



# (Cost) Efficient Monocoques For Future Mobility

FRP Composite Monocoques offer cost-effective solution to meet demands of Future Mobility

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# CONTENT

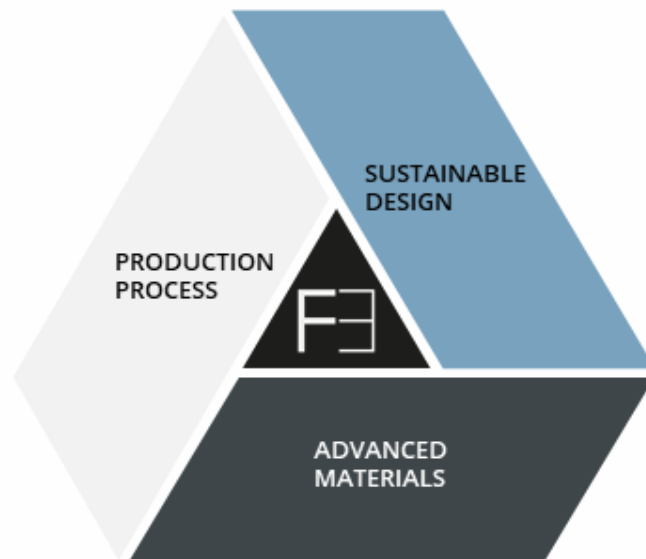
- ABOUT FORWARD ENGINEERING
- FUTURE MOBILITY: STATUS & OUTLOOK
- POTENTIAL OF MONOCOQUE DESIGN
- LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN
- MONOCOQUE DEVELOPMENT
- CONSIDERATION OF COST & LIGHTWEIGHT
- SUMMARY & OUTLOOK

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# YOUR PARTNER FOR AUTOMOTIVE. COMPOSITE. SOLUTIONS.

Industry Leading Design & Engineering Partner for Sustainable Products and Economical Lightweight Solutions



- “Material & Production Based Engineering” – From concept to series production
- Accelerate product development with standardized development processes
- Increase confidence in performance-, cost- and CO2 forecasts
- Reduce validation costs & time with target-oriented CAE-analysis
- Enable well-founded decisions & empower our customer with unique material and technology know-how
- Offer independent & flexible service in a strong composite network in Germany and globally

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# FUTURE MOBILITY | WHY WE SHOULD THINK ABOUT IT NOW!



- Shifting demographics
- Rapid advancements in technology & demand for carbon neutral mobility grows
- Higher demand for (individual) Mobility



- Large resource investments in Future Mobility around the globe
- Current Knowledge must be used to improve Future mobility applications from the beginning

# WHAT IS FUTURE MOBILITY?



# FOCUS OF THIS PRESENTATION



VERTICAL  
MOBILITY



HIGH  
SPEED  
TRAINS



INDIVIDUAL MOBILITY



PEOPLE  
MOVER



SPORT  
CARS



PASSENGER  
VEHICLES

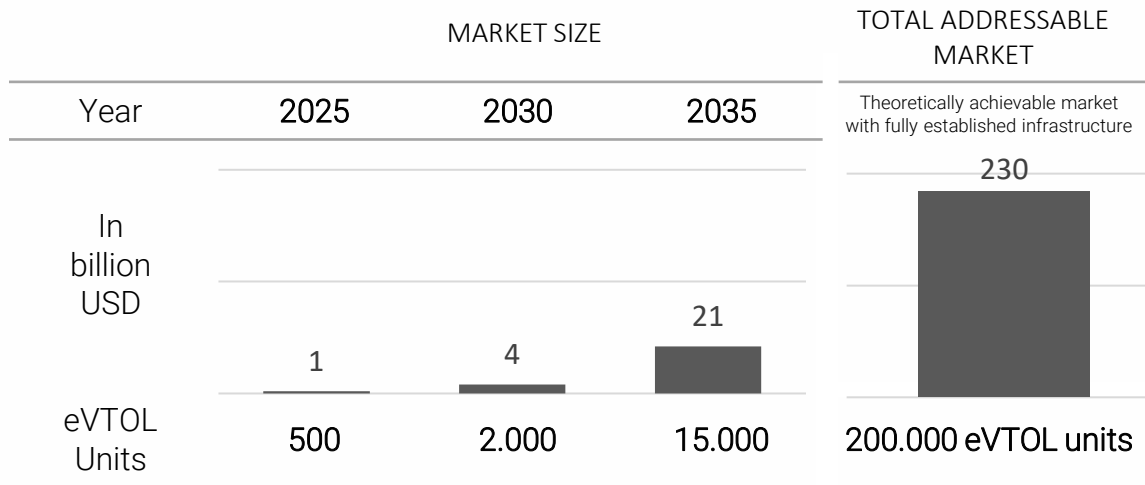


# FUTURE MOBILITY ON OUR DOORSTEP

Example



## VERTICAL MOBILITY



Source: Porsche Consulting "The Future of Vertical Mobility"

- Future Mobility sees a big investment all around the globe in the last years

**AIRCRAFT**  
**Archer Aviation takes billion-dollar eVTOL order from United Air**

**Volocopter extends Series C funding to \$94M with backing from logistics giant DB Schenker and others**

**German air taxi startup Lilium gets funding from Tesla investor, crosses €1B valuation**

- Several market studies predict large market growing in this and the next decade

# WHAT DO THEY HAVE IN COMMON?



- High amount of acceleration and deacceleration
- Passenger “cabins” with
  - High demand on structural performance
  - High demand on structural safety (crash) and passenger safety
  - High demand for integral design
  - Low-cost target with quantity depended business case



- Monocoque covers these demands best
  - Entry Scenario for Carbon Fiber
  - Learning from Automotive Experience and transfer to Future Mobility

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# WHAT IS A MONOCOQUE?



