REQUIREMENTS FOR THE PREPARATION OF THE PRODUCTION OF AN INTERNAL CATALYST.

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1-6-2023

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ABSTRACT

The current master's degree thesis follows the goal of analysing the viability of the implementation and commercialization of an internal catalyst.

The in-cylinder catalyst is an additional method, placing the component in the combustion chamber, much closer to the combustion process, which allows to reduce the emissions of gases such as carbon monoxide, hydrocarbons… at the very source of emission (the catalyst is applied on the glow plugs). These solutions are necessary because the reduction of exhaust emissions from vehicles is a key aspect of reducing the negative impact of transport in the environment.

The application of this method is known as a supplementary method of exhaust gas aftertreatment. Currently, there are numerous scientific investigations analysing the efficiency of this system in stationary conditions, and the dynamic states studies, in which this thesis is based on, were carried out by the tutor of these project (Monika Andrych-Zalewska, DEng. – Faculty of Mechanical Engineering, Wrocław University of Technology), being a member of an investigation team, conducting a real driving emission test.

During the development of the project the following topics are going to be addressed: description, preparation and risks related to practical application/potential implementation; lack of barriers in the implementation and commercialization; and the benefits of the implementation of the system.

The main motivation for undertaking these studies about the application of this concept is that it could help to deal with the carbon footprint, ensuring commitment to the 2030 Agenda objectives, and to help to build a sustainable future for next generations.

Key words: internal catalyst, in-cylinder catalyst, exhaust gas aftertreatment, carbon footprint, real driving emission test.

1 Introduction.

1.1 In-cylinder catalyst.

Piston combustion engines are one of the most common sources of power in transport. Despite of the fact that in its origin was only used in stationary conditions, this kind of engine has been developed to be used in vehicles, such as motorcycles, cars, trucks…

Due to this popularity, since its first uses has undergone a constant evolution in different directions in order to improve its efficiency, increase the power, and nowadays, there is a strong emphasis on improving the exhaust gas quality.

This emphasis comes from the current legislation in most countries of the world, since the concern about the climatic situation of the planet, and the relevance of combustion piston engines to this issue, as one of the most widely used energy sources today, their contribution to climate change and the greenhouse effect is more than significant.

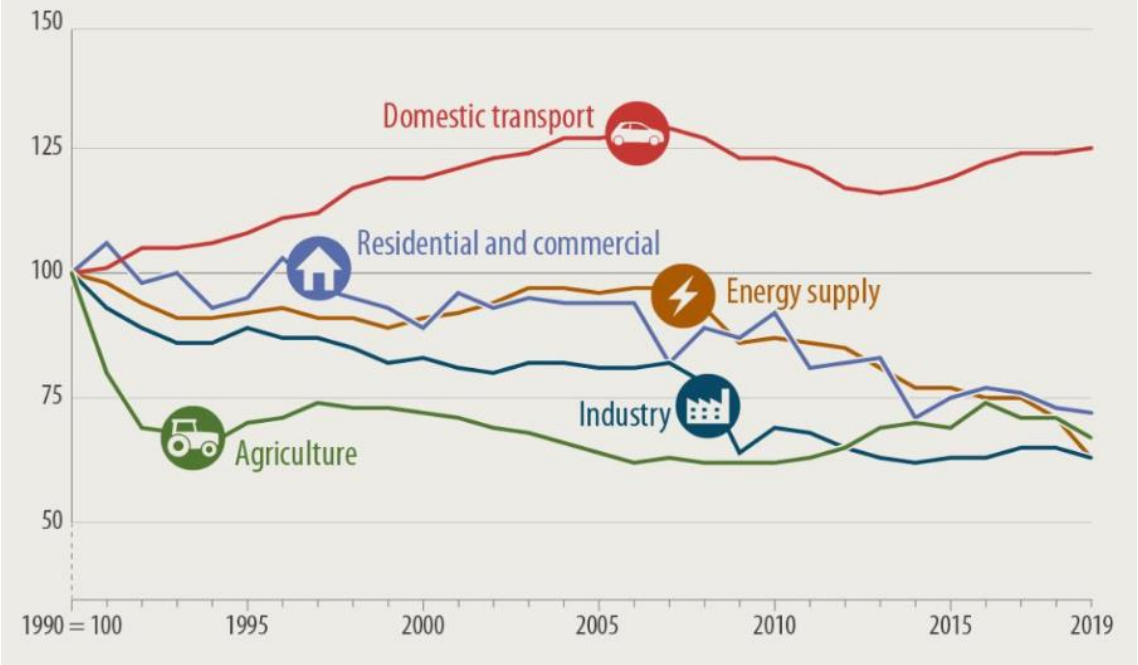

Fig. 1. Evolution of emission levels by sector since 1990 in the UE. Source: European Parliament.

As shown in the figure above, the domestic transport is the leader source when it comes to production of CO_2. Which means that, to deal with the emergency regarding to pollution, decrease the emission of harmful gases from these engines is a key issue.

The main porpoise is to take care of emission gases as close as possible to the source, and the closest it could be is inside of it, in the combustion chamber. With this idea, the concept of an internal catalyst arises and the studies about it start, since the current catalyst are close to the source, but not inside it.

1.2 Motivation.

Aware of the major problems facing the planet today, including those arising from global energy demand and the pollution that the generation of global energy demand and the pollution that the generation of this energy brings with it, this dissertation aims to make a personal contribution, showing a personal contribution pollution, this thesis aims to make a personal contribution, showing a commitment and desire for a cleaner future, commitment and desire for a cleaner future, and finding a way to do so by carrying out this project.

Furthermore, the interest in combustion engines and the chance of improving them seems very attractive to me, so work with something so new and with such a large scope for research, makes the topic of this thesis fit my requirements. Considering that, in addition to the interest in the technical part of the work, it is necessary to add the analysis of the motor market in general, study it and try to predict the possible acceptance or rejection of the topic discussed throughout this thesis, the in-cylinder catalyst.

1.3 Scope.

Over the course of the thesis, different topics are going to be covered, starting from the description of the in-cylinder catalyst and its practical application or potential implementation, emphasising in the technical analysis of this innovative method.

