Project Title:

QUalifying and Implementing a user-centric designed and EfficienT electric vehicle

Project Acronym: QUIET

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Publishable Executive Summary

One aims of work described here is to realize a (part of the) vehicle door with improved crash behavior, good thermal insulation properties, high stiffness and low weight. A promising approach to accomplish this is a combination of fiber reinforced composite material combined with a novel aluminum-hybrid foam. The proposed aluminum-hybrid foam was already presented in D3.1. Furthermore, it is planned to improve the structural and thermal properties of the current closures of the Honda validator vehicle. The main focus is thereby put on stiffness and crash safety. The target weight reduction is 20 % compared to the existing construction, while the comfort elements are maintained, and the thermal inertia of the closures is reduced.

With selected polymer glazing, project goals can be reached from viewpoints of lightweight structure and also for usability and durability. For safety purpose, front windshield cannot be implemented but after further investigation maybe this one can be also replaced by lightweight polymer one.

For the demonstrator car, possibility of lightweight closures was investigated. At the beginning of the project, the current steel-based structure was modelled and virtually tested with finite element analysis method to have a baseline strength and crashworthiness. For composite redesign, these baseline results and CAD models i.e. original shape of the closures were used as input parameters. First step of lightweight redesign was the assessment of manufacturability and partitioning of the closures into reasonable parts from viewpoint of manufacturing and strength calculations. After that, material tests were carried out on several kinds of composite materials to generate inputs for the optimization process. This optimization was multi-purpose one which dealt with strength-crashworthiness-insulation-mass parameters. After the optimization process, composite manufacturing instructions i.e. composite layer build-up and a manufacturing document were prepared and sent to manufacturing partners. For manufacturing composite closures, several type of manufacturing processes like vacuum infusion and vacuum assisted prepreg technologies were used which fitted into the project timeframe and budget but these ones are only appropriate for smaller series. Possible upscale of production were estimated based on literature and manufacturing experience. The results which are achieved in weight reduction meet the QUIET project goals, approximately 20 % in each part. For economic upscaling, SMC, RTM, or T-RTM technologies would be better but the costs are also significantly higher than steel or aluminum manufacturing costs nowadays.

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Abbreviations and Nomenclature

Table 1: List of Abbreviations and Nomenclature.

Symbol or Short name	Description
APM	Advanced Pore Morphology
CAD	Computer Aided Design
CF	Carbon Fiber
DoE	Design of Experiment
EV	Electric Vehicle
FEA	Finite Element Analysis
FEM	Finite Element Method or Finite Element Modeling
FMVSS	Federal Motor Vehicle Safety Standards (USA)
NDA	Non-Disclosure Agreement
PC	Polycarbonate
PVB	Polyvinyl butyral
RTM	Resin Transfer Molding
SMC	Sheet Metal Compound
WP	Work Package
HVAC	Heating, Ventilation and Air Conditioning
TPU	Thermoplastic Polyurethane
T-RTM	Thermoplastic Resin Transfer Molding
UN/ECE	Economic Commission for Europe of the United Nations

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1. Introduction

QUIET aims at developing an improved and energy efficient electric vehicle (EV) with increased driving range under real-world driving conditions. This is achieved by exploiting the synergies of a technology portfolio in the areas of: user centric design with enhanced passenger comfort and safety, lightweight materials with enhanced thermal insulation properties, and optimised vehicle energy management.

The developed technologies will be integrated and qualified in a Honda B-segment electric vehicle validator. Among these, a novel refrigerant for cooling, combined with an energy-saving heat pump operation for heating, advanced thermal storages based on phase change materials, power films for infrared radiative heating and materials for enhanced thermal insulation of the cabin will be investigated. Further focus is put on lightweight glazing for windows, as well as light metals like aluminium or magnesium for seat components. Optimized energy management strategies, such as pre-conditioning and zonal cooling/heating the passenger cabin as well as user-centric designed cooling/heating modules will further enhance the thermal performance of the vehicle. WP3 involves developing new lightweight vehicle components with improved thermal performance in order to reduce the entire vehicle weight and to guarantee improved passenger-compartment insulation. For the windshield, different technologies and structures based on innovative approaches will be investigated. Furthermore, vehicle components like lightweight doors will be developed and realised by combining novel materials for enhanced thermal insulation with lightweight composites. Additionally, lightweight materials such as composites will be used for realising closure components for optimising the weight of the reference vehicle. All developed lightweight components (windshield, doors and seats) with improved thermal performance will be ready for integration into the reference vehicle at the end of WP3.

1.1. Description of the deliverable - Goals

One goal is to develop lightweight closures like side doors, trunk lid and engine hood, the windshields and side windows for the closures.

Further goal is the implementation of the demonstrator closures with improved parts concerning weight and thermal properties. The existing steel design of closures by Honda is the baseline for the new improved design. Target is to substitute steel parts with fiber reinforced composite in case of closures and layered glass with pure plastic in case of windows.

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2. Lightweight windshield and side windows

In M4 (T3.1: Lightweight windshield components with improved thermal performance) the investigation for possible QUIET windshield concepts started with a research comparing the physical parameters (thermal insulation and weight) of standard glazing techniques (like laminated safety glass and tempered safety glass) with established plastic glazing techniques (e.g. PC-polycarbonate) and with mechanically high performant aluminosilicate glasses as well.

2.1. Glazing techniques

Nowadays, standard glass glazing techniques for windscreens cover the application of laminated safety glass (LSG). The typical design of LSG consists of two layers with a thickness about 2.1-2.5 mm and an interlayer (e.g. PVB-Polyvinyl butyral –PVB is common– but also thermoplastics like TPU-thermoplastic polyurethane or EVA-ethylene-vinyl acetate) with a thickness of about 0.38-0.76 mm [1]. Side and rear glasses are commonly made of tempered one-layer safety glass with a thickness of about 3-5 mm [1]. Compared to the standard glass glazing (i.e. standard windscreen with 2x2.10 mm glass-layers and 0.76 mm PVB interlayer) modern thermoplastic glazing techniques, e.g. 5 mm polycarbonate (PC) layer, show 50% less specific weight (11.3 kg/m² vs. 6 kg/m²) and 70% less thermal conductivity compared to laminated safety glass (0.8 W/(mK) vs. 0.21 W/(mK)) [2]. A weight reduction without bigger limitations in mechanical requirements can also be achieved through reducing the glass thickness by using improved standard glass technology. Nevertheless, drawbacks are hereby that thermal isolation and acoustic behaviour will be reduced. The same disadvantages are valid when using thin and light hybrid glass compositions (like aluminosilicate glasses) and hence these costly technologies were no longer pursued.

