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“A CAR FOR EVERYONE“- THE WINNING CONCEPT OF THE INTERNATIONAL FORD MODEL T CHALLENGE

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A team of the Institut für Kraftfahrzeuge (IKA) of RWTH Aachen University needed only three months in order to develop an innovative vehicle concept which is capable of carrying conventional as well as alternative drivetrain modules thanks to its scalable design – a modern “car for everyone” for the year 2015 with a basic sales price of less than 7000 US dollar.

Keywords: Concept requirements, development of the concept, technical specifications, topology optimisation, drivetrain system

INTRODUCTION

Over a production duration of 19 years, about 15 million units of the legendary Ford Model T have been sold. The Ford Motor Company has launched the Model T Challenge 2008 under five universities worldwide to celebrate the 100th anniversary of the Tin Lizzy in order to find out the best concepts for a successor.

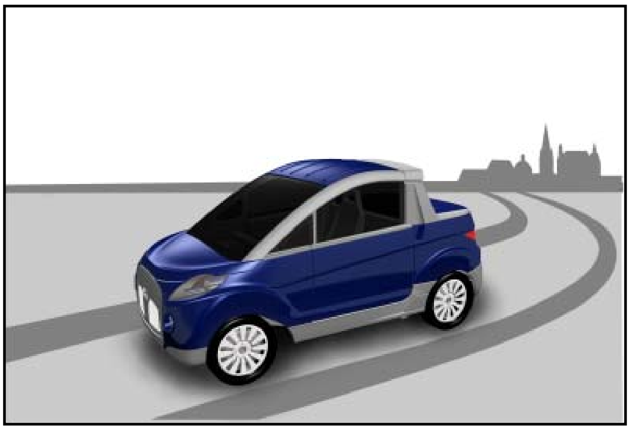

Figure 1. Ford model T challenge

The demand was to develop a modern Model T in only three months time while being simple, robust, light and compelling. Besides these hard facts, space for at least two passengers, a range of 200 km as well as a maximum basic sales price of 7000 US dollar were required with the latter surely being the hardest challenge.

APPROACH

A scientific approach, though inspired by the industrial development process, was chosen for the development of the concept vehicle, Figure 2. Based on the demands that were given for the challenge, the requirements for the vehicle have been analysed. This included a detailed examination of the success factors of the predecessor, the historic Model T, as well as an investigation if and how these could be transferred to a modern car. The scenario analysis revealed further boundary conditions and economic requirements of the relevant markets. The main driver was the very ambitious basic sales price though

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from which target costs for every module had to be derived using a target cost calculation.

The requirements which had been depicted in the analysis phase were then collected as concept specifications for the definition phase. Based on these, the actual concept development started which was characterised by highly parallel processes and a permanent cost controlling. In order to generate not only concept ideas but technical feasible solutions in the very limited time given, strategies for efficiency increase had to be applied. It was mainly the parallelisation of component development and styling, traditionally an up-front process, which significantly saved time. The rough styling was decided based on hand sketches while the detailed surface construction was done in parallel to the body structure. This again could be increased using topology optimisation.