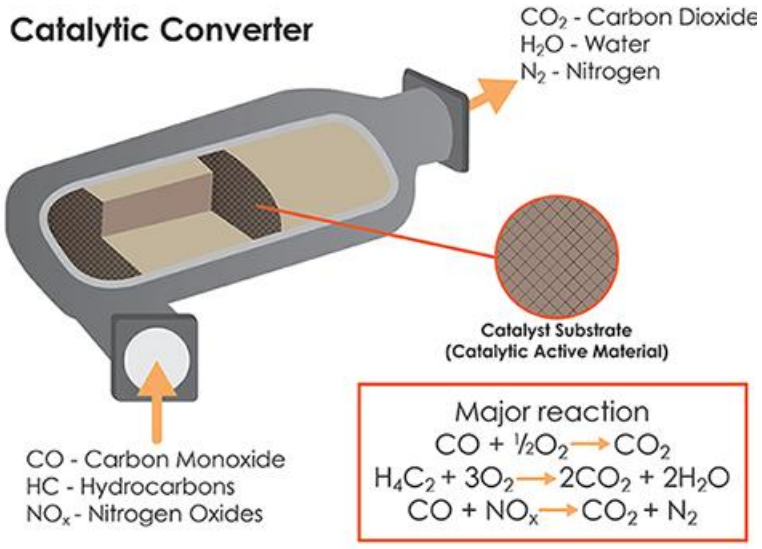

Fig. 2. Chemical reaction of a generic catalyst. Source: Utah Educational Network.

Once the concept is clear enough, the tasks of preparation for the practical application or potential implementation start. Being concerned about the functionality of the internal catalyst, questions such as how it can be introduced in the current market should be answered.

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When talking about something new both in a new market, as well as in an established market such as the motor market, risks related to it are found; so, an analysis of all setbacks that can appear must be conducted.

Just as there are risks, when it comes to such a novelty, we are talking about the existence of a niche market, which is a great opportunity in the market. Therefore, this, together with the other options presented by the implementation of the system, have to be studied and demonstrated, as well as the presence or absence of barriers to the practical application of the in-cylinder catalyst.

Finally, as a conclusion of the studies carried out, all benefits of the implementation of the internal catalyst must be presented as a final conviction that this is an application that will help in the future to achieve cleaner exhaust gases and thus more environmentally efficient combustion engines.

2 Theorical framework and technical description.

2.1 What a catalyst is and how it works.

A catalyst is a substance that speeds up a chemical reaction without being used up or chemically changed. They are used usually to a particular reaction, this is because a perfect fitting catalyst for one reaction is unlikely to have any effect at all on a different reaction, so different catalysts are needed for different reactions.

When it comes to the exhaust systems of a vehicle, catalysts are a key component in make those gases cleaner, or less harmful. In a combustion engine, fuel and air are burned in presence of O_2, which makes exhaust gases rich in Nitrogen Oxides (NO_x), Cabron Monoxide (CO) and Hydrocarbons (HC), components with a high rate of damage to the environment.

Here it is when catalyst play a major role, they work decreasing the potential damage the exhaust gases can make. When these gases go through the catalyst, the chemic damaging components are oxidised and converted into less harmful gases such as Carbon Dioxide (CO_2), water (H_2O) and Nitrogen (N).

Catalysts need to be in a specific working condition and in an appropriate shape, if they are damaged, they could make the exhaust gases even worse than original ones. This makes regular maintenance a key to secure the vehicle works within the emissions regulations [1].

2.2 Past and present of catalysts.

The fight against vehicle emissions is not a modern phenomenon, and the first big step was the compulsory fitment of a catalytic converter way back in the 1970s, in the USA, as a response to the implementation of the Clean Air Act, which established stricter emissions standards, through the device was invented twenty years before.

The catalysts used in the early years were primarily made of a ceramic substrate coated with a precious metal, that facilitated the chemical reaction. Over the years, catalyst have become more advanced, with the addition of more sophisticated materials and designs to further improve their efficiency and durability. Nowadays, the use of catalyst is compulsory, and they can transform the 98% of harmful emissions into less toxic emissions. The location of the catalytic converters is in a box between the combustion engine and the final section of the exhaust duct, where the chemic reaction happens [2].

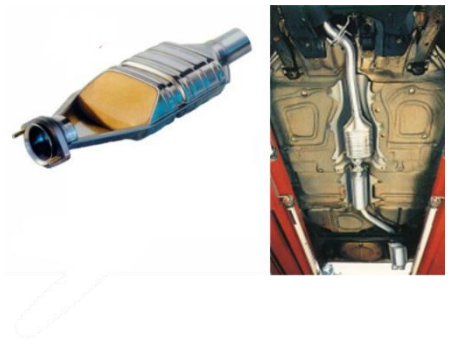

Fig. 3. Catalytic converter on a gasoline car. Source: Dieselnet technology guide.

2.3 In-cylinder catalyst and a future proposal.

The current need to reduce emissions from internal combustion engines or to make them less harmful, has led to a great deal of research into possible alternatives to current exhaust gas cleaning methods. One of the alternatives that has recently emerged is the use of internal catalytic converters, the idea stems from the premise that the efficiency of catalytic converters is high only when the reaction in the pistons takes place under stoichiometric conditions, in addition to the specific required temperature, which is achieved by an appropriate location of the exhaust system. Thus, a concept was born to place the catalyst in the combustion chamber itself [3][4].

Fig. 4. In cylinder vs current catalyst.

Investigations in regard with this concept have shown some benefits about it, the tests were done covering the outlet valve with platinum. Main advantages observed during the testing were the reduction of smoke opacity in Diesel engines, reducing the ignition delay; reduction of carbon monoxide and hydrocarbon in the exhaust gases of a diesel engine powered by methanol and diesel.

Regarding nitrogen oxides reduction using the in-cylinder method, it is based on the use of platinum catalyst, but the cost of this alternative is too high to be used, so it is replaced

with molybdenum compounds. An effective effect that a catalytic layer on some elements of the combustion chamber was shown, reducing the concentration of carbon monoxide and hydrocarbons, which only depends on the properties of the catalyst used and the operating conditions of the internal combustion engine.

