned by a university and an industrial partner”. They guarantee universities access to crucial resources, needed to accomplish tasks that are not performable inside the universities or in a spin-off with a venture capitalist. Industrial partners provide expertise, entrance to a dynamic ecosystem of hypothetical trading partners and organizational routines.

Open science innovation: diverse components, comprehending end users, cooperate in the innovation and creation. This approach is spreading in the economy more and more. Some of the major examples are Linux, Wikipedia and Youtube. It requires the existence of a platform where everyone can work and provide his contribution.

1.11.4 Factors affecting the development of academic entrepreneurial competencies

Once identified the possible channels through which a process of TT can occur, we tried to find out which are the determinants that make a TT process from university to the market more propense to success. According to the paper “30 years after Bayh-Dole: reassessing academic entrepreneurship” (Grimaldi, Kenney, Siegel, and Wright; 2011) there are some determinants, which influence the advancement of the formation of academic entrepreneurship competencies, and these components can be categorized in three different layers: system level, university level and scientist level.

System level: universities benefit from commercialization of their knowledge when their local ecosystem is supportive. In developed contexts, the local community can select the best projects by itself, so the universities may choose a passive strategy. Conversely, in less advanced contexts, institutions, such as governmental bodies, have to be proactive, being careful and ensuring protection to the start-up projects (Clarysse et al., 2005). In these conditions, the crucial role of universities is to build bridges and facilitate contacts.

University level: more and more universities have begun to invest in the development of internal structures and support mechanisms, with the objective to accelerate the process of TT and encourage commercialization of scientific and technological knowledge. Business plan competitions are a recent innovation; benefits comprehend coaching in diverse fields connected to the creation of a business, consultancy services, cash awards, and a chance to develop a system of connections through the financial and industrial community.

University incubators are a good example of a supportive policy in the early stage of technology lifecycle. University incubators, differently from other incubators, offer some additional advantages such as faculty consultants, student employees, library services, related R&D activities and others.

University venture funds represent another noteworthy policy, fully or partly financed with university resources. However, there is a wide literature attesting that this methodology is unlikely to be successful due to the limited number of viable ventures generated by almost all universities.

Individual scientists: country-level and university level factors affect their involvement. They should agree with the mission of the university and their commitment depends also on how much financial and non-financial support, they can get from institutions. A tricky consideration is that professors usually are not particularly interested in commercialization, academics decided to work in the university because they were not fascinated by the business context (Grimaldi et Al., 2011).

It is essential to establish a trustworthy relationship between academics and the technology transfer offices, many TTOs became too zealous in demanding the rights to any invention of individuals associated with the university. This led to academics' discontent, but also to legal litigations initiated by universities against their employees, causing a relevant damage of image for the parts involved.

1.12 LICENSING/PATENTING VS. SPIN-OFF CREATION

The mechanisms to transfer knowledge from university to the market can be various, as it has been exposed upward, but, with a simplification and synthesis effort, there are two methodologies more adopted than the others (Macho-Stadler, Pérez-Castrillo, 2010). The first one is **licensing agreement**, as already presented for Markets for Technology, which, historically and in the numbers, is the most important. Alternatively, there is the creation of **spin-off firms**, which is less frequent because contracts are much more complex and not all the innovations are appropriate for a spin-off. The practice of developing academic spinoffs began to spread 30 years ago, instead of selling a license, a start-up firms is constituted to develop and commercialize the technology and the university acquires a part of the stocks of the new firms, becoming a shareholder of the new company. This phenomenon can create some concerns, as an increase attention on the short-term applied research rather than long-term basic research. Since the benefits will come from the remuneration for applied research and the monetary benefits for basic research appear to be far in time.

The papers "Incentives in university technology transfers" (Macho-Stadler, Pérez-Castrillo, 2010) and "university revenues from technology transfer: licensing fees vs. Equity positions" (Bray; Lee, 2011) are useful to dig deeper in the mechanisms of these two propagation alternatives that will be described in the following paragraphs.

1.12.1 University licensing contracts

Two main technicalities differentiate university licensing from other licensing agreements (Bray, Lee, 2011). First, the larger part of university projects requires some additional development to get to the market; second, the academic institution almost never commercializes the final product, so the risk of competition in downstream market for commercial partners is very low.

Traditionally, the university raises money from technologies through royalties and/or a fixed fee. Royalties' amount varies with the level of production or sold products making use of the technology at issue. A drawback with royalties is the increase of the perceived marginal cost (how much it costs to produce an additional unit of the good). In particular, this is why the licensee is not going to produce the quantity he could have produced with a diverse payment system, because he feels that producing more pieces, he is only paying more fees to the licensor. A fixed payment does not have this distortionary effect, but, on the other hand, it does not permit risk sharing with uncertain revenues, a fixed amount has to be paid anyway by the licensee, both in case of positive or negative result.

When subscribing the contract between firm and university there are two possible source of information asymmetries. First, the information on the technology can be hidden or not exposed clearly, maybe because a patent does not protect the technology already. Obviously, a firm is ready to pay more for a promising innovation, so, it is in the interest of the university to signal the good prospects of its technology. A suitable signal could be the use of royalties: if the university is confident in the success of the technology, it will opt for royalties, which guarantee a variable return, related to sales or further development (Macho-Stadler, Castrillo, 2010). A second case happens when the firm on the market has more knowledge than the TTO about market opportunities. A possible opportunistic behavior may arise: the firm will assess that the commercial value of the innovation is inferior to what it is in reality, in order to obtain a convenient price for the license.

Once the two parties (i.e., the firm and the university) have signed the contract, the development stage begins, in this stage, cooperation between academic innovators and the firm is crucial to reap all the benefits from the innovation. However, the transfer of knowledge is slow since there is not a strong incentive for the academic innovators to transfer their knowledge, but the inclusion of royalties in the agreement provides incentive to this transfer (Macho-Stadler et al. 1996). Accordingly, the more embryonic an innovation is, the more likely is the presence of royalties in the agreement.

A further problem of moral hazard is the trickiness to attest from outside the decision taken by the firm in the development stage. If the royalties to be paid to the university are high, the firm will have less interest in the positive outcome of the project. It is crucial to find a trade-off between the incentive to motivate the innovator (high royalties) and to motivate the firm (low royalties).

In the final stage of commercialization, universities have a minor role, because of the scarce propensity of academicians to enter in the market behavioral attitudes, so to directly contract on the market selling products. Consequently, in an optimal contract the commercialization stage should not influence the payment to the university. Practically, the university should be paid before this stage, for example, with remuneration based on the achievement of technical milestones in technology development.

1.12.2 University spin-offs

Spin-off contracts are usually complex because they involve both control and cash flow rights. The parts implied are usually: the TTO, the researcher or research team, an outside financer, who can be a venture capitalist (VC, formal financier with many funds to manage) or a business angel (BA, an informal financier, a wealthy person investing his money), and usually a manager.

There are three stages in the process: the development stage, the commercial stage and the exit stage.

The main problem of the development stage is to certify the expected profitability of the project (Bray, Lee 2011). Usually the researcher is more informed on the scientific value, while the BA/VC has a better knowledge on the process of commercialization. The best-positioned entity is generally the TTO that has competencies in both the fields. Therefore, the TTO should signal profitable projects by acquiring financial stakes in them, hence, the TTOs can own both founder (as a university representative) and financial shares (as an external investor to signal the appropriateness of the project). It can happen, and it is quite frequent in the real world, that the TTO has no cash to invest, consequently, there are some alternative channels to signal the profitability of a project. For example, granting senior stocks to the financier, to warrant that, in case of failure, are the first to be repaid.

After the contract subscription, in the development stage it should be ensured a proper effort and cooperation between researcher and entrepreneur, that sometime are the same person, while VC or BA are not as important as in the commercialization and exit stage. A significant portion of the payment is in shares, the number of which can rise when milestones are reached (for example when the MVP phase is completed, or when a certain quota of pieces have been produced/sold), stimulating participants. Other mechanisms to provide incentives are a financing structure based on stages, and anti-dilution clauses.

When development stage ends, it begins the crucial commercialization stage, in which the financing effort is increased and, often, new financiers are involved, causing other asymmetric information problems. Old investors are better informed than new ones, a way to signal the expected profitability is to allocate convertible preferred stocks to new entrants. The second signaling device is a further participation of current investors in the venture. It is easier with VC than with business angels. This is an advantage of being financed by a VC, but, on the other hand, a VC holding a large part of the stake of the company has a large bargaining power and can use it to modify the initial contract.

The commercialization stage is a compound of further technical evolution and an advance in its commercialization. The involvement of the researcher is still important at this point, but inputs from the VCs/BAs are also crucial, because they offer services such as: evaluation of business opportunities, growth strategies, management coaching, identification of suppliers and later on, the preparation and execution of an exit strategy.

The final stage is exit, when the business is bought by a major incumbent or moves through an IPO (initial public offering, practically, it is quoted on the stock exchange)(Bray, Lee, 2011). Generally, the common interest is in maximizing the exit value, but there can still be some conflicts of interest. For instance, venture capital firms have incentives to grandstand: take actions to signal their capacities to potential clients, in particular, by bringing their investees to an IPO too early, leading to underpricing, in order to raise their profiles (Gompers, 1996). A second possible conflict can occur when the manager of the spin-off is interested also in non-pecuniary returns, such as maintenance of its position and reputation.

1.13 ADVANTAGES AND DISADVANTAGES OF ACQUIRING EQUITY IN START UP PROJECTS

Bray and Lee (2011) investigated how the universities make money through their intellectual property, comparing equity in spin-off companies, so owning a part of the shares of the company, which is developing the technology and licenses to external figures that pays a fee and usually even royalties on the sales.

Interviewing more than 100 licensing managers of different technology transfer offices, Bray and Lee (2011) discovered that 60% were enthusiastic about equity, 30% were favorable and only 10% were contrary to equity.

Typically, there are two parts on which the compensation for intellectual property transfer is structured, a license fee to obtain the technology and a royalty on sales. The fee usually is between 10.000$ to 50.000$, but it can reach 250.000$ for extremely promising technologies (according to 2011 US data), while royalties percentages are between 2% and 5%, but it can arrive at 15%. In the last years, licensing managers have started to associate this strategy with the purchase of equity. Normally, the university acquires a 5% equity position in the spin-off company in place of the licensing fee and/or a reduction on the royalty rate.

Looking into the TTO in the sample of Bray and Lee, it comes forth that universities that own equity have TTOs that are well-established and larger, with big royalty stream and more invention disclosures every year. This last element is relevant because only a small fraction of the innovations is suitable for a start-up company as exposed by an academic work that estimates the fraction at 3% (Nelsen 1991).

1.13.1 Reasons for equity in start up projects

The number of deals that a university can subscribe using equity is much higher, because, in many cases, start-up companies does not have the financial resources necessary to pay the license fee and have to abandon the project. This ensures an advantage both for the university, which can make more deals and obtain bigger revenues streams, for the start-ups, which can begin their business without a big cash outflow, and for the community, because there are many more projects attempting to elaborate the technology, guaranteeing faster development.

A second advantage is that the university retain some value even if the company forsakes the technology, event that is relatively common in an ultra-competitive, fast-paced world as market for technologies.

There is also a psychological advantage, when the university demands cash for everything, people in the company start thinking that the only purpose of the university is to get their money and an adversarial relationship may develop. While, if the university hold a part of the company, the context is totally different, and the academic institution is seen as a proficient partner, truly interested in the success of the firm.

Taking equity gives the chance for a hypothetical jackpot application, which will warrant an amount of money much larger than a traditional license. Associated with a strong licensing program, acquiring equity in start-ups can raise at the peak the economical return realized by the universities, from their intellectual property.

Finally, the time required to generate value is much shorter with equity positions. A license needs typically 8 years to generate value, because the technology is licensed at an embryonic stage of its lifecycle and necessitate time to be ready for the market. On the other hand, with equity the university can be remunerated much earlier, usually 3 or 4 years if the company make an IPO.

1.13.2 Reasons against equity in start ups

Firstly, more or less 3% of disclosures are appropriate for start-ups, the great majority are more suitable for licensing to an established company (Nelsen, 1991). Secondly, the success of start-ups is far to be assured or even probable. As one licensing manager said, “A big payout is nice, but you can’t live on it. It is not the bread and butter of the TTO. You have to have a royalty stream to live off of” (Bray and Lee, 2011). An additional factor that shrink the acquisition of equity is correlated to the business skills of the entrepreneur: If she is talented in her field but lacks totally business and managerial capabilities, it could be dangerous to invest buying equity.

Another possible negative aspect, but this is common also with the other strategies of technology transfer, is an excessive commercialization of universities. It causes conflicts of interest (Blumenthal et al. 1997) and alienation from the core activity of academic institutions, formation of the new managerial class, even if empirical studies have not confirmed this topic, until now.

A final case, quite rare, emerges when equity is not the most profitable option. Some innovations produce million dollars every year through licenses, instead than a “una tantum” payment in the moment of the IPO, for example “blockbuster drugs”.

1.14 ROLE AND REQUIRED CAPABILITIES OF UNIVERSITIES IN THE CREATION OF SPIN-OFFS

The role that universities should have to support research-based businesses is one of the noteworthy topics concerning the market of technologies. Rasmussen and Wright (2015) provide a document that helps to understand the reasons behind the foundation of spin-offs: “How can universities facilitate academic spin-offs? An entrepreneurial competency perspective”.

Universities’ spin-offs have different attributes with respect to corporate spin-offs, as shown by Buenstorf (2007); Zahra et al. (2007); Ensley and Hmieleski (2005); and Colombo and Piva (2012). Usually, technologies coming from the academic world are at an embryonic stage of development (Jensen and Thursby, 2001). There are also cultural divergences between the academic and the business environment: typically, firms born from a university have a limited availability of commercial competencies (Colombo and Piva, 2012).

It is not obvious that an academic can found a spin-off, because there are some characteristics that are a must have for an entrepreneur, in case the academic does not possess these features he should consider to involve another figure, that could be a private, a venture capitalist or a fund that is able to provide those fundamental aspects. Relying on a framework by Rasmussen et al. (2011) on entrepreneurial competencies, it is possible to disclose three processes required to develop a new venture:

a. The ability to foster a practicable business opportunity (opportunity development competency). These factors grant the opportunity development competency:
    - Connections between user and the industry in the research activity.
    - Attention to opportunities coming from serendipity process.
    - Maintaining contacts with the scientific community during the creation of the new ventures.
b. The ability to encourage people providing energy and meaning to the entrepreneurial process (championing competency).
c. The ability to procure the needed resources to establish the new venture (resource acquisition competency). It is connected to the ability to acquire capital flows, human capital, physical

assets, technological and organizational resources, both from internal (colleagues and research networks) and external (government, venture capitalist and industrial partners) actors. Even soft skills, intangibles, are relevant, mostly in the initial phase of production (Lichtenstein and Brush 2001).

1.15 BAYH-DOLE ACT, WHAT IS IT? WHICH HAS BEEN ITS IMPACT? ADVANTAGES AND DISADVANTAGES OF ITS INTRODUCTION

1.15.1 Historical background

During the late 1970s, in the U.S., new science-based technologies, mainly developed in the universities, entered in the industries. The original reason behind was a growing worry in America about the increasing competition from Japanese firms. Higher and higher pressures facilitated the creation of new organizational units within universities, focused on technology licensing. A fundamental support to evaluate the historical trends in the market for technologies during the 20th century and especially the impact of the Bayh-Dole Act is provided by Sampat (2006) with his work "Patenting and us academic research in the 20th century: the world before and after Bayh-Dole".
As Forman (1957) demonstrates, the debate on the policies that a government should adopt in terms of patent's rights is old. US congress had appraised the argument of who should obtain rights from patents obtained from publicly funded research for 70 years before the introduction of Bayh-Dole Act. According to Kilgore, accepting that privates keep ownership of patents is a "giveaway" of the results of taxpayer-funded research to large corporations, hardening the aggregation of the economic and scientific power. On the other hand, V. Bush asserted that, giving contractors those rights, would maintain their incentives to be part of the public R&D projects and to create commercially useful products.

1.15.2 The piece of legislation

The Bayh–Dole Act has been thought as an answer to this climate of metamorphosis, providing incentives to universities to commercialize university-based technologies. Sampat explains that: "the Bayh-Dole Act (1980) swept away the patchwork of individual agency-controlled investment promotion agencies (IPAs) and instituted a uniform federal patent policy for universities and small businesses under which they obtained the rights to any patents resulting from grants or contracts

funded by any federal agency.” In September 1978, Senator Dole and Senator Bayh proposed the University and Small Business Patent Act. It presented a unitary federal patent policy, which gave universities and small businesses rights to any patent obtained through government-funded research. The opposition to the proposal of Bayh-Dole had been almost inexistent, for diverse reasons. First, the program was aimed to ensure patent rights only for small businesses and universities, defeating the argument that such patent-ownership policies facilitate big businesses. Second, the law that it would cause a profit at the expense of the public, such as a reimbursement provision, whereby institutions have to give back a portion of licensing income to the agencies that founded them, or boundaries on exclusive licenses (5 years from commercial sale). Third, this law had been proposed during the erosion of US commercial competitiveness in the late 70s.
Bayh–Dole Act also force researchers working with federal funds must to expose their discoveries to the technology licensing office. Many other European and Asian countries approved similar frameworks. The promulgation of these laws happened in a period of reduction of public financing to the academic institutions. This shrinking process forced universities to raise their efforts in the commercialization of technologies, in order to get the funds that they were not receiving anymore by the public.

1.15.3 Effects of the Act and of patenting on academic careers

Subsequently to the introduction of Bayh-Dole Act, almost all the major universities in United States opened a TTO and raised their attention on licensing results. In Europe, the TTOs presence was less significant and management of intellectual property ownership by universities was weaker.

The results were astonishing: an article of the economist defines the Bayh-Dole Act as “possibly the most inspired piece of legislation to be enacted in America over the past half-century”.

After Bayh-Dole Act introduction, academic patenting augmented dramatically, as shown by the figures 2 and 3 representing the numbers of and incomes from patents before and after the approval

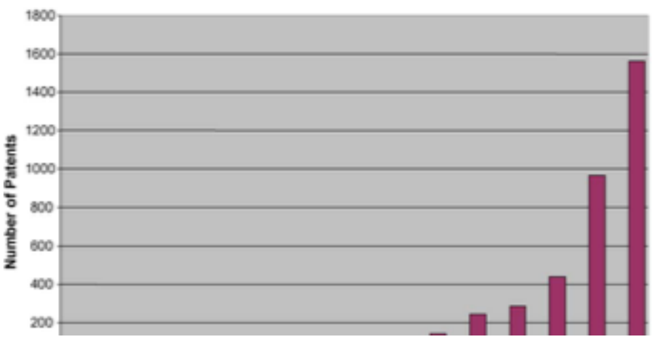

Figure 3: number of patents after Bayh-Dole Act by year

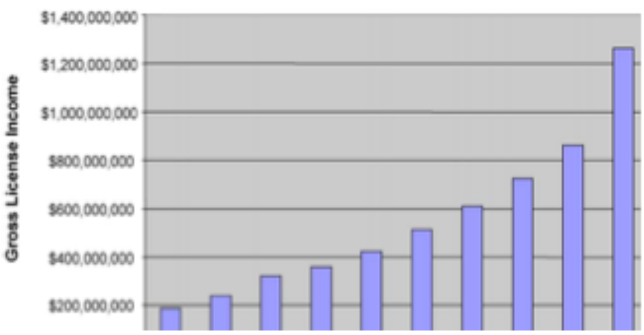

Figure 2: Value of patents after Bayh-Dole Act by year

of the Act. Anyhow, knowledge, expertise and technologies can be moved from university to society in a wide gamma of ways, academic patenting is just a possibility, other channels embody the generation of academic spin-offs, licensing, collaborative research, contract research and consulting (Bonaccorsi and Piccaluga, 1994; Meyer-Krahmer and Schmoch 1998; D'Este and Patel, 2007; Wright et al., 2008).

It is commonly recognized that academics who obtained some patents, produce a higher number and qualitatively superior studies with respect to their non-patenting colleagues (Agrawal and Henderson, 2002; Azoulay et al., 2007; Breschi et al., 2007). Even if the participation in commercialization may not affect academic careers and achievements, it is common thought that it can advance their stature (Moutinho et al., 2007). For what concerns the likely relocation of research towards more applied topics, Hicks and Hamilton (1999) found out that the amount of basic research in the US universities maintained a stable level between 1981, when the Bayh–Dole Act has been voted, and 1995, while university patenting augmented importantly. Thursby and Thursby (2002) proved that the licensing acceleration was mostly caused by universities' attempts to wide their level of commercialization rather than modifications in research orientation. To conclude, it is proven that researchers cooperating with industries exercise superior grade of secrecy compared to their colleagues.

1.16 EUROPEAN SITUATION

"University patenting and its effects on academic research: The emerging European evidence" (Geuna, Nesta; 2006) is a review of the literature on patenting by universities in EU.

Structural funds have been crucial for the European ecosystem since the mid of the 20th century. The reduction of available resources of the late 80s and 90s and the variations in the scientific public support drove governments to distribute funds through different channels, following the problem-oriented plans. Moreover, nowadays, researchers are pushed to bond their research activity with technology transfer activity. In many EU countries, academics now get a portion of the royalties coming from the innovations proposed by them, even though the institution in which the technology has been developed owns the right of the patents.

Looking at the European patents of the last two decades of 20th century, we should include University-invented patents, defined as "those patents that have a member of university faculty among the inventors whether or not the university is the patent assignee", because during those years, many researchers ceded the control on the patent to the financing firm. Balconi et al. (2003) identified that out of 1475 university-invented patents in Italy in the period 1978–1999 only 40 patents had university assignees.

We can study university-invented patents according to the distribution across different science fields. In the US 41% of academic patents in 1998 were in the area of biomedicine revealing a remarkable attention on discoveries in the life sciences and biotechnology spheres of study. In Europe results have been similar but less robust than in the US, Cesaroni and Piccaluga's data present a dominance of patenting in the broadly defined area of chemistry and human necessities. Some studies tried to clarify the impact on European academic research of augmented dependence on industrial funding. The majority are case studies of a single university, for which little statistical support is provided. Two studies, however, one by Gulbrandsen and Smeby (2005) on Norway and one by Ranga (2003) on the Katholik Universiteit van Leuven (KUL) in Belgium, approach the question in a more systematic way. Results indicated that: first, faculties receiving capital from industry did less basic research than researchers without external funds. Second, about 20% of interviewed people affirmed that contract research is tricky in terms of autonomy of research. In both the studies above, it is proved a significant positive affiliation between university research funding by industry and patenting.

1.16.1 Italy and Technology Transfer Offices

According to the previous paragraphs, an important factor in the commercialization level and quality of the universities is the presence of a TTO. report by Netval (2012) provide an interesting overview of the Italian situation, which takes into account 61 Italian universities, 55 generalist and six scientific oriented ("politecnici"). It emerged that all of them had a technology transfer office, and 25 of them created it between 2004 and 2006. This information clarifies the importance and the necessity of having a TTO nowadays for all the universities, not just for scientific ones. Furthermore, another evidence emerging from these data is the increasing relevance of TTOs, the first ones were created in the 90s, but since 2000, the number of institution founding a TTO increased dramatically, with a boom between 2004 and 2006 due to governmental grants.

In 2012, at the time of the study, 47.5% of TTOs were part of a scientific park, while the 50.8% were directly participating in incubators' projects. The two main activities pursued by the TTOs in Italy, according to the interviews of the Netval's study are the creation of spin off companies and the collaboration with the industry and contract research, both with a 98.2% of positive answers.

The fact that the industrial context is mainly composed by small and medium enterprises (SMEs) is a relevant factor for Italy; it can be a threat to the work of a TTO because there are less, with respect to other European and extra-European countries, large firms able to express a structured demand of technologies and knowledge. On the other hand, it can be also as an opportunity because the lower number of possible partners may help to structure a more focused offer and bring to useful processes of growth and aggregation in different industries.

1.17 AN ALTERNATIVE TO COMMERCIALIZATION: ACADEMIC ENGAGEMENT

Commercialization of knowledge by academic institutions is a way through which universities can have a real, quantifiable and instantaneous impact on economy (Markman et al., 2008). To facilitate this process, in many cases universities have set up specific mechanisms, as technology transfer offices (TTOs), science parks and incubators (Clarysse et al., 2005; Siegel et al., 2003), and they established encouraging internal guidelines (Thursby et al., 2001).

However, knowledge can be transmitted through many other channels. In the paper by Perkmann et al. (2013) "Academic engagement and commercialization: A review of the literature on university–industry relations", the authors point their attention on academic engagement, defined as: "knowledge-related collaboration by academic researchers with non-academic organizations, including both formal (collaborative research, contract research, and consulting) and informal (like providing ad hoc advice and networking with practitioners) activities". It has an old tradition, in particular for technical and practical universities.

The analysis done by Perkmann and colleagues intends to figure out if the mechanisms behind academic engagement are the same than those behind commercialization, or whether academic engagement is conceptually diverse, and it needs to be managed in a different way by researchers and policy-makers.

When the main objective is to obtain a financial remuneration, we can talk of commercialization; by contrast, academic engagement have wider objectives. Academic engagement is an inter-organizational partnership, where the agreement can be financial, so the academics work for a salary, or non-financial, for example to access to materials and instruments. Often, commercialization is a subsequent step to the academic engagement. In fact, operating on shared targets with industrial partners may provide academics ideas on what could be marketable, and hence, the chance co-developed invention, or advance an academic spin-off.

The data of the Research Value Mapping Survey (2012) showed that 17% of US academics at research-oriented institutions get an industry support in the year before the research value mapping survey (2012). 18% offered consulting services to a company (Bozeman and Gaughan, 2007). Similarly, in Germany, one fifth of academics produced at least one paper in conjunction with industrial partners and 17% worked as salaried consultants (Grimpe and Fier, 2010).

Considering academic engagement, there is a smaller number of academics that do it compared with commercialization. Lissoni et al. (2009) show that in three European countries only 4–5% of academics had participated in academic engagement in the year before the study. The US by the Research Value Program provided a comparable result, with about 5% (Bozeman and Gaughan, 2007).

1.17.1 Impact on academic engagement and on technology transfer of individual characteristics, organizational and institutional context

Individual characteristics are relevant to clarify the phenomenon: typical participants in academic engagement are males and academic seniority positively relates to collaboration with the industrial world, due to the larger amount of contacts, experience, and previous collaborations with the industries. Another significant aspect is the researchers' quality and success, the more academically proficient is an academic, the more is likely to be engaged with industrial collaborator. It seems that productivity of researchers and fortune in fund raising is an indicator for firms looking for collaborators (Perkman et Al., 2013).