WIKIPEDIA  
The Free Encyclopedia

## Monocoque

[ˌmɒnəˌkɒk, -ˌkɒʊk], noun

is a structural system in which loads are supported by an object's external skin, similar to an eggshell, is a French term for "single shell".



FORWARD  
ENGINEERING

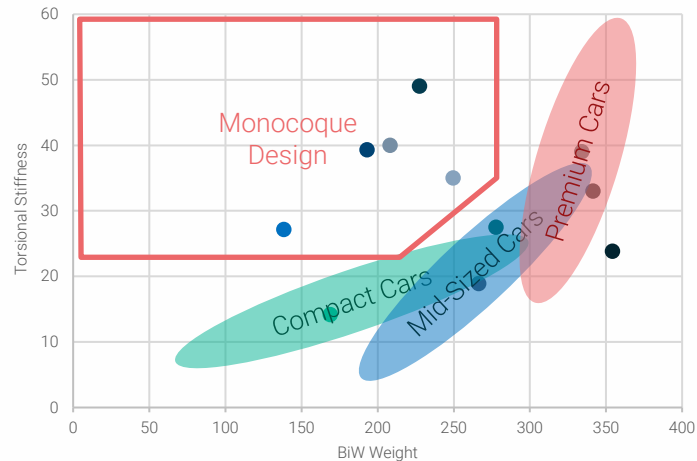
## MONOCOQUE

[ˌmɒnəˌkɒk, -ˌkɒʊk], noun

is fiber reinforced plastic (FRP) dominated structural shell, which carries all the main loads of a vehicle. The shell itself can be made of one piece or joined together of multiple.

# POTENTIAL OF MONOCOQUE DESIGN

## STRUCTURAL PERFORMANCE



Monocoque design offers a high stiffness to weight ration

- Increasing of vehicle dynamics possible
- Increasing of passenger safety possible
- Positive weight saving spiral applicable

## PASSENGER SAFETY



Overall structural integrity of Monocoque design is higher compared to other vehicle platforms due to.

- Less connections/bolts/joints
- Load transferring fibers/designed load paths across the whole body
- Performance orientated design

## INTEGRAL DESIGN



Monocoque designs offers a huge potential for function integration and integral design

- Possibilities from integration of joining technologies
- .. up to structural integration of complete parts (e.g. battery housing)

# POTENTIAL: SUMMARY



- Carbon Fiber enables a huge lightweight and performance potential
- Monocoque design increases this potential even more



- Monocoque design must be implemented into the design process from the beginning
- Holistic approach for development and implementation into overall car concept needed
- State of the art technology understanding needed
- Deep material understanding needed

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# LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN

## TRUST IN THE MATERIAL

- Monocoques for automotive applications are state of the art in various scales

BMW i3



<25.000 p.a

Rimac C-Two



~52 p.a.

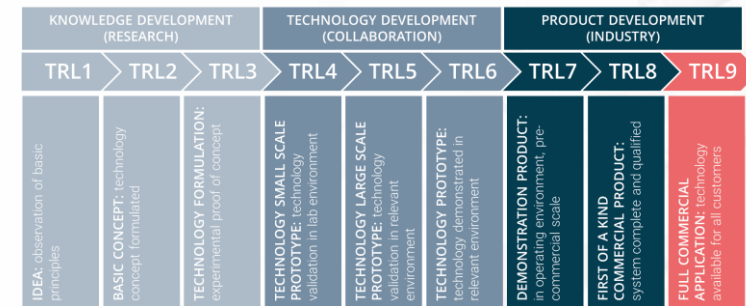
Mercedes W09



~ 2 p.a.

- FRP as a manufacturing material is
  - accepted as automotive material by the people
  - proven to be applicable in large series application

