WorldAutoSteel Membership

automotive group of the worldsteel

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Baosteel
China Steel
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Kobe
Nippon Steel
NUCOR
POSCO
Severstal

Sumitomo
ThyssenKrupp
USIMINAS
U. S. Steel
voestalpine
Today’s Presentation

• Past steel projects and impact on vehicle structures

• The new drivers of structural design

• Future Steel Vehicle
  - Objectives
  - Design methodology
  - Preliminary results

• Conclusions
Investment in Automotive

**ULSAB**
UltraLight Steel Auto Body

**ULSAC**
UltraLight Steel Auto Closures

**ULSAS**
UltraLight Steel Auto Suspensions

**ULSAB-AVC**
Advanced Vehicle Concepts

$60 Million
Impact of AHSS Solutions

Body Structure Weight vs. Gross Vehicle Weight

Body Structure: W/O Closures + IP Beam + Engine Cradle
450 Kg

2001-2003 Steel BIW
2004-2008 Steel BIW
2004-2008 Top 10 Steel BIW

(a2mac1 database 2001-2008 production vehicles)
Impact of AHSS Solutions

Body Structure Weight vs. Gross Vehicle Weight

**Body Structure:** W/O Closures + IP Beam + Engine Cradle
450 Kg

2001-2003 Steel BIW
2004-2008 Top 10 Steel BIW
Aluminium

-28%  -9%

(a2mac1 database 2001-2008 production vehicles)
Impact of AHSS Solutions

Growth of AHSS

Source: Ducker Worldwide
Body Structure Weight vs. Gross Vehicle Weight

Body Structure: W/O Closures + IP Beam + Engine Cradle
450 Kg

2001-2003 Steel BIW
2004-2008 Top 10 Steel BIW
Aluminium

(a2mac1 database 2001-2008 production vehicles)
Investment in Automotive

**Future Steel Vehicle**

**ULSAB**
UltraLight Steel Auto Body

**ULSAC**
UltraLight Steel Auto Closures

**ULSAS**
UltraLight Steel Auto Suspensions

**ULSAB-AVC**
Advanced Vehicle Concepts

[www.worldautosteel.org](http://www.worldautosteel.org)
Why Future Steel Vehicle?

Automotive CO₂ Emissions Regulation.

Source: International Council on Clean Transportation

<table>
<thead>
<tr>
<th>Year</th>
<th>USA</th>
<th>Japan</th>
<th>Europe</th>
<th>Australia</th>
</tr>
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<td>2003</td>
<td>260</td>
<td>220</td>
<td>180</td>
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<tr>
<td>2030</td>
<td>80</td>
<td>60</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>
Why Future Steel Vehicle?

Early Introductions of Dedicated Platform Advanced Powertrain Vehicles

- Honda Clarity FCX
- Mercedes E cell Plus
- Mercedes F cell
Why Future Steel Vehicle?

Body Structure Weight vs. Gross Vehicle Weight

Body Structure: W/O Closures + IP Beam + Engine Cradle
450 Kg

2001-2003 Steel BIW
2004-2008 Top 10 Steel BIW
Aluminium
SLC (Super Light Car)

1. SLC states 35% mass reduction ( = €7.80 / kg)

(a2mac1 database 2001-2008 production vehicles)

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FutureSteelVehicle
Will provide steel solutions to address:

- Future emissions regulations
- Advanced powertrains vehicles
- Competitive material solutions for 2015 to 2020
FSV Steel Technologies

FSV’s Steel Portfolio

| Mild 140/270 | DP 350/600 | TRIP 600/980 |
| BH 210/340 | TRIP 350/600 | TWIP 500/980 |
| BH 260/370 | SF 570/640 | DP 700/1000 |
| BH 280/400 | HSLA 550/650 | CP 800/1000 |
| IF 260/410 | TRIP 400/700 | MS 950/1200 |
| IF 300/420 | SF 600/780 | CP 1000/1200 |
| DP300/500 | CP 500/800 | DP 1150/1270 |
| FB 330/450 | DP 500/800 | MS 1150/1400 |
| HSLA 350/450 | TRIP 450/800 | CP 1050/1470 |
| HSLA 420/500 | CP 600/900 | HF 1050/1500 |
| FB 450/600 | CP 750/900 | MS 1250/1500 |
| HSLA 490/600 | | |

**Expanded range of steel grades**

- Denotes steel included in ULSAB-AVC
- Denotes steel grades added for FSV
What’s New?