Modern thermoplastic glazing techniques can fulfil the requirements for certain lightweight automotive glazing components, while improving thermal performance at the same time. However, some significant disadvantages of plastic glazing shall be pointed out.

Costs

Standard glass is basically a cheap material, whereas PC is an expensive polymer material. This makes it necessary to compensate higher material costs e.g. by functional integration (i.e. recessed grip, wind deflector, etc.).

UV-Stability

Polymer glazing materials are prone to yellowing. Additives can improve the situation, but a desirable durability is very difficult to achieve. Anyway, yellowing will be accepted by consumer (or is not seen) if windows are tinted.

Low abrasion resistance

This problem can be drastically reduced by appropriate coating-techniques.

Safety concerns

Polymer materials are not allowed for front windscreens because it cannot be easily broken by first aiders or emergency services in rescue cases. Currently, no consideration for windscreens made of plastics are provided in the Regulation No 43 of the Economic Commission for Europe of the United Nations (UN/ECE) "Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles" and its annex 14 deals only with "Rigid Plastic Glazings Other Than Windscreens".

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Suppliers

Beside the provision of the most promising windshield concept for the QUIET demonstrator, T3.1 aimed also providing a selection of a proper supplier for lightweight windshield components. In total 16 material and component suppliers were considered and contacted during the exploration phase.

2.2. Implementation

Finally, more detailed negotiations started with COVESTRO as the company is very interested and encouraged in gaining experiences using their glazing material in a real application. Additionally, COVESTRO offered the best portfolio/expertise package. The correspondence with COVESTRO revealed producing a small batch of PC sheets for the new glazing would exceed the budget in this project. Therefore, they offered to use sheets, which are already on stock from previous R&D projects. COVESTRO has already sent some samples of the existing sheets to HRE. Using the sheets, HRE checked the applicability of the sheets for replacing the glazing of the original demonstrator vehicle. A non-disclosure agreement (NDA) has been set up by HRE to regulate the data transfer between HRE, AIT and COVESTRO regarding the glazing of the Honda Fit EV. After completing the signing process of the NDA, HRE sent the geometric dimensions of the glazing components to COVESTRO. COVESTRO offered PC sheets available in three different tints, i.e. blue (almost transparent), green, and grey (cp. Figure 1), and thicknesses. For thermoforming and coating of a small number (i.e. around 5 pieces) of sheets at a reasonable price COVESTRO recommended (after a cost analysis) to entrust the specialized company KIRSCH Kunststofftechnik GmbH with these tasks. KIRSCH Kunststofftechnik is able to provide thermoforming, hard- and IR-coating (as required) for PC sheets and has a long-lasting partnership with COVESTRO over several years and projects. The company has shown high level of work quality and have always been the lowest or near the lowest bidder.

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Figure 1: PC sheets available in the colors blue (almost transparent), green and grey

In an initial step, KIRSCH Kunststofftechnik GmbH prepares (for stability investigations) a PC sample based on front left side window. The sample will be used to determine whether a 3,5 mm thick side window will be sufficiently strong or whether a 5 mm thick glazing must be used for the front side windows. After selecting the appropriate dimensions, KIRSCH Kunststofftechnik GmbH processes the PC sheets and produces one complete set of new glazing (cp. Figure 2), except the front windscreen. This component will not be exchanged, due to the above-mentioned safety concerns and the non-compliance with Regulation No 43 of the Economic Commission for Europe of the United Nations (UN/ECE). The required authorisation (i.a. time-consuming process) for driving on public roads with a PC windshield seems highly unlikely. After confirmation of feasibility by HRE (e.g. thickness of windows), different configurations for glazing options were discussed. Figure 2 depicts the preferred choices in descending order determined by HRE and AIT.

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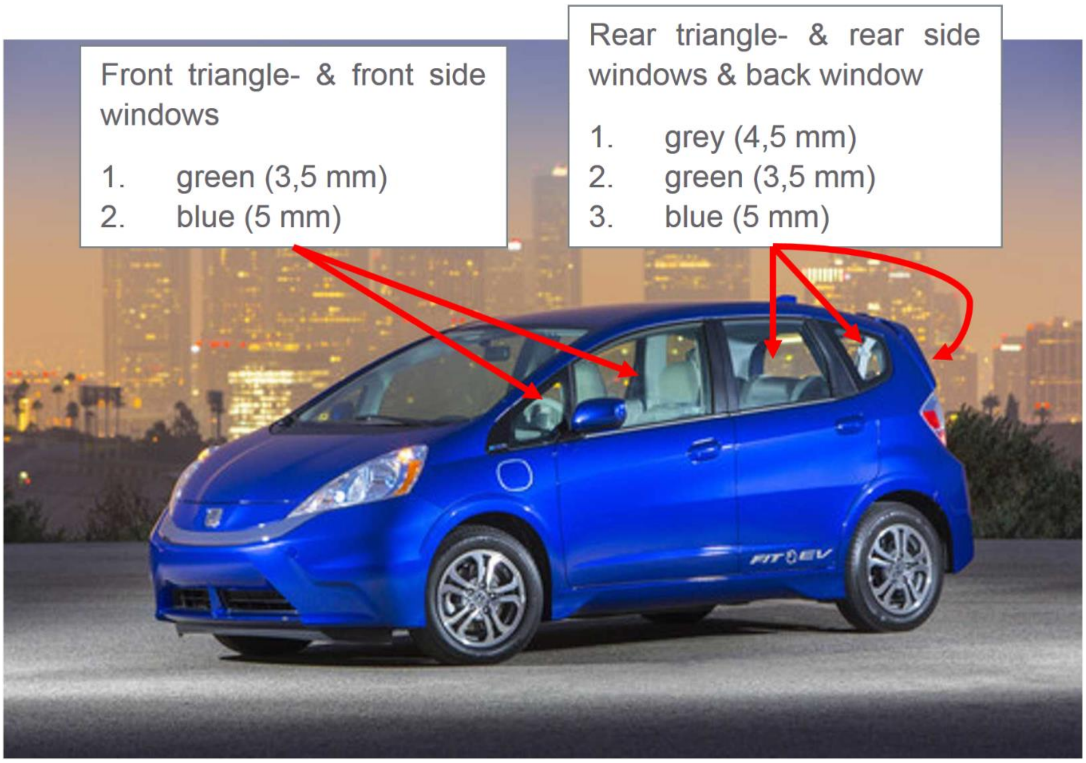

Front triangle- & front side windows

1. green (3,5 mm)
2. blue (5 mm)

Rear triangle- & rear side windows & back window

1. grey (4,5 mm)
2. green (3,5 mm)
3. blue (5 mm)

Figure 2: Glazing options / choices in descending order determined by HRE and AIT

In Table 2 the possible weight reduction compared to original Honda Fit EV windows (made of glass) is itemised concluding a further total weight reduction of about 35 %. This calculation takes into account the second option (5 mm thickness) for the front windows which is heavier than the first option (3.5 mm thickness). In case the 3.5 mm windows are stable enough, the weight reduction will be therefore even higher.