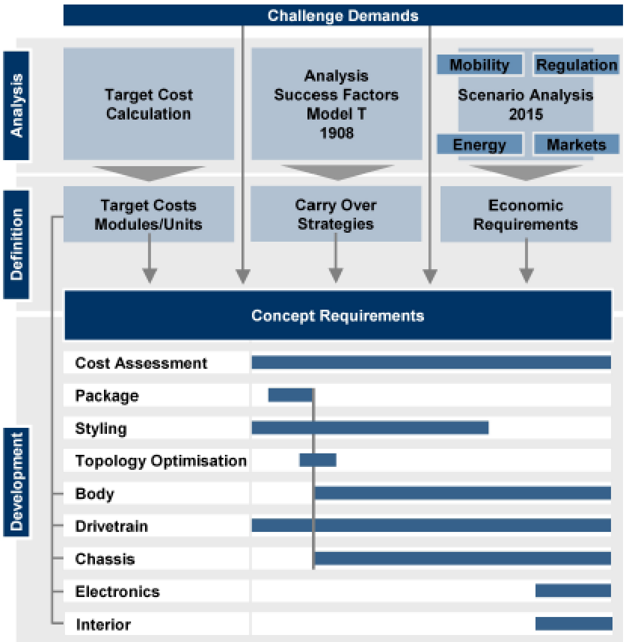


Figure 2. Flow chart of the concept development

THE SUCCESS FACTORS OF THE HISTORIC MODEL T

Only five years after the foundation of Ford Motor Company in 1903, the production of the Model T started. Its success was gained by fulfilling the market demands of those days to a very high level. Besides a classic passenger car, it was also used as a truck, tractor or even tank. In addition, the main success factors were the low sales price of 650 US dollar and its robustness for the poor and unsurfaced roads of the era.

Furthermore, the simple construction allowed easily repairing or adopting the car for other applications. Today's trend towards multi-material design was also consequently utilised those days. Hence, a modern concept has to combine the success factors of the historic model with the dominant requirements of a car to be launched in 2015.

SCENARIO ANALYSIS

With the aim to meet the major demands that a world car has to accommodate in the 21st century, a scenario analysis for the target year 2015 was carried out. Social, economic and technologic trend studies, for example [1, 2], have been regarded and were amended by own findings. The major influencing factors are given by the mobility demand, legal regulations, the availability of energy and the market situations. The focus was placed on the markets of the Triad as well as of emerging and developing countries.

The need for mobility is increasing worldwide. Individual mobility will stay the basic need of mankind. With alternative means of transport being able to fulfil these needs only to a limited amount, the vehicle market will grow especially in the emerging countries. Besides the trend to mega cities, the majority of the population will still live in rural areas. Regional differences in availability and development of transport systems, infrastructure and routes have to be regarded for the target scenario. The new Ford Model T as a world car has to meet not only the requirements and customer demands of accessed markets but also increase the brand awareness and attractiveness in export markets to be accessed. In parallel to individual mobility, customers also ask for automobile individuality. Open source approaches with defined interfaces can be adapted to vehicles and offer one potential solution for conflicts in relation with the individualisation of a mass product.

Furthermore, the age structure of clients is of importance. The age pyramid is showing an aging population. This aspect is to be met by the concept amongst others by optimised ergonomics offering a high and up-right seat position. One central feature of the scenario analysis was the question which energy sources are available and accordingly which drivetrain options are best-suiting for the year 2015. The results show that the internal combustion engine will keep its dominant role besides all on-going efforts towards hybrid and electric vehicles, Figure 3.

Main factors are the energy infrastructure as well as lasting high costs for electric energy storages.

Alternative propulsion concepts will gain importance in some markets though due to legal requirements (city limitations and CO2 taxation) as well as demands by customers with ecological awareness.