Broad Bandwidth of Manufacturing Options

- Conventional Stamping
- Laser Welded Blank
- Tailor Rolled Blank
- High Frequency Induction Welded Hydroformed Tubes
- Laser Welded Hydroformed Tubes
- Tailor Rolled Hydroformed Tubes
- Hot Stamping (Direct & In-Direct
- Laser Welded Blank Quench Steel
- Tailor rolled Blank Quench Steel
- Roll Forming
- Laser Welded Coil roll Formed
- Tailor rolled Blank Roll Formed
- Roll Form with Quench
- Multi Walled Hydroformed Tubes
- Multi Walled Tubes
- Laser Welded Finalized Tubes
- Laser Welded Tube Profiled Sections
What’s New?

Design Optimization

Light Weight Front End Structure

2007 GDIS

Donor Vehicle

Donor Vehicle Rail
Rail: 16.34kg

A/SP LWB Concept

TWT Concepts

Mass Reduction

22.4%

32.0%
What’s New?

Design Optimization

Light Weight Body
Structural Optimization Process

2008 GDIS
Topology Optimization used to define Major Load Paths

Packaging Volume
Holistic Drivers
• Safety
• NVH Refinement
• Durability

Topology Results
Spatial load image

Beam Model
87 paths

BIW Design
202 components

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What’s New?

Design Optimization

Future Generation Passenger Compartment

2009 GDIS

Multidiscipline Optimization (Grade, Gauge, Geometry)

Passenger Compartment Mass

- Baseline: 264.7 Kg
- Optimized Design: 224.9 Kg
- Optimized w/ Maximum Adhesive Benefit: 210.6 Kg

- Mild: 77%
- HSLA: 17%
- Dual Phase: 4%
- Martensitic/Bainitic: 2%

Future Steel Vehicle

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What’s New?

Design Optimization

FutureSteelVehicle Pilot Program 2009 GDIS

Donor Vehicle

Mass Reduction

22.4%

32%

45%

Donor Vehicle Rail

A/SP LWB Concept

TWT Concepts

FSV Pilot Project

Topography Optimization

FutureSteelVehicle

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Lightweighting technologies

• Expanded materials portfolio

• Expanded manufacturing technology portfolio.

• Aggressive design optimization technologies
FSV Design Drivers

Manufacturing Cost

$
FSV Design Drivers

Mass Reduction

for fuel economy and emissions reduction

Source: International Council on Clean Transportation

Source: Argon National Lab
FSV Design Methodology

Phase 1 – Technology Assessment
Powertrain Layout
Styling & CFD
Topology Optimization
Low-Fidelity 3G Design Optimization

Phase 2 - Report & Decision for Phase 3
Final Design Confirmation FEA
Gauge Optimization
Detail Design

Body Structure Sub-System Optimization
Design Confirmation FEA

T1
T2
T3
T4
T5
T6
Benchmarking
Size and type of vehicle (2020)
Performance
NA-Europe-Asia
(EDAG, Germany, India & China)

Technology Assessment
Latest auto technologies
Low rolling resistance tires
Light weight
Glass
Seats
LED Lighting & Displays

Technology Assessment
Batteries
Wheel motors
Drive by wire
Fuel cell
Hydrogen storage and infrastructure (Corland Study?)
E85 and bio-diesel

OEM’s
Directions
Trends

Styling / CFD CAE
Future (2020) safety and structural:
Performance requirements
Future CO2/fuel efficiency requirements

Environmental Impact
CO₂ greenhouse gasses
Well to wheel efficiency
Life cycle assessment
Energy sources and usage
CO₂ sequestration

Drive Train Module
Technical Specs
Quantum
SFCV / Tongji

worldsteel Existing and Ongoing Programs
ULSAB
ULSAC
ULSAS
ULSAB-AVC
FPC
Weight Compounding-ASD

Phase 1 Deliverables
Vehicle Package
VTS (Vehicle Tech Spec)
Plug-in hybrid
Fuel cell hybrid
Electrical vehicle