## ESTABLISHED SUPPLY CHAIN

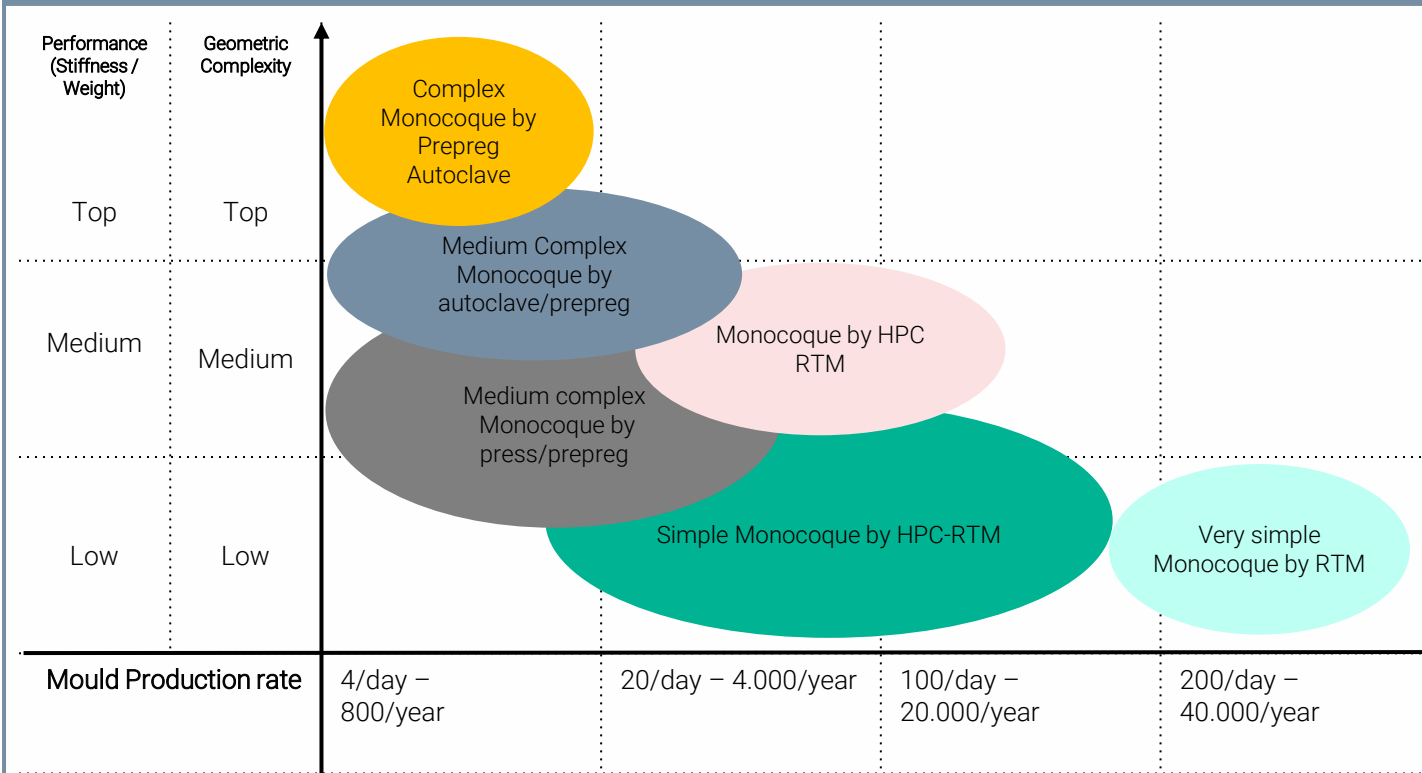


- Certification of supply chain and a large number of industrial environment like
    - engineering services with deep understanding
    - manufacturers with series application possibilities
    - cost efficient material suppliers with large scale of different materials
- Cost efficient high performance FRP structural parts are on the market with high TR Levels



# LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN

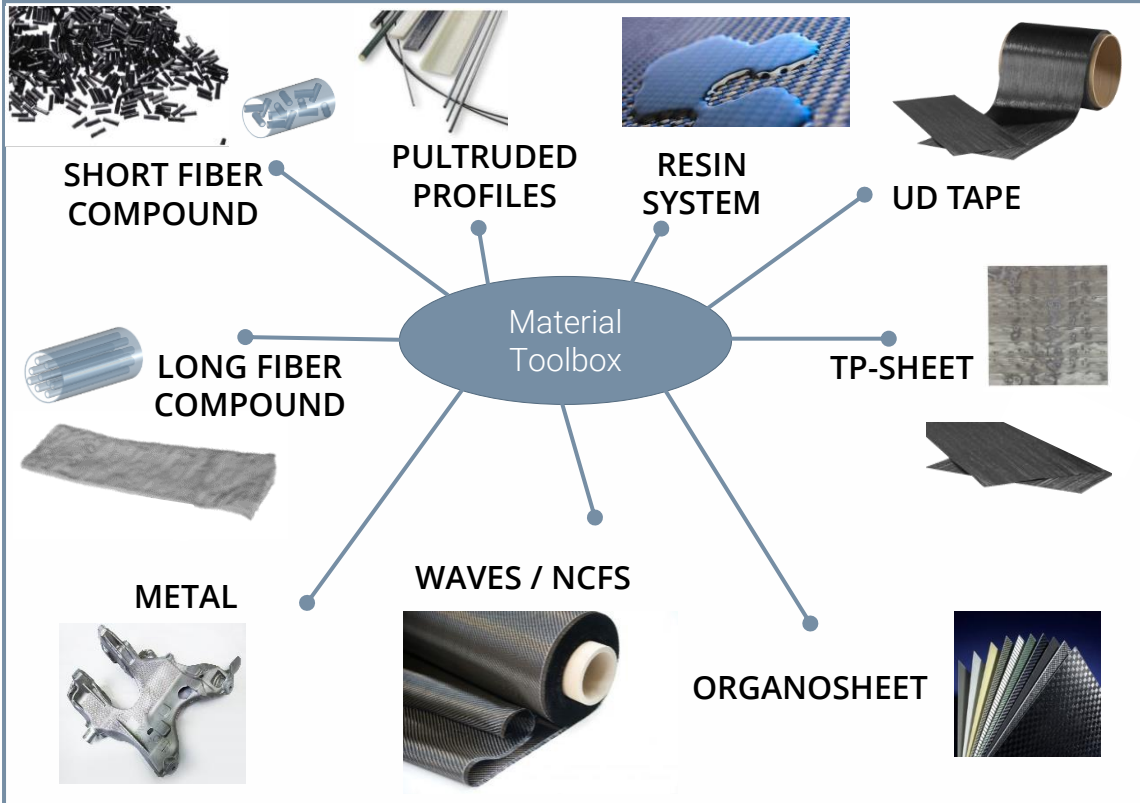
## INNOVATIVE MANUFACTURING PROCESSES FOR MONOCOQUES