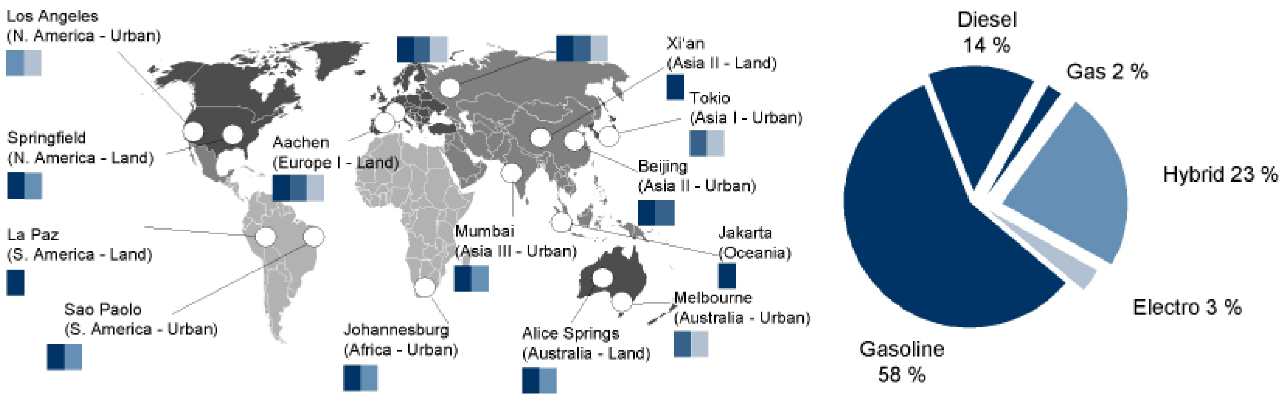


Figure 3. Distribution of propulsion systems and markets in 2015

MODEL T CONCEPT FOR 2015

The low sales price was a key challenge during the development of the concept. Different studies have shown that low-cost cars can be offered profitably at a sales price of 7,000 $ or even below [3, 8, 9, 10, 11]. Consistently, changes in production, sales and distribution but also design are claimed to be necessary in order to succeed. This includes low-investment for on-site assembly of smaller volumes in lean production with increased manual processes. Standardised low-cost components, which are used by different brands and produced in low- cost countries, so-called “industry modules”, enhance the economy of scale. The global vehicle structure has to be designed for basic functionality with low complexity of parts. A modular design of the vehicle enables further economy of scale and reuse of particular parts. At the same time, this carry-over reduces R&D costs that can be further optimised by extensive implementation of simulation tools. For automotive low-cost strategies, the part of logistics and sales is important. A reduced centralised dealer network is essential. Even sale via internet is an option. Finally, marge and costs for marketing have to be reduced.

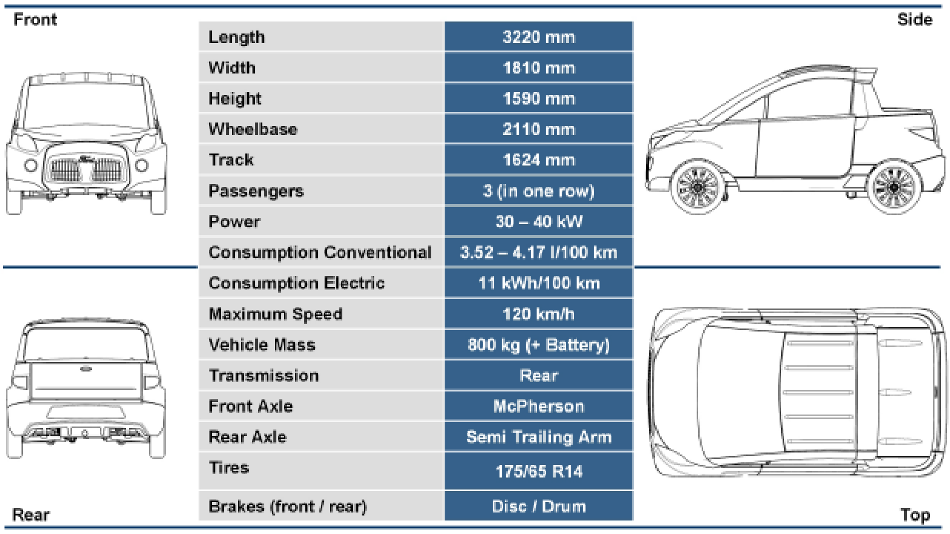
The aspects motioned above were considered in the early concept phase when setting the target costs for the Model T. The subsequent concept development was attended by target costing. Therefore, target costs for the main components body, chassis, interior and electronics had to be established first, Table 1.

Accordingly, the maximum allowable cost of each component had to be established, assuring not to exceed the basic sales price of 7,000 $. The percental distribution is based on a typical c-class vehicle (class of compact vehicles) [3]. The different cost items were derived from this percental distribution while the concept specification was determined from the scenario analysis, following market economy principles, as well as the major success factors of the historic Model T and the cost target.

