Weight Reduction with Aluminum: Part of All Cost-Effective Fuel Economy Improvement Strategies

Final Report September 2012

Information Release

This presentation, describing recent study results by Scenaria for The Aluminum Association, is applicable for release in the public domain.

Contents

Executive Summary

- This report analyzes the fuel efficiency and cost impacts of downweighting with aluminum in contrast to and in combination with other fuel improvement technologies in order to meet higher future fuel economy targets.

- NHTSA powertrain and vehicle technologies were compared by their fuel economy benefits and net cost to consumers as stand-alone or as bundled technologies. The net cost to the consumer, influenced by future fuel prices and up-front cost, can be used to prioritize the attractiveness of the technologies within the regulatory solution space.

- CONCLUSIONS:
  - As a stand-alone technology, the most extensive weight reduction (20 percent) is a leading technology for all cost of adoption and future fuel price scenarios examined. The more extensive the weight reduction, the more cost effective to the consumer.
  - At high weight reductions (> 20 %), additional benefits such as increased design flexibility and improved performance, handling and safety are achievable.
  - Weight reduction achieves consistent fuel economy improvements in combination with <u>all</u> advanced fuel economy improvement technologies.
  - No cost-efficient technology can achieve a 50+ MPG target without significant weight reduction.
  - Weight reduction with aluminum gives automakers flexibility in introduction of other often more expensive technologies to achieve improved fuel economy:
    - A weight savings of 1.5 % (MS1) provides incremental help and is a leading technology up to 40 MPG
    - A weight savings of 7.5 % (MS2) is a leading improvement technology from 41 to 43 MPG
    - A weight savings of 20 % (MS5) is a leading improvement technology from 44 to 58 MPG
  - Weight reduction is a leading technology up to the assumed 2025 fuel economy standards and is a long term sustainable "technology platform" for other advanced fuel improvement technologies.

Introduction

Purpose

To meet future fuel economy standards, automakers must adopt new or updated fuel efficiency improvement technologies such as improved internal combustion engines, transmissions, hybrids, weight reduction, etc…

This report addresses:

- **The selection of technologies process, in assessing both the cost to manufacture, net cost to consumer and fuel economy improvement**
- **The effect of uncertainties such as energy price and future regulation stringency on the technology selection**
- **The comparison of the benefit from individual "stand-alone" technologies and "bundled" technologies**
- **The sustainability of the weight reduction technologies in linking their incremental improvement into a longer term road map and identifying how weight reduction complements the adoption strategies of other fuel efficiency improvement technologies**

Introduction

Background

The Aluminum Association possessed assumptions of costs and benefits for future weight reduction using aluminum and needed an objective assessment of the cost-effectiveness of regulatory fuel efficiency improvements made from systems with weight reducing technologies in comparison to other technologies available. The Association contacted Scenaria, Inc. to study the relative competitiveness of weight reduction using aluminum to 2025 in the U.S. market.

This report has been prepared in accordance with Scenaria's contracted scope to The Aluminum Association, as documented in Scenaria's proposal for project #00A1005, "Mass Reduction Competitiveness as a Fuel Economy Improvement Technology within Future Uncertainties."

Introduction

Background (cont.)

Fuel economy standards are highly complex with many interacting factors, time dynamics, and uncertainties for external factors such as technology costs, energy costs, and vehicle miles travelled (VMT). Scenaria proposed a macro level view of the future U.S. market and an assessment of weight reduction technologies' likely position across all relevant scenarios.

Scenaria conducted a model-based assessment of weight reduction technology against other candidate fuel economy improvement technologies. The assessment was done by comparing each technology's cost, potential fuel savings and cost of ownership for selected scenarios.

Input parameters of cost and benefits of weight reduction technologies were provided by the Aluminum Association.

Input parameters to the Scenaria System Engineering Tool for all other technologies came from NHTSA's VOLPE model inputs for the 2012-2016 CAFE rule. This provides a robust and rigorously peer reviewed basis for modeling.

The outcome is an assessment of viability for weight reduction technologies based on most cost-effective fuel efficiency gains as evaluated in systems with other fuel economy improvement technologies for a mid-sized passenger car class.

