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3D PRINTING FOOD: THE SUSTAINABLE FUTURE

Master Thesis

Environmental Management and Cleaner Production (621H7002)

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You could look at nature as being like a catalog of products, and all of those have benefited from a 3.8 billion year research and development period. And given that level of investment, it makes sense to use it."

Michael Pawlyn
1. Summary

English

Nowadays, eating food is a normal activity in our style of life. Actually, most of us do not realise about which are the processes till food arrives to our dishes. However, is the supply chain balanced? Is all the food resourceful? Will this situation change or not on the further years? Does supply food chain work correctly? Which are they problems and how to solve them?

From this background, it has recently appears on the media 3d printing technology, described by many scientists as a new revolution of the industry. With this technology is possible to manufacture whatever piece or instrument, where the only border is the imagination.

Crossing this limit, printing 3D food idea is presented. However, what does 3D printing food mean? How do 3D printers work? Will this technology fix the actual situation and improve the future? Is somebody investigating and doing research on this area? Which impact will have 3D food?

In conclusion, during this thesis 3D printing food will be assessed from the point of view of a life cycle assessment and a sustainable perspective.

Español

Hoy en día, comer es una actividad normal en nuestro estilo de vida. De hecho, la mayoría de nosotros no se dan cuenta acerca de cuáles son los procesos hasta que la comida llega a nuestros platos. Sin embargo, ¿es equilibrada la cadena de suministro? ¿Es toda la comida aprovechada? ¿Cambiará esta situación, o no, en los siguientes años? ¿Funciona correctamente la cadena de suministro de alimentos? ¿Cuáles son sus problemas y cómo resolverlos?

A partir de esta situación, ha aparecido recientemente la tecnología de impresión 3D en los medios de comunicación; descrito por muchos científicos y entendidos en la materia como una nueva revolución de la industria. Con esta tecnología es posible fabricar cualquier pieza o instrumento, donde la única frontera es la imaginación.

Cruzando este límite, se presenta la idea imprimir alimentos en 3D. Sin embargo, ¿qué significa imprimir comida en 3D? Cómo trabajan las impresoras 3D? ¿Será esta tecnología capaz de arreglar la situación actual y mejorar el futuro? ¿Está alguien investigando en este área? ¿Qué impacto tendrá la comida 3D?
En conclusión, durante esta tesis la impresión 3D de alimentos será evaluada desde el punto de vista de una evaluación del ciclo de vida y una perspectiva sostenible.

Català

Avui en dia, menjar és una activitat normal en el nostre estil de vida. De fet, la majoria de nosaltres no s'adonen sobre quins són els processos fins que el menjar arriba als nostres plats. Però, és equilibrada la cadena de subministrament? És tot el menjar aprofitada? Canviarà aquesta situació, o no, en els següents anys? Funciona correctament la cadena de subministrament d'aliments? Quins són els seus problemes i com resoldre'ls?

A partir d'aquesta situació, ha aparegut recentment la tecnologia d'impressió 3D en els mitjans de comunicació; descrit per molts científics i entesos en la matèria com una nova revolució de la indústria. Amb aquesta tecnologia és possible fabricar qualsevol peça o instrument, on l'únia frontera és la imaginació.

Creuant aquest límit, es presenta la idea imprimir aliments en 3D. Però, què significa imprimir menjar en 3D? Com treballen les impressores 3D? Serà aquesta tecnologia capaç d'arreglar la situació actual i millorar el futur? Està algú investigant en aquesta àrea? Quin impacte tindrà el menjar 3D?

En conclusió, durant aquesta tesi la impressió 3D d'aliments serà avaluada des del punt de vista d'una avaluació del cicle de vida i una perspectiva sostenible.
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2. Introduction

2.1. Research problem

3D printing food is being investigated and researches are being developed on this area. 3D printing is presented as a new option and the next industrial revolution. Thus far, somebody thought, why not printing 3D food?

Nowadays, the whole world population increase and the forecast is about 9 billion people will need to be feed at 2050. However, how would be the future if today the world situation is not balanced? Therefore, if food supply chain is not working today, the situation tomorrow will be chaotic and would be too late.

3D printing is presented such as a sustainable and reasonable option. Therefore, our objectives across the thesis are to detect which are the hotspots on the actual system and then study whether 3D printing food will bring us solutions or not. The methodology of all the text is explaining the basic concepts of environmental conciseness. Then, information about the actual world situation is given.

Afterwards, 3D food printing is introduced and different techniques used in 3D printing technology are introduced. Once the basics steps are done, supply chain is explained accurately from obtaining food through the final consumption using a life cycle assessment methodology. Also 3D printing proposals are introduced if it is possible.

2.2. The aim and the objectives of the thesis

The main porpoise of the study is making a comparison between the methods and technologies used today and new opportunities brought by 3D printing food. According to this principle aim, others take place:

1) Analysing the current situation of waste and consumption across the whole world. Detecting the hotspots of our system is needed before analysing 3D printing food. Then, implanting 3D printing food may change the system.

2) Food supply chain will be compared between traditional methods and 3D printed food. In addition, suggestions of 3D printing food ideas will be introduced in each part of the supply chain, whether it has potential. Otherwise, advices will be
suggested. Implanting 3d printing will not take sense whether the entire system does not work properly.

3) Reducing waste will be analysed in all possible areas. 3D printing food is expected to change our actual consumption point of view. Therefore, its potential should be studied.

4) The entire analysis will be discussed. Decisions concerning 3D printing food potential have to be taken at the end of the thesis.

2.3. Object of the thesis

The object of the thesis is assessing 3D printing food potential while sustainable principle is required across the whole analysis. In order to do this task, the following methodology will be followed:

1) The necessary concepts of sustainability and their tools will be introduced in order to understand better the study on chapter 3.

2) Basic information about 3D printing technology required to understand each part will be provided on chapter 4. Actual 3D printing techniques will be introduced. Then, 3D food printing researchers and equipments will be explained.

3) Life cycle assessment (LCA) is the pillar used during the study. Supply chain system will be analysed with this methodology across chapter 5. The aim is detecting what is working wrong in the system.

4) In each part, advices and suggestions will be provided. Implementations and ideas will be achieved, whether 3D printing technology has the potential on that certain area.

5) Sustainable requirements of 3D printing food will be assessed on chapter 6. Water, energy and food consumption and waste will be compared with the actual background and 3D printing food future one

6) Conclusions after the whole analysis will be done. The information will be summarized, while 3D food potential is discussed.

2.4. Statement

1) 3D printing food will be introduced at huge scale during the following years.
2) 3D printing food technology has more potential in industry applications than householder field, on a short range of time.

2.5. Introduction to food waste

“One-third of all food produced for human consumption on the planet, about 1.3 billion tonnes, is lost or wasted each year, according to the Food and Agriculture Organization report of the United Nations prepared by the Swedish Institute for Food and Biotechnology” (Web, 2013).

Every time we go to malls or supermarkets, we are absolutely sure we find food if that is our intention. Every day some activities are done in order to supply our fridges. These are included in the technical word called supply chain. On this sector, there take place management activities which ensure us that food is in the commercial places when we need to refill our kitchens.

Starting since this scenario, it seems that there is not any reason to take care about this issue. Nevertheless, is enough food to feed all the whole population in the world? The answer probably is an agreement, because it seems we produce a huge amount of food per year, in order to supply everybody. Perhaps, the question does not focus on the real aim. Thus, let's change a bit it: is the actual situation balanced?, in order words, is all the food available in all the world as we have in the occident? Is it consumed properly, or we waste?

In this case, it changes to a completely disagreement because supply chain is unbalanced. In many places of the world, obtaining water or food is a challenge and not the whole population has access to food with the same opportunities. Therefore, we live in a low efficiency situation between the consumption and production.

Food is wasted in all the ensemble parts of supply chain. The concept starts from agricultural production till the final consumer’s householders throughout all the processes and transports that food has between opposite sites.

Just to introduce some details, in all the occidental countries still available food is thrown away. It is calculated that between 25% and 50% is the amount of food that is lost in all the process since the food is tasted by the householders. In consequence, that means that we just not only lose food. We lose all the resources that they are needed to produce food and it results into a non good economic performance.

Nevertheless, some studies say that we may produce more food than today in the future. The arguments are that the population will increase a lot in the next following
decades. In contrast, many large and important companies do not realise about all the raw material which they waste. The solution is not to produce more amount of food, otherwise convert our production and consumption point into an efficient with a better performance. Even that, the solution seems to be difficult.

On one hand, the competiveness works in a framework where all the companies try to innovate with technology and new products or ideas. Their aim is to obtain good economic results as soon as possible. Nevertheless, many times these processes do not take care about impact on the environment and they just improve the economic efficiency owing to the business and the environmental point seem to conflict each other.

On the other hand, the environmental taking care practices have been rising these years. It is linked with social progress and sustainability processes. This behaviour restricts the processes which pollute, wastes materials and generates harmful residues.

Nowadays, food is produced on large agricultural and farming areas and industrial process. Then, food is brought to the householders via management activities till the shops and big supermarket areas. According to (Colin, 2013), there are two frontiers or limits in the food crisis while industries develop economic activities: environment and cultural aspects.

First of all, it is noticed that in our shops is possible to find food from other foreign regions which is imported. Few years ago, the available food was just seasonable and regional. Thus, useful technologies (such as freezing or cooling) help to keep the food in good conditions and allow transport of vegetables and fruit. For instance, transporting chicken using a truck needs an efficient cooling system inside it. Otherwise, the temperature inside arise too much and the animals die. Therefore, without this technology was not possible to transport life animals in large routes...

Secondly, the cultural impact is relevant. In most of the countries, the food is considered something more relevant than just food that we must consume in order to survive. Some costumers try to eat healthy food. This is a cultural behaviour that is gaining strength, this lasts few years.

Food has evolved to other points of view. Food is considered like a way to obtain new sensations or flavours. Appraising food consist on analyse its properties such as taste, softness, toughness...even exist some prizes that recognize good chefs or restaurants.

Other costumers seek easy ways to cook. These are brought by the manufactured and process food. The industry gives them the opportunity to feed themselves without having previous cooking knowledge.
Summarizing all the concepts described till now, the most important issue is friendly environmental activities. Whether it is damaged, the production, transport, distribution and feeding will not be possible. In consequence, dealing with cultural, industrial activities which look for rather economic performance, and implanting improvements are “hot spots” in order to ensure sustainability.

Experts said that whether waste food is not controlled the whole population will be in difficulty. All the above concepts commented mean an economic issue. Economic fluctuations are the consequence, which explains us what happened or is happening now. In order words, whether the world population will increase the following years, we will need more amount of food. Production will increase as the same way as the costs. Increasing production means to rise costs, thus is better to manage the actual production in order to avoid rising food prices.

According to (Colin, 2013), the actual cost will higher than today in 30%-50%. Moreover, the prices had increased owing to the food speculations, the recent bio fuel companies which recently start to buy vegetables like cereals in order to create alternative fuels like biodiesel. Then, transesterification process uses raw material to produce combustible.

2.6. Overview data waste

It is said that one picture values more than thousand words. Therefore, let’s introduce some information that could describe the situation more accurately about food waste. First of all, we will introduce some data from UK country, in order to begin to understand the magnitude issue.

“The amount of food wasted per year in UK households is 25% of that purchased (by weight). The avoidable food and drink wastes are thrown away for two main reasons: 2.2 million tonnes is thrown away due to cooking, preparing, or serving too much; and a further 2.9 million tonnes because it was not used in time.” (Colin, 2013).

Moreover, 7million tonnes of food and drink are thrown away every year and it represents the 19% of the total purchase food and could fit in nine football stadiums. In addition, 4, 4 million tonnes of those could have been consumed. It results in a 17 million tonnes of CO₂, (adapted from lovefoodhatewaste, 2014).

Comparing the waste per capita between Europe and North-America against Sub-Saharan Africa and South/Southeast Asia, the first one is 95-115kh/year and the second
one is 6-11kg/year (Office of Knowledge Exchange, Research and Extension - FAO, 2011, adapted). Thus, industrialized regions waste more than other regions.

As we introduced, the supply chain involves all the activities that they are necessary since the food is created till is wasted in our dishes. Each step is connected to others. In consequence, whether one step does not work efficiently, the process will not have good performance, and the efficiency decreases. In order to understand the situation, we will explain the key causes that make the process inefficient.

Explaining a bit the economic reasons that bring us to this situation, it is seen that during last century the progress in agriculture and the food industry has increased. It means that the industrialized countries developed enough technology to improve food production. Moreover, the quality has increased together with the availability amount of food; in consequence, the prices have decreased.

The situation could be seen doing a comparison between the past with the actual scenario shown in figure 1. When the time increase the consumption increases. In addition, the general consumption increases whereas, the percentage of consumed food decreases. In conclusion, in this country the performance of the supply chain has decreased.

When we talk about waste, first one is necessary to analyse the economic and social behaviour. This is a useful tool in order to identify the problem and take the appropriated decision. Classifying waste, we deal with three different kinds of countries: non-developed countries, income-countries and developed countries.

Figure 1: Food consumption as a percentage of final domestic consumption and total amount of final domestic consumption in Italy

Source: (Barilla center for food and nutrition, 2008)
Firstly, non-developed countries have limited financial and technical resources. The low level in technology makes hard to maintain the food in good conditions after the handling process. It complicates agriculture performance developed in short area. Many times, it is deficient and when buildings and infrastructures like roads are not in good conditions. Moreover, the weather conditions damage harvests because there do not have tools to prevent the situation. Finally, the absence of management and logistic activity complicates the supply chain.

Secondly, we have the rest of the regions. Transitional countries have greater technology and access to them. Management is more developed than the others and provides greater performance, avoiding in many cases waste looses.

On the other side of the coin, the developed countries have all the suitable conditions to produce and distribute food efficiently. However, production is higher than the real amount needed. In consequence, part of the production is not sold and it is thrown away. Summarized with the logistic and management looses, makes waste too much high. Therefore, these countries need a consciousness of waste. Low price of food makes that people do not care about waste. Often, the food is not valuated enough. In figure 2 is appreciated the amount of food which is lost every year in some European countries.

**Figure 2:** Food consumption of some countries.

**Source:** (Barilla center for food and nutrition, 2008)
Checking some information about the world will help to understand the unsustainable situation of food management in the world. In order to do this task, taking a picture of some interesting information would help.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>885,837,388</td>
<td>Undernourished people in the world</td>
</tr>
<tr>
<td>1,600,324,381</td>
<td>Overweight people in the world</td>
</tr>
<tr>
<td>533,441,461</td>
<td>Obese people in the world</td>
</tr>
<tr>
<td>17,435</td>
<td>People who died of hunger today</td>
</tr>
<tr>
<td>$ 271,316,777</td>
<td>Money spent for obesity related diseases in the USA today</td>
</tr>
<tr>
<td>$ 107,779,336</td>
<td>Money spent on weight loss programs in the USA today</td>
</tr>
</tbody>
</table>

**Figure 3:** Some World food Statistics. Picture took at 26/11/2014 13:40 (UTC+02:00)

*Source:* (worldometers.info, 2014)

Linking with the classification above, the information given describes a bit the whole consumers which they live nowadays in the whole plantes. Looking around the actual population data in the world, it is 7.276.963.362 people and the overall population growth is 125,323 people at 26/11/2014 at 13:27 (Addapted from: worldometers.info, 2014).

Making conclusions about figure 3, on one hand almost one billion of people are lacked of food. On the other hand, two billion people in total are under non suitable weight. Summarizing people undernourished and overweight people we obtain a result of 3 billion people. These 3 billion people are in unbalanced situation according to food consumption. Simplifying the current world population to 7 billion people, we obtain an approximate result of 40% unbalanced people in food issue.

To sum up this overview, there is a stunned contrast. On one hand, there are people who are not available to obtain food and even have healthy problems. On the other hand, overweight people are 2, 4 more times than undernourished one. In consequence, the actual situation is lacked of a good distribution. There are parts of the world which have more food than the necessary, while others are lacked of it.
3. Sustainable knowledge

3.1. Background

Nowadays, we are living in a scenario where the actual crisis is felt in the whole world. It seems to be a malfunction caused by the behaviour of our economy style. This one is the consequence of some facts that bring us to this situation. Therefore, some of the main pillars that are unbalancing the system are:

1) The increase of the population during these last 30 years. In consequence, the demand of energy and resources such as raw materials has increased. Moreover, the trend is continuing to increase during the next 30 years with a final growth of the energy demand in a 56% more than today. It would be as a result of the income countries such as China or India, which they are in development ways.

2) No reasonable and uncontrolled use of raw materials. “Our current global situation: Since the 1970s, humanity has been in ecological overshoot with annual demand on resources exceeding what Earth can regenerate each year. It now takes the Earth one year and six months to regenerate what we use in a year”. (footprintnetwork, 2014).

This means that we are exceeding the biocapacity of the environment: water, forests, fauna, food… Therefore, whether our wasting behaviour is going in that way, one day the environmental resources will not be enough to give us the necessary amount to subsist.

3) Environmental degradation caused by economy activities. Our habits and style of life are strongly linked to our social-economy view. In order to maintain our waste, it is necessary to develop economic activities providing us the resources we need.

The problem falls in that most of them damage the environmental media. This is caused owing to there is a non-balanced situation between cost and environmental sustainability. In other words, some company activities are considered that them are more profitable whether it pollutes than deal with the impact.

All of these “hot spots” are the causes of the environmental crisis which we are suffering. Actually, this one may be separate in two parts. On the one hand, we have a global environmental change represented by all the changes that we may appreciate in
climatic conditions, hydrology issues and biologic aspects. For instance, the hardest ones are: the greenhouse effect, desertification, pollution of air and water media, acid rains, toxic or radioactive scraps...

On the other hand, we have the social global change leaded by the globalization phenomena. News happened in one country arrives at the other part of the world in just few minutes. The media and all the technologies we have and we are still developing, brings us amazing opportunities. Even though, the world is interconnected and important incidents occurred affects at least some neighbour countries. It is provided by new telecommunications and transports ways, biotechnology research, computer science and dangerous weapons that have been created since the incidents on the WWII.

Secondly, there is economic issue. The economy has changed from an independent to interdependence and global one. Moreover, the world production has been multiplied per 20 since the beginning of the XX century while the waste of fossil combustibles such as, coal, petrol, gas... is following an exponential function, so the waste has increased too much this last 60 years. (Source: Adapted and translated for Universidad Alcala de Henares)

After the Second World War some countries grew fast. However on the decade of the 70’s was needed a restructuration of the productive process because of the petrol and energetic crisis that we suffered. Afterwards, on the decade of the 90’s the globalization phenomena appeared since nowadays where the interdependence all over the world is present. Moreover, the distance between rich people and poor people becomes every day larger.

Finally, there is the social and political situation. Nowadays, we live in an uncertain background where everything is possible. During these last 30 years, appeared a migration from the country side towards large cities and the women’s role became important, fortunately. Moreover, international institutions play an important role in our society. However, the conflicts have increased and this fact creates insecurity.