Switching to the organizational context, it is primary the status of the university where the scientists work to determine the level of presence in activities such as academic engagement and commercialization. The relation may seem counterintuitive, because it is negative: the higher the prestige, the status and the age of the university, the lower will be the part of academics engaging with the industry (D'Este and Patel, 2007; Ponomariov, 2008; Ponomariov and Boardman, 2008). This probably happens because smaller research institutions receive fewer resources and, consequently, academics are forced to establish collaboration with industrial partners in order to obtain required resources. As it is evident from the section above, wide literature has studied the role of university (Owen-Smith and Powell, 2001) and technology transfer offices (Lockett and Wright, 2005; Siegel et al., 2003) for commercialization. Contrary to the academic engagement, data prove that, with a growing fame of the university, the chance of the researchers to be involved in commercialization augments (Di Gregorio and Shane, 2003; Mansfield, 1995; O'Shea et al., 2005;

Owen-Smith and Powell, 2001). Moreover, when there are official technology transfer instruments, commercialization rate rises (Markman et al., 2005; Phan and Siegel, 2006). In conclusion, we may suppose that academic engagement performs as a resource mobilization instrument for the best performing academics at less celebrated institutions, where smaller amount of resources is available.

Finally, analyzing the institutional context, scholars focused on the relation to a scientific field of study and the countries' regulations. In applied science fields, like engineering, it is likely that an engagement is set up, while in social science, knowledge is transmitted through personal connections and labor mobility. Whereas, there are not enough evidences to compare national policies. The great majority of studies is pinpointed on North American and European countries comprehending the UK, Spain, Germany and Sweden. Considering these countries, there are not notable alterations in the determinants of academic engagement, between UK and Germany (Haeussler and Colyvas, 2011), Germany and US (Grimpe and Fier, 2010), or Sweden and Ireland (Klofsten and Jones-Evans, 2000).

Comparing the effects of commercialization and academic engagement, it is possible to conclude that: first, commercialization appears to guarantee a beneficial impact on research productivity, while the results for academic engagement are ambiguous. Second, neither engagement nor commercialization seem to push researchers towards more applied fields of study, abandoning long-term research. Third, the two types of industry interactions drive to an augment of secrecy level.

1.18 TECHNOLOGY TRANSFER: A SYNTHESIS

In the following Tables (4, 5, 6), we summarize the main topics that we have analyzed in the first chapter about TT, from universities to the industry.

TT effectiveness measurement criterion	Description
Pure out of the door	Neither the uses nor the motive of the intellectual property handovers is considered
Out-the-door with transfer agent impacts	Some aspects of the economical and non-economical return for the original developer of the technology are taken in consideration
Out- the-door with transfer partner impacts	Some aspects of the economical and non-economical return for the buyer of the technology are taken in consideration
Market impact criterion	It aims on the commercial outcome of the transferred technology, examining effects on regional and national economic growth
Political reward criterion	Transfer agent is compensated because the technology has an extensive national socio-economic impact Or the industry reports to the policymaker that the transfer agent is a reliable industrial partner, so the policymaker recompenses him
Opportunity cost criterion	It considers the technology transfer activity as a non-fundamental function, a secondary activity to other more urgent tasks to be managed.
Scientific and technical human capital criterion	The attention is on forming and strengthening institutional and human capabilities, even without achieving particular objectives.
Public value criterion	It considers that the economic return is not the only relevant aspect of a TT process and it tries to measure all those aspects related to the public benefit generated by that TT process

Table 4: Technology Transfer effectiveness measurement criterion

Technology commercialization methods	Description
Internal approaches	
Utilization of the TTO	The phase of commercialization is internally managed by an entity called technology transfer office, that is part of the university and has the specific task of commercialization of university developed technologies
Quasi-internal approaches	
Business incubator	A property-based organization focused on accelerating the growth and success of entrepreneurial companies through the provision of business support, resources, and services
Outsourcing of commercialization	Outsource the commercialization stage to experts, subscribing long-term contracts with hybrid public-private companies that commercialize their intellectual property
Externalization approaches	
University research parks	Physical districts whose ambition is venture acceleration through knowledge agglomeration and resource sharing
Regional clusters	A way to close the distance between major metropolitan areas and all those mid-range universities that lack the resources to be top of the tree players
Academic spin-offs and start-ups	New ventures initiated within a university setting and based on technology derived from university research
Licensing	Defines the terms under which one party can take advantage of intellectual property in possession of another entity
Contract research and consultancy	Hire some consultants that are dedicated to the phase of market analysis and commercialization of the technology
Joint venture spin-offs, alliances and collaborations	New ventures in which technology is assigned to a company that is jointly owned by a university and an industrial partner
Open science innovation	Diverse components, comprehending end users, cooperate in the innovation and creation (ex. Linux, Wikipedia…)

Table 5: Main channels to commercialize a technology developed in the university

Reasons to acquire equity in a start up	Reasons to NOT acquire equity in a start up
The number of deals that a university can subscribe using equity is much higher, because, in many cases, start-up companies do not have the financial resources needed to pay the license fee and have to abandon the project.	More or less 3% of disclosures are appropriate for start-ups, the great majority are more suitable for licensing to an established company
The university will still retain some value even if the start up forsakes the technology, event that is relatively common in an ultra-competitive, fast-paced world as market for technologies	The success of start-ups is far to be assured or even probable
Taking equity gives the chance for a hypothetical jackpot application, which will warrant an amount of money much larger than a traditional license	The business skills of the entrepreneur: If she is talented in her field but lacks totally business and managerial capabilities, it could be dangerous to invest buying equity.
The time required to generate value is much shorter with equity positions, 3-4 years (IPO) instead than 8-10 years with a license	An excessive commercialization of universities, generating conflicts of interest and alienation from the core activity of academic institutions
Psychological advantage, when the university demands cash for everything, people in the company start thinking that the only purpose of the university is to get their money and an adversarial relationship may develop	There are some innovations that produce million dollars every year through licenses, instead than an "una tantum" payment in the moment of the IPO, for example "blockbuster drugs"

Table 6: Advantages and disadvantages of investing in start up equity for a university

CHAPTER 2: NANOCARBONUP TECHNOLOGY FOR THE FUNCTIONALIZATION OF sp^2 CARBON ALLOTROPES

2.1 INTRODUCTION

In this second chapter, we will start digging deeper on the technological innovation proposed by the research team at Politecnico di Milano: the NanoCarbonUp Technology.

Briefly, NanoCarbonUp is a technology that leads to the sustainable functionalization of sp^2 carbon allotropes.

The Chapter starts presenting the concept of allotropy, describing the allotropes of carbon: what are they and their main characteristics. In particular, we discuss sp^2 carbon allotropes.

In the following, the core of the discussion is the functionalization of sp^2 carbon allotropes. A brief sum up of prior art is reported.

Then, we introduce the NanoCarbonUp technology. We will organize the presentation of NanocarbonUp in two layers. There will be a project-oriented view, with the aim to explain motivations and objectives of the research, which led to NanoCarbonUp. We will clarify where does this technology came from, its main principles and fundamental reasons. Then there will be a clarification on the reasons to apply this functionalization technique to the carbon allotropes and which are the advantages of adopting this method instead than a traditional one.

The second aspect analysed will be a technical description of the technology: from the synthesis of the molecule which acts as functionalizing agent to the functionalization process and its results.

It will be briefly demonstrated why it can be considered as a GPT.

A paragraph concerning the potential applications of NanoCarbonUp will follow, revealing the great potential of pervasiveness of this technology and corroborating the “GPT hypothesis”.

Once we have treated the processes that stands behind NanoCarbonUp and the technology itself, we will introduce the group that created it. We will present its philosophy and its principles, alongside with its objectives.

The main objective of the ISCaMaP group is, as we will explain later on, the environmental sustainability. This concept will lead us to the last part of the chapter: we will start talking about environmental sustainability in general, going through concept such as bio-based materials and their importance to the group and to the technology, the Green Chemistry and the definition of circular economy.

2.2 ALLOTROPY. CARBON ALLOTROPES

2.2.1 Allotropy

Allotropy is a term coming from the ancient Greek, it means "another form". It could be considered as the peculiarity, possessed by some chemical elements, to be existent in different forms, two or more, in the same state of aggregation. Allotropes are the same element, but with a different structural base: the atoms of the element are connected in a different way. The term allotropy is adopted only for the chemical elements, not for the compounds, that is a body made of different elements kept connected by chemical bonds. Allotropy alludes thus only to diverse forms of an element within the same state, solid or liquid or gas. In the case of compounds, the term polymorphism should be used.

It is possible that for some elements the allotropy remains stable even in diverse states. For example, ozone (O_3), an allotrope of oxygen, exists in all the three states: solid, liquid and gaseous. On the other hand, it is as well possible that the allotropy is not maintained in different states of aggregation. An example is the phosphorus, which has many solid allotropes that, in the liquid state, are all converted to only one form.

Why an element should assume a diverse structure, a diverse allotrope? The determinants are light, pressure and temperature at which they are exposed, and if these conditions changes, the equilibrium of that particular element in that particular form could become unstable.

Different allotropes of the same element have different properties and show different behavior.

2.2.2 Carbon allotropes

Carbon is a chemical element, with C as the symbol, with atomic number 6, which means that it has six electrons and six protons in the nucleus. Its atomic mass is equal to 12.01115 amu (atomic mass unit) and it has atomic radius of 0.077 nm.

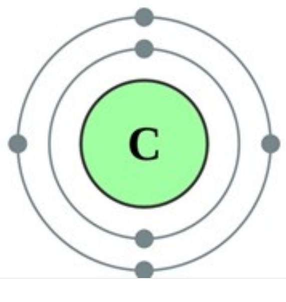

Figure 4: carbon atom

Carbon is widely diffused in nature, it is the fourth most abundant element in the solar system and it is present in the sun, comets and stars. Starting from carbon it is possible to synthetize an enormous number of materials, including complex hydrocarbons like petroleum, gaseous hydrocarbons like methane and various coals.

However, carbon is different from other elements because it can generate several allotropic forms, with different hybridization of the carbon atom.

It seems worthwhile to dwell upon the concept of hybridization.

2.2.3 Carbon allotropes hybridization

Three different types of carbon hybridization exist: sp, sp^2 and sp^3.

s and p orbitals are mixed together to form hybrid orbitals, whose geometry is in Figure 5.

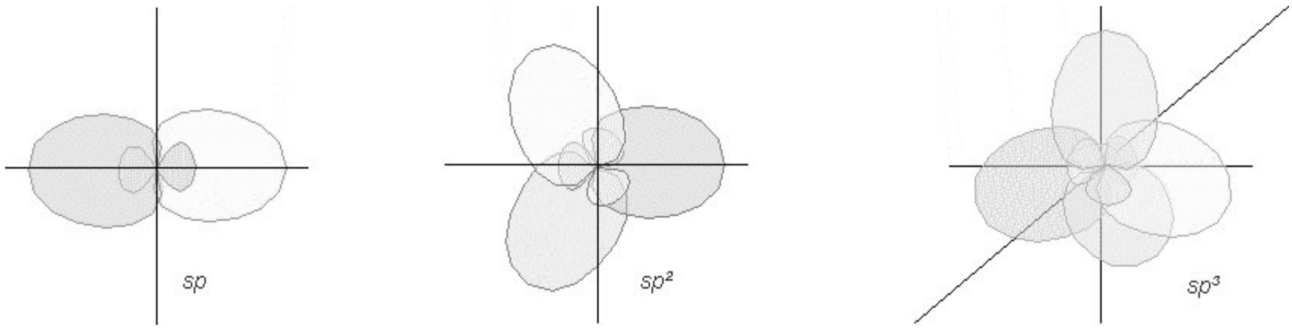

Figure 5: hybridization alternatives

sp hybrid orbitals

One p orbital and one s orbital are mixed to form sp hybrid orbitals, with an angle of 180°. Molecules with sp carbons are linear as in the case of acetylene.

sp^2 hybrid orbitals

At the end of the sp^2 hybridization process three hybrid orbitals are obtained, oriented with an angle of 120 degrees between them. A p orbital remains perpendicular to the plan created by these three new orbitals.

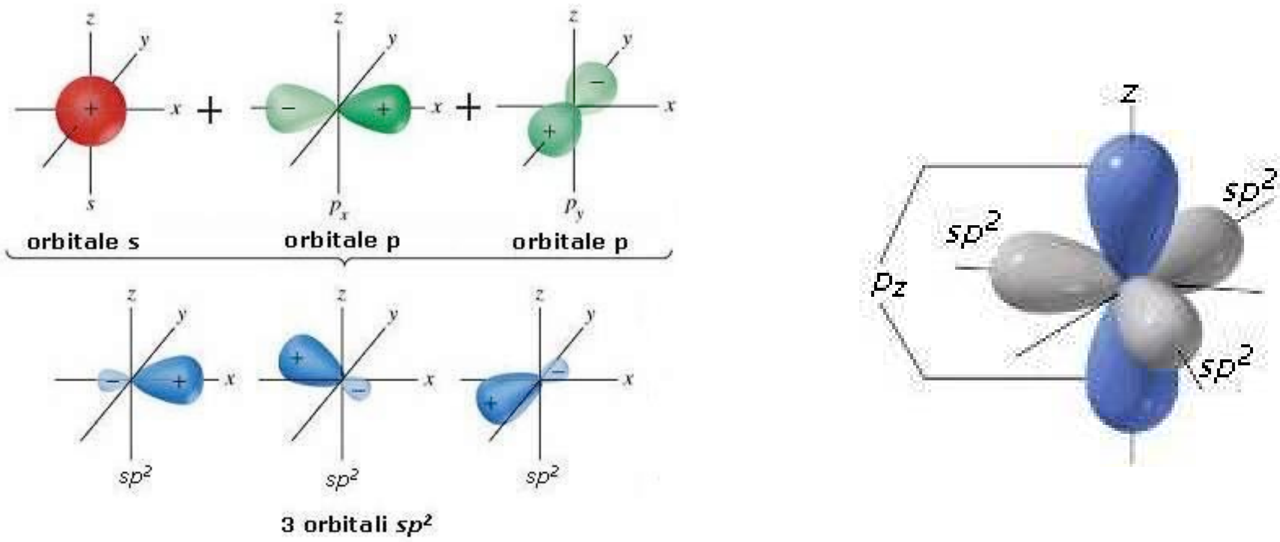

Figure 6: sp2 hybridization

The lateral overlapping of p orbital create π bonds. σ + π bonds give rise to a so called double bond. The lowest molar mass example of a chemical with sp^2 hybridization of carbon atoms and a double bond is ethene. Carbon atoms in graphitic materials have sp2 hybridization. The net of π bonds allows the delocalization of electron and thus the electrical conductivity.

In figure 7 are represented the most important sp2 carbon allotropes, besides the sp3 carbon allotrope: a) diamond, b) graphite, c) lonsdaleite, d) C60 buckminsterfullerene, e) C540, Fullerite f) C70, g) amorphous carbon, and h) single-walled carbon nanotube.

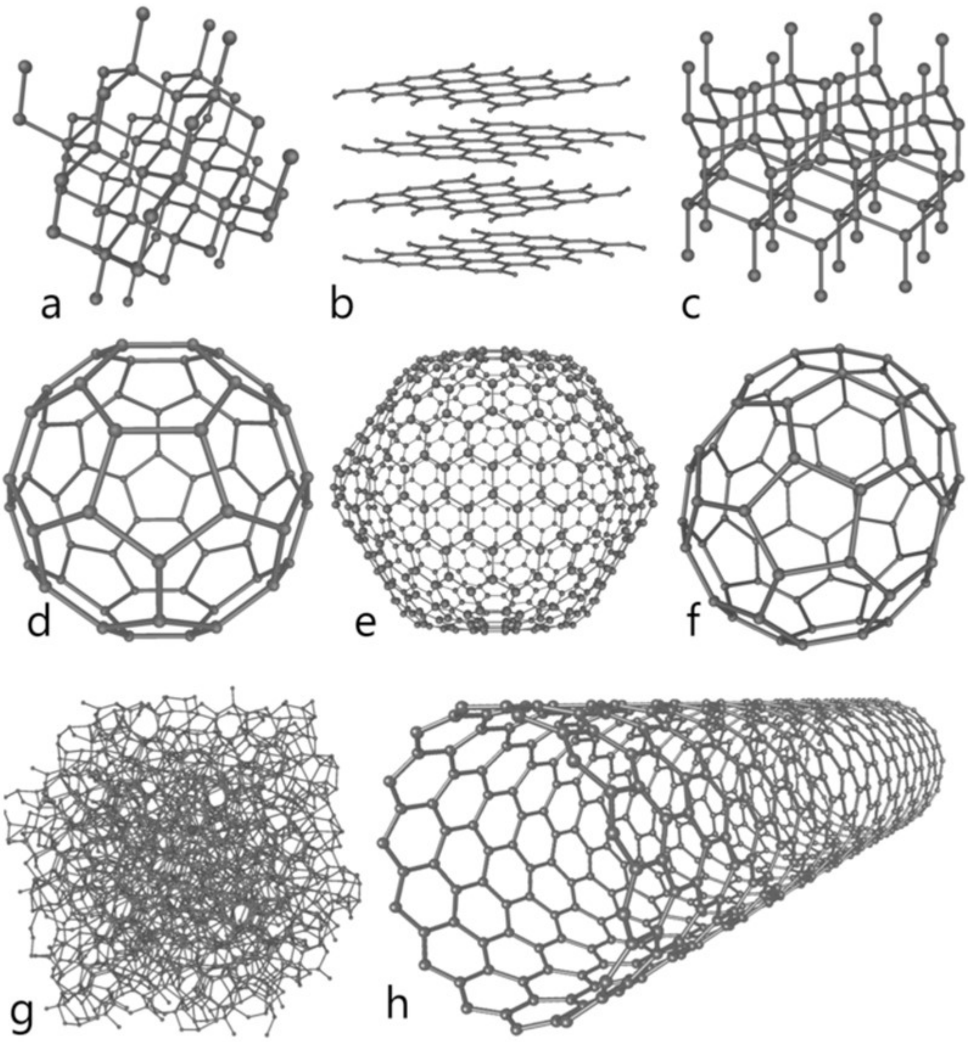

Figure 7: carbon allotropes

Figure 8 shows the most investigated and used sp^2 carbon allotropes. They are graphene and graphene related materials, graphite, carbon nanotubes (single walled and multiwalled), carbon black. It worth observing that all of these carbon allotropes can be considered as derived from a graphene layer, by simply stacking or wrapping one or more layers. The carbon allotrope in Figure 8 are definitely not produced by stacking or wrapping graphene layers. However, the graphene layer is constitutional unit of all of them.

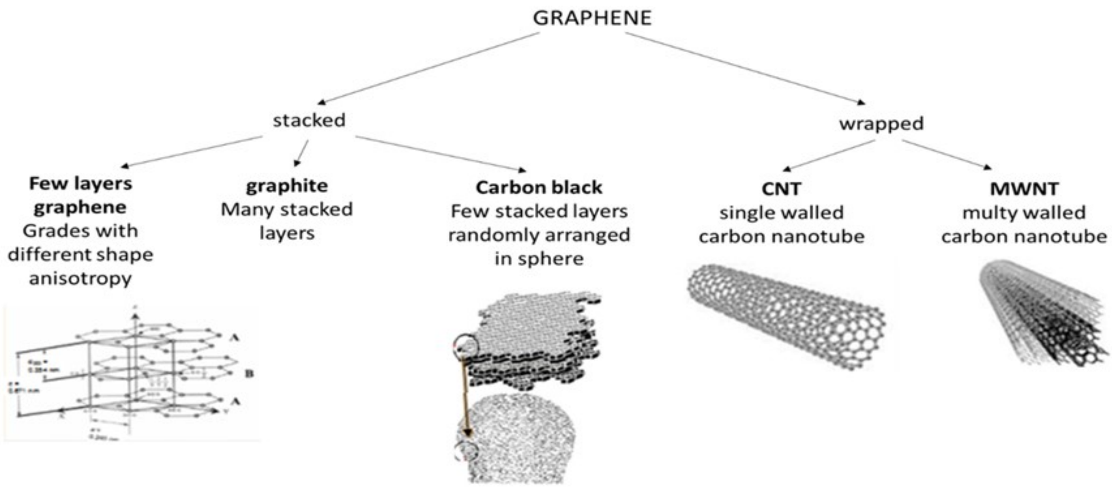

Figure 8: most relevant sp2 carbon allotropes

Carbon black (amorphous carbon) is a largely diffused carbon allotrope: is one of the 10 most diffused chemicals.

sp3 hybrid orbitals Four orbitals are obtained by mixing one orbital and three p orbitals. The 4 orbitals orientate themselves with a 109.5 degree angle between them, as it is shown in Figure 9.

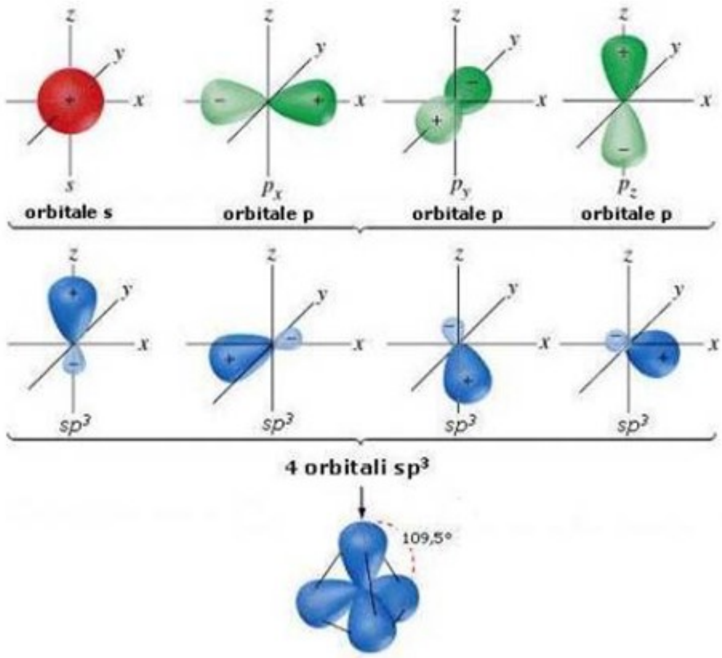

Figure 9: sp3 hybridization

A typical example of sp3 carbon allotrope is diamond. The strong covalent single bonds, sigma bonds, between carbon atoms in sp3 hybridization explain the strength of diamond that is the only carbon allotrope with this hybridization. In sp^3 hybrid bonds electron are located between two carbon atoms. Diamond does not have electrical conductivity. The strong connection between the atoms allows the transmission of mechanical energy. Diamond is well known for its very good thermal conductivity.

In conclusion, from the description of carbon allotropes' hybridization, it appears clear why they have so different properties. Diamond is transpicuous, abrasive, and it is a thermal conductor and an electrical insulator. Graphite is opaque, has very interesting properties as lubricant, and, contrarily to diamond, is a thermal insulator good and a conductor of electricity

In the following, we discuss in detail some of the most diffused and used carbon allotropes.

Diamond

Diamond, probably, is the most known form of carbon. It shows the highest level of hardness and conductivity (thermal) with respect to any other material in nature. Furthermore, its rigid lattice avoids impurities by the majority of other elements. Another feature of this specific form of carbon is that it does not generally respond to any chemical reagents, even strong bases and acids. Diamonds are used in many different industries for many different operations: drilling, cutting, grinding, and in the semi-conductor industry. The economic value of Diamond is extremely high given its scarcity and difficulty in reaching and collecting it.

Graphite

A second well-known allotrope of carbon is graphite, that, differently from diamond, conduce electricity and is a semi-metal. It is considered, in normal conditions, the most stable form of carbon. There are three different types of graphite in nature: crystalline flake graphite, amorphous graphite and lump or vein graphite. The structure that link atoms can be hexagonal or rhombohedral.

Starting from graphite, it is possible to generate a wide specter of materials, including lubricants, gas adsorbed and strong fibers, with the same trigonal sp2 bonding between carbon atoms.

In graphitic material (same structure of graphite but in addiction they have also non-graphitic carbons, or structural defects), the shape, size, degree of imperfection of the crystallite, porosity and the level of impurities could vary sensibly from one material to another, causing different properties of the various sp2 allotropes.

The economic value of graphite is much lower given the fact that it is more diffuse and easier to collect than diamond, even if the possible application fields of this peculiar carbon allotropes are enormous.

Graphene

One of the most important achievement reached in the last years is the isolation of a single layer of graphite called graphene with the ''scotch-tape method''.
Graphene, shown in Figure 10, has outstanding features in physical, thermal and electrical fields, it is based on a crystal form made of two carbon triangular sub-lattices which allowed the formation of two energy bands described by Dirac. Its particular electrons distribution explains new phenomena such quantum Hall effect at room temperature and Klein paradox that can be a starting point for new applications on nanoscale carbon-based materials.

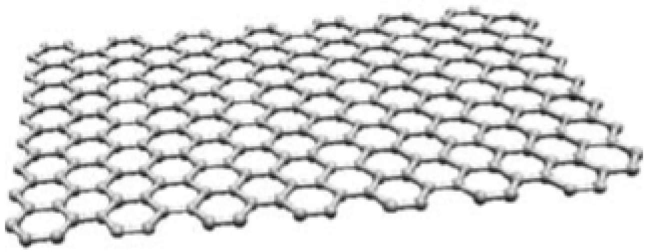

Figure 10: graphene layer

It is a semi-metal or zero-gap semiconductor, so it has a significant mobility of electrons, due to its extraordinary features, is still studied in many laboratories worldwide.
A possible application of graphene is to substitute silicon in high-performance electronic devices.
For what concerns the thermal properties, encouraging outcomes has been achieved with graphene sheet acquired by chemical exfoliation. These sheets evidence high thermal conductivity values, in the order of magnitude of thousands W/m K. Some eventual applications could be in the fabrication of polymer composites with important thermal conduction and the production of heat dissipaters.
Thanks to its excellent electron transportation at room temperature, graphene is very likely to be used for the coming nanotechnology applications and for the development of biosensor and chemical biosensor.

Carbon nanotubes

Carbon nanotubes (CNTs), discovered in 1991 by the Japanese electron microscopist Sumio Iijima, in particular are cylindrical carbon molecules, shown in Figure 11.

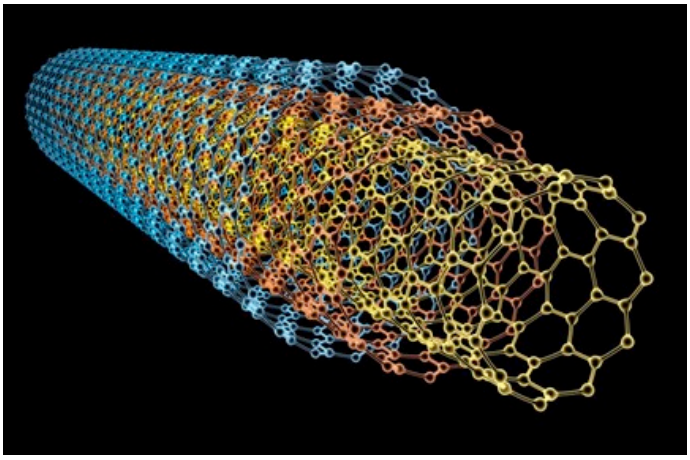

Figure 11: multi walled nanotube

They show unprecedented strength, 100 times stronger than steel and with a Young's modulus that can reach 1 Tpa, and remarkable electrical and heat conductivity. Whereas buckyballs are spherical, a nanotube is cylindrical, with at least at one end typically topped with a hemisphere of the buckyball shape. A single carbon nanotube can be compared to "rolled up" sheet of graphene. In Figure 11 is represented a multi walled carbon nanotube, but also single walled tubes exist. Their size determines the name, indeed, the diameter of a nanotube is only a few nanometers wide, 50.000 times smaller than the width of a human hair, but the length can reach some centimeters. We highlight two types of nanotubes: single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs, concentric cylindrical tubes bonded by weak van der Waals forces). Their extended conjugated π-network assures good quantum optoelectronic properties. However, there are also downsides, the π–π stacking interaction causes as-produced tubes pack together, obscuring all their quantum properties. The functionalization of carbon nanotubes may solve this issue.

