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STEEL E-MOTIVE

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WorldAutoSteel

RICARDO

Contributions of PHS to the Innovative Body Structure and Performance Attributes of Steel E-Motive

George Coates, WorldAutoSteel

George Coates

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Today's Agenda

- Introduction to WorldAutoSteel and Steel E-Motive
- Program Motivation, Vehicle Specifications
- Steel E-Motive: Vehicle, Body Concepts and Innovations
- Key PHS Solutions for Front and Side Crash Performance
- Question and Answer

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voestalpine ONE STEP AHEAD.

Why Did We Choose a Mobility as a Service Vehicle?

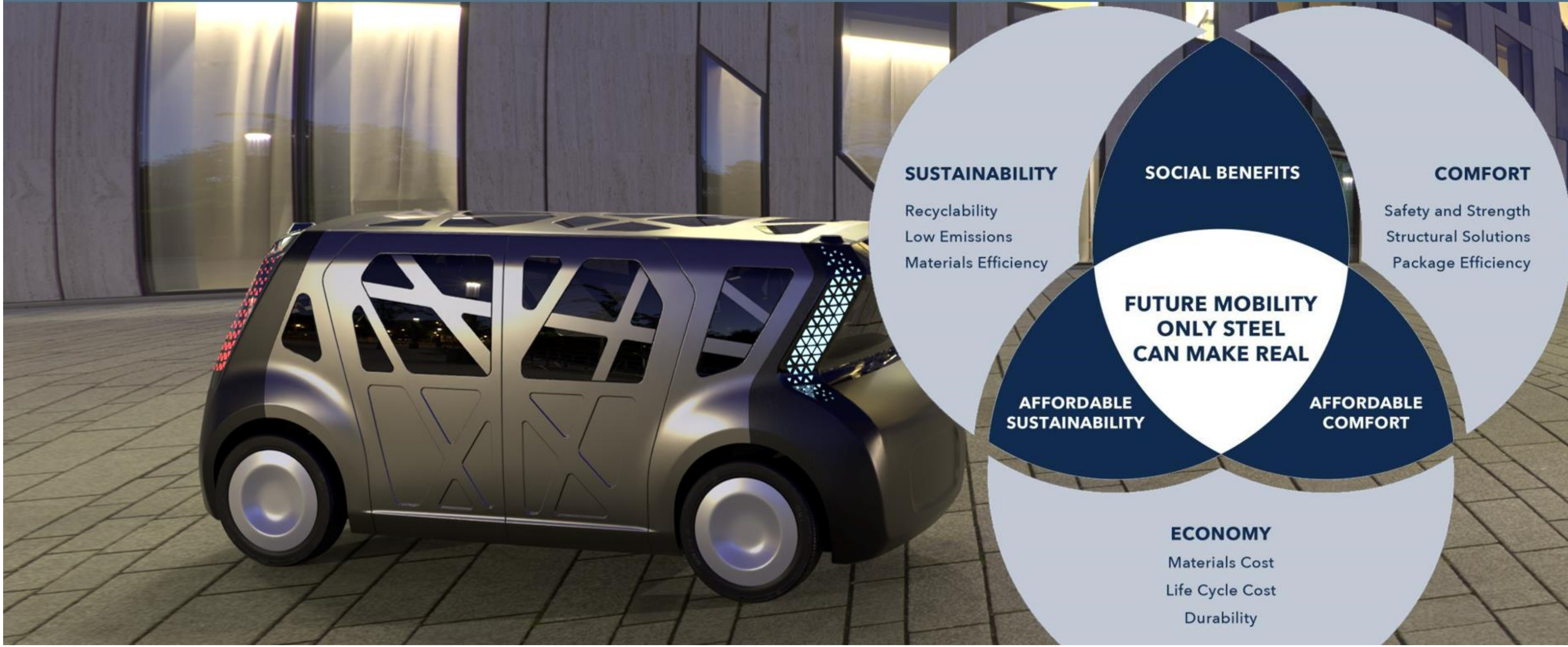
Global Net Zero Emissions ambitions

Urbanization and waning interest in vehicle ownership point to new transport opportunities in megacities.

Extensive research over a five-year period revealed global investment and growth in autonomous MaaS fleet ownership.

Our goal was to demonstrate that steel could be a significant enabler for reaching Net Zero Emissions with comfortable, sustainable, and affordable mobility solutions.

Presenting an Advanced High-Strength Steel Body Structure For a New, Fully Autonomous "Mobility as a Service" electric vehicle
Steel E-Motive: Future Mobility that only steel can make real



The Steel E-Motive program is a response to the automotive transportation shift, developing a new, fully autonomous MaaS vehicle

Development of body structures for a clean sheet fully autonomous ride sharing vehicle

- Key Vehicle features conceived for level 5 autonomy
- Designed to meet or exceed stringent high-speed crashworthiness standards
- Engineered to be affordable both to manufacture and to own
- Planned for sustainability

Project Timing and Key Activities

	July 2020		2021				2022				2023			
Task/Project Months	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Engineering Phases	Phase 0	Phase 1						Phase 2			Phase 3			

- Confirmed vehicle targets
- Exterior vehicle style
- Vehicle package
- Body architecture layout
- LCA & cost tools in place
- Marketing & Comms plan
- Competitor material benchmark study

PHASE 0
PRE-STUDY

- Development of innovative steel body structure concepts for Future Mobility Vehicle
- Engineering evaluation and selection of concepts. Virtual validation at body system and vehicle level (ie. crash)

PHASE 1
CONCEPT DESIGN

- Design optimisation of Urban and Extra-Urban vehicle derivatives
- Creation of 3D printed underbody demonstrator
- Draft Engineering Reports
- Develop and Implement Communications Strategy

PHASE 2
DESIGN VALIDATION

- Technical papers
- Conference presentation
- Concept launch events
- Virtual Reality Demo
- Capstone Projects with key Universities to demonstrate innovation and functionality

PHASE 3
DISSEMINATION

Evolving Steel Grade Portfolio

1998

Ultralight Steel Auto Body

11 HSS AND AHSS GRADES

IF 260/410
IF 300/420
DP 300/500
DP 350/600
TRIP 450/800
HSLA 490/600
DP 500/800
CP 500/800
TWIP 500/980
HSLA 550/650
MS 950/1200

2011

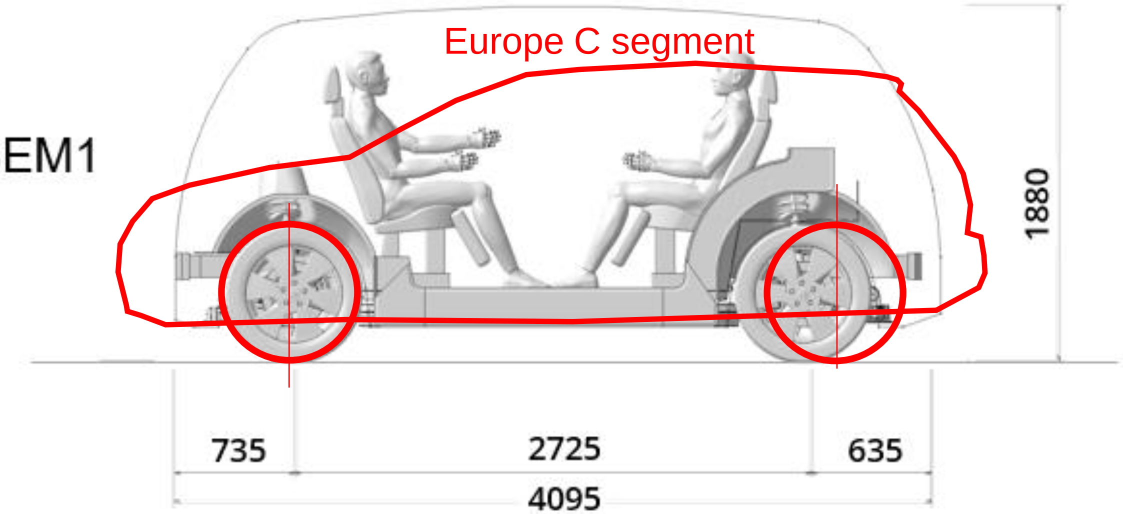
FutureSteelVehicle

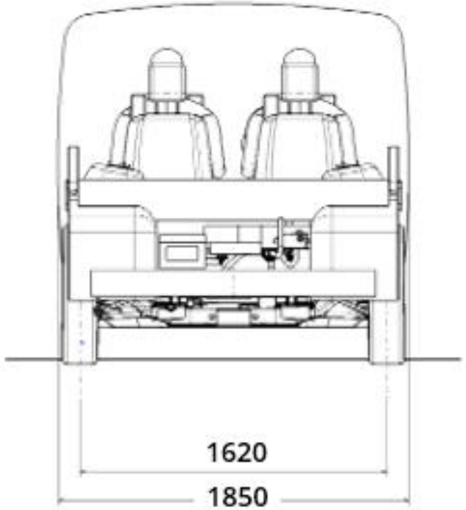
26 AHSS GRADES

DP 300/500	CP 600/900
FB 330/450	TRIP 600/980
DP 350/600	DP 700/1000
TRIP 350/600	CP 750/900
TRIP 400/700	CP 800/1000
FB 450/600	DP 800/1180
TRIP 450/800	MS 950/1200
CP 500/800	CP 1000/1200
DP 500/800	CP 1050/1470
TWIP 500/980	HF 1050/1500
HSLA 550/650	DP 1150/1270
SF 570/640	MS 1150/1400
SF 600/780	MS 1250/1500

2 Steel E-Motive vehicles, based on a shared platform, intended for urban and extra-urban mobility services

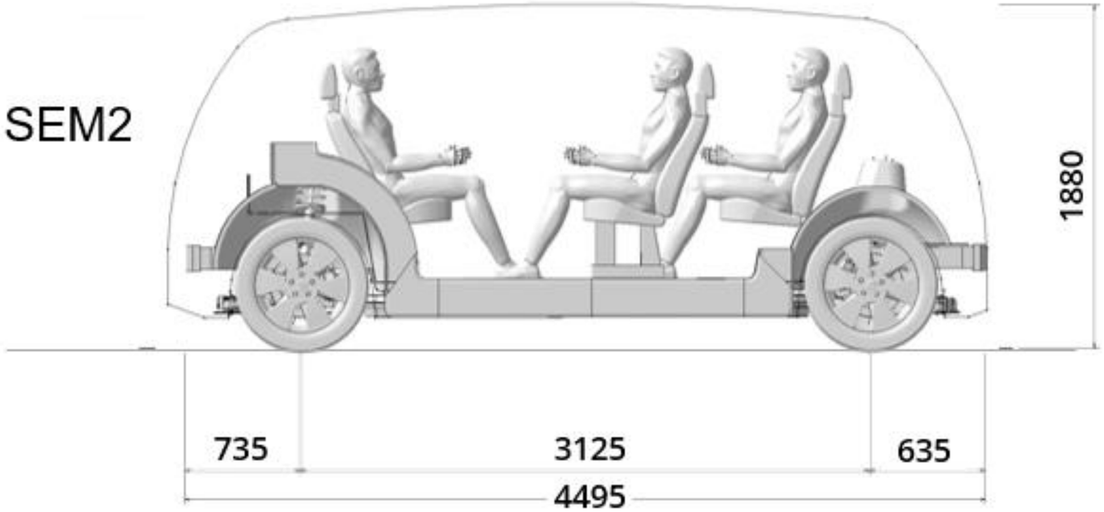
SEM1

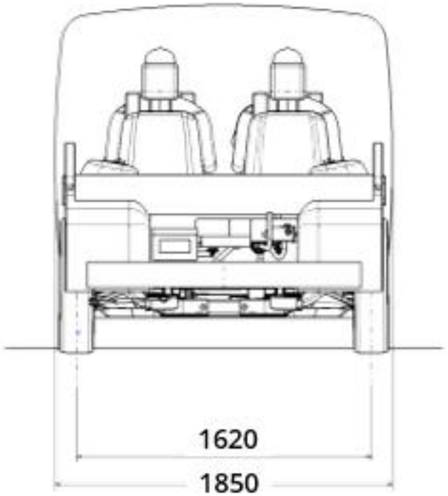




- 4 passengers, urban (city) mobility operations
- 75kwH battery
- Front electric motor
- Level 5 autonomy
- 1512 kg kerb weight

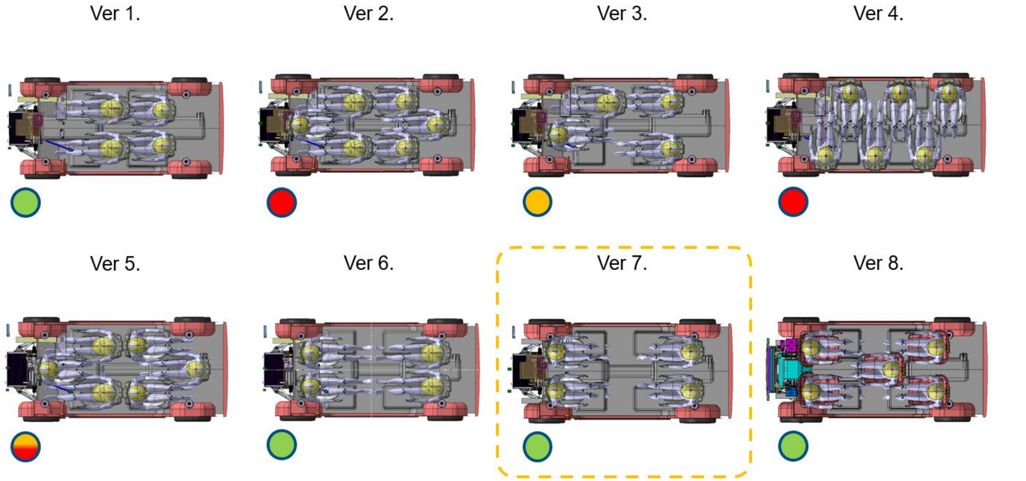
SEM2





- 6 passengers, intra-city mobility
- 96kwH battery
- Front and rear electric motor
- Maximum commonality SEM1-SEM2. 400mm wheelbase stretch
- Level 5 autonomy
- 1873 kg kerb weight