Table 2: Weight estimation for glazing

Part	**Glass* thickness**	**Glass weight**	**PC** target thickness**	**Weight reduction by material**	**Weight reduction absolute**	**Quantity per vehicle**	**Total weight reduction target**
Front side windows	4.0 mm	3.7 kg	5.0 mm	-40 %	1.50 kg	2	3.00 kg
Front quarter light	3.5 mm	0.8 kg	5.0 mm	-31 %	0.25 kg	2	0.50 kg
Rear side windows	3.5 mm	2.5 kg	4.5 mm	-38 %	0.95 kg	2	1.90 kg
Rear quarter light	3.1 mm	0.9 kg	4.5 mm	-30 %	0.27 kg	2	0.54 kg
Rear windscreen	2.8 mm	3.5 kg	4.5 mm	-23 %	0.81 kg	1	0.81 kg
SUM							**6.75 kg (-35 %)**

* Density Glass $\varrho_{glass} = 2.5\,\frac{g}{cm^3}$

**Density PC $\varrho_{PC} = 1.2\,\frac{g}{cm^3}$

3. Lightweight closures

Lightweight closures are an essential element of weight reduction goals in the QUIET project. This task is to analyze the baseline steel closures (Figure 3) of the demonstrator Honda Fit EV car and based on this, a redesign using light but high strength materials is carried out. The project aims to reduce weight by no less than 20 % and improve thermal insulation and reduce thermal inertia.

Figure 3: Original steel closures on a Honda Fit EV (left) and at the ECON workshop partially disassembled (two on the right)

The redesign process needs a clear plan, which can be followed and contains necessary steps from the first to the last phase of the development. This plan (Figure 4) guarantees the success of the project including an optimization process of the new lightweight structure making e.g. weight-stiffness and weight-insulation trade-offs.

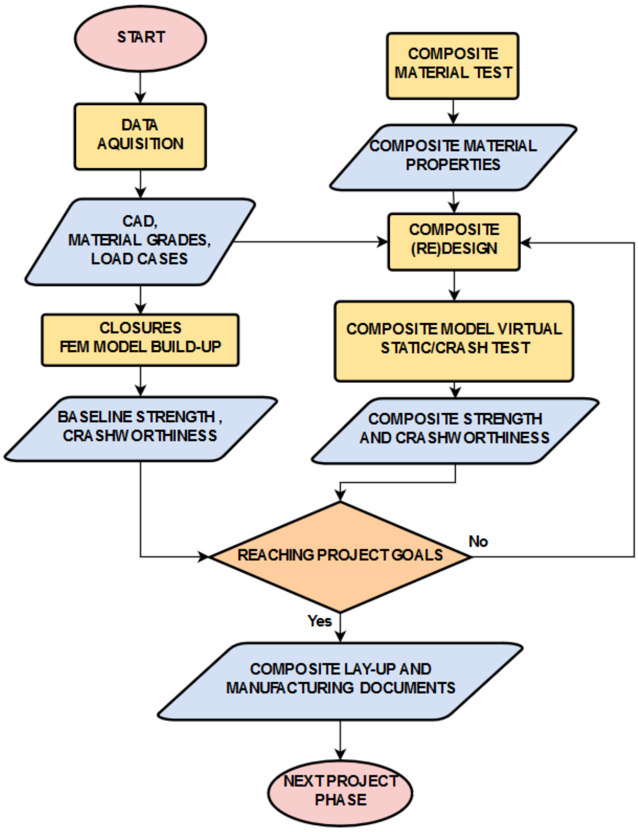

Figure 4: Flowchart of lightweight redesign process by ECON

3.1. Data acquisition and baseline simulations

First step of this project part was the data collection from Honda. This data acquisition covered the following areas:

- CAD data of closures (front and rear side doors, tailgate, trunk lid) (Figure 5),
- Part lists and weight data of closure components,
- Material grades of above-mentioned parts,
- Available static and dynamic load cases for investigating the structures,
- Expected results of static and dynamic load cases,
- Physical model of closures, real closures for further investigations.

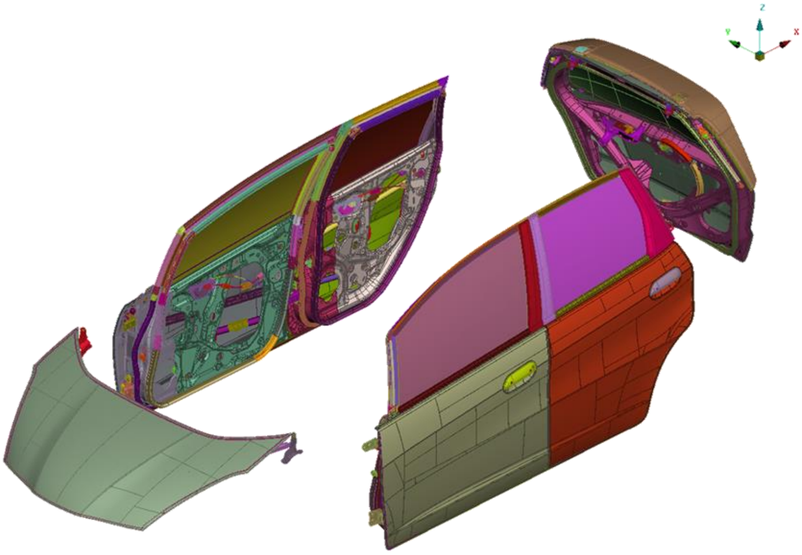

Figure 5: CAD models of Honda Fit EV closure

Based on the data of the vehicle platform, material properties and CAD data acquisition, an extensive investigation was performed to find the baseline stiffness, strength and crashworthiness of steel closures. Having a reliable baseline is really important for finding the best possible solution for closures regarding targeted weight reduction and thermal performance improvement viewpoints.