Since their discovery, carbon nanotubes (CNTs) have showed remarkable properties, promising to advance scientific process and technical applications. They are one-way channels of conduction; their ability to transport overcome the typical semiconducting systems and, in theory, are seen as a replacement of silicon in the new electronics applications, being more energy efficient by more than one order of magnitude.

The outstanding mechanical stability and lightness of carbon nanotubes has caused them to be seen perfectly adapt for the space elevator.

Carbon nanotubes show also a good compatibility with biological environments, which causes possible interactions and bio-applications: they have been studied as nano-capsules for drug assumption or to respond to the environment acidity, and release drugs close to cancer cells.

Carbon black

As already reported, carbon black is one of the ten most important chemical in the world. The level of consumption of carbon black worldwide was at 13.2 million metric tons, or at US$13.7 billion, in 2015, and reached 13.9 million metric tons, valued at US$14.4 billion in 2016. Global consumption is expected to keep a CAGR (compound annual growth rate) of 5.6% between 2016 and 2022, arriving at 19.2 million metric tons, US$20.4 billion, by 2022.

These data do not show only the wide adoption of carbon black worldwide but demonstrate also a pattern of continuous rise in the usage in the next five years.

It is mostly adopted, around 70%, as a pigment and reinforcing phase in automobile tires. Carbon black can be used to drive heat away from the tread and belt area of the tire, diminishing thermal detriment and extending tire life. More or less one fifth of global production is used for belts, hoses, and other non-tire rubber goods. The rest is adopted for the great part as a pigment in inks, coatings and plastics. All these applications are target of the NanoCarbonUp technology commercialization, as we expose in the third chapter of the thesis.

Specifically, carbon black is fabricated by the unfinished burning of heavy petroleum products such as FCC tar, coal tar, ethylene cracking tar, with the adjoining of a little amount of vegetable oil.

The carbon allotropes discussed above can be defined as nanomaterials.

In order to be called as nanomaterial, it should have all its external and internal structures contained in the nanoscale that generally, according to different definitions, varies from 1 to 100 nm. Usually the sp2 carbon allotropes are categorized as nano-structured or nanometric. For instance, carbon black is catalogued as a nanostructured filler because it is composed by main particles that have all the sizes inferior to the threshold of 100nm, and all the particles are bonded together to generate a final aggregate of 200nm as minimum.

Another example of nanostructured filler is silica, while graphene, nanotubes and connected materials are nanometric fillers because the primary particles that compose them does not have to be joined but can be isolated and independently absorbed by the polymer matrix.

Other allotropes

Currently, more than 500 hypothetical 3-periodic allotropes of carbon have been discovered according to SACADA database.

Most relevant allotropes, which we have not treated above, are glassy carbon, atomic and diatomic carbon, carbon nano-foams and lonsdaleite.

2.3 FUNCTIONALIZATION OF SP2 CARBON ALLOTROPES

2.3.1 What is functionalization?

The functionalization is a process which introduces functional group on a substrate. It is well known that the functional groups determine the chemical reactivity of a chemical substance.

Functionalization is done with the objective to enlarge the possible functions, attributes, peculiarities, capabilities and properties of a material or compund by modyfing the surface chemistry of such material. It is an essential procedure adopted in the chemistry, materials science, biological and textile engineering, and nanotechnology worlds.

Basically, the functionalization is based on the combination of molecules and/or nanoparticles to the surface of the material, that could be done through a chemical bond but also just through absorption, so the molecules that you should be attached to the original material adhere to the surface without generating a ionic or covalent bond.

Some of the possible applications and advantages of functionalization are:

- Functionalization can transform a water-absorbing material in a waterproof one
- Functionalization can modify the color of a material
- Functionalization can make a surface antibiotic
- Functionalization can be used to create chemical sensors ("artificial noses")
- Functionalization can transform a non-magnetic materials in a magnetic one
- Functionalization can be applied to generate sophisticated batteries

2.3.2 Why to functionalize carbon allotropes

Coming to the topics of interest for the purpose of this thesis, it is crucial to functionalize carbon black fillers because the reactivity of the filler allows improving the compatibility of the fillers with the polymer matrix, ideally to establish a chemical bond between the filler and the polymer chains, reducing the filler-filler interaction. This way, it is possible to promote large mechanical reinforcement with a limited energy dissipation.

Silica and Carbon black are nanostructured fillers, composed by primary particles and structured together to generate aggregates with a length of at least 200 nm. Carbon nanotubes, graphene and related materials are nano-metric, but they are not structured, so they can be divided and dispersed in the polymer matrix as primary particles. The aspect ratio of nano-metric fillers is much higher than the one of nanostructured.

Furthermore, nano-metric fillers' interfacial area with the polymer matrix is sensibly vaster than the nanostructured fillers, so, consequently, form higher level interactions.

However, is the interaction between filler and polymer matrix stable? Aggregates of carbon black and silica incorporate empty spaces that guarantees the inclusion and immobilization of a part of the polymer matrix; this feature is of crucial importance for the process of reinforcement that allows generating stable interactions between fillers and the polymer matrix. On the other hand, nano-metric fillers are unstructured, so they cannot freeze the polymer chains.

The main problem of carbon fillers is that there not exist functional groups adapt to react with the polymer chains or other composite constituents. The need to have reactive carbon fillers is extremely high and the way to obtain them is to functionalize carbon black, for example, in tyre compounds functionalized fillers could cause an extremely relevant decrease of rolling resistance. The chemical reactivity of a nano-metric filler such as carbon nanotube would lead to dramatic reinforcement.

In Figure 12 below are summarized the main effects and advantages of functionalized carbon black.

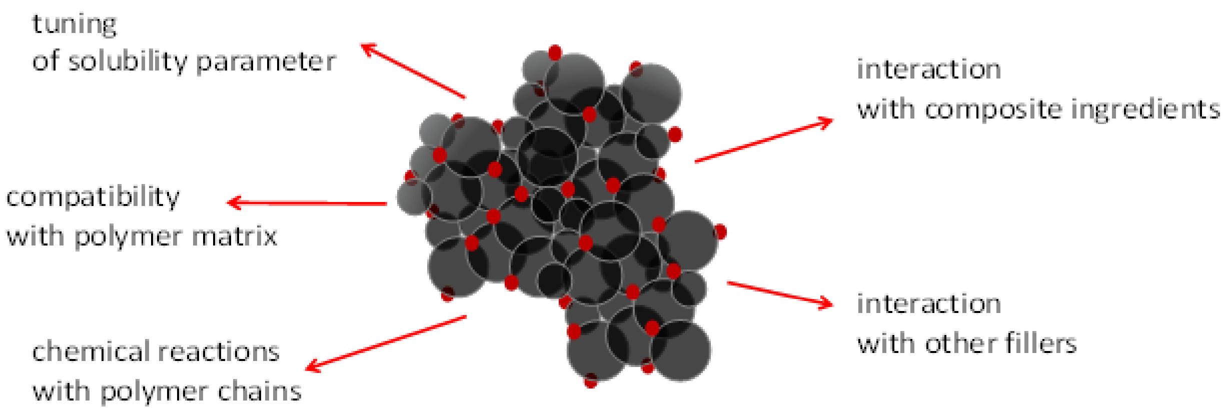

Figure 12: effects of functionalization on carbon black

2.4 FUNCTIONALIZATION TECHNOLOGIES. PRIOR ART

2.4.1 The research on the functionalization of carbon allotropes

The research on the functionalization of sp^2 carbon allotropes focuses on the most important carbon allotropes: carbon nanotubes, graphene related materials and carbon black.

In the present chapter, focus is in particular on functionalization of CNT, because of the great properties and potential applications of these allotropes and because of the rich chemistry, developed for functionalizing CNT.

Carbon nanotubes possess unique properties, but they require to be modified in order to provide biocompatibility and solubility. Even if carbon nanotubes guarantee good properties and performances, two main limitations hamper their practical use. The energy on the surface of CNTs is drastically diverse with respect to the one of matrices (of popular polymers or solvents) and it is possible that CNTs do not guarantee chemical compatibility to the organic matrices. Compatibility of CNT with the matrix is a known problem (Song et al., 2005). Furthermore, the absence of irregularities on CNT surface does not favor the interaction between matrix and CNTs (Ajayan et al., 2000). Indeed, there have been severe limitations to the full exploitation of carbon nanotubes as reinforcing fillers because of the poor interfacial interaction between polymer matrix and carbon nanotubes. Dispersion and compatibility problems in the case of CNTs are particularly relevant, more than in the case of conventional fillers such as carbon black, since nanotubes have typically small diameters with high aspect ratio (>1000) and, so, they hold a large surface area.

Functionalization of CNT makes functionalized CNTs one of the most interesting aspirant for a large amount of applications, going from organic electronics, to nanodevices. Indeed, most of the applications of nanotubes reckon on the fact that the tubes are isolated and in their original state. Unfortunately, as-produced nanotubes are not even close to satisfy these requirements, as they typically are strongly bundled together, with different typologies of impurities coming from the growth processes.

Functionalized carbon nanotubes can reveal impressive properties and performances.

Summarizing some of the possible benefits that functionalized carbon nanotubes can have:

functionalized carbon nanotubes:

- guarantee higher strength of interfacial bonding
- assure larger dispersion;
- increase the outstanding properties of CNTs;
- have more significant impact on cell viability;
- present higher biocompatibility;
- evidence superior flexibility;

- could be adopted for intumescent fire delaying coating to retard the heat transmission to the substrate to avoid an increase in the body temperature and a decline in the body strength;
- show higher surface activity;
- are more easily connectable with other materials

Many different solutions have been proposed in the last years to face the functionalization challenge and render nanotubes available for applications, both for single walled (SWNT) and multiple-walled (MWNT) carbon nanotubes.

There is a wide literature that attempts to identify technological paths developed to functionalize carbon nanotubes. In Figure 13 are represented some of the most known functionalization processes developed until now.

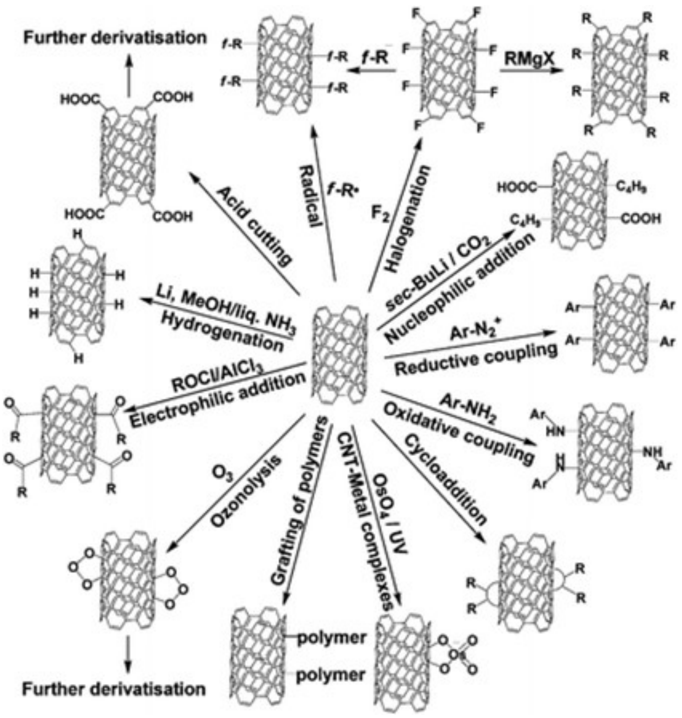

Figure 13: main historical functionalization approaches

There are some reviews that are useful in order to make an organized examination of the different functionalization strategies, one of them is for sure “Advanced carbon nanotubes functionalization” (Setaro et al.; 2017). It summarizes the main approaches established so far, with a particular attention to the necessity to maintain an equilibrium between the efficacy of the functionalization and the desirable tubes’ properties.

Figure 14 highlights the three main methodologies used to functionalize single walled carbon nanotube: (a) the endohedral functionalization; (b) covalent; (c) noncovalent exohedral functionalization approaches.

The first factor to consider is where the functionalization takes place:

- The endohedral functionalization wants to fill the inner part of the tubes, as shown in Figure 14 (a).
- The exohedral functionalization aims to increase the number of functionalities and properties working on the external walls of the tubes (Figures 14 (b) and (c)).

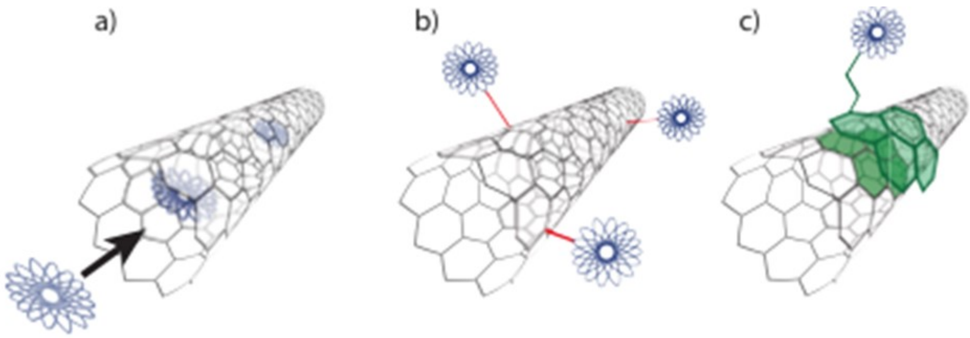

Figure 14: the three alternatives to functionalize nanotubes

Endohedral functionalization is hindered by the dimension of the functionalities that fit into a tube's inner diameter, which at its maximum dimension can reach 2 nm. Exohedral functionalization, on the other side, does not have to face this problem and can virtually attach functional groups of any size.

Covalent, exohedral, functionalization

The covalent strategy counts on covalent chemistry to connect the proper groups onto the tubes. This method guarantees the strength and stability of the bond, but the disadvantage is that it come at the cost of the electronic, structural and optical cohesion of the single walled carbon nanotubes. Because of this chemical treatment, the carbon atoms on which the functional groups are linked are transformed from sp^2 to sp^3, degrading the nanotubes connubial.

It is a general knowledge in the academic environment that studies nanotubes that covalent bonds dismantle the optoelectronic properties of single walled carbon nanotubes. A weak covalent reaction as well, even if performed for a little interval of time, irrevocably annihilates the emissive properties of nanotubes.

Typically, this functionalization strategy of carbon nanotubes not only generate a high amount of defects, causing the destruction of π-conjugation system in nanotubes layers, but it is done utilizing intense acids and strong oxidants, that are strongly environment unfriendly. Thus, relevant efforts have been done to invent frameworks that are beneficial to apply, cheap and generate less damage to CNT structure.

Exohedral non-covalent functionalization

The positive aspect of non-covalent functionalization is that it does not modify and damage the conjugated system of the nanotubes sidewalls as in the covalent case, and, consequently, it does not perturb the properties of the material at the end of the procedure. The carbon nanotubes are functionalized in a non-covalent way using aromatic compounds, surfactants, and polymers, engaging π-π stacking or hydrophobic interactions. A picture of non covalently functionalized nanotube is in Figure 15.

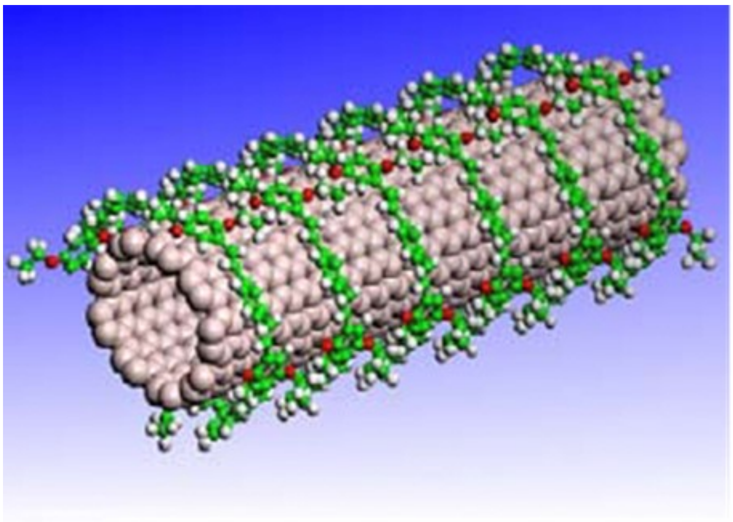

Figure 15: exohedral functionalization

Non covalent modification can be unstable. Interaction with the environment can lead to the removal of the functionalizing agent, with precipitation and re-bundling of the tubes.

To conclude, when it is the moment to choose a functionalization strategy, there is a tradeoff to face, a decision to take, if favoring the strength and yield of the functionalization process, granted by the covalent approach, or, on the other hand, if preferring the conservation of the quantum characteristics of the tubes, granted by the noncovalent strategy.

In Table 7 are resumed the main aspects characterizing the covalent and non-covalent functionalization.

Table 7: comparison of covalent and non-covalent functionalization

Non-covalent functionalization	Covalent functionalization
van der Waals interaction	Formation of stable Chemical bonds
Structural network is retained	Destruction of π-bond transition
No loss of electronic properties	Loss of electronic properties
Wrapping of molecules over the CNT surface	Done by side wall and end cap attachment
Done by absorption of polymer, surfactants, biomolecules, nanoparticles etc.	Done by oxidation, lahogenation, amidation, thiolation, hydrogenation etc.

2.4.2 Examples of advanced functionalities

The abovementioned review presents also some examples of advanced functionalities of carbon allotropes.

In particular, one of those is to exploit carbon nanotubes as sensors, more precisely as biosensing platforms. In this case, it is crucial to create an immobilization process that does not affect nanotubes' properties or affect their sensitivity to environmental changes.

A further study field, in which the non-perturbing feature of non-covalent frameworks can be useful, is the sorting of CNTs, that is mandatory for all the industrial applications.

The excitation transmission from particles immersed in the nanotubes' sidewalls or immobilized really close to them represents a final example of advanced functionality enacted onto the SWNTs. Non-covalent frameworks are, in this case, compulsory in order to prevent any perturbation of the optical answer of the nanotubes and any damage to the emissions from the hybrid compounds. Backes et al. (2013) explained, in diverse papers that small aromatic fragments such as pyrene or perylene have the chance to complete these tasks.

Further applications of carbon nanotubes, opportunely functionalized, specifically in biological related fields are:

- Use of functionalized nanotubes as drug transporters due to the high drug loading capacity, high mechanical strength, ultrahigh surface area and adequate chemical stability. CNTs has been adopted to carry diverse peptides, nucleic acids, and small molecular drugs into living cells.
- Use of functionalized nanotubes in gene therapy due to the adoption of small interfering RNA to reduce the deterioration of the homologous messenger RNA. The specificity and efficacy of this methodology are essential factors.
- Use of functionalized nanotubes in biosensor industry due to the great optical properties, for example photo-luminescence, transforming them in a promising option for biological detection. The great part of the biosensors created till date are based on electrochemical sensors including a reference electrode, a working electrode and a counter electrode.
- Use of functionalized nanotubes in bio-imagining, including fluorescence imaging, Raman imaging, photoacoustic imaging, magnetic resonance imaging and nuclear imaging.

2.4.3 Conclusion: main drawbacks of existing functionalization technologies

To conclude this paragraph, it is important to underline the main drawbacks of the existing functionalization techniques.

The paragraph has been dedicated to the functionalization of CNT, because it allows to highlight the aspects, which are common to all the carbon allotropes.

Covalent functionalization methods require to perform chemical reactions, with a number of reagents, solvents, catalysts. They can be hardly scaled up. Such methods lead to modify the substrate, whose properties are altered.

Non covalent functionalization is less stable by definition. To increase the stability of the interaction, large amount of modifier should be used and this leads to cover the surface of the carbon allotropes, reducing its ability to transfer its properties to the matrix.

These drawbacks can be faces and overcome by the application of the NanoCarbonUp methodology for the functionalization of sp2 carbon allotropes.

2.5 NANOCARBON UP TECHNOLOGY. DESCRIPTION

In this paragraph, we present NanocarbonUp technology.

In the first part of the paragraph, there is a project oriented view, with the aim to explain motivations and objectives of the research, which led to NanoCarbonUp.

In the second part of the paragraph, there is a technical description of the technology: from the synthesis of the molecule which acts as functionalizing agent to the functionalization process.

2.5.1 The research strategy

Where does this technology came from?

Professor Galimberti and his team at Politecnico di Milano (Department of Chemistry, Materials and Chemical Engineering "G. Natta") proposed this technological innovation. The name of the group that developed the innovation is ISCaMaP, acronym of Innovative Sustainable Chemistry and Materials and Proteomics Group. Prof. Galimberti is responsible for the research on materials.

Which are the fundamental reasons and principles that drive the project and the whole group in general?

The whole innovation bases on the crucial concept of sustainability. Indeed, the mission of the Group is to generate innovation for sustainability, in the field of chemistry, materials and proteomics. Research is performed in the light of the following strategy: to prepare innovative materials from natural sources, opposed to environmentally unfriendly and even dangerous substances, and from wastes and residues, with the attempt to generate a circular economy, as it will be explained in the next paragraphs. In particular, chemical building blocks are prepared and platforms are then developed based on them. When using natural sources, careful attention is payed not to use sources, which could impact on the food chain.

What about the research on proteins?

The research on proteins plays an important role. In fact, it is often hard to have a positive economic balance developing chemicals from natural sources. Substances present in lower amount, but with high added value, such as proteins, could allow to envisage also an economic profitability. The objective to work on proteins is thus to extract the maximum potential value from the selected natural source.

Figure 16 summarizes such research approach.

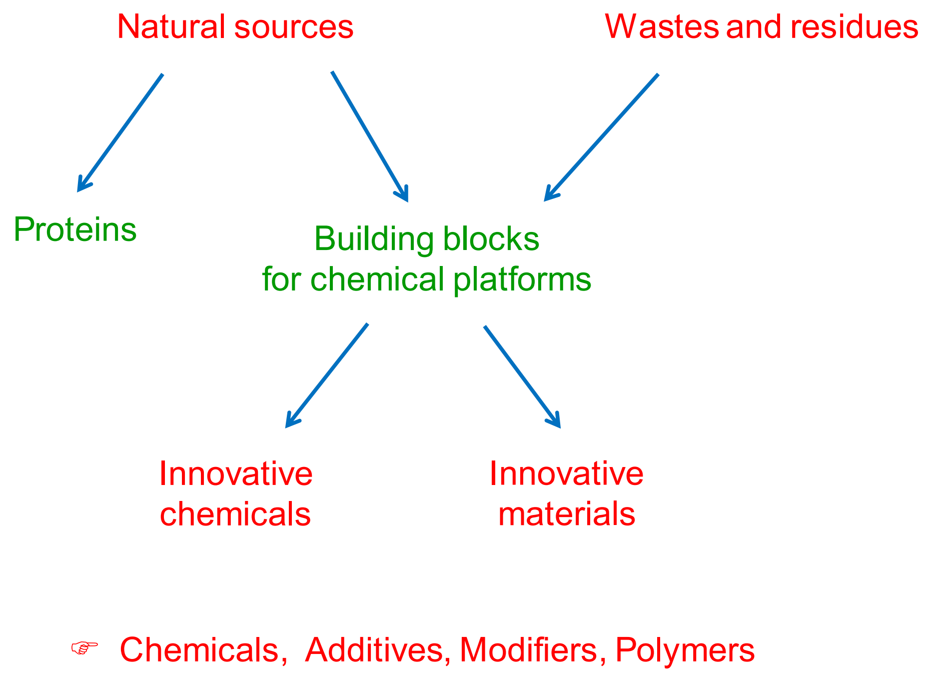

Figure 16: the pillars at the base of NanoCarbonUp

2.5.2 The starting building block for NanoCarbonUp technology

Selection of the starting building block for the research activity was made taking into consideration the state of the art about availability and interest of natural sources. For example, the US Department of energy, more than ten years ago, indicated the list of chemicals shown in Figure 17. In 2010, Joseph J. Bozell and Gene R. Petersen revised the DOE's Top 10 Report and presented an updated assessment of possible target structures. Some of the chemical compounds portrayed in Bozell and Petersens' research is present in the DOE's original list, but a number of new compounds also showed up, and delineated advances in technology development. Figure 17 shows the first 2004 list compared to the 2010 list.

Building blocks in 2004 (Werpy et al.)	Additional building blocks in 2010 (Bozell and Petersen)
Succinic, fumaric and malic acids	Biohydrocarbons
2,5-Furan dicarboxylic acid	Ethanol
3-Hydroxypropionic acid	Lactic acid
Aspartic acid	Furans
Glucaric acid	
Glutamic acid	
Itaconic acid	
Levulinic acid	
3-Hydroxybutyrolactone	
Glycerol	
Sorbitol	
Xylitol/Arabinitol	

Figure 17: list of biosourced chemicals identified as the most promising for the development of chemical platforms. Comparison of building block in 2004 and 2010

They are grouped, from the top, as a function of their current interest. In fact, for example glycerol has been already largely investigated, also in the ISCaMaP Group.

NanoCarbonUp technology was generated starting from glycerol (IUPAC: propane-1,2,3-triol; Formula: $C_3H_8O_3$; 92.09 Da) as the starting block.

Its structure is in Figure 18.

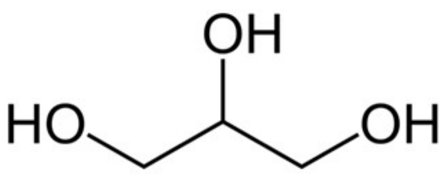

Figure 18: the structure of Glycerol

Glycerol is a cheap raw material, easily available, not toxic and biodegradable. It is the main by-product of bio-diesel production: in 2010, were available 1.2 million ton of glycerol: 65% came from the biodiesel industry. It is important to underline that glycerol meets all the criteria indicated for the selection of a suitable bio based building block for the development of chemicals and materials' platforms. Such criteria, summarized by Bozell and Petersen are synthetized in Figure 19:

1. ***The compound or technology has received significant attention in the literature.*** A high level of reported research identifies both broad technology areas and structures of importance to the biorefinery.
2. ***The compound illustrates a broad technology applicable to multiple products.*** As in the petrochemical industry, the most valuable technologies are those that can be adapted to the production of several different structures.
3. ***The technology provides direct substitutes for existing petrochemicals.*** Products recognized by the chemical industry provide a valuable interface with existing infrastructure and utility.
4. ***The technology is applicable to high volume products.*** Conversion processes leading to high volume functional equivalents or utility within key industrial segments will have particular impact.
5. ***A compound exhibits strong potential as a platform.*** Compounds that serve as starting materials for the production of derivatives offer important flexibility and breadth to the biorefinery.
6. ***Scaleup of the product or a technology to pilot, demo, or full scale is underway.*** The impact of a biobased product and the technology for its production is greatly enhanced upon scaleup.
7. ***The biobased compound is an existing commercial product, prepared at intermediate or commodity levels.*** Research leading to production improvements or new uses for existing biobased chemicals improves their utility.
8. ***The compound may serve as a primary building block of the biorefinery.*** The petrochemical refinery is built on a small number of initial building blocks: olefins, BTX, methane, CO. Those compounds that are able to serve an analogous role in the biorefinery will be of high importance.
9. ***Commercial production of the compound from renewable carbon is well established.*** The potential utility of a given compound is improved if its manufacturing process is already recognized within the industry.