- For each production volume different materials & manufacturing processes are available
  - Each combination has specific potentials regarding cost and performance
  - For most Future Mobility Application, a mix of technologies is the best approach
  - Forward Engineering gives guidance in a structured process to define the best selection
- Innovative production processes have been developed in the last 5-10 years offering new design possibilities
- Forward Engineering is enabling this potential

# LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN

## DIVERSIFIED MATERIAL TOOLBOX

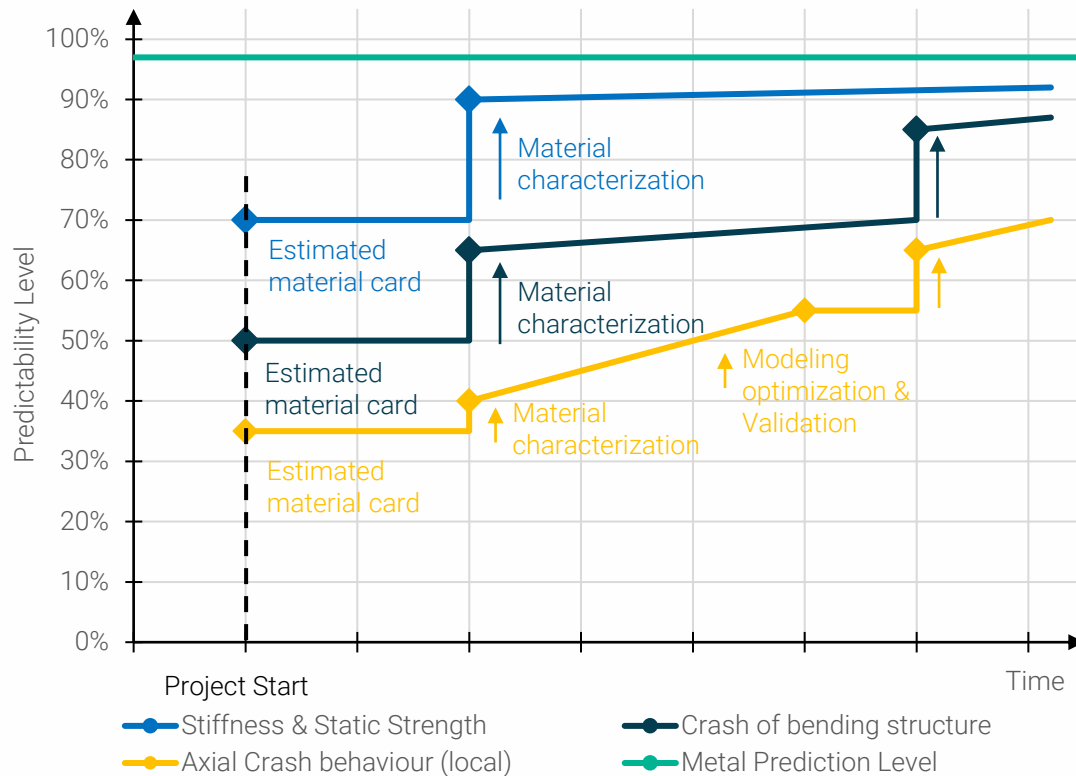


## ADVANCED JOINING TECHNOLOGIES

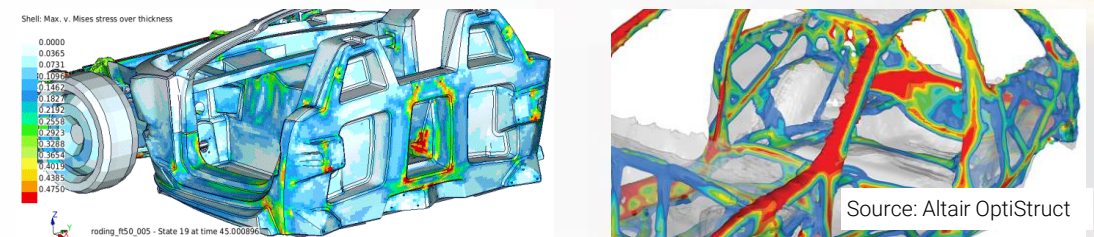
Structural	Semi-Structural	Non-Structural
Adhesive Bonding 	Adhesive Bonding 	Adhesive Bonding 
Riveting 	Riveting 	Riveting 
Bolted connection 	Bonding Fastener 	Onsert technology 
	Blind rivet nut 	Direct screw connection 
Insert 	Insert 	

# LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN

## VALIDATED CAE WITH HIGH PREDICTABILITY LEVEL

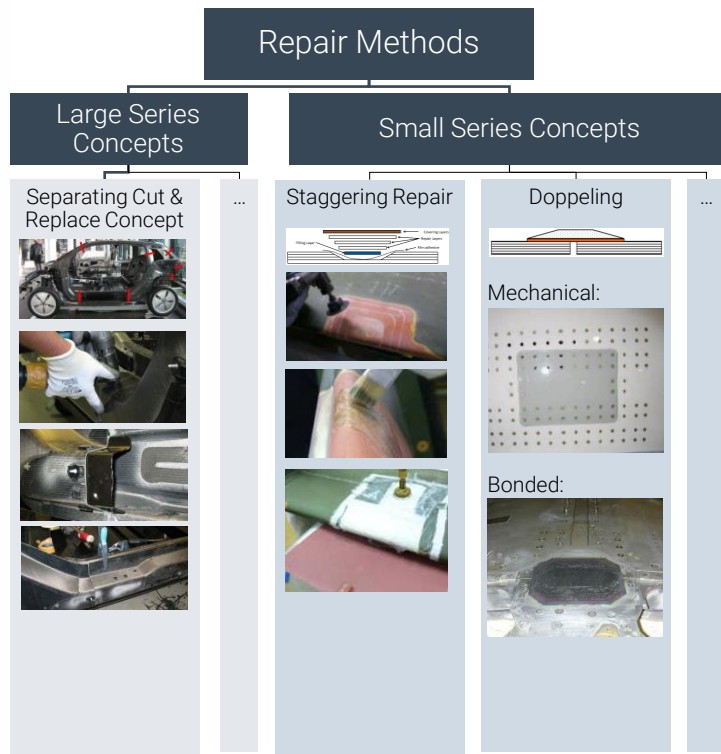


- Material card creation and validation is necessary for composites and needed for a high prediction level
- CAE for composites structures is still more challenging than for metal structures, but meanwhile state of the art
- Forward Engineering has In-house CAE Modeling capabilities with lot of experience in material card development
- Standardized FE Development process for material card development



# LEARNINGS FROM AUTOMOTIVE MONOCOQUE DESIGN

## ESTABLISHED REPAIR METHODS



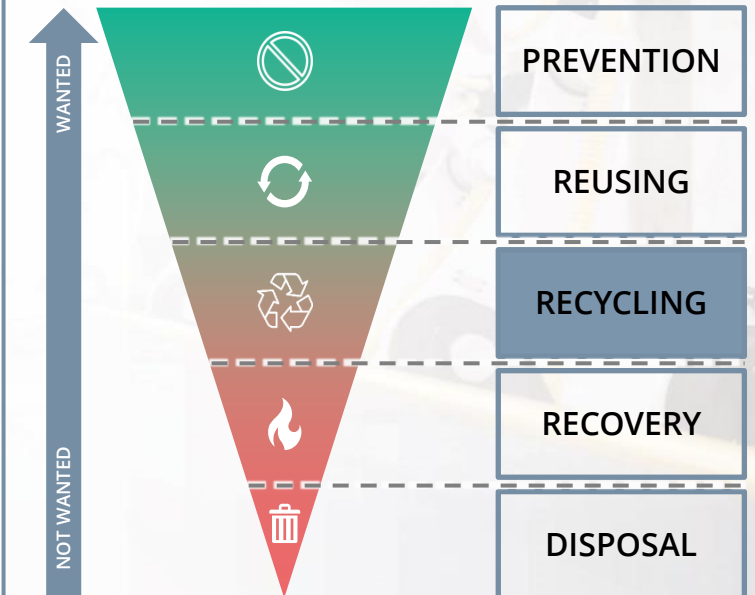
## QUALITY MANAGEMENT FOR SERIES PRODUCTION



- What is “acceptable” for CFRP manufacturing to keep production costs and scrap rate as low as possible
- Design for Tolerances in Joining & Assembly processes
- Adapted tolerances for trimming, post treatment & finish