After data were collected for static (acc. to HRE) and dynamic (crash, acc. to FMVSS 214) load cases, finite element models were built for closures and Finite Element Analysis (FEA) simulations were performed of original steel closures of the FIT EV (Figure 6). In both cases ANSA preprocessor was used for building FEM models which were solved in ANSYS for static load cases and in LS-Dyna for side crash load cases. The evaluation of results i.e. the postprocessing was performed in META for all load cases. These FEA results are the target in stiffness (static load cases) and energy absorbing (during side crash) for lightweight composite designs.

At first phase of the process, targeted areas for redesign were the front and the rear doors on both sides, because large part (~70 %) of the closure weight is given by these items and evaluation criteria are well defined in these cases, as well.

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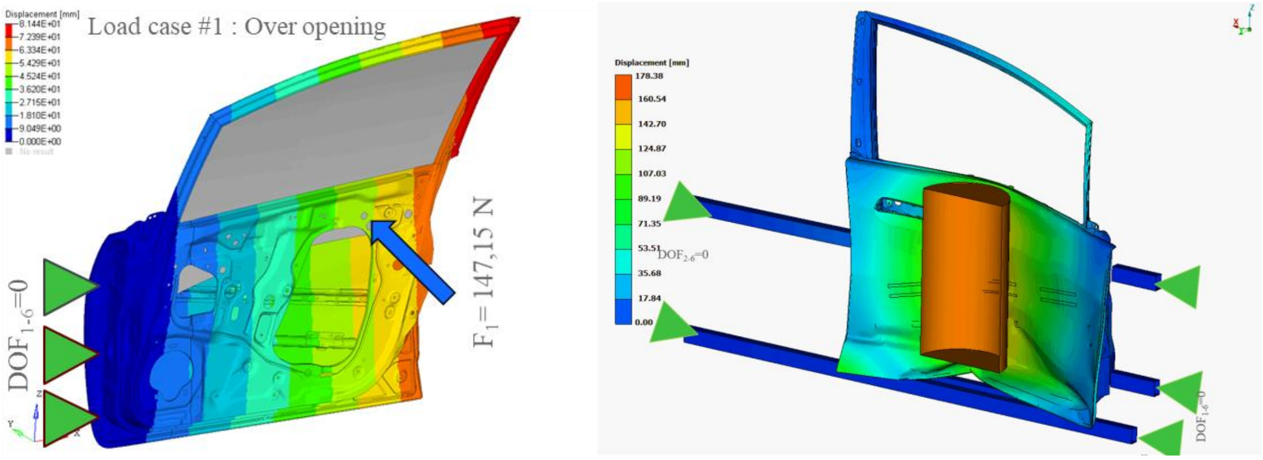

Figure 6: Baseline virtual FEM tests on front side doors, static structural (left) and dynamic side crash (right)

3.2. Material tests and composite redesign

For accurate and successful composite redesign, the composite samples were tested (Figure 7) from large spectra of materials and manufacturers as well. This was necessary as properties of the materials are largely process-dependent and errors can be minimized this way. Large spectra of tested materials contained several types of composites for simple and for more complex manufacturing processes which allows to proceed the redesign considering economic upscale. In this case, only one or a few demonstrator parts will be manufactured this way as the cost of a larger production can only be estimated, dividing cost of design, tools, raw materials and manufacturing by the size of the mass-production.

After choosing manufacturing partners for each picked technology, test specimens were produced for mechanical characterization of potential composite materials. Mechanical (e.g. tensile and shear) tests were performed by ECON on composite specimens with unidirectional woven and -non-woven carbon fibre reinforcement.

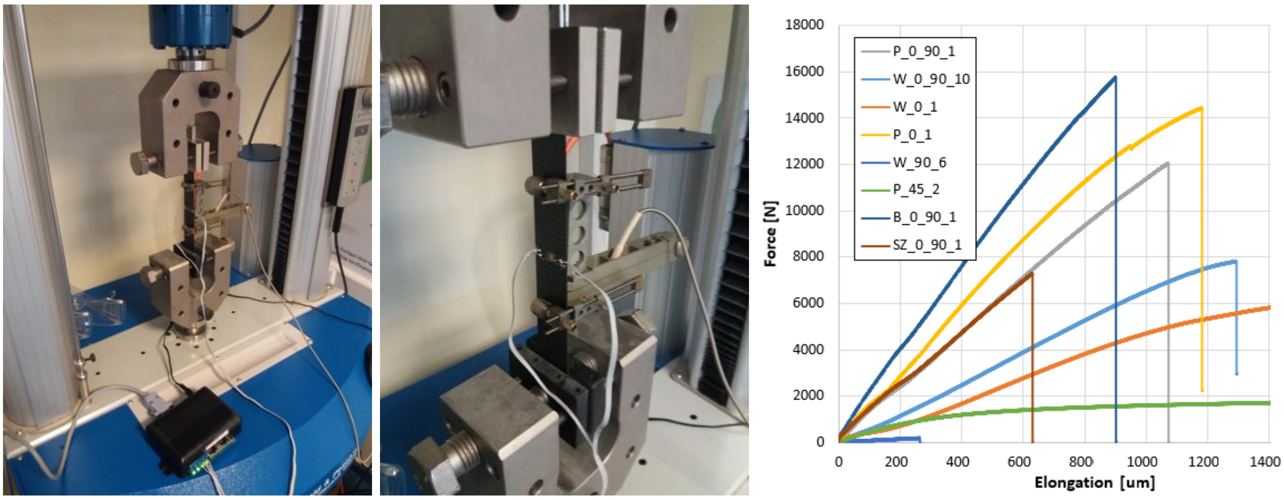

Figure 7: Tensile test on composite specimen equipped with precision clip-on extensometer strain gauges at ECON headquarters and raw force-elongation curves of investigated composite materials

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For lightweight composite parts, more than one composite manufacturing process was designed to use. It helps calculating possibilities for economic upscale of production. Representing smaller and medium scale series, an out-of-autoclave prepreg technology and a vacuum infusion composite technology was selected. The former process is dedicated to the elements of front doors and the latter is for the elements of rear doors. Both mentioned processes are cost effective regarding mould-making and small series test manufacturing but can also be easily upscaled or used as baseline for higher series as well.