Level 5 autonomy enables freedoms for positioning of the occupants. We opted for an inward facing configuration, with front occupants rear facing



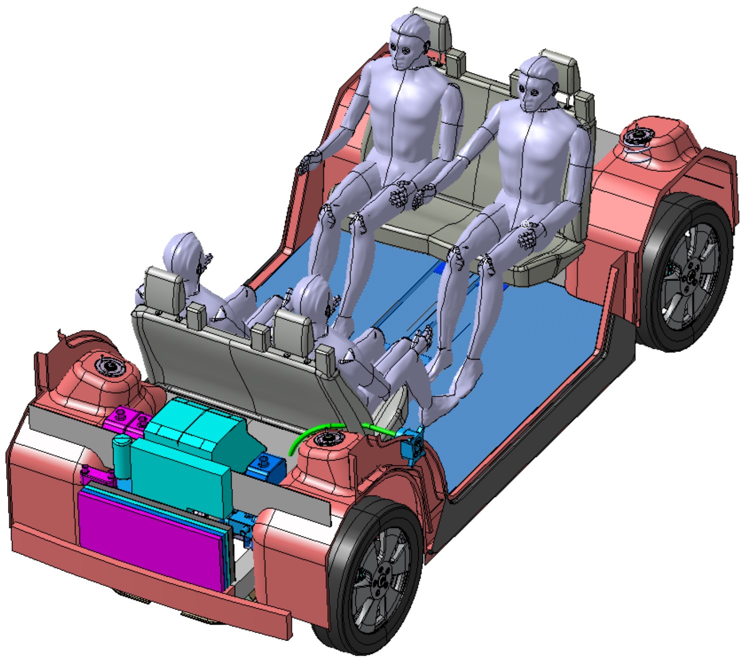
Seating configuration options considered

Continued development for Phase 1

Meets requirement

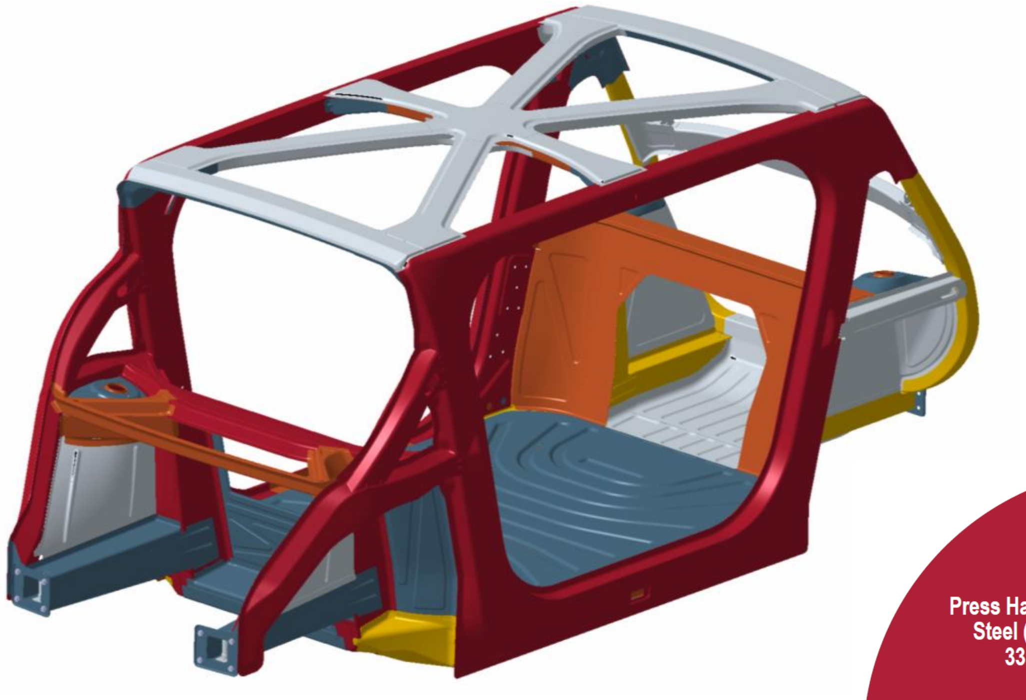
Not recommended

Disabled user virtual reality assessment



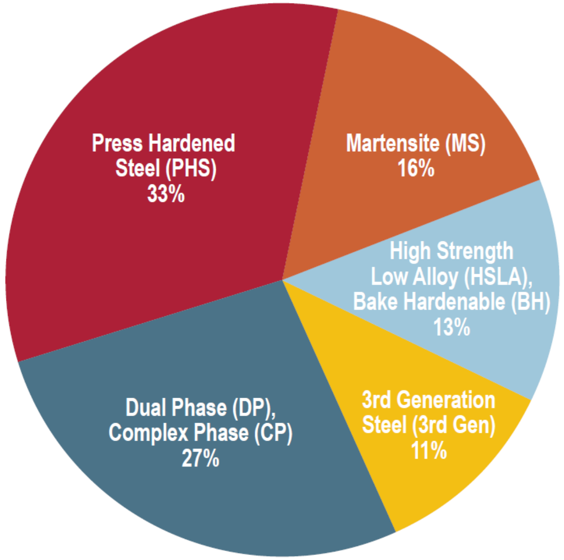
- Inward facing configuration selected
- Preferred for communal ride sharing versus 2 row
- Enables spacious, open interior
- Drives requirement for flat floor
- Front occupant positioning drives exterior styling
- Disabled user friendly

Steel E-Motive, SEM1 Body in White Advanced High-Strength Steel grade utilisation



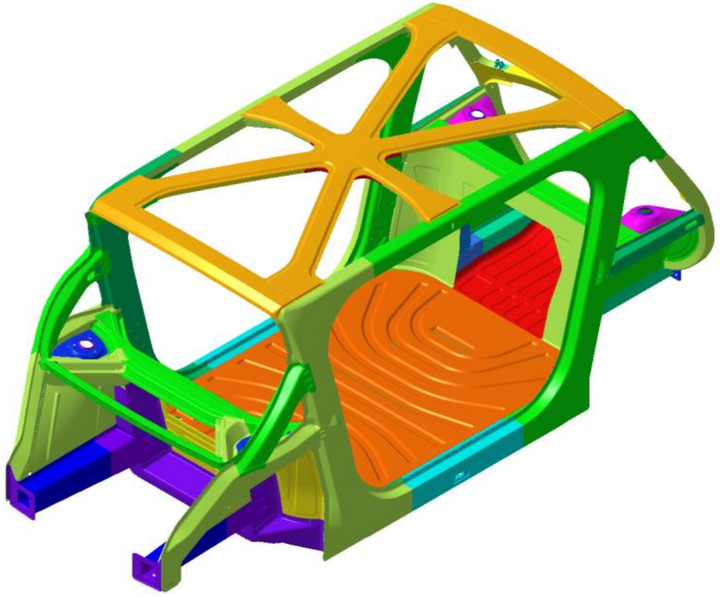
BIW weight = 282 kg

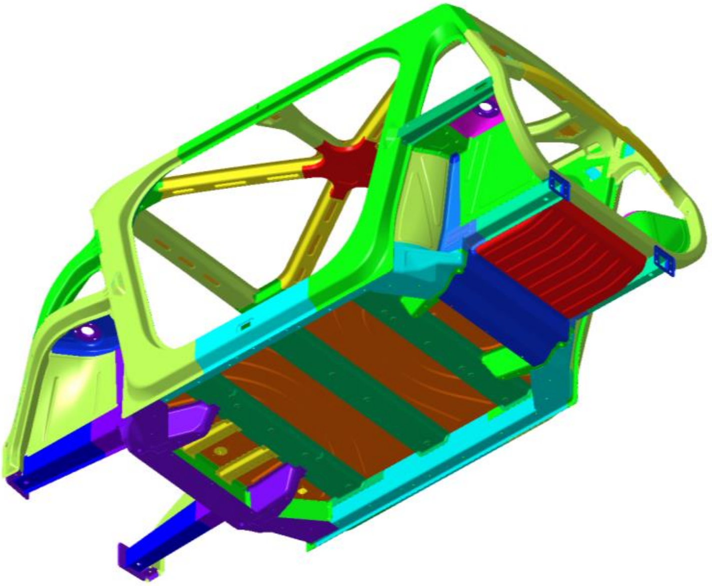
Avg. Tensile Strength = 1259 MPa



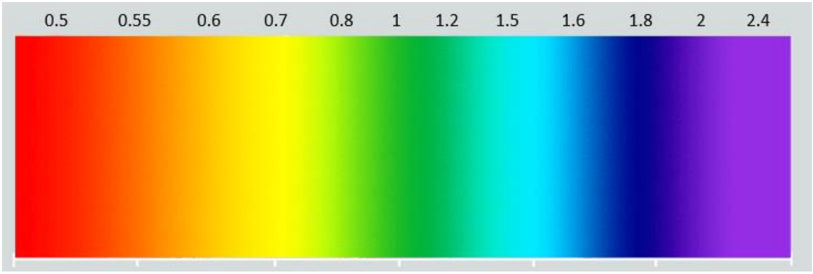
- Purpose design BIW for fully autonomous vehicle
- Stamped, fabricated, high-volume solution
- AHSS portfolio allows the right steel grade and gauge in the right place =
  Infinite Tune-ability
- 66% Gigapascal steels (> 1000 MPa tensile strength); allow lightweighting without sacrificing performance

Wide range of AHSS gauges enabled a further dimension of tunability

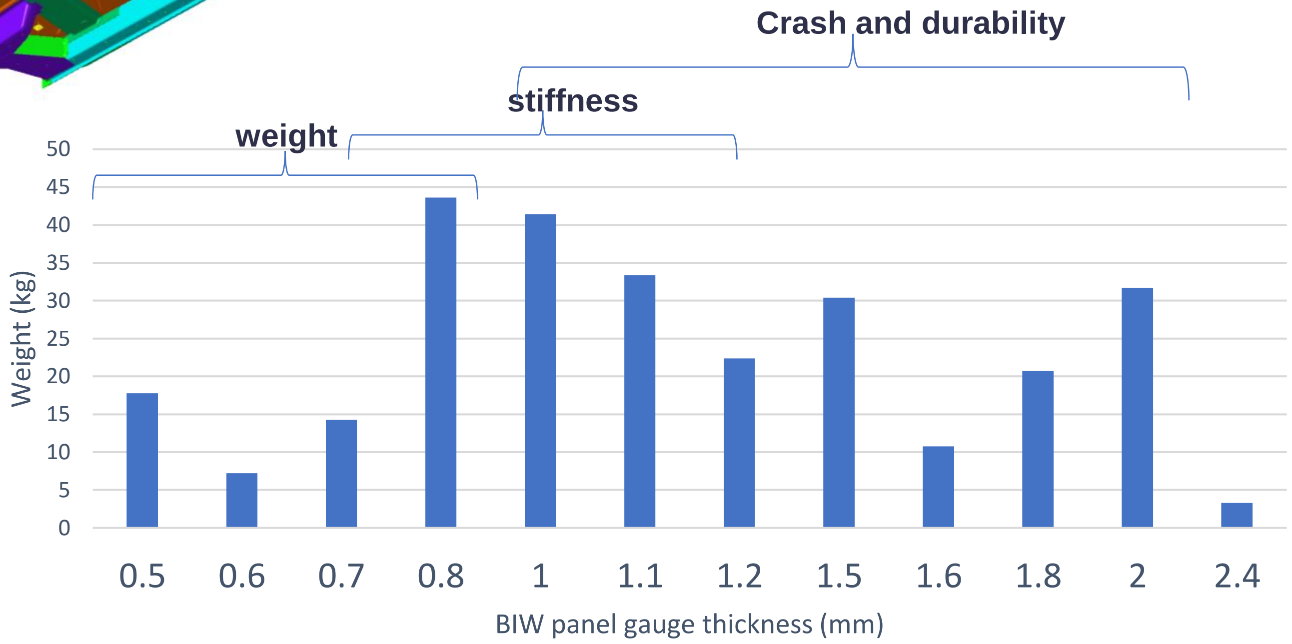




- Utilise thickness where it’s needed (and where it’s not needed)
- Average gauge thickness 1.23mm
- 0.5mm to 2.4mm gauge



Panel gauge thickness (mm)