Structural Optimization

Light Weight AHSS Body Structure Concepts
and
New Opportunities for Steel

Source: FSV Phase 1 report
FSV Advanced Powertrain Options

Worldwide over 70% market share between two vehicle sizes: Small cars (up to 4,000mm, A/B class) and Mid-Class cars (up to 4,900mm, C/D class)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Front Leg Room (mm)</th>
<th>Rear Leg Room (mm)</th>
<th>Luggage (Liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSV 1</td>
<td>1065</td>
<td>825</td>
<td>250</td>
</tr>
<tr>
<td>FSV 2</td>
<td>1065</td>
<td>925</td>
<td>370</td>
</tr>
</tbody>
</table>

FSV 1
4-door hatchback
3700 mm

FSV 2
4-door sedan
4350 mm

PHEV20
Electric Range: 32km
Total: 500km
Max Speed: 150km/h
0-100 km/h 11-13 s

BEV
Total Range: 250km
Max Speed: 150km/h
0-100 km/h 11-13 s

PHEV40
Electric Range: 64km
Total: 500km
Max Speed: 161km/h
0-100 km/h 10-12 s

FCEV
Total Range: 500km
Max Speed: 161km/h
0-100 km/h 10-12 s
FSV Battery Electric Vehicle (BEV)

Required battery size for 250 km driving range:

FSV – BEV Battery design options

Battery Pack
Energy density 130 Wh/kg

Battery Pack
Energy density 180 Wh/kg

Intermediate shape 160 liters

T shape 277 liters

I shape 166 liters
FSV Safety Requirements

Meet or exceed existing & upcoming safety requirements

<table>
<thead>
<tr>
<th>Regulation</th>
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<tr>
<td>Roof Crush Rollover (FMVSS 216)</td>
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<tr>
<td>Roof Crush/Rollover (IIHS)</td>
</tr>
<tr>
<td>Electronic Stability Control (ESC)</td>
</tr>
<tr>
<td>Pole Impact</td>
</tr>
<tr>
<td>Front Impact</td>
</tr>
<tr>
<td>Bumper Impact</td>
</tr>
<tr>
<td>Ped-Pro (Pedestrian Protection)</td>
</tr>
</tbody>
</table>

![Safety Impact Diagrams]
Other Advanced Technologies Evaluated

- Low Rolling Resistance Tires
- Lightweight glazing
- LED lighting
- Instrument and panel displays
- Lightweight seating
- ‘By-wire’ technology
Minimum Vision & Obscuration Requirements

- 16° Approach Angle
- 13° Ramp Breakover Angle
- 25° Departure Angle

Minimum Angles & Clearances

- 150 mm Ground Clearance
- 390.0 mm
- 1065.0 mm
- 850.0 mm
- 328.0 mm
- 495.0 mm
- 780.0 mm
- 2524.0 mm

T1: Styling & CFD
T2: Topology & Optimization
T3: Low-Fidelity 3D Design Optimization
T4: Body Structure Sub-System Optimization

Powertrain Layout

Phase 1 - Technology Assessment

FSV BEV Packaging

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FSV Styling & CFD

Coefficient of Drag (CD) Target: 0.25

First styling theme

CFD – Computational Fluid Dynamic

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Styling & CFD – Cooling Air Flow Motor Compartment

Front air intake opening optimized for the required cooling flow
Styling & CFD - effect of external features

Drag Coefficient 0.24 with rear wheel skirt

Drag Coefficient 0.27
FSV: BEV Final Styling

Utilities Access and Charging Port
<table>
<thead>
<tr>
<th></th>
<th>BIW Mass (kg)</th>
<th>Powertrain Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FSV</strong></td>
<td>190</td>
<td>329</td>
</tr>
<tr>
<td><strong>VW Polo 2010</strong></td>
<td>231</td>
<td>233</td>
</tr>
</tbody>
</table>

FSV BIW mass target
Design Optimization Process Overview

Process Enablers:
- Model Parameterization Tools (SFE-Concept)
- Multi-Disciplinary (MD) Optimization Tools (HEEDS, GENESIS)
- Analysis Tools (NASTRAN, LS-DYNA)
- High Performance Computing

ESL = Equivalent Static Loading
MD = Multidisciplinary
3G = Geometry, Grade and Gage