Therefore, the main dimensions were defined at first, influencing not only the outer appearance but also some essential technical properties. The trend towards smaller cars is apparent. One reason among others is the fact that the average number of passengers per ride is as low as 1.4 [4]. Accordingly, the team agreed very early that a modern Model T shall be positioned in the C-class. At the same time, there is an increasing demand for interior space and luggage by the emerging markets in which the new Model T shall be the first vehicle. The compromise of compact appearance and offered space was finally found in a short but wide vehicle with relatively high ground clearance and an up-right seat position for the passengers, Figure 4.

Table 1. Target cost definition in US dollar

Basis sales price 7000 $			
Production costs 4970 $		Additional costs 2030 $	
Assembly	890 $	Logistic	420 $
Body	980 $	Marketing	560 $
Chassis	800 $	Overhead	420 $
Drivetrain	880 $	Guarantee	250 $
Interior	750 $	Marge	420 $
Electronics	630 $		



Length	3220 mm
Width	1810 mm
Height	1590 mm
Wheelbase	2110 mm
Track	1624 mm
Passengers	3 (in one row)
Power	30 – 40 kW
Consumption Conventional	3.52 – 4.17 l/100 km
Consumption Electric	11 kWh/100 km
Maximum Speed	120 km/h
Vehicle Mass	800 kg (+ Battery)
Transmission	Rear
Front Axle	McPherson
Rear Axle	Semi Trailing Arm
Tires	175/65 R14
Brakes (front / rear)	Disc / Drum

Figure 4. Technical specifications of the new Model T

The width of the car allows sufficient space for three passengers in one row. The driver is centrally positioned and slightly ahead of the two passengers. This avoids different models for left and right hand steering. The concept is characterised by modularity, scalability and individuality, going from derivates, Figure 5, that are based on the scalable basic structure via changeable outer plastic panels to the drivetrain concept.

Package, vehicle architecture as well as structure of the modern Model T are easily adoptable for usage as a hybrid drive, a plug-in hybrid drive or pure electric drive. The base model is driven by a gasoline engine as internal combustion engine (ICE). Its position in the rear of the car, together with the semi-trailing arm axle, is supporting an efficient package, can easily be accessed and thus allows the modularisation of the drivetrain.

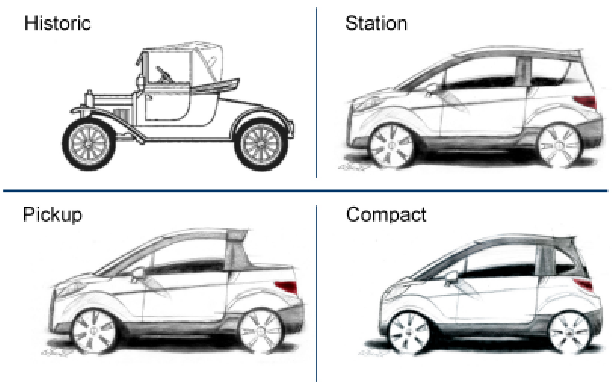


Figure 5. Styling of the derivate vehicles

In the front section there is a high freedom of package. This offers space for a maximum of passive safety.

Besides technical concept specifications, styling requirements for the new Model T had to be defined. A complete retro-styling approach as often used for remakes of automotive icons did not seem feasible from a technological, economic and design zeitgeist point of view for the 100 years old Model T. The idea was rather to transfer distinctive elements of the historic styling such as the massive cooler frame or the characteristic wheel house arc and to combine them with current styling characteristics. A worldwide commonly used design concept is believed to foster the brand identity, an aspect that is gaining importance for success in the market due to an increasing technical unification. Following the definition of the concept specifications, the development of the different main vehicle components started in parallel. Body and drivetrain development are described in detail in the following chapters. At the end of the project, a cost assessment of the complete concept was carried out. Table 2 shows the overview of the total costs for the different drivetrain options of the variant compact pickup model.

The efforts for cost models increase more than proportional with the degree of detail respectively accuracy. Hence, an efficient cost prognosis must be based on analogies. Starting with comparable components with known cost structures, the costs of the new Model T components have been scaled using values such as dimensions, weight, power, energy content etc. [3, 5, 6]. While current market prices have been used for standard components, the electric drivetrain had to be calculated using price prognoses for future price development under mass production assumptions [7].