## RECYCLING METHODS

Carbon Fiber End of Life Scenarios



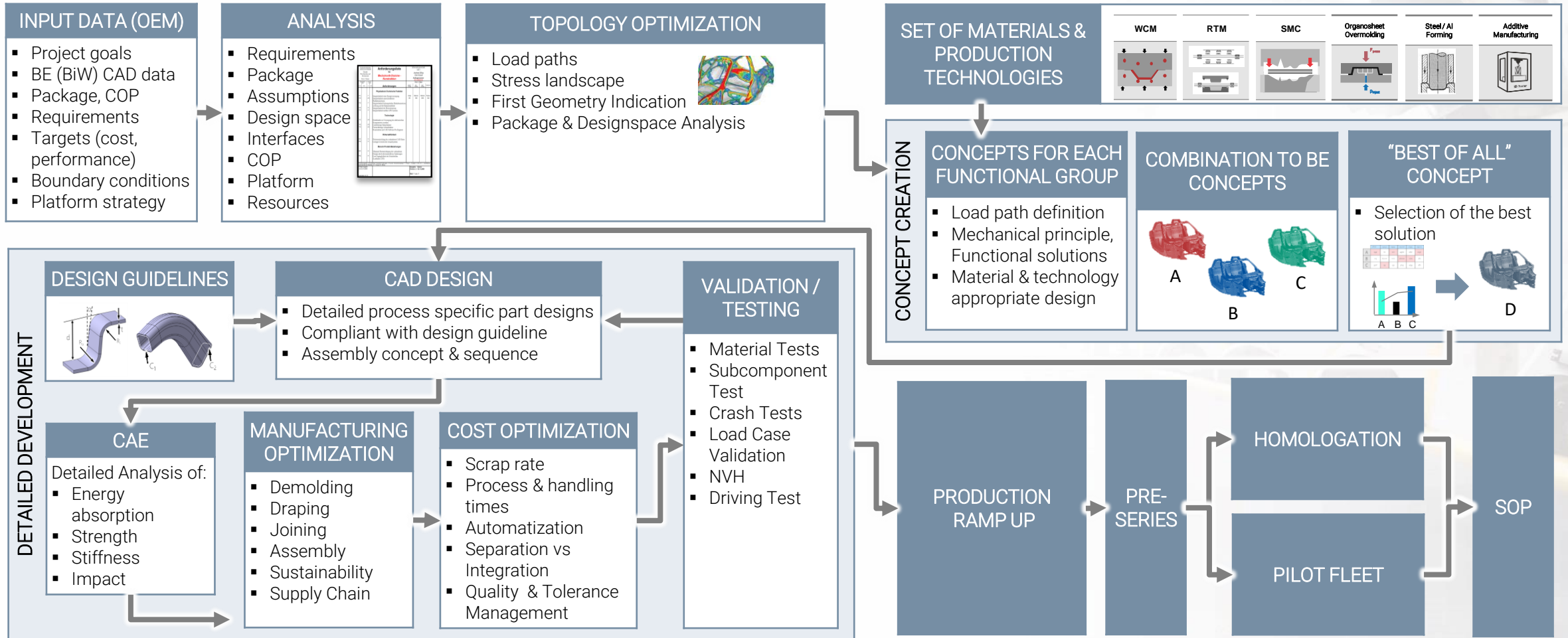
European Waste Framework Directive (2008/98/EC)

- Producer responsibility → “polluter pays” principle

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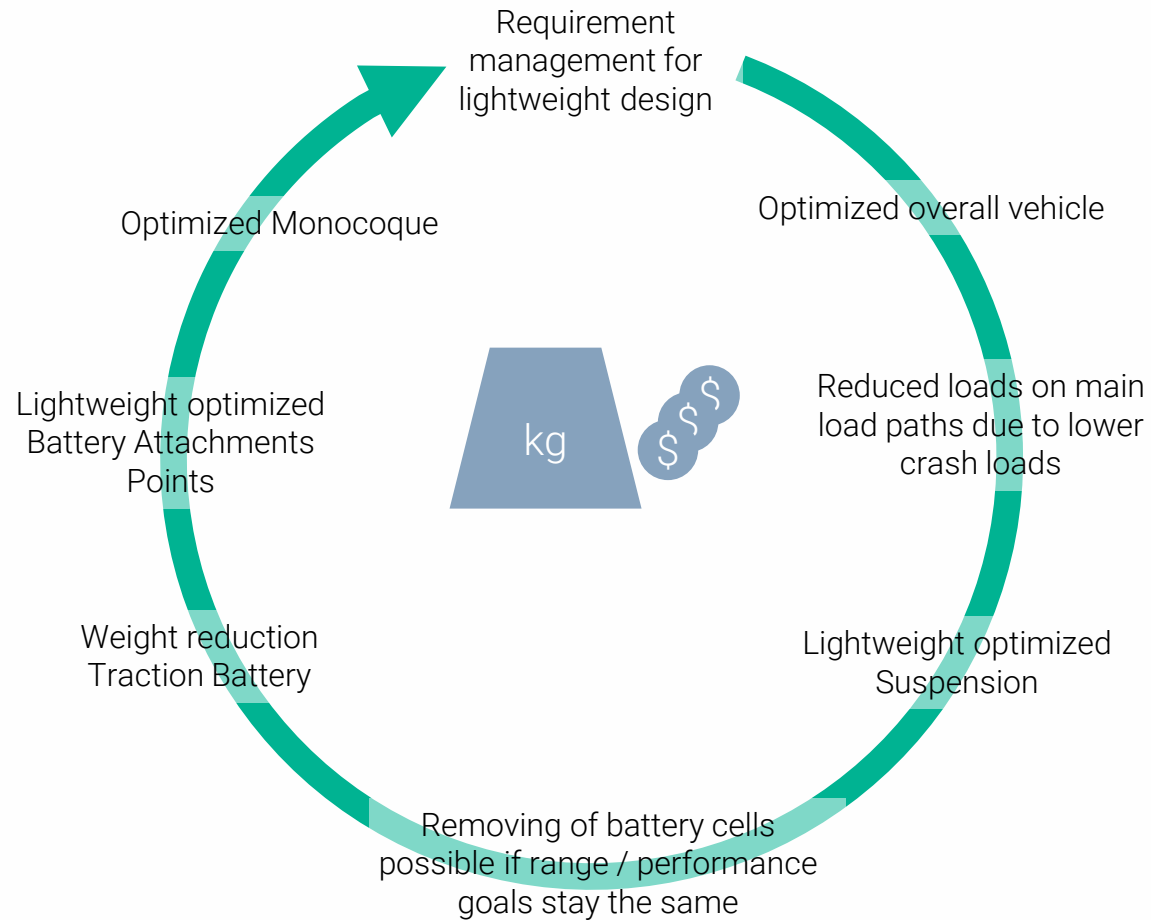
# FE'S HOLISTIC MONOCOQUE DEVELOPMENT METHOD