For composite redesign, the first and most important thing to be ensured is that the geometry can be manufactured from this material type. This sub component has to be geometrically relatively simple with no undercuts and limited amount of small details. According to this theory, a partitioning was done on a side door (Figure 8) where panels skins and crash beams were selected as subcomponents which are applicable with small or no modification to be produced using composite materials. These mentioned parts cover about 80 % of structural mass of side doors and about 90 % of heat transfer area counting only the steel components. Window frames are chosen to be kept in original form because they would not be able to adapt as simple to composite manufacturing as QUIET project needs it according to the budget and time frame.

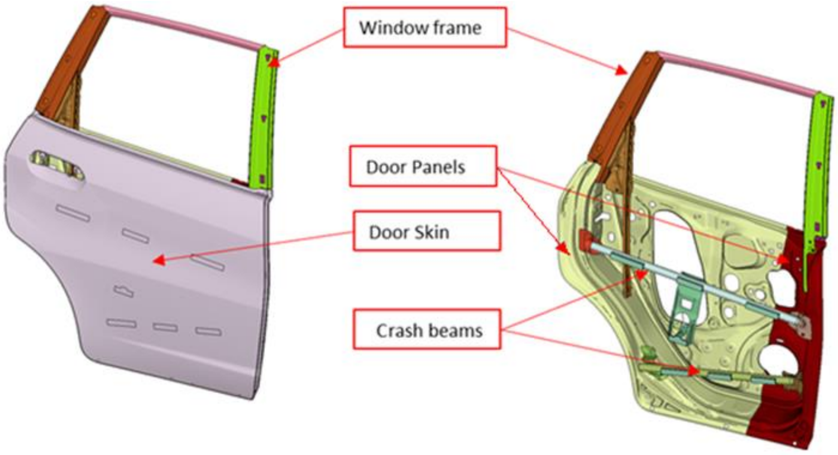

Figure 8: Partitioning of side door structure for composite redesign

Material selection is in harmony with manufacturing processes and light weight reduction goals, high strength carbon fibre (CF) reinforced epoxy polymer composites were chosen according to the recommendation of manufacturing partners. This kind of materials assures low weight via low density (1.4-1.6 g/cm^3 << 7.8 g/cm^3 of steel) besides high tensile strength (500-1500 MPa >> 250-350 MPa of steel) and low thermal conductivity (~4.5 W/(m K) << ~60 W/(m K) of steel). For type of reinforcement unidirectional, biaxial and woven CF structures are also selected.

For mould making the original shapes of steel closures were used, but some simplifications and modifications were made because of manufacturing purposes and differences between steel and composite design allowances.

Based on the mechanical test results of the selected composite materials, a virtual FEA aided composite layer optimization was carried out on the partitioned door sections which helped to find the best possible layer build-up e.g. position of layers (fibre directions) and number of layers (laminate thickness). First step of the optimization process was identifying areas which are more and areas which are less responsible for stiffness and energy absorption. This process was carried out by doing a Design of Experiment (DoE) process. DoE

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helped to find areas where higher strength or stiffness is needed for reaching our targets. Of course, the division of surfaces was done considering manufacturing possibilities. After DoE aided partitioning, composite lay-ups were optimized from surface to surface. Main targets of optimization were to keep the static stiffness and crashworthiness of the original steel construction but considering manufacturing possibilities e.g. feasible layer thicknesses and fibre orientations. Composite lay-ups for manufacturing (Figure 9) were the results of the lay-up optimizing process, which were sent to manufacturing partners for consultation and for production.

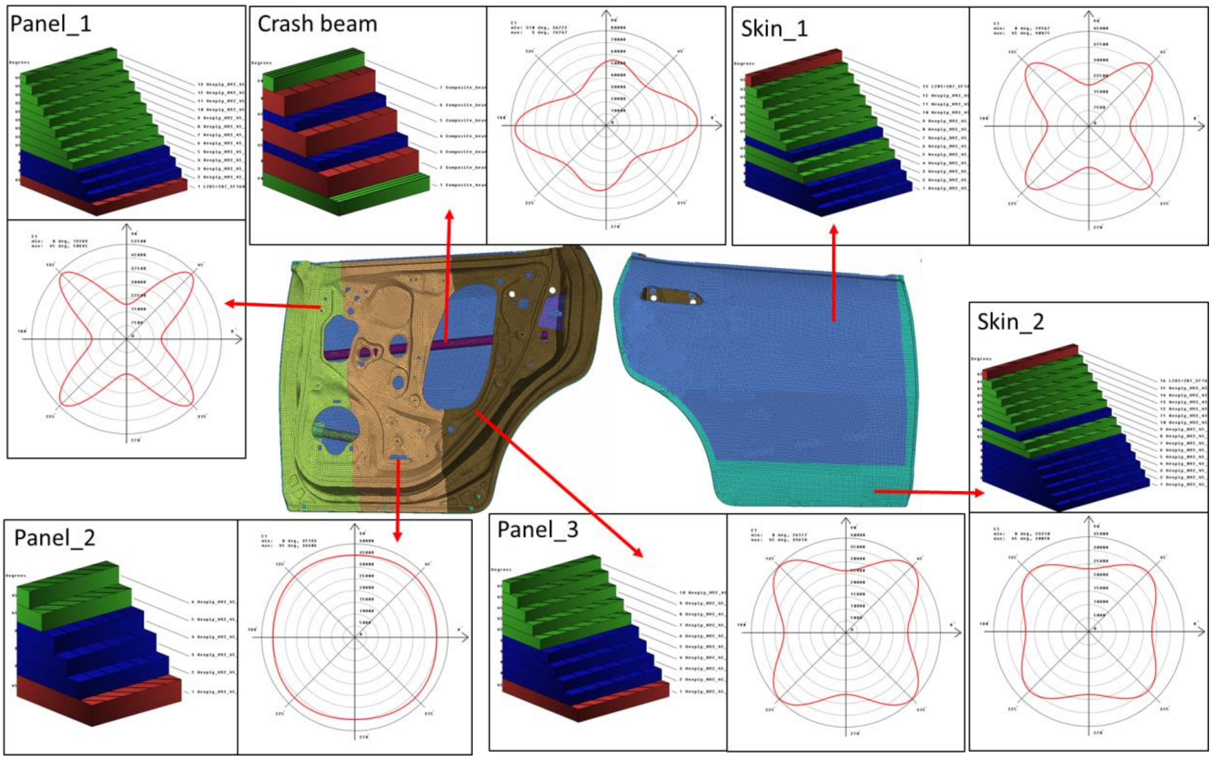

Figure 9: Identified and lay-up optimized composite areas, their stacking sequences and stiffness on polar coordinates demonstrated on the skin, panel and crash beam of Honda Fit EV rear door

Materials developed in T3.2 (Materials for enhanced thermal insulation) and its results the APM foam were considered as good energy absorbent, therefore they will be used as core material for crash beams of side doors (Figure 10).