Between all this backgrounds, it was being developed the environmental conscience. Humanity has been changing the behaviour and the concept against our activities and the environmental impact. Nowadays, the demand is increasing in energy and resources. In addition, these resources are becoming limited, the prices rise and our energetic dependence grows constantly.

In order to prevent these situations and take care about the resources that we find in the environment, we design and improve methods which take care about it. The final aim is not to waste and use resources wisely and preventing environmental damages.
3.2. Environmental Conscience

Traditionally, the industries have been used end-of-pipe methods. In order words, they prevent that the residues from the process will be realised to the environment. However, these techniques just pass the waste’s process into another media and they do not fix the problem. Even though, it is possible to distinguish clean processes and heavy pollution processes.

For instance, in water treatment plants that they use reverse osmosis, it is extracted salt by diffusion in membranes. However, it is needed to remove these ones after certain time and the energetic demand that this equipment needs is so high. The reason is that the salt gets inside the membrane and obstacles the correct separation.

Another example is the use of scrubbles. They are good separating dust that some gases streams have. Despite of that, like in the example given above, the dust remains in the filters and is needed to remove again using new ones after some time. In the same line, we have other methods such as activated carbon. This has a large specific area of separation per amount of mass that can separate. The problem becomes when it is needed to clean using thermal treatment, which consists on an oxidation of all the material that was inside.

Nevertheless, the examples given take part in the list of friendly environmental process and good measures. Dirtier one is for example incinerators. This facilities burn the garbage and residues using kilns. During the processes the material is being oxidized because of the high temperature that is inside the oven. Then, some polluted gases such as \( \text{CO}_2, \text{CO}, \text{NO}_x, \text{SO}_2 \) are released. Last ones are produced whether the process is not designed correctly. Even though, it is not possible to avoid them completely. Then, it is needed an end-of-pipe method that will separate the particles.

New environmental strategies consist on giving solutions to the causes that we commented. Thus, the new goals are: reducing raw material and energy consumption, the residues decrease or implanting some green systems. This concept will improve the final production, where we will lose less material during the process.

Focusing on environmental managing tools, there are two main ways to deal with pollution and emissions: command and control and economic instruments. Both deal on changing the behaviour of waste towards a sustainable point of view, reminding companies that whether they use water, air... this means they waste.

Summarizing concepts, an economic instrument brings the tools to analyse risk and appraisal of an improvement. Thus, the aim of an environmental implantation is to make the
environmental point a suitable part on a business. In fact, they are used in decision-taken management or appraisal. Implanting new technology or improvement requires some steps. They have to be followed in order to obtain good results and to ensure good practices during the processes.

3.3. Sustainable development

3.3.1. Overview

Environmental and sustainable management involves dealing with sustainable processes. The main goal is to ensure economic activities, which involve industrial processes, will not degrade the environment while production will not be damaged. In addition, increasing productivity, decreasing consumption of raw materials and energy, implanting feasible investments in technology, arising competiveness or improving performance, are facts which take part in the analysis.

The importance of an environmental assessment has to be considered. Focusing on the environmental costs is possible to obtain benefits. The porpoise is reducing or avoiding costs while the final products or others profitable processes are not affected. In order to rectify them, it is useful to elaborate analysis and studies with indicators that will show the profits to company’s investors and stakeholders.

Acting on the economic environment of the company, usually gives improvements on the account. For instance, linking the environmental management with commercial department is a way to act in social aspect. First of all, the image of the company improves because its processes are respectful with the environment. People usually enjoy that. The reason is that some company which takes care about pollution respects the air and the resources is looked in a better way by the society. Thus, costumers and investors would be more interested in spend their money in the cleaned company.

When some measures have been taken by a company to obtain more environmental efforts measures, the performance could be analysed. Identifying four accounting costs is a way to ensure that one environmental implementation will be efficient. Those are:

1. Expenditures for environmental protection measures, which includes all the information used by the company with the porpoise of dealing with environmental issues.

2. Potential savings. It determines which “hot-spots” could exist in the process. It is related with energy, raw resources and residues generation performance.
3. Cost accounting for investment decisions. This one takes part of the decisions taken department and it is important to determine whether one future implementation will be or not profitable, and how the company will finance the cost of the investment (own capital, loans, shares...)

4. Internalization of external costs. This accounting consists on dealing the costs caused to others in the company own account.

Talking about environmental system costs, the resulting impact of a company could take two first decisions: reduce or avoid pollutants or continuing without taking decisions. The second one often produces damage to the environment, and in consequence, it has negative social impact. Then, the costs will increase because of legislation that usually punishes pollution which goes across the limit established. Whether the first decision was wrong, it is possible to change to the first one which consists on implanting environmental protection measures and continuing with internal costs appraisal.

The information of implants will be accordingly updated and monitored. Knowing how affects these to production performance, is vital. It is recommended that new improvements have not to be plane. It is required an exhaustive analysis of how material, energy and raw materials flows works, while the improvement is being implanted. In order to implant technology or benefits, some useful tools could deal rather with decisions taken. For instance, it is possible to analyse the options using these resources: cleaner production, environmental management accounting, eco-design, preventive environmental management and life cycle analysis.

In order to reach and understand easily the aim of this thesis, we will introduce: cleaner production, eco-design and life cycle analysis. These tools will be useful to deal with the appraisal.

3.3.2. Cleaner production

"Cleaner production means a continuous application of an integrated preventive environmental to processes, products and services to increase overall efficiency. This leads to improved environmental performance, cost savings, and the reduction of risks to humans and the environment" (Jurgis Kazimieras, 2008, p.24).

Fundamentally, cleaner production is based on a continued process where the goal to achieve is good performance and works with a precaution and preventive methods. We should understand this knowledge from the point of view of non-static information. In other words, this has to be a continuous method where information is updated.
Moreover, the technique is not only included in environmental aspects and it has to be dealt in economic issues. The porpoise is to reduce waste and residues generation. In order to do this task, cleaner production tries to avoid or solve reducing the totally amount of waste since the upstream till the downstream of the process, including recycle or feedback whether is possible. The concept means to understand wasting and environmental impact like a part of costs. We should not confuse end-of-pipe control and cleaner production.

On the one hand, end-of-pipe deals with the impact avoiding those pollutants to be released to the environment. Thus, the waste is not reduced, and besides, it increases because products or equipment are needed in order to not to contaminate.

On the other hand, cleaner production improves industrial and economic performance. The benefits reached are: improving environmental situation and reducing overall costs. Moreover, the public image of the company will improve, thus, costumers and stakeholders will be more interested in the company.

However, cleaner production has some limits. For instance, financial issues will break down improvements. Therefore, it is completely recommended to follow know-how rules; otherwise, implementations will be useless. Also is recommended implanting a fluent information system between all the members of the team. The porpoise is to prevent financial and management problems.

Nevertheless, cleaner production is more profitable than polluting the environment during many years. The reason is that many of basic implementations do not require huge investments and also is possible to avoid environmental taxes or fees set by governments. Furthermore, the pollution control system is not necessary and the cost of equipments and chemicals, in order to deal with pollutants, are avoided.

To sum up, cleaner production is a useful tool when dealing with environmental costs and preventing pollution is required. The technique consists on establish a reducing implant system where inputs, process and outputs are controlled. Minimizing waste is possible to save money while the process could be optimized. Moreover is possible to improve the image of the company and it will affect the amount of costumers and stakeholders who will increase sells or invests. However, this method will not arrive too much far whether the human resources are not managed in a properly way and an efficient appraisal system is needed to be implanted.

3.3.3. Eco-design

Eco-design is an approach to design a process or a product which will be friendly with the environment. During the design, many aspects are dealing in order to not to pollute.
Some of them consist on analysing activities, processes, inputs, outputs, manufacturing, disposal etc. Designing and assessing the whole life cycle is the aim. The porpoise is thinking in each step which the product or process will and focusing accurately on to minimize the impact.

Principally, economic and environmental aspects are dealt. The correct balance between both concepts is essential like in every project or idea which will be profitable. As always, they usually are on opposite sides. Normally, environmental solutions are related with costs without profits. However, a good eco-design could find the correct balance situation. Even though, this design should have some features which includes ecological and environmental design and being respectful with the society.

According to (Jurgis Kazimieras,2008), there are four R approaches in order to prevent pollution in products: repair, refine, redesign and rethink. All of them are focused on solving certain problems. For instance, repair tries to fix the actual situation using methods like end-of-pipe. Then the second and third R improves the situation in a friendly environmental way. The second tries to increase the performance of the product, while the third one seeks materials or processes using new technology and knowledge. Finally, last R represents the useful and sustainable tool to change the product from the beginning.

Related to eco-design, the most important Rs are the third and the fourth one. Both deals the problem in the same direction and change the product or the process from the beginning. The others improve the current problem. However, it does not mean that the solution has just to be cleaned. The concept is to seek the most suitable decision which should include respectful decisions with the environment.

Making an overview to the different possibilities in eco-design we could work in four main fields: processes, materials, products and activities. Even though, in the next lines we will classify them in two fields: On the one hand, improving the actual process (first and second Rs); and in the other hand, redesign or implant a new design (third and fourth Rs).

First of all, working in processes consists on making it more effective. It is the easiest option because is just to improve the actual process without spending too much money. However, it often does not fix the situation. Products which contaminate the environment are not replaced by the cleanest ones. Then, replacing materials is a useful tool in order to substitute the harmful ones. The aim is to investigate new materials which could have the same or better mechanics and chemical features than the current one. In this case, studying the life cycle product is vital.

Conceptually, start an eco-design project is the same. The only improvement is including environmental and pollution conscience. Thus, we should ask ourselves the typical
5WH questions (What, Where, When, Who, Why and How). Answering these six questions we will be able to decide whether the idea could be considered to study or not. It is recommended to make a brain-storm in order to obtain information and establish targets, goals and defining the product.

The motivations which could be interesting to a company about eco-design are quite similar to cleaner production. The final aim is to improve the full performance and fulfil customers and stakeholders. The company has to check the actual economic internal situation and to analyse its position in the business setting. On the one hand, the internal motivations, which could be suitable to the company, are to improve production, save inputs and prevent waste while the limits established by the policies are obeyed.

On the other hand, external factors are to accomplish governmental legislation. For instance, one car has to fulfil different specifications or features in the UE than in USA. Then, whether the company will want to open new markets has to deal with these issues. Apart from that, studying the market demand is always useful. Starting a new product will not be profitable whether costumers will not be interested in, or whether the competence has developed a similar product and we will not be able to compete with them. Furthermore, the social and industrial trends will affect the developing of the product, thus, considering trends is useful in order to implant eco-design.

In conclusion, when one product is available at the market, it is needed a period of time since the company will receive benefits, in case the product is profitable. Pay-back depends on the scale of the implantation, bigger it is more time is needed to recover the investment. However, eco-design is the balance between economy and environmental taking care and also it is a powerful tool.

### 3.3.4. Life cycle assessment

"Life Cycle assessment is a methodology for assessing the environmental impacts and resource consumption associated with the existence of products throughout the entire cycle of the products-from cradle to grave. A central characteristic of life cycle assessment is thus the holistic focus on products (or the functions they fulfil) rather than on individual processes." (Jorgensen, 2000,p.156-p.157)

Nowadays, there are too many factors at the marketplace. Markets are moved by concepts such us offer and demand, profitability, being in fashion...where the costumers and companies interact each other with three main actions: producing, selling and purchasing. Manufacturers select production methods, suppliers and materials, while consumers decide whether to consume the product or not, depending on their criteria.
Nevertheless, last century started an emergence of environmental taking care conscience. Processes and products are evolving in a friendly way towards it, where the sustainability is the key to enhance the viability of a process or product. Therefore, using tools to analyse this viability of a product before his implementation is needed. In this background was born the life cycle analysis assessment.

Life cycle assessment (in forward lines called LCA) analyses the product in all his entire life and considers all the potential impacts throughout his life. In other words, it describes the product since the beginning till the end. Its aim is to describe accurately all the processes and steps needed since the product or process is created using raw materials, energy and other inputs, since it is not useful or has to be disposed, as well as, environmental issues are included. Each process is analysed covering all the environmental indicators and the industrial installation needed is appraised as well.

LCA applications could be divided in four main fields of action according to the porpoise wanted to reach: non-comparative assessments or comparative ones in existing products, non-comparative assessments of potential products, and finally set strategies in order to achieve a certain aim (adapted from Jørgensen, 2000). Using one or another is related to the type of information needed to evaluate some aspects. For instance, the second type could be useful whether the aim sought is a study of the competence, while environmental impact is implanted on the product. However, the third one will have different points to deal because it belongs to product development strategies where the product developed is not in the market. Even though, it is possible and recommended to study all the fields which are necessary to obtain success.

Apart from industrial LCA interest, there is also motivation in consumers and governments. First of all, consumers claim relevant and reliable information about what they purchase and consume. They just not seek information about when the product will be consumed. The porpoise is to obtain information about all the life cycle of the product step by step, specially focusing on disposal and raw materials.

Then, government interests are to control products will not pollute the territory. The basic concept is not to damage the resource which we find in the nature. Otherwise, humanity will not obtain resources in a non-large future. In consequence, governments control pollution establishing pollution limits. The main aim of governments is to prevent environmental damages and make contaminators responsible about their activities.

Thus far, we commented and reported how useful is LCA and which are the main areas and interested parts on the method. However, how could we structure a LCA? The answer is given and suggested by SETAC (Society of Environmental and Toxicology and Chemistry) and agrees with ISO 14040.
The life cycle assessment is divided in the next phases:

1) **Definition of the goal and scoping** of the assessment. The aim of the appraisal is to make a comparison with other hypothetic cases.

2) **Inventory** of the fluxes (inputs and outputs) for the processes that take place.

3) **Impact assessment** which is divided into classification, characterization, valuation and improvement analysis and improvement analysis.

4) **Interpretation** of the impact profile according to the defined goal and scoping including a sensitivity analysis. (Adapted from Jorgensen, 2000 p.160 and Arvanitoyannis, 2008,p.98)

Firstly, the purpose is to define the goal of LCA. On this step, the information resources are selected. The goal defines the aim of LCA and which are the features which will be evaluated. For instance, the goal may be the impact evaluation of new technique or processes implementation. Or the aim can be the environmental impact of new materials implanted in a process. In any case, the porpoise is to establish the limits where the appraisal will not deal with.

Talking about scoping, the analysed product is described by functions. The porpoise is focus as maximum as possible on the utilities of all the products compared. Then, a scheme of the process system is made in order to delimitate the limitations of the appraisal. Usually each step of the process is analyzed in a qualitatively way and the whole life cycle is detailed. Also other aspects such as timescale and criteria followed during the appraisal are made.

Secondly, during the inventory phase the collected data is related to all the fluxes which each process has. Normally, mass and energy fluxes are attached in the appraisal in order to show the processes in a better perspective than words. The quality of the information has to be trustable. The data resources have to be reliable and whether the appraisal is about an actual process is suitable to work with recent data.

Once the data is collected, the next step is doing an impact assessment. During this part of the life cycle assessment, the aim is to make an interpretation of all the available information collected. The explanations will use the scoping information and giving arguments about which changes are significant in all the studying areas.

Normally, the assessment area includes four steps. First of all is made a classification where the information in the inventory is related to the impacts. Using this method is possible to determinate how relevant or not is the inventory information in the current
problem. Secondly, the classification is characterized in order to define the magnitude of potential impacts. Characterization is based in outputs of the study case.

Then, the analysis is compared with a reference situation where the information is clear and detailed. The process is called normalization and all the information is compared with a reference in order to determine the scale of the impact. Here is presented the impressions of the relative magnitudes and is the beginning of a future suitable decision-making.

Last step of this part is to relate importance to impacts and their weights are discussed and assigned. The consequences can be related to human or environmental health or resource base. During this part is developed a cause-effect study linking emissions to their origins. However, the information given in this part is not objective at all. Determine the weight of one activity is relatively subjective. Even though, the objective data collected is incorporated to make decisions and advices.

Afterwards, the author or authors makes an interpretation. LCA gives the necessary tools to collect data used to understand the potential or actual impacts. However, without any interpretation the study given is not enough and nobody will take advantage of all the information. Thus, no interpretation or advices are written the study will not take any sense.
4. 3D printing as innovative solution

4.1. Background

Introducing 3D printing background, the earliest ones have appeared with relevance in the decade of 1980’s. Those were considered and called RP (Rapid Prototyping). The porpoise was to design prototypes in a fast way, as well as not making the process too much expensive. Then, Carl Deckard filed a patent in 1987 in the US for the Selective Laser Sintering (SLS) technology. In addition, Scoot Crum patented a new 3D printer technology in 1989. This time the technology patented was Fused Deposition Modelling (FDM).

Then in Europe, Hans Langer and his company EOS GmbH (from Germany) focused on Laser sintering (LS). Nowadays, EOS systems are implanted in industries in order to develop prototypes and 3D printing application. EOS first product was available in the market at 1990. Then, other important technologies appeared such as Ballistic Particle Manufacturing and Solid Ground Curing. (Adapted from 3D printing industry, 2014)

Thus far, we introduce the most relevant technologies in order to know the background and the origins of 3D printing technology. Then, during the last decade of the XX Century, R&D started to implant RP in industrial processes. In consequence, 3D printing technology started to differentiate in two main fields. The first one was related to high technology innovation, which is really expensive and difficult to implant in industry process.

This technology is characterized to have complex technology and engineering where the area dealt is aerospace, for instance. The second one was focused on manufacturing 3D printing systems. The aim of these investigations was developing and improving prototypes which were profitable and was possible to sell in the market, in other words, desktop machines that nowadays are in the market.

However, in 2007 3D system introduce to the market a 3D printer equipment. This has the lowest price that was seen before, but 10.000$ still was too much expensive. Even though, the technology was not good received buy the costumers as was expected. This equipment is important because many companies since then try to compete to make a site in the market. Thus, in order to sell a suitable product to the big audience, the key is to offer a product with a relative low cost in comparison with the expensive high-tech technology.

Actually, the first equipment available to purchase, which has successful results in the market, was in 2009. They introduce to the market the Rep Rap replication method. The concept is based in free development and replication. Finally, during the years 2012- 2013,
3D printers had significant changes at industrial level and their market has established and consolidated, in large part related to the Rep Rap.

4.2. 3D printing concept

Recently, technology has modified our life more than any other fields. The implantation of these new making up has improved our general status of life. However, most of them require time in order to check their magnitude and scale of change. For instance, one of the most important technologies which have revolutionized the world is internet connexion. Nowadays is impossible to imagine a society without connexion to internet.

However, the first research results appeared in 1969 when Stanford and UCL universities established a connexion between each other and was not till 2006 when the number of internet achieved hundred thousand million users. In consequence, since technology appears till is implemented and the real impact and the potential are highlighted is needed time.

On the same way, 3D printing technology is believed to change and start a revolution. 3D printing technology has started to appear breathly in mainstream and in the media. The technology is presented like the tool which will revolutionize the actual production concept.