Besides the economic and production-wise cost reduction strategies mentioned above further conceptual cost reduction methods enabled the low basic sales price. In addition to the avoidance of a left and right hand steering model, some comfort functions have not been implemented but are technically compensated to a certain extent. Furthermore, only standard tools are required for production, the passenger seats are not adjustable and planar glazing as well as module and common part strategies are used, altogether having a positive cost effect. According to the historic Model T, long production duration is planned. The changeable outer panels, the lighting parts and the interior allow an easy re-design and technology updates, thus keeping the Model T modern and appealing over a long time.

Table 2. Cost overview in US dollar of the variant compact pickup model for different drivetrain options

	ICE	Hybrid drive	Plug-in hybrid drive		electric drive	
			15 km	56 km	75 km	140 km
Production costs	**4930 $**	**5340 $**	**6890 $**	**8190 $**	**7410 $**	**11,790 $**
Assembly	890 $	890 $	890 $	890 $	890 $	890 $
Body	960 $	960 $	960 $	960 $	960 $	960 $
Chassis	742 $	742 $	742 $	742 $	742 $	742 $
Drivetrain	780 $	1280 $	2830 $	4130 $	3350 $	7730 $
Interior	750 $	750 $	750 $	750 $	750 $	750 $
Electronics	588 $	718 $	718 $	718 $	718 $	718 $
Additional costs	**2070 $**	**2100 $**	**2160 $**	**2210 $**	**2180 $**	**2360 $**
Logistic	420 $	420 $	420 $	420 $	420 $	420 $
Marketing	560 $	560 $	560 $	560 $	560 $	560 $
Overhead	420 $	420 $	420 $	420 $	420 $	420 $
Guarantee	250 $	280 $	340 $	390 $	360 $	540 $
Marge	420 $	420 $	420 $	420 $	420 $	420 $
Total	6780 $	7440 $	9050 $	10,400 $	9590 $	14,150 $

BODY

For the body development the trade-off between low-cost and lightweight had to be put in focus, since both requirements were formal objectives of the challenge. The team added the additional target to design a body type compromising the special demands of conventional and electrified drivetrains in a common platform. This is to enhance the market relevance of alternative drivetrains by cost reduction due to economies of scale. In addition, to enable various derivates the body should be designed scalable in length and should be made of simple parts manufactured using standard tools.

Comparing different types of body design showed that these requirements in total can be met best using a hybrid design of steel deep-drawing parts and profiles together with plastic outer panels. On the one hand the team applied structural lightweight design techniques for the cost efficient steel basic structure. On the other hand for the body panels the lightweight potential of the material was used. The principle of structural lightweight design is to select the topology of the structure based on the loads acting on it. This means material shall be applied at the actual load paths only. In order to determine these load paths, the team used the method of FEM-based topology optimisation. The staring point for this was the available design space for the body. This describes the volume that remains when subtracting the wheel envelopes, the interior space and all package components from the volume enclosed by the outer contours of the vehicle. The design space was meshed and the load cases such as static torsion and bending as well as quasi-static dummy loads for front, side and rear crash were applied. After calculating and masking the finite elements that are less relevant for the load cases in terms of stiffness, the abstract load paths could be analysed. This topology had to be interpreted and transferred to producible and joinable parts using CAD tools, Figure 6.