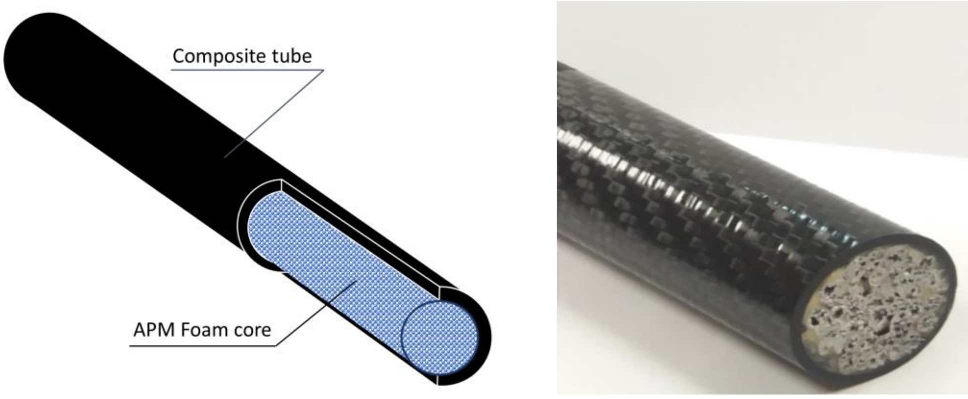

Figure 10: Side door composite tube crash beam filled with APM material, developed and produced by IFAM in theoretical way (left) and in the demonstrator model (right)

After the virtual optimization process, we could estimate the outcome of weight reduction intensions. According to the calculations, a mass reduction of 21 % and 18 % can be achieved for rear and front doors considering structural and non-structural parts (e.g. sealants), as well. These numbers do not contain the mass reduction of glass components (windshields and windows) mentioned in T3.1, therefore further decrement is obtainable and the project goal (~20 %) seemed clearly reachable at this stage of work. The thermal conductivity of the used composite material is one order of magnitude lower (~5 W/mK) compared to the originally used steel material (~60 W/mK). Calculating thermal inertia from density, thermal conductivity, and specific heat capacity of the original and lightweight material, it means ~80 % decrement of inertia in the targeted structural elements. Calculating with the global structure of the door, it could be up to ~40 % thermal inertia reduction.

3.3. Composite manufacturing and products

The manufacturing of composite closures starts with fabricating manufacturing tools for composite shells, that are the outcome of the formerly mentioned partitioning process. Because of the size of the project (low production number) molds were made out of composite as well using the original shapes of the steel closures a master surface. There are two kinds of molds in this project, laminating and bonding process molds. Laminating molds are negative caves where the laminating process can be done i.e. the creation of composite shells. Other tools are for the assembly process when the composite shells e.g. of skin, panel, crash beams, and original steel window frames are bonded together with structural adhesives. After the lamination is done according to the laminate plans, composites with vacuum bags are cured at elevated temperature (~80-100 °C) for a few hours in a furnace to get their final shape and strength. After heat treatment, demolding process i.e. removal of composite shells from the mold was done. After this followed accurate positioning in the bonding tool and creating adhesive joints for inner and outer shells, crash beams and other parts like inserts, hinges, connection points for handles and bolt-on elements. Crash beams filled with APM were also positioned and bonded into the composite structure. After the bonding process, a second heat treatment was done for curing the structural adhesive itself, then polishing of visible outer surfaces was done.

When the whole structure is ready for final assembly, bolt-on elements, patches, sealants, etc. are added to the composite side doors (Figure 11).

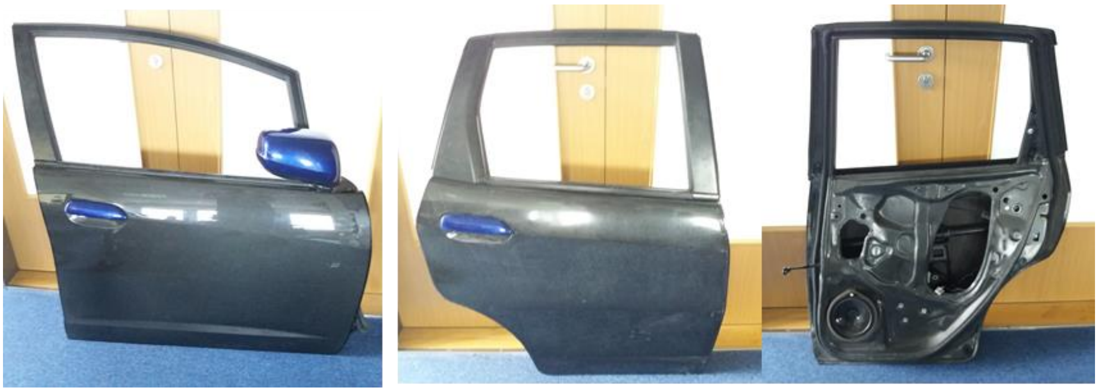

Figure 11: Manufactured lightweight composite front and rear side doors at ECON office

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3.4. Results

Weight reduction

Based on the calculated weight data and manufactured products, it can be concluded that in case of side doors 20% mass reduction can be achieved as targeted (cp. Figure 12). For the engine hood and trunk lid, these weight losses can also be obtained (production of these items are ongoing).