Analytical Approach

The potential attractiveness of weight reduction technologies, compared to or in concert with, other fuel economy improvement technologies is analyzed in two ways:

1. **Stand-alone technology**
   For a set of assumptions, conduct stand-alone comparisons of each of 26 NHTSA fuel economy improvement technologies to all others to determine the order in which <u>individual</u> fuel economy improvement technologies would be selected for packages to meet fuel economy targets / regulations

2. **System level bundles**
   For a set of assumptions, determine the prevalence of weight reduction technologies in the most cost-effective (lowest consumer Net Cost) bundles of technologies

Assumptions

- All 2012-2016 NHTSA final CAFE rule technologies were used and assumed available
- Weight reduction inputs were updated by The Aluminum Association (see the input data section)
- Assessments were made for Net Cost and incremental upfront cost. No technology demand volume was computed.

Other:

- The Scenaria model was used to perform the analysis. NHTSA Volpe model for technologies, costs and benefits, and applicability were used as input.
- The tools / methodology developed for this project are Scenaria property.
- With the exception of the Mass Reduction Technology family, any fuel economy technology / technology package output data or results from this study require the prior approval of Scenaria before being made publicly available (via web, publication, etc.).

Input Data

NHTSA Mid-Size Passenger Car class fuel consumption and cost input data as used in the Volpe model (2012-2016) were used to represent the field of vehicle and powertrain technology under this study.

System level fuel consumption is computed as per NHTSA's Volpe model, which accounts for positive and negative synergies between technologies. Technology acronym definition and tree structures are included in Appendix A. Hybrid technologies, which were assessed by NHTSA as having special volume learning curve characteristics, were assumed to reach a volume of 150,000, allowing for a 20% volume learning curve reduction in their cost in this study.

For this study and as was used by NHTSA for the 2012-2016 rulemaking, the technology cost data is in 2008 dollars.

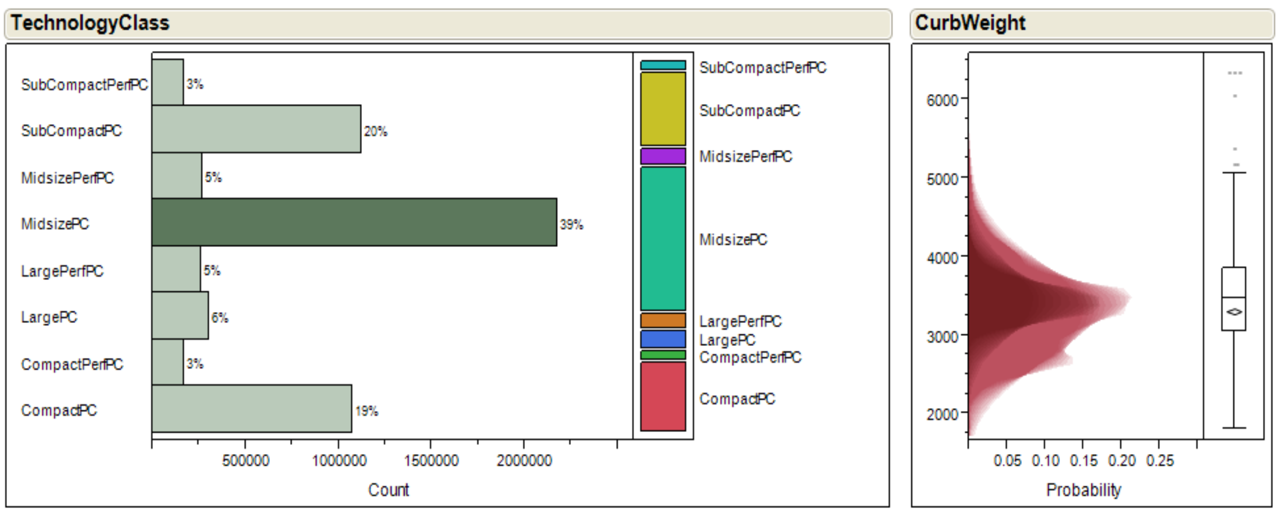
Baseline Vehicle

Reducing weight with aluminum provides benefits with the state of technology today, and will enable additional benefits in the future.

WARDS (2010) data was used to define a representative midsize passenger car vehicle in the United States.

The midsize passenger car technology class has the largest volume of the passenger car regulatory classes. The average curb weight for this class is 3,438 lbs. Other characteristics are shown on the right.