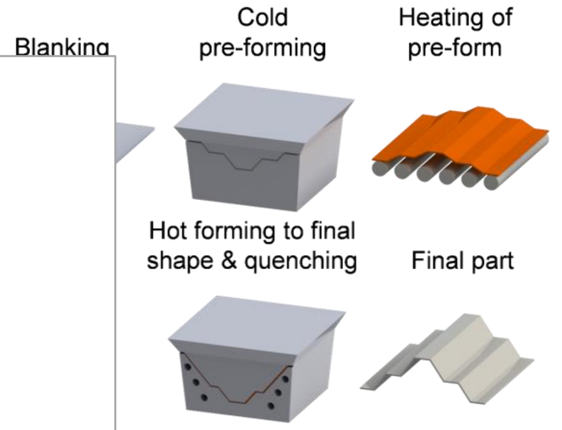


SEM1 Body in White fabrication methods

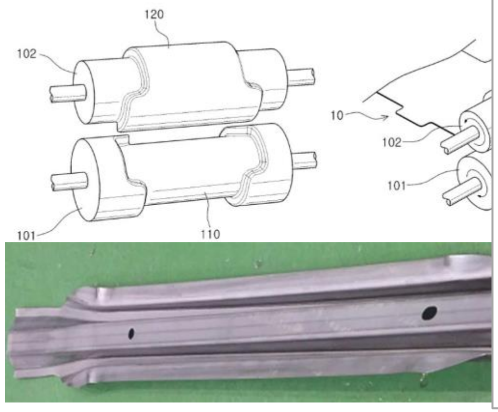
Roll Forming

Tailor Welded Blanks

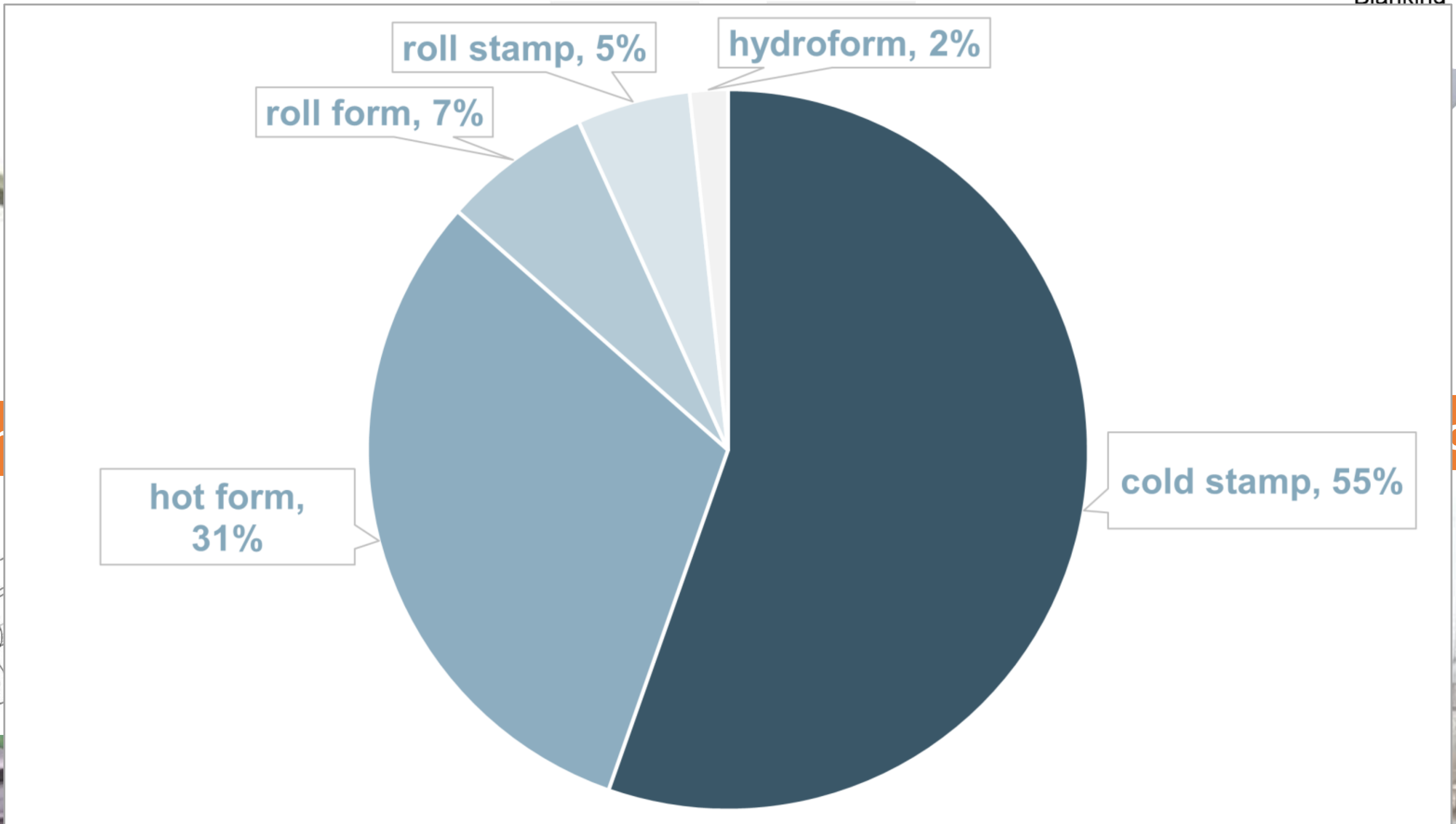
Hot Forming



Roll Stampin



old Stamping



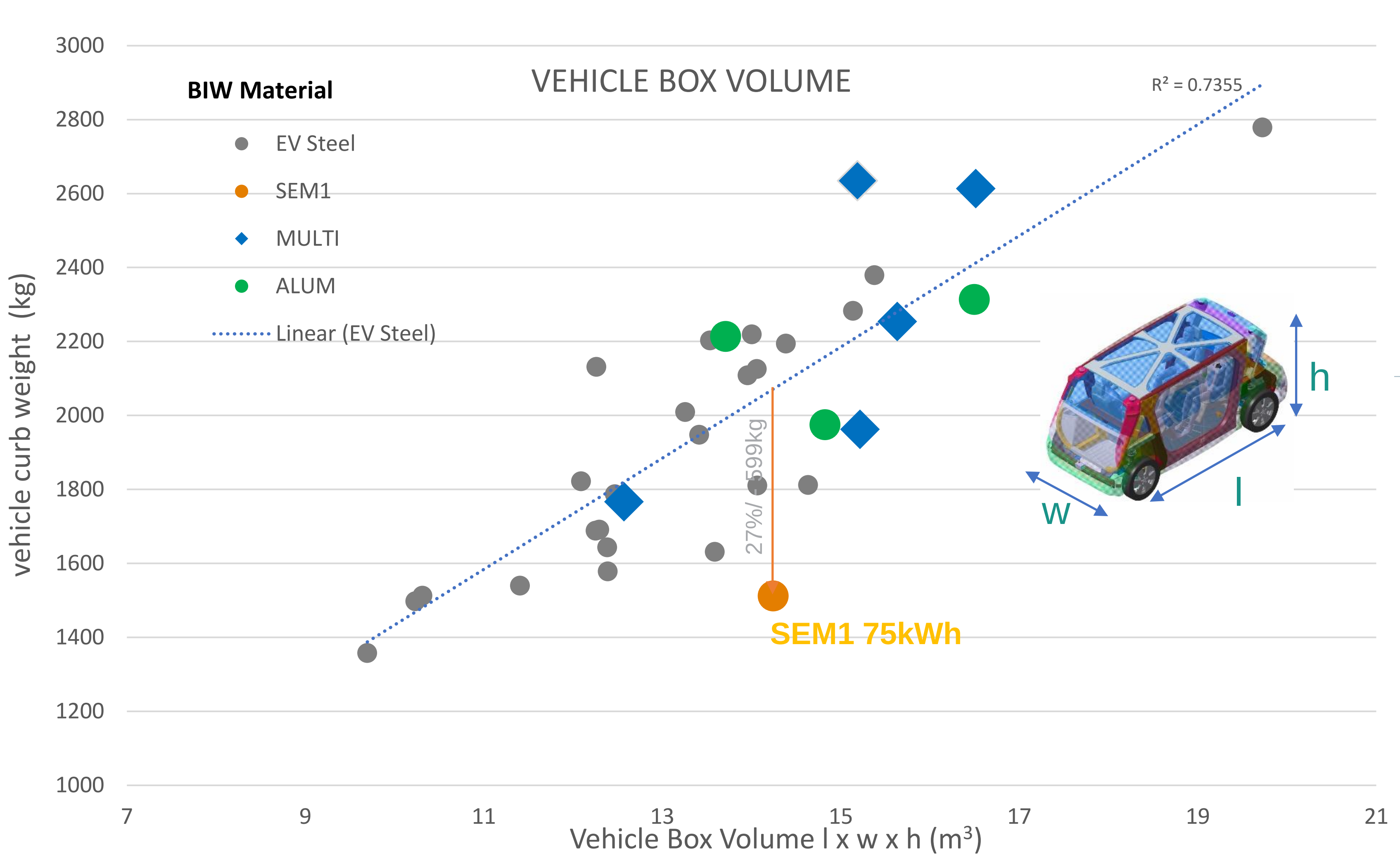
BIW Fabrication Processes (by weight)

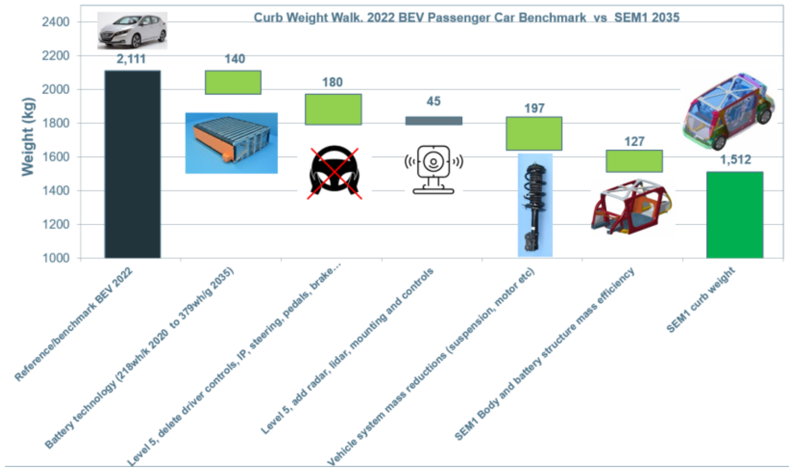
SEM1 Body in White PHS Applications (30 parts)

Wt Avg = 1.28mm

CAD PART NUMBER	PART NAME	CAD/PLM gauge & grade code	Gauge thickness (mm)	Material Grade (code)	Advanced High Strength Steel Category	Part mass (kg)	Fabrication Process
3438889	A POST INNER LH	1.2_PHS-CR2000T-MB	1.2	PHS-CR2000T-MB	Press Hardened Steel	5.06	Hot form
03440399	C POST INNER LH	1_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	4.02	Hot form
3451542	ROOF SIDE RAIL INNER LH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	2.15	Hot form
03553241	A POST INNER RH	1.2_PHS-CR2000T-MB	1.2	PHS-CR2000T-MB	Press Hardened Steel	5.06	Hot form
03553334	C POST INNER RH	1_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	4.02	Hot form
03553379	ROOF SIDE RAIL INNER RH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	2.15	Hot form
03709256	OUTER RING TWB RH	TWB_PHS-CR2000T-MB Apillar 1.2, PHS-CR1000T-MB Upp	TWB 1.2, 1.0	TWB_PHS-CR2000T-MB, 1.2, PHS-CR1000T-MB Upp	Press Hardened Steel	16.69	Hot form
3820779	REINFORCEMENT LATCH RIGHT LH	1.5_PHS-CR1000T-MB	1.5	PHS-CR1000T-MB	Press Hardened Steel	0.56	Hot form
3824181	REINFORCEMENT LATCH LEFT LH	1.5_PHS-CR1000T-MB	1.5	PHS-CR1000T-MB	Press Hardened Steel	0.55	Hot form
03842798	REINFORCEMENT LATCH LEFT RH	1.5_PHS-CR1000T-MB	1.5	PHS-CR1000T-MB	Press Hardened Steel	0.55	Hot form
03842803	REINFORCEMENT LATCH RIGHT RH	1.5_PHS-CR1000T-MB	1.5	PHS-CR1000T-MB	Press Hardened Steel	0.56	Hot form
03448749	VERTICAL DASH BRACE LOWER OUTER FRONT LH	2.0_PHS-CR1500T-MB	2.0	PHS-CR1500T-MB	Press Hardened Steel	2.05	Hot form
03448755	VERTICAL DASH BRACE LOWER OUTER FRONT RH	2.0_PHS-CR1500T-MB	2.0	PHS-CR1500T-MB	Press Hardened Steel	2.05	Hot form
03585862	GLANCE BEAM INNER LH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	1.72	Hot form
03585863	GLANCE BEAM UPPER TRIANGULATION INNER LH	1.0_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	0.92	Hot form
03585867	GLANCE BEAM OUTER LH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	1.75	Hot form
03601006	GLANCE BEAM UPPER TRIANGULATION OUTER LH	1.0_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	1.04	Hot form
03618387	GLANCE BEAM OUTER RH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	2.19	Hot form
03618389	GLANCE BEAM INNER RH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	1.72	Hot form
03618390	GLANCE BEAM UPPER TRIANGULATION INNER RH	1.0_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	0.92	Hot form
03618391	GLANCE BEAM UPPER TRIANGULATION OUTER RH	1.0_PHS-CR1500T-MB	1.0	PHS-CR1500T-MB	Press Hardened Steel	1.08	Hot form
03630344	VERTICAL DASH BRACE LOWER INNER LH	2.0_PHS-CR1500T-MB	2.0	PHS-CR1500T-MB	Press Hardened Steel	1.82	Hot form
03630345	VERTICAL DASH BRACE LOWER INNER RH	2.0_PHS-CR1500T-MB	2.0	PHS-CR1500T-MB	Press Hardened Steel	1.82	Hot form
03640758	STRUT CROSS MEMBER FRONT	1.0_PHS-CR2000T-MB	1.0	PHS-CR2000T-MB	Press Hardened Steel	2.73	Hot form
03640760	GLANCE BEAM UPPER REACTION LH	0.8_PHS-CR1500T-MB	0.8	PHS-CR1500T-MB	Press Hardened Steel	0.52	Hot form
03640761	GLANCE BEAM UPPER REACTION RH	0.8_CR1200Y1470T-MS	0.8	PHS-CR1500T-MB	Press Hardened Steel	0.52	Hot form
03671385	VERTICAL DASH BRACE UPPER FRONT LH	2.0_PHS-CR2000T-MB	2.0	PHS-CR2000T-MB	Press Hardened Steel	0.62	Hot form
03671386	VERTICAL DASH BRACE UPPER FRONT RH	2.0_PHS-CR2000T-MB	2.0	PHS-CR2000T-MB	Press Hardened Steel	0.62	Hot form
03671429	VERTICAL DASH BRACE FRONT LH	2.0_PHS-CR2000T-MB	2.0	PHS-CR2000T-MB	Press Hardened Steel	4.51	Hot form
03686769	VERTICAL DASH BRACE FRONT RH	2.0_PHS-CR2000T-MB	2.0	TOTAL MASS	Press Hardened Steel	4.51	Hot form