The main concept, which 3D printed machines bring us, is that humanity will be able to print 3D objects. Printing in 3D view offers the opportunity to print whatever was not able since the technology has appeared. Thereby, the technology opens the gates to a world where it would be possible to print almost everything which technology will allow. Therefore, technology will be the only limitation. (Adapted from:Liz and Kyle von Hasseln, 2013 conference)

Furthermore, with this technology is possible to print new objects. 3D printing concept does not mean just to copy and replicate things which today already exist. Looking forward to the future, new ideas will be designed and the future seems to be great. Another advantage of 3D printing is the possibility to create objects when and wherever the owner or designer will want. Thus, managing it in a properly way, will be allow us a better control system of consumption products. Controlling the inputs will be possible to manage raw material consumption and to avoid unnecessary waste. In addition, it will be possible to manage the time processes and improve performances of the processes.

Nowadays, 3D printers work with materials such as: plastics, metals, ceramics, paper, biomaterials... Actually, materials are available in a wide variety such as: filament, pellets, resins, granules... For instance, printing plastics is useful. When polymers pieces are
manufactured using injection process, the polymer is heated in an infinite screw. Then, the polymer is injected on moulds. These are designed accurately according to the study of their flux and the contraction which it suffers at the start of becoming solid. In addition, whether production needs to change the features of the piece a new mould will be needed to use.

However, 3D technology gives the opportunity to not to use mould. Therefore, the moulds will not be needed and operational costs will decrease. The improvement will be gain freedom in processes and change them from a static production to a dynamic one. In contrast, the geometrical and flux study will be more difficult.

Generalizing, the possibilities to investigate or implant 3D printing technology are enormous. They include almost the whole industrial processes, medical resources, aeronautic etc. Nowadays, one of the most important applications of this technology is developing prototypes. However, a huge industrial scale implementation will appear early. Some scientists or experts ensure that 3D printing technology will begin a revolution.

For instance, one of the fields of implementation is medical applications. Reading this titular will help us to understand the magnitude of the technology and its possibilities:“3D printed heart replicas used to save lives of babies with congenital heart defects” (Posted in 3ders.org, 2014). Medical field is one of the most personalized one. The reason is that each person is different from the others, genre, weight, high and multiple factors should be analyzed. In conclusion, medical care systems are one of the most important areas of application.

Quite similar to medical field, aerospacial applications are grateful to receive the 3D printing technology. The development of new prototypes requires accuracy. Suitable aerodynamic profiles needs detailed designs and it could be useful, in my opinion, in doing semblance analysis (studying prototypes at small scale with the same geometry or other considerations).

More application can be applied in automotive. For instance, bumpers of commercial cars are made with polymers, copolymers or composites. In consequence, these materials are usually manufactured with injection processes, and it is necessary to design moulds, as we commented. Thus, implanting this technology will not be necessary to create moulds and costs will be avoided while design performance will improve. Going further this title will help: “I drove a 3D printed car. It wasn’t for long, and it wasn’t far, but it was a singularly awesome experience”. (Unaloff, 2014).

Furthermore, architects can implant 3D printing in order to show their buildings at small scale. After a rigorous design and analysis of the infrastructures, architects will be able to
create 3D models in a relatively easy way. Going further, some organizations are researching in printing real buildings since foundation till the tip of them.

On the same way, artists and designers can also work. For artists is a new possibility to create original art, new trends or to find new expressions. In addition, the art world will receive this technology in order to investigate ancient or not artist works. This would help artists to understand better how other artists worked. Also can be a useful tool for restorers which they will be repair sculptors or artist works more efficiently and accurately.

However, the porpoise of the companies which create and design 3D printing technology is to do business. Nowadays, there are some printers in the market but their price is expensive, and costumers seem not to have access to the technology. In this way, 3D design and developing companies should try to decrease the printers cost to make cheap the sell.

Finally, one of the most emergent applications is in food field. This technology has been implanted in research programmes and investigations are going in a properly way. Some experts ensure that 3D printing technology implanted in food would change the concept, which today we have about consuming and preparing food. Dreaming about future, it will be presented in a background where 3D printers will print dishes in a healthy, testable and succulent way.

4.3. 3D printing food concept

“A 3D food printer is a device that can be produce (any kind of) food product starting from a series of basic ingredients using printing or other deposition technologies.” (Bommel, 2012). Thus, the concept is to construct food since the beginning till the end and shape food or dishes. The idea seems easy, however, making up the technology and dealing with its implementation on equipments is a hard job to do. Research and investigation is needed to seek the answer or answers which will give us the solution.

Once the main concept is explained, the next step is answering the next question: Why would humanity print food whether it is available now? The question can be answered just thinking how can we create and improve gastronomy field. Nowadays, gastronomy involves too many aspects such as: culture, economy and sustainability.

For instance, consumers can be segmented in three levels according to their attitudes in front of parameters like price or what consumers look for on food. Classifying them in relation with the intensity of the consumption is possible to distinguish three levels: first one represents consumers who related food with culture in a strong way such as religion
believers. Some consumers have a link between which they eat in their religion. Another example can represent somebody who does not eat certain food in order to follow a diet. One case can be paleodiet based on eating like the first humans did, avoiding refined sugars such as pasta.

Second group belongs to consumers who always are interested in seek new experiences in food taste. Also they distinguish between different types of food, gastronomy or seasonable food. This segment represents a 61% of the full consumers. Somebody who takes care about the precedence and quality of food can fit perfectly in this group.

Last but not the least, 27% of the consumers belongs to who are not committed with world of food. They just want to enjoy tasting and eating food, as long as; food knowledge has less importance than their own pleasure and sustenance.

However, this is a classification is not strict and just helps to segment the market in order to distinguish possible costumers; when an appraisal is done. In conclusion, some consumers can move or mix between other groups. (Adapted from: The Hartman Group, 2014).

Another reason is the increase of population which the world is living. According to the statistics given in the 7.2 part, nowadays the situation is unbalanced. Thus, whether the whole world population will increase the problem will increase, as well. According to worldometers.info, the whole population in the world will arrive at 8 billion people on 2014.

Therefore the unsustainable situation will become worse than today. One of the suggestions is to decrease or eliminate waste, implanting 3D printing technology. Whether the food is possible to produce at the right place and few times before to his consumption, avoiding unnecessary waste during the actual manufacturing processes will be feasible. However, how imagine food of the future?

Imagine food future is a complex task. Nobody can predict the future situation. What is clear is this technology gives us amazing opportunities to create and improve new food. Everybody expects that the next food generation will be similar to the actual one, but just pressing one button of our own 3D printer in our houses. Therefore, the technology has to be able to offer us these expectations, because consumers will not accept food which will not be suitable and tasty at first impression.

In this point, also is opening a new opportunity. Each person is different in all the fields which compound a human being, and nutrition is not an exception. Depending on parameters such as activity, habits, age or genre the organism needs different diets, in
order to obtain the best healthy state and performance in all our activities during the day. Therefore, manufactured personalized food will be an excellent idea.

The most difficult concept founded in 3D printing is to reproduce food structures and flavours. Food is extremely complex. In the nature the most complex structures are proteins. They are compounded by repetitive boundaries called amino-acids. Depending on the order inside molecule and their distribution, the protein will do one function or another. In addition, these structures are really sensible to pH or temperature changes. Giving one example, when milk is overheated for a long time, the globular proteins contained in it will lose their 3D structure. In consequence, nutritional value is lost.

Another example is glucids chains. They are formed by monomers formed by glucose, basically. However, just changing one chemical bond, everything can change, even our metabolic digestion. For instance, the bond between two glucoses is made by O-glycoside bond. Thus, there are many differences between the positions where the bound is formed. The extremist situation is done between maltose and cellulose. The bond is formed in the same position of the molecule, but the only difference is the relative plane position of the other ring. In result, the first one is available for animal digestive system and cellulose is the basic structure of wood. Even though, looking medical advances using 3d printers requiring high technology and knowledge is the key.

Summarizing, in this chapter we have dealt with 3D printing meaning and we discussed this technology bring us the opportunity to print and create new food. We review its background and explaining 3D printing is able to change our growing production system. In addition, recently has started to investigate 3D printing food. 3D food is fulfil for everybody and adapted to their necessities. However, food complexity makes a difficult task creating new food.

Next step is introducing 3D printing techniques. Then, the supply chain will be analysed while 3D printing is implanted in that areas where is feasible.
5. Life Cycle Assessment of 3D printing Food

5.1. Goal definition

3D printing food is one of the most emergent applications of 3d printing technology. Thus far, 3D printing technology is really useful in all human activities fields. Moreover, all the impact and progresses, which have started during these last 4 years, seems to be a concept which we will be dealing with at recent and far future.

Therefore, the aim of the study is to answer the next question: is 3D printing technology sustainable? Is this technology feasible in order to change the actual concept of producing? Has 3D printing food the enough potential to modify all the process structure? Whether the answer is affirmative, will it reduce food waste?

The porpoise of this study is answering these questions making a comparison between the methods and technologies used today and new keys brought by 3d printing technology. This will compare the actual situation in the industry with a hypothetic implementation at huge scale of 3D printers.

In addition, impact and sustainability will be dealt with emphasis while other topics such as economic issues, social acceptation and impact will be introduced as well. Even though, the principal goal of this study is to take decisions about whether the 3D printing food applied to world food is sustainable.

Nowadays, a balanced background is need whether technology, products or processes will be introduced to the market. This background involves too many factors or features which should be accomplished if the goal is to obtain successful results. Whether one of them is not successful will not be well accepted.

Likewise to every product or process, 3D printing food has benefits, barriers and points against it. Thus, analyzing these aspects will be a suitable task in order to give reasonable information. Knowing the strengths and the weaknesses of 3D printing food, will help to understand which potential has to change everything.

Finally, the results will be discussed and analyzed to obtain answers to the above questions and extracting conclusions after all the analysis.
5.2. Scoping

5.2.1. Assessment criteria

In this study 3D printing food technology implantation will be analyse and compared against the actual scenario. During the previous pages, the importance of a good management in food waste concept was explained as well as the main environmental techniques and concepts.

Afterwards, supply chain will be explained form two different point of view: “black box draw” and processes. In the first part, the main fluxes of whole process will be explained and then, we will focus the information on accurately waste on each step.

The complexity of 3D printing is extended. To simplify the analysis, we will take the next following hypothesis:

1) **3D technology enough developed:** In the future the technology will have developed to a state where 3D printing food will compete with the actual technology.

2) **Full implementation.** 3D printing food will be implanted in industrial processes and in our homes. The price of the equipments can be achieved by the average salary of the population.

3) **Constant variables:** other areas which affect indirectly food cost will not be assessed accurately.

4) **3D printing and traditional processes:** at least the recent future will implant 3D printing in the actual processes. 3D printing will not substitute the entire equipments.

In spite of the hypothesis considered above, we will emphasis where the implementation can or not reduce waste. Other areas will be considered during the 3D printing food technology implementation throughout the supply chain. Many times, the information given will bring enough tools to understand the actual situation. Then, we will make emphasis on 3D food printing opportunities or weaknesses.

Finally, the supply chain will be introduced. The porpoise is to identify the actual and potential impacts of the supply food system and compare if the implementation of 3D printing food can solve the actual problems in food waste.
5.2.2. Printing process

The actual process of each 3D printing starts with the design of the object using a computer aided design program, abbreviated as (CAD). Using a computational program the designer is able to design with accuracy the object. However, if who wants to print is not able to use the program (because of lack of knowledge), also downloading a previous created model is an option. An aside before continuing with the explanation is these programs have not to be CAD. CAD program licenses such as AutoCAD or Solidworks are expensive. However, there are few programs like the free version of Google SketchUp or the Blender option which can offer similar features.

Once the 3D model is created, the next step is to print the object in 3D dimensions. In order to do this task, the information of the design is send to the printer. The idea is likely a normal 2D printout. The information saved inside a document is send to the printer. Then, the program manages the information and gives instructions to the printer. During this process, 3D model design is sliced into planes. The concept is to split up the design and then the printer assembles all the layers formed.

Once the printer has started to print the first layer, it is necessary to print the next one. However, how can they make in order to fix the layers and stick them each other? Layers normally are fixed using suitable binders which do not damage the functions or features of the printout. For instance, one binder used in ultimate 3D food printers is sugar and water in the first commercial 3D printing food developed by 3D Systems called Chefjet 3D printer (Jamie&Adam review of Chefjet, 2014).

In spite of all the simple way which it looks like, printing process is more complicated than just push maximum two buttons. Before the machine prints is necessary to make some adjustments. Moreover, when the printer is doing its job and the material are coming off, the work has not already done. Fluxes and printing time have to be controlled in order to obtain satisfactory printings. Otherwise, the geometry will not be the appropriate one as the 3D design.

Finally, after printing process some pieces need to be fixed. For instance, complex geometry can give problems. In some printouts with others materials, which are not food, is possible to see some defects of the object not existed in the 3D computer model. Thus, a final process is needed to remove the extra material which can be considered as a defect.

5.2.3. General Printing techniques

Talking about existing techniques in 3D printing field, there are too many different of them. Basically, 3d printers are based in Additive Manufacturating (AM). As we commented,
the main concept is splitting the 3D model design and then to assemble it again layer by layer.

Nowadays, 3D food printers are in development state and just few commercial companies have introduced printers at the market. Arriving at this point is difficult to make emphasis in a specific technique. However, the most highlighted technologies implanted in other fields like in plastics or metals will be overviewed. The current techniques are: Stereolithography (SLA), Selective laser sintering (SLS), Direct metal laser sintering (DMLS), Electron beam melting (EBM), fused deposition modelling (FDM) and Laminated object manufacturating (LOM). (Adapted from Bommel conference, 2012)

Stereolithography (SLA)

SLA converts liquid polymers or plastics into solid objects and is the first technology introduced at the market and commercialized. The stereolithographic melts photopolymers using laser. When the photopolymer is in contact with the laser, the polymer resin reacts and then the photopolymer become a solid where the reaction which takes place is called cure.

Analyzing the structure of this polymer will be easy to understand the process. Basically, there is compounded by monomers which are selected and studied in order to give physical features to the final object. Then chromophores are added to the monomers in porpoise of adding chromatic properties (colours). Afterwards, exposing the polymer to a fountain of light (UV-visible) starts a normal polymerization Many times, photoinitiators are added to start an addition polymerization, where the initiator compound starts the reaction.

Conceptually, the equipment is formed by: a UV laser, a tank where the liquid polymeric resin will be, a perforated platform inside the tank and the computer equipment to send the information to the printer. Then, the laser focuses on the surface of the liquid and the polymer starts to polymerize. When the surface is converted into solid, below the surface there is a platform. Whether this platform goes down is possible to submerge the printed solid and continuing with the process. Afterwards, pieces need manual removal.

Using SLA is possible to obtain accurate results and respecting complex geometries. However, it needs post treatments after the printing, and sometimes, the life of the materials could be affected. Moreover, the printings need a lot of time. Small objects can be printed between 6-12 hours while the biggest can take even days. Even though, the whole time process depends on 3D printer dimensions.
DLP

The process and the technology are quite similar to stereolithography. DLP works with photopolymers as well. However, during the process the light is projected to the liquid surface with the shape required of each layer. Once the surface is printed, the layer is repositioned with new polymeric material. DLP can be related more on stamping process while the SLA is more linked to drawing process.

![Figure 4: Scheme of DLP](https://thre3d.com/)

The accurate designed mirror projects light pattern of each slice of the object on the polymer surface of the liquid. When the actual layer is printed, there are two designs depending on the model of 3D printing. The first one consists on pulling up the object of the resin and the second one is pulling down the object covering the solid of resin and creating new space to stamp.

The advantages are less depth needed than in SLA. Thus, with this technique is possible to save resin and the waste is reduced. Moreover, the resolution and quality of the printing is similar while the operation times are reduced as well. However, like in SLA post treatments are needed in order to finish the object.

**Selective laser sintering (SLS) and Laser Melting**

Both technologies work with powdered material. The laser is reflected to a space where the powdered material is deposited, called bed. Then the laser traces the shape of the first layer of the object on the surface of the bed. When the laser and the material are in contact, last one melts. Afterwards, the liquid losses heat and become solid again. However, during the solidification process the particles fused forms a solid.
When the layer is already build up, the bed drops one position and one roller smoothes the surface and let the surface completely plane. The solid layer is hidden bellow the dust and the laser repeats the operation.

Talking about operation, the chamber is completely sealed in porpoise of maintenance the appropriate conditions to melt the powder. Once the process is finished, it is necessary to put away the piece. Thus, the non melt powder is removed and saved for next printings.

The advantage is bed makes easy support features. It protects the object being printed and the complexity of the geometry is not an obstacle during the process. However, the process needs heat inputs and cooling times cannot be overviewed. Moreover, the process has problems with porosity. Some parts of the bed have different densities during the process and it can suppose different amounts of material in the different layers.

Also can be applied to metals but more heat is needed because of the high fusion temperature of metals. Comparing this method against SIA or DLP, the final resolution of the pieces or objects achieved is worse than them.

**Electron beam melting (EBM)**

EBM is a process used just by Arcam company from Sweden. The concept is melting powder material inside a vacuum chamber using electron beam. The idea is quite similar to SLM despite of EBM uses a vacuum chamber while SLM uses laser in an inert gas chamber.

The process takes place in a powdered bed inside a vacuum and encapsulated chamber, in order to avoid harmful oxidation effects from oxidation. Then, the temperature is increased till an optimal point to melt the metal. Afterwards, the electron beam, controlled by electromagnetic coils, starts to print the layer. This allows a good control of the electron beam and also is possible to print various parts of the object, while an accurate resolution and good results are achieved, even if the geometry is complex. When the layer is finished, a powdered layer is spread over the printed section. Then equipment is ready to print the next cross-section of the piece.

**Fused deposition modelling (FDM) and Freeform Fabrication (FFF)**

This technology was developed by Scott Crump and commercialized by Stratasys in 1990. Recently, equipments using similar technology have appeared and are known as Freeform Fabrication systems (FFF). This word is used to refer technology which has been invented using similar technology but is not property of Stratasys Company.
The layers are built up using extrusion. The raw material is introduced into the equipment in filament shape. Then the filament is heated in order to melt the material and to transport it to the nozzle using extrusion. The material is deposited in a platform which cools and material converts into solid. Then, the platform below of the layer printed moves downward the same length than the layer printed.

However, this technique has lack of overhanging structures. In order to bring solution to this problem, a second nozzle is incorporated to the equipment. The goal of this nozzle is to add soluble water material in order to construct support material. When the process is finished, support material is dissolved in water and is removed from the object.

Obtained results are reliable and accurate. However, post-treatments are needed to obtain the characteristics desired in the piece made. For instance, whether the final product requires smooth surface is necessary to apply a surface treatment. They can be chemical treatments or mechanical methods but FFF has less accurate models. Moreover, there are adhesion problems between layers, sometimes, and operation times are slow.

**Laminated object manufacturating (LOM)**

LOM works layering sheets of material and sticking the slices using glue. When this step is done, the printer cut the shape of the cross section and no needed material is removed. Finally, another sheet of material is deposited on the layer already printed. The first step is laying the material on the plate, adding the amount of glue required on the sheet and distributing it properly. Finally, another slice is put it on the surface and gets stuck.
applying pressure, while a tool similar to a knife cuts the shape of the new layer.