Example Statistics on the U.S. Fleet



Baseline Vehicle Specification:

FE: 33.1 mpg (27.5 City, 44.3 Hwy)
Style: Sedan
Structure: Unibody
Drive: Front
Footprint: 47 sqf
Curb Weight: 3438 lbs.
includes 330 lbs. of Aluminum

Engine:

Fuel Delivery: SFI
Aspiration: NA
Valvetrain Design: DOHC
Cylinders: 6
Valves per cylinder: 4
Displacement: 3.0L

Transmission: 6sp Automatic

Assumptions: No Aero, Dynamic Load nor Mass Reduction technologies on board the baseline vehicle.

Weight Reduction Levels

Three levels of weight reduction were evaluated as materials substitution (MS) 1, 2 and 5:

MS1 1.5 % (50 Lbs.) - represents conversion of some closure panels to aluminum

MS2 7.5 % (250 Lbs.) - represents conversion of all closure panels to aluminum

MS5 20.0% (700 Lbs.) - represents an all aluminum body (BIW and closure panels)

Weight reduction technologies are cumulative:

MS1 is a sub-set of MS2
MS2 is a sub-set of MS5

Materials substitution costs at all three levels (MS1, MS2, and MS5) were varied between \$0.5/lb. - \$2.0/lb. (\$1.0/lb. is used by NHTSA).

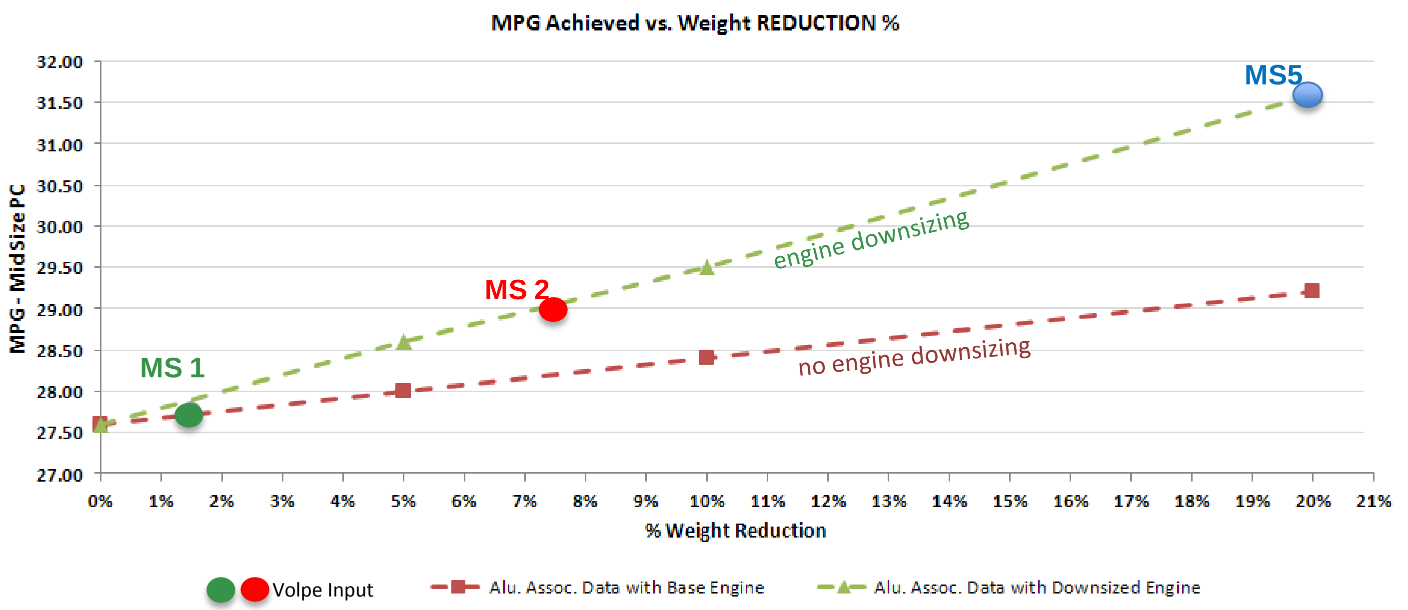
Fuel Economy Benefits from Weight Reduction

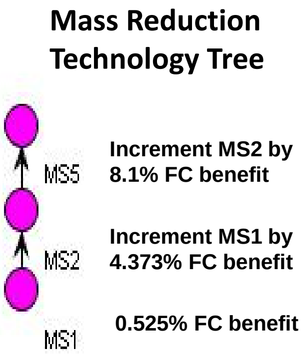
DRIVEALUMINUM

- **MS1 and MS2 fuel consumption benefits are unchanged from NHTSA technology assessments for midsize passenger car regulatory class vehicles.**

  Fuel economy assessment for MS2 and MS5 technologies include impact of engine downsizing to maintain constant performance.