The tests were carried out only in stable conditions of engine operation, but the latest test tried to determine the benefits using the in-cylinder method primarily in dynamic real conditions.

3 Preparation for practical application and implementation.

The introduction of a new concept, product or patent in a market is a critical process that requires careful planning and execution to ensure a successful launch. It is essential to develop an effective strategy to communicate the product's benefits and unique features to potential consumers and to establish its positioning in relation to the competition. In addition, factors such a market segmentation, market research, pricing and selection of appropriate distribution channels must be considered. Once a solid go-to-market strategy has been prepared, it is important to measure and analyse the results to identify areas for improvement and adjust the strategy accordingly [5].

Tab. 1. Steps in product implementation. Source: Own.

1 Planning	2 Design and development	3 Testing and validation	4 Launch	5 Post-launch

Some benefits related with a good strategy regarding the product implementation are [6]:

- Reduced risk of delays or disruptions.
- Improved communication.
- Lower costs.
- Increased product quality.
- Improved customer satisfaction.

3.1 Analyse and identify the target market.

A target market is a group of people or consumers - identified by a company - with similar characteristics that make them potential customers for its products or services. Based on their needs, a brand makes relevant marketing decisions.

A target market can be defined by several common qualities, for example: age, lifestyle, preferences, location, interests, among others. Knowing the customers helps to create messages that target only those who are willing to pay for the product or service being offered. Choosing the appropriate target clients will save money and time, since finding clients is likely the biggest time-wasting task in a business, because is the most essential task but makes absolutely no cash. Therefore, the fast clients are found, the more time is available to make money [7].

In the case of the internal catalyst, it is not a question of finding a specific customer profile as such, but of finding a way to commercialise the concept and to get the major combustion engine manufacturers to start implementing it. Therefore, the success of this new way of using catalytic converters depends on empirically

demonstrating the efficiency and improvement over the current arrangement of these chemical elements. In this way, any manufacturer will be pushed to implement the in-cylinder catalyst if it wants to comply with the efficiency requirements that are imposed at a legal level in more and more parts of the world.

Currently there are many engines' producers investing in developing power sources that will unseat fuel combustion engines as we know, some of them are [8]:

- Mazda: currently in an alliance with eFuels, trying to find an economic way to produce zero emissions fuels. They have already found how to do it but the process is too expensive yet to be used.
- Toyota: in the last conventions of the brand, they have made known that in their roadmap they have established to reduce the number of vehicles with conventional engines by 50% for 2030 and to stop producing them by 2035. Their main bet is on the Hydrogen engines.

This are just two examples of different brands that have these plans for the mid-future. But the plan for the UE is to allow production of combustion engines if the total of vehicles produced in a whole year is less than a thousand.

So the conclusion is: almost all brands will be interested in using the in-cylinder catalyst until 2030 for sure, but from 2030 onwards the focus should be on small producers, or luxury manufactures, whose annual production is very limited and it is certain that they will continue to produce combustion engines for their customers and remain below the EU limit. Some of the potential customers in the long term are: Porche, Ferrari, Lamborghini, McLaren…

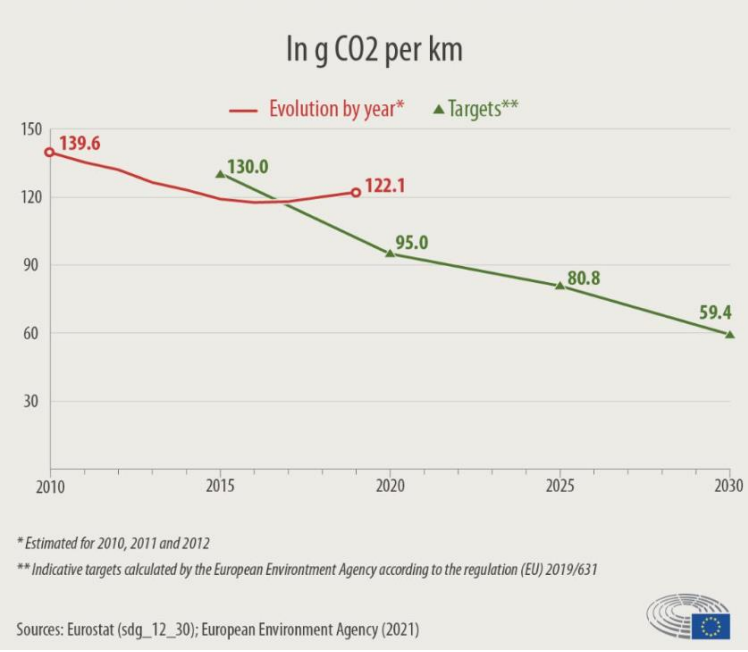

Fig. 5. Recorded vehicle emissions and goal until 2030. Source: European Parliament.

As shown in the figure above, the change between the existing emissions and the target established for the upcoming years is drastic, so every solution that helps to achieve this goal will be helpful. This means that once the efficiency of the in-cylinder catalyst is proved, no engine manufacturer will be reluctant to implement it.

Emission reduction results can be seen in the simulation tests under real driving conditions in the following figures.

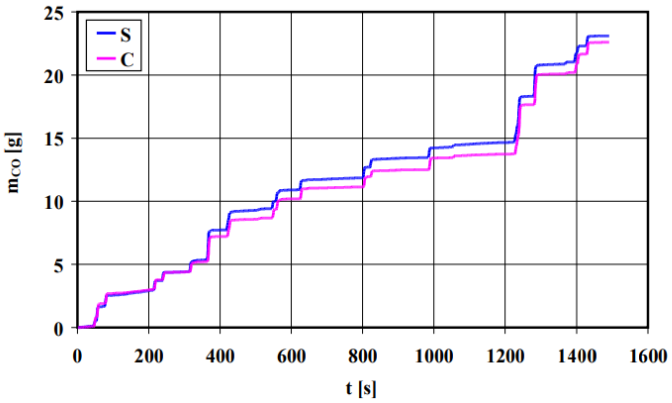

Fig. 6. Carbon monoxide emission rate in the Malta test for the standard engine (S) and for the engine with the internal catalyst.