**Figure 6: Draw of LOM**

*Source:* (https://thre3d.com/)

Talking about object features they are: “Objects printed using LOM are accurate, strong, durable and generally show no distortion over time which makes them suitable for all stages of the design cycle.” (how laminated object manufacturing works, https://thre3d.com/).

However they have less accuracy than SLA and SLS. Sometimes, is difficult to remove or peeling the extra material of the final object. In contrast, no chemical reaction is needed and the prices is less expensive than other processes commented. In addition, it is available to print parts of the object with full color.

**Inkjet powder printing**

Inkjet powder printing is also known as binder printing. The technique consists on spraying liquid binder on to a powder bed. The method is similar to a normal 2D printer used in offices or in printings using paper, where the ink is printed on the surface of the paper. However, the paper is substituted by a sheet of layer made of powder.

The process starts spreading the first layer of powder using a roller. Then, a piston homogenizes the layer density applying pressure, while the exceed powder is removed. Afterwards, the printer adds blinder and splits it on the surface of the material printed and new powder is added forming a new layer.

Using this technique is also possible adding colour to the layers which are being printed. Also, another head printer can add colour after the binder is deposited on the actual
layer. In contrast, mechanical properties of the objects manufactured using this process are worse than other techniques. Powdered materials have problems in bounding particles between each other because of the low adherence. In order to improve mechanical properties, objects can receive a post treatment.

**Inkjet material jetting**

Inkjet material jetting allows printing not just one material. The concept is similar to a normal 2D printer which jets photopolymer instead of ink. When the material has jetted on a surface, a UV light cures the process or polymerization. Then the material solidifies.

This method allows to print in different materials while is possible to select different ones at these same time, even combining them forming different compounds. Materials can be selected in the 3D model before the printing and the parts of the piece. Selecting the suitable material to print is an important improvement, because time operations are reduced. In other processes, the parts of objects are printed separately and then assembled. Thus, the design of the pieces is just one, in contrast to other techniques.

The only post operational process needed to finish the printout is to pick up the piece from the holding platform. However, the object has stuck during the polymerization and it is necessary to unhook the piece from the surface dissolving with water the gel.

### 5.2.4. Food printers 3D developers

**Foodini (Natural Machines)**

This model is being designed by Natural Machines company where its headquarters are in Barcelona (Spain). The equipment will be available in specialized shops and in internet at the beginning of the first quarter of 2015. According to their website, the mass production of the equipment will start during the second quarter in 2015 and the available price will be 1000 euros approximately.
The model is presented in a kind of modern cube box equipment. Foodini offers a wide range of printing dishes such as hamburgers or raviolis. “Some examples of food we have printed: pastas (ravioli, gnocchi, spaghetti, ...), burgers (veggie and meat), chicken nuggets (and chickpea nuggets as a vegetarian alternative), quiche, pizza, “designer” fish & chips, hash browns, cookies, crackers, brownies, chocolate, etc.” (Natural Machines website, 2014).

The system works with capsules where food will be inside. The designers affirm food inside capsules will be fresh and will be two options in order to print food: fresh food prepared by the consumer or the possibility to buy food fresh capsules pre-prepared industrially.

Foodini works with open steel capsule models where is possible to introduce fresh food and then printing. In addition, foodini system uses nozzles instead of syringe technique. Avoiding this technology, printing times are reduced in comparison with other actual 3D food systems in the market. The aim is focused on restaurants and householders. However, the price would be an obstacle to arrive to the public.

**Chefjet (3D Systems)**

3D systems company has developed a 3D printer where is possible to print 3D objects shapes made of safe-food. The 3D printer builds up layer per layer the 3D model in CAD and it was showed off in the CES (Consumer Electronic Shown) in Las Vegas. The structure is made with sugar and water in order to stick each layer.

The idea started with Sugar Lab company founded by Liz Von Hasseln and her husband Kyle. Then the company was purchased by 3D systems.

Chefjet pro was designed at the beginning just to print sugar shapes. However, the final product works with other food such as vanilla or chocolate. The printer is sold with a cookbook and all the kind of food, which the 3d printer is able to print, classified in: cakes, candy, sugar cubes...

About some technical and operation specifications, Chefjet has 254x355x457mm of dimensions and is able to print 1 inch per hour in the vertical axis while the printing accuracy is 1-2mm. Also, there is a touchscreen which allows control and checking operation and size of the object. Moreover, is possible to change some operation parameters. In spite of all the good features of the printer, the inconvenient are the time operation and its price of $5000
for Chefjet and $10000 for Chefjet Pro. Thus, the equipment is destined to important and avant-garde chefs and restaurants who want to include innovative food and to experiment.

Finally, the company has developed a social site called Cubify where is possible to download 3D models and then print them. In addition, artistic costumers can upload and share their designs with the rest of the community. (Adapted from 3d-food-printers.ireviews.com, 2014)

NASA Investigation

“Using progressive 3D printing and inkjet technologies, SMRC will design, build, and test a complete nutritional system for long duration missions beyond low earth orbit. The 3D printing component will deliver macronutrients (starch, protein, and fat), structure, and texture while the ink jet will deliver micronutrients, flavour, and smell.” (NASA SBIR solicitation, 2012).

This paragraph can be found in a document where the aim is to start a research where food will be printed during astronaut’s missions. The objective is to design technology which will allow astronauts to obtain balanced food. The main idea is to create macronutrients food using proteins, fats and glucids. However, this kind of food will be unflavoured. Thus, low quantities of micronutrients will be added in order to improve flavour and maintain the physical and psychological state of astronauts. 3D printing food is interesting during this type of missions because the food will be printed and consumed without waste, essential whether the food supply is limited.

Furthermore, the population at the end of the century will be about 12 billion people, according to the document. Nowadays, with the actual food system, the prices will increase and food will not be able to be obtained for everybody. Therefore, the whole system will be in dangerous and is necessary to change it. Finally, the document explains some implantations during wars.

Private Investigation

“Barilla launches 3D printed pasta contest with Thingarage” (MOLITCH-HOU, 2014). This new was published at the end of August in 3dprintingindustry.com website. According with the new, Barilla has contacted TNO organization in order to start a project which involves 3d printing pasta techniques:” Dutch scientific research firm TNO to work on a custom 3D pasta printer, capable of printing 15-20 pieces of pasta every two minutes.”
Then, the new informs about one quiz where participants will present their 3D model in CAD and some size requirements. Thus, the participants will deal with geometry problems during the printout and the 3D model will pass the test printing.

Finally, the winner model will be printed by the prestigious Italian brand Barilla. Therefore, the aim to implant this kind of quiz is investing in 3D printing technology applied to food. In conclusion, whether this famous brand is investing in 3D printing food research it means other important companies develop and invest on the same technology.

Cornucopia

This is an investigation studio of new technologies. On their website there are many interesting photos of 3D printing machine prototypes. However, it was not possible to determinate what kind of 3D food equipments are developing. On their website is written:

“MCS is a creative studio dedicated to technically innovative and experimental work. Blurring the boundaries between matter and computation, the studio designs objects, installations, and live experiences with an imaginative and anti-disciplinary approach.

Our work has been featured in galleries, festivals and museums all over the world, including Ars Electronica, Design Miami/, The Creators Project, and The Corcoran Gallery of Art. Our client list includes some of the world’s most influential art collectors and brands, such as BBC, Cartier, Intel, Natura, Publicis, and Budweiser.” (Adapted from Coelho website of cornucopia).

TNO

“TNO is an independent research organisation that employs some 3,000 specialists. We believe in the joint creation of economic and social value. We focus on transitions or changes in five social themes: Industry; Healthy Living; Defence, Safety & Security; Urbanisation and Energy. Innovation with purpose is what TNO stands for. We develop knowledge not for its own sake, but for practical application.” (https://www.tno.nl/en/).

Nowadays, TNO is a project funded by the European Union and the institute is working with many private companies. However, these companies are not revealed. One of the applications which TNO is working on is medical care application on 3D printing food. The aim is providing people, with chewing and swallowing problems, dishes using puree and nutritional balanced. In that way, people will have better quality of life, according to Van Bommel.

The results of investigations have been showed off using chocolate in an Eindhoven event. Equipment melts chocolate and refrigerates the shape instantly using nitrogen. The
structure of chocolate will resist on time, because the internal structure cannot reorganise itself.

As we saw, many techniques are used in 3D printing. However, the most extended techniques in commercial equipments are extrusion methods using capsules. In 3d printing food, potential is found on FFF (extrusion method) and powdered bed. Now the entire supply chain will be analysed.

5.2.5. Food supply chain

Every process involves inputs and outputs where the first inputs receive treatments in order to transform it into another more profitable and useful. Simplifying at small scale, each product can be defined as a cycle: raw materials, production, use, disposal and feedback. All the activities found in a product are classified inside one of these fields, and food industry is not an exception. In addition, each activity can be described in simple terms following a “black-box” drawing.

Making an overview of the food supply chain method, we can describe it in a black diagram box where the process is viewed from an outside point of view. The steps and processes which take place during the food supply chain are not considered and just the inputs and outputs are shown. Describing figure 8, we find all different types of food going inside the process. In addition, the draw includes all materials needed in order to make the supply chain working properly.

Inputs and Energy supplies

Talking accurately about inputs, food is the most important. Many times food is processed. However, some of them they are just transported without suffering any transformation. This can be the case of local and small markets and local suppliers who sells food directly to the consumer.

However, not only food is included as an input. For instance, cardboard and plastic is included in the group packaging material. Even if cardboard and plastic are not comestibles, they are necessary in order to transport food between boundaries of the supply chain, as long as, pallets make feasible and easy the task. In the same way, we classify recipients including all materials needed in order to protect and conserve food in good conditions. For instance, steel cans and plastic recipients are usually used to create protective atmosphere with nitrogen or vacuum. They are necessary to prevent damages to the food and extend the product expiration dateline.

All chemical products used in chemical split in two groups. On the one hand, chemicals make reference to all the products like pesticides or fertilizers, which they help to
improve food production, protecting food or growing it up faster. On the other hand, additives are chemicals added to maintain food available for its consume or to modify the structure or appearance of food. For instance, EDTA is added to food to prevent oxidation of fats and oils. In contrast, pesticides are used to eliminate insects or parasites which use produced food to feed; and fertilizers give vegetables oligoelements (B, Cu, Fe…) and macronutrients (N, P, K).

Auxiliary materials group is referred to materials used during the process but they are not included at the final product. Cleaning up the industrial facilities requires detergent materials or other resources; and office material (like papers used during processes such as bills or detergent products) does not make part of the final product, but they are necessary to keep on with the process activities.

Finally, there is a special group which sometimes is overviewed. Microorganisms are present in a lot of important processes and they deserve special attention in alcoholic and lactic fermentations. For instance, during beer processes yeast transform sugars into alcohol.

Once we describe material inputs, processing food needs energetic supplies. They are necessary to develop the industrial activities. Most of them use water and electricity. Therefore, these supplies are strictly necessary in all industrial facilities.

First of all, water is used in industry because of its excellent physic and chemical properties. Water is used to clean vegetables and is the main media for many processes such as boiling and beverages processes. Also this media is used by industries to maintain food in good conditions.
Figure 8: Black Box diagram of supply chain

Source: Own resource using Libreoffice Draw
In addition, water is used like dissolvent and media reactions because of its excellent properties in solubility and amphoteric features. In addition, depending on the media water can make complex with substances.

For instance, in basic media water makes complex with metals in dissolution while EDTA is used in acid media. Also another application is buffer dissolutions. They are a combination of different chemical compounds where there is an acid-base equilibrium. This buffer solution is used for instance in colas beverages. They use carbonic acid and phosphoric acid in order to maintain the pH level, allowing the CO$_2$ gas formation and giving gas flavour properties.

Secondly, there is energetic topic. Energy can be obtained basically in two ways: renewable and non-renewable founts in supplies facilities or depending on the company in the same industry. Energy is used to move machines using electricity or heating processes. However, in this diagram we will not focus on how food industry obtains energy from the supply because they consume or electricity or other founts such as gas, coal or scraps. Burning them food industry obtains energy which can be used in two forms: heat or work.

Normally, industries burn gas, fuel or other resources inside a boiler. The porpoise is giving heat to the processes which requires it. During the combustion the combustible realize heat which is received by water. Then, water is heated up and changes its state into steam. Then steam is transported inside pipes to the equipments which need to increase the temperature. When steam is cold and changes into a gas state is sent again to the boiler.

**Outputs, residues and emissions**

Once the inputs and energy supplies are used and transformed; outputs are obtained. However, we distinguish between products and residues or emissions. First ones have value and are possible to reuse or to consume, while residues and emissions are not useful. In addition, companies try to eliminate as soon as possible residues.

After the end of the supply chain we obtain food. Food includes processed or not processed food. Last one has not received treatment in an industrial process, or at least, has not been cooked or transformed. However, it is possible that has received processes in order to keep it save. Nowadays, non processed food is less available than processed one. Even though, ecologic food is available in some specialized food stores. This type of food is called ecological food. For instance, in the shell of eggs is written a code number where the first one determines the origin of the egg.
At the end of the supply chain we can classify available food in two huge groups: consumed food and expired food. The first one is eaten by consumers while the second one is not consumed by anybody. Last one can be called waste food. Food not consumed means loses in resources, time, energy and money. In conclusion this kind of food is not going anywhere is just thrown away. This group also includes food which is lost during all the processes which take place in all the supply chain.

Making reference to valued material classification, it includes all the products which have value but they are not inside the product. These can be used in other economic areas which cannot be related with the final product obtained. For instance, peel of fruits or dried fruit can be used in order to obtain energy in biomass facilities. Actually, it can be part of residues but we consider it like a useful subproduct which at the beginning is not destined to be eaten as expired food is.

Pallets are an essential part during supply chain food. They go in and out of the supply chain. They are useful to manage and communicate all the boundaries found in all the process. Actually, all industrial processes involve the use of pallets. Depending on the shape, the distribution and amount of food, which they can carry, the efficiency during managing and distributing food can be better or worse.

Finally, we find on the draw residues and emissions. The concept of a residue is some element or material which has to be disposed or eliminate. Resides do not have economical value. This is the reason because in this text non consumed food is considered a residue in the draw. However, this does not mean expired food has not value. It had before expiring, thus, the aim is to avoid its expiring, adapting the production to the market demand of food.

We talked few lines above about using energy and water. However, industrial processes pollute water and the environment. Combustions produce CO, CO2, NOX, SO2 emissions among other harmful pollutants for the environment. This emission can be reduced despite of nowadays with the actual technology is impossible not to emit any pollutant.

In the same way, pollution in water is another inevitable consequence. Processes like heating commented above uses water in order to heat up machines or giving heat to the process. However, the most important waste of water is generated by the agriculture. They use practically the 70% of the total wasted water (Adapted from UPC Chemical Industry slices subject, 2013).

Inherent to all processes there is also vibrations or acoustic contamination. During the movement of element machines, work is lost because of friction between pieces or
materials. The energy is lost in two ways: heat and vibrations. Last one is dealt like an emission. The intensity of sound has to be controlled because can affect the environment and the health of fauna or even people.

5.2.6. Processes within supply chain: Overview

Food supply chain is a complex process where the final aim is to provide food to the householders. The process is a complex mechanism where all the steps concepts are connected and the minimum change affects all the system. Companies usually are focused on one activity inside the supply chain and they are segmented by type of activity, food and processes developed.

As all complex mechanism or process small changes can produce an important effect in all the steps. For instance, recently the price of flour has increased during this last years. Biodiesel companies needs to buy cereals in order to produce the combustible and for that reason the demand of flour has increased and the price as well. Thus, the final price of manufactured prices, such as bread, has increased because bread companies have to pay more money to obtain the raw material.

Describing the system, all the activities during supply chain can be classified in one of the following steps: obtaining raw food, processing and distribution. The first one includes agriculture, farming and fishing. Processing is a heterogenic concept where food is processed in different industrial activities, in order to improve or make more attractive food, offering it in a wide range of different products. Then distribution food activities are linked with transport and correct managing of all the supply chain. This activity is gaining weight and is necessary to implant it between all the steps connected to make efficient the supply chain. Finally, consumption takes place in the supply chain addressee, the stakeholders.

![Flux diagram of supply chain](source: Own resource using Libreoffice Draw)

As we said few lines above, even the smallest changes in the supply chain can unbalance it and the consequences can have big scale. Talking since this base, what will happen whether the supply chain implants 3D printing food technology? Will improve the efficiency of the current situation?
5.2.7. Process within supply chain: Raw food

Agriculture provides the entrance of food to supply chain. Thus, controlling this sector and its waste is really important. Agriculture management is crucial in order to avoid pollution and to damage the ecosystems. Its activities are directly related with soil and water. For this reason, a non efficient or the absent of a good management can produce harmful effects to the environment.

At first time, it seems not possible to implant 3D printing food technology. However, during this step is possible to detect some important environmental impacts which can affect all the entire supply chain. Therefore, good practices and environmental potential impacts can be described in order to make the process sustainable.

Actual legislations are focused on to reduce waste and to make efforts in good practices. Legislations enhance the correct use of the resources minimizing waste. Farmers have to understand their obligations while they take conciseness about looking after the environment. Nowadays, the activities recommended implanting managing are in poultry and livestock activities, growing vegetables and plastics and other resources.

Poultry and livestock

Regulating these activities is a good beginning to make sustainable food. However, minimizing their environmental impact requires enhancing benefits to the farmers and developing precautions.

Manure is one of the resources which has to be dealt. Manure is an organic complex material which changes his chemical composition during the time. This material includes all the faecal and urinary wastes of the livestock which lives in the production facilities. In addition, is possible to add water or other compounds, in order to improve its properties or just to change the aggregation state.

State of the material is important because depending on the phase inside the manure is possible to find different nutrients which are needed to grow faster vegetables. Liquid phase contains huge portion of all the potassium and nitrogen compounds while phosphorus compounds are located in solids. Therefore, containing the liquids in suitable facilities is important to avoid leaks which can contaminate the soil, water and air surroundings.

Some environmental potential problems related with manure are surface water and ground water pollution. Other problem related to the fertilizer is eutrophication. This phenomena takes place in ecosystems which involves lakes, for example. The massive abundance of phosphates or nitrates is used by algae and this microorganism starts to
reproduce on the surface of the water. In consequence, the sun radiation cannot arrive at the deepest part of the lake.

In consequence, the vegetarian species cannot develop photosynthesis and the oxygen becomes consumed. As a result, the oxygen in the lake is not enough to maintain a sustainable ecosystem. Then the species start to die and the biomass starts to accumulate on the deepest part of the lake, where bacteria and other species decompound the material consuming the oxygen and creating no oxygen parts.

Furthermore, manure can be the responsible of diseases and health problems in animals and humans due to the pathogenic organisms which can grow in polluted water. To prevent these situations, the recommended storage has to ensure a capacity of one year (P. Jacobs & Associates, 2001).

Farms have to install runoff containments. This part consists in two actions: preventing unnecessary waste water during livestock operations and to contain tainted water and prevent leaks. This contaminated water has to be dealt apart from manure storage and livestock facilities. Depending on the features of the soil, the material used in waterways can be for instance paved or grassed. Runoffs will be added to existing manure storage, avoiding excess liquid which will increase mixing and homogenous processes.