- **MS 5 fuel consumption benefit was chosen to match Aluminum Association fuel economy simulation data (which used a midsize passenger car baseline at 27.6 MPG metro-highway fuel economy).**

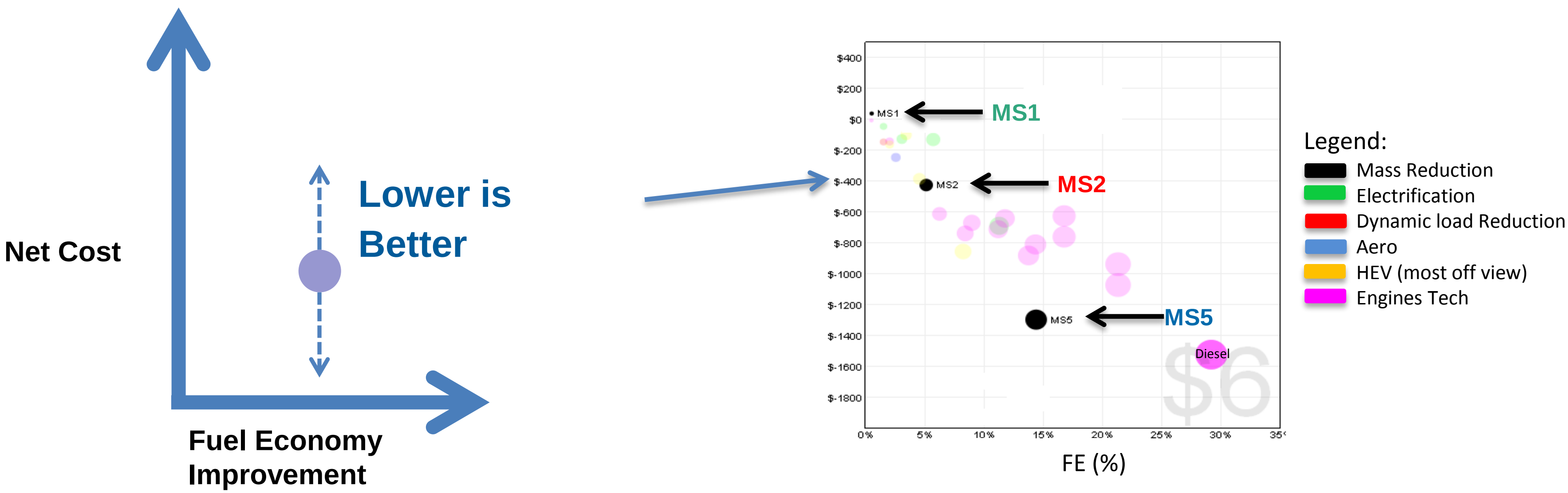




Stand-Alone Technology Assessment

- **Method for comparing individual technologies**
- **Net consumer cost used to compare the technologies**

$$\textit{Net Consumer Cost} = \textit{Technology Cost} - \textit{Fuel Consumption Savings}$$