Figure 19: Selection criteria for biobased building blocks

Large research activity has been made all over the world and in the ISCaMaP Group on glycerol. One of the most interesting derivatives is 2-amino-1,3-propandiol, also known as serinol, shown in Figure 20.

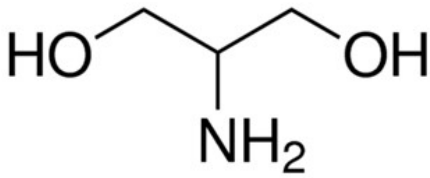

Figure 20: the structure of Serynol

Serinol is commercially available, it can be obtained from glycerol or dihydroxyacetone. It is not toxic and has the crucial advantage, with respect to glycerol, of the chemoselectivity, brought about by the amino group in place of the hydroxy group.

The basic idea was to exploit the chemoselectivity of serinol, creating innovative molecules that could play different functions. The innovative molecule at the basis of NanoCarbonUp technology is the so called serinol pyrrole (SP), IUPAC name 2-(2,5-dimethyl-1H-pyrrol-1-yl)-1,3-propanediol, shown in Figure 21.

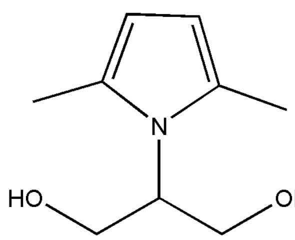

Figure 21: 2-(2,5-dimethyl-1H-pyrrol-1-yl)-1,3-propanediol (SP)

Serinol pyrrole has been defined a Janus molecule, i.e a molecule with two faces and twofold reactivity, with inspiration to the Roman god Janus, who is represented with one body and two faces. Why SP should have a dual reactivity? Because it has one hydrophilic moiety, with the two hydrophilic groups and an aromatic electron rich liphophilic ring. Different chemical reactivity by the two moieties can be clearly envisaged.

Because of the presence of the aromatic ring, affinity and, in case, reactivity can be expected with sp^2 carbon allotropes, which are based on aromatic rings.

The synthesis of SP was made through the reaction pathway shown in Figure 22.

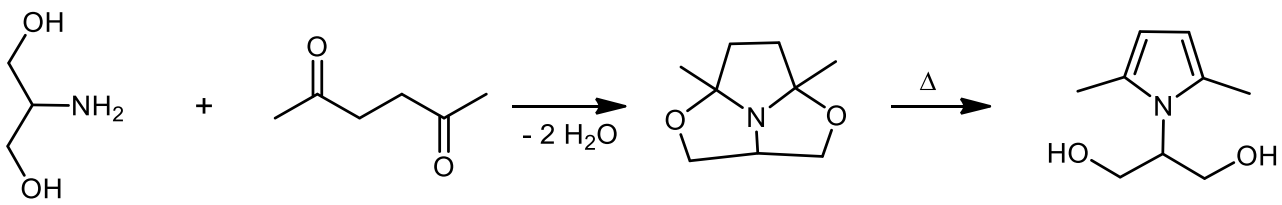

Figure 22: main features of the chemical reaction

We report as follows the main features of this reaction.

(i) The procedure is really easy: it is enough to mix reagents and to heat them.

(ii) Solvents or catalysts are not required.

(iii) The only byproduct is water.

(iv) The yield is typically 95%, up to 99%, with a typical atom efficiency of about 85%.

(v) Therefore, serinol pyrrole, from the selection of the building blocks to the synthesis, is indeed a sustainable molecule.

Last, but not least, many primary amines can be used in place of serinol for preparing pyrrole derivatives. We will not discuss them in the present thesis, but they have been already prepared by the research groups and have been used to enlarge the applications of NanoCarbonUp technology.

2.5.3 A functionalization technology for carbon allotropes: motivations and objectives

At the beginning of this paragraph, which aims at presenting and discussing the NanoCarbonUp technology, it is worth dwelling upon the motivations for developing a functionalization technology for carbon allotropes.

Why to apply this functionalization technique to the carbon allotropes?

Because carbon allotropes, such as graphene and carbon nanotubes (single walled and multi walled) have outstanding properties as previously reported in the chapter, in terms of mechanical, electrical and thermal properties. Carbon black is largely diffused and it is used in many industrial applications.

Why functionalization is so crucial?

The objective was to modify the chemical nature of the carbon allotropes, allowing their compatibility with many different environments and allowing the preparation of many different composite materials.

This way, it is possible to fully exploit the potential of the carbon allotropes. The great properties of the nanocarbon allotropes are brought to the macroscale, allowing their use at the industrial scale.

A versatile technology

For a functionalization technology of carbon allotropes, it is of the outmost importance to be versatile, that means to be able to functionalize many different families of carbon allotropes. As mentioned above, because of the chemical nature of serinol pyrrole, functionalization should occur on sp^2 carbon allotropes.

Versatility means also to functionalize the carbon allotropes with different families of functional groups, so modifying the solubility parameter of the carbon allotropes over a broad range of values, allowing then the compatibility with many different environments.

A sustainable technology

Basic feature of the functionalization technology had to be the sustainability:

(i) Chemicals easily available, not expensive and not toxic

(ii) Procedure inspired to the principles of green chemistry

(iii) High yield

(iv) To avoid wastes.

The last point appears of great importance. Functionalization technologies of carbon allotropes are known to produce a large amount of wastes.

2.5.4 NanoCarbonUp technology

The NanoCarbonUp technology is here described with reference to serinol pyrrole as the functionalizing molecule.

Adducts of serinol pyrrole with a carbon allotrope were prepared with the help of either thermal or mechanical energy.

Some papers published the technical details. Figure 23 briefly summarize the procedures.

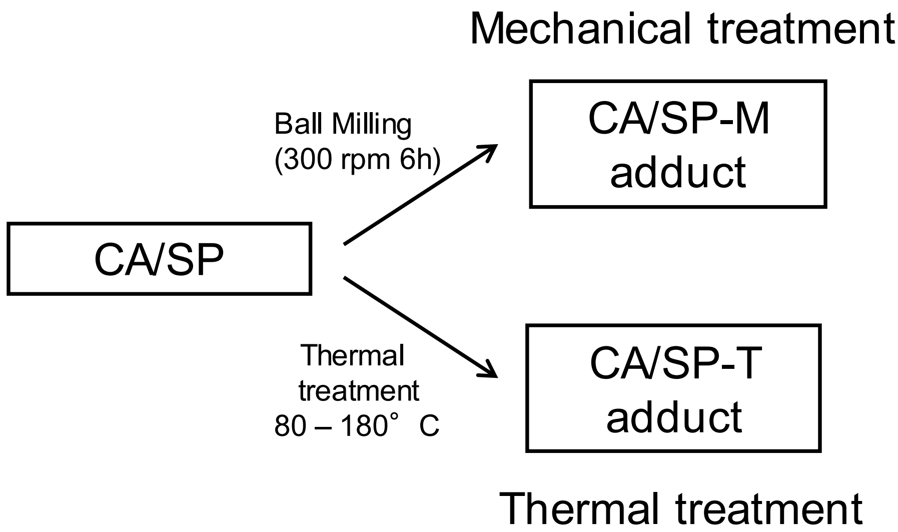

Figure 23: the mechanical and thermal treatment

We report some basic features of this functionalization reaction as follows:

(i) Solvents or catalysts were not used

(ii) The efficiency of the functionalization process was always higher than 90%, by adopting both the mechanical and the thermal donation of energy. In the case of carbon allotropes with large surface area, functionalization yield was almost quantitative

(iii) Thanks to such high yields, wastes were not produced

(iv) The structure of the substrates was not altered.

In particular:

- There was no appreciable modification of the graphene layers in graphene related materials and there was not intercalation between the layers

- Carbon nanotubes and carbon black maintained their structure

(v) Many different pyrrole derivatives, other than serinol pyrrole, can be used for the functionalization of the carbon allotropes, modifying their chemical nature, with a wide range of solubility parameters.

It is worth reporting some data that could better illustrate the above listed points.

Table 8, which follows reports data of functionalization yield, shows that the yield was very high for different types of carbon allotropes.

Table 8: results of functionalization on different carbon allotropes

Type of carbon allotrope	Commercial grade[b]	Surface area m^2/g	Functionalization yield (%)	
			From TGA	From Soxhlet extraction
High surface area graphite	Nano 24	353.2	91	91
GnP	Graphene Nanoplatelets	750	95	94
Carbon nanotubes	Nanocyl 7000	275	n.d.[c]	94
Carbon black	N326	77	n.d.[c]	90

Figure 24 shows Raman spectra of:

(i) A high surface area graphite (HSAG) and the functionalized derivatives, thermal and mechanical

(ii) Carbon nanotubes (CNT) and the functional derivatives

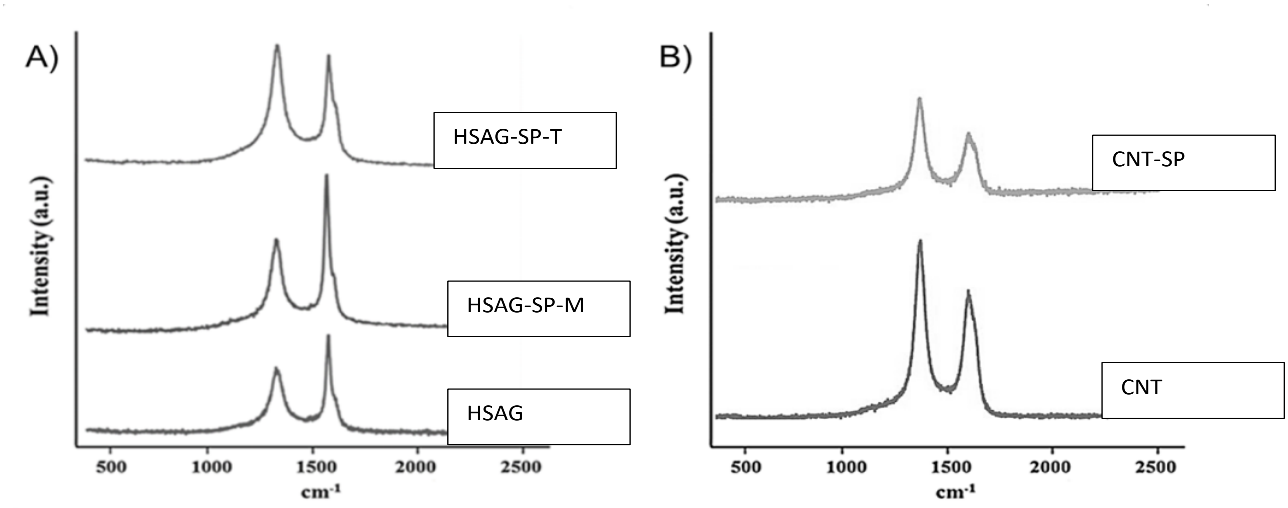

Figure 24: HSAG test results

Without going into any detail of Raman spectroscopy, it can be said that iIn the Raman spectra, the G peak at higher wavelength is attributed to C=C stretching vibration of crystalline graphite, whereas the D peak at lower wavelength appear when defects are in the graphene layers. It is thus possible to comment that the functionalization reaction does not lead to further enhancement of disorder in the graphitic materials.

2.5.5 NanoCarbonUp technology: novel and innovative?

European Patent EP 3209604 B1 has been granted. This Patent covers the functionalization of carbon allotropes with serinol pyrrole. This is the best demonstration that NanocarbonUp is novel and innovative.

From a technical point of view, most innovative aspects of the technology are:

(i) the absence of solvents and catalysts

(ii) the absence of wastes

2.5.6 NanoCarbonUp technology: main results

Relevant results have been already obtained. They allow envisaging many potential applications. Figure 25 reports such results and we summarize them in the following.

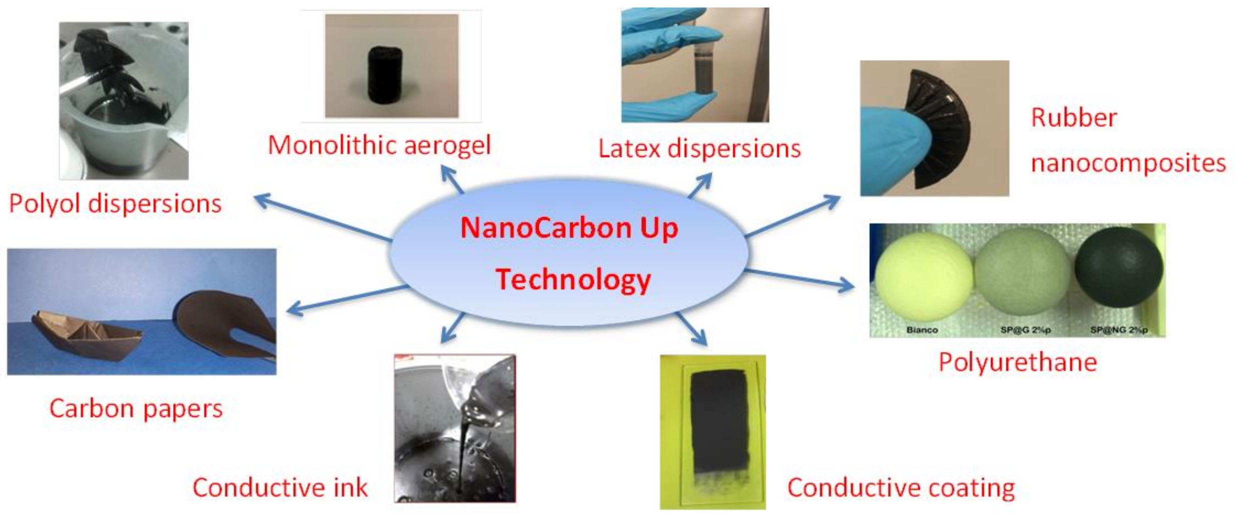

Figure 25: potential applications of NanoCarbonUp technology

(i) Stable suspensions in water of graphene related materials have been prepared. They were stable for weeks up at a concentration of about 10 g/L and were stable, even though for lower times, even up to 200 g/L.
(ii) Conductive inks have been prepared with graphene related materials functionalized with SP
(iii) Dispersions of graphene related materials were prepared in polyols, stable for weeks
(iv) Poly(urethanes) were prepared starting from the stable polyol suspensions
(v) Stable dispersions of graphene related materials and carbon black, both functionalized with serinol pyrrole, were prepared in natural rubber latex
(vi) Nanocomposites based on natural rubber were prepared starting from the masterbatches taken from latex dispersions
(vii) Nanocomposites were prepared based on other types of rubbers, with different types of fillers
(viii) Rubber nanocomposites based on carbon allotropes functionalized with serinol pyrrole were characterized by better dispersion of the filler(s) and, as a consequence, lower dissipation of energy
(ix) Bionanocomposites, with electrical conductivity and good mechanical properties, were prepared based on graphene related materials and chitosan. Such composites were carbon papers and aerogels
(x) Thermoplastic composite material were prepared
(xi) Different primary amines allowed to prepare different pyrrole compounds and thus allowed to functionalize carbon allotropes modifying their solubility parameters in different directions. This aspect is not treated in this thesis, which reports results obtained with serinol pyrrole

2.6 A PERVASIVE TECHNOLOGY. MAIN APPLICATIONS

With reference to the three fundamental characteristics of GPTs, we could find them into NanoCarbon Up:

- *Pervasiveness*: NanoCarbonUp potential application sectors are countless and disparate. We present some of them in this paragraph.
- *Improvement*: as we have already said, improvement in efficiency could show up through a decline in prices, an increase in quality, or both. Since the main application sectors of NanoCarbonUp concerns lightweight and smart materials – which we will treat hereafter – we may say that both of these could be attained.

- *Innovation spawning:* NanoCarbonUp can be considered a "modular" technology; it is not a final product itself. Firms will create and improve their products using NanoCarbonUp as the ground technology. The modularity of this technology is highlighted by the distance among some of the potential application sectors.

After having discussed the abovementioned characteristics and properties, we would like to analyse in detail what actually are the potential applications of this technology.

We could envisage two main wide directions for the applications of NanoCarbonUp:

- Lightweight materials
- Smart materials

We discuss them in the following.

Then, main application fields are considered:

- Healthcare
- Biotechnology
- Aerospace and defense
- Ground and air transportation

2.6.1 Lightweight materials

Why NanoCarbonUp should be suitable to prepare lightweight materials?

Because it allows a better compatibility of the carbon allotrope with the polymer matrix, this way enhancing its effectiveness. A lower amount of carbon allotrope, particularly carbon nanotubes and graphene related materials, could be used, this way reducing the weight of the final good. As discussed in the following, the weight reduction is one the main objectives in designing innovative materials.

Demand for lightweight materials

Demand for lightweight materials in the automotive, aerospace, construction and other related industries has increased in recent years due to environmental concerns, government regulations and consumer demand. Lightweight materials such as carbon fiber are increasingly being used in cars and trucks to decrease weight, and so costs thanks to the increased consciousness about fuel emissions that led to vehicle manufacturers shifting to products that can diminish the weight of automobiles, while preserving strength. To have an idea, according to a Grand View Research insight

(a U.S. based market research and consulting company), the lightweight materials market size was evaluated at USD 113.78 billion in 2016 globally and is forecasted to record a Constant Annual Growth Rate (CAGR) of 8.9% from 2016 to 2024, reaching USD 225.3 billion size.
Figure 26 presents the North America lightweight materials market size by products over a time horizon from 2016 to 2024, considered a good proxy of the global trends.

Figure 26: global demand for polymers and composites 2013-2024

Aluminum, high-strength steel, titanium, magnesium, polymers and composites, and other materials are utilized to satisfy the industry's emission objectives. Automotive manufacturers have started working on multi-material designs involving lightweight materials to boost fuel efficiency of vehicles.
In the following, we present also a graph showing the global lightweight materials market size by application, in 2016.

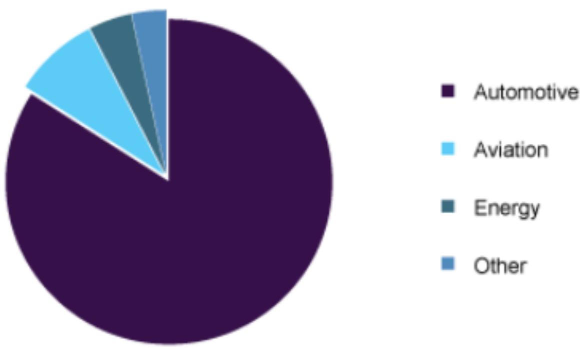

Figure 27: global lightweight materials market size

As shown in Figure 27, the automotive segment led the market with regard to revenues related to lightweight materials, with an 86.03% share. In this application sector aluminum, polymers and composites, and high strength steel are the most used products.

Smart materials, on the other hand, are materials that bear some features that can be substantially modified in a regulated manner by external factors: For instance, temperature, stress, moisture, pH, magnetic or electric fields, light, or chemical compounds. Smart materials are the basis of many applications, including mass transit aerospace, automotive, civil engineering, sensors and actuators, or medical equipment and artificial muscles.

The variation could occur within the material itself, as in one of its properties or physical state, or the material may be the means to convert other things, such as forms of energy or the surrounding conditions.

2.6.2 Smart materials

Thus, there much emphasis has been put on smart materials as providing the solution to the stubborn issue of ever-increasing energy use by building or transportation systems.

According again to a Grand View Research market insight, the smart materials market size was valued at USD 32.77 billion, globally in 2016, and is forecasted to face a persistent growth at a CAGR of 13.5% from 2017 to 2025. The ever-increasing demand for sensors and actuators in consumer electronics, aerospace & defense, and consumer goods have boosted the demand.

In figures 28 and 29, we present the US smart materials market revenue by application (2014-2025) and the global smart materials market revenue by application field (2016).

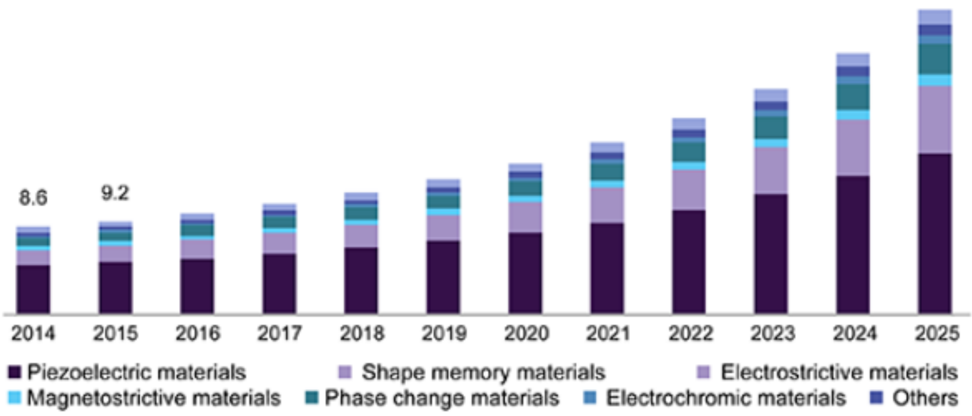

Figure 28: US smart materials market revenue by application (2014-2025)

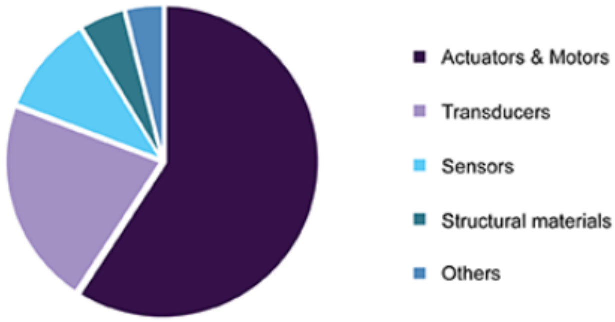

Figure 29: global smart materials market revenue by application field (2016)

Despite the potentially infinite applications, going into a further detail, we identified four sectors for the technology, all with a great potential of spreading the technology itself to a significant number of sub-application fields: healthcare, ground and air transportation, aerospace and defence, and biotechnology industries.

In the

2.6.3 Healthcare

According to a research conducted by Y. Zhang, Y. Bai, and B. Yan in 2010, thanks to their capacity to permeate biological membranes and their low level of toxicity, functionalized carbon nanotubes facilitate several medicinal applications. These applications include the diagnosis and healing of cancer, infectious illnesses and central nervous system problematics, and adoptions in tissue engineering.

The continuously raising incorporation of carbon nanotubes in the healthcare industry for therapies such as cancer, hyperthermia, gene therapy, tissue regeneration, and artificial implants is drastically one of the main reasons of the growth of the carbon nanotube market. Its superior mechanical and transport capabilities are the major causes for growth of the market. According to some market researches, the total carbon nanotubes market is forecasted to grow from USD 3.43 Billion in 2016 to USD 8.70 Billion by 2022, at a CAGR of 17.09%, and the healthcare industry can be considered as one of the main agents.

The global novel drug delivery systems (NDDS) in cancer therapy market size was evaluated, instead, at USD 4.31 billion in 2016 and is projected to grow at a CAGR of 22.9% until 2025. Here follows a graph showing the forecasts of the US NDDS in cancer therapy market, by product, in USD billion.

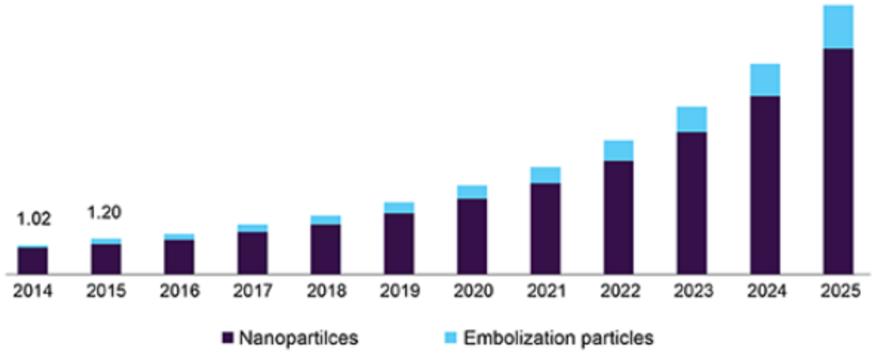

Figure 30: US NDDS in cancer therapy market, by product, in USD billion

2.6.4 Biotechnology

There has been increasing interest into the incorporation of carbon nanotubes into biological systems, such as proteins, DNA, and living cells. The exploration of carbon nanotubes in biomedical applications is ongoing, from the already cited drug-delivery carriers and implants, to substrates for vaccines bio-transistors, ultrafast DNA sequencing, biosensors, and other devices.

A report edited in 2004 by Lux Research, the leading provider of tech-enabled research and advisory solutions, forecasted that in 2014 rising nanotechnologies would be embodied into 23 % of drugs and that nanotechnologies would result in $2.6 trillion in product revenue, that is 15 % of global gross manufacturing output. It also forecasted that products embodying rising nanotechnologies would constitute $920 billion in value added, accounting for 2 percent of global gross domestic product.

In this regard, Table 9 from a 2013 OECD report showing the industries where the added value (USD billion) stands in nano-manufacturing, estimating the Value of Advanced Materials (VAM).

	2008	2015	2020	2030	2050
Energy	7,1	14,3	18,9	37,0	175,7
Transport	9,6	13,1	15,8	24,3	52,6
Environment	24,6	38,2	48,0	86,8	352,2
Health	27,0	32,1	37,4	55,0	115,2
ICT	29,6	38,8	46,6	70,7	152,2
Other / Cross-cutting	3,6	13,5	19,3	42,2	250,8
Total projected value of identified VAMs markets	101,7	150,0	186,1	316,0	1098,6

Table 9: value in different industries of nano-manufacturing

2.6.5 Aerospace and defence

NASA has recently (2017) revealed the adoption of carbon nanotubes to enhance aerospace systems.

NASA's Space Technology Mission Directorate is fervently interested in nanotechnology that may decrease the mass and enhance the performance of aerospace systems. One of the most recent findings demonstrates that compounds that use carbon nanotube reinforcements could drive to a 30% reduction in the total mass of a launch vehicle. We report an extract of interview of Michael Meador's, the Program Element Manager for Lightweight Materials and Manufacturing at NASA's Glenn Research Center in Cleveland on May 30, 2017: "No single technology would have that much of an impact to abate the mass of a launch vehicle by that much. I'm not trying to be cliché, but that is a game changer!"

Meador also highlighted the big payoff that may come from weight savings, performance, or reduced power consumption. He observed that the payoffs this investment are not just for aerospace applications, but the application of carbon nanotube materials could reduce weight of ground and air transportation vehicles and drive to a great savings from less fuel consumption and also diminishing carbon dioxide emissions.