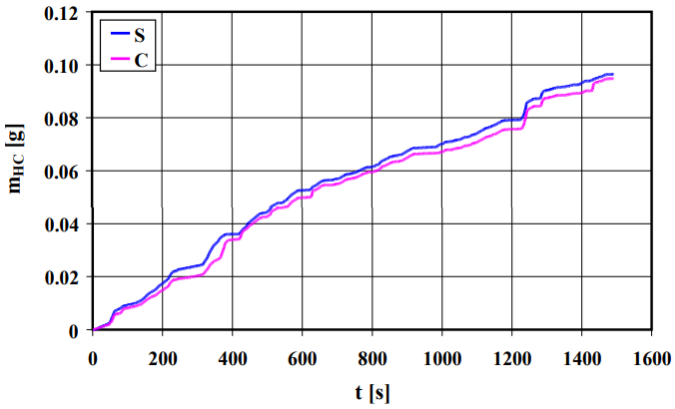

Fig. 7. Hydrocarbons emission rate in the Malta test for the standard engine (S) and for the engine with the internal catalyst (C).

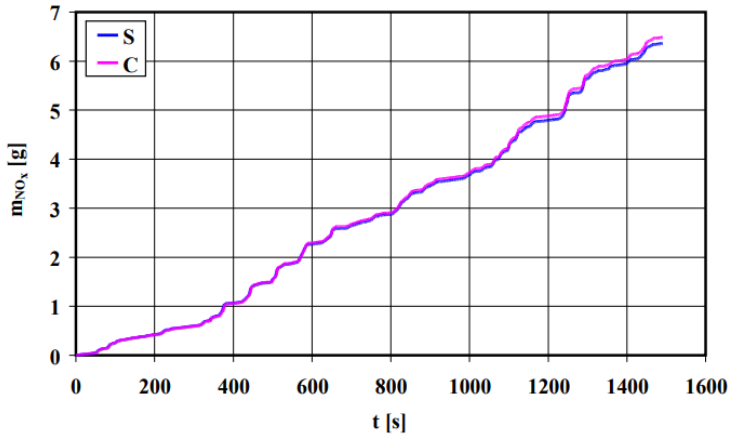

Fig. 8. Nitrogen oxides emission rate in the Malta test for the standard engine (S) and for the engine with the internal catalyst (C).

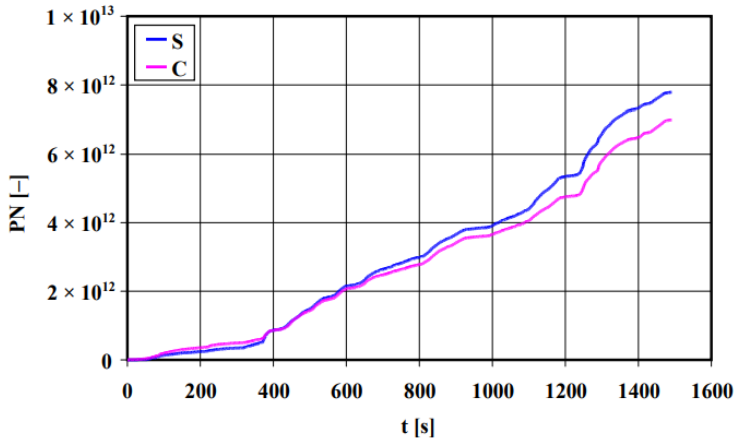

Fig. 9. Particle number emission rate in the Malta test for the standard engine (S) and for the engine with the internal catalyst.

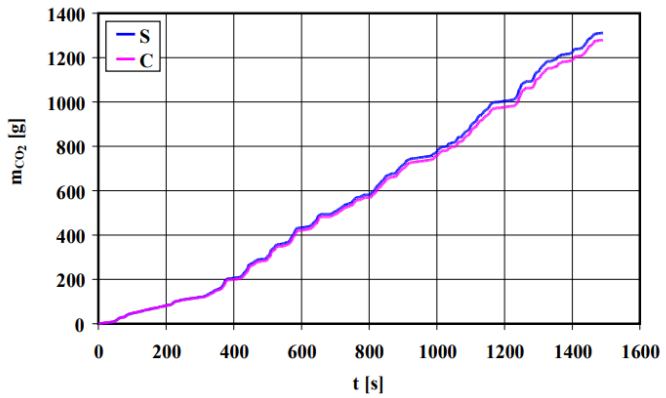

Fig. 10. Carbon dioxide emission rate in the Malta test for the standard engine (S) and for the engine with the internal catalyst.

From all these graphs it can be concluded that the change from external to internal catalyst generates a remarkable reduction in all the toxic elements present in the exhaust gases, which makes the in-cylinder catalyst a more than interesting proposal for engine manufacturers from now on.

3.2 Analyse competitors and competition.

The first step in analysing the existing and potential competitors is identifying who they are, and once they are all identified, study how they work, their value propositions, their marketing strategies, and finally, make a SWOT analysis to compare both proposals [9].

In the new vehicle era, there are a lot of emerging proposals to reduce exhaust gases emissions, such as electric vehicles, hybrids, and other vehicles with renewable power sources, among others.

Now, some of the current alternatives to improve the efficiency of combustion engines are presented [10]:

- **Electrification of vehicles:** this is the most used alternative nowadays, it consists of a 100% electric power source of the vehicles, the main advantages are: zero emissions - although it will be explained later why this is not entirely the case-, zero acoustic pollution and less maintenance costs (electricity is cheaper than fuel).

  But this kind of power supply has also many downgrades, the low autonomy, longer time to charge the batteries rather than just refuel the vehicle, etc. and going back to what was mentioned in the previous section regarding the cleanliness of emissions, although the vehicle does not generate exhaust gases directly, most of the electrical energy is also generated with fossil fuels that also pollute the environment, therefore, it cannot be said that they are totally clean. Furthermore, if everyone had an electric car, it would be impossible to meet the potential demand for electric energy with today's means, so it does not seem to be a viable solution for the long-term future [11].

- **Synthetic and recyclable fuels:** is a solution in its earliest stage of development, although manufacturers such as Mazda have been able to produce fuels of this type that do not generate harmful gases for the environment, they have not been able to generate them on a large scale to supply a considerable demand for them, so for this solution to become a reality we still have to wait a few more years.