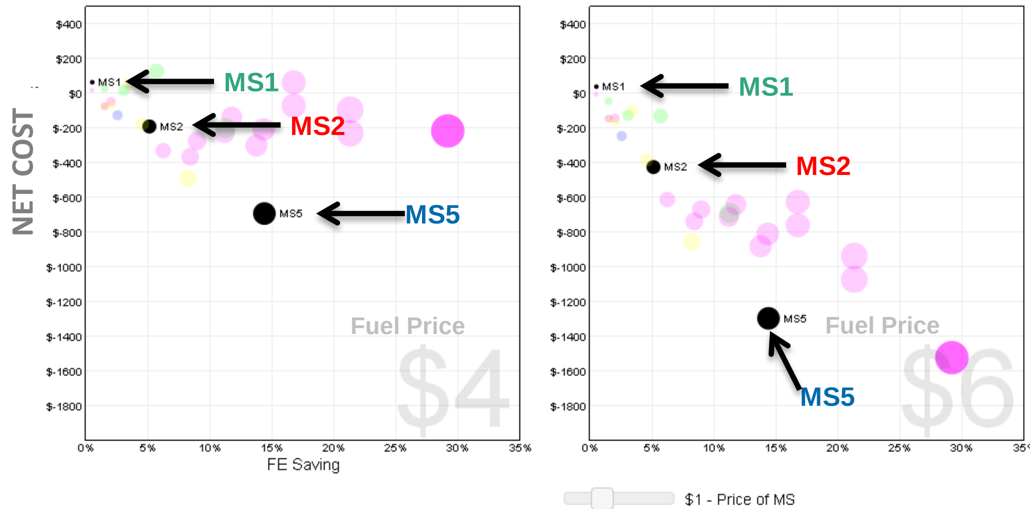


- **Bubble <u>size</u> represents relative fuel savings over a 5-year period**
- **Net Cost changes (up or down) due to changes in fuel price and Technology Cost**
- **Fuel price was varied from $2.0/gal to $6.0/gal.**
- **Negative Net Cost technology represents consumer cost savings**

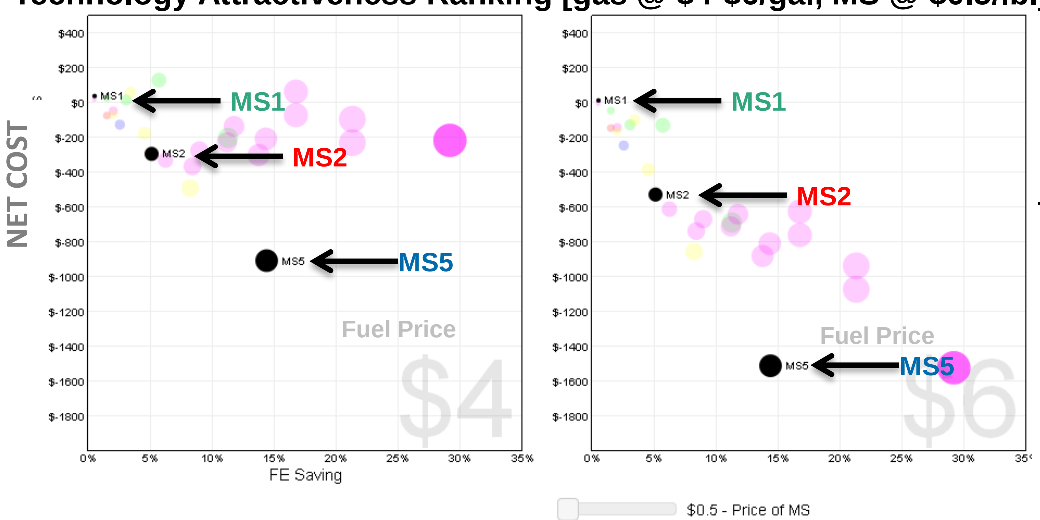
Fuel Economy Technologies Increase Consumer Savings as Fuel Price Increases

Technology Attractiveness Ranking [gas @ $4-$6/gal, MS @ $1/lb.]

Lower is Better



Technology Attractiveness Ranking [gas @ $4-$6/gal, MS @ $0.5/lb.]



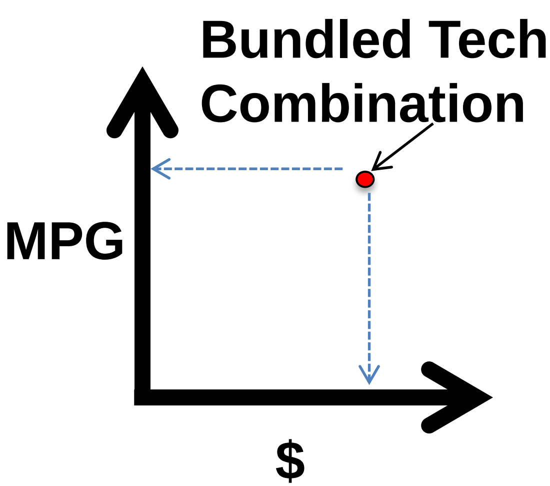
- **MS5, with higher fuel economy benefit, is consistently within the Top 2 most cost effective technologies**
- **At higher fuel price, MS5 remains the most cost effective non-engine related technology**
- **MS1 and MS2 technologies at $1/lb. weight saved are less cost effective than most engine and transmission technologies. They remain attractive due to relatively low cost and ease of introduction.**
- **At $0.5/lb., MS2 becomes a Top 10 technology**