Combined factors enable SEM1 to achieve a 27% lower kerb weight compared to a conventional BEV passenger car

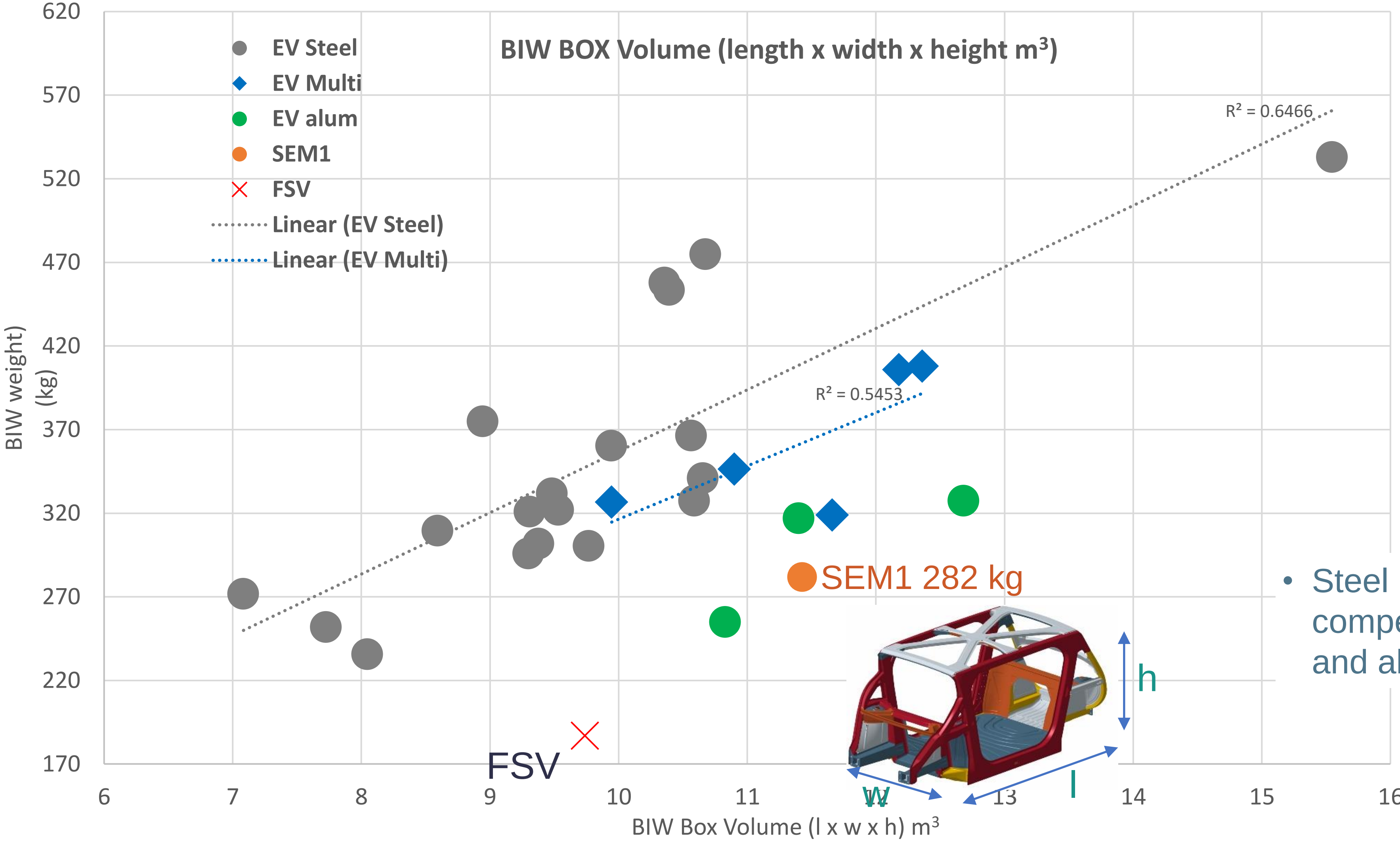




- SEM1 vehicle curb weight is 27% lighter than 2018-2022 EV average (steel BIW)

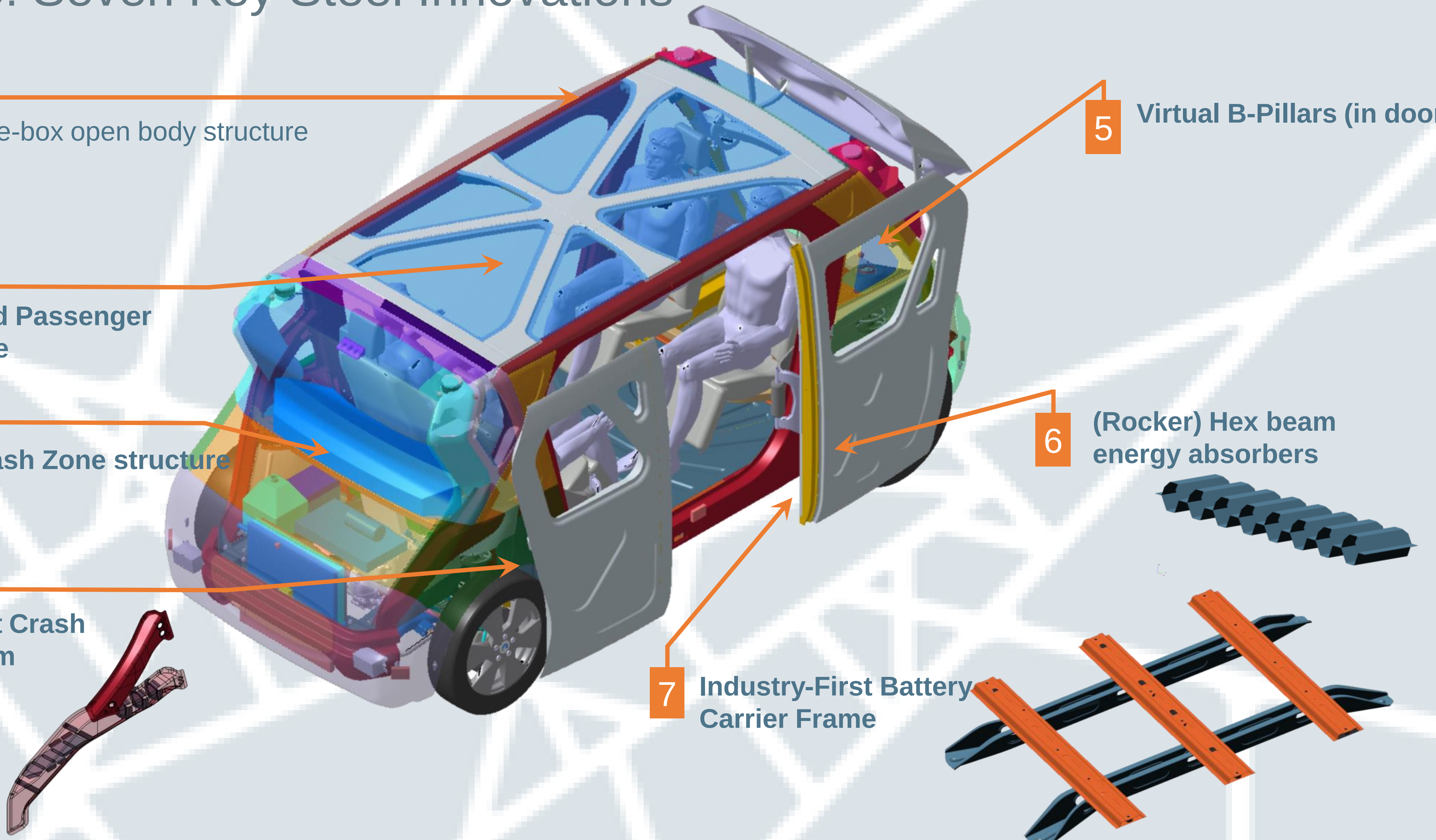
- Battery technology
- Autonomous vehicle
- BIW weight reduction
- Vehicle/secondary lightweighting

SEM1 BIW weight is competitive with aluminium and multi-material structures of comparable size



- Steel E-Motive BIW weight is competitive with multi-material and aluminium body structures.

Steel E-Motive: Seven Key Steel Innovations



1 **B-Pillarless**, one-box open body structure

2 **AHSS Extended Passenger Protection Zone**

3 **Short Front Crash Zone structure**

4 **Small Offset Crash Glance Beam**

5 **Virtual B-Pillars (in doors)**

6 **(Rocker) Hex beam energy absorbers**

7 **Industry-First Battery Carrier Frame**

Performance and Key Metrics

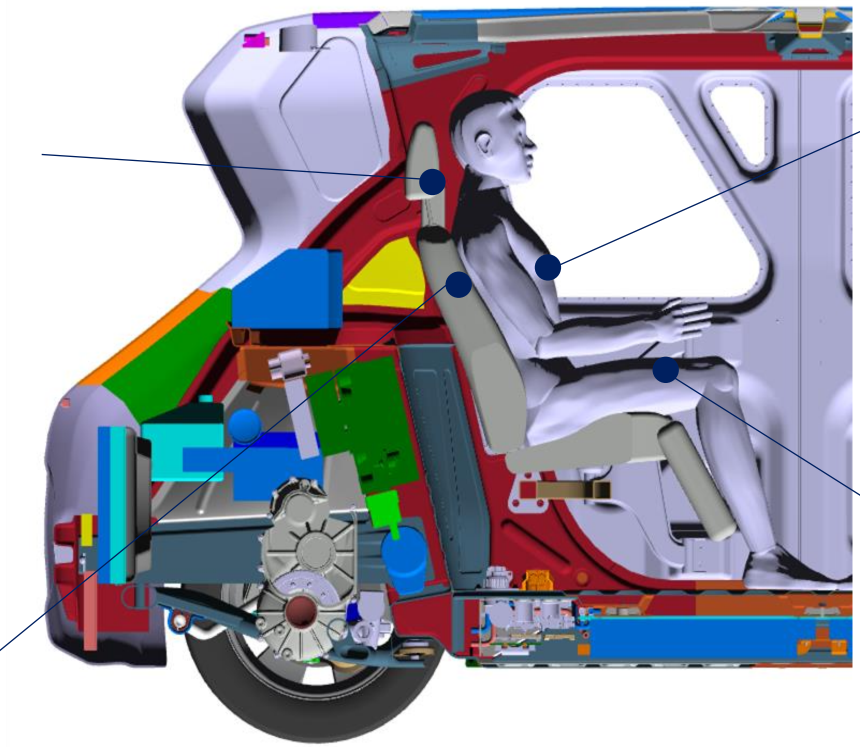
We've shared a bit about our Steel E-Motive Purpose, Body Concepts and Innovations. Now let's examine:

- Front and side crash performance
- Body Structure Cost and Sustainability

Front crash: Different approach and considerations are required for the protection of rear facing front occupants

Occupant head and torso is closer to the front crash zone

Occupant deceleration loads are primarily through the seat frame and mounting structure

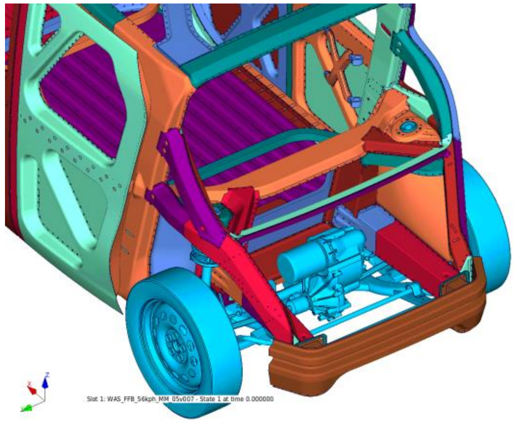


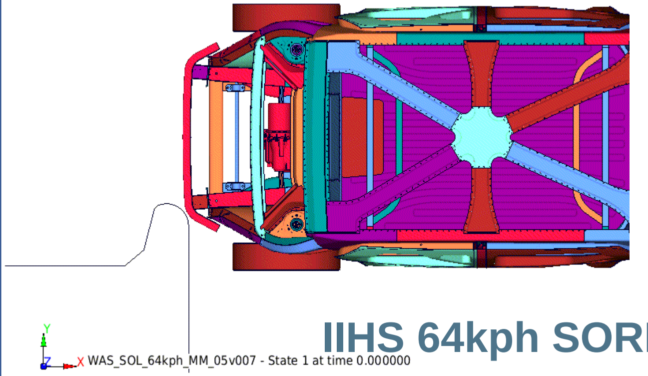
Seat belt loads are generally lower than forward facing. No frontal airbag

Legs, feet, arms lower risk of injury from intrusion (no dash, steering wheel)

Use of PHS and innovative geometries contribute to impressive front crash performance, despite compact vehicle size and occupant position