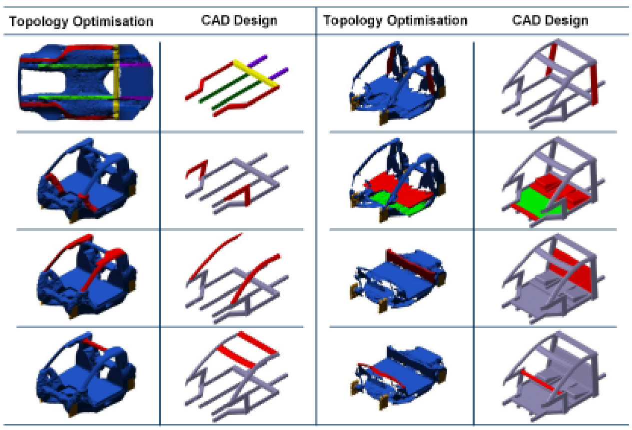


Figure 6. Topology optimisation and CAD design

Following the results of the topology optimisation the CAD model includes a main longitudinal member that merges the sill, a very stiff rear crossmember designed as an integral part with the passenger backrest, a sandwich floor structure and two longitudinal floor members. Each part is characterised by a stretched shape. In addition, all parts in the area close to the rear crossmember are parallel and exactly straight-line. This way, the body can be scaled in length at this area as well as at the front and rear overhangs, Figure 7. For the doors and lids that show a profile-intensive design, the hinges are integrated in the support structure.

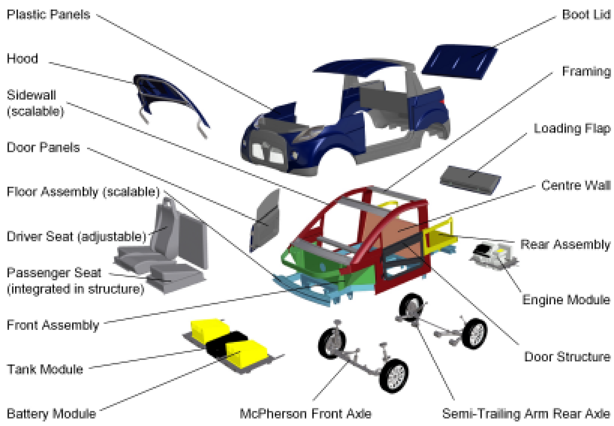


Figure 7. Vehicle components

DRIVETRAIN

The background for the drivetrain concept was defined by the results of the scenario analysis. The demands of future drivetrain systems with regard to efficiency and emissions will become stronger due to rising energy prices and stricter legal requirements. Considering these, potential drivetrain concepts for the modern Model T were analysed and compared regarding re-powering infrastructure, qualification for vehicle integration, total efficiency and production costs, Table 3.

In addition to conventional drivetrains based on combustion engines, unconventional systems were taken into account. However, the comparison of the different systems revealed that for 2015 the internal combustion engine will still offer the best compromise. Reduced fuel consumption can be achieved by combining efficient, downsized engines with lightweight compact-class vehicles.

However, electrified drivetrains should not be neglected in order to serve the growing demand for these vehicles in the Triad markets. Consequently, the modern Model T offers different drivetrain options on the same platform. The systems are going from the conventional gasoline drivetrain via hybrid and plug-in hybrid to the battery electric vehicle. Both battery electric ve-

Table 3. Qualification matrix for drivetrain systems

	Re-powering infrastructure	Qualification for vehicle integration	Total energy efficiency	Production costs
Compressed air	-	--	--	++
Gasoline engine	++	++	0	++
Diesel engine	+	++	0	+
Electronic hybrid	0	+	++	0
Hydrostatic hybrid	0	--	++	--
Fuel cell	--	--	+	--
Battery electric drive	0	0	++	--
Hydrogen ICE	-	0	0	0
Natural gas ICE	-	+	0	0

hicle and plug-in hybrid are able to run fully in electric mode. A modular drivetrain construction kit was developed for this in order to maximise the number of common components, Figure 8.

Since the daily range has significant influence on the operating costs for the plug-in hybrid drive option, the emissions and the efficiency of the vehicle, the battery system is designed in a modular way. This means, the customer can select the energy content of the battery based on his personal demands, for example the distance from home to office. In the next step, the components of the different drivetrain options were dimensioned and selected considering the outer vehicle dimensions, the vehicle mass, the top speed, an assumed aerodynamic drag coefficient of 0.3 and different driving cycles.

For dimensioning and further evaluation of power requirement and energy consumption, a model library for simulation of longitudinal dynamics in Matlab/Simulink was used. Depending on the particular driving cycle and the drivetrain system, a peak power requirement from 17 to 28 kW was determined. Consequently, a 30 kW ICE or a 40 kW hybrid drive were selected. With the level of drivetrain electrification, the costs increase, Table 3. However, operating costs and emissions can be reduced. For instance CO_2 emissions vary between 54 g/km and 100 g/km for the different drives while a specific CO_2 emission of 500 g/kWh for electric power generation is assumed.