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# MEANING OF LIGHTWEIGHT FOR FUTURE MOBILITY

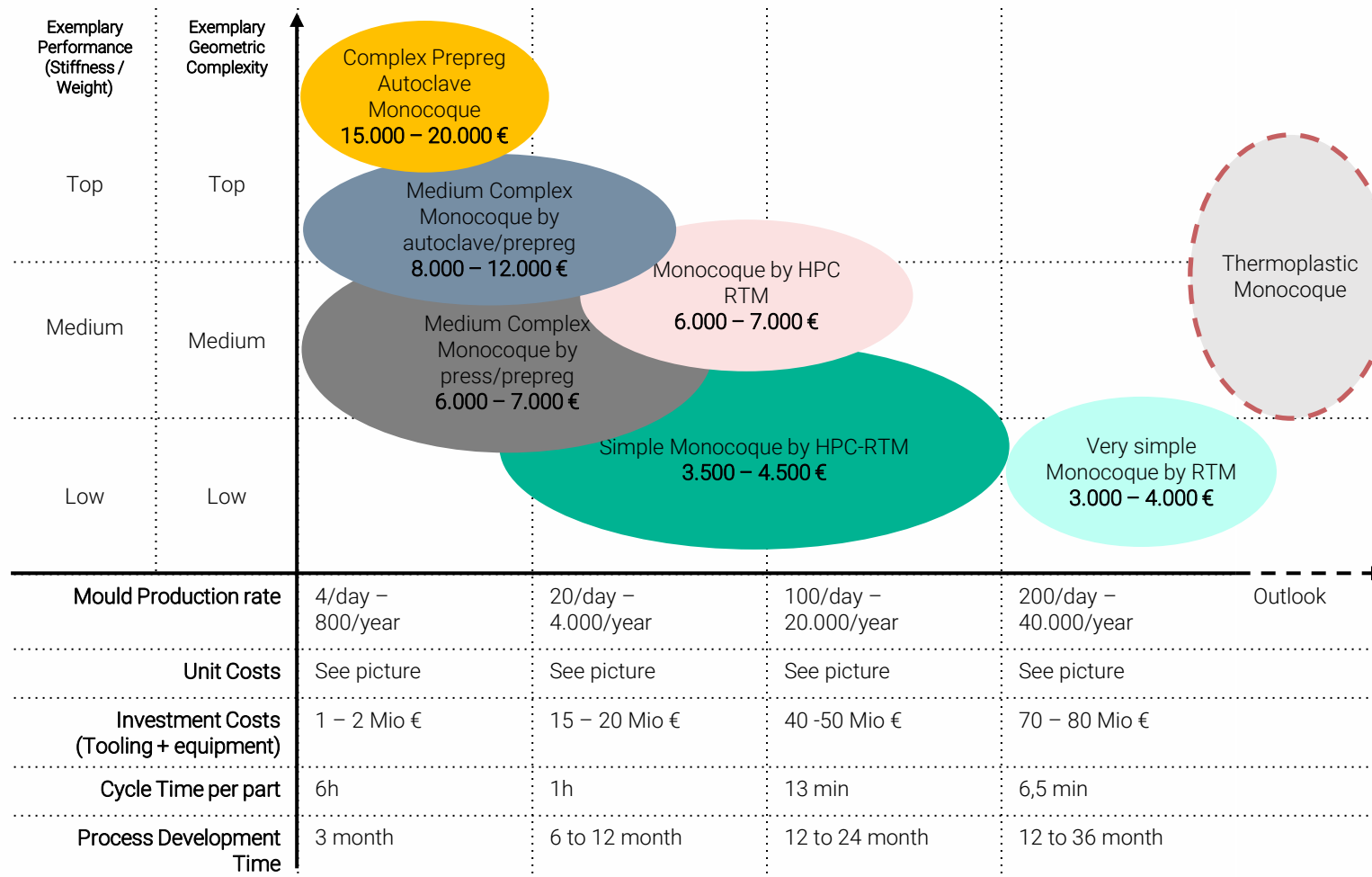


Lightweight design is mandatory for all aviation applications and applications with lot of amount of accelerations and decelerations processes to minimize energy consumption!