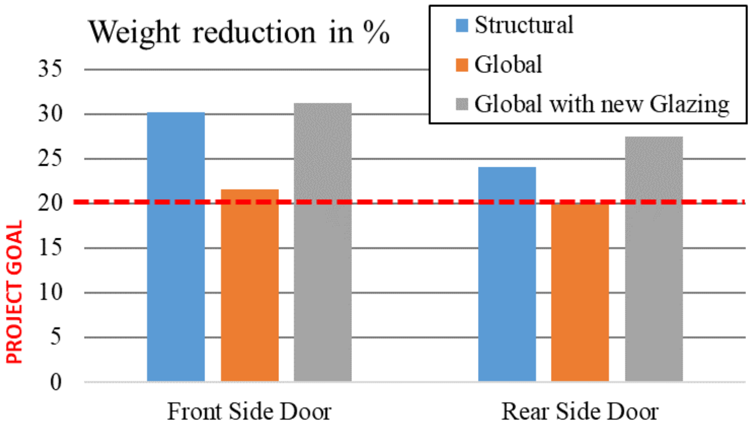

Figure 12: Calculation of weight reduction in case of composite closures

Partitioning of the structure

Partitioning is taking place during the design or redesign process and its goal is to create manufacturable surfaces with sufficient strength and reasonable cost. During the partitioning complex geometries are divided into components, e.g. side door skin and panel like the original design, but for composite design. Below this component level, there is another one to create subcomponents like partitioning the skin plates (see Figure 9). In case of components there is the option to choose different composite manufacturing methods to minimize costs of labour, tooling and raw materials. For this redesign process, several manufacturing methods were chosen to estimate costs and to test their appropriateness for the current project.
Afterwards the partitioning parts were produced with the following techniques:

- Window frames (original steel structure was kept);
- Door panels (composite hand lay-up, vacuum infusion, prepreg + vacuum bagging);
- Door skins (composite hand lay-up, vacuum infusion, prepreg + vacuum bagging);
- Crash beams (simple geometry, available on the market, purchased);
- Filler material for crash beams (APM manufactured by IFAM).

Different composite manufacturing processes

The possibility of economic upscale using different methods for composite closures has been investigated in close cooperation with the assigned partners. Different manufacturing methods are technologically feasible, and the choice depends on the intended production volume. Furthermore, different processes could be preferable for different application, the number of units to be produced, unit numbers and quality (strength, repetitiveness) demands (Table 3). Based on this, for low number of units in small series or prototyping a simple hand lay-up technology can fit, but for a larger number of units a process with higher quality and repetitiveness, e.g. vacuum infusion or resin transfer molding (RTM), can be a better choice.

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For composite closures of the QUIET project, the right balance between the low number of "prototype" units, structural strength, project budget, and cost estimation of the upscale have to be find. Three different techniques were chosen: Hand lay-up, Vacuum infusion and Prepreg + Vacuum bagging. These techniques are perfect to demonstrate reachable goals in field of lightweight construction of closures and they also fit to the project budget but mass production cannot be imagined using them.

Table 3: Possible economic upscale using different methods for composite closures* [3] [4]

Manufacturing method	Quality, precision, repetitiveness	Tooling Cost	Part per year [unit]*
Hand lay-up (vacuum assisted)	+	$	100-200
Vacuum injection (infusion)	++	$$	300-500
Prepreg + Vacuum bag	+++	$$$	100-200
Prepreg +Autoclave	+++++	$$$$$	100-200
Composite Pressing (SMC)	+++++	$$$	10000-50000
RTM	+++++	$$$	1000-5000
T-RTM	+++++	$$$$	10000-50000

*estimated for a mediums size medium complexity carbon reinforced polymer composite part

Costs and automation

For mass production, it is important to face the project costs of feasible processing solutions for automotive applications and make the comparison to the conventional techniques. For automotive application, more productive processes like Composite pressing (Sheet Molding Compound, SMC) or Thermoplastic-Resin Transfer Molding (T-RTM) are feasible solutions in case of higher volumes.

Cost of composite raw materials (Table 4) can be from 1.2 to 3.7 times higher, compared to conventional steel and aluminum. But there is another effect of weight savings due to the density difference which can moderate the cost gap. Embodied energy is also an important factor which shows that in case of glass fiber it can manage lower energy consumption compared to a steel body.

Table 4: Specific cost and other properties of automotive raw materials [5]

Material	Cost [€/kg]	Density [kg/m3]	Specific strength [kNm/kg]	Embodied energy [MJ/kg]
Steel	0.4 - 0.6	7800	38	45
Aluminum	0.7 - 1.6	2600	130	227
Composite for SMC	1.5 - 1.9	1200	150-400	33-226
Composite for RTM	2.6 - 4.8	1200-1600	150-400	33-226

The total cost of manufacturing consists of several other factors than material like labor, equipment tooling, overheads and other costs (Figure 13). Considering the whole process, specific cost of composite manufacturing is 2-3 time higher in general compared to steel components.

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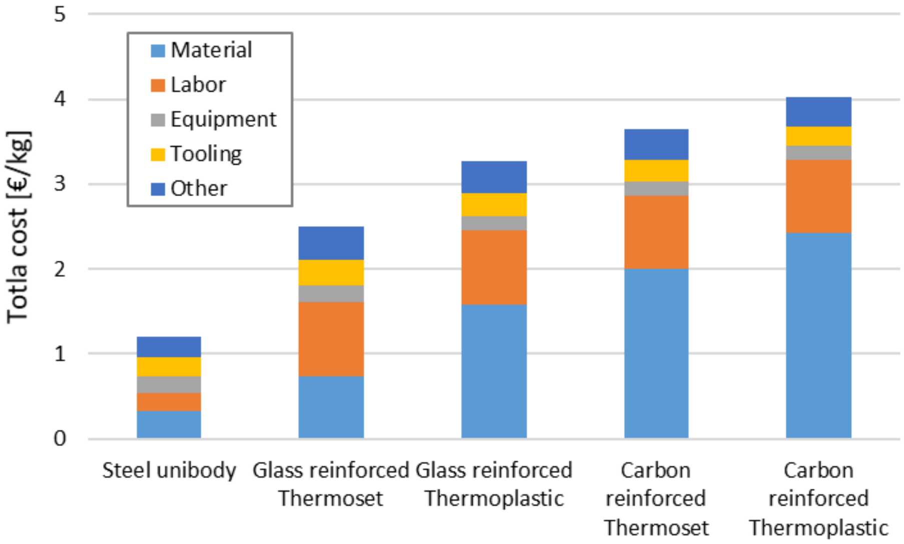

Figure 13: Cost component comparison of various composite RTM and T-RTM in contrast of conventional steel for mass production in high series [4]

For the current project a rough estimation can be made for lightweight closure costs (Figure 14) based on the manufacturing experiences and literature background mentioned above.