Other problem consists on odours released by bacteria activity degrading manure. In this case, we can find two types of biological reaction: aerobic and anaerobic reactions. The first one releases CO₂, which is inodorous, while the second one produces odorous gases. Avoiding this, it is possible to control the reaction with the temperature or introducing oxygen to manure (moving it).

Even though, manure can be applied to the land. The objective is to provide crops with nutrients, which are necessary to grow them properly, while the residue of the farms increases value and can reduce costs and environmental impacts. To do this, manure can be treated with physical, biological or chemical process.

Firstly, solids are separated of the liquid using physical methods. Then, composting manure is used in biological processes. Here is possible to distinguish aerobic and anaerobic processes as we commented few lines above. Aerobic processes need oxygen and involve activities such as mechanical agitation or air injection, while anaerobic processes needs digesters.

Composting is used to reduce volume of organic material, while the manure acquires added value. In addition, compost reduces fertilizer purchases while it prevents soil erosion. Other benefits are selling the overproduction of manure to other companies which
can need it such as golf fields, or for instance, reducing the odours while the time storage is increased because compost is more stable.

Finally, in order to prevent odours during spread manure operations, we include a schematic table in table1. Summarizing the information, it is recommended to spread manure during sunny days with windy. With this factors sunshine will dry the manure while the air will dilute the excess of odours. However, damp conditions without windy cannot move the gases.

**Milkhouses**

The main problem of these facilities is wasted water. Good management conditions in these facilities have to implant a reduction and reuse of water. These facilities consume a large amount of water in milking systems. Averaging the wastewater per cow is about 14.1 litres (Adapted from P. Jacobs & Associates, 2001).

Milk is a suspension where solids are in a liquid phase. For that reason, wasted water in this kind of facilities has solids and fat. In addition, detergents, acids, manure and other particles or compounds can be present.

Reducing waste should consider, for instance, prepping the cow manually. Washing manually needs less water than automatic processes. In the same way, cleaning up wasted feed manually avoids wasting unnecessary water while the levels of iron and metals should be analysed.

Reusing resources can be related to cooling systems. After the extraction of the milk the temperature is at corporal temperature of cows. However, it is necessary to cool it before saving in agitated tanks. The water used can be useful to feed the livestock, whether the temperature is suitable and the cooling system is well designed. In addition, saving wasted water can reduce the chemical products used during cleaning operations, because if its conditions are good, water can be used from one cycle to another.

Thus far, we talked about all the residues generated by poultry and cattle. However, what about their necessities and their taking care activities? First of all, cattle need pasturing. Traditionally, cattle is allowed to pasture in fields where is possible to find water on rivers, for example, because cattle is healthier and more productive if they can obtain water form natural founts.

Even though, recently is recommended not to do that in order to protect water infections or diseases linked to the animals and to adapt the facilities to receive fresh water. Thus, some farmers have adapted a mixture process which involves outdoor pastures bordered with fences mixed with treated water.
Furthermore, the disposal of dead animals has to be considered in all farm facilities. The objective is to avoid diseases and hazards. When the animal dies sometimes is because of illnesses and it contributes to infect other livestock. In addition, the carcasses will attract undesired animals such as flies while odour gases will be produced.

Disposing dead livestock and poultry there are different options. First of all, the most recommended option is to contract the services of a dead removal company. These companies pick up the carcasses and dispose them in a properly way. This is an easy way to deal with the issue, though, external activities often are expensive.

Secondly, composting is a suitable option to deal with dead animals. Represents a low cost disposal while is more or less acceptable and clean. This kind of disposal is useful to deal with poultry and small animals. An appropriate method consists on maintain an aerobic media, while the temperature in the most is increased more or less above 55ºC. Like all kind of composts, this one has to work in an adequate proportionality between the total amount of nitrogen and carbon (25:1).

Vegetables and fruit

Vegetables and fruit well not disposed generate blights and diseases. Every day food is culled using standard measures and other quality features. Therefore, much food is discarded just for none suitable patterns for market specifications. However, this amount of food should be disposed using one of the following methods: adding value processes, animal feed, composting, land spread or burial (Adapted from P.Jacobs&Associates, 2001).

All these treatments are shown on table 2 classified in product nature. During adding value, food is for example dehydrated and then processed. Other less profitable options consist on feeding cattle or obtaining manure to feed harvests. The worst option is burial, where vegetables are disposed under the grown and the amount of food disposed should be controlled.

None related food waste

During farm activities, other waste none related with food, poultry or livestock takes place. The necessity of using chemical products, machinery and materials makes waste. For instance, some farmers protect their crops with plastic films which have to be disposed. The correct way is to storage them indoors to prevent their degradation caused by the sunlight, while is compacted in order to make easy transports operations.

Also pesticides represent a dangerous and hazard impact for the environment. Part of pesticides is left inside the containers. Not removing them can cause environmental
impact. Removing it, companies save raw materials avoiding unnecessary purchases, while the measure prevents poisoning livestock or people and contamination.

Containers and paper bags contain pesticides or fertilizers. The best option to deal with them is to establish contact with external companies or returning the containers to the suppliers, which often recycle the containers. In addition, it is also possible to contact with environmental authorities of the region, which can pick up the residues. Thus, the correct process is: rinsing the containers, in order to remove toxic substances, and then externalize empty plastic container collection. Moreover, agricultural activities are not allowed to burn residues or burying them.

Finally, other kind of residues generate are animal health care products, machinery and oil. First one includes expired repellents or medicines and other health products. The best option is to disposal them in veterinaries and following a good practices management. In the same way, old machinery, refrigerators, pumps and tires replaced have to be disposed in suitable specialized locations, as well as used oil which can be returned to dealers.

Fish sector

Non fish disposed correctly and throw it away to the marinas or ports can cause unbalanced situations fort the ecosystem. For instance, throwing away the fish involves the decomposition of this food inside the water. Thus, in order to decompose the organic material disposed, bacteria and other microorganisms will need oxygen. In consequence, the ecosystem turns more anaerobic each time.

However, some good practices include disposing fish in the ecosystems where the fish comes from. Activities such sport fishing can dispose the fish directly to the sea, because the amount of fish cannot damage the environment or destroy the ecosystem. In contrast, some states do not allow this activity and fish is removed in a properly way. In the same way, also is possible to encourage and establish game fishing without killing the animal. Applying this practice is possible to make competitions or fishing without damaging sea.

Installing cleaning stations is another option to deal with fish waste. In these facilities, boaters and fishers can clean the fish which has been caught. Normally, there are large tables enough to clean the fish while fresh water is provided while barriers or receptacles avoid solid circulation across the water supply. However, it is suitable to maintain the facilities as much clean as possible in order to encourage users to do the same. Finally, wasted fish is collected in containers and then disposed as ordinary organic residue and sent to local sewage disposal system.
Composting is also a good option in order to add value to the residue. Well-designed methods can deal with the disposal, while cash input, from commodities sold to gardeners or farmers, can finance part of the maintain cost. In addition, is possible to take advantage of some fish parts freezing them, in order to use afterwards as bait in fishing activities.

Lines above we have discussed which areas and how they should take measures in collecting and obtaining raw food. Despite of implanting 3D printer is not feasible in this area, advices and suggestions have been done to ensure good practices and performance in the agriculture, livestock and fishing. Now let’s analyze an important area of application: food industry.

5.2.8. Process within supply chain: Manufacturing food industry

Processing food definition

Nowadays, our society is plenty of technology and automatic processes where products are manufactured or created and food industry is not an exception. Recently, the increase of the whole population demands a large and efficient system capable to supply food to everybody. However, what is exactly means processing food?

“Food processing is defined as the practices used by food and beverage industries to transform raw plant and animal materials, such as grains, produce, meat and dairy, into products for consumers. Nearly all our food is processed in some way. Modern food processing is sometimes defined as taking place at a plant or factory. This is distinct from food preparation, which usually takes place in kitchens. Many activities—washing and cooking, for example—are common to both processing and preparation. The companies that process foods are sometimes called food manufacturers.” (Johns Hopkins Center).

Processing food reasons

Nowadays, food is processed due to the huge demand of the markets conditioned by people habits, their style of life and nutritional necessities. Much different food is processed every day and it is becoming more difficult to identify all the food which goes out from the food manufacturers to retailers, groceries and large supermarket areas from our not specialist point of view. However, it is feasible to recognize processed food functions.

First of all, the oldest aim of processing food is to keep it in good conditions till it will be consumed. Conserving consists on apply some processes which includes heat treatments (boiling, freezing...), microbial processes (fermentation), chemical processes (reducing acidity...) or adding food or chemicals in order to stabilize or prevent the microbial
growth. For instance, meat can be salted, milk receives fermentations process in dairy facilities or fruits can be conserved as jams.

Other extended process is pasteurization used to eliminate a part of microbial population inside liquids. Thus, the aim is conserve it more time and makes feasible transport at large distances. Despite of this, pasteurization also is well extended across all food processes which deals with liquids such as beers or juices.

Therefore, with all these methods food is preserved and people’s health is secured. Using sugar, heat treatments or salt is possible to build up a barrier against pathogens which are harmful for our health. In consequence, the aim of canned or processed food is to extend life of food avoiding it to be decomposed. Then, preservation and security food are strictly linked each other and one does not take any sense with the other.

Talking about healthy issues, nutrition has become really important in our society. Nowadays, people seek for healthy nutritional properties and minimum quality guaranteed, when the product is bought at shelves of the retailers. Food manufacturers have found out about this trend and have developed two measures: enrichment and fortification. On one hand, enrichment means to restore food properties lost during processing activities. On the other hand, fortification means to give extra qualities to food which usually are higher than in a natural way. (Adapted from Johns Hopkins Centre).

Thus far, we introduce just arguments referred to food arguments, in other works, about food quality, nutrition and preservation. However, food industry attends other people demands which are indirectly related with the fact of eating. As we commented at the introduction of this thesis, people look for food which is suitable in all the aspects which they consider.

Nowadays, people are busy working and we live in times where hurry up is usually. Some of them, they do not want to spend their valued time cooking but they want to consume suitable food. In this background, food manufacturers offer products which can be just heated in a microwave spending just few minutes or food such as salad which is ready to eat whenever they desire.

However, what about eating every day the same dish? Food manufacturers go beyond of this issue bringing costumers a wide range of different food, which many times is recommended or focused on certain segments of the market. Canned food for babies is specifically processed and cooked for them, certain kind of milks which there is an added extra amount of calcium and nutrients for children (who are growing up), or energy drinks are focused on giving mineral salts to sports people.
In conclusion, there are many different kind of processed food available in grocery, retailers and supermarket areas. All the products are well designed by food manufacturers due to costumers’ necessities. Nowadays is possible to find even food without presence of gluten, a set of proteins which is not tolerated by celiac people. Other examples example of food variety are in confectionary and backing sector, where the types of food is really large; or vegetables which offers many different salads, for instance, conserving their fresh properties inside a package.

Energy management

Nowadays, whatever industry or process requires energy because is the key which makes feasible our system. Energy takes many faces such as heat, potential, chemical or other types. Energy is a concept which should be understood as a magnitude which is transferred and then transformed to other forms. For instance, combustibles store potential energy. However, the best option is to burn it making a chemical reaction process called combustion. During this chemical reaction the combustible release calorific energy because the final products have less enthalpy than the original reactive. Then, we can take advantage of this process obtaining useful energy to move an engine or transferring the energy to an appropriate media, like water, and used it in processes.

According to (Minnesota Technical Assistance Program, 2014) in this state is consumed about “565 million kWh and 74 million therms annually, where 1 therm is equivalent to 1000 kcal. In consequence, managing energy in a wisely and effectively way is obligated to reduce costs and unnecessary waste. Therefore, energy is not an exception in food processing industry. Energy provides equipments of the processes with: calorific, mechanical or power energy.

Electrical energy is obtained mainly moving an axis and then connecting it to a transformer which is connected to a power generator. The most profitable example is turbines where steam flows at certain velocity and pressure, and moves the axis.

Equipments are powered by supply system which is usually provided by companies operating at national scale selling power supply. This kind of energy is used to feed power moved with electrical engines, pumps, compression systems, mixers, impellers, fans… or just to light up the facilities when it is required by light conditions.

According to (Minnesota Technical Assistance Program, 2014) in this part of U.S. is consumed about “565 million kWh and 74 million therms annually”, where 1 therm is equivalent to 1000 kcal.
First of all, heat has the main role in processing food. Heat is used to feed equipments such as boilers, reactors (where calorific energy is required to be provided or cooled, depending whether the reaction is endothermic or exothermic), in processes while controlling the heat of food is essential at the same time.

Thus, it is essential to control correctly all the equipment and food. The parameters which can inform and control in an easy way the state are really huge. However, the essential ones in food industry are: the temperature, pressure, pH, moisture and time. However, knowing exactly the food properties and behaviour in front media conditions is fundamental on dealing with process control.

Refrigeration

The aim of a refrigerator is cooling food in order to maintain it in good conditions. However, this process is not spontaneous when we talk from a thermodynamic point of view. Heat transfer goes from hot focus to cold focuses, in order works, from high temperature to low temperature parts.

Solving this problem, refrigerators use compressors which they work with electricity. Refrigerators work with a cooling fluid which is compressed in a compressor where the fluid changes the gas state to liquid. Then, the liquid flows in a heat exchanger called condenser where the liquid decreases its energy. Finally, the refrigerator is expanded in a valve in order to work at another heat exchanger pressure, called evaporator, where the fluid absorbs calorific energy from the media in contact, normally the air which is in contact with the food to maintain it cooled.

Therefore, the basic steps to improve a refrigeration system are to check sealing properties of doors, windows or other elements which can be a focus of heat looses. Another option is to change the insulation material for another more suitable. In addition, checking fans conditions and attack angle of them in the evaporator and condenser should improve cooling systems.

Besides improvements in cooling systems, also there is place for alternative and combined technology. For instance, it is possible using ultrasonic waves to make freezing operations faster. The wave goes across the food piece and increases the ice crystal nucleation. Other operations consist on freezing using jets at high velocity, which they will arrive to the surface of food freezing it fast. This is really useful for thin food. (Adapted from George M Hall (Centre for Sustainable Development of University of Central Lancashire, 2010).
Nevertheless, sometimes is not just about having the best technology equipment. Adapting some few simple measures on the employees’ behaviour or adjusting some parameter will be enough to achieve a good performance and save energy. Some examples are:

1) Reducing freezing times will reduce the energy associated for example with fans.

2) Reducing times when doors of the freezers are opened and reducing frequency operation.

3) Plan defrosting schedule due to not to affect production and do it efficiently. Food release moisture when it is freezing and ice layers are formed on the surface of the condenser and the global heat coefficient decreases.

4) Using heat from the condenser to transfer heat to other processes which require it to work. It may be useful on pre-heated boilers.

5) As simple as turning off lights when they are not necessary.

**Heating**

Heating increases the total energy of a substance in order to provide this energy to all the equipments: boilers, heat tanks, heat pumps, heat exchangers, dryers, kilns… As we see, there are many equipments which work with this kind of energy as an input and gives treatments to food in: sterilization, evaporating, drying operations or heating treatment at certain time in kilns in order to start a fermentation operation on a cake, for example.

Basically, heating processes start with a combustion where the combustible release the internal energy and transfer it to a properly fluid which has a high latent heat coefficient. This substance is capable to transport a lot of energy per mass unit while its cost is cheap. The answer as we said during the introduction to this thesis is water.

However, other fluids are used to transport energy such as refrigerants oils or even air. First ones are used to reduce temperature in processes which temperature control is required like freezing processes, as we saw, or exothermic operations which requires more heat dissipation. Others require oil like for example during frying operations where the heat media used can use olive oil, for instance. Finally, air is the cheapest thermal fluid used in heat transfer because its abundance. Many times air refrigeration is used in forced ventilation where air is propelled by fans in order to remove warmed air faster.

Therefore, recovering heat from processes is an interesting issue to be considered in order to make more profitable production. In fact the most useful tool is process integration. This area studies options to interconnect processes where energy or materials from one
operation are released and can be used in other operations. However, heat recovering projects need to be studied attending some previous aspects (Adapted from Energy, mines and Resources Canada paper):

- **Compatibility between source and demand**: The first step is to study whether the energy source has good quality and the amount is enough to feed process. In addition, studying how the implantation will affect schedules is important not to delay or affect other processes. Some examples are preheating boiling water from combustion gases released in a boiler or recovering water from turbines at low pressure.

- **Accessibility**: During this step the aim is to localize and consider if the energy recovering process is reasonable to achieve. For instance, recovering heat from cooled steam is easier than recovering air heat. Thus, the media conditions will affect the recovering. In consequence, the objective is to implant recovering heat from sources which have high heat transfer coefficient. Recovering heat from gases is more expensive than in liquids or steam.

- **Distance between source and demand**: The larger the distance is, less profitable is the heat recovering. For instance, transporting water inside pipes is an operation which requires some aspects to consider. When water flows inside a pipe, heat is lost by two methods: conduction across the pipe material and by convection between the air on the surroundings of the pipe and pipe external shell. In addition, during winter long distances should be taken care. If the temperature and the pressure are enough low, water can convert into ice and break the pipe.

- **Product quality**: The quality of the heat waste should be considered, especially in food industry where any contact with potential contaminant agents must be avoided. Thus, recovering heat from powdered streams should use processes where leakages are impossible. For example, using a fan to refrigerate can cause air fluxes. Then these can move wheat particles from storage areas to processed food for celiac people, which will be chaotic.

- **Financial issues and regulatory aspects**: The most important part of an industrial activity is to earn money. In consequence, if the process is not economically feasible, the project will not go forward. In addition, not accomplishing the environmental policy or contaminating food during any process is not allowed. For this reason, streams which have pollutants and there are risks to contaminate food, are not suitable to use in without the appropriate measures.

**Scraps management**
Some operations in industry produce organic residues from food which has received some treatments. Most of the organic residue is from activities where food receives separation processes. For instance, peeling fruits is the best example here. The peel removed from some fruits is a residue generated because it is not included at the end of the product. According to (P.Fellows, 2000), the following operations generate residue:

**Cleaning**

Cleaning is used to clean the surface of food which is going to be processed. The aim is to remove all the contaminants which are not desired during the process or at the end of the product. Thus, cleaning operations separates from food: metals, soil, roots or stones, for example, which can damage the equipment; and contaminants. Last one whether they are not removed at the beginning, the factory will need to spend money on to neutralize them. Therefore, correct cleaning is a simple method to reduce food wastage, improving economic performance and securing consumers’ health. Mainly cleaning is divided in three groups):

- **Wet cleaning:** The best method when soil from crops, dust and pesticides are desired to be removed. In addition, the method uses cold or warmed water which damages less food than dry methods. However, using warmed water may accelerate microbial spoilages, unless many water treatments are done. In consequence, many water effluents are generated with dissolved and suspended particles, (BOD and COD levels increase), while much water should be purchased and the industry will pay more for discharges.