- Consideration of weight & cost Spiral
- To design a cost efficient and lightweight Monocoque the whole vehicle concept has to be matched with the Monocoque
  - Holistic vehicle design and understanding is key  
→ Potential of Monocoque design can be maximized
- Enhancing effort to realize lightweight monocoque enables sustainable development for entire vehicle



# OPTIMIZATION: MASS – COST PERFORMANCE



- Volume depends on Manufacturing process
- Observations
  - **Very Simple RTM Variant** offers cost saving potential at attractive volume margins
  - **Simple HPC-RTM solution** offers lightweight potential at attractive costs level
  - **Complex Prepreg Autoklav Chassis** offers max. lightweight potential
- Outlook: Thermoplastic Monocoques enables huge potential for complexity and performance

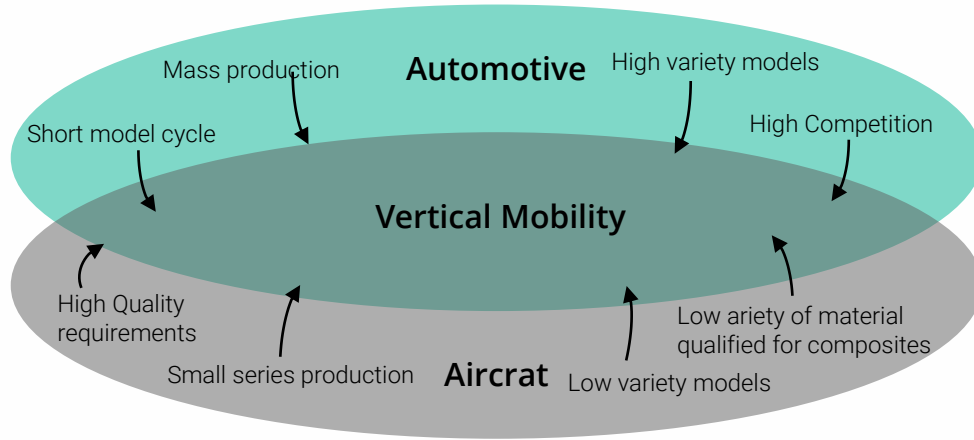
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# THE FUTURE OF MONOCOQUE DESIGN

WHAT'S NEXT?

## ACCELERATED DEMAND FOR MONOCOQUES DUE TO VERTICAL MOBILITY APPLICATIONS



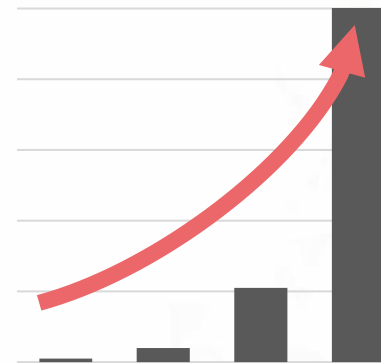
## ENVELOPING TECHNOLOGY

...leading to new design possibilities and increasing potential for Monocoque Design



## GROWING MARKETS

...in each application will increase attractiveness of the applications



## NEW MARKETS WITH DISRUPTIVE MOBILITY CONCEPTS

...like micro mobility or Out-of-the-box combination of mobility applications will further push composites for mobility



## INNOVATION SPIRAL

New technologies leading to new applications leading to new technologies...



# SELECTED REFERENCES FOR FRP MONOCOQUES



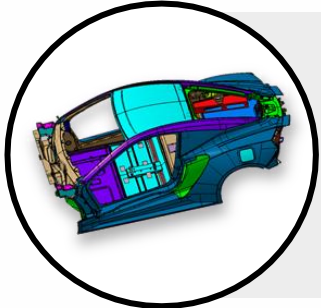
## RODING ROADSTER FRP MONOCOQUE

Patented Roding Carbon Cell in RTM shell-design, only 75kg @ 19kNm/°  
2008 - 2012  
Design | CAE | Production



## SPORTSCAR FRP MONOCOQUE

RTM Monocoque for an exhibition and test fleet Development  
2013 - 2015  
Design | CAE | Prototyping



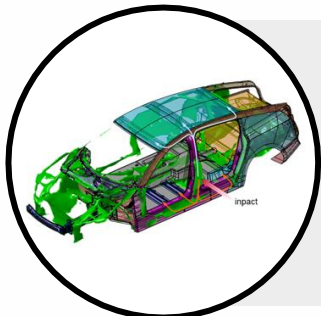
## SPORTSCAR FRP MONOCOQUE

Epoxy-based CFRP body (Prepreg & VARI), with Aluminum subframe  
2016 - 2017  
Design | CAE | C-NCAP



## C CLASS FRP BODY IN WHITE

5 Star C-NCAP Multi material BiW, 30% weight saving  
2018 -2020  
Design | CAE C-NCAP



## SEDAN GT FRP MONOCOQUE

Epoxy-based CFRP in monolithic and sandwich for high end EV BiW  
2017  
Design | CAE C-NCAP



## HYPERCAR FRP MONOCOQUE

One Shot RTM Monocoque with additional Prepreg parts for Small Series Hyper Car  
2018 – on going  
Design | CAE | Manufacturing Support

# THANK YOU!

## (Cost) Efficient Monocoques For Future Mobility



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