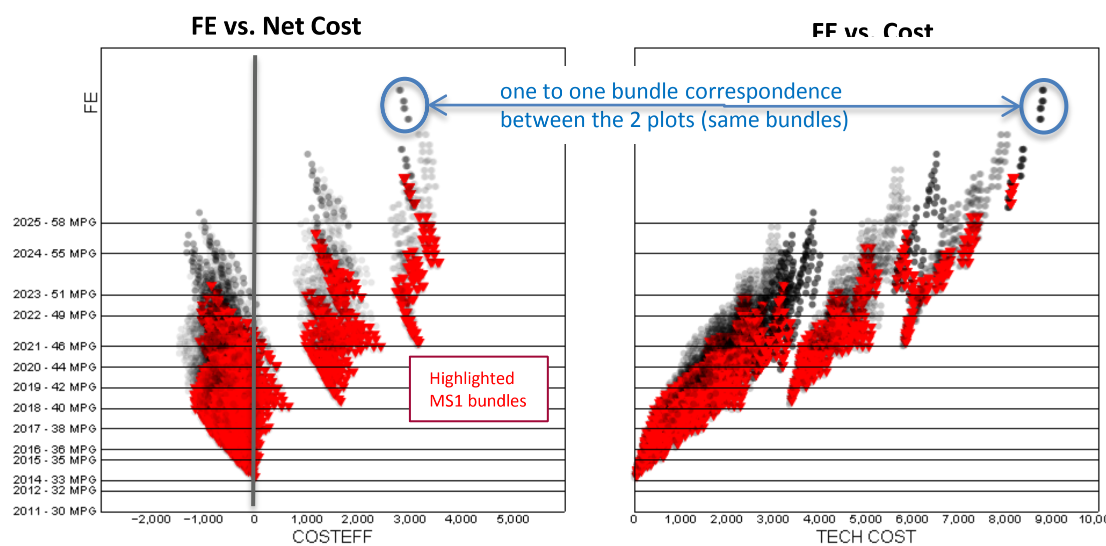
Legend:

- Mass Reduction
- Electrification
- Dynamic load Reduction
- Aero
- HEV (most off view)
- Engines Tech

Technology “Bundle” Assessment

- Technology “bundle” is a technically feasible combination of available fuel economy improvement technologies
- Each technology bundle has a unique Fuel Economy (FE), initial Technology Cost (TC), and Net Consumer Cost or Savings (NC)
- All possible NHTSA identified technology combinations are represented
- Each combination (bundle) is represented by a dot in the “cloud” chart