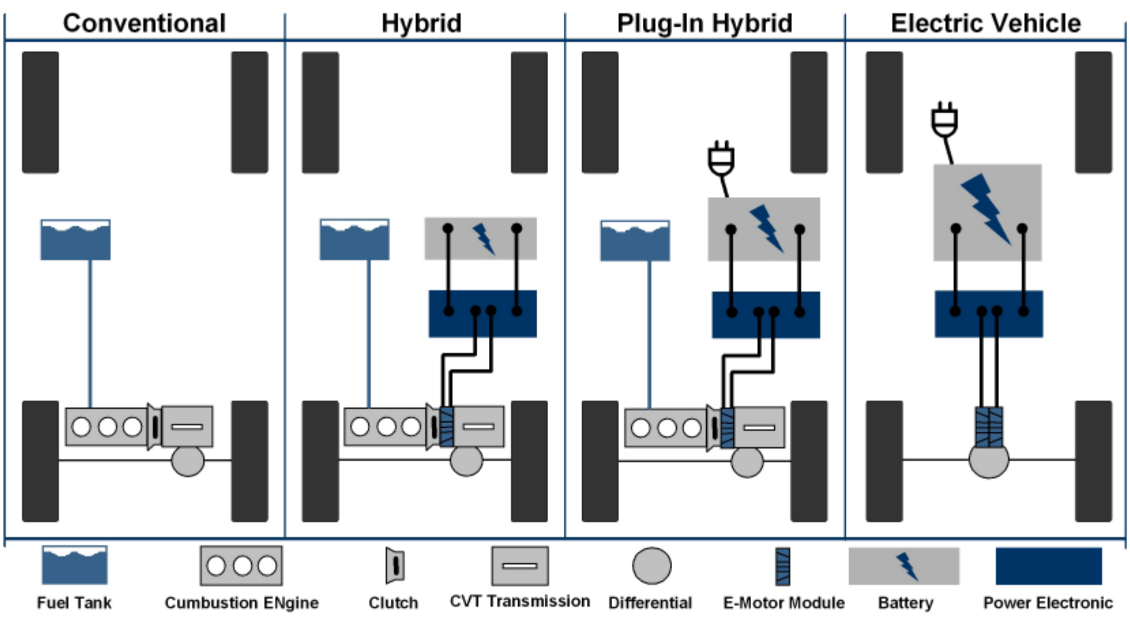


Figure 8. Drivetrain construction kit

SUMMARY

Only three months were needed by a team of the Institut für Kraftfahrzeuge (IKA) of RWTH Aachen University in order to develop an innovative vehicle concept which is capable of carrying conventional as well as alternative drivetrain modules thanks to its scalable design – a modern “Tin Lizzy” for the year 2015 with a basic sales price of less than 7000 US dollar.

An efficient approach and an effective realisation of requirements allowed the concept to be simple, light and compelling – following the spirit of its predecessor. A focus was therefore placed on a simple production and a robust design of chassis and body as well as possibilities for an individual styling by using changeable outer panels. The modular drivetrain allows to offer alternatives to the at least in the medium-term still dominant internal combustion engine such as hybrid or battery-electric traction.

The IKA made it possible to develop a completely new vehicle concept which fulfils all given requirements. These were depicted both from the challenge by the Ford Motor Company as well as a detailed analysis of the aimed markets in 2015. The biggest challenge was given by the basic sales price which was not to be exceeded. In the end, real costs were estimated to be slightly below with only 6780 US dollar. A new interpretation of historic constructions based on modern technologies allows interesting solutions for low cost vehicles in very short time. Finally, the team of ika thanks the Ford Motor Company for being part of the Challenge 2008 which was inspiring and fostered the creativity of students as well as researchers. It was an outstanding example which both stimulated and supported the personal advancement of young academics.

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