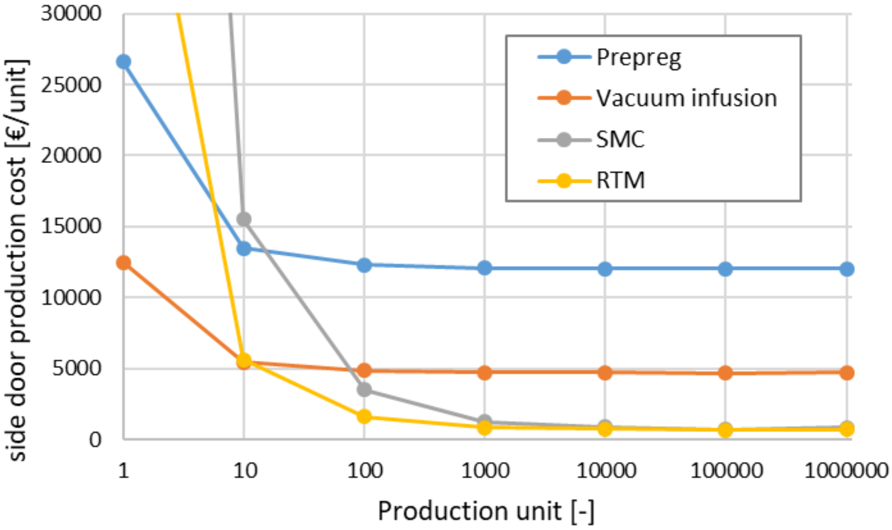

Figure 14: Cost estimation for a side door besides several production techniques

Out of the presented solutions, production costs of aluminum-polymer hybrid foam APM (Figure 15) must be considered as well. The assumption is made that based on the assumption for that crash beams of the closure set of a car about 6 meters of APM rods are needed with 24 mm diameter and density 0.53 g/cm³, which means about 1-1.5 kg of APM rods per car.

For this prototype manufacturing, APM rods are produced using a lab scale equipment. The price for the foamable aluminum wires is very high because the amount ordered (0.5-1 ton) is very low from the producer's point of view. Therefore, for an amount of up to 1 ton of APM (i.e. 1-1000 cars) the price for the raw materials (foamable aluminum wires, PA12 adhesive) and the manufacturing procedure will not change significantly, so the price will remain at about 100 €/kg. For an amount of 10000 cars (units), i.e. 10 tons, it will be necessary

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to change the shaping procedure: shaping would not be done in a mold, but by a (continuous) extrusion process. Also, the costs for the raw materials will start to reduce. Therefore, one expects that the price will reduce to about 50 €/kg. For an amount of 100000 cars (units), i.e. 100 tons, it will be justified to optimize the manufacturing process of the foamable aluminum wire (e.g. optimized die). The costs for the raw materials, e.g. the aluminum powder, will also reduce further. It is expectable that the price will reduce to approximately 20 €/kg. For a real mass production of about 1,000,000 cars (units), i.e. 1000 tons, a price of 10 €/kg seems realistic. This is not far from the value of 8 €/kg, which was calculated by IFAM before in 2006. This cost cannot be comparable with conventional steel crash beams and especially their fillers because in this case there is no filler in the beam.

The successive deliverable D3.3 (Assessment report for new lightweight components) will deal with the completed comprehensive assessment report about the simulation results, the proposed manufacturing methods and the possibility of the (holistic) economic upscale of production.

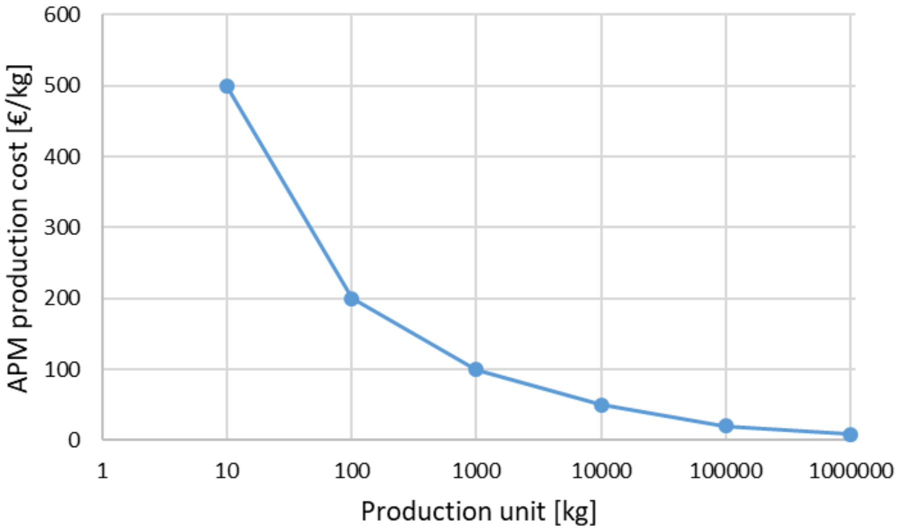

Figure 15: Cost of APM core material production calculated by IFAM

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4. Conclusions

With the selected polymer glazing, project goals can be reached from viewpoints of lightweight structure and also for usability and durability. For safety purposes, the front windshield cannot be implemented.

For the demonstrator car, the possibility of lightweight closures was investigated. At the beginning of the project, the current steel-based structure was modelled and virtually tested with finite element analysis method to have a baseline strength and crashworthiness. For composite redesign, these baseline results and CAD models i.e. original shape of the closures were used as input parameters. The first step of the lightweight redesign was the assessment of manufacturability and partitioning of the closures into reasonable parts from viewpoint of manufacturing and strength calculations. After that, material tests were carried out on several kinds of composite materials to generate inputs to the optimization process. This multi-purpose optimization dealt with strength-crashworthiness-insulation-mass parameters. After the optimization process, composite manufacturing instructions i.e. composite layer build-up and manufacturing documents were prepared and sent to manufacturing partners. For manufacturing composite closures, several types of manufacturing processes like vacuum infusion and vacuum assisted prepreg technologies were used which fitted into the project timeframe and budget but they are only appropriate for smaller series. Possible upscale of production is estimated based on literature and manufacturing experiences. Results achieved in weight reduction meet the QUIET project goals, approximately 20 % was achieved in each part. For economic upscaling, SMC, RTM, or T-RTM technologies would be better but their costs are also significantly higher than steel or aluminum manufacturing costs nowadays.

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4	**QPD**	qpunkt Deutschland GmbH	Germany
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7	**IFAM**	Fraunhofer Institute for Manufacturing Technologies and Advanced Materials IFAM	Germany
8	**ATT**	ATT advanced thermal technologies GmbH	Austria
9	**ECON**	eCon Engineering Kft.	Hungary
10	**RUB**	RUBITHERM Technologies GmbH	Germany
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13	**JRC**	Joint Research Centre - European Commission	Italy