- **Gasoline engines:** many producers have decided to just reduce the weight and the cylinder capacity of their engines to reduce the fuel consumption, with different techniques such as overfeeding to compensate the power loss.

- **Cylinder disconnection:** this alternative consists of an intelligent use of the cylinders, using one or another number of cylinders depending on the power required by the consumer at any given moment.

- **More developed particulate filters:** many investigations are currently directed to develop new filters for diesel engines to get cleaner exhaust gases.

- **Regenerative braking:** accumulation of braking energy in a series of capacitors, which will contain sufficient electrical energy for the vehicle's accessory systems, such as the headlights or the air-conditioning system. In this way, consumption can be reduced by up to 10%.

- **Friction reduction:** bearings have already significantly reduced friction levels in accessory units, replacing plain bearings in camshafts, balancer shafts, turbochargers, and tappets. In the turbo, bearings can reduce cold friction by up to 80% and improve response, which increases efficiency by 2.5%, accelerates torque delivery and reduces richness of the mixture, which minimises NOx.

- **Hydrogen engines:** this could be the most real alternative being contemplated today, since, if an economically profitable process for obtaining hydrogen is achieved, a totally clean source of energy could be obtained, with zero emissions, which would completely displace any other type of engine. Although it still seems that this option is far from being implemented, large amounts of resources are being invested due to the confidence in this alternative, which is here to stay as it is an inexhaustible source of energy. For example, Toyota have already confirmed that they have developed an engine able to work only with Hydrogen and will be ready to implement it by 2030 [12].

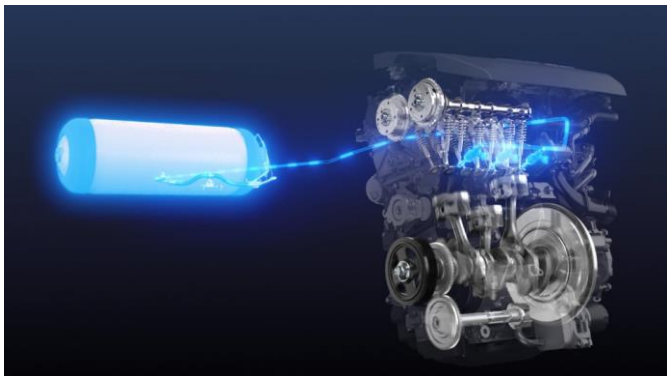

Fig. 11. Hydrogen engine. Source: Toyota.

All these alternatives go in the direction of improving the efficiency of today's vehicles, from the combustion process to the accessory elements of the vehicle. This is why most of them are not competitors as such to the in-cylinder method, but could complement this proposal, making the whole vehicle package more efficient and environmentally friendly.

3.2.1 SWOT analysis.

SWOT (strengths, weaknesses, opportunities, and threats) analysis is a framework used to evaluate a company's competitive position and to develop strategic planning. SWOT analysis assesses internal and external factors, as well as current and future potential.

A SWOT analysis is designed to facilitate a realistic, fact-based, data-driven look at the strengths and weaknesses of an organization, initiatives, or within its industry. The organization needs to keep the analysis accurate by avoiding pre-conceived beliefs or grey areas and instead focusing on real-life contexts [13].

- **Strengths**: The main strength lies in the fact that the increase in efficiency of combustion engines is a must for the coming years, as no real alternative is expected for several decades. In fact, the IEA (International Energy Agency) estimates that by 2050, 57% of vehicles will be powered by combustion engines, and by 2060, 23%. With this in mind, engines manufacturers should welcome any improvements in emissions reduction with open arms.

- **Weaknesses**: the current form of catalyst use is well established, and there may be parts of the industry that are reluctant to modify the assembly lines of certain engine parts for only a slight increase in the efficiency of their power units.

- **Opportunities**: as mentioned above, legislation is getting tougher and tougher regarding vehicle emissions, so there is a certain desperation or urgency to improve current engines in this respect. The fact that there are such ambitious targets for 2030 may mean that now is the time to try to bring something to the market that will certainly go some way towards meeting those targets.

- **Threats**: the constant investment by manufacturers in alternatives that would unseat fossil-fuelled combustion engines may at any moment hit the right key, and one of the above-mentioned potential alternatives may become a reality, making the use of the internal catalytic converter "useless".

Fig. 12. SWOT analysis. Source: Own.

3.3 Identify the value proposition and positioning the product.

The value proposition provided by the internal catalytic converter comes from, as demonstrated above, the obvious improvement in the exhaust gas treatment system, with a solution that would improve the harmfulness of the exhaust gases in all its elements.

What it brings to customers willing to implement this novel use of catalytic converters is to stay within the current legislation on the consumption levels of combustion engines, which is becoming increasingly complex and tougher in terms other targets it sets, with their respective penalties for manufacturers who do not comply with them within the established timeframe [14].

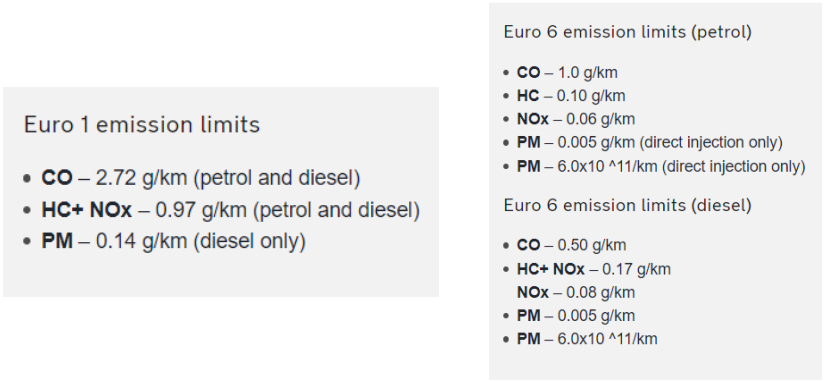

Fig. 13. Limits to improve air quality and health established by the EU (Comparison between the 1992 goals vs 2015). Source: EU.