USNCAP 56kph FFB

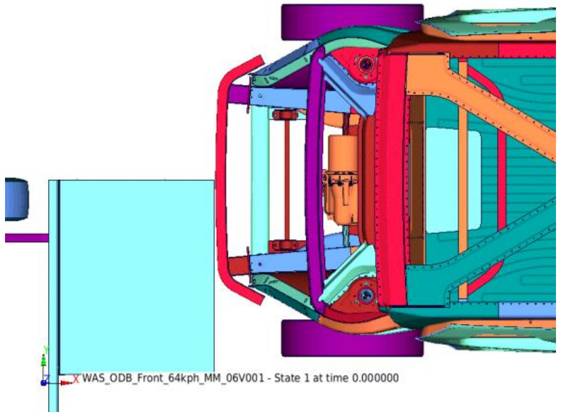


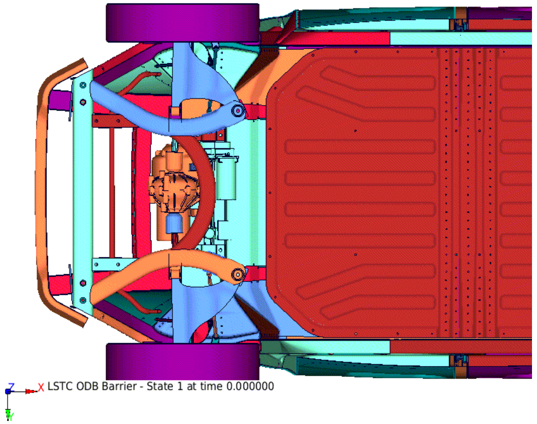


IIHS 64kph SORB

- Development focussed on 4 front crash test loadcases – requiring both crush and strength characteristics from body structure
- Challenging to achieve crush-strength balance with short front overhang and occupant position
- IIHS “good” rating achieved
- “glance off” achieved in IIHS SORB test

EuroNCAP 50kph MPDB





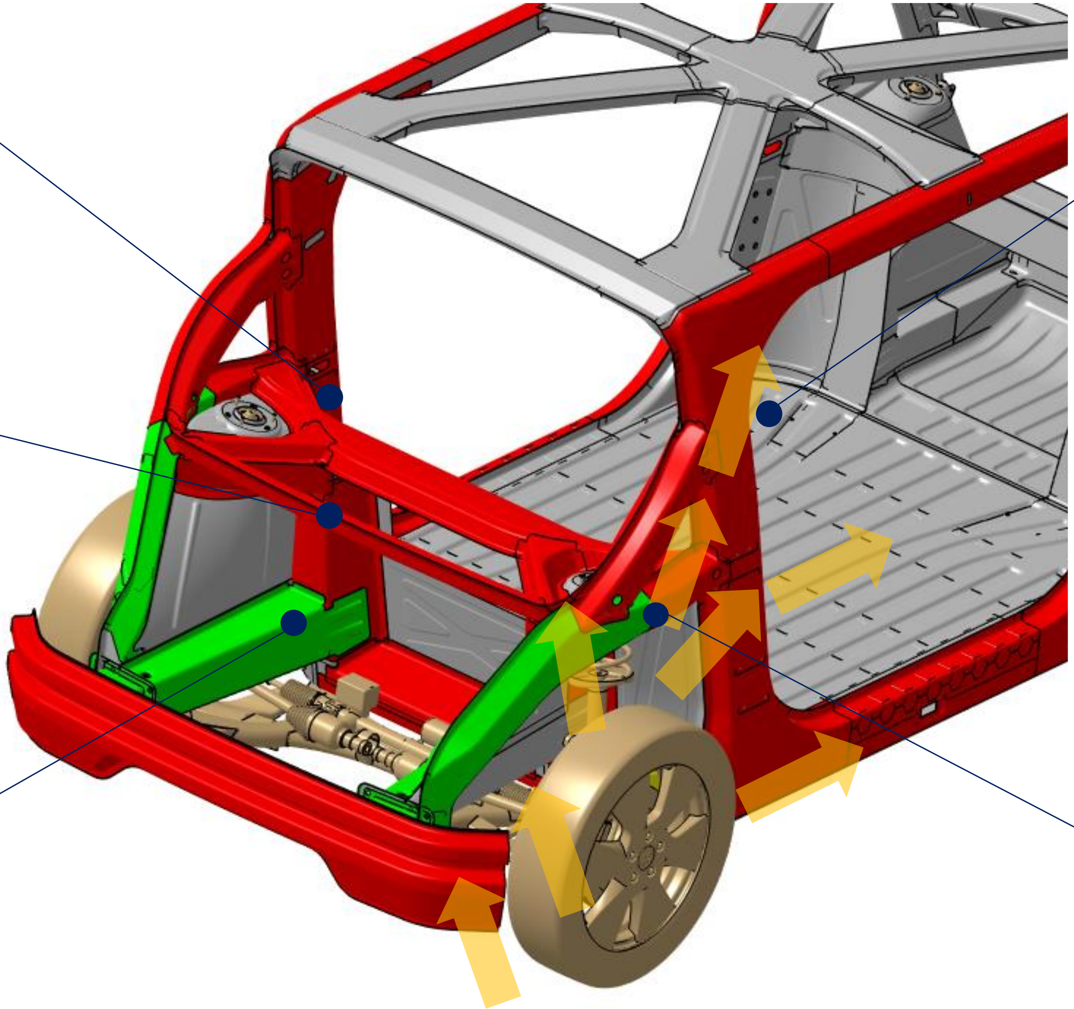
IIHS 64kph ODB

Front crash structure engineered to balance the requirements of USNCAP FFB, IIHS ODB, IIHS SORB and EuroNCAP MPDB loadcases

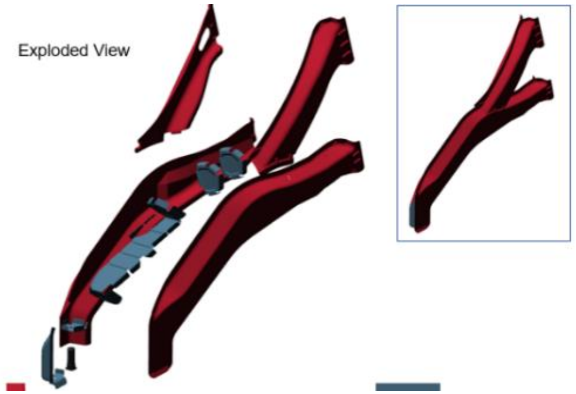
PHS1900 **Front strut brace** protects occupants and supports SORB load barrier reaction

PHS1900 **vertical dash brace and #1 bar** reacts crush loads and minimises intrusion to battery and cockpit

Longitudinal crush rail: TWB DP980, tuned for FFB crush performance. Plan view angle optimised for Small Overlap Barrier engagement



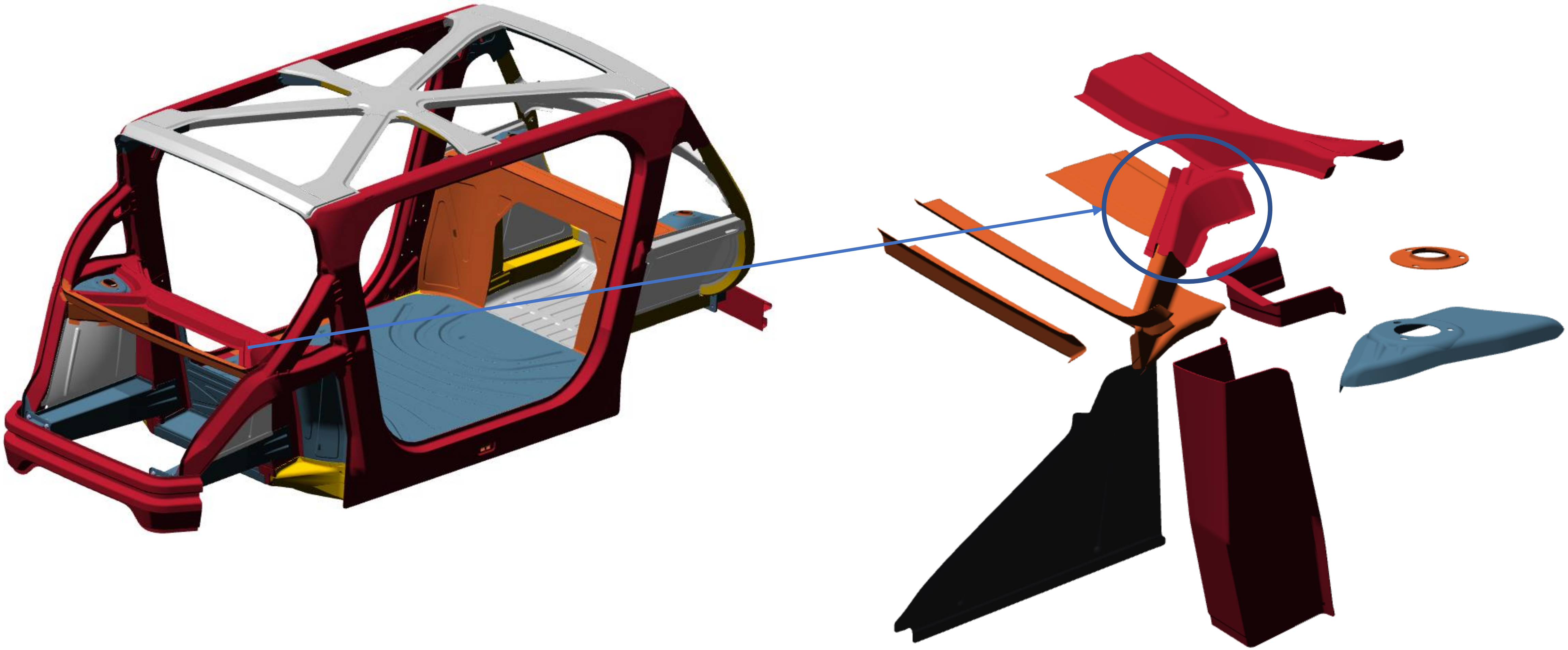
UHSS PHS + MS occupant protection zone



PHS1500 **"glance beam"**, engineered to crush in Frontal Rigid Barrier and provide lateral load reaction in the Small Overlap Barrier

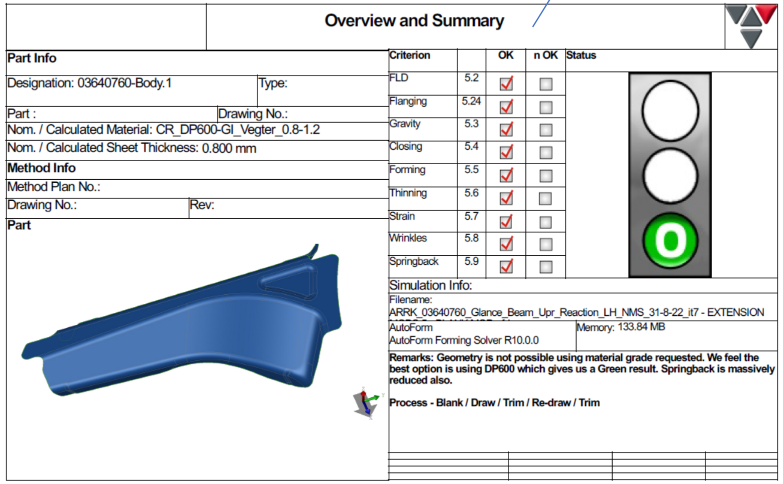
Note: components have been removed from this image for clarity. Design shown is development, not final design

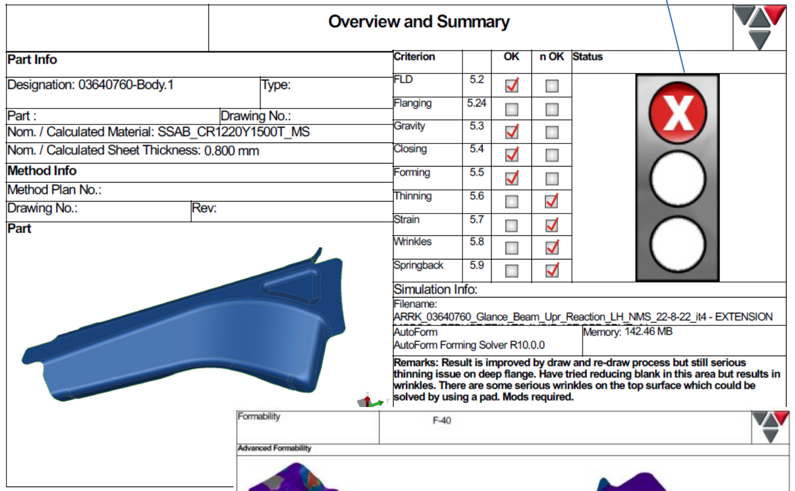
Front Glance Reaction Beam Upper – case study

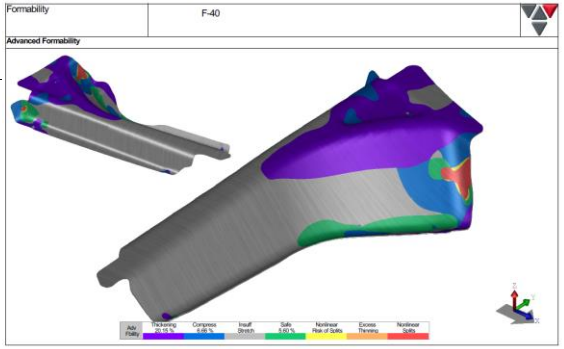


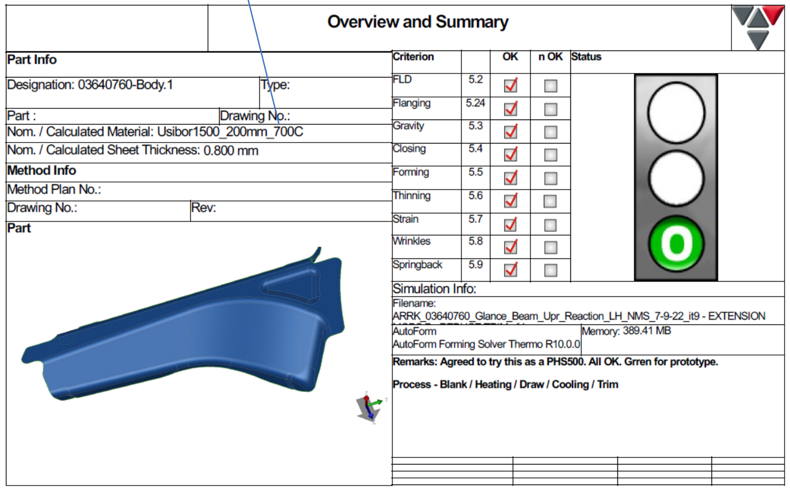
Front Glance Reaction Beam upper

Attribute / Design	1	2	3
Grade	DP600, 0.8mm	MS1470, 0.8mm	PHS1500, 0.8mm
Forming	Yes ✓	No ✗	Yes ✓
Front crash performance	X (below target)	Yes ✓	Yes ✓