Table 10 shows the 2011 global revenue estimates, according to the listed consulting and market research companies, for the aerospace and aviation market impacted by carbon nanotubes.

Chemark Consulting	Aircraft coatings market 2008 USA: $140 million
Lucintel	Aerospace composites market 2011: $2.5 billion Aerospace composites market 2017: $4.9 billion
ORNL	Aircraft de-icing: $5000 per aircraft
Materials World	Thermal spray coatings market 2010: $1.35 billion
Modumental	Global thermal barrier coatings market: $3.75 billion
DOE	Maintenance, repair and overhaul of aircraft engines estimated to be $29.2 billion in 2018
Barhat	Global demand for EMI/RFI (ElectroMagnetic Interference and Radio Frequency Interference) shielding options is estimated about $4.5 billion in 2011 and is expected to increase to$5.2 billion in 2016
Ceresana Research	Global flame retardant market 2018: $5.8 billion
BCC Research	Global flame retardant market 2008: $4.1 billion Global flame retardant market 2014: $6.1 billion
Teal Group	Unmanned Aerial Vehicles (UAVs) global market 2012: $6.6 billion UAVs global market 2020: $11.4 billion
Smart Structures, Inc.	Total global aviation market 2010: $618 billion
Aviation benefits beyond borders	Total global aviation market 2010: $618 billion
TechNavio	Global Aerospace Composites market 2016: $3.95 billion
Invest Korea	Total global aviation market 2010: $400 billion
Deloitte	Total global aviation industry 2009: $382 billion

Table 10: global revenue estimates

2.6.6 Ground and air transportation

Automotive industry

The crucial drivers for the employment of polymer nanomaterials-enabled parts in the automotive industry are primarily the abatement of vehicle's weight, the enhanced engine efficiency (in terms of fuel saving), the decreased CO2 emissions and the superior performance (in terms of higher safety, greater comfort and greater drivability). Figure 31 below highlights the usage of polymer nanomaterials parts.

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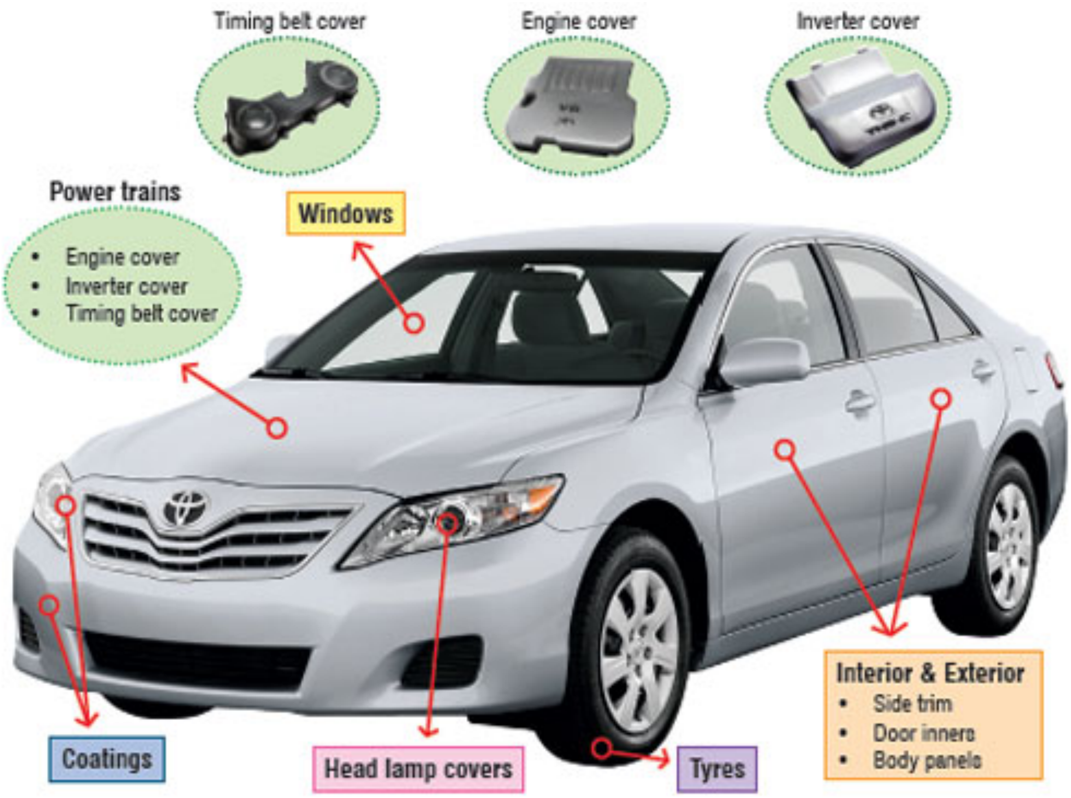

Figure 31: applications of polymers to automobile industry

Table 11 illustrates some examples of commercially available nanomaterials.

Product	Key benefits	Applications	Manufacturers
Polymers			
Polyolefin nanocomposites	2 fold cheaper than nylon nanocomposites, don't need drying, stiffer, stronger, lighter, more easily recycled, high temperature resistance, good impact properties	step assist, heavy duty electric enclosures, seat backs, sail panel, box rail, rocker covers, side trim, grills, hood louvers, instrument panels, fenders…	LyondellBasell, ube industries, Ltd
Nylon nanocomposites	improved modulus, strength, heat distortion temperature, barrier properties	Timing bel cover, engine cover, fuel line, fuel tanks	RTP company, UBE industries, Ltd, Unitika Ltd, nylon corporation of America
Elastomeric nanocomposites	Higher durability, reduced weight, less rolling resistance, easy rubber processing	tyres	Yokohama tyre corp., Pirelli, goodyear tyre, inMat.inc
Nanomaterials			
Nanoclays	Low cost, organophilic, barrier properties and flame retardancy of polymer matrix	Additives and reinforcements	Southern Clay products, Inc., Nanocor, Elementis, Sud Cheimie
Carbon nanotubes	High electrical and thermal conductivity, low coefficient of thermal expansion	Additives, reinforcements, electrostatic painting, EMI shielding	Bayer, Hyperion Catalysis international, Nanocycl, Zyvex Corp.

Table 11: examples of commercially available nanomaterials

G. Mastinu and M. Ploechl (2014) highlighted and numerically specified the reduction of the tyre mass and benefits in terms of CO2 emission of vehicles. The authors defined the energy E required to travel 100km as:

$$E = A * C_x * 1.9 + 10^4 + m * f_R * 8.4 * 10^2 + m * 10 \qquad \text{[kJ/100km]}$$

where A is the cross section area of the vehicle, C_x is the drag coefficient, m is the vehicle mass, f_R is the rolling resistance of tyres.

Vehicle type	Data					Percent variation of E due to 10% variation of		
	Rated;Power; kW	A	C_x	f_R	m	Aerodynamic drag coeff., C_x	Rolling resistance, f_R	Vehicle mass, m
Mid-range	140	2.2	0.26	$12 \cdot 10^{-3}$	1560	2	4	9
Compact	55	2.0	0.29	$10 \cdot 10^{-3}$	1120	4	3	8
Sports	310	1.95	0.29	$12 \cdot 10^{-3}$	1650	2	4	9
SUV	200	2.3	0.41	$14 \cdot 10^{-3}$	2640	2	4	9

Table 12: data by car group

Mass reduction is evidently a must for green mobility and a target (or a challenge) for the present and future of automotive technology. From this perspective, Table 12 shows the variation of E due to single parameter variation (for different vehicles).

Decreasing the mass of a tyre implies an important abatement of the energy consumption E (for travelling 100 kilometers) as well as a significant decrease of the rolling resistance f_R.

Table 13 defines the energy needed to travel along a 100km distance, if we reduce 10% the mass of the tyre.

Vehicle type	Tyre (example)	Vehicle mass reduction	Percentage Energy saved due to mass reduction only	Percentage Energy saved due to rolling resistance reduction	Total Percentage Energy saved due to mass reduction
Mid-range	195/70 R15	4 kg	0.1	4	4.1
Compact	155/70 R13	3 kg	0.2	3	3.1
Sports	245/45 R19	>5	<0.5	4	4.5
SUV	>R20	>6	<0.2	4	4.2

Table 13: advantages by car type

According to a report published by Frost & Sullivan in 2011[2], carbon nanotubes was expected to penetrate around 3.6% within automotive composites. If 1% carbon nanotubes are loaded in these materials, it was estimated that their market for auto composites would have been $35.52 million. It is curious to observe that the market share in 2015 of automobile tyres was 23% of the whole nanotechnologies market in the automobile industry, and it was completely committed to the sphere of nanocomposites.

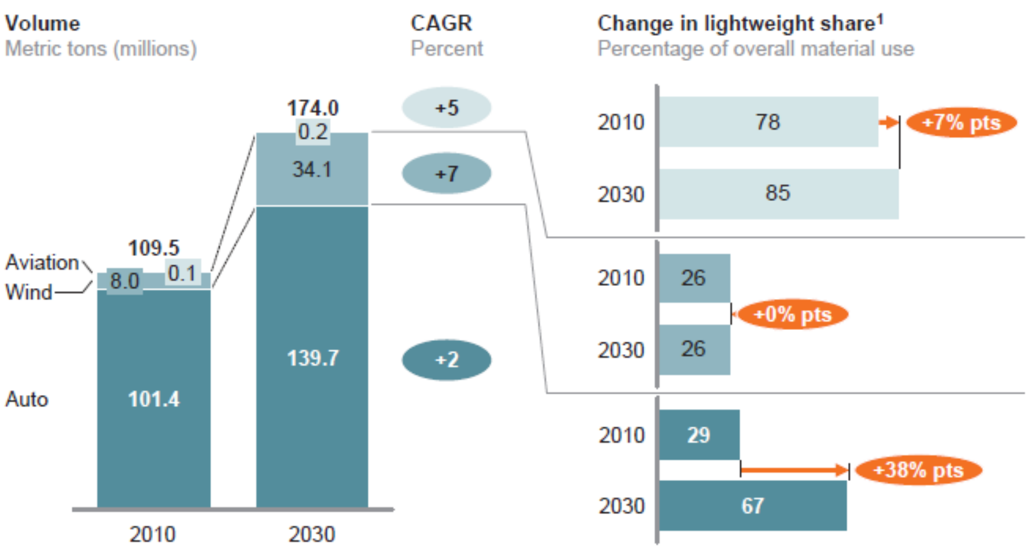

Figure 32: increase of volumes in automotive industry

According to a McKinsey market study, volumes will increase considerably over the next 15 years, resulting in a related growth in the employment of materials across automotive, aviation and wind industries. The automotive sector will encounter the most relevant changes in terms of material mix, since its lightweight share could increase from roughly 30 to about 70%.

Aviation industry

[2] https://www.nist.gov/sites/default/files/documents/cnst/Valenti-NIST.pdf

To better understand the benefits stemming from the employment of carbon nanotubes in the aviation industry, we present a 2004 study by the American Institute of Aeronautics and Astronautics about the likely effect of CNT supplemented polymer composite on business aircraft efficiency and economics. Thanks to the 14.05% reduction in structural mass from aluminium airframes to carbon nanotubes reinforced polymers structured airframes, on average, the outcomes demonstrate a considerable reduction in fuel consumption by an average of 9,8% and a rise in flight range of 13,2% in average. The research considered four aircraft flights: Boeing 747-400 and 757-200, Airbus A320, and Embraer E145.

These benefits of fuel savings and increased flight range for the air carrier translates into clear economic advantages. For instance, the carbon nanotubes reinforced polymer structured 747-400 permit to lower the costs of an estimated $10.000 per flight on the 5,676 nautical miles route from Los Angeles (LAX) to Seoul, South Korea (ICN). Table 14 highlights the economic evaluation of the four aircrafts on respective popular routes, with relative distances specified in Table 15, divided by "low", "nominal" and "high" mass categories.

Table 14: Economic evaluation of the four aircrafts on popular routes

Airframe	70% Single-Walled Nanotube
Low	
747-400	$4,03.,03
757-200	$720.70
A320	$164.14
E145	$37.41
Nominal	
747-400	$9,535.57
757-200	$616.37
A320	$150.44
E145	$32.32
High	
747-200	-
757-400	-
A320	$149.56
E145	$20.71

a

Table 15: Distances of popular routes

Airframe	Route	Distance
747-400	LAX-ICN	5676 nmi
757-200	SFO-ORD	2119 nmi
A320	JFK-FLL	984 nmi
E145	IAH-DAL	241 nmi

However, even if we have focused on four macro-sectors, we would like to underline that the potential applications are almost infinite, from sport to wind turbines or energy storage. Anyway, the NanocarbonUp pervasiveness and functionalized carbon allotropes has been widely demonstrated.

2.7 THE ISCAMAP GROUP: PHILOSOPHY AND OBJECTIVES

Paragraph 2.5.2 already explained the research strategy of the ISCaMaP Group.

Indeed the philosophy of the Group is inspired to two main words: sustainability and innovation.

It is important to underline that sustainability is a holistic concept, made up by different aspects: low environmental impact, technical feasibility at the industrial scale, economic feasibility.

Research, education and engagement with the industrial world are the ways selected to develop the mentioned strategy and philosophy.

The group is promoting green chemistry, a concept that we explain in the next paragraphs. The group is developing a research program that designs novel chemicals/bio inspired chemicals, chemical processes and materials and investigates analytical protocols, new applications and assessment for alternative uses. Doing so, they are integrating the chemical sciences, environmental sciences and biological sciences with engineering, providing technical support to industry and community organizations to advance green chemistry, proteomics and polymer technologies.

Furthermore, Chemistry and Materials researches aim at developing chemicals and polymers, to be used mainly as additives and compatibilizers, for example in composite materials. The attention to composite materials allows to promote multidisciplinary approaches, pursuing sustainability in synergy with apparently far technological fields such as the mechanical engineering. NanocarbonUp technology is a successful example of the ISCaMaP strategy and its synergy with mechanical engineering generated at first LiDuP (Lightweight construction and durability performance) for light weigh, durable and low impact materials.

“Nothing is more powerful than an idea whose time has come” (Victor Hugo).

2.8 THE EVER-INCREASING ATTENTION TO SUSTAINABILITY

We have already stated that NanoCarbonUp can be considered as a GPT thanks to its characteristics, especially its pervasiveness. We have also presented the main objective of the group: *sustainability*.

Now, according to Professor Galimberti, the generality of this new technology could be considered as the mean to reach the final objective, which is the environmental sustainability.

In the recent years, the awareness of the global need for environmental sustainability have significantly increased. Environmental sustainability can be described as the rates of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely. If they cannot be continued indefinitely then they are not sustainable.

This awareness led to a constantly rising need to generate bio-based polymers, which can substitute petroleum-based ones. Several researches in this domain have shown the incredible potential in developing high-performance functionalized polymers, stemming from plant biomass.

We define renewable polymers as those generated from lately harvested biological feedstock. This is opposed to the generation of polymers from the limited provision of fossil resources, particularly petroleum, which cannot be renewed once utilized. A number of factors, defined below, prompt the interest in renewable and sustainable polymers and make the development of these polymers a real need, a challenge and a chance.

The main factors encouraging the interest in renewable polymers are those that have motivated the interest in renewable energy. These include the understanding of the limited availability of petroleum and other fossil resources, the understanding of the fact that few countries control the access to those resources, and the awareness of the huge climate impact caused by the increased presence of greenhouse gases in the atmosphere, because of the continued burning of fossil resources.

An interesting characteristic of bio-based products is that they hold the potential to substitute petroleum thanks to the abundance of chemical building blocks. The generation of bio-based materials from the leftovers stream of bio-refineries, a concept that we treat in the next paragraphs, has the possibility to originate extra revenues, reducing the expenditure for biofuels and making them more attractive in comparison with fossil fuels.

According to European Parliament data about the environment presented on its website, today Europe utilizes 16 tons of material per person per year, and 6 of these turn into waste.

As a result, investments in bio-based feedstock could potentially draw a future in which fossil fuels have a secondary. For instance, in 2010, Europe generated 2.5 billion of waste and only the 36% of it had been recycled, while the remaining part had been burned or landfilled.

2.8.1 Bio-sourced materials

Following this theme of sustainability, we would like to get into the field of bio-sourced materials. Bio-sourced materials are entirely, or partially, obtained from products of biological nature, apart from materials fixed in geological formations and/or fossilized. With regard to industrial procedures, enzymes are utilized in the creation of chemical building blocks, detergents, pulp and paper, textiles, and so on. Through fermentation and bio-catalysis instead of conventional chemical synthesis, it is possible to achieve a higher process efficiency, with a subsequent reduction in energy and water consumption, and an abatement of toxic waste. As bio-sourced materials are obtained from renewable raw materials such as plants, they can help in the abatement of CO_2 and provide further advantages, in particular, the reduction of toxicity or novel product features (e.g. biodegradable plastic materials).

According to European Commission website, "the segment of bio-based product, as a key enabling technology, is one of the priority areas with a high potential for future growth and addressing societal challenges. The bio-based products segment is "a priority area with high potential for future growth"

In addition, according to the European Commission, "the bio-based products and biofuels represent approximately € 57 billion in annual revenue and involve 300,000 jobs. According to forecasts, the bio-based share of all chemical sales will rise to 22% by 2020, with a compounded annual growth rate of close to 20%."

These European data alongside with the global bio-based market chemicals forecasts, which predict that the market will to grow from $6474 million in 2016 to $23976 million by 2025, at a CAGR of 16.16% between 2017 and 2025, are an indication of the world's economy direction through a more sustainable approach to production**.** This is mainly because of the anxieties regarding the environment due to threatening and unsafe chemicals and depletion of fossil resources that is driving to the increment of the production of the bio-based chemicals.

For instance, focusing on the potential chemicals market for bio-based products, the bio-based chemicals largest market is the Asia-Pacific one and the demand for these chemicals in the previously mentioned area is expected to grow during the forecast period (2017 – 2025), according to a market study carried by Inkwood Research[3]. The availability of feedstocks alongside with the technological improvement and the consciousness of bio-based chemicals is becoming the base for the future development of the market.

[3] https://www.inkwoodresearch.com/reports/asia-pacific-bio-based-chemicals-market/

The second-largest bio-based chemicals market is Europe, thanks to the implementation of new value chains with bio-based feedstock, which is the generation of bio-chemicals and bio-refineries. Germany is the market leader, followed by France, UK, and Italy.

Besides the general shifting of the world through a greener and more environmentally sustainable paradigm, the remarkable presence of biomass is another crucial factor. According to the Statistical Review of World Energy of June 2011, we extracted the following data.

Country	Consumption (C)		Reserves (R)	Independency from external supply index (C/R)
	Thousand barrels daily	**Billion barrels yearly**	**Billion barrels**	
USA	19.148.1	7.0	30.9	4.4
China	9.056.7	3.3	14.8	4.5
Japan	4,450.7	1.6	0.0	-
India	3.319.4	1.2	9.0	7.5
Russia	3.199.3	1.2	77.4	66.3
Saudi Arabia	2.812.3	1.0	264.5	257.7
Brazil	2.603.5	1.0	14.2	15.0
Germany	2.440.9	0.9	0.0	-
South Korea	2.383.6	0.9	0.0	-
Canada	2.275.8	0.8	32.1	38.6

Table 16: data on biomass

Between 1980 and 2010, oil reserves doubled, but the daily oil production pace increased at a rate of around 30% as well. Residual life progressively increased, but, nowadays it is stabilizing; thus, while in the past, the growth rate of brand new discovered reserves exceeded the oil extraction and production pace, in the recent years the two rates evened out. Assuming that no further reserves are going to be discovered, at the current production pace, the global oil reserves will have a residual life of around 40 years.

On the other hand, 200 gigatons of biomass are produced on the earth every year and humans use just the 4%. This simple overview demonstrates the incredible potential of bio-based products.

2.8.2 Green chemistry

Another interesting topic linked to sustainability that we would like to introduce is the one called

“Green chemistry”. Starting from the concept that “Human beings are at the center of concerns for sustainable development, they are entitled to a healthy and productive life in harmony with nature”, as in the Rio Declaration on Environment and Development in 1992, we can say that one of the most important objectives of sustainability is the abatement of the negative consequences of the materials that we produce and utilize.

With respect to the definition provided by Anastas and Warner in 1998, Green Chemistry is the usage of a set of criteria that diminishes or eradicates the adoption or creation of dangerous for health substances in the design, manufacture, and applications of chemical products. Indeed, Green chemistry obtained global recognition and acceptance with the disclosure of the 12 Principles of Green Chemistry, again by Anastas and Warner in 1998. Here follows the list of these principles.

The 12 Principles of Green Chemistry

1. It is better to prevent waste than to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximise the incorporation of all materials used in the process into the final product.
3. Synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents) should be made unnecessary wherever possible, and innocuous when used.
6. Energy requirements should be recognised for their environmental and economic impacts and should be minimised. Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. Unnecessary derivization (e.g. protecting/deprotecting groups) should be avoided wherever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.
11. Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Substances and the form of a substance used in a chemical process should be chosen so as to minimise the potential for chemical accidents.

Figure 33: the 12 principles of green chemistry

The main objective of the Green chemistry is, for sure, the resource efficiency and waste minimization, which stem from the second principle and lead to the topic a circular economy, which we discuss later in our research.

Green chemistry and resource efficiency also aim to the employment of renewable raw materials in the green production of fuels and commodity chemicals from biomass, in contrast to their unsustainable fabrication from non-renewable fossil fuels such as oil, coal and natural gas. A technology much have two prerequisites, to be labelled sustainable: (i) natural resources should be utilized in proportion that do not inadmissibly consume provision in the long run and (ii) the production of residues should take place at

paces no faster than can be absorbed promptly by the natural environment.

2.8.3 Towards a green and circular economy

Now that we have presented the waste minimization and the resource efficiency optimization as two of the objectives of the Green chemistry, we would like to talk about the direct consequences of these factors: the so-called circular economy.

We start from the concept of E (environmental) factor, by Roger Sheldon. The E factor is the real amount of waste generated in the process. It differs from AE (Atom Economy) – that is computed "by dividing the molecular weight of the product by the sum total of the molecular weights of all substances formed in the stoichiometric equation for the reaction involved" – in two relevant manners. Firstly, it takes the product yield into account and waste from all of the auxiliary components, such as solvent losses and chemicals utilized in work-up, which are neglected by AE. Second, AE is employed to single steps but the E factor can easily be employed to a multi-step process, so that a comprehensive assessment of the entire process is facilitated.

An elevated E factor indicates a higher level of waste and, subsequently, larger negative environmental effect. The optimal E factor is zero. Put in a simple way, "the E factor is kilograms of raw materials in, minus kilograms of desired product, divided by kilograms of product out", to quote Roger Sheldon. Below there is Table 17 that shows the E factors in the chemical industry, divided by segment. It clearly highlights the enormous waste problem.

Industry segment	Tons per year	E factor (kg waste per kg product)
Oil refining	10^6 - 10^8	<0,1
Bulk chemicals	10^4 - 10^6	<1 - 5
Fine chemicals	10^2 - 10^4	5 - 50
Pharmaceuticals	10 - 10^3	25 - >100

Table 17: E factor in the chemical industry

At this stage, it is just as evident how much is needed a move from an old linear flow of materials in a ‘take-make-use-dispose’ economy, to a greener, circular one that look for the elimination of waste through conscious design of products and processes with resource efficiency and recycling in mind. Wherever the complete elimination of wastes is not achievable, another clue issue is, as already said, the reutilization of them.

Furthermore, the actual costs of the traditional ‘take-make-use-dispose’ production chains should take into account the costs of asset usage/depletion, waste management and environmental pollution, which are externalized, at this point. These costs necessitate to be internalized and new economic indicators are required that consider resource efficiency and circularity. To quote Roger Sheldon again, “we need to rethink how we can close the loops of production chains and optimize resource efficiency”.

CHAPTER 3: A CASE STUDY ON THE TECHNOLOGICAL TRANSFER OF NANOCARBONUP

3.1 INTRODUCTION

The aim of the third chapter is to conduct a qualitative study on the possible paths to introduce the NanoCarbonUp technology in the industrial environment, to explore further possible applications and development opportunities. First, if we are able to identify a proper way to transfer NanoCarbonUp from Politecnico di Milano to the market, we will be able to advance diverse products in different industries. Then, this study will provide a good case for further research interested in finding a general path to transfer a technological innovation developed in the academic environment in the productive system.

Many different paths to commercialize the NanoCarbonUp technology may be feasible, so the aim of the third chapter is to collect evidences on which it is the most suitable for this specific technology, or, at least, to discover the advantages and disadvantages of the different paths in relation to this specific technology.

We already have many information about the NanoCarbonUp, as exposed in chapter two, as well as we know the main channels through with an innovation developed in academia can be introduced in the economy, as exposed in chapter one. The main objective of this third chapter, through an extensive qualitative study, is to understand what is the proper "introduction to the market" path for this specific innovation, according to its characteristics and peculiarities.

The third chapter proceed as follow: firstly, we present of the methodology adopted to investigate our case. After an introduction of the case study methodology applied to our case, we will focus on the interviews we organized to collect the required information, explaining who are the interviewees and why do we propose them our questionnaire, specifying its main areas. There will be a distinction between industrial experts and academic experts.

At the end of the interviews, we were able to collect a significant amount of relevant notions, and almost all the points elaborated and discussed in the questionnaire had some significant insights. We will present in the key findings sections the most significant information collected during these interviews, following the structure highlighted in the first part of the chapter, so following the four main sub sections of the questionnaire.

3.2 THE APPLICATION OF THE CASE STUDY METHODOLOGY TO THE NANOCARBON UP CASE

A first fundamental first decision that we had to make while designing our study dealt with the choice between qualitative and quantitative research.

We opted for a qualitative approach and specifically on a case study approach. In the following section, we illustrate the characteristics of this methodology, its advantages and disadvantages and why we opted for it.

The research in this case is extremely "applied", because it has the goal to investigate a concrete subject with a great practical relevance. Clearly, this research bases on what has been studied and presented in the first two chapters of this thesis.

A case study is an intensive analysis and a description of a single system limited in space and time. Usually, with this method, research finds out topic or question(s) of interest and determines what is known doing a careful analysis of multiple sources of information about the "case." Finally, the report of outcomes of the process is narrative in nature, it is composed by a series of illustrative descriptions of the key aspects and key findings of the case (Merriam, 2001).

A further definition of case study is provided by Yin (2003) and describes it as "conducting an empirical investigation of a contemporary phenomenon within its natural context using multiple sources of evidence; it is not simply a catchall category for research that is not a survey, an observational study, or an experiment and is not statistical in nature".

Firstly, our case study addresses a phenomenon. What do we intend with the term phenomenon? It can be a situation, an event, an activity or a program. In this case, the introduction and development in the market of a technological innovation, the NanoCarbonUp.

Second, the phenomenon should be studied in its natural context (Gardners, 1999), in fact, in this case we will analyze it collaborating with industrial experts working for companies that may become partners in the commercialization of the NanoCarbonUp technology and with the researchers who developed the innovation since the beginning.