- **Dry cleaning:** These processes are used for small and strong products like nuts. For instance, some operations are air classifiers or magnetic separators. The first ones use a stream of dry air which is based on pneumatic transport where the air and the particles follow a fluid behaviour. Therefore, nuts can be separated from soil, stones or leaves by pneumatic transport using density differences between them.

- **Removing contaminants and foreign bodies:** The aim is to separate physically contaminants or objects which can damage our health. In this group is included, for instance, ferrous material separation using electromans. Other techniques used to detect foreign bodies are X-Ray, ultraviolet, ultrasonics, microwave…

**Grading**
Food quality is analysed to satisfy production demand parameters. For instance, eggs are inspected using tungsten lights, in order to inspect twenty factors according to the shape; presence of fertilizers or just unsuitable consumption features because of rot state or breakages. Others analysis are made in chicken or meat where they are checked and analysed similar parameters.

Furthermore, many grading processes are developed in laboratory analysis where some parameters such as meat composition (proteins, sugars, fats, moisture, colour or microbial activity) are measured. For example, in beer production many aspects are controlled in order to maintain the quality of the brand. Therefore, tasting proves are taken by experts. However, processes like this requires qualified staff. In consequence, costs increase.

An important part during grading process is sorting, which provides tools needed to separate and classify food and making uniform the production without important statistic deviations.

**Peeling**

Peeling is the operation used to remove unwanted parts of food and improving the final appearance of the product. However, the amount of food removed should be enough to not to increase costs too much. Peeling operations can be done in five processes depending on the media, tools or products used: flash steam, abrasion, use of knife and caustic peeling. However, here we just comment basic details:

- **Flash steam peeling:** As the name seems to indicate it consists on causing a flash evaporation. Therefore, the food is contained inside a vessel and steam is introduced at high pressure. Then, the steam heats the surface of food but without cooking it, because heat conductivity is not enough to allow a heat transfer inside the food. Finally, the pressure is decreased instantly and the water bellow evaporates suddenly and the skin is removed.

  “This type of peeler is gaining in popularity owing to the lower water consumption, minimum product loss, good appearance of the peeled surfaces, a high throughput (up to4500 kg h⁻¹) with automatic control of the peeling cycle, and the production of a more easily disposable concentrated waste” (P.Fellows, 2000).

- **Use of knife:** This technique uses knifes or some sharp blade which peels the surface of the food. The method can use stationary food (it does not move) or stationary blade. Indeed, the aim is just one of the element will rotate across the surface which is desired to peel.
- **Abrasion:** Food is introduced in bowls which is being rotated by normally an electric engine. The surface of the bowl is abrasive and the food starts to release the skin because of the friction forces which remove the peel. This method brings low costs on peeling operation and saves energy; but needs hand finishing to fix food imperfections and product loss range is higher than flash peeling.

- **Caustic:** Uses sodium hydroxide as a peeler. Food desired to be peeled is introduced at heated dissolutions of this chemical compound at low concentration. Then, the skin becomes softer and is removed using high water sprays. However, as is easy to see, the chemical reaction damages food quality. In addition, giving chemical treatment increases peeling costs by two ways: chemical and processes cost and discharges of hydroxide pools or treatments given to neutralize the solution.

### 3D printing food study case overview: pasta

Analyzing new alternatives such as 3D printing is necessary. Nowadays, the demand of energy is increasing and the natural resources are limited. Therefore, working on industry and remoulding it with new technology and knowledge is necessary.

3D printing technology can use multiple techniques. However, extruding processes seem to be the easiest option to implant at huge scale. This technology receives the name Freeform Fabrication (FFF), as we see in 8.2.3. However, powdered beds will be useful but more expensive. This technique is perfect to work with food pastes. Therefore, 3D can be implanted in confectionary, pasta and bakery industries. We have selected pasta as an example because its popularity and the extended market which it is being selling. In addition: “Barilla launches 3D printed pasta contest with Thingarage” (MOLITCH-HOU, 2014). Therefore, a study case of an industrial implementation takes sense to be studied.

Actually, the basic equipment model proposed is an FFF implanted at high scale: volumetric pumps, pipes, valves, supports and heat exchanger. Focusing on the equipment the hypothetical facilities are shown on the figure 10:

- First of all, water will be stored in a Tank T-1. The tank can have a heating coil or can be a jacket tank. It will depend on the study. The tank will be preheated using the condensed which come from U-1.

- Warmed water will flow from T-1 till T-2, which is a heated tank similar to T-1 but adding a mixer to homogenize and add ingredients. Semolina will be stored in a silo and will be transported using pipelines till T-2. We recommend having different highs between S-1 and T-1 in relation with T-2. Taking advantage of the height,
transporting will be easier because the potential energy is higher. However, if the tank and silo are full at certain capacity will not be any problems with transport.

- 3D printer is the line process from V-2 till the end of A-1. V-2 controls the amount of paste which goes inside pump B-2. We recommend B-2 will be a volumetric pump because the fluid pumped is a paste and its viscosity will be high.

- V-3 is a valve which represents a nozzle like in FFF. It will control the amount of dough printed. Then, U-1 will be responsible of the pasteurization process and will control the temperature of dough at the end of V-3. This step is crucial to eliminate pathogens.

- A-1 will be an air refrigeration system which also dries pasta at the same time. The design proposed is a shaft where below will be an axial fan. Axial fans provide more air flux than rotational one. Then, moisture and heat can be removed easily and faster. In addition, the extrusion should take place in other places at the same time. Figure 10 is a scheme but we recommend having a lot of nozzles and shelves to increase production.

- Heating facilities are formed by one main boiler (H-1), pipelines, V-4, V-5 and V-7 and two purges R-1 and R-2.B-1 should be a rotational pump which returns condensate at the work boiling pressure. Pressure of the boiler should be a bit higher than the equipment requirements. Steam, when fluxes through the pipelines, looses pressure.

- Purges need to be done in order to eliminate steam condensate which affects the steam quality and should be returned to the boiler using a recovery pipeline. Finally, salts control at the boiler water should be done to prevent corrosion problems.

- We recommend working with two parallel valves on the critical points. If one valve is deteriorated or does not work, production will not stop.

- The whole process should be automatic and it is recommended to install online controls and good practices on the staff.

Let’s analyze the actual raw materials and energy consumption in a hypothetic case:

- The normal proportions during mixture are: 75% of semolina and 25% of water.

- The fresh water will go inside T-1 at an average temperature of 15 ºC and it is desired to achieve a 100 ºC temperature.
-The boiler work in a pressure of P=2.5atm and uses gasoil. Its maximum capacity is 1200 l of water. The combustion process has a performance is stoichiometric and has a performance of 88%. In addition. The combustible will not have any S contain.

- The impeller system has a maximum power of 12 HP.

- Rotative pumps will have a power of more or less 1.5HP.

- The pressure in the extrusion is 1.5lb/in²

- Diary production is 5000kg of dry pasta. Its moisture is 12%.

- Air forecast conditions: sunny day. P=1atm, T=15ºC and relative humidity of 34%

- Stationary and theoric study where heat and pressure looses are not considered.

- http://www.contactopyme.gob has been consulted in order to obtain data as well as (P.Fellows, 2000)

- Pump work will not be calculated because its amount is not compared with the total energy demand.

**Resolution**

**Raw mass flow**

First of all, we will obtain which is the amount of water used during the mixing process. In order to do that, we use the relation: 25% of water during mixing process.

\[
\frac{5000\text{kg dry pasta}}{1\text{kg dry pasta}} \cdot \frac{0.88 \text{Kg semolina}}{1\text{kg dry pasta}} \cdot \frac{0.25 \text{kg of } H_2O}{1\text{Kg semolina}} = 1.100\text{kg } H_2O
\]

Thus, the total amount mixed is 6.100kg.

**Heat demand**

Once we have calculated the water used, the heat needed on heating up fresh water is:

\[
Q = m \cdot cp \cdot \Delta T \quad (5.1)
\]

\[
Q_{T=1} = 1100\text{Kg} \cdot 4.18 \cdot (100-15) = 390.830\text{KJ}
\]
Then, during the extrusion the temperature process is about 45 °C. However, we calculate the Cp average of the mixture. According to a pasta packet from Gallo (Spanish brand) dry pasta is compounded by: 12g of protein, 71.5g of carbohydrates and 2g of fats. Then, our mixture base of calculation is 110.5g: 85.5g of organic mass and 25g of water.

Data: \( C_{p\text{protein}} = 1.380 \text{KJ/Kg} \cdot ^\circ \text{K} \) \( C_{p\text{carb}} = 1.55 \text{KJ/Kg} \cdot ^\circ \text{K} \) \( C_{p\text{fat}} = 1.67 \text{KJ/Kg} \cdot ^\circ \text{K} \)

\[
\overline{C_p} = \sum_{i=1}^{n} C_{p_i} \cdot X_{f_i} = \frac{4.18 \cdot 25 + 12 \cdot 1.38 + 68 \cdot 1.55 + 2 \cdot 1.67}{110.5} = 2.07 \frac{\text{KJ}}{\text{Kg} \cdot ^\circ \text{K}} (5.2)
\]

Knowing that the temperature after T-2 is 38°C and the extrusion process is isothermal at T=45°C, the heat needed to heat up pasta, using (5.1, is):

\[ Q_{U-1} = 6100 \text{Kg} \cdot 2.07 \cdot (45-38) = 88.389 \text{ Kj} \]

And total heat required is:

\[ Q_{T-1} = Q_{U-1} = 479.219 \text{ Kj} \]

**Steam**

Steam is obtained in the boiler H-1 at a pressure of 2.5 bar and it will provide all the heat energy demand in the facilities \( Q_{T-1} \). Checking steam tables we obtain two enthalpies: \( h_{sat} \) and \( h_i \). The first one represents the total energy of a saturated steam while the second one is the energy remained when the water turns into liquid.

\[
m_2 = \frac{Q_{T-1}}{h_{sat} - h_{liq}} = \frac{479219}{2716.5 - 535.37} = 219 \text{ Kg of steam (5.3)}
\]

Boilers usually work doing a feed back of the condensed. We save:

\[ Q_{saved} = m_s \cdot h_{liq} = 219 \cdot 535.37 = 117.246 \text{ Kj} \]

Another option is use L-2 to recover part of the heat used in U-1. For instance, reducing the pressure of the condensate from 2.5 bar to 1 bar using a valve:

\[
m_{s-1} \cdot h_{liq} = m_{steam} (P) \cdot h_s (P) + m_{liquid} (P) \cdot h_2 (P) (5.4)
\]
\[ m_{2-U1} = m_{2-1} + m_{3-1} \] (5.5)

where 5.4 is an energy balance and 5.5 the mass balance. Solving the system equations, obtaining \( m_{s-U1} \) using 5.3 applied to U-1 and substituting enthalpies looking for at the tables:

\[ m_{s-U1} = 40.52 \text{ kg} \quad m_{s-1} = 2.11 \text{ kg} \quad m_{I-1} = 38.41 \text{ kg} \]

Even though, a pump should compress \( m_{s-U1} \) till the boiler pressure:

\[ W_b = m_I \cdot (h_{out} - h_{in}) = 40.52 \cdot (535,37 - 417,36) = 4,781 \text{ Kj} \] (5.6)

Therefore the total energy saved is: \( E_s = 2,11 \cdot 2675 - 4781 = 863 \text{ Kj} \)

Feeding back is not too much profitable because the biggest part of consumption is in heating up water and drying process as we will see.

**Boiler**

The energy required to feed the process in the boiler is:

\[ Q_{boiler} = Q_{Total} - Q_{saved} = 361.972 \text{ Kj} \]

The combustion takes place at 15\(^\circ\)C where gasoil \( \rho(15\text{oC}) = 850 \text{ kg/m}^3 \)

\[ C_{14}H_{30} + 21.5 \cdot (O_2 + 3.76 N_2) \rightarrow 14 \text{ CO}_2 + 15 \text{ H}_2\text{O}_{(g)} + 80,84 \text{ N}_2 \]

PCI=42275 Kj/kg

PM=198g/mol

\[ m = \frac{Q_{Total}}{4 \text{H}_C} = \frac{45721.9}{45278.2} = 11,33 \text{ Kg of gasoil} \] (5.7)

Using \( \rho \), the performance of the boiler, the ideal gases equation \( P \cdot V = n \cdot R \cdot T \) the combustion reaction; and knowing that the minimum temperature to avoid condensations of combustion gases is \( T=63\text{oC} \) and \( P_{output}=1\text{atm} \)

\[ \frac{11,33 \text{ Kg of gasoil}}{850 \text{ Kg}} \cdot \frac{1}{0.88} = 15,14 \text{ l gasoil} \]
And output gases:

\[ M_{CO_2} = 25.27 \text{ m}^3 \quad M_{H_2O} = 27 \text{ m}^3 \quad M_{N_2} = 145 \text{ m}^3 \]

**Drying process of pasta**

First of all we calculate the amount of moisture evaporated during the process doing an enthalpy balance. The air used will have a pressure of 1 atm, \( T = 15^\circ\text{C} \) and relative humidity of 34\% (sunny day).

\[ m_{\text{dry}} \cdot w_1 + 1100 \text{ kg } H_2O = 5000 \text{ kg pasta} \cdot 0.12 \text{ kg } H_2O/m_\text{air} \cdot w_2 \quad (5.7) \]

\[ Q_{\text{air}} = m_{\text{dry}} \cdot \Delta H (5.8) \]

However, first of all we heat up the air from 15\(^\circ\text{C}\) till 40\(^\circ\text{C}\). Using psychometric diagram:

\[ w_1 = 0.004 \text{ kg } H_2O/\text{kg dry air} \quad \Delta H_{\text{air}} = 51-24.5 = 26.5 \text{ KJ/kg dry air}. \]

Secondly, we will dry pasta using adiabatic process. Therefore the enthalpy of air will not change and the air will extract moisture till saturation point: \( w_2 = 0.013 \). The process can be showed in figure 20 in annexes.

Finally, we solve 5.7 and 5.8:

\[ m_{\text{air}} = 55.555 \text{ kg dry air} \cdot 0.85 \text{ m}^3/\text{kg air} = 47,222 \text{ m}^3 \quad Q_{\text{air}} = 1472 \text{ MJ} \]

The amount of energy and air consumed per kg of dry pasta is:

\[ \frac{Q}{kg \text{ pasta}} = \frac{Q_{\text{boiler}} + Q_{\text{air}}}{m_{\text{pasta}}} = 366.8 \text{ KJ/Kg pasta} \]

In conclusion, the 80\% of the whole energy demand in pasta facilities are the heating process of pasta. Therefore, 3D printing should improve and reduce waste in this area. In addition, we recommend to design properly the contact area in the boiler, heater and during drying.
A traditional plant follows a similar scheme to figure 11. Compared with figure 10:

- B-2 is a volumetric pump which gives pressure using an infinite screw. Then, pasta is extruded using a mould while U-1 maintains the temperature.

- Afterwards, a rolling system makes a thin layer of the extruded dough. This process takes about 20 seconds more or less. In addition, a vacuum machine makes flat the dough to the optimal amount of water and without air bubbles. 3D printing does not need this process because pasta is shaped while it is extruded.

- Pasta is shaped with cutting blades or stampation processes. Then, pasta is dried on T-3 for 6-8 hours where temperature, moisture and other parameters are monitored. Using 3D printing will may possible just drying it with forced refrigeration system A-1.

Summarizing the information, 3D printing will manufacture pasta using less steps than traditional methods. The only extra cost is using forced refrigeration system. However, designing shapes which allows more air contact will help to reduce refrigeration and dry costs. In case will not be profitable a complete drying system with forced ventilation, a system like T-3 in figure 11 will be used. However, 3Dfood information will be controlled by a complex CPU which can manipulate and adapt the production to the requirements.

Finally, main processes like cooling, heating or scraps obtained during other operations have been commented. Then, a hypothetical extruded 3D pasta flux has been suggested. Then traditional method has been compared with 3D food suggestion, where 3D printing food has less processes, more control and do not depend of moulds. Thus, packaging is the next step.
Figure 10: Scheme overview of a hypothetical implantation of 3D pasta printing

Source: Own resource using Libreoffice Draw
Figure 11: Scheme overview of a hypothetical traditional pasta plant

Source: Own resource using Libreoffice Draw
5.2.9. Process within supply chain: Packaging and Distribution

**Food packaging functions**

Food packaging roles are to contain food products and keep them in good conditions until they are consumed. Food is protected against mechanical and environmental hazards which can damage or affect food final quality. Thus, packaging offers protection during distribution and makes easy transportation tasks. In addition, communication between all the parts involved in distribution is provided, because identification of food is given on labels and instructions for consumers about how to open or use food is provided.

In addition, packaging processes are automated, well adapted and included in production lines at high speed, where is possible to package 1000 packs per min or more, according to P.Fellows. Furthermore, many companies have developed intelligent storages where food is saved till is sold and distributed out of the manufacturing facilities.

Apart from all protective features which packaging activities have, product managers include marketing principles to catch the attention of consumers. Thus, packaging can improve commodities whether brand image and style presentation are well designed. The aim is to create a standout image of the product and make it different through the costumer’s eyes. However, the design should be suitable to all distribution and transportation activities.

In conclusion, packages should have functional shapes and sizes, making easy distribution and keeping the food in good conditions while is held inside of the recipient without leakages. Besides, packaging gives information required by consumers or any person, company or public department who needs to obtain data of the product. Finally, packages follow legislations and not damage the environment while the design allows an easy disposal.

Easy and environmental friendly disposal is really important: “Food is the only product class typically consumed 3 times per day by every person. Consequently, food packaging accounts for almost two-thirds of total packaging waste by volume (Hunt and others 1990). Moreover, food packaging is approximately 50% (by weight) of total packaging sales.” (Kenneth Marsh, 2007).

According to this information, the amount of residues generated by packaging is really heavy. The hotspot during packaging is the fact which is not possible to consume packaging materials. Food often is consumed by householders and then the package is
thrown away to the garbage. Therefore, the solution is to develop a design where the package will be recycled or disposed in a respective environmental way.

**Materials used in food packaging**

Nowadays, making the right decision concerning packaging material plays a fundamental role. Many factors contribute on the kind of material used to protect and transport food.

Talking about different materials founded on packaging we find a huge range of different materials and options. Normally, food packages combine many materials in order to obtain the most suitable and balanced situation between functions and cost, while research investigations are being done to investigate new materials.

However, not all materials are allowed to use to protect food. Allowing or not a material is concerned to specific government administrations. For instance, in U.S. the regulation is made by the Food and Drug Administration (FDA). Firstly, manufacturers inform the administration reports about chemicals migration to food products, before introducing the product to the market. When food is in contact with materials, there is a potential risk where there is a mass transfer between some agents through the food; whether the material is not stable across the time and it would degrade or just migrate into food.

The aim of these reports is to identify substances which are not present in the original food and are from manufacturing, packaging, transport media... Thus, the objective is to protect consumers’ health avoiding harmful components for human health. However, some migrations are allowed whether some limit is not exceeded and there is some reasonable control. Then, the substances are catalogued and regulated as indirect food additives. (Adapted from P.Fellows, 2000).