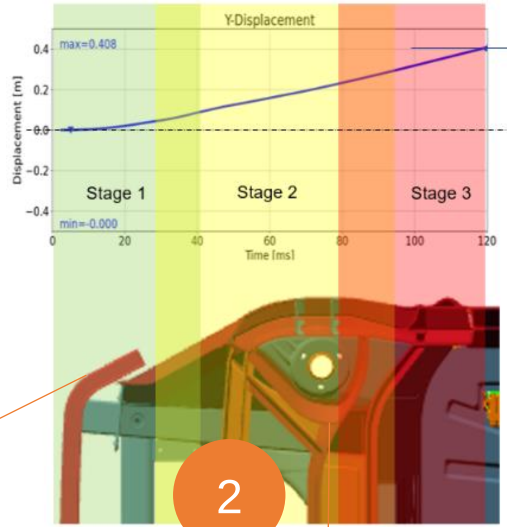


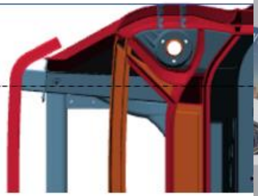


Splits & excessive wrinkling in MS1470

Strategy for IIHS 64kph SORB glance off: ensure high strength lateral (Y) loadpath and axial crush (X) throughout crash

- Objective: Deflect complete vehicle by 1/4 car width before contact with A pillar
- Approach: Divide IIHS SORB crash event & front structure into 3 stages
- Ensure body structure design can achieve high Y strength and load reaction during each stage





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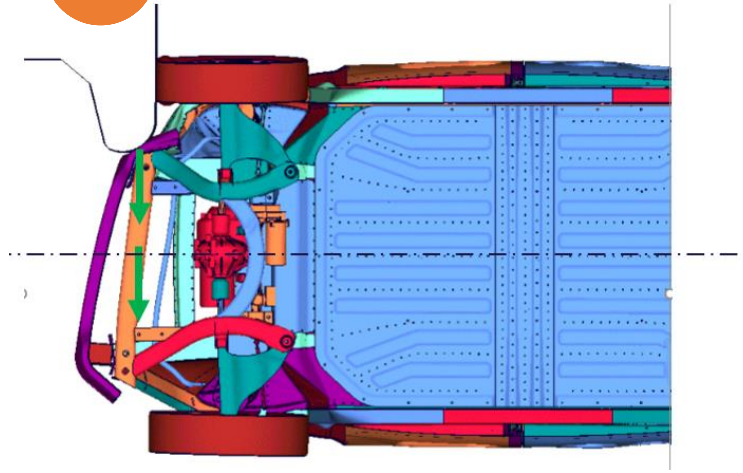

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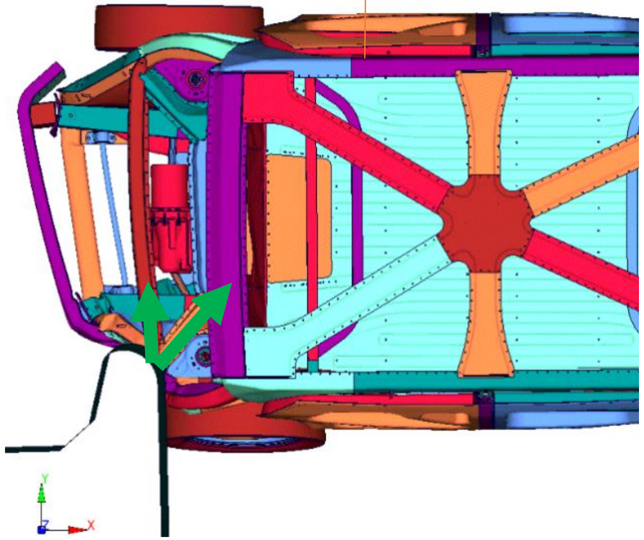

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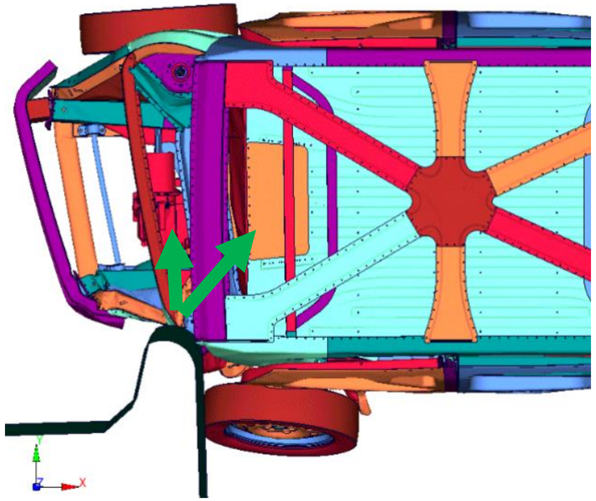
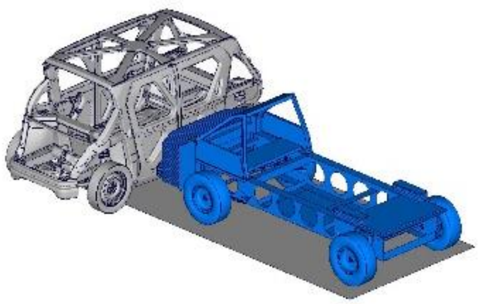
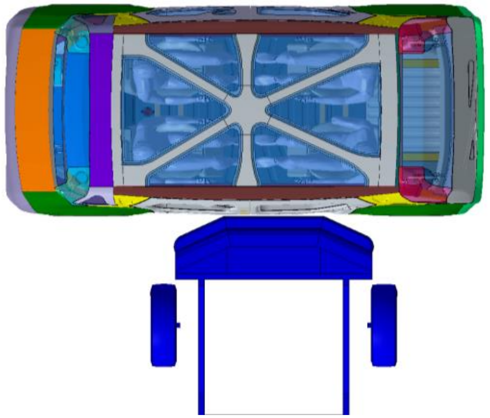


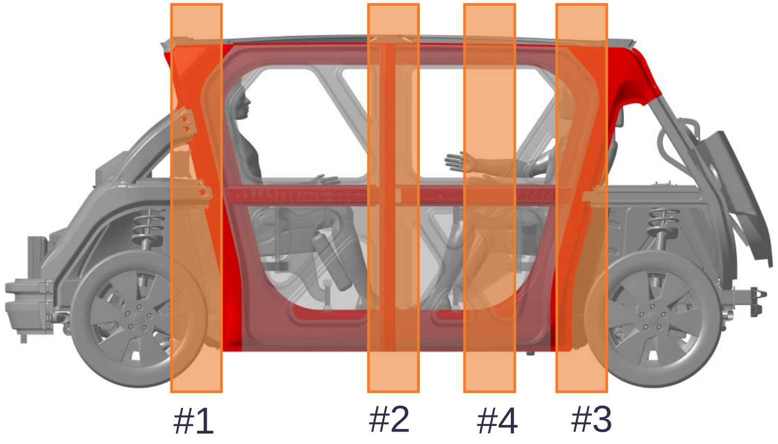
Side crash: Barrier alignment and loadpath strategy

IIHS 60kph side barrier (v2) alignment to SEM1



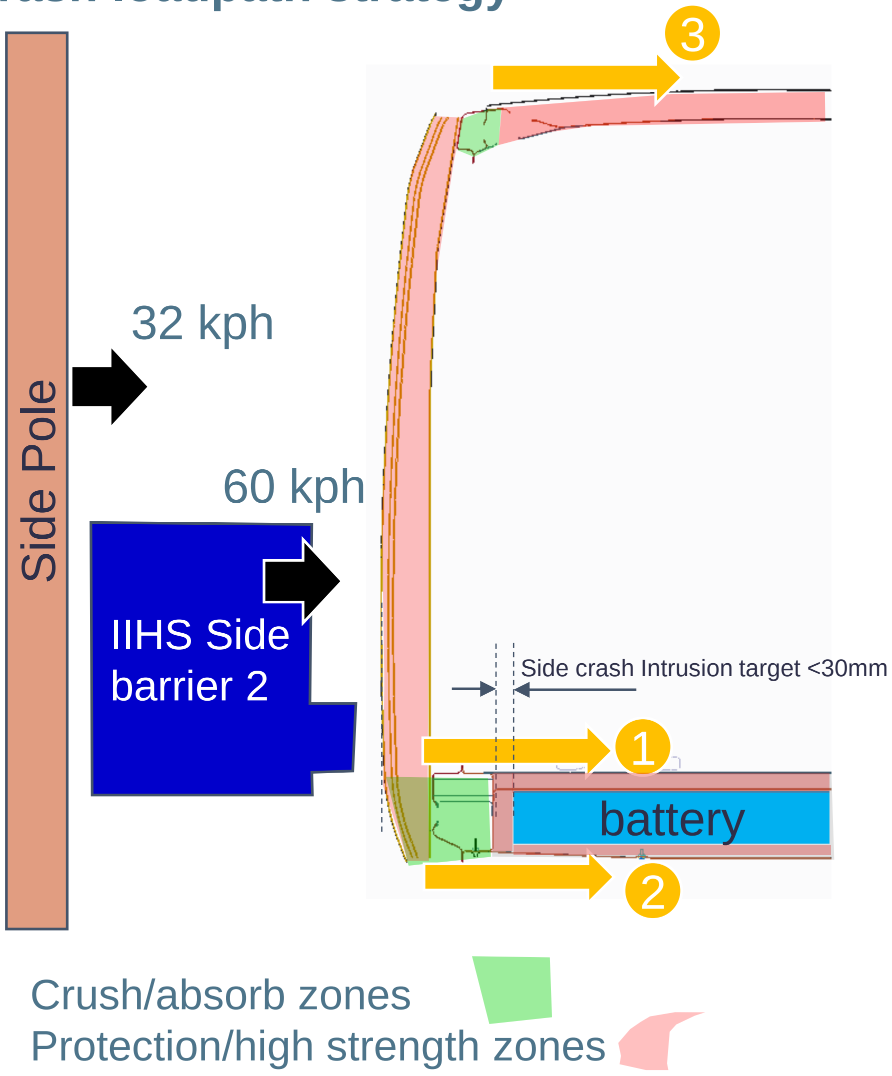


USNCAP 32kph side pole assessment locations

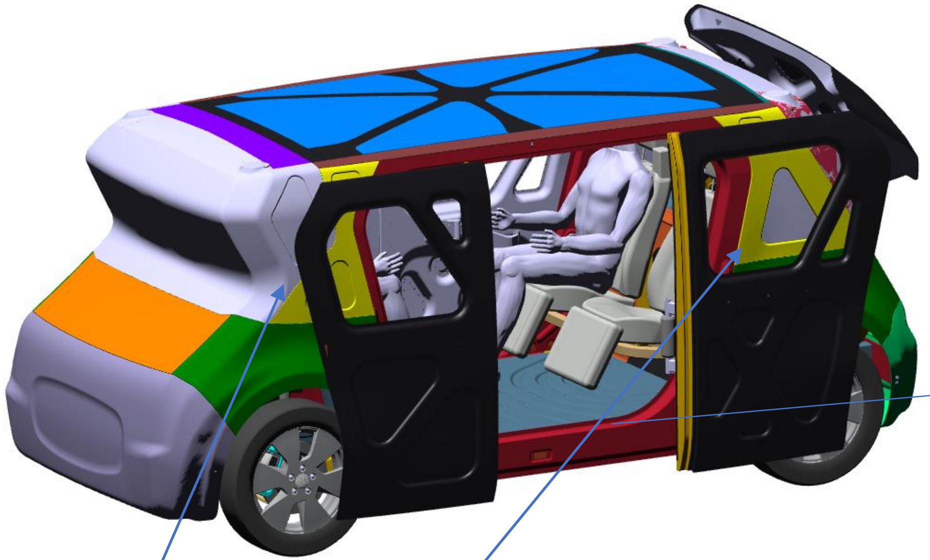


A and C pillar locations provide primary side crash protection; occupants in a more favorable location for side barrier

Side crash loadpath strategy



Steel E-Motive Press Hardened Steel Door Ring - impressive performance



Front and rear quarter clip
on panels 0.6mm
CR260Y/370T-BH
(not specifically engineered)