T1 - ESL
MD Topology Design Optimization

T2 - MD LoadPath Topology and 3G Optimization

T3 - Sub-Systems MD 3G Holistic Optimization

Select Major Members Manufacturing Process
Topology Optimization Load Cases

**Phase 1**
- Technology Assessment
- Packaging
- Styling & aerodynamic
- Non-Linear Dynamic Topology Optimization (LF3G)
- Sub-System Topography Optimization
- Detail Design
- Design Confirmation
- Gauge Optimization

**Phase 2**
- Final Design Confirmation
- Report

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Topology Optimization Results

Phase 2 Report
Final Design Confirmation
Gauge Optimization
Design Confirmation
Detail Design
Sub-System Topography Optimization
Non-Linear Dynamic Topology Optimization (LF3G)
Linear-Static Topology Optimization
Phase 1 Technology Assessment
Packaging
Styling & aerodynamic

T1
T2
T3
T4
T5
T6
Multidisciplinary (MD) Topology Design Optimization

- Topology optimization drives the material of structure to where it is most effective.
- Allow Topology Load Path Optimization to influence locations and shape of components based on Packaging.
- Topology Optimization is interpreted by engineering judgment.
Design Optimization Automated Process

ACP = Accelerated Concept to Product
MD 3G = MultiDisciplinary Geometry, Gage and Grade

Geometry

Monitoring

MD 3G Optimization

Design Solution

ACP Automated Process
Low Fidelity 3G (Geometry, Gauge & Grade) Optimization

Phase 1 - Technology Assessment
Powertrain Layout
Styling & CFD
Topological Optimization
Low-Fidelity 3G Design Optimization

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LF3G Optimization Results
LF3G Optimization Results

Phase 1 - Technology Assessment
Powertrain Layout
Styling & CFD
Topology Optimization
Low-Fidelity 3D Design Optimization

LF3G Optimized Body Structure Geometry
Low Fidelity 3G Optimization – Results Interpretation

LF3G Optimized Body Structure Geometry – interpreted to sheet steel design

'LF3G Optimized Geometry'

'Sheet Steel design'

150
130
LF3G Rocker Section

115 mm
120 mm

1.6 mm
Sub Systems 3G Opt – Selection of Manufacturing Process

Phase 2 Report
Final Design Confirmation
Gauge Optimization
Design Confirmation
Detail Design
Sub-System 3G Optimization
Non-Linear Dynamic Topology Optimization (LF3G)
Linear-Static Topology Optimization
Phase 1 Technology Assessment
Packaging
Styling & aerodynamic
Sub Systems 3G Opt – Selection of Manufacturing Process

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Sub System 3G Opt – System selection load path mapping

- Front NCAP
- Front ODB
- Rear ODB
- Side Pole
- Roof
- Bending Torsion

Loadcase: Front NCAP, Front ODB, Rear ODB, Side, Pole, Roof, Bending, Torsion

Sub System 3G Opt – System selection load path mapping

- Phase 1 – Technology Assessment
- Powertrain Layout
- Styling & CFD
- T1
- T2
- T3
- T4

Body Structure Sub-System Optimization

Low-Fidelity 3G Design Optimization

Resultant Force (% total load)

- Sub System 3G Opt – System selection load path mapping

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Body Structure – Sub System 3G Optimization

Variables for optimization:
1. Section Geometry using control points
2. Material Grade
3. Panel Gauge
Body Structure – Sub System 3G Optimization

- Phase 1: Technology Assessment
- Powertrain Layout
- Styling & CFD
- Topology Optimization
- Low-Fidelity 3G Design Optimization

S2S1: T1
S3 S4: T2
S5: T3

- Move together for flat mating condition
- Independent Control Points
- Hold seal flange
- Rocker reinf
- Floor side inr
- Space (common)

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Body Structure Sub System – Rocker Solutions

Section control points – constraining method determines the manufacturing solution.