Third, case study research is highly descriptive (Hatch, 2002), it bases on extensive and mixed sources of information, and here there are some interviews and a serious work on background theoretical material.

To conclude and in contrast with experimental research, case studies are usually more exploratory than confirmatory; that means that in a case study the researcher normally tries to find out themes or categories of solutions rather than proving relationships or testing hypotheses (Merriam, 2001). Indeed, in this case, we faced this procedure without a pre-established solution to validate, but in order to compare the different possibilities and eventually extrapolate from the data obtained the best option to further develop and insert in the market products based on the NanoCarbonUp technology.

For sake of intellectual honesty, we want to list the main limitations generally related to the adoption of this typology of experimentation. First, case studies are sometimes attributed of insufficiency of rigor; second, case studies give an incomplete foundation for scientific generalization, since they consider only a little number of subjects. Third, case studies are often marked as too long and hard to direct, giving rise to a huge amount of documentation (Yin, 1984). However, the detailed information obtained from case studies does not only assist to inquire into or explain the data in real-life conditions, but also facilitate to clarify the ramifications of real-life environments, that experimental or survey research might not catch.

However, on the other hand, as explained before the advantages of the case study methodology are several, especially for the purpose of this thesis. We chose the case study methodology because it allows to reach a profound level of detail, with richer data and greater depth, especially when, as in this case, a holistic, in-depth investigation is required.

3.2.1 Case study definition steps

A case study unfolds in three main steps (Merriam, 2001):

- Study design: case study research designs or approaches can be based on their function, characteristics, or disciplinary perspective
- Qualitative data collection: acquisition of knowledge from secondary sources and interviews, to academic and industrial experts
- Data analysis: the aim of this activity was to obtain an interpretation of the bulk of data collected that contributed to our understanding of how is possible to transfer NanoCarbonUp to the firms, in different application sectors, in the most proficient way as possible.

3.2.2.1 Study design

The study design is crucial for the purpose of a good case study.

Here, the main objective is to find the most appropriate path to introduce the NanoCarbonUp technology in the market, considering the peculiarities that a GPT has, and the interaction between

universities and firms, trying to identify possible partners, in reachable industries, to favor a further exploitation of the technology.
Merriam (2001) suggests that there are different orientations to conduct a case study research, such as ethnographic, historical, psychological, or sociological. Case study research designs may also be classified as intrinsic, instrumental or collective (Stake, 1995). Types of designs include exploratory, explanatory, and descriptive (Yin, 2003).
In addition to their disciplinary orientation, case study research designs may be classified as intrinsic, instrumental, or collective. We opted for an intrinsic case study that because of our desire to know more about a peculiar individual, group, event, or organization. Our interest is focused mainly on finding the most appropriate way of introducing to the market the specific innovation developed by ISCaMaP group and not the more general proposition to understand which is the best path to introduce a given innovation in the market.
A final decision on the study design is between exploratory, explanatory, and descriptive designs. In this case, there is not a category that perfectly fits the target of our case study. Our study has some characteristics of an exploratory study, which seeks to define research questions, but also some other characteristics of a descriptive one. Indeed, we are attempting to identify and describe what is the most suitable path for the NanoCarbonUp. While the last alternative seems quite far from our case, because explanatory designs attempt to determine cause-and-effect affinities.
The descriptive approach partially covers our target, but not completely, because we do not have a complete and predetermined process to follow to introduce the technological innovation in the market, but we have to identify the best one, so we cannot limit our activity to a descriptive effort.
In the study design phase, we started as well to identify those professionals who can be listened as experts with the goal to give us important hints to find the best way to enter in the market.
At the same time, we collected the material, mostly from academic sources, to become experts in the field of GPTs and the different channels through which universities collaborate with firms in the market. Moreover, we gain expertise on the NanoCarbonUp, as exposed in chapter two. This activity has been done thanks to the precious help of professor Galimberti, who provided us a vast amount of material in terms of documents, articles, presentations, conference press transcriptions about the environment in which the technological innovation at issue should be connected.
From this first phase, we learned that there is not a unique and dogmatic channel through which to transfer a technological innovation to the productive system. The most suitable path depends on the specific characteristics of the innovation, and of the needs of the development team, both in

the early stage of the technology life cycle, so the inventors, and the mature stage of the development, so the team that is required to adapt the innovation to the industry making it practical and economically profitable. We will further explain this concept in the next paragraphs.

3.2.2.2 Collection of qualitative data

The second phase, collection of qualitative data, can be segmented in different activities:

- Information collection on the technology from secondary sources including: scientific articles, presentations, specialized journals and workshop overviews.
- Interviews to industrial experts, working for different firms operating in businesses related to the NanoCarbonUp technology and that could become potential partners in its commercialization.
- Interviews to researchers of Politecnico di Milano, members of the ISCaMaP group, who have been involved in the development of the NanoCarbonUp technology since the beginning, in order to have the point of view of the academics who were at the forefront of the technology development.

Secondary sources

Case study researchers often examine existing papers or create new documents in order to collect the knowledge connected to the research questions (Merriam, 2001). In our specific case, we collected information mainly starting from, and then integrating, the material that Professor Galimberti provided us. In general, there are four main categories of documents sources: Internet, private and public records, physical evidence, and instruments created by the researchers.

The material used in this phase included some scholarly work, press materials in the form of journal and magazine articles, the content of blogs, websites, advertising, and power-point presentations for academic conferences.

The material was oriented on the specific technology developed by Galimberti's research group, but not only, because there were also aspects related to a broader view such as the importance of sustainability. The abovementioned material explained the concept of biomasses and bio-sourced materials, the shifting towards a green and circular economy, the principles of the green chemistry and many other topics that were useful to understand the reasons that led to this project and the general environment of active research that is emerging in the last years around these topics.

We summarized the results of this document review in a narrative form in the second chapter of this thesis.

A second way through which it is possible to collect qualitative information consists in the use of fieldwork observation. This means visiting companies, incubators, start up, university research teams directly in the environment where they work and propagate their ideas, and interact with them in the most open and direct way possible, through unstructured talks were questions are open and informal.

Unfortunately, we were not able to apply this channel of data gathering because of the scarcity of resources, both intended as time and social capital.

Interviews

On the other hand, a path that this thesis followed to gain knowledge is the collection of information through interviews. We did these interviews to industrial experts coming from different companies operating in businesses in some relations with the potential applications of the NanoCarbonUp with the objective to understand their interest in the NanoCarbonUp, their requirements and willingness to invest in projects based on NanoCarbonUp.

Moreover, we organized the interviews also with academic experts of Politecnico di Milano, members of the ISCaMaP group to have the standpoint of the university, showing their needs and interests in the commercialization of an internally developed technology.

We report the complete questionnaire, both for the industrial and the academic experts, at the end of the thesis in the appendix

Identification of the experts

The first element to define is how to find the key participants whose knowledge and opinions may provide important insights. We looked for experts having direct experiences in the launch of new technologies and innovations in fields coherent to a potential further application of NanoCarbonUp. In this activity as well, the contribution of professor Galimberti was crucial, as we linked us with firms to which industrial experts belong and put us in contact with them.

We set simple criteria for the inclusion of an expert, name s/he should:

- Be working for a firm that may become a partner in a development project according to the previously identified potential application industries, such as wearable technologies and automotive. Since the number of potential applications is very wide the number of potential interviewees remained high after this step

- Have previous experience in projects that may come to the final target to introduce a new technology in the market
- Already had, or should be going to start a cooperation with Politecnico di Milano, specifically on the NanoCarbonUp project. So, all the interviewees have a significant knowledge of the technology at issue and of its potentialities in the industrial world

We have identified three managers adapt for the purpose of the interviews:

- Gianluca Pitzanti, R&D Laboratory Manager, Vibram. He started his career in 2001 in Ciba, leading global company dedicated to producing high-value effects for its customers' products, such as protection, color and strength to plastics, paper, automobiles, buildings, home and personal care products and much more. He left the company in 2002 and started working at MarconiGomma, a company active on the market of rubber compounds production for third parties, and stayed there as Quality Assurance Manager for 7 years. He moved to Intermarp Italia Spa, a company operating for a long time in the rubber sector and specialized in the production of technical articles and seal rings, and worked as a Rubber Technologist before and R&D Responsible then. He finally moved to Vibram in 2015 as a R&D Laboratory Manager. Vibram is a global company that manufactures and licenses the production of Vibram branded rubber outsoles for footwear. It could be considered as a target firm for NanoCarbonUp since the technology is perfectly suitable for all that is Wearable Technologies. NanoCarbonUp can help strengthen the rubber and the soles, also providing increased traction and stability.
- Luca Giannini, Material Advanced Research Manager, Pirelli. He started his career as a researcher at Montell Italia Spa in 1998. He then moved, always as a researcher to Norpharma Spa in 2000. He finally started working at Pirelli in 2002 as a senior researcher. In 2003, he became Project Manager Innovative Compounds – Nanomaterials until 2016, when he became Material Advanced Research Manager. His background explains itself why he is a suitable business profile for this thesis. Pirelli needs no introduction and NanoCarbonUp technology is perfect for the tire business for the lightening of the structures according to environmental, economic and social sustainability.
- Corrado Fontanesi, General Manager, EPTAtech. After many professional experiences in consultancy firms such as Ernst and Young Consultants, Framfab Spa – which he co-founded –

EDS Consulting Services and so on, he became Leader of the Consulting component of the EDS Application Modernization and SOA Practice in EMEA for Hewlett-Packard from 2008 to 2009. He then became Vice President of Hyperion Srl, a start-up, operating in the Intelligent Surveillance Software Market. He worked then for 5 years, from 2010 to 2015, as a Partner for Italcanova Srl. In 2015, he finally moved to EPTAtech, initially as a Responsible for the Printed Electronics Business Line, becoming General Manager after 2 years.

EPTAtech is a company that provide materials to the printing industry with a main focus on innovative offering for Printed Electronics, that is a set of printing methods used to create electrical devices. As we will explain in the following paragraphs, the aim of the collaboration of EPTAtech with Politecnico di Milano is to disperse the carbon allotropes within an ink to make it conductive and sell it for Printed Electronics applications.

For what concerns the academic interviews we applied some similar filters to the process of selection of the academic experts with respect to the ones applied to the industrial experts but, clearly, we had to figure out also some other kind of factors specifically related to the academic world. In particular, the filters applied have been:

- The academic experts clearly should work at Politecnico di Milano, specifically the chemistry department
- They should have a good to profound knowledge of the NanoCarbonUp technology, both in terms of specific technology and in terms of field of application, potential competitors, existing markets, requests from the market…

Please note, we did not consider Professor Galimberti as an academic expert to be interviewed since he is the co-supervisor of this thesis and it could create a conflict of interests.

We have identified two academic experts adapt for the purpose of the interviews:

- Vincenzina Barbera, Assistant Professor at the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano. After a PhD in Medicinal Chemistry at Università degli Studi di Catania from 2009 to 2012, she moved to the research team of Politecnico di Milano. Her scientific activity has been mainly devoted to organic synthetic methodologies of interest in the field of the heterocycles and other organic compound.

  Her role in the research team of NanoCarbonUp is formally of co-inventor and R&D

Responsible. She supports and promotes the ideas of all the team members, favoring the development of new and specific research projects.

- Attilio Citterio, Head of the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano. Professor Citterio is a senior Professor in Politecnico, with a great experience in projects concerning both inorganic and organic chemistry and, consequently, with a noteworthy knowledge on the necessities of the university in this typology of projects. One of his mayor interest research area is the synthetic chemistry related to fine chemicals, to energy and environment, and the study of environmentally friendly product and processes, biomass exploitation, green chemistry and green metrics. However, Professor Citterio was not directly involved in the project, so, his opinion can be considered truly objective on the value of the NanoCarbonUp technology. Professor Citterio is the coordinator of the activity of three full time professors, two researchers and a varying number, between 10 and 15, of people working in the industrial sector. He was director of the chemistry department in the past.

The questionnaire

We organized the industrial interviews as long semi-structured talks. With the term semi-structured talk, we intend, according to Hancock and Algozzine (2006): "researchers ask predetermined but flexibly worded questions, the answers to which provide tentative answers to the researchers' questions. In addition to posing predetermined questions, researchers using semi-structured interviews ask follow-up questions designed to probe more deeply issues of interest to interviewees. In this manner, semi-structured interviews invite interviewees to express themselves openly and freely and to define the world from their own perspectives, not solely from the perspective of the researcher".

Hancock and Algozzine (2006) proposed different alternatives: interview as informal conversation, interview as guided conversation, interview as open-ended responses and interview as fixed responses. We opted for a style of interview as open-ended responses that means that specific wording and sequence of questions are predetermined, all participants are asked basic questions in the same order, and all questions require open-ended responses.

To conduct them, we developed an interview guide, composed by 31 questions to ask each interviewee and segmented in four macro topics of interest, which we chose based on our background framework.

We, as interviewers, could pose additional questions for clarification or deepening or skip questions that respondents had already answered. Moreover, during the interviews we tried to avoid, whenever it was possible:

- Yes/No questions, to allow the interviewees to broaden the concept in their answer
- Leading questions, to prevent from prompting or encouraging the answer wanted
- Multiple-part questions, in order to be synthetic and go straight to the point
- Questions with uninformative answers, selecting in advance only the material useful to our work.

The four macro topics treated in the interviews have been:

I. Background questions, aimed at knowing the personal history of the interviewee (e.g., "*Which function do you belong and which is your role in that function?"*). Still in section one we inserted a couple of high level questions on the technology transfer in general and from universities to firms, also applying the case to the NanoCarbonUp at this point (e.g. *"can you briefly describe the procedure of introduction of a university developed technology inside your specific firm?"*). Most of the interviewees answering to these questions, after a general description, directly applied the case of the NanoCarbonUp technology to their business.

II. Question related to the NanoCarbonUp technology, aimed at learning what the interviewees think and know about this specific technology (e.g., "*Did you know something about this technology before this interview? If yes, what?*" "*How many people would be dedicated to the process of introduction of the technology?").* this section is composed of 11 questions that can be divided in four sub sections:

    a. *Inside the technology, level of knowledge and potentialities:* to testimony the competence of the experts that has been interviewed, not only in the general development process of new technologies, R&D projects and collaborations with the universities, but even specifically for NanoCarbonUp project, we asked if they were acknowledged about this technology and if yes, since when.

    b. *The technology inside the company, how does it fit?:* We examined the methods and the procedures through which NanoCarbonUp might be inserted inside the production lines of the companies.

    c. *Technology state of the art and timeline:* in this subsection the aim is to inquire into the actual evolution state of the technology, understanding, in the companies' experts opinion, the level of development already achieved by the technology and the time required to complete the full progress and commercialization of some products based on NanoCarbonUp.

d. *Advantages coming from the adoption of this technology: w*e concluded section 2 with three questions aiming to analyze the perceived value and the added value of NanoCarbonUp. In order to complete this analysis, we highlighted two of the most important characteristics of the technology, the sustainability and the potential pervasiveness of such technology.

III. Role of the university, aimed at understanding which should be the tasks and hints that the academic group can do (e.g., "*Why, in your opinion, the university should be interested in investing time and resources to develop NanoCarbonUp with your company?*"). In this section of the questionnaire, the objective was to dig deeper on the required features that a university must possess to be attractive for the industrial environment and, vice versa, which should be the characteristics of an industrial company to become a qualified partner for a university. In addition, the results, positive and negative aspects emerged in the companies, from previous experiences or collaborations, comparable to the one required in this case, have been analyzed. We asked some questions also on the expectations coming from this project and we concluded with some technical details related to the management of the technology, in terms of secrecy in relation with the necessity of the university to diffuse the knowledge.

IV. Future developments, aimed at understanding potential criticalities in future and aspects that will emerge in the early or medium/long term future (e.g. "do you think that the negative syndrome of "not invented here" will emerge? If yes, which instruments do you think can be applied to limit and avoid it?"*).* It is possible to formulate a couple of subsections. The first one is related to the possible problems, restrictions and difficulties that the development of NanoCarbonUp technology may face inside the companies; while the second one is about possible agreements with other companies to further improve the technology developed in the academic environment by ISCaMaP group.

For what concerns the academic interviews, the methodology was similar to that used in interviews with industrial experts. In particular, the interview guide is still grounded on the concept of semi-structured talk and we tried to maintain all the questions that could be posed to both the groups of interviewees, and to present them in the most similar manner. Of course, we did some adjustments to the original interview guide to allow us to investigate in deep on the experience, behavior and opinions of academic researchers.

In particular, the questionnaire presented to the academic experts contains 13 questions, the macro phase remained the same of the questionnaire targeting industrial experts except for the fourth section that has been delated. Moreover, we reduced the number of questions in each of the sections, according to the coherence of the questions with the role of the academic experts, who cannot respond to questions oriented to the firm's experts. On the other hand, in section three (the role of the university), we posed four additional questions to the academic experts that have not been presented to the industrial experts. We presented the four additional questions in a specific sub-section within section 3.

The organizational details of the interviews

The industrial interviews took place between the second half of September and October 2018, two of them were conducted face-to-face in offices in Politecnico, while the last one, with the Pirelli expert, occurred via Skype since it was impossible to organize a physical meeting. The average duration of the interviews was between 40 and 50 minutes, the shortest one was of 41 minutes while the longest of 53 minutes. For all the interviews to industry experts, after that we had the permission to do so, we audio-recorded the meeting, which we then transcribed. We additionally triangulated our qualitative evidence as much as possible with other information sources, such as press articles and web interviews.

Interviews with academic experts occurred in parallel to the interviews to the industrial experts, so the period is almost the same, from the second half of September to the second half of October 2018. In particular, the interview with Professor Citterio took place in his office in Politecnico di Milano, for a total length of 35 minutes, while the interview to Professor Barbera has been done through Skype since it has been impossible to arrange a physical meeting.

For all the interviews to academic experts, after we had permission to do so, we audio-recorded interviews, which we then transcribed. We additionally triangulated our qualitative evidence as much as possible with other information sources, such as press articles and web interviews.

In Table 18, we summarize the organizational structure of our encounters:

Interviewee	Date	Firm / Group	Channel	Time	Location
Fontanesi	24/09	EPTAtech	Face to face	53min	Via Mancinelli
Giannini	28/09	Pirelli	Skype	41min	-
Pitzanti	10/10	Vibram	Face to face	43min	Via Mancinelli
Barbera	26/09-12/10	ISCaMap	Email	-	-
Citterio	25/10	ISCaMap	Face to face	35min	Via Mancinelli

Table 18: organizational details of interviews

3.2.2.3 Data analysis

As Eisenhardt (1989, pp. 539) wrote: "Analyzing data is the heart of building theory from case studies, but it is both the most difficult and the least codified part of the process."

The third phase of our case study is indeed data analysis. This phase started in parallel to the collection of qualitative data and continued until October 2018. The aim of this activity was to obtain an interpretation of the bulk of data collected that contributed to our understanding of how is possible to transfer NanoCarbonUp to the firms, in different application sectors, in the most proficient way as possible.

Hancock and Algozzine (2006) wrote that the examination and interpretation of case study data must be ongoing, thus researchers may reach provisional conclusions and refine research investigations. They also presented some guidelines to summarize and interpret information and data: as has already been said, the ongoing refinement of the core research questions, bearing in mind the newly collected data; the constant focus on the research questions being investigated; and the development of a method for labeling and storing every piece of information gathered.

As concerns the first two points the interview guide that we prepared allows us to examine each new piece of information in light of our core questions, which have been fine-tuned interview after interview.

We structured the analysis of data in a sequence that follow the flow and the logic of the interviews done to the industry experts and university researchers. Thus, we divided the data retrieved by these interviews in the four main section of the questionnaire, with a further "sub-division" according to some common findings that came out from the interviews.

Eisenhardt (1989) presented two main steps in the analyzing of data: within-case analysis and cross-case search for patterns. Within-case analysis may support researchers to deal with a huge amount of data. Despite the fact that our case study consists of just five interviews to experts, the idea to

be close with every single case as a stand-alone entity allows the sole structure of each case to come up before we analyze features through cases.
The second step, not necessarily chronologically but coupled with within-case analysis, consists, indeed, in a cross-case search for patterns. One of the strategies proposed by Eisenhardt is to separate the data-by-data source. For example, divide the data coming from observations, from questionnaires, from interviews, or from documents. Of course, when two patterns from two different data sources back up each other, the conclusion is more powerful. In particular, we had two main data sources to consider: questionnaires and proper interviews. Thanks to the defined structure of the questionnaire, which has been used to support the interviews too, we tried to identify some kind of common answers, which may help us to formulate strong conclusions. Completely opposite answers to the same question have been helpful too in this cross-case analysis, because they allowed us to consider the existence of different approaches and point of view, maybe according to the particular features of the companies interviewed.
We tried to draw up an "a priori" sequence of steps to organize the data analysis.
The first step was the identification of pieces of potentially relevant information for understanding and defining the best path to introduce the ISCaMaP technology into the market among the broad corpus of qualitative information. For example, the description of the current processes of introduction of a new general technology inside the interviewed potential partner firms could give us a great insight to shape the best possible path.
The second step consisted of coding these pieces of information. We initially thought we could have used Nvivo® to store and analyze the bulk of the qualitative data provided in formats compatible with this software.
The third step consisted of organizing and categorizing the information collected from the interviews.
The fourth step consisted in the study of the data and categories identified in steps 1-3 until we achieved a convincing interpretation of which could be the best possible way to introduce our technology in the market, making reasonable sense of the data. This fourth step is where our conclusions have been drawn.
As suggested by Hancock and Algozzine, there is the possibility that these steps may need a certain level of redefinition, while conducting the interviews. Of course, we needed to modify them. First, since the relatively small number of interviews that we have conducted, we cut off step two. We did not consider as a primary need to "code" the information collected, also because it would have

taken a considerable amount of time to get the access to the software. Thus, we decided to code, store, and analyze the information gathered by ourselves.
In addition, step three was "a priori" descripted in a general and non-specific manner but, while conducting the interviews, we have been able to define a clear organization of data. Indeed, as it has already been said, we organized the data trying to follow the same structure we used in the interviews, further investigating and splitting it in additional sub-sections linked to the common patterns identified.

3.3 KEY FINDINGS

In this section, the outcomes of our research will be exposed according to a simple structure, we will follow the flow of the questions as posed in the interview guide, highlighting the main points emerged during the interviews. We expose the findings according to the four macro-sections of the guide:

I. Background information about the interviewee,
II. NanoCarbonUp technology,
III. The role of the university,
IV. Possible future developments.

Furthermore, we will attempt to integrate in these four areas the suggestions coming from the industrial and academic experts as much as possible, in order to provide the widest possible vision on the matter.

3.3.1 Section 1: Background information

3.3.1.1 Introduction to the interviewees

In this section, the questions focused on the business and academic profile of the interviewees. We asked about the function they belong to and their role in it, as regards the industry experts, and the research team they work in, when talking with the academics.
We have already presented in detail the interviewees in the "identification of the experts" paragraph.

3.3.1.2 Introduction of an outsourced technology in the firm

Two interesting questions in this subsection we asked only to the "industrial" interviewees have been: "can you describe briefly the process of insertion of a university developed technology inside your company? Which are the figures involved, how does it work the diffusion and the communication inside the firm? Are there some opportunities/previsions of continuous improvement even after the first introduction?"

In the circumstance of more basic and less applied research, in the majority of cases there is a mandatory passage through the research and development departments of the companies, where it is determined, which is the most suitable area of application for the project. After that, it is possible to start to work on the procedures to transform and make more practical the technologies, adapting it to the topic of interest.

In particular, Giannini said, "*in a big company as Pirelli, with an extensive R&D department, it is necessary to do business driven research and that every R&D project must be clearly defined in all his functions and objectives along the production lines*".

Furthermore, Pitzanti said that, in relation with the NanoCarbonUp technology, they have already started to develop a research project to functionalize the carbon black fillers, in order to insert graphene or other allotropes inside different types of rubber. However, at the moment of writing, their attempts have been unfruitful in terms of gaining that performance advantage required by their customers, or, at least, in the ability to communicate to the customers the augmented value. For this reason, the occasion to introduce the NanoCarbonUp technology, collaborating with Politecnico di Milano, seems really advantageous for them.

Moreover, since they have not found the way to properly take advantage of these categories of technology yet, other investments in R&D have been planned in new contexts, even parallel. Therefore, the answer to the question "could new channels of development and continuous improvement of the technology be opened after the first collaboration?" is definitely positive.

In the case of EPTAtech, Fontanesi specified, "*the process of insertion of a university developed technology in the company may change according to the level of maturity thereof: for instance, if the technology is already "mature", the responsible of industrialization right away takes it in charge. If the technology is a component of the final product, then the R&D department is taken onboard as well*". Talking about NanoCarbonUp specifically, Fontanesi added that it is about the functionalization of an electrically conductive material such as carbon, but they have to make it possible to use it within an ink. Thus, a further "research" step to draft the final ink composition is required (for instance, the type of resin used and the percentage of conductive material exploited have to be studied).

Every industry expert that we asked mentioned the licensing option as the preferred one. Specifically, Pitzanti said that, being his company quite virtuous in this kind of practices, they do not have a strongly preferred way of interacting with the university. Anyway, considering the solutions proposed the most suitable, the most adopted and the easiest to implement is the "usage of licenses" option. At the same time he clarified that a required passage for a technology coming from outside the company is through the R&D department, that starting form a general and high-level technology, can adapt it to the peculiarities of the specific firm.

Fontanesi clearly separated the possible paths in two blocks: start-up and equity on one side, licensing and co-development on the other one. He said that the best possible options depends on the type of technology and, again, on its maturity: start-up and equity are suggested when the technology is ready to be quickly launched on the market, but this view lapses when it is just a component of the final product. Licensing and co-development are preferred if there already is a patent or the support from university is still necessary.

From these answers we can extrapolate that, at least in Italy, there is a preference for the license system over the co-development and the use of equity, the more virtuous is a company the more is prepared to interact with the university in different manners and to adapt to the necessities of the university. A differentiator could be the state of advancement of the technology, the more the technology is developed the more is probable that the best option is the license.

Larger and multinational companies are less flexible compared to smaller companies, at least in this case, as emerged by the answers of Pirelli, which preferred the licensing channel but has shown a much lower elasticity with respect to the alternative channels to integrate an outsourced technology. Indeed, they told that the only possible path for them is through the institution of R&D commissioned contracts guaranteeing the license to Pirelli.

A further topic explored is the best possible path to insert a new technology developed in the university inside a firm. This is an extremely relevant question for the purpose of this thesis and asks the crucial point that we are trying to find out in this thesis. To assist the interviewees in answering the question, we suggested them four of the main paths that we identified in the first chapter of the thesis: the use of a license system, an organized system of co-development and academic engagement, the foundation of a start-up using a sort of joint venture system, or selling a portion of the company equity to the university.