3.4 Formalise the product concept.

The product description is the vital element on a website that aims to attract, inform, and convince the consumer to buy an item. This section is made up of the features, functions, and values by which the product stands out: what makes it different and why it gives value to the user.

When we refer to the features and functions of a product, we are talking about a technical description, which is part of the total description of a product. Therefore, in order to be complete, it is important that you take into account the technical description.

The technical description of a product is the one that answers questions such as: what is it, what is it for, what is it made of, or how is it used?

- **What is it?** It is an alternative to the use of external catalytic converters, but the principle of operation is the same. The main difference is that instead of locating the catalytic converter in an element external to the engine, as it requires very precise temperature conditions. The use of these catalytic converters could be optimised by locating them inside the cylinder itself, treating the gases from the same point of emission.
- **What is for?** Improve the efficiency of combustion engines to get closer to the goals established.
- **What is it made of?** Platinum or Molybdenum.
- **How is it used?** The use of these catalytic converters could be optimised by locating them inside the cylinder itself, treating the gases from the same point of emission.

3.5 Defining metrics to measure results.

Since the main objective is to bring manufacturers closer to the objectives, it should be considered that the reduction of harmful gases is a significant % compared to the rest of the solutions.

Furthermore, due to the financial investment to be done to complete the development of this method, there should be found an economic return thanks to exploit the product, considering the public grants for the topic covered.

Once the metrics are defined, a roadmap have to be done in order to achieve a successful launching.

3.5.1 Economic viability.

An economic study must be conducted in order to analyse the economic viability of the project, a sequential process of the expenses and incomes expected from the projects are presented:

- **Final development:** government support to improve the efficiency of combustion engines and meet climate targets for the short to medium term. The UE has developed a plan of financial support for research that go in line with the goals established. From all the research eligible for this type of aid and subsidies, the in-cylinder can be found inside the category:

  "Addressing major societal issues, such as climate change, sustainable transport and renewable energy."

- **How can the patent be exploited:** between all the different ways of get economic return, to exploit the patent of the in-cylinder concept, the appropriate option is to sell the patent to different customers that can use the patent for their own benefit, so the entity that sells the patent get cash for the idea and a small part of the following earnings from the exploiters.

- **Direct return from changing to internal catalyst:** with the current external catalyst, producers spend around 200€ (considering that the price may change considerably from one manufacturer to others), but with the change, they could save up to a 25% per unit, which is a significant amount considering the current producing volume of internal combustion engine.

  So the expected payback period, depends on the sales and producing volume (the more volume the quicker will the investment be profitable)

3.5.2 Define the next steps to be done in the investigation.

- **Final adjustments:** this means that the development of the internal catalyst must be done in order to secure the improvement over other current methods, and get it prepared for it use and exploitation from the customers.
- **Patent the idea:** once all final tests have been conducted, the project is prepared to be patented.

3.5.3 Potential customers analysis.

Potential clients were mentioned before, so next step to be done is to analyse this customer needs and how can they be satisfied thanks to the patent. Possible questions to ask in order to get an idea of the needs of the customers are:

- How far is the client of emission objectives for the following years?
- Is the client willing to change the production lines in order to implement the internal catalyst?
- what has been the attitude of this client in the past to proposals of this nature?

3.5.4 Present the proposal to the clients.

Once the goals of how customers can be attracted are clear, the project is ready to be presented to the potential clients.

Situations that can be used to publicise the product are conventions of future projects for the automotive world or direct meetings with the person responsible for authorising the potential purchase and exploitation of the patent.

3.5.5 Reception and analysis of the feedback from the customers.

When there is already an agreement with the customer, tests to implement the product should be conducted, and it is a key step to achieve success to listen carefully and collect appropriately the feedback a customer can provide.

With the feedback collected, it is possible to adjust the catalyst to satisfy final customer needs and give it last details in order to get it commercialized and exploited. Nevertheless, the work does not end here, the feedback and necessities of the customer must be listen to achieve continuous improvement and get it better during the use of it.

3.6 Prepare product launching.

A launch plan is an element inside the marketing strategy that gives specific details when a new product is introduced in the market.

This plan gives guidance to create new strategies and actions to be taken in order to make customers conscious about the product, with clearly defined objectives. In this plan, some key points must be covered:

1. Market study.
2. Competitors investigation.
3. Focus groups to get all kinds of ideas.
4. Communication strategy definition.
5. Customer service plan.
6. Product roadmap.

All these points have been covered during the development of this section, so the product launch is clearly defined and the only step yet to be done is the actual introduction of the internal catalyst in the market.

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To introduce the in-cylinder catalyst in the market, the marketing plan must be defined and the actions to be taken to make engine producers conscious about the proposed concept.

Appropriate environment to make customer know about the internal catalyst would be:

- Presentation to I+D and purchasing department of the objective customers.
- Energy efficiency conferences related to the motor world.
- Conventions related to the topic covered.

These are some different ways to make people know about the new catalyst concept, and places to take advantage and convince producers to exploit the proposal.

4 Risks related to a potential implementation.

When talking about the risk analysis that should be conducted when a new product is introduced in the market, is the structured monitoring of risks that may affect the deadlines and quality of a project. The analysis involves define the risks, asses the probabilities of occurrence, outlines steps to take to avoid those risks and determine how to address them if they arise [14].

1. **Identify risks:** the main risks that must consider when it comes to implement the in-cylinder catalyst are:

    a. Successful development of an alternative to the current combustion engines, that would make this kind of power source an undesirable option, making the new catalyst completely useless.
    b. Problems when exporting tests to the real application and finding that the success of the data collected is not the same when implemented in the new engines.
    c. Too expensive maintenance in comparation with the external catalyst, since it is mandatory to open the engine to secure the maintenance of the internal catalyst, while the current one has its own element in the vehicle.
    d. Not enough financial support to complete the development of the method.
    e. Producers showing themselves reluctant to implement the new concept.
    f. Departing from the previously outlined roadmap, be it in terms of deadlines, budget, etc.
    g. There is another risk associated with the fact that there is already a patent on a concept or product very similar to the in-cylinder catalyst that would not allow the in-cylinder catalyst to be re-patented, therefore it should be considered that solutions such as those presented below would make it difficult to take ownership of the in-cylinder catalyst patent.