Cantrail/roof outer
PHS-CR1000T-MB
1.5mm

Tailor Welded Blank Outer Ring

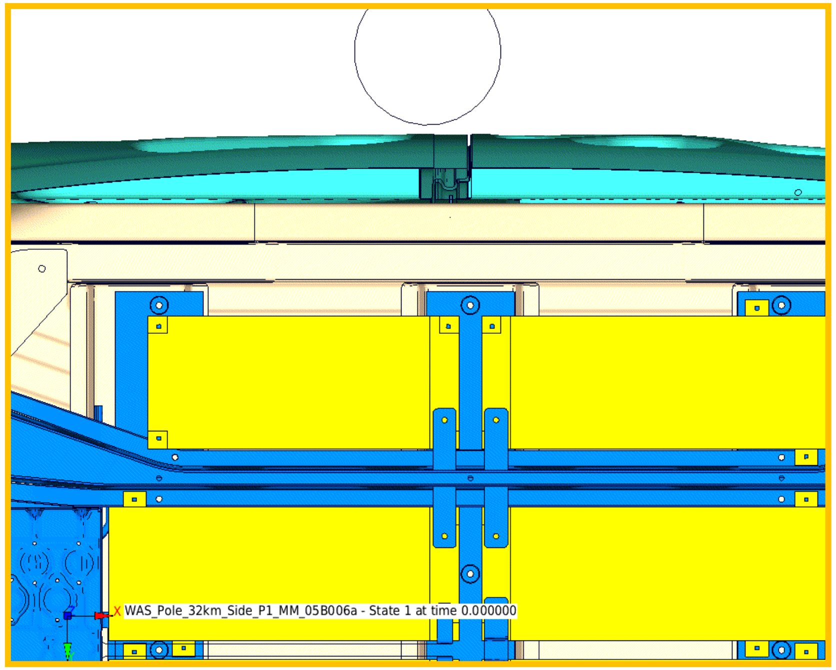
A pillar
PHS-CR2000T-MB
1.2mm

C pillar
PHS-CR1500T-MB 0.8mm

Rocker PHS-CR1000T-MB
1.5mm

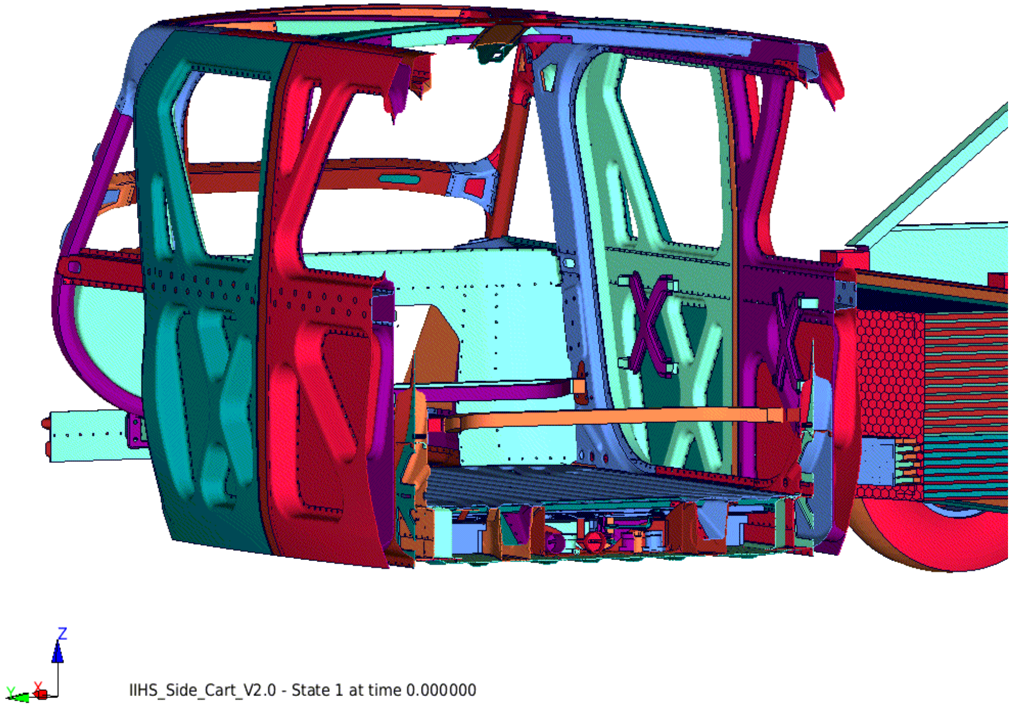
Side crash performance. Very good battery and occupant protection and IIHS “good” rating achieved (barrier 2)

USNCAP 32kph side pole (battery protection)



<30mm intrusion to battery maintained for 4 test locations

IIHS 60kph side barrier II (occupant protection)



- IIHS “good” rating (based on predicted intrusions)

Steel E-Motive Press Hardened Steel Door Ring

Overview and Summary

Part Info

Designation: 03694699-Body.1	Type:Heating
Part No.:	Drawing No.:
Nom. / Calculated Material: Usibor 2000 / Usibor 1500 / Ductibor 1000	
Nom. / Calculated Sheet Thickness: 1.2mm / 1.5mm / 0.8mm	

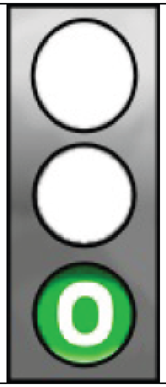
Method Info

Method Plan No.:	
Drawing No.:	Rev:

Part

Criterion		OK	n OK
FLD	5.2	☐	☐
Thickness	5.24	☑	☐
Gravity	5.3	☑	☐
Closing	5.4	☑	☐
Forming	5.5	☑	☐
Thinning	5.6	☑	☐
Martensite	5.7	☐	☐
Temperature	5.8	☑	☐
Hardness		☐	☐

Status



Simulation Info:

Filename:
ARRK_03694699_Outer_Ring_TWB_NMS_7-9-22_it3 - EXTENSION MODS 8 - MOD

AutoForm
AutoForm Forming Solver Thermo R10.0.0

Memory: 2068.16 MB

Remarks: All issues resolved now, including the split we were seeing on one of the weld joints.

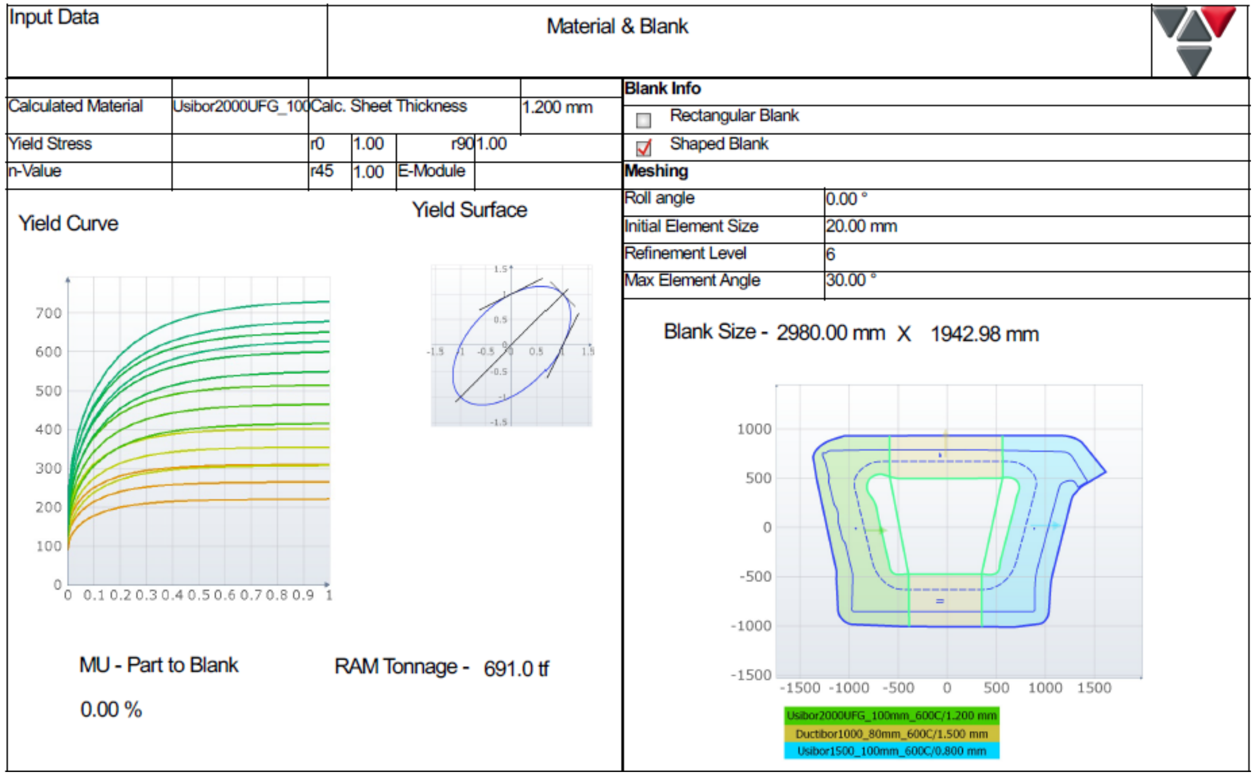
Process - TWB blank manufacture / Heating / Draw / Quenching / Laser Trim

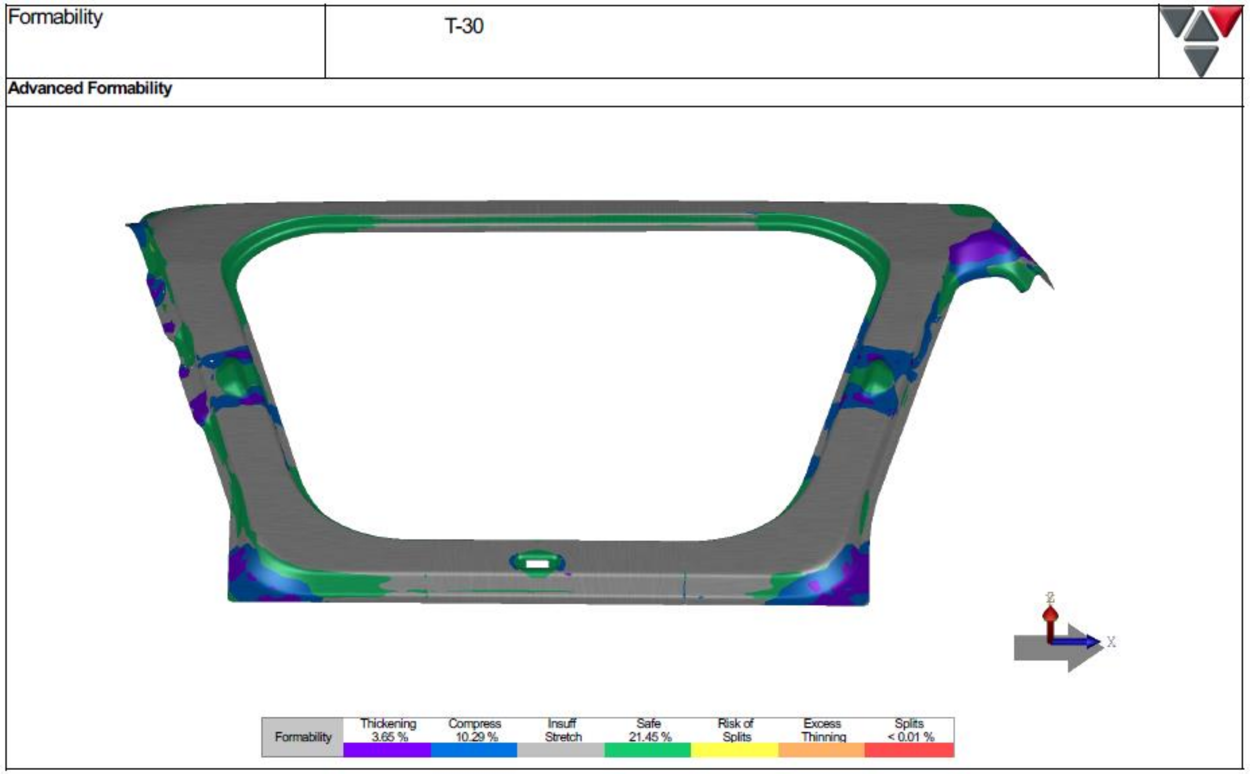
Weight	16.7kg
Cost	$44.16
# blanks	4

Cost breakdown

Equipment	Tooling	Building	Maintenance	Energy	Labor	Overhead	Process Materials	Materials Balance	Total
$2.74	$0.82	$0.27	$0.41	$0.85	$2.15	$1.02	$0.00	$35.92	$44.16