Across all the extended list founded in packaging materials it is possible to distinguish many different materials. Some of them have been used since the beginning of times such as glass and metals, while there are other materials appeared recently in all the packaging context. During the following lines we will summarize a bit some materials commenting their benefits and weaks.

For instance, PVC suffers UV degradation when it is in contact with sun light or other founts of light. The polymer without additives is unstable and the light excites the double bound. The result is the lost mechanical properties of the polymer.

**Glass**
Glass was used to protect and contain food by Egyptians using the method of hand blowing. However, during this last century all the process has been mechanized and nowadays is possible to obtain glass recipients cheaply and quickly. Traditionally, glass is manufactured melting sand, soda and limestone at 1200-1500ºC inside a kiln. When everything is totally melted, the melted glass is removed and is prepared to shape it.

This process consists on disorder the crystals which form the sand compound by silicon structures. When the crystals have been melted the internal order of the crystal is lost, and the result is an amorf material with different properties. When the paste is cold enough, the visible structure is a transparent and fragile material which allows the light passing through it. However, glass manufacturers add additives in order to stabilize the structure, because silicon organizes again in different structures across the time.

The result is a transparent material. Coloured glass is also possible to be found instead clear glass. For instance, brown glass is used in food in order to prevent the light will affect the product. This is the example of alcoholic beverages or fruit juices like orange one, which its vitamin C is damaged in presence of light radiation. Instead of coloured glass, clear glass is useful to show off the product inside and to create a more attractive situation to the costumers.

Furthermore, glass advantages include that the material is odourless and has chemical inert properties which ensure not to have migration from the package into food. Glass is impermeable to gases; thus, allow maintaining the freshness of the food. In addition, the material resists high temperature which is important to make high temperatures processes in order to sterilise food. Moreover, the natural composition of glass makes this material completely respectful with the environment.

However, glass has some disadvantages. The worst point on using it as a packaging material is the final weight of the recipient or pot. Despite of this, glass techniques are focused on to reduce the thickness, the full weight makes transportation more costly than other low materials such as plastics. In addition, the material is really brittle and is susceptible to break when it receives impacts or even pressure or temperature changes. For these reasons, defects on the glass such as bubbles or crystal network defects have to be avoided.

Metal

“Metal is the most versatile of all packaging forms. It offers combination of excellent physical protection and barrier properties, formability and decorative potential, recyclability, and consumer acceptance". (Kenneth Marsh, 2007). According to this article, the most extended metal materials in food packaging are aluminium and steel.
Aluminium

First of all, the most important aluminium properties are good flexibility, malleability and resilience. Flexibility and malleability provide modelling the material, property really useful in packaging while resilience decreases the risk of breakages as it happens with glass which is more fragile than aluminium. Moreover, aluminium is a lightweight material which offers lower costs than glass during transporting.

Furthermore, aluminium provides a barrier against atmosphere conditions avoiding migration of moisture, odours or microorganisms into food while resist corrosion problems. Aluminium provides a layer of aluminium oxide which protects the metal form more oxidation. For instance, aluminium is applied to make cans or to protect soft-drink cans, natural or fired tomato, canned food such as tuna fish, pet food…

Also aluminium can be rolled using thin sheets and then making an annealing treatment in order to achieve the desired properties since obtain aluminium foil form. This type is presented and available in a wide range of thicknesses. However, obtaining aluminium in this shape is not possible to achieve using recycled aluminium.

Despite of all the good properties, using this material purely is expensive compared with other materials such as plastic, cardboard or paper. However, aluminium brings good properties to packaging. Thus, how to make cheaper packaging while we can maintain a similar quality?

The answer is a mixture between cheaper materials than aluminium, like plastic or paper and adding aluminium. Therefore, the combination of both materials forms a composite where the cheapest material is the matrix. On one hand, aluminium layers are used like binding material and added to paper or plastic. Plastics allows heat saleability but not ensures a completely barrier because is porous.

Aluminium provides the necessary properties and let mechanical properties to the other material. Because of aluminium cost, this method is only used to protect valued food like dried soups, spices…

On the other hand, also is possible to reduce more packaging costs using just a thin layer of aluminium. Again aluminium will bring the protective properties to the package. The typical example is snack bags, for instance. However, recycling processes is not considered.
because of the non feasible process where aluminium should be separated from the rest of materials.

Steel

Basically, steel is an alloy between carbon and iron. However, steel represents an important sector in all the economic activities: building sector, steel industry, chemistry... In addition, steel manufacturers add elements like molybdenum, manganese or other metallic elements which improve steel resistance against chemical corrosion like stainless steel or just mechanical features. In order to select easily the particular alloy, which is suitable to our necessities, it is designed an international code called AISI, where the steel process is described with a letters code and the composition of the steel with numbers.

Talking about steel in food packaging, the material is really extended in it. However a tinplate treatment is required in order to protect steel. Steel is compounded by Fe fundamentally. Observing a potential redox table, Fe has a reduction potential of -0.41V which means Fe trends to be oxidized easily. Moreover, can food can be maintained in good conditions in some cases during years. According to this information, protecting steel against atmosphere conditions and even from the food inside the recipient is required.

Protecting food steel is made adding a tin surface treatment dipping steel on to melted tin or using electrolytic tinplates treatments. In addition, the metal is covered with coatings from epoxy or vinyl nature in order to create an inert barrier between food and the metal. Also migrations are prevented. Tin will be in contact with the presence of an aerobic atmosphere. In this conditions it is formed an oxide which is stable in time and protects the metal below the oxide.

Tinplate provides excellent barrier properties to gases, water vapour, light and odours. Also it is possible to prepare sealed food and hermetically because its formability. According with that information, this packaging is used in can drinks, processed food or containers for powdered food which have for instance floor or sugar and freshness is required to maintain.

In addition, this kind of packaging is well disposed and recycled and reused material does not lose any quality. Comparing steel with aluminium, the costs are cheaper using the first one as an option. Thus, this material is earning presence instead of aluminium which apart from being more expensive is not profitable to recycle it.

Plastics
Plastic is an extended concept which includes a wide range of materials. Since the first plastic was made by Alexander Parkes in London, plastics have become an important pillar in our society because their functional and low cost properties. Plastics are obtained using two methods: condensation or addition polymerization reactions.

On one hand, polycondensation reactions grow the chain by condensation reactions and releasing lower molecules such as H₂O or HCl during the bond formation. During this process the reaction involves monomers with at least two groups on it. Whether the monomer have just one reactive part, the reaction will finish from one site because is not possible to interact both functional groups.

On the other hand, polyaddition reactions are defined to follow a certain reaction system which involves a starting agent which will start the chain mechanism. In order to obtain this kind of polymers is required at least two different monomers.

In addition, plastics are classified by their behaviour in front of temperature. Basically, two groups are distinguished: those which just can be melted once and when they solidify is not possible to obtain again a liquid state (thermosets); and those others which can be melted as many times as they are exposed to the appropriate temperature called thermoplastics.

Thermosets are characterized by the strength and durability. However, they are not used in food packaging and instead of them; thermoplastics are the most suitable option for this kind of packaging. Thermosets are used in other applications like coatings or in automobiles where more time is solicited.

“The use of plastics in food packaging has continued to increase due to the low cost of materials and functional advantages (such as thermosealability, microwaveability, optical properties, and unlimited sizes and shapes) over traditional materials such as glass and tinplate.” (Kenneth Marsh, 2007)

Once we have just set thermoplastics are really extended across food packaging, thermoplastics are the most suitable candidate to food packaging. These plastics are easily shaped and moulded while the recycle and reuse is relatively cheap. Recycle is made just separating plastics according the origin resin and then melted again.

Instead of all the wide range of plastics available and used for food packaging, here just the main polymers will be commented. For each food or product there is a specific suitable packaging material. However, commenting all plastics is not the porpoise of the work. Therefore, polyolefines and polyesters are going to be described because they are the most extended plastics used in food packaging, according to (Kenneth Marsh, 2007)
Polyolefines

In this group two polymers are highlighted: polyethylene and polypropylene both manufactured using. The first one is divided also in two subgroups: low (LDPE) and high density polyethylene (HDPE). Low density polyethylene reacts under high pressure while high density polymer is manufactured in low pressure conditions. The difference between them at molecular distribution is LDPE is more branched than HDPE.

HDPE is strong, tough, resistant to chemicals and moisture exposures while is permeable to gas. It is used in many applications such as milk bottles, juices or even in retail or trash bags. In contrast, LDPE shares similar properties with HDPE but it is flexible and easy to seal. Thus, this polymer is used in applications where heat sealing is needed. Lids or squeezable food bottles such as ketchup or mayonnaise are made of HDPE, for instance.

Another plastic used in food packaging is polypropylene (PP) denser and has better properties than polyethylene. This polymer is transparent, resists chemicals and provides a good barrier against water vapour. The vantage of this polymer is its melting point: 160ºC. This plastic is really suitable for precooked food which can be reheated using microwaves. PP is also found in yogurts containers or margarines tubes.

Polyesters

Polyester family is synthesized by condensation reactions between carboxylic and alcohols groups, in chemistry called esterification, and the reactions release water as well as the desired plastic. The most important polymers used in food packaging in this family are PET, polycarbonate and PEN. About polycarbonate is used in replacement of glass in applications like baby bottles. However, whether the polymer is in presence of some detergents, it can release bisphenol A which is really toxic.

Finally, PEN properties are quite similar to PET but improving retention skills. In addition, PEN has higher melting point which allows washing treatments at high temperature to clean plastic and eliminate any microbial presence. Therefore, reusing the container or recycling is feasible. However, the cost of PEN is 3 or 4 times more expensive than PET.

PET

PET is a short name of Polyethylene terephthalate which is obtained in presence of ethylenglicol and the terephthalic acid. The polymer exists in two forms: amorphous and semicrystalline. Their properties are really useful when the aim is to protect food against
gases. In addition, the plastic offers protection against heat and acid media but not in basic one.

PET is applied to beverage and water packaging for its excellent retention of gases retention, transparency and lightweight. However, the material is used in two main applications in food packaging: in containers like bottles and jars, and in thin oriented sheets which can resist tangential efforts such as in snack food wrappers, according to Kenneth Marsh’s paper.

**Paper and paperboard**

“Paper and paperboard are sheet materials made from an interlaced network of cellulose fibbers derived from wood by using sulphate and sulphite. The fibres are then pulped and/or bleached and treated with chemicals such as slimicides and strengthening agents to produce the paper product.” (P.Fellows, 2000).

Paper is not used in food packaging for food which requires long time periods of protection. When paper is used with protective aim is normally applied in contact with food. However, the paper is treated with coats or impregnating materials which increase the poor barrier protection of paper. This paper is the most important one because is one of the materials which is used in the famous and well extended package called Tetra Brick.

For instance, the strongest paper used is kraft paper, whose name is from the process received which is called Kraft. Another example is sulphite paper which is weaker than kraft paper. However, the paper receives a glazed treatment and the surface is coated in order to improve printing properties on the surface and allow better transfer of ink.

**3D printing food packaging proposal**

With the settlement of 3D printing technology around all the industries and houses, packaging may be modified inside food area. The new technology will use different methods in order to manufacture food or just cooking it in our kitchens. This technology will try to improve and revolutionize the actual system making it more efficient. For this reason, the technology should improve all the actual aspects, and packaging is not an exception in my point of view.

Talking more accurately, ultimate Foodini equipment will use opened capsule system. This fact offers the possibility to introduce food as we imagine till now. Adding fresh ingredients inside the capsule will bring us the possibility to choose whatever food we desire, according to the technical features of the machine. However, also is possible in closed systems such as the offer presented by 3D systems called Chefjet. The only
difference between both techniques is the possibility or not to be able to introduce food; whose origin is decided by users when they want to prepare a dish.

In all this market, where few types of equipment are being designed or have just appeared in it, what seems clearly is all costumers machines will work with capsules. Introducing food in this kind of recipients seems to provide the food in an efficient way such as coffee machines working with capsules found in many houses.

Obtaining some information looking at coffee sector we will realise how food householders packaging will evolve during the following years. Searching information about coffee sector is possible to find articles headlined such as: "HiLine Coffee Company to offer capsules through traditional retailers, introduces new website" (dailycoffeenews.com). Reading this new, lector can realise how much profitable is coffee market, where main companies compete each other to win a place in this market, where capsules system has arrived recently.

From this background, it is possible to estimate a future where prepared food capsules will be available in supermarkets and shops. Surely, new packaging system in food will appear. As we commented, food companies will take advantage of this kind of equipment, manufacturing fresh and prepared food available for these new 3d printers.

Given some hypothetical ideas, from the non knowledge point about researches focused on new materials, packaging is possible to be linked with 3d printing. The new technology will bring opportunities which we could not imagine before because the technology was not discovered. For instance, imagining some kind of comestible polymer which can offers the same or better features than plastic or cardboard packages.

The idea seems not realistic at the beginning. However, in a website called tintacomestible.com, there is already available comestible inks and even sugar paper. In addition, many 2D printers can be built, thus, if this technology has been developed in 2D, why not to apply this technology to packaging at the end of 3D printing in wrapping process?

In addition: “Commercialization of bioplastics is underway. NatureWorks, LLC (a stand-alone company wholly owned by Cargill Inc.) manufactures polylactide from natural products (corn sugar). After the original use, the polymer can be hydrolyzed to recover lactic acid, thereby approaching the cradle-to-cradle objective (that is, imposing zero impact on future generations). In addition, Wal-Mart Inc. is using biopolymers by employing polylactide to package fresh cut produce (Bastioli 2005).”
And what about atmosphere conditions or even pathogens which can grow up on the surface of the package? The answer to this question is dealing with all the possible causes which can damage food. Therefore, the aim is to develop resisting packaging material and comestible. In order to do this task, the material will be resistant to mechanical alterations such as: packages falling down or blowing each other during transport, chemical causes which can modify food features or atmosphere changes in temperature and moisture.

For instance, water activity in food, also called $a_w$, is an important parameter when we are dealing with food expenditure time. Basically, $a_w$ in food is referred to the partial vapour pressure of water at a certain temperature. In practice the parameter define the amount of water inside food. Depending on the amount of it, food is susceptible to be attacked by one or another pathogen: bacteria, fungus… This parameter can be controlled by thermal treatments, the presence of sugar or salt…; and is very important in freezing operations. Some deteriorations caused by $a_w$ are shown on figure 10.

Observing a bit figure 12, we see that below an aw of 0.70, the option to have microorganism in our food is eliminated. However, food properties and flavours are extremely linked to $a_w$. For this reason, much food will lose their properties and will not be attractive to costumers.

Other options of 3D printing food include not just cooking fresh food obtained from markets or other retails. For instance, obtaining food from industries as everybody does with pasta may be come in handy. None of us thinks about preparing traditional pasta every day a part form specific restaurants or family meals. The point is costumers just search for an easy way to cook pasta and obtain an acceptable and nutritional quality. An important shape to present food in capsules will be powdered food. Powder is easy to transport and has light weight. However, this shape has in food has the capability to absorb moisture really fast because its high surface contact rate.
Talking from this point of view, precooked or prepared food will be offered to costumers in packaging format well known and used till now. Despite of that, materials used till now has to evolve as it has been done during these last 30 years. 3D printing is a technology which has enormous potential and can bring to the society new balanced situation in food supply chain.

However, the technology should be complemented with other knowledge areas like, for instance, new materials researches. Nowadays, the aim to obtain a suitable material is that one which not just is recyclable or reused. Being recyclable should be the minimum requirements which they should have and other features should be attended.

Talking more accurately about these features, we will start with light weighting packaging. Lighter containers, cans, jars… provide less consume of materials and energy.

For this reason, controlling material amount and fluxes is important to reduce consume. Thus, the objective is to manufacture packaging with the most suitable material and manufacture activities; and research on new materials whether the actual packaging solutions are not the best ones.

Furthermore, recycling and reuse are important. In my point of view, reusing containers is a better option than recycling. The first one consists on reincorporate packaging, which has been used, to the supply chain and doing again the same function. The best example here is glass bottles used to hold water sent to the water industry again. Here, they clean the bottles treating them and refilling again.

Figure12: Relationship of food deterioration rate as a function of $a_w$

Source: (http://www.fao.org/)
However, many times this is not feasible because of the expensive cost which reusing suppose to the industries. This is the case of plastic such as PET which disposing and reselling it is more profitable than reusing again. As many plastics, PET looses properties at long time scale and to reuse it, a repolymerization process should be done.

Recently in polymers sector is becoming a specific polymer called biopolymer and biodegradable polymers. The first one is made totally or partially by polymers which origin is found in the nature. This is not a new concept because cellulose has been used and is being used to manufacture many derivates. For instance, cellulose derivates can be divided in soluble or non soluble in water.

Then, why not using biopolymers in order to synthesise better materials? Certainly in food there are many edible types: “Edible films are derived from plant and animal sources such as zein (corn protein), whey (milk protein), collagen (constituent of skin, tendon, and connective tissue), and gelatine (product of partial hydrolysis of collagen).” (P. Fellows, 2000).

Biopolymers are really interesting in many areas of research like their application in medicine. In addition, in food sector can be really useful for coating. For instance, eters of cellulose, apart from all the applications which they have, are really extended in food bakery industry in order to maintain the consistence and to stabilize the flavour in food.

Despite all the benefits which biopolymers can bring to the society, their use should be controlled. Imagining a hypothetical situation where all the packaging is made of biopolymers, which would be their origin? The answer is clearly, the nature. Thus, in order to obtain the entire amount required for packaging the nature will be exploded more intensely. In addition, the elementary food such as flour or rice will increase the price. It is happening with Biodiesel case.

According to The Guardian newspaper online version there is a new which is written: “The World Bank estimates that between June and December 2010 an additional 44 million people fell below the poverty line due to rises in food prices. The bank's president, Robert Zoellick, called for the world to "put food first".” (Tim Rice the guardian online version, 2011. Therefore, some biopolymers which can be integrated in massive scale should be controlled.

Furthermore, recently the nanopolymers research has become really interesting. This kind of polymers provides the necessary tools to create polymers at nanometre scale. The best example here is a polymer called graphene which many scientists see on it the material of the future. Despite of this, graphene is just made of pure carbon and has the best properties which can be found in a material since today. However, graphene has not
3D printing food: the sustainable future

be commercialized because of the high cost to obtain it. Therefore, creating accurate materials require accurate techniques like 3D printing.

Summarizing all the 3D packaging proposal, 3D printing food technology will change packaging. Powdered food will provide a good way to transport food and make it with less weight. However, its specific contact area makes it weak in front of moisture. Other possibilities have been commented such as comestible biopolymers which protect food from the environment.

About amount of packaging managed by the industry, recycling systems and costumers’ behaviour; the most important part is the material used for packaging and a good conscience on being environmental friendly. Fortunately, the options to deal with this issue seem to be opened, feasible and the answer will not be just in one material or way to act.
6. Required sustainability of 3D printing food

6.1. Important areas

6.1.1. Objectives

Once supply chain has been analysed and 3D printing food is introduced to the market, the point now is to identify all the aspects which can damage the environment using 3D food printers. Thus, the aim is to analyse the potential impacts and their origin. After that, the aim is to study whether 3D printing food is capable to give tool to fix the actual background. In addition, 3D printing food potential technology impacts will be analysed. Finally, social impact and acceptation will be assessed. However, pollutants and emissions will not be explained accurately, because the aim of this impact is to analyze waste.