We posed the same question to the academic interviewees as well.
Professor Citterio stated that the almost only channel adopted by Politecnico di Milano is licensing, agreeing with the industry experts. He then highlighted the greatest difficulty in the interaction with firms for the university: "*if the initiative starts only from the university there is a structural difficulty on the part of the companies in accepting the idea that this should be transferred as such, in general there should be a period of maturation that must be done within the company*". This is one of the reasons why Citterio has always preferred to do business in connection with industry, to do joint patents, to make them involved since the begin.
Developing the licenses is a non-basic problem. For the university the best idea is to keep more roads open in order to move more freely. Licensing is probably the only form with which the Politecnico structure, or the individual researcher, can think of justifying his relationship with the company in a way that is not so exclusive as to be able to keep more alternatives open.
Professor Barbera focused her attention on the phase of development at which this communion of interests become proficient and necessary for all the parts, indeed she said that the best moment to start a project together is the scale up. The resources available from the universities are of the "laboratory-pilot" type. Professor Barbera admitted that at the university level, with the resources available, it could be tough to realize the eventual scale up. For this reason, approaching the company during this phase is an advantage both for the university, in order to make known the technology, and for the company itself that can take advantage to be the first to introduce on the market a new technology.

3.3.2 Section 2: The NanoCarbonUp technology

In section two we decided to dig deeper on the perception that NanoCarbonUp technology has in the companies and the individuals that have been asked to. With respect to the academic part, this section is sensibly reduced, but still presents some questions on the characteristics and advantages of NanoCarbonUp technology that the ISCaMaP group was attempting to achieve and achieved.

3.3.2.1 Inside the technology, knowledge state and potentialities

Here we firstly asked if the industry experts were acknowledged about this technology and if yes, since when. All the parts questioned answered positively, Pitzanti and Fontanesi said that they are already cooperating with the team of Professor Galimberti and they were informed about this

project for one year and a half more or less, while from Pirelli the answer was even stronger, since they stated that the project was co-developed with Pirelli since the beginning.
Once clarified the expertise and the level of knowledge about the NanoCarbonUp technology, we explored the key factors that make this technology and the whole area of functionalization of carbon allotropes sensible to a potential change in terms of performance and value added to the final product.
Pirelli gave us a technical motivation to assess the potential positive aspects of the introduction of this technology, while the feedbacks from Vibram and EPTAtech were more market oriented.
Specifically, Giannini stated, "*It is a technology that allows to modify the surface of the filler and therefore to modulating dispersion and interaction with the polymer matrix, so it is an enabling technology for the world of composites*".
The more commercially oriented view is related to the future channel of production of the technology, as exposed by Vibram R&D responsible, who declared, "*the technology is particularly relevant for applications in the fields of climbing, both indoor and outdoor. We identify in this technology a possible upgrade for what concerns the rubber soles for the shoes that they sell specifically for climbing*". Pitzanti highlighted how much this sector needs an improvement, it is strongly required by the final customers and the trend in technological improvement has been relatively flat in the last years.
They are trying to generate technological improvements both from inside and outside their company, making experiments to functionalize carbon black, insert graphene or other carbon allotropes in the rubber compounds. However, still now, they were unable to find that value added, really perceived by their clients. Consequently, an investment in NanoCarbonUp appears to be a good chance to find out a way to solve this customer need.
As for EPTAtech, the aim is to disperse the carbon allotropes within an ink to make it conductive and sell it for Printed Electronics applications. Moreover, some "offline" experiments conducted together with professor Galimberti highlighted a positive electrical behavior to elastic stresses. Thus, stretchable electronics and wearable technologies are two potential field of application for NanoCarbonUp, according to EPTAtech. "*This is quite a "hot topic" nowadays*", stated Fontanesi.

3.3.2.2 The technology inside the company, how does it fit?

In this subsection, the first aspect checked out was if, once integrated in the company, there would be a specific function or team dedicated to the project, a sort of task force, or, if it would be integrated inside other functions already operating in the company.
In this case, we had no unilateral consensus on a choice above the other. Pirelli and Vibram want to integrate the project into other macro functions or teams already operating inside the company, while Fontanesi stated that "*in EPTAtech, the most suitable path is to create a new team dedicated to this project, collaborating with the original Politecnico's team*".
Giannini specifically defined in which function the project would land, saying that it would be managed in the flow of rough materials and processes, and the whole area of material and processes would be integrated partially in the project, with the goal of re-analysing the standard formulations and processes, adapting them to the new material, if required.
Pirelli was unable to give us an estimate of the number of people dedicated, even partially, to the NanoCarbonUp project, but we can obtain some useful insight on the topic considering the indications furnished by the other two companies.
In Vibram, they have planned to work on this technology especially with the resources of the R&D department, divided in pure R&D, making prototypes and their characterizations, and tester team sector, responsible of numerical and on field verification the options provided by the pure R&D department, with a total of 7-8 people partially dedicated to this project.
In EPTAtech, as stated above, they have made a different hypothetical solution: the team could be composed by 2 people from within the company and one person from the Politecnico's team, plus some coordination activities done by professor Galimberti. The two people from EPTAtech could be an R&D specialist and a person mainly dedicated to the potential application fields of the technology.
A second aspect considered in the positioning of the Politecnico's technology in the companies is related to the objective that drive the project and, in general, which can be the fields of application for this peculiar technology.
Speaking about the expected results of the companies coming from a further development and implementation of the technology inside the firm we found a divergent pattern.
In the case of relatively smaller companies such as Vibram, the goal was wider than in the case of Pirelli. From Pitzanti, we received an answer attesting the desire to take advantage from this project in different manners, from implementing existing products, adding features and improving the

actual performances, to the creation of completely new lines of production in order to better compete in the current markets, but even enter and possibly cannibalize new markets.

On the other hand, the goal of Pirelli is more specific, the core target for the project is to advance the quality and performances of their existing products, they stated, "*the aim is to make compounds for improving tires*".

A further aspect examined is if the potential application industries that we highlighted in the final part of the second chapter are suitable for this kind of technology and if they can see some other potential industries. The opinion of experts in the development of technologies oriented to the creation of a final product is definitely interesting.

Interviewees agreed with us on the technology's potentialities, approving the hypothetical application sectors that we identified. They added that, being the technology "high level in the value chain", the potential applications are wide. It is difficult to determine which one could be a profitable application sector at this state of evolution of the technology. Thus, it is necessary to see how is adaptable on a specific problem in a definite sector to assess its probability of success in that field.

The interviewees are experts in the technologies' development process, but they are specialized in the sector to which they belong, so, as stated by Pitzanti, their "*opinion on other application sectors might be inconsistent or, at least, it should require some additional confirmations from experts closer to those fields*". The enlargement of the interviewed experts can be a further improvement to our study, adding opinions from people in different businesses and in different positions along the value chain.

Anyhow, all the interviewees declared their interest in, and the appropriateness of, NanoCarbonUp for their business.

3.3.2.3 Technology state of the art and timeline

To understand the actual state of evolution of the company we investigated if, to introduce the technology in the company, was it necessary to proceed with a feasibility analysis or, on the other hand, the technology has already reached that progress required to be implemented inside the company.

We collected two answers attesting the sufficient progress in the technological development and a third one, from Vibram, more prudent, assessing the necessity for a feasibility analysis. It is possible to conclude that the valuation on the state of evolution of a technology is not objective but contextual, it depends on many circumstances, what can be good for a company can be not enough for another one.

Coming to the specific, Pirelli provided us a precise picture of the state of the art on the introduction of this technology and made known that a first feasibility analysis was positively concluded. The next step for the industrial introduction of a new material/technology is an experimental activity, firstly on a laboratory scale and then on a pilot scale, in order to identify the potentiality of the technology itself, declined on the reality of the products and processes actually available.

The second aspect investigated in this section is the future of the technology and its developments. Basically, how much time is required in order to see some products based on the NanoCarbonUp technology present in the market.

The answers clearly were connected to the ones provided to the previous question, since the time remaining to complete the passages to land on the market are associated to actual level of development. Consequently, for the companies considering the feasibility analysis as a not necessary step, the time horizon to enter in the market with a finished product is much more defined and shorter.

In the case of Pirelli, they are oriented on a period that could vary from 2 to 4 years.

EPTAtech expects to launch a first series of finished products within a year. According to Fontanesi, "*the introduction on the final market of the technology is very time-consuming and it is composed of two steps: first, the proper introduction of a new ink made of a certain functionalized material, then the client in turn has to bring to the final market a brand new product*".

In contrast, Pitzanti, said that the time horizon is not determinable yet, because, at the moment of writing, they have not achieved a sufficient maturity with regard to commodity products (not high-range and luxury), and, until now, they do not see outlets in the channels where they make products (quite poor even of technology). Until the product and the technology applied to it do not really make a difference to the customer, the time to get to the market is not quantifiable.

We proposed the question about the time required to reach the market also to the academics, since they may give some additional insights on the state of the art of the technology from those who better know it.

Professor Citterio asseverated that it is a very complex discourse, with a broad scope. NanoCarbonUp technology has a major flaw, collies with much older carbon compounds, there are many companies that have similar technologies already oriented to products with their market.

It should be identified the niche of application that is so specific as to make it penetrating and then expand. Nevertheless, without the niche is very complex. For instance, in the Politecnico, a method of production of carbon allotropes, after seven years and at least three attempts with companies to develop the technology in an applied way, has not yet been able to find an area of application that is as specific and unique as to make the technology necessary.
Carbon technologies are highly studied worldwide, so introducing something so specific that it becomes necessary is not simple. In this case, it is essential to find companies that have the specific niche where products of this kind can give a quantified margin in economic terms for the company and on which to engage a broader initiative. Anyhow, Professor Citterio is quite confident that this technology can have success but cannot quantify the time required to do so.
Professor Barbera said that the technology is ready to be introduced in the market, because it gave rise to nine different patents, and these patents have been thought for some technical details that the companies are attempting to solve.

3.3.2.4 Advantages coming from the adoption of this technology

Here the focus was oriented on the theme of sustainability since, as vastly exposed in chapter 2, the ISCaMaP group has in the sustainability one of the main pillars of its work. Additionally, this specific technology is based on eco-friendly substances and the process of production of serynol-pyrrole is non-toxic and non-dangerous for the environment.
Assumed that the technology is sustainable, we asked to the interviewee if this factor, that is becoming every day more important in the nowadays business world, could be positive for their business as well.
For all the interviewee the theme of sustainability is relevant and, from the answers, we had the opportunity to understand better why. For instance, Pitzanti said, "*in Vibram, our attention to sustainability is relatively young, but we are working a lot on it, because it can guarantee both advantages in terms of image and in terms of compliance to regulations, that are becoming stricter and stricter*".
In general, Fontanesi's statements corroborate this hypothesis, but there are no or little image benefits, in his opinion.
A second positive aspect of the technology that we analyzed with the industry interviewees was related to the features that can make this project a General Purpose Technology. As exposed in the first chapter, a General Purpose Technology have to respect three main elements to be called a GPT:

pervasiveness, continuous improvement and innovation spawning. Precisely, we asked if, in their opinion as industry experts, the NanoCarboUp technology respects the three features characterizing a General Purpose Technology, and, consequently, if it can be considered a GPT.
The answers have been generally positive, in addition, the interviewees attempted to apply their case to the three features, as in the case of Pirelli. They responded, "*It is a technology for modifying an important component of composites, so it can be considered general purpose and highly pervasive. The technology has then to be developed in specific sub-fields of application to identify the actual potential, on the finished product the expected effect is of continuous improvement*".
Pitzanti remarked that almost all the new technologies at the beginning of their lifecycle have to respect, at least partially, those three characteristics, because without them is quite difficult to land on the market with a final product. The generality of a technology emerges with the ability to maintain the three features during the development of the products based on that technology. At the same time, he agreed with us on the potentialities for the NanocarbonUp technology to become a GPT.
Fontanesi presented the problem that NanoCarbonUp is going to solve (stably disperse huge amount of carbon in aqueous solutions) as one of its main characteristics of generality. In addition, the possibility of a continuous co-development with Politecnico lay the foundations for its continuous improvement.
Finally, we asked which could be a fair valuation of the project and the amount of resources, time and money that the company might be available to spend on this project.
Vibram and EPTAtech showed a significant interest in the project, while Pirelli was more conservative since they answered that the value should be evaluated after the detailed experimental phase in the laboratories and pilot programs.
In Vibram the answer was that they are already spending a big part of their R&D budget on this category of projects. They are attempting to reach improvements of the soles related to the introduction of different categories of carbon allotropes, so they are already structured to spend money and resources. In case of positive feedbacks from the feasibility analysis, they can invest significantly in the project.
EPTAtech is willing to invest, but they do not have a precise business plan yet: some funds have been allocated but it is not clear yet if and how much they could be enlarged.
We posed the same question about NanoCarbonUp as a GPT to the academics and we had a positive acknowledgment, as well. Professor Barbera confirmed, "*one of the greatest advantages of this*

technology is the versatility". She revealed that since the beginning the idea was to create something pervasive, so, applicable in more than one field.
Moreover, the peculiarity of being pervasive of NanoCarbonUp technology emerged even more with the advancement of the project, because, during the years, working with companies, they found that such technology had a high capacity to spread, as it seemed to acquire new value and meaning.
On the other hand, Professor Citterio answered that, to some extent, it is pervasive because it could be applied in very different fields, from coatings to reinforcement of materials, to characteristics of electrical and thermal conductivity. But it must be confronted with many technologies and competitor methods. The two are true both, NanoCarbonUp is pervasive and can be improved systematically, but it is also true that it is not easy that it is from the beginning.
However, professor Barbera underlined a further advantage of the technology, in her opinion the most important one. She asserted that the "*ease of execution is the first value of such technology. Depending on the technical problem or the application, we can find a suitable, specific and adapt solution.*"
Professor Citterio replied that it is difficult to give a valuation now because we do not know yet how wide it will be, it is necessary to introduce on an applied ground in order to then be able to leave them for further evaluations.
Some aspects that can make it valuable are, for example, the possibility to convey controls of thermal and electrical conductivity, which are two measurements that are generally not easy to do with many materials, especially plastic compounds. With NanoCarbonUp you can have a much finer measurement than what is currently being done.
The other sector is that of structural materials, for uses of reinforced property control, release of components in a controlled manner that are requests, but in this direction is not the only technology and therefore must absolutely have a comparison assessment to be able to decide if this has significant advantages over the others.
The concept expressed above is clearly linked to the one of pervasiveness and adaptability of the technology to multiple fields and problematics.

3.3.3 Section 3: University role in the technology transfer process

3.3.3.1 Which are the tasks of the university?

The first and maybe most important question that we posed in this section was related to the expectations on the role of the university in the development and its function in the transaction process from theoretical environment to actual utilization in the industrial field.
From the interviews to industrial experts, we had quite similar feedbacks, but also some specific insights from the different companies.
The university role in the upcoming steps of the technology evolution is to sustain and help the company in the process of better understanding the potentialities and possible expansions and applications of NanoCarbonUp technology as "*subject matter experts*", using Fontanesi's words. Universities have almost no role in the commercialization and product development process since these competences are mainly spread within the company.
Specifically, Pitzanti told us, "*finding the right division of tasks is not easy at all, since burdens are flexible and the interactions between the two parts are delicate. Companies know final product features while the university better handle the filler structure. Anyhow, a strong and frequent exchange of information and ideas is surely positive, even if the on the academic side we may give a little or no help in the product development*".
Pirelli suggested some useful insights, because, in their case, the role of the university should be to help the R&D department with the goal to gain the conformity of materials obtained in the R&D department both at lab and industrial scale. Moreover, the university can have a function even in the continuous improvement of the technology, for example trying to apply it to different categories of carbon allotropes.
Academic experts answered the same question. Professor Citterio made known that the goals of university and industry are often misunderstood and then, in the end, many initiatives fall. The philosophy that he adopted is of building a big direct relationship, so, if there is a new development or a problem to be solved, the company is immediately involved to carry on together the project.
The logic of the university is and must be to make proposals, to quantify at the scientific level that they are not saying preliminary analysis but already sufficiently advanced, and to intuit the potentialities. But "*it cannot be the university to take care of the production, it must be translated into something that someone accepts as credible for its development and this aspect is complicated*". For example, with Pirelli, several projects have been successful because, having a consolidated relationship, academics are able to understand the problems at the level of manufacture and final products and therefore to go back up to the solutions on the row material level.

3.3.3.2 Why this match and not another one?

We tried to find out why, both for the university and for the industrial company involved, should be useful starting a common project.

Firstly, we asked to industrial experts why the university should be interested to initiate a common process with their company.

Giannini, form Pirelli, said that the project started from the very beginning with the aim of a collaboration with the university. The ability to implement it to the industrial scale can bring benefits to the company and to the university. Specifically, it could be a good signal for other companies interested in developing a project with the supervision of the university. It could also give an "industrial" validation to the theoretical concepts elaborated by the ISCaMaP group, according to both Fontanesi and Giannini.

Fontanesi put it in some kind of "philosophical" terms saying, "*the final objective of the university should be aiming to see our projects realized into final products, sold on the real market*".

Another point emerged with Pitzanti is that working with their company could be a great advantage for the younger members of the Politecnico's research team because they may gain the opportunity to be hired in future by Vibram. This last aspect highlighted is an advantage not only for the university but also for the company that has the chance to build a priority channel in the recruiting process.

In Vibram, they stated that, excluded the opportunity to create a preferential channel for the recruitment process, they do not have clear expectations upon the beginning of this specific collaboration.

On the other hand, in Pirelli and EPTAtech, they are looking for some specific competences in a partner and, in this case, in Politecnico. They are seeking specific competences not owned in the company, vision on technological and scientific trends also in fields apparently distant from that of tires and inks, reactivity on the problems related to the introduction of new materials.

Fontanesi put on the table a crucial point: he said that companies expect innovative and brilliant ideas from universities, but Italian ones mainly focus on basic research, more than applied research. This is a huge problem nowadays, because on the company side there must be an individual capable to bond together the basic technology developed by the university and the potential applications, otherwise it would lose its potential value. Politecnico itself does not do more applied research than other universities, in Fontanesi's opinion. "*To find this applied approach, you have to look abroad. Especially Finland, which I know*" stated the General Manager of EPTAtech.

In parallel, we questioned the academics on their expectations from the company involved in the project.

We had some significant and different elements that emerged. Professor Citterio remarked, "*the important thing is to identify the right person within the company to talk to. It is essential to have someone who understands the needs of the university, to what extent the university can arrive, so as not to misunderstand the objectives. It is much more important to have a person with rather advanced knowledge available to listen and understand who then transfer within the company and propose to the core, rather than having a direct contact with the core*".

Professor Barbera, speaking from the academic side, divided the required characteristics of a potential partner company in two elements, chronologically separated. Firstly, they require technical support, while in a second moment the most important condition is the availability of monetary resources to further progress the inquiry.

3.3.3.3 The university role by functions and under different points of view

Which are the activities and expectations that the university must respect, comprehending the role of the academic technology transfer office, the role of the university as research team and, finally, as institution?

The TTO, technology transfer office, has a crucial role in the academic research management, because, if it fails to complete its work, there is the same dramatic effect that happens when an R&D department in a company is not able to transfer to the production a technology when the moment is arrived.

Fontanesi remarked how the Italian TTOs are relatively young, and mainly focused on negotiation aspects, rather than on promoting their technologies. They should foster a greater interdisciplinary. "*It's almost impossible to see just a university professor and his patent, with no need for any other help from other fields to see his technology actually applied to final products*". Again, this is a major issue in Italy. Nowadays, an individual could not bring an innovation just on his own, there is a clear need for interdisciplinary. This point works for collaboration among companies as well, not just between universities and companies.

From the research team, the requirements are related to the specific competences that the academic experts can bring to the company team. A deeper knowledge on the process of functionalization and a wider vision on the general trends than the company, that is more oriented on the main market in which it operates.

Finally, the university can help transferring the knowledge and expertise coming from different projects in different subjects but with some underlying common features. There are some situations where the partner company could also play the role of a sort of "supplier" to the university: for instance, the Politecnico Electronics department may have some innovative idea about stretchable electronics and EPTAtech could be his knowledge supplier.

A project done in communion with the university, and Politecnico in particular, can bring some advantages to the companies even from a reputational point of view.

It is not the main reason to start a project with the university for our industrial experts, but some positive side effects may emerge sometimes.

While Pitzanti make known that a collaboration on a research project with Politecnico might guarantee to Vibram some fiscal advantages, the EPTAtech General Manager stated that fiscal benefits emerge every time when co-working with public entities, not only with universities.

In particular in Italy, thanks to the "Credito di Imposta su Ricerca e Sviluppo", – an incentive program for R&D launched by the Italian previous government – doing research is rewarded from a fiscal point of view. They both agree on reputational benefits stemming from a collaboration with universities.

A further aspect emphasized by Pitzanti is that working with universities may offer the possibility to the company to create new contacts and projects with other firms collaborating as well with the university. In the specific case of Vibram and relatively to this project, thanks to the contacts with professor Galimberti they took part to a common open call with Politecnico and other three companies.

To conclude this section a statement by Pitzanti can attest the importance of the cooperation with a university for a company, he said "*the advantages are several and in different fields, and their impact is quite relevant*".

3.3.3.4 Historical feedbacks and previous collaborations

Once analyzed the requirements from the future and actual collaboration, a couple of questions about previous experiences of the interviewees with different universities, and Politecnico specifically, have been posed.

All the experts attested that their companies have already done more than one project with some academic partner.

In Pirelli they have carried out several projects and they have a strong tradition of collaboration with Politecnico di Milano, always with positive results.

In Vibram, Pitzanti asserted that, since the short time that he is working in that company, he does not know the results or positive and negative aspects of a collaboration with a university, for his new company. However, talking about the current experience in collaboration with Politecnico, the feedback is definitely positive, since the cooperation "*have enriched us as pure knowhow and, also, it has opened us new doors for further research*".

Fontanesi, before moving to EPTAtech, had the possibility to work with two projects with two different universities: University of Milano – Bicocca and University of Salerno. In particular, with University of Milano – Bicocca, the path followed to introduce the new technology was to own a share of equity of the startup that have been created in that situation. Both projects had negative outcomes, mainly because of the lack of interdisciplinary approach. Both the technologies proposed by the two universities were extremely basic and they needed the contribute from different disciplines to reach the final market.

The expectations from Politecnico, besides the reaching of the market with relevant volumes and the economic success, is to see a little bit more of this interdisciplinary attitude.

Academic experts answered to two similar questions, precisely if they had some previous experiences of projects promoted with the support of an industrial company and which have been the results, positive and negative aspects of such eventual experiences.

Professor Citterio clearly had many experiences of collaborations with companies and made us an example: two years after graduation they put in production a chemical product that is still in production now. It was the best way to do it at the time and it still is. The goal was to find simpler, more compatible, more environmental friendly processes. This, when you reach, give birth to projects that are robust, which can be kept active with small modifications, with a long life on average.

Other projects are much more contingent, for example with pharmaceutical companies some have gone into port and others have remained at the level of the "interesting but there's nothing they can do about it".

Professor Barbera declared, "*In my previous experience as university researcher, I had many opportunities to cooperate with different companies and the results have been generally positive thanks to the generation of knowledge exchanges between the two parts, university and industrial company*".

3.3.3.5 Technical details

This final subsection aims to build a deeper understanding on the patent management, so, how it is possible to protect the universities requirement to publish, compared to the companies' necessity to keep secret the most important elements and processes of the technological procedure, in order to maintain the competitive advantage on the market.

A second aspect that have been inspected is merely technical, it is related to the patent office utilized to protect the technological process, if there is one office internal to the company or if external offices have been used.

About the first issue, all the three industry interviewees said that usually there are no problems related to the necessity of the university to publish, if there is the desire to find the right compromise and the cards are put on the table since the beginning of the project. Since in this case the relationships seem to be good, it should be easy to find an agreement on what can be divulgated and what cannot be.

Relatively to the patent office that the companies usually adopt the interviewees gave us different responses. In Vibram they have their own internal office and the usage of that office is a "conditio sine qua non" for them. In Pirelli they have an internal structure that manage the process of securitization of the technology but sometimes they, the internal function, ask for the intervention of external figures loyal to the company. In EPTAtech, on the contrary, they use an external lawyer, which is a usual supplier of this kind of activities. However, they are willing to evaluate another potential solution with Politecnico.

On the academic side, professor Citterio declared, "*the companies are very reticent, when the idea works and is good, they tend quickly to keep it for themselves, but this method of licenses is one of the few ways guaranteeing a real innovation and a quantifiable advancement*".

3.3.3.6 Questions to academic experts only

As anticipated in the introduction paragraph on the academic interviews, in this final subsection we present the findings of the four questions posed only to the academic experts.

The first of these questions is about how it is possible, from the university side, to ensure the continuous development of the technology even after the beginning of the common project with a company.

Professor Citterio stated that it is a problem of the TTO: it has to give the right information to the companies in order to persuade them to invest, but without giving up more than necessary. A solution can be with a form of license that is not exclusive, but something that allows the innovation to be introduced in multiple companies. It is not trivial, because companies are very keen to have exclusive access, in 90-95% of patent cases of Politecnico with a company, at the end, the propriety of the patent is of the company. At Politecnico they always try to have at least permission to continue to develop if the patent is not more of interest to the company.
The second question is about the control that the university have on what is produced at the end of the project, in terms of production but also of economic results, in terms of royalties for instance.
The answers clarified that, especially in Politecnico di Milano, the control on the final production is really good, because there is an efficient technology transfer office that accompany the inventors from the patenting to the research of potential partners until the industrial production.
Professor Citterio has always tried to ensure that contracts are never annual, but at least three-yearly, to ensure that there are people who create skills on that subject. This made possible to obtain publications, recognitions and companies have arrived at peaks that lead them to want to bring technology to industrial level.
The third question is related to the steps coming after the agreement with a potential partner, so, specifically, if they keep doing joined research with the company or if they switch to another area of study.
There is a deadline above which no longer agrees, an innovation to be innovative cannot exceed 3 years. They often work on 4-5 themes at the same time because on 5, a maximum of two go in port.
The final question presented to the academic experts only, was if there is acknowledgement about the activity done by, and the merit of, the university and by the single researcher considering the existing Italian rules.
Professor Barbera declared, "*On paper, yes. One of the three missions of the university is to foster economic growth, through the transformation of knowledge produced by research into knowledge useful for productive purposes. Indeed, this is partially true, because in order to make a good career in the university environment we are asked to publish our research and it is impossible in presence of patents*."
Professor Citterio said that the economical return is not so big, but with medium-long term contracts with the companies, around three years, it is possible to develop new patents on that topic if it is interesting and made some publications.

3.3.4 Section 4: Future developments

3.3.4.1 Restrictions and difficulties in the transfer of the technology

One of the potential problems emerging from the introduction of a technology not invented within a company concerns the diffusion of the new technology itself, once the development has been completed, and the possible resistances from those people that were working with the old technologies.

It is possible that some problems or malcontents emerges when a new technology substitute the older one. This happens particularly when the new technologies come from outside the company, but, once is undoubtedly determined that it is better or more promising than the old one, it is generally accepted and everybody starts to work and focus on the new technology.

In Pirelli they have highlighted another reason why the new technologies may cause problems.

New technologies lead to resistances related to the risks arising from lack of experience on what is new. This is handled by building specific experience on a laboratory and pilot scale and scaling the introduction on an industrial level beginning from relatively uncritical products.

The second question is related to a specific problem of outsourced technologies with respect to internally developed ones: the “Not Invented Here” (NIH) issue.