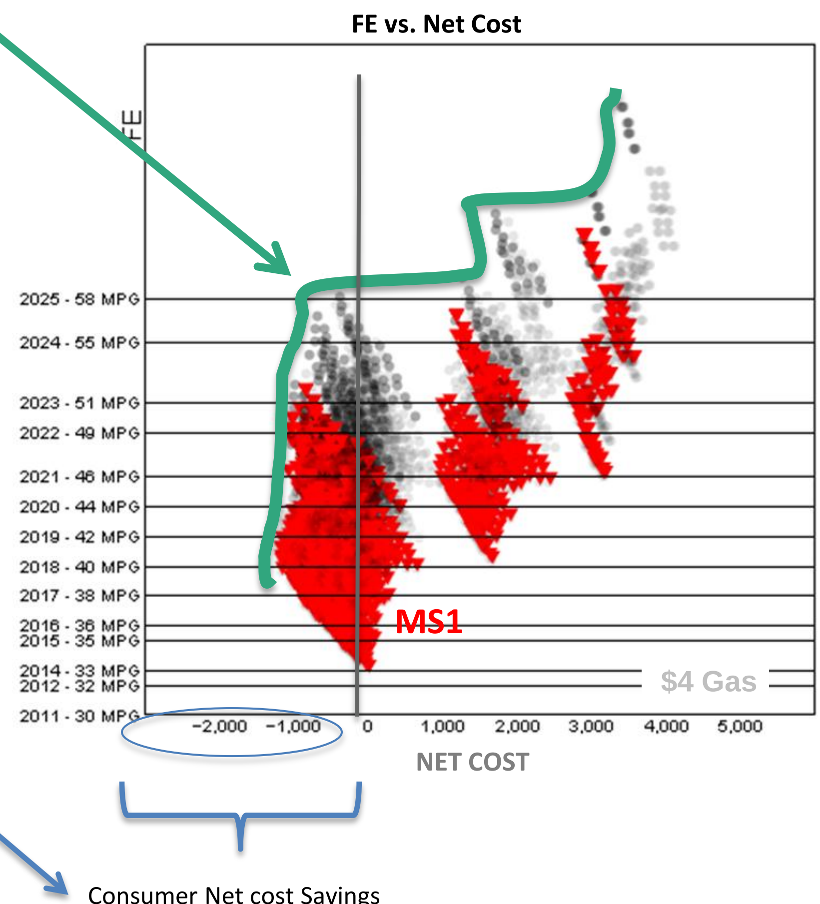
NC =
TC − Fuel Consumption Savings

TC = Up Front System Cost

Efficient Technology Frontier -

Maximum Consumer Cost Savings

- The "efficient frontier" represents the most cost effective technology combination for a given fuel economy target
- In this example, the red highlighted parts of the cloud represent a technology of focus for analysis (in this case MS1)
- Each point represents a technically feasible bundle of advanced fuel economy improvement technologies
- Negative values represent net cost savings to consumers. (Fuel cost savings over 5-year period exceed initial Technology Cost.)



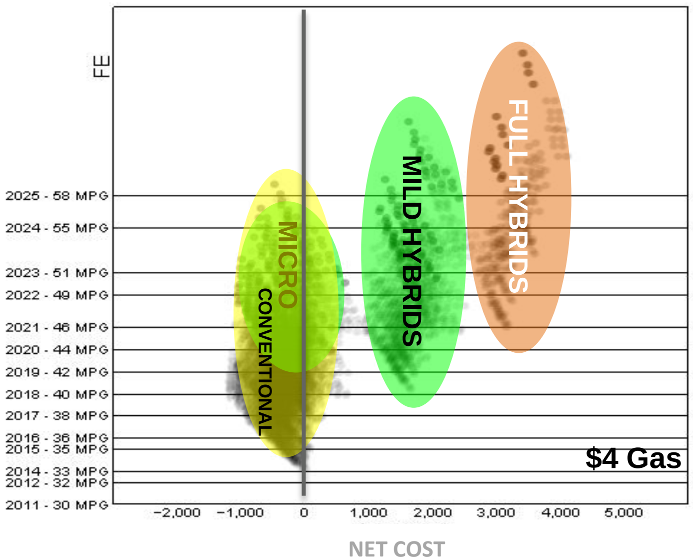
Fuel Economy Technologies –

DRIVEALUMINUM

Effectiveness and Cost (Initial and Consumer Net)

- **All feasible technology bundles were evaluated to provide a full picture of technology alternatives for midsize passenger vehicles.**