6.1.2. Water waste

Withdrawn and consumed water

First of all we should differentiate between two concepts: water withdrawn and water consumed. On the one hand, water withdrawn concept makes reference to all the full amount of water which has been extracted from the water resources such as rivers, water wells or lakes, for example.

On the other hand, water consumption measures the amount of water lost. In other words, the water which is not returned to the nature or artificial water resources. Water consumed is linked to water which is lost during processes by for instance: atmosphere evaporation, food moisture, water which forms part of a product like in the case of beverage industry, or watering plants, which afterwards, they will lose water by transpiration processes.

Searching where water is consumed

Once we have introduced these concepts it is time to view some statistical data about water consumption per region. Analyzing the figure 13 we can detect two aspects: withdrawn and water consumption. First of all, the trend on the forecast in all the countries is to withdraw more water than the past century. However, the consumed water is different according to the world continent. Then, the first thing which is easy to see is the increasing trend of waste in Asia and affirmations like the following one confirms the graphic: “In 2000,
about 57% of the world’s freshwater withdrawal, and 70% of its consumption, took place in Asia, where the world’s major irrigated lands are located” (UNESCO, 1999).

Asia has countries which are emerging and increasing their economy extremely fast. At the start of the century, country economies such as China or India have started to increase. However, the total amount of world population between both countries is more or less a 40%. Thus, supplying people needs management of the water resources.

Nevertheless, a paper published says: The 38% of the whole hydraulic resources are consumed by China India and U.S. “The agriculture sector represents a 92% of the total amount of water and each united states citizen consumes an average of 2842 cubic metres, according to an study of an ecological footprint of1996-2005.”(Translated and adapted of http://www.compromisorse.com).

About the rest of the world seems not changing that much. Developed countries are implanting harder policy against useless consume and waste of water; while non developed countries do not have the enough resources to obtain water from their founts. Nevertheless: “In the coming decades, the most intensive rate of water withdrawal is expected to occur in Africa and South America (increasing by 1.5-1.6 times), while the least will take place in Europe and North America (1.2 times)” (Harrison and Pearce, 2001; Shiklomanov, 1999; UNESCO, 1999).

Figure13: Water withdrawal and consumption assessment and trend.

Source: (http://www.unep.org/)

Another important point is to locate which activities consume more water. According to figure 14, the 67% of water consumed is from agricultural activities. Therefore, the efforts
to reduce drastically the water consume is in agriculture field. According to the data above, the most consumers of water have huge harvests and crops areas.

![Figure 14: Percentage of water consumption per sector](http://www.unep.org/)

**Source:** (http://www.unep.org/)

### 3D food printing

One of the most important points on 3D printing food assessed, in this thesis, is to be sustainable and environmentally friendly technology. Being objective, printing food will decrease the amount of food, at least food thrown away because of none correct management or prevision about food.

Food is compounded by carbohydrates, proteins, fates, vitamins and other oligoelements. However, many parts of them have water. According to the table 6, many fruits and vegetables contain at least 79% of water as. In consequence, reducing food waste is translated in less water consumption. Thus, it takes sense to have agriculture as the largest waster of water.

Observing figure 13, the aim on reducing water waste is agriculture sector. However, regulating water consumption in that field is difficult to achieve, because 3D printers need to use raw food in order to do their printouts. In spite of that, we have localized agriculture as the major waste point but 3D printing technology just can reduce waste whether after the next steps in supply chain.
6.1.3. Food waste

As we saw on the background scenario, the world lives in an unbalanced feeding situation. There are regions of the world where people do not have access to food while others have too much abundance and food is lost. Today is difficult to assess the reduction food waste which 3D food printers will reduce. However, the main aim on this technology is to fix, at least, all food resources which are thrown away to the garbage every year in developed countries. Furthermore, emerging countries will reduce their waste whether they implant the developed technology once it is possible to achieve by them.

Analyzing the situation in a developed region will be able to decide whether reducing food should be or not concerned to 3D printing food. In order to do that, we introduce some information about food wasted in Europe which is reflected on the table 4. The total amount wasted in just Europe is about 77 million tonnes per year, which from my point of view is an incredible amount of food wasted, just in a small region as Europe.

In consequence, extremely measures should to be taken in order to fix this situation and to reduce this amount of non profitable food. Table 4 shows us the waste break down, where the 70% of total waste is from manufacture and householder origin.

In front of this data, it is obvious to start attacking the problem on these two sectors; because is the most important part of the total amount. 3d printing food technology will be implanted in manufacturing and householders fields, thus, the printers have the potential to change this background.

Looking for more information, analyzing the actual flux diagram of supply chain parts will be able to detect where 3d printing food will be useful. The diagram describes the processes from the point of view of waste, not about the food cycle.
Nevertheless, food printing offers a different alternative. The key word is control. Using 3D food printing process is controlled. Preparing food is decided by the owner of the 3D equipment. As in a TNO conference during a TedX conference, it will be possible for everyone, who will have a 3D printer at home, printing food while you are arriving at home after a work day. For instance, it is feasible using an app on your cellphone which provides information about your arrival to your 3D printer.

Therefore, the equipment will be able to inform the customers the necessary amount of food which is necessary to purchase, taking in mind some parameters about people who live there: number, sex, age, activity...

Thus, 3D printing proposal is a bit different. Supposing a background where the total implanted technology of 3D printing food will be at 25% of the whole European food consumption. Then, the total amount of food wasted is about 25% less affected by the currently processes and the total food not wasted by the traditional methods will be about 19 million tonnes.

In conclusion, 19 million tonnes of food will not be thrown away. However, 3D printing food will not eliminate the total amount of food processed, because in all the processes is impossible to obtain 100% performance. Instead of that, resources and food will be saved.

Apart from all the benefits contributed by 3D printers, attacking food waste is necessary to change behaviours on population. For instance, many people are not awoken about what they throw away to the garbage. Food value is not considered enough throughout developed countries, because food cost is. Reasons should be searched in lack of awareness and knowledge about food consumption and waste problem.

On the other hand, there is a general waste attitude where people do not manage properly food purchases. Many times, they buy food without checking their fridges before going to the closest retailer. In consequence, food which is going to expire early is replaced by new food and the other is disposed. In the same way, there are two realities in front of food consumption: an abundance one and an unbalanced situation, as we saw on the first approach.

Finally, all this problems are feed by the “low cost of food”. In comparison with developed salaries and rents, buying food supposes less cost than in other regions. Thus, all this factors are feed-back.
6.1.4. Energy consumption

Renewable and non-renewable energy

When we talk about energy resources they are classified in two different types depending on the resource origin: non-renewable and renewable energy. On one hand, non-renewable is the conventional one which has been used for ages such as coal, gas and the most important today oil and nuclear energy.

Talking about basic differences, non-renewable energies take the energy from resources which will be consumed and they cannot be produced again. For instance, oil and coal are the result of millions of years of organic mass decomposed under certain conditions. They are used because of the low cost, the profitable market, which suppose a dependent energetic society, and the calorific power which has these resources.

On the other hand, renewable energy deals with natural resources which are available on the nature. For instance, energy of wind caused by pressure difference on the atmosphere is taken in advantage and used to move windy turbines on mills. The energy obtained is clean and does not damage the environment. However, maintenance costs are more expensive than traditional methods and some of them damage the background image.

Energy consumption and trend

Even though, when non-renewable resources will be exhausted, they are the future of a society extremely linked to energy. However, nowadays the share of the total energy used per day is the 20%, as we can see on the figure 16. Thus, there is a large way to run before all this situation will improve.

According to this statement, managing properly the resources is needed. Otherwise, the actual society will not go further with the expectation of 1 billion people more each 15 years.

Furthermore, the pillar of our society, oil, will be finished in 39 years more or less according to the forecast of the world trend. However, this data is according on the natural resources which can be exploded with the actual technology on drills and the resources localized since today.
Anyway, the situation is more critical because oil is used today for many materials in our society. Basically, petrochemical industry lives from synthetic materials where oil is receives treatment on refineries and is divided in oil fractions.

However, what about the most recent forecasts about energy consumption? “Worldwide energy consumption will continue to increase by approx. 50 quadrillion Btu every year. Thus starting from 207 quadrillion Btu in the year 1970, it is predicted to skyrocket to a value of 702 quadrillion Btu in 2030. Here emerging economies (led by China and India) will be the key contributors to the world energy consumption in the future.” (A.Evers, http://www.hydrogenambassadors.com/).
Furthermore, according to the figure 17 energy consumption will increase a 25% since 2015 to 2030. The data has sense because emerging economies such as China and India are located in Asia, and this continent has more than the 60% of the whole population. Even though, energy consumption should be well managed and avoiding unnecessary waste and energy leaks.

![Figure 17: Energy World trend](image)

**Source:** EIA, System for the Analysis of Global Energy markets 2007-2005

### Table 5: World energy consumption by end-user (quadrillion Btu) 2011

<table>
<thead>
<tr>
<th>End-use sector</th>
<th>Energy used</th>
<th>Energy losses</th>
<th>Total energy use</th>
<th>Share of total energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>29</td>
<td>34</td>
<td>62</td>
<td>12%</td>
</tr>
<tr>
<td>Industrial</td>
<td>200</td>
<td>66</td>
<td>266</td>
<td>51%</td>
</tr>
<tr>
<td>Residential</td>
<td>52</td>
<td>40</td>
<td>92</td>
<td>18%</td>
</tr>
<tr>
<td>Transportation</td>
<td>101</td>
<td>2</td>
<td>103</td>
<td>20%</td>
</tr>
<tr>
<td>Electric power sector</td>
<td>204</td>
<td>142</td>
<td></td>
<td>39%</td>
</tr>
</tbody>
</table>

**Source:** Adapted from U.S. Energy administration and Information, 2011

### 3D printing food

Implanting 3D printing has the potential to reduce energy consumption and make it more efficient. Making an analogy on other 3D printing sectors is possible to use free from fabrication on polymers, instead of the traditional. Then, using 3d printing on polymers will reduce defects on the pieces or the fact of needing a certain mould for each piece.
Therefore, costs will be reduced on moulds and defects on problematic parts will be avoided.

Furthermore, one well designed process is more feasible to have less energy and material leaks than four or five processes. In conclusion, 3d printing food technology, why should be different?

6.1.5. Social acceptation

How 3D printing food will be received by the markets and people? From my opinion, this is the key of every product introduced to the market. The world has lived many technological improvements and specially these times, where technology changes really fast, as it was never seen.

In addition, we live market competitions in all the sectors where all the companies try to gain a place. For instance, we have and had many cases such as: the market battle between VHS format of JVC format and the Betamax from Sony, or Windows system in front of MAC and Linux. In 3D printing food there are some proposals and people who is investigating such as Foodini (naturalmachines) or Chefjet (3d Systems).

Going further, people starts to be interested in a product when there is equilibrium between the cost of obtaining the product and the purchasing power of who is interested in buying it. In addition, the product should satisfy some necessities which can be new, offered by the product, or better satisfied than others.

According to that, nowadays is impossible that 3d printing food will become a partner of our microwaves in our kitchens, because its cost is too much expensive than their features. In the cheapest scenario, we will purchase a 3D printer food (Foodini) for about 1.000$.

Furthermore, it is becoming a general conciseness about food quality and less processing steps in our dishes. This can be a barrier if people think 3D printers area worse option than actual processes. Also, it is possible that companies or industries which will not want to implant 3D printers, will try to convince people that this technology is more harmful. Finally, the actual 3D printers are too slow. It is not feasible that somebody will wait hours to eat. Even the technology is really new, this is a starting barrier.

On the other hand, printing food offers a new scenario of investigation and a huge range of opportunities. The fact of printing food gives us the opportunity to create and design new food, not just from the shape. Going further, aliments can be designed from the beginning with the porpoise of offering food with determinate nutritional value. Adapting the idea from TNO conference, on their slides it is commented that sport people, children,
seniors or pregnant women have different nutritional necessities. Thus, why not designing food according their necessities and saving waste?

### 6.1.6. Food hazards

There are three major hazards which can be introduced across the whole food supply chain: microbiological, chemical and physical hazards.

Firstly, microbiological hazards occur because food is always on contact with an environment where is plenty of microorganisms which can damage our health when they are inside our body. Potential hazards on these groups are bacteria, yeasts, viruses, parasites and fungi. Depending on the microorganism, different techniques are needed in order to ensure healthy food consumption. For instance, viruses are not visible with a light microscope and some of them resist cooking or freezing treatments.

Secondly, chemical hazards are presently at any point of the supply chain. The origin of these hazards is from food surface contact where the chemical is transferred to food and becomes contaminated. One of the most important hazards is metal presence on food. On table 7 metal limits presence in food is shown. For instance, Hg is one of the most harmful for human health and is becoming a problem in fishes which are located at the top part of the ecosystems, such as salmon. Another potential hazard are migrations from the containers to food. Zinc and copper are the best example of this kind of hazard, because some metal can food containers are made of allies of Fe-Zn(steels).

Other hazards of this type are compounds added to food intentionally in order to improve food colour or enhance flavours. However, most of them are not accepted by costumers and all the additives should be clearly informed on labels. “Foodservice establishments are prohibited by law from using sulphites to maintain product freshness. However, they are still approved for use in some food processing operations, for example, processing shrimp and manufacturing wine. If they are used, the product must be clearly labelled.” (Cooperative Extension Food Safety Education, 2015)

Finally, physical hazards are related with foreign bodies or strange objects which arrive at food during food processes because a non correct measures when dealing with food. Examples of this are: soil, hair, stones, dirt… Therefore, it is suitable to implant and engage a know-how methodology. The strategy is to follow the instructions of a prevention program called Hazard Analysis Critical Control Point (HACCP).
6.1.7. SWOT analysis

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S1. Personalized food.</strong> Food can be adapted to the nutritional necessities of everybody. Depending on genre, age or activity food can be designed to satisfy their necessities.</td>
<td><strong>W1. Householder equipment.</strong> 3D printing equipment should compete against all the cooking electrical appliances which we have. 3D printing will be a complement in our kitchens. However, it would be difficult to gain the supremacy.</td>
</tr>
<tr>
<td><strong>S2. Reduced waste.</strong> Implanted at huge scale it can save energy, water and food thrown away. Furthermore,</td>
<td><strong>W2. Printing times.</strong> Actual equipments need too much time to print food. Food should be prepared faster. Nobody wants to wait 5 hours for their meal or industrial production suffering delays. Time is money.</td>
</tr>
<tr>
<td><strong>S3. Controlled process.</strong> Printing food means controlling when and where we will consume food. Therefore, food consumption will be controlled and less food wasted.</td>
<td><strong>W3. Technological barriers.</strong> Designing and printing 3D objects is not an easy task. Thus, there is an inherent difficult on the process. Sintering food from the beginning is complicated.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Threats</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1. Expensive cost.</strong> The cost can be too much expensive. As we see on 7.2.4, commercial equipments cost minimum 1000$. Therefore, the cost should decrease to be accessible.</td>
<td><strong>O1. New food.</strong> Food gives the option to explore new food which till now was not able to eat or create. This fact gives an exclusive feature and differentiates the product from the rest.</td>
</tr>
<tr>
<td><strong>T2. Traditional methods.</strong> 3D printing technology arrives as a substitute product.</td>
<td><strong>O2. Different technologies.</strong> 3D printing food can be printed using different methods:</td>
</tr>
</tbody>
</table>
Thus, the technology will compete against the actual technology.

### T3. Processed food

Nowadays, it is starting a general conciseness where unprocessed food is healthier. It can affect the revenues if people consider 3D printing as a bad process for their health. FFF or powdered beds can be suitable options.

**Marketing and publicity.** What about printing the company’s logo on a biscuit or designing new comestible packaging? These are some examples of what is possible to do in order to introduce new methods.

#### Figure 18: SWAP table

**Source:** Own source

Once the swot analysis is done, we complement swot analysis introducing informational graph in figure 19. Strengths and opportunities have more weight than the rest of points. The reason is 3D food will be exploded and the benefits brought are more profitable than worse aspects. Experimenting and creating new food is a powerful tool. However, making the equipment efficient should deal with people opinion about 3D printing and improving technological aspects.

During this part of the thesis, energetic, water and wasted food has been dealt. The actual situation has been presented and then requirements to 3D printing have been explained. In conclusion, background is presented as an increasing demand in all 3 sectors. However, energy and water consumption will decrease if food waste is reduced. Therefore, 3D printing is a powerful tool to minimize waste.

Even though, 3D printing food has his limitations inherent to their complexity and the actual prize. Personalized food seems to need more time and investigation, and sometimes population will not may accept 3D printing if it is seen as a more processed food than the one available today. Despite of that, their benefits provided are really strong.
Figure 19: Informational graph

Source: Own source using creately.com
7. Conclusions

The thesis has analyzed all the supply chain. During the analysis, the actual problems related with waste have been explained. We found the world is living a period where at 2050 the system is expected to sustain 9 billion people with an approximate growing rate of 1 billion people per 15 years. In addition, energy consumption will increase a 25% since 2015 to 2030 while water consumption is mainly focused on agriculture sector with a 67% of total water used.

Just in Europe, the 70% of total waste is from manufacture and householder origin with a total waste per year of 77 million tonnes of food. Supposing an implanted 25% of 3D printing, 19 million tonnes of food will not be thrown away per year in Europe. At the same time, water and energy resources will be saved because that food will not be grown and processed with looses.

3D printing food has the potential to fix the situation with a properly development. An implantation at huge scale in industry facilities is possible to achieve. As we see in the study case, the equipment perfectly fits on a common food industry which uses extrusion such as pasta. The most important advantage of 3D printing food is moulds are not used, has more product versatility, new food is able to be manufactured and less processes are needed.

In contrast, householder equipment has less social acceptation in my point of view... Nowadays, commercialized equipments cost: $5000 for Chef jet, $10000 for Chefjet Pro and 1000$ approximately for Foodini. Therefore, the actual price makes not feasible a massive purchase. In addition, its large cooking time of about hours for a short amount of food makes it not practical. As all new technology, they follow some common structure: army development, industrial implantation and then householder commercialization. This is the example of GPS, for instance.

About the pasta case, the 80% of the whole heat demand in pasta facilities are the drying process of pasta. Therefore, 3D printing should improve and reduce waste in this area. More or less the energy consumption estimated is 366,8Kk/kg pasta.

Talking about packaging, 3D printing can offer powder food, biopolymers or other materials or shapes which can be suitable for packaging functions. Therefore, food protected using a wrap from apple peels can be an idea about how packaging can evolve.

In conclusion, benefits and new options which would be brought are enormous, but making a prevision about how far will arrive is difficult to predict. What is sure, is 3D printing food is an open door which humanity has already cross.
8. Acknowledgements

First of all, I would like to say it has been a pleasure working with Professor Zaneta Stasiskiene, who proposed me the topic of this thesis. Also, she has assessed me during its developing.

Finally, I would like to say thank you to my mum for her unconditional support during the developing of this thesis and all these years.
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