Steel E-Motive Press Hardened Steel Door Ring, final design

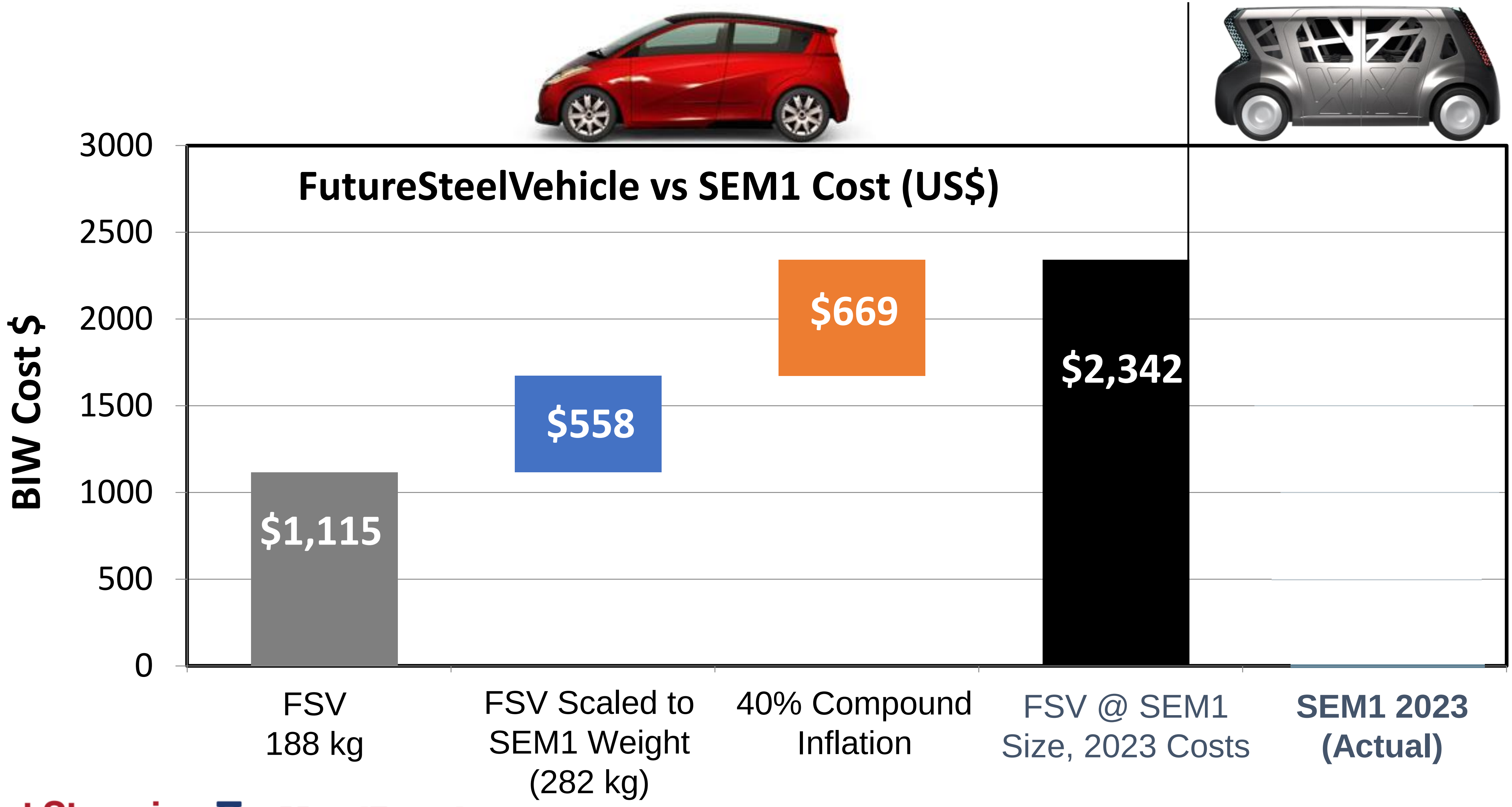




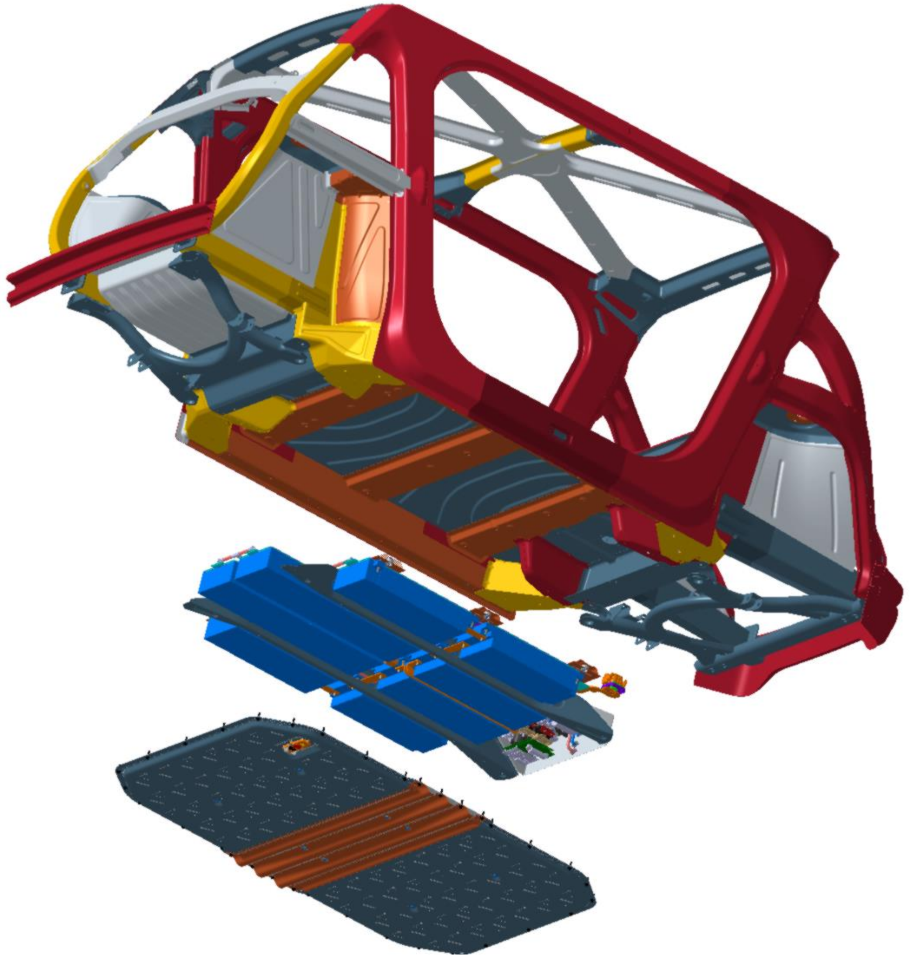
Confirming forming feasibility, preliminary process parameters

Play Video: Steel E-Motive Features

Steel E-Motive Body Structure Cost



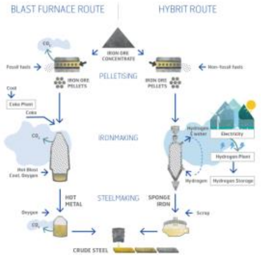
Engineering Decisions To Reduce Cost



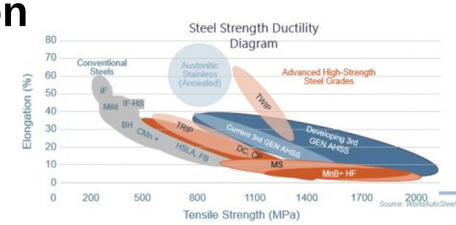
- Gauge optimization: overall thicknesses (1.2mm average)
- Expanded use of high material utilization processes (45%) – less material = lower costs
- Elimination of body side outer
- Elimination of traditional battery box
- Elimination of a conventional B-Pillar
- Production capable using existing manufacturing infrastructure

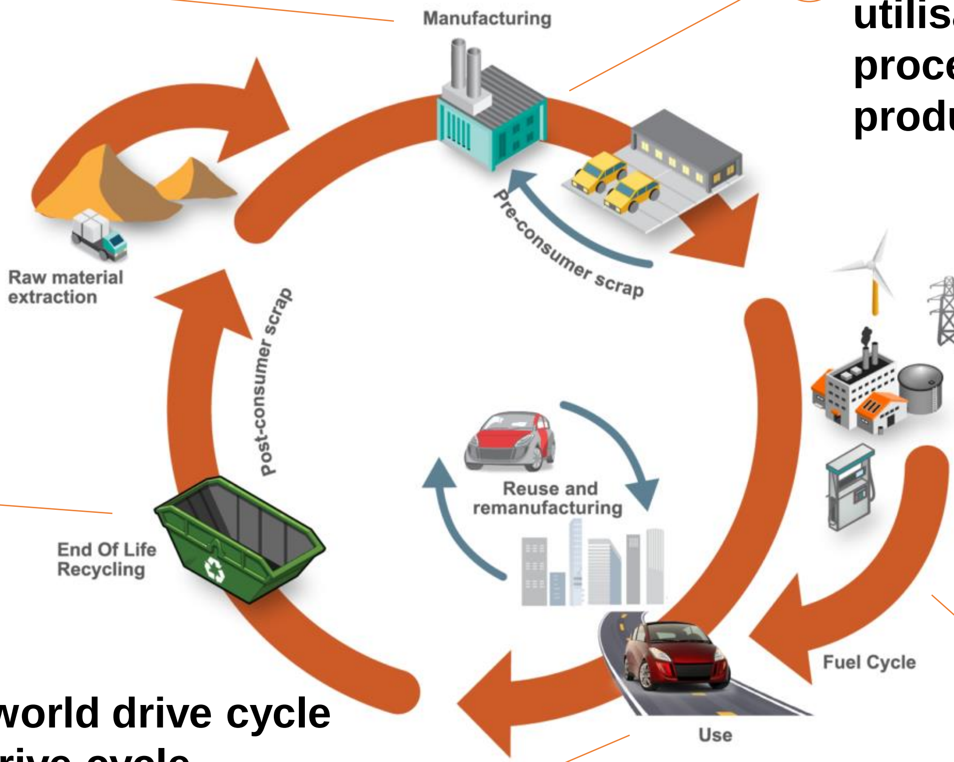
ENVIRONMENT & SUSTAINABILITY: Comprehensive life cycle assessment and optimisation, demonstrating potential for 86% reduction in GHG (2022 vs 2035 scenario)

1 **Decarbonise steel production (e.g. hydrogen Electric Arc Furnace)**

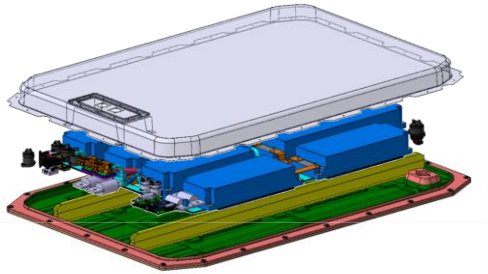


2 **Optimise vehicle design, material utilisation and fabrication processes to minimise production emissions**

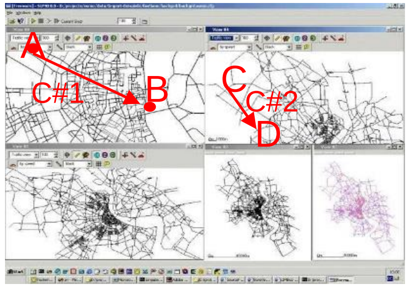




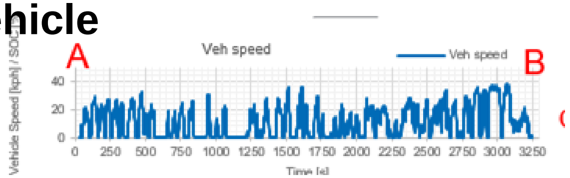
3 **HV battery production emission study and > 2030 forecast**



6 **Recycling. End of life methodology**



5 **Real world drive cycle and drive cycle smoothing with autonomous vehicle control**



4 **Decarbonise electricity grid supply for xEV. Global variations and >2030 forecast (production and vehicle use)**

Image source: SSAB, ArcelorMittal

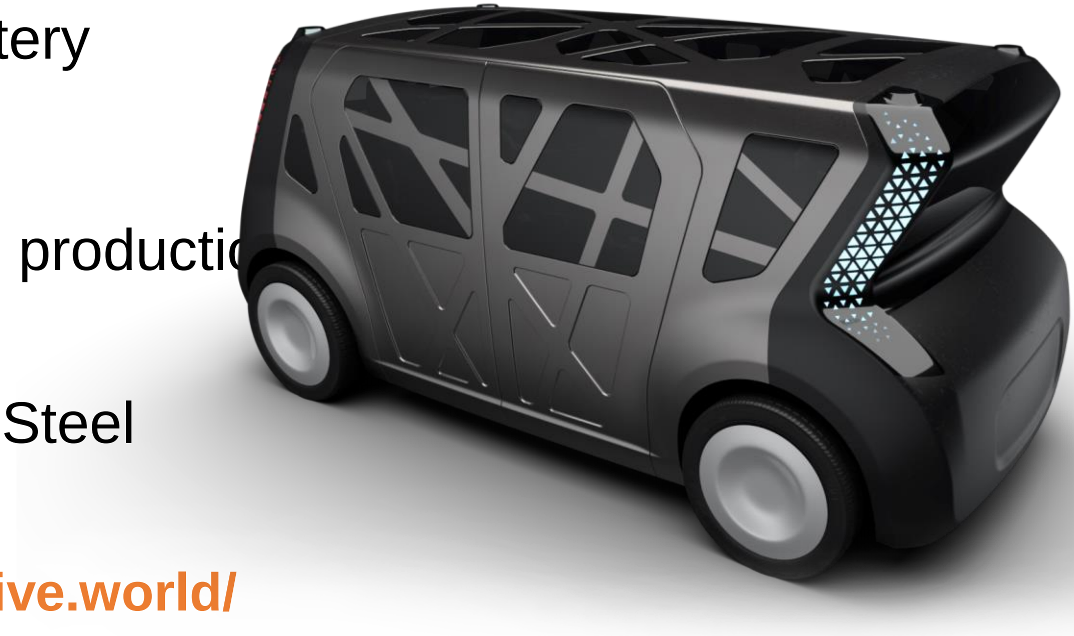
Steel E-Motive – Summary

STEEL E-MOTIVE

IN PARTNERSHIP WITH

WorldAutoSteel RICARDO

- The Steel E-Motive program has engineered innovative vehicle and body structure concepts, taking into consideration the freedoms and challenges offered by full autonomy
- Through application of the complete steel grade portfolio, the Steel E-Motive concept demonstrates:
  - Safety – exceptional protection of occupants and battery
  - High levels of occupant comfort and accessibility
  - Competitive weight
  - Cost effective design, suitable for global high-volume producti
  - A clear path and contribution to net zero emissions
- Solutions can be Plug & Play, Select & Adapt and New Steel Product integration.



Engineering report freely available at https://steelemotive.world/

How to Experience Steel E-Motive

3D PRINTED PROTOTYPE

AUGMENTED REALITY TOUR

Download Full Report
steelemotive.world

Thank you !

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www.steelemotive.world