2. **Classify risks:** probability and impact.

    Probability: five different categories that goes from 0% chance of occurring to 100%.

    Unlikely: 0-20%
    Seldom: 20-40%
    Occasional: 40-60%
    Likely: 60-80%
    Definite: 80-100%

    Impact: value of the negative effect in three different aspects: schedule, cost, and technical performance:

Insignificant: no negative effect.
Minor: does not cause major disruptions or changes in the roadmap.
Moderate: threaten operations.
Critical: without the appropriate treatment, would end with the project.
Catastrophic: jeopardize the whole project.

	PROBABILITY				
IMPACT	Unlikely	Seldom	Occasional	Likely	Definite
Insignificant					
Minor			f		
Moderate	d	c			
Critical	e	b		g	
Catastrophic				a	

Tab. 2. Risk's matrix. Source: own.

a. The development of alternatives is something that may occur soon or later due to the huge current investments and efforts to find a solution and stop using fuel as power source. This would mean the end of the project since catalyst has no sense if fuel combustion engines disappear.
b. The problems related to export tests to real applications have to be taken into account, since it has been proven in similar conditions but not the exact ones, so is a factor to consider. It would be something critical, but it does not mean it has no solution, it would only mean that there is more work to do in the in-cylinder catalyst, and if not, all work done has meant nothing.
c. The application of the in-cylinder catalyst in the long term has not been proven yet, so there is a possibility that this kind of method entails more expensive and sophisticated maintenance, with the possibility of making the project economically inviable, so some corrections must be taken if this becomes a reality.
d. The possibility of not finding enough economic resources has to be considered but is something really weird since all projects related to a sustainable future are easily sourced.
e. Despite all benefits shown, producers could consider that the new method does not improve the old one enough to make the change, so it is crucial to make a good marketing of the product.
f. This point is common to all projects, once a roadmap is defined, there will always be problems related to the achievement of all goals set in that plan but is a minor problem that usually can be solved easily, with no more impact than a small loss of money or not strictly follow the schedule.
g. The fact that after all the development, a patent can not be defined because of the existence of another similar, is likely to happen, since there are already solutions with comparable impact in the exhaust gases, such as: diesel particulate traps, selective catalytic reduction systems, catalytic oxidation

technologies or gasoline particulate filters. This would mean that it is not possible to sell it and get economic benefits from it. The way to avoid this to happen is doing the proper research about those similar patents and define the in-cylinder catalyst in a way that makes possible to establish the patent.

3. **Decisions to be taken based on risk:** depending on the type and nature of the risk the options available are:

    - Avoid: decide not to proceed with the activity that introduced the unacceptable risk, choosing an alternative more acceptable that meets business objectives, or choosing an alternative less risky.
    - Reduce: implementing a strategy that is designed to reduce the likelihood or consequence of the risk to an acceptable level, where elimination is excessive in terms of time or expense.
    - Transfer: move the risk to another party, such as outsourcing the management of physical assets. The third party accepting the risk should be aware of and agree to accept this obligation.
    - Accept: making an informed decision that the risk rating is at an acceptable level or that the cost of the treatment outweighs the benefit. No further action is taken however, ongoing monitoring is recommended.

4. **Develop a risk treatment plan:**

    - Specify the treatment option agreed: avoid, reduce, transfer, or accept.
    - Document the treatment plan: outline the approach to be used to treat the risk.
    - Assign an appropriate owner: accountable for monitoring and reporting on progress of the treatment plan implementation.
    - Specify a target resolution date.

The route to follow if each one of the risks mentioned comes to reality is:

a. Reduce the consequences, is something out of control, so nothing could be done to avoid it, which means the work should be directed to minimize the impact. The responsible of such a decision is the head of the project and whoever is making the economic support.
b. Reduce the impact of it, make alternative plans or solutions in case it happens. The human resources carrying out the tests are responsible of make the alternative plans or investigations.
c. Two strategies could be followed in this case, reduce it by studying how to make maintenance easier, or just transfer it to maintenance engines specialists.
d. Accept the risk because it is highly probable that economic resources are going to be found.

e. Reduce the impact by creating an appropriate marketing plan that will make producers find attractive enough the proposal.
f. Accept and reduce because they are problems that are going to happen, but some work has to be done in the direction of minimize the impact of them, creating plans of action for each particular case.
g. Reduce the impact of the risk with an appropriate preparation when applying for the patent, making it enough distinguished from other similar concepts.

5 Demonstration of the lack of barriers for the implementation.

Before defining the barriers that the in-house catalyst will face, several steps must be followed that will lead to the establishment of the possible barriers that the market will put in place:

Define the object of study: the main objective of this study to be carried out is to determine what are the barriers to entry that may exist in the engine market to introduce a new product to replace an existing one.

Identify the target market: once the objective has been defined, an exhaustive definition of the market at which the product is aimed must be made, as any decision from now on will be conditioned by the customer at whom it is aimed, and what he/she can expect from the proposal. In this case, the market is narrowed down to every engine manufacturer in the current automotive market, as any of them could implement this measure, except those using exclusively electric engines or any other alternative energy source to the internal combustion engine.

Research the industry and the market: the next step is to carry out a study of these identified customers, or of the market itself, in order to define what the needs are and how they are to be covered: the need to be covered on which the internal catalytic converter focuses is that of reducing the harmfulness of exhaust gases from combustion engines. With this, a study must be carried out on how receptive the market is to implement this new catalytic converter concept.

Identify the barriers to entry:

- Design and development of the internal catalyst: originally it was a complex idea, whose development was still null, requiring a large investment in terms of economic input, human resources, and time. Over the years, these resources have been obtained, which has allowed the relevant tests to be carried out on the use of this catalyst, demonstrating that it is a viable option with a view to complying with the pollution standards imposed by the EU.

- Implementation in the existing engines: the current use of catalytic converters is in a separate part in the exhaust system, so the current operation would have to be modified, eliminating this part and studying how it can be integrated into the engine cylinders. During the studies carried out, it has been shown that by impregnating the inner perimeter of the cylinder with a specific catalyst, the expected results in "cleaning" the exhaust gases of the engine can be achieved.