- Stamping AHSS
- Roll-forming AHSS
- Hydroforming AHSS
- Extrusion Aluminum

FutureSteelVehicle
Body Structure Sub System – Rocker Solutions

Stamping AHSS

Roll-forming AHSS

Hydroforming AHSS

Extrusion Aluminum

FutureSteelVehicle
Body Structure Sub System – Rocker Solutions

<table>
<thead>
<tr>
<th></th>
<th>Conventional Stamping</th>
<th>Hot Stamping</th>
<th>Roll Forming</th>
<th>Hydroforming</th>
</tr>
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<tbody>
<tr>
<td>Blanks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LWB</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TRB</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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Body Structure Sub System - Selection

1. Mass
2. Cost
3. Total Life Cycle Assessment – GHG Emissions; CO\textsubscript{2} Equiv (kg)
   - Vehicle use phase (200,000 km)
   - Material Manufacture
   - Vehicle Manufacture
   - Vehicle recycling

LCA Ref: fka & UCSB
Cost Assessment Model

Process Data
- Blank size, Cycle Time, Press Type & Size, Tooling Cost

Cost Model
- Component Costs
- Material
- Labor
- Equipment
- Building
- Maintenance
- Tooling

Energy, Maintenance Parameter FSV
- Values (sample)
  - Energy consumption rate: 1000 kW/hr
  - Space requirement: 150 sqm/line
  - Manpower: 2 worker/line
  - Line Rate: 240 hits/hr
  - Reject rate: 1.00%
  - Press line die average change time: 30 mts
  - Press line lot size: 1500
  - Maintenance Percentage: 10%

Material Data

Labor Parameters
- Annual Paid Time: 3525 hrs/yr
- Indirect workers (Overhead): 0.25 per direct worker
- Wage (including benefits): $45.00/hr*

Building, Equipment Parameters
- Interest (Equipment, Building etc.): 10%
- Equipment life: 20 yr
- Building life: 25 yr
- Building unit cost: $1,500/sqm

Same approach - MIT advanced Materials Lab used for ULSAB
FSV: Rocker Optimization – Closed Roll-form from TWC

1.2 mm DP700/1000

1.4 mm DP700/1000

Tailor Welded Coil (TWC)

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>%</th>
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<tbody>
<tr>
<td>Total</td>
<td>$15.66</td>
<td>100%</td>
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<tr>
<td>Maintenance</td>
<td>$0.09</td>
<td>0.6%</td>
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<tr>
<td>Building</td>
<td>$0.07</td>
<td>0.4%</td>
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<td>Overhead</td>
<td>$0.44</td>
<td>2.8%</td>
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<tr>
<td>Energy</td>
<td>$0.42</td>
<td>2.7%</td>
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<tr>
<td>Labor</td>
<td>$0.76</td>
<td>4.8%</td>
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<tr>
<td>Equipment</td>
<td>$0.37</td>
<td>2.4%</td>
</tr>
<tr>
<td>Tooling</td>
<td>$0.97</td>
<td>6.2%</td>
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<tr>
<td>Material</td>
<td>$12.53</td>
<td>80.0%</td>
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</table>

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### Importance of Life Cycle Assessment

Material production greenhouse gas (GHG) emissions:

<table>
<thead>
<tr>
<th>Material</th>
<th>GHG from Production (in kg CO₂eq/kg of material)</th>
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<tbody>
<tr>
<td>Steel</td>
<td>2.0 – 2.5</td>
</tr>
<tr>
<td>Aluminium</td>
<td>11.2 – 12.6</td>
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<tr>
<td>Magnesium</td>
<td>18 – 45</td>
</tr>
<tr>
<td>Carbon FRP</td>
<td>21 – 23</td>
</tr>
</tbody>
</table>

Current Average GHG Emissions Primary Production

Footnotes:
- All steel and aluminium grades included in ranges.
- Difference between AHSS and conventional steels less than 5%.
- Aluminium data - global for ingots; European only for process from ingot to final products.
## Rocker - Total Life Cycle Assessment – CO2 equiv (kg)

<table>
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<th></th>
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<tbody>
<tr>
<td>Baseline - Rocker 10.26 kg</td>
<td>15,980</td>
<td>2291</td>
<td>5.7</td>
<td>14,640</td>
<td>-956.8</td>
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<tr>
<td>Solution 1 - Stamping</td>
<td>+53.2</td>
<td>8.6</td>
<td>0.4</td>
<td>48.0</td>
<td>-3.8</td>
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<tr>
<td>Solution 2 - Hot Stamp</td>
<td>-37.1</td>
<td>-18.0</td>
<td>3.9</td>
<td>-32.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Solution 3 - Roll Form</td>
<td>-182.6</td>
<td>-44.9</td>
<td>-0.7</td>
<td>-158.6</td>
<td>21.5</td>
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<tr>
<td>Solution 4 - Hydroform</td>
<td>-248.2</td>
<td>-67.5</td>
<td>10.1</td>
<td>-223.4</td>
<td>32.5</td>
</tr>
</tbody>
</table>
Body Structure Sub System – Front Rails