Technology Islands

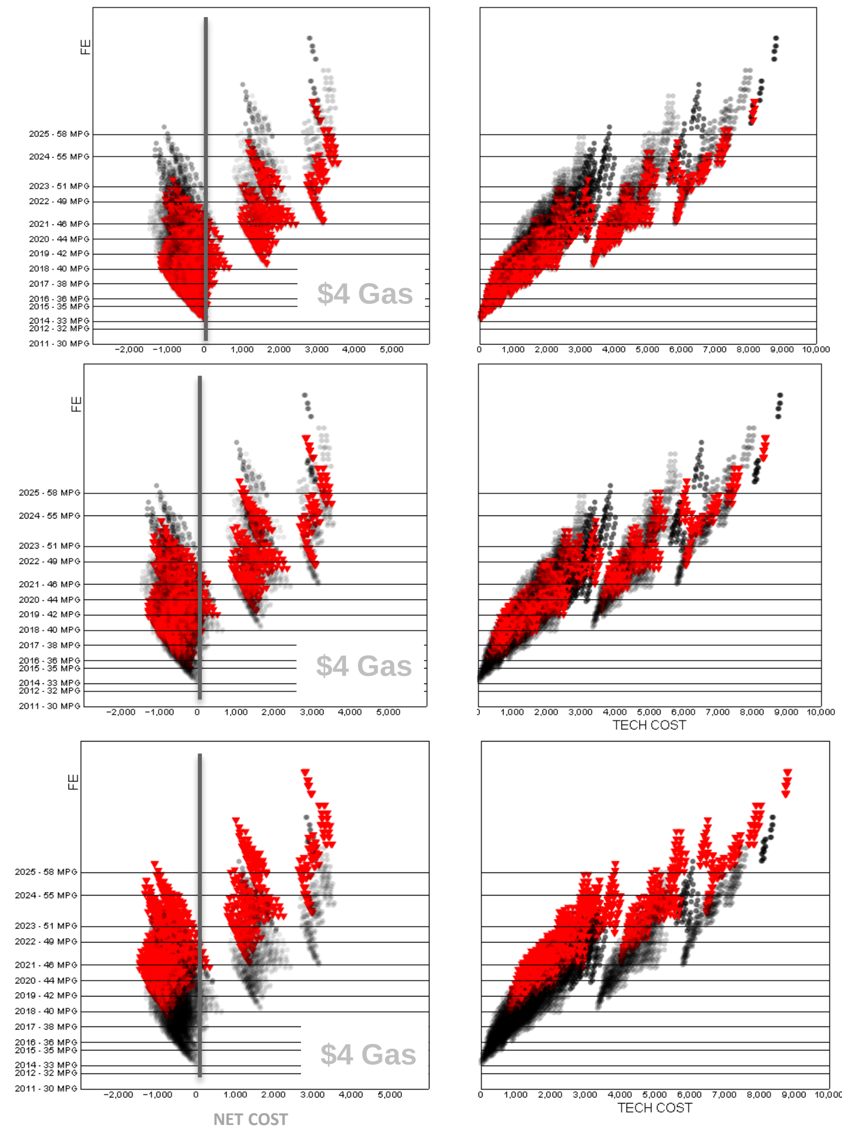


FE vs. Net Cost | **FE vs. Cost**

MS 1 [$1/lb.]

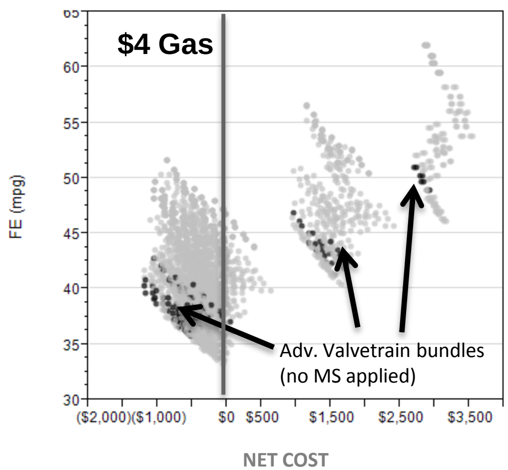
MS 2 [$1/lb.]

MS 5 [$1/lb.]

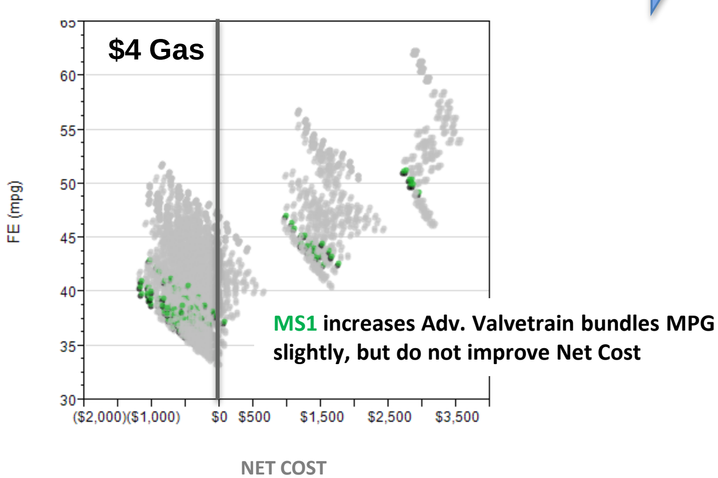


Weight Reduction with Aluminum - Increased Fuel Economy and Reduced Consumer Net Cost