According to Fontanesi, this *“NIH syndrome may be stronger within big MNCs than within smaller companies. This because individuals of a small company actually have its best interests, while within MNCs need to emerge and the environment is more competitive*.”

Giannini said that “*no material technology is "drop in": each business function and production unit must contribute to develop specific aspects that allow at least potentially to avoid the negative NIH syndrome – the contributions of each must be recognized and encouraged – in Pirelli there is for example a premium system for new patents*.”

Pitzanti said that in Vibram, when the outsourced technology is superior to the internal ones under every point of view, it cannot exist the problem of NIH and, even if somebody is resistant to the new technology, the introduction continues as well, because the main goal of everybody have to be the best for the company.

Fontanesi presented some instruments to keep NIH syndrome under control: incentives and prizes for new patents, “reputation rewards” – that is the official recognizing of the contribution, and so on. "*Of course, if the NIH issue arises on the R&D responsible of the big MNC, then it may be very hard to handle*", said EPTAtech General Manager.

3.3.4.2 Agreements with the university and other firms

Here we firstly investigated the opportunity to extend the relationship between the company and the Politecnico, with further R&D agreements in which the company may contribute developing to a higher level the technology and not only focus on the commercialization path.

The feedbacks have been quite positive. For instance, with Pirelli there is already an R&D agreement that attests the role of the company in the commercialization of the NanoCarbonUp technology, but also the continuous improvement in partnership with the activity of the academic research team. EPTAtech as well is planning a three-year cooperation with Politecnico about this project, with the possibility to further extend the collaboration to other areas, such as electrically functional inks.

In Vibram, the answer has been positive too, but for a different reason: keep working with an institution such as Politecnico di Milano can guarantee those several advantages highlighted in the previous subsection.

Then, we inspect the practicability of forming alliances and agreements with other companies about this technology.

Responses have been divergent. Pirelli's feeling about this possibility was quite negative, since they declared that generally is better to avoid such activities, except for cases in which the relative markets are clearly identified and non-overlapping. On the other hand, in Vibram the opinion was that, not only this kind of agreements are accepted, but are also advised, maybe because of the smaller size of the R&D department workforce and resources. Thus, they have the opportunity to spread the costs and the fields of research.

Fontanesi advises this possibility too, at least regarding this project, because there is a sort of supply chain to create. "*EPTAtech is a chemical formulation company, not a chemical synthesis one, so a synthesis step to functionalize materials is required. We have already identified a potential partner*".

CHAPTER 4: CONCLUSIONS

In this section, we summarize what we main findings of our research work, on how it is possible to enhance the technology transfer and commercialization of the NanoCarbonUp technology and on which are the best paths to this end.

The first two chapters set the theoretical background and the context of application of our research. Specifically, in the first chapter, we surveyed the literature on GPTs and the TT mechanisms between firms and universities. In the second chapter, whose style resembles that of an industrial report, we describe in detail the NanoCarbonUp technology developed by ISCaMaP group.

From the first two chapters, relevant aspects emerged, such as the current trend of business model innovation towards the GPT, the concept of Market for Technology, and the fundamental characteristics of a GPT. Then the concept of technology transfer and its methodologies, the comparison among licensing and spin-offs, and the Bay-Dole Act. In addition, chapter two highlighted and explained the concept of functionalization, which is crucial to understand NanoCarbonUp. Then the concept of sustainability, alongside with the Green Chemistry, the circular economy and the importance of bio-based products have been clarified.

In chapter three we applied the knowledge about GPTs and TT, which we have learnt in developing the first chapter, and the knowledge of the application domain we have acquired by developing chapter two to gain novel insights on the issues under investigation through direct interactions with academic and industry experts.

We describe in this chapter the relevant elements emerged from the case study presented in the third chapter, highlighting the interesting insights that the experts interviewed gave us. For instance, the great pervasiveness of NanoCarbonUp that makes it a GPT, or the NIH syndrome. Moreover, licensing has been identified as the most suitable path for the commercializing of NanoCarbonUp and we discussed the relevance, the value and the readiness of the technology to get to the final market. Finally, we demonstrated the mutual need for firms and universities to continue to work together, after the licensing of a technology. Moreover, experts often advise agreements among firms because companies that operate upward in the supply chain may need partners from downward to reach the market, or maybe firms with small R&D departments will need support.

After having analyzed the evidences stemming from the interviews, we conclude by discussing the limitations of this research and, in connection to them, we presented the possible developments of our work.

4.1 NANOCARBONUP IS A GENERAL PURPOSE TECHNOLOGY

In our opinion, NanoCarbonUp is a GPT, possessing the three fundamental characteristics: pervasiveness, continuous improvement, and innovation spawning.

We discussed this issue with the interviewed experts, who share our opinion. In particular, they highlighted the great pervasiveness of the technology and the fact that it has a considerably high importance in the value chain, since it is upward in the supply chain and its potential value added could be applied to many different fields. Likewise, they mentioned that it is not easy to assess the potential of this technology because of its position in the supply chain, since it is difficult to predict the results of the potential final products ex ante.

The experts also have positive opinions on the continuous improvement of the technology. All the interviewees stated in their answers that they want to continue to advance the technology, together with the university, to find new applications for existing and new products, new allotropes to functionalize and to continue the research of market niches for NanoCarbonUp technology.

A further consideration on the generality of this technology is connected to the applications that the companies made of the technology itself. We proposed some possible application domains including: solve technical problems, improving existing products, creating new products and enter in new markets. In the case of relatively smaller companies such as Vibram, the focus was wider than in the case of Pirelli, because in Vibram they want to adopt NanoCarbonUp for all these reasons, while in Pirelli only to solve a technical problem. This analysis helped us to understand that the technology is adapt for a variety of scopes, making it even more pervasive.

Finally, we shared with the experts the applications sectors that we identified in the last part of the second chapter, asking them if, in their opinion those could be good targets for the technology. All the answers stated the appropriateness for the application sectors highlighted.

From the academic side the idea was that it can become pervasive but, at least at the beginning, it is necessary to find the right niche to land on the market and then expand.

For these reasons, we concluded that NanoCarbonUp can be properly considered a General Purpose Technology.

4.2 INSIGHTS ON THE PATHS TO COMMERCIALIZE NANOCARBONUP

Probably, the most important topic treated in the interview guide relates to the choice among the diverse channels through which a firm can introduce a new technology developed by an external third party, in particular by a university. This is the central tenant of this thesis.
More specifically, we proposed four alternative technology transfer channels between industry and university, considering the most relevant among those discussed in chapter one, asking them to reflect upon the most advantageous ones. These paths are licensing, academic engagement, use of equity and foundation of a start-up; experts converged on the idea that the most preferable one is licensing. Indeed, every potential industrial partner that we asked mentioned the licensing option as the preferred one, but there were various reasons beyond their choices. As the experts said, "*licensing and co-development are preferred if there already is a patent or the support from university is still necessary*", like in the NanoCarbonUp case. In addition, the strong preference for the licence methodology is due to the features of this particular technology, which is at the right level of maturity and it is just a component of the final product. In other contexts, the best possible path might be the use of equity or the creation of a start-up, for instance, when the technology is ready to be launched quickly on the market.
The more virtuous is a company the more is prepared to interact with the university in different manners and to adapt to the necessities of the university. Larger and multinational corporations can be less flexible compared to smaller companies as emerged by the answers of Pirelli, which preferred the licensing channel but has shown a much lower degree of flexibility with respect to the possible channels to integrate an outsourced "component" technology.
From the academic side, we had the same feedback on the preference on the license system, indeed Professor Citterio attested that almost all the agreements done by Politecnico di Milano are done with this scheme for several reasons, such as the possibility to work with different firms in case of non-exclusive agreements. The proper moment to give a licence is when it is necessary to scale up from the laboratory scale to the industrial scale.
It seems clear, from the information collected, that the most appropriate channel to reach the market for NanoCarbonUp technology is through a licensing system; moreover, it is in accord with the plan originally thought by Professor Galimberti and even with the personal opinion of the writers.

4.3 IS THE TECHNOLOGY READY TO LAND ON THE MARKET?

A further important aspect that we analysed in the case study is to estimate the level of readiness of the technology to satisfy the needs of the markets.

According to the experts we interviewed, the technology is extremely promising and ready for transfer to the R&D departments of different industrial companies, but not, at the moment of writing, to be used in the production of final goods. The time required to complete this last step varies across firms, depending on their knowledge and financial possibilities, of course.

We can say that the technology is promising because all the potential partners that have been listened agreed on their interest in the features and advantages of the technology and, either they already are cooperating with the university on this project, or they are intentioned to start a collaboration. Furthermore, as explained by Professor Barbera, the technology has already given rise to eight different patents, and each of these patents has been done in order to solve an industrial need.

From the academic side there is agreement on the appropriateness of the timing to interact with the industrial context because, in order to understand if the technology will never become successful, it is necessary to find some firms willing to invest in it, creating the right niche for a future expansion on a wider scale and different markets.

However, according to the experts the technology is not ready for the introduction in the final products. The time required to reach the market varied company by company: one year in the case of EPTAtech – a considerably short time horizon –, 2 to 4 years according to Pirelli, while Vibram set the time horizon as "indeterminate", because the technology is not even close to the resolution of their requirements at the moment.

A further element that can give some insights on the state of evolution of NanoCarbonUp technology is the necessity of a feasibility analysis prior to the introduction inside the firm's projects. Clearly, those who were oriented on a shorter time horizon to land on the market were also less interested in the feasibility analysis, indeed, only Vibram expert thought it was necessary.

From this qualitative evidence, we can conclude a "one size fits for all approach" of the evaluation of the state of evolution of a technology is not possible, but it depends on many circumstances: what can be good for a firm does not necessarily fit the one. For NanoCarbonUp we conclude that, in general, the state of advancement of the technology is considered rather high, since in 2 out of 3 cases, the time horizon to see the technology in a final product sold on the market is lower than four years and no feasibility analysis is required.

4.4 RELEVANCE OF THE TECHNOLOGY

The case study investigates also some topics that permit to understand the value added provided by the technological advancement offered to the actual industrial context.

To direct question, all the experts interviewed declared that the NanocarbonUp technology operates in a field that is of general interest nowadays.

All the industrial experts agree that the technology is of interest for their firms both from a technical point of view, like in the case of Pirelli, and from a commercial point of view, as in the case of Vibram. In particular, Vibram has identified the application domain of the technology in climbing shoe's soles, a segment where an improvement is strongly required by their customers.

Another element speaking in favour of the relevance of this technology is the amount of resources that firms dedicated to its development.

Here, we can notice different patterns attributing different level of importance to the development of NanoCarbonUp. In 2 out of 3 cases, there will not be any resources totally dedicated to this project, in a sort of task force, but it will be integrated in other functions of the company. On the other hand, in EPTAtech they would opt for the creation of a new team collaborating with the original Politecnico's team. However, in those cases where resources are just partially dedicated to the introduction and development of NanoCarbonUp, it is forecasted to allocate 7 to 8 people. On the other hand, when resources are fully dedicated to the task, the total amount of people allocated is lower, 2 to 3 according to EPTAtech.

A final element considered to understand the technical relevance in a commercial environment of NanoCarbonUp is that we had a testimony from Pitzanti that in the Vibram case they were already doing research on this topic, even before knowing the research project of Professor Galimberti.

An important insight comes from Professor Citterio, who said that this technology touches on a field that is one of the most studied, and that there are several other technologies that can be considered similar, so, in order to gain value, it has to demonstrate to be superior, at least in some features to the competitors. A field in which it is really promising and potentially diverse from the rest of technologies is in the measurement of thermal and electrical conductivity, while when used in structural material it can be a good technology, but it is difficult to see the real difference from other similar technologies.

From these elements, we can recognise a discrete to good relevance of this technology, intended as the single technology and the whole area of interest, but not top-level relevance in the plans of the companies, moreover it can have a differentiating power in thermal and electrical measurement with respect to the existing technologies.

4.5 THE VALUE OF THE TECHNOLOGY

We have asked which could be a fair valuation of the technology to the industrial experts. They ensured a significant interest in the project, because Vibram and EPTAtech asserted their conviction to invest relevantly in a project based on NanoCarbonUp technology, while Pirelli replied that in order to give a fair valuation of the project it is necessary to wait until the detailed experimental phase in the laboratories and pilot programs were conducted.

We were unable to obtain a numerical valuation of the technology, but we can appreciate a relevant value given to the NanoCarbonUp technology by all the potential industrial partners.

The sustainability is another aspect to consider, it is relevant in the 2 out of 3 cases, since for EPTAtech is only a positive "secondary effect", but it does not give great advantages, if not in the compliance to regulations that are stricter and stricter. For the other two companies it is another relevant characteristic adding value to the technology.

Further aspects that help to understand the importance of the technology for the companies is the amount of resources dedicated to the project, that, as wrote before, is quite high, especially considering the small-medium dimension of companies such as EPTAtech and Vibram; and the desire to continue to invest on this technology.

4.6 "NOT INVENTED HERE" SYNDROME IS AN ISSUE

In the "Restrictions and difficulties in the transfer of the technology" section of chapter three, we presented Fontanesi's idea about the Not Invented Here syndrome. He said that this phenomenon might be, in his opinion, stronger in big multinational companies, rather than in smaller firms.

According to the responses of the other interviewees, we may say that this assumption could have some solid grounds. Indeed, about Vibram – which we can consider the "smaller" company – Pitzanti said, "*When the outsourced technology is superior to the internal ones under every point of view, it cannot exist the problem of NIH*". While Giannini presented this syndrome as a real issue in Pirelli, talking about the need to have every single function and business unit going in the same direction and talking about the ways to make it happen.

From the academic side as well there was agreement on the potential problems coming from the NIH syndrome, for example Professor Citterio mentioned that he always try to build a strong direct

relationship with the company and to start working with the company at an early stage to avoid this problem.
However, all the respondents agreed on the instruments that help to avoid, or limit at least, the NIH syndrome. The crucial point here is to recognize and encourage the contributions of every individual, both in monetary and reputational terms. In the first case, through salary incentives and bonuses or a premium system for new patents, as suggested by Giannini; in the second one, through the official recognizing of the contribution within the company.

4.7 IT IS NECESSARY TO CONTINUE TO WORK TOGETHER

It emerged from every interview that a continuous collaboration is needed to constantly improve the technology features, from its introduction to the commercialization. All the interviewees, both on the academic and industrial sides, agreed on the role that the university should play in this continuous collaboration process: the university must be the “subject matter experts”. Although this collaboration necessity was expected, it is noticeable that this is true not only for relatively smaller companies, but also for large corporations such as Pirelli.
In addition, continuous collaborations help the interaction between the universities and the firms; thus, it is easier to handle the needs of the academics to publish together with the secrecy requirements of firms. Another benefit from this facilitated interaction is the possibility, from the university side, to exploit the partner firm’s knowledge for other purposes.
It also emerged that, if the university can guarantee a certain level of collaboration, providing its specific technical competences that the firm could not assure by itself, the possibilities of further collaborations on new projects increases.
According to Professor Citterio, in Politecnico the objective, is to obtain a contract of three years, because it is the right time horizon to understand the potentialities of the technology, develop other patents on the same subject and make an appropriate amount of publications. Moreover, when the duration of a project takes more than three years it is difficult to define it as an innovation, in the Professor’s opinion.
If the continuous collaboration is a kind of implicit request of the industrial partner to universities, and universities are prepared and able to satisfy this need, it has been highlighted from the previous experiences of the interviewees a point where the academic entities may progress: inter-disciplinary. As we have already mentioned, the lack of inter-disciplinary is a major issue, especially in Italy, nowadays. This linked with the fact that Italian universities mainly conduct basic, not applied

research is one of the causes of failure of joint projects between universities and firms, and some of the presented experiences of the experts corroborate this evidence.

The most important thing is to find the right person inside the company, who is able to understand the needs and objectives of the university and transmit it to the firm members, intended as workers and core functions. This is the so-called “gatekeeper”, who is a kind of intermediary between the university and the firm, facilitating the introduction of the newly invented technology.

4.8 FURTHER AGREEMENTS AMONG FIRMS

Talking about the feasibility of creating alliances and agreements with other firms, we identified two different potential patterns as well. Once again, it relates to the size of the firms and their respective R&D departments.

Smaller firms with smaller R&D departments not only admit the possibility to form alliances and cooperate with other firms, but sometimes they advise it, such in Vibram case. On the other hand, big multinationals like Pirelli prefer to avoid this kind of activities, also because they usually do not need help from the outside. Occasionally, when relative markets are clearly identified and non-overlapping, they may consider the possibility of further agreements with other companies.

Sometimes, as in EPTAtech case, this possibility is advised, not concerning the size or R&D department size, but as a matter of supply chain. Companies that operate upward in the supply chain will often need partners from downward to reach the market.

Table 19: Summary of the main findings

Key message	Description
NanoCarbonUp is a GPT	NanoCarbonUp is a GPT, because it possess all the three fundamental characteristics: pervasiveness, continuous improvement, and innovation spawning. Both the industry experts and the academics confirmed this thesis.
Licensing is the most suitable path of commercialization	All the experts agree that licensing is the most suitable path of commercialization for NanoCarbonUp. Both "*licensing and co-development are preferred if there already is a patent or the support from university is still necessary*", such as in this case.
NanoCarbonUp is not ready to be introduced in the final products	According to the interviewees, the state of advancement of the NanoCarbonUp is rather high, since 2 firms out of 3 forecast the time horizon to see the technology in a final product sold on the market as lower than four years, with no need for a further feasibility analysis.
Relevance and value of the technology	All the industry experts agreed that NanocarbonUp operates in a field that is of general interest nowadays. However, different disposal of resources and effort are proposed. We obtained different answers regarding a fair evaluation of the NanocarbonUp technology: some of the interviewees confirmed their will to relevantly invest in the technology; some opted to wait until the detailed experimental phase in the laboratories and pilot programs were done.
Not Invented Here syndrome	The interviewees agreed on the ways that help to avoid the NIH syndrome. The crucial point here is to recognize and encourage the contributions of every individual, both in monetary and reputational terms
It is necessary to continue to work together	The continuous collaboration is a kind of implicit request of industrial partners to universities, and universities are prepared and able to satisfy this need. On the other hand, the lack of inter-disciplinary is a major issue, especially in Italy, nowadays.
Further agreements among firms are often advised	Smaller firms with smaller R&D departments often advise the possibility to form alliances and cooperate with other firms. In addition, companies that operate upward in the supply chain will often need partners from downward to reach the market.

4.9 Future developments and limitations

We describe in the following the limitations that should be taken in consideration when approaching to our work and the potential future developments resulting from them.

A first limitation to consider is that our study is concerning only the specific case of NanoCarbonUp, so a potential evolution of this work is to include it in a wider study that aims to analyse other cases of technology transfer from universities to firms. This would be useful in order to find the diverse drivers and consequences of technology transfer and the determinants of this choice.

The relatively small number of interviews constitutes another limitation to this study: a greater number of interviews would have guaranteed a more precise indication to key messages we have drawn from our analysis. The subsequent constraint is about the questionnaire: the greater the number of interviews, the greater the possibility to improve and adapt to specific cases the interview guide. We thus welcome future work, which enrich the set of interviewed experts, both from the academic side and the industrial side to amplify the knowledge base, the expertise and the set of opinions that contributed to add the value to this research work. This new set of interviews should be conducted in different stages of the evolution of NanoCarbonUp, so that it may be studied its trajectory, analysing the achieved results and how it arrived to that condition, comparing it with the presentation that we made "ex ante", in our case study. With this kind of analysis, it would be possible to understand better which are the steps and the modes for the final part of the commercialization from the firm to the final consumer in the open market.

A further development is the depth and breadth of this study. Both in the first and in the second chapter it is possible to enrich even more the literature reviewed, in order to present a more complete overview of the arguments treated in the thesis. In particular, the information concerning the existing solutions for the functionalization of carbon allotropes, presented in the second chapter, may be amplified. This might present a limitation to this work.

We could spot another limitation to this work in the lack of fieldwork observation. We did not engaged into direct observation of firms that were adopting technologies coming from academic institutions, let alone observed the subsequent implications within the firm. This would have constituted a considerable boost to our thesis, but it has not been possible due to significant amount of time, but also that such activity would have required. However, this type of collection of qualitative data through fieldwork observation represents a potential development to this work. To do so, it will be required the introduction of an observation guide, similar to an interview guide, specifying the location/time/date of the note, positions/names of people under observation, peculiar actions or events, and initial interpretations and impressions of the events and activities under inspection.

In addition, a possible future evolution is to enrich the case study in the third chapter adding some additional numerical data on the results of different commercialization paths, since our study is mainly qualitative. This kind of quantitative data, in terms of number of technologies that opt for a commercialization strategy instead than another and even average economical results of the different options, may be collected from primary sources, such as surveys, or from secondary ones, such as patents.

To sum up, this thesis concerns the specific NanoCarbonUp case. Thus, it should not be used to formulate a general commercialization strategy for technologies invented within the academic environment and it should be integrated into a broader study to get a kind of “certification” status. Nonetheless, this work could be a useful starting point for further studies concerning the technological transfer from university to firm.

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APPENDIX

Questionnaire 1: addressed to the industry experts (in Italian, as posed to the experts)

ANAGRAFICA CLIENTE

1. A quale funzione appartiene?
2. Qual è il suo ruolo nella funzione?
3. Descriva brevemente il processo di inserimento di una tecnologia sviluppata in università all'interno della sua azienda. (attori e funzioni interessate, diffusione e comunicazione in azienda, previsione di sviluppo continuo anche dopo introduzione…)
4. Quale ritiene che possa essere il miglior path di inserimento di una tecnologia sviluppata in università all'interno dell'azienda?
5. Noi abbiamo identificato 4 principali soluzioni: *licensing*, *co-development*, *start up*, *equity*. Potrebbe elencare quelli che per lei sono i punti a favore e a sfavore di ciascuna di queste soluzioni?

NANOCARBON UP TECHNOLOGY

6. Era a conoscenza di questa tecnologia? Se sì, da quanto tempo?
7. Lo ritiene un ambito sensibile e interessante? Perché?
8. Il progetto dedicato a questa specifica tecnologia sarebbe integrato in una funzione aziendale o sarebbe un corpo a sé stante all'interno dell'azienda?
9. Quante e quali posizioni ricoprirebbero le persone all'interno dell'azienda dedicate a questo progetto? Sarebbero totalmente dedicate (task force) o solo parzialmente?
10. Quale sarebbe l'obiettivo dell'introduzione di questa tecnologia? Risolvere un problema tecnico, migliorare i prodotti esistenti, arrivare a nuovi prodotti, aggredire nuovi mercati?
11. Per la tecnologia in questione, pensa sia più appropriato procedere con una feasibility analysis oppure la tecnologia appare già matura per un progetto più a lungo respiro?
12. Noi abbiamo identificato questi possibili settori evolutivi, sono percorribili a suo modo di vedere? Perché? Gliene vengono in mente altri?
13. Quali potrebbero essere le tempistiche per lo sviluppo e introduzione sul mercato di prodotti contenenti questa tecnologia?

14. La tematica della sostenibilità è molto rilevante oggi giorno, lo è anche per la sua azienda? Uno degli elementi "strutturali" di questo progetto consiste nell'utilizzo di materiale eco-sostenibile, lo considera un valore aggiunto per la sua azienda?
15. Un altro grosso vantaggio di questa tecnologia è la versatilità: la ritiene un'innovazione *"general purpose"*? Perché? Che grado di *"pervasiveness", "continuous improvement"* e *"innovation spawning"* riuscite ad identificare in questo processo tecnologico?
16. Quale ritiene possa essere il valore dell'innovazione tecnologica proposta? Quanto sarebbe propenso ad investire in un progetto con questa tecnologia (in termini di tempo, denaro, risorse…)?

RUOLO DELL'UNIVERSITA'

17. Quale sarebbe il ruolo dell'università in questo processo?
18. Perché l'università dovrebbe essere interessata, a suo modo di vedere, a investire in un progetto con la sua azienda?
19. Viceversa, cosa cerca in un partner per lo sviluppo di una tecnologia, in particolare il Politecnico?
20. Che livello e che forma di collaborazione cerca dall'università, intesa come ufficio di trasferimento tecnologico?
21. E intesa come team di ricerca?
22. E intesa come istituzione? Ad esempio, può portar benefici d'immagine, sgravi fiscali…
23. La sua azienda ha avuto modo di sviluppare altri progetti con università come partner?
24. Quali sono stati i risultati? Aspetti postivi e negativi? In particolare, con il Politecnico?
25. Quali sono le aspettative da una possibile interazione con il Politecnico?
26. Come si tutela la necessità dell'università di pubblicare?
27. Con quale ufficio brevettuale si segue lo sviluppo dei brevetti alla base della tecnologia? Ve ne è uno interno? L'ufficio brevetti deve essere concordato fra università e azienda o l'azienda ha già i suoi, fidelizzati?

SVILUPPI FUTURI

28. Una volta completata lo sviluppo, come viene curata l'accoglienza / diffusione della tecnologia in azienda? Vi potrebbero essere resistenze da parte di coloro che curavano e curano le vecchie tecnologie?
29. È possibile tenere sotto controllo la sindrome negativa del *"Not Invented Here"*? Quali strumenti possono essere identificati (scheda incentivi, premi per nuovi brevetti…)?
30. È prevista la definizione di accordi R&D con l'università (oltre a quelli di licensing)? Potrebbe essere intenzione dell'azienda voler fare sviluppo continuo della tecnologia, oltre che curare la sua applicazione?
31. Si potrebbero definire accordi con altre aziende?

Questionnaire 2: addressed to the academics (in Italian, as posed to the experts)

ANAGRAFICA

1. Qual è il suo ruolo nel team / dipartimento?
2. Secondo la sua esperienza, quale ritiene che possa essere il miglior path di inserimento di una tecnologia sviluppata in università all'interno dell'azienda, se presente?
   Ne abbiamo identificati principalmente quattro: *licensing*, *co-development*, *start up*, *equity*.

NANOCARBON UP TECHNOLOGY

3. Secondo lei, quali potrebbero essere le tempistiche per lo sviluppo e introduzione sul mercato di prodotti contenenti questa tecnologia?
4. Un grosso vantaggio di questa tecnologia è la versatilità: la ritiene un'innovazione *"general purpose"*? Perché? Che grado di *"pervasiveness", "continuous improvement"* e *"innovation spawning"* riuscite ad identificare in questo processo tecnologico?
5. Quale ritiene possa essere il valore dell'innovazione tecnologica proposta?

RUOLO DELL'UNIVERSITA'

6. Quale, secondo lei, sarebbe il ruolo dell'università più appropriato nel processo di introduzione della vostra tecnologia in azienda?
7. Come si tutela lo sviluppo della tecnologia licenziata?
8. Si ha controllo reale su quanto venga prodotto (royalties)?
9. Si continua a fare ricerca congiunta o si passa ad altro tema?
10. C'è riconoscimento per il docente / ricercatore dalla luce delle regole dello Stato? Se no, cosa suggerisce?
11. Che livello e che forma di collaborazione cerca dall'azienda partner?
12. Ha già avuto modo di sviluppare altri progetti in università, con aziende come partner?
13. Quali sono stati i risultati? Aspetti postivi e negativi?