Stamping 3 piece AHSS

Stamping 2 piece AHSS – LWB

Stamping 2 piece Aluminum

Hydroformed AHSS

T4

Body Structure & System Optimization

T3

Low-Fidelity & Design Optimization

T2

Static & Crash

T1

Powertrain Layout

Plating – Technology

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Body Structure Sub System – Shotgun

Stamping 2 piece
AHSS – LWB

Stamping 2 piece
Aluminum
Body Structure Sub System – Rear Rail

Stamping
AHSS – LWB

Hydroforming

Stamping Aluminum

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Body Structure Sub System – Roof Side Rail

- Stamping AHSS – LWB
- Hydroforming
- Stamping Aluminum
Body Structure Sub System – Tunnel Support Rails

Stamping
AHSS – LWB

Roll forming
AHSS

Roll forming
Aluminum

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Future Steel Vehicle

American Iron and Steel Institute
## Rocker Cost, Mass & LCA CO₂ eq Assessment

<table>
<thead>
<tr>
<th>HF3G Technology Assessment</th>
<th>HF3G Manufacturing Interpretation</th>
<th>High Volume Manufacturing Feasibility</th>
<th>Sub-System Mass (kg)</th>
<th>Manufacturing Cost ($)</th>
<th>LCA CO₂ Savings (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>B ST</td>
<td>Conservative</td>
<td>10.26</td>
<td>19.99</td>
<td>0</td>
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<tr>
<td>Stamping Solution (HEEDS Mass)</td>
<td>ST</td>
<td>Conservative</td>
<td>10.95</td>
<td>21.33</td>
<td>53</td>
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<tr>
<td></td>
<td>ST TRB</td>
<td>Mid-Term</td>
<td>10.52</td>
<td>24.18</td>
<td>16</td>
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<tr>
<td></td>
<td>ST LWB</td>
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<td>10.47</td>
<td>27.86</td>
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<td>HST</td>
<td>Conservative</td>
<td>9.80</td>
<td>24.98</td>
<td>-37</td>
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<td>HST TRB</td>
<td>Mid-Term</td>
<td>9.66</td>
<td>27.68</td>
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<td>HST LWB</td>
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<td>Roll Form (HEEDS Mass)</td>
<td>RF</td>
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<td>Aggressive</td>
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<td>RF TWC</td>
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Rocker Technology Options
(Mass vs Cost Value)

Parallels of Constant Value ($9.39/kg)

Increasing Value

FSV – Mass Paradigm Shift
FSV – Rocker Cost, Mass & LCA CO2 eq Assessment

Rocker Technology Options
(Mass vs Cost Value)
Parallels of Constant Value ($9.39/kg)

Rocker Technology Options
(LCA CO2 reduction, Cost & Value)
Parallels of Constant Value
($100/tonne)
FSV – Shot gun, Mass & LCA CO$_2$ eq Assessment

**Shotgun Technology Options**
(Mass vs Cost Value)

Parallels of Constant Value ($9.39/kg)

- AL
- ST TRB
- HST TRB
- HST LWB
- ST LWB
- B ST

**Shotgun Technology Options**
(LCA CO$_2$ reduction, Cost & Value)

Parallels of Constant Value ($100/tonne)

- AL
- ST TRB
- HST TRB
- HST LWB
- ST LWB
- B ST

Future Steel Vehicle

WorldAutoSteel.org
Conclusion

FutureSteelVehicle

Gauge Optimization
Design Confirmation
Detail Design
Sub-System Topography Optimization
Non-Linear Dynamic Topology Optimization (LF3G)
Linear-Static Topology Optimization
Packaging
Styling & Aerodynamic
Phase 2 Report
Phase 1 Technology Assessment
Final Design Confirmation
Thank you for your attention