- Efficiency and performance: as previously mentioned, during all the tests carried out, a measurement of all the elements that make up the exhaust gases has been performed,

observing a clear reduction in each parameter with respect to the external catalytic converter, so we see another barrier that will not cause problems thanks to the empirical results obtained.

- *Economic viability:* this is one of the most diffuse barriers at this point, as the economic return that the implementation of this catalyst method can offer is a total unknown. Therefore, it is not a barrier that has been eliminated, but we can state with certainty that it will have a high acceptance rate considering how demanding current legislation is regarding emissions, so if we assume that many manufacturers implement it, we can also assume an economic return that will make the project economically viable [16].

Assessing the impact of barriers to entry: In general, any of the barriers to entry presented are a setback to the implementation of the in-house catalyst, however, all the barriers identified do not appear to be sufficient to prevent successful implementation of the in-house catalyst.

Strategies to overcome the barriers: If any of the above-mentioned barriers do occur, the strategy to follow depends on how sensitive it is for the project. The only barrier of which there is no certainty is the one that corresponds to the economic viability of the project, however, in the worst case scenario, no economic benefit is obtained, but the costs associated with the tests and human resources would be covered, as the studies have been carried out under previous funding, so it would not be an impediment to seek the final implementation of the product.

Analysing the competitive environment: this point has been mentioned in previous sections, such as threats to the product and project risks.

Drawing up conclusions: as has been verified as the possible barriers have been developed, a priori, it does not seem that there will be any impediment to the implementation of the internal catalyst on the part of the engine market, so that once the development and research has been completed, no problems should be encountered in introducing the product on the market.

In summary, the introduction of an in-house catalyst into the engine market would face technological challenges, integration into existing engines, engine performance concerns, production costs, compliance with regulations and emission standards, and the need to gain market acceptance. Overcoming these barriers would require a strategic approach and significant resources to research, develop and demonstrate the benefits and effectiveness of the in-house catalyst in terms of reduced emissions and improved engine performance.

6 Description of the benefits of the application.

The use of an internal catalyst in combustion engines can provide several significant benefits, both in terms of engine efficiency and reduced pollutant emissions. Some of the key benefits are presented below:

1. **Reduction of pollutant emissions:** The internal catalyst is primarily aimed at reducing emissions of pollutant gases such as nitrogen oxides (NOx), carbon monoxide (CO) and unburned hydrocarbons (HC). By promoting more complete and efficient combustion, the internal catalyst can contribute to the improvement of air quality and the protection of the environment.

   As a summary of the results of the tests carried out, the reduction achieved in each of the main harmful elements in the exhaust gases is shown here as a percentage.

   - A relative reduction in carbon monoxide emissions by 12.9%.
   - A relative reduction of hydrocarbon emissions by 9.3%.
   - A relative increase in emissions of nitrogen oxides by 14.3%.
   - A relative decrease in the particle number by 9.8%.
   - A relative reduction of carbon dioxide emissions by 5.1%.

2. **Compliance with environmental regulations:** The use of an in-house catalyst can help engine manufacturers comply with increasingly stringent regulations and emissions standards set by governmental authorities and regulatory bodies. This is especially important in regions where there are strict limits and regulations for vehicle emissions.

   The current regulations imposed by the European Union are average CO2 emissions from new cars were 122.3 g CO2/km in 2019, better than the EU target of 130 g CO2/km for the period 2015-2019, but well above the target of 95 g/km set for 2021 onwards.

   The new legislation paves the way for achieving zero CO2 emissions for new passenger cars and light commercial vehicles by 2035. There will also be intermediate emission reduction targets for 2030 of 55% for cars and 50% for vans compared to the 2021 level.

   The targets are expressed in percentages because the 95 g/km standard will have to be recalculated according to the new emissions test, which is more stringent and better reflects real driving conditions.

   The revised regulation should help citizens through further development of zero emission vehicles (better air quality, energy savings and lower cost of vehicle ownership), and stimulate innovation in zero CO2 technologies.

   Parliament and EU countries reached an agreement on the rules in October 2022. The Parliament approved the text in February 2023, and it still needs to be formally adopted by the Council.

3. **Improved engine efficiency:** A well-designed and optimised internal catalyst can improve engine efficiency by promoting more complete combustion and reducing energy losses associated with unwanted emissions. This can result in improved engine performance, increased power output and fuel efficiency.

   The application of the internal catalyst reduced the emissions of carbon monoxide, hydrocarbons, carbon dioxide, and particulate matter. As a result of these changes (mainly the reduction in the emission of carbon dioxide), a reduction in the fuel consumption took place, and thus an increase in the overall engine efficiency. This can be explained by an increase in the engine thermal efficiency caused by an increase in the oxidation rate and, consequently, an increase in the heat release rate.

4. **Lower cost and weight:** Compared to traditional external emission control systems, internal catalytic converters can offer advantages in terms of cost and weight. By being integrated directly into the engine, the need for additional external components is eliminated and the overall complexity and weight of the exhaust system is reduced.

5. **Increased durability and service life:** Internal catalytic converters, being protected inside the engine, are less exposed to adverse environmental factors such as corrosion and mechanical damage. This can result in greater durability and longer service life compared to external catalytic converters.

It is important to note that the benefits of using the internal catalyst may vary depending on the specific design and implementation, as well as engine operating conditions. In addition, extensive testing and certification is essential to ensure that the internal catalytic converter meets emissions standards and performs effectively under real-world driving conditions.

7 CONCLUSION

Taking into account all the information gathered throughout the project, a formed decision can be made on the feasibility of introducing and exploiting the in-cylinder catalyst patent in today's automotive market.

the final assessment is that it is a very risky bet, because although it is economically profitable and a priori it seems a safe investment and that it is very easy to find points in favour and difficult to find against, the reality is that it is a very volatile market and sensitive to new patents that can displace this type of catalyst.

However, it seems to be an assumable risk considering that the deadlines estimated by the high governmental authorities allow an assured return on investment, and unless there is a sudden irruption of alternative engines to internal combustion engines, the patent of the study will continue to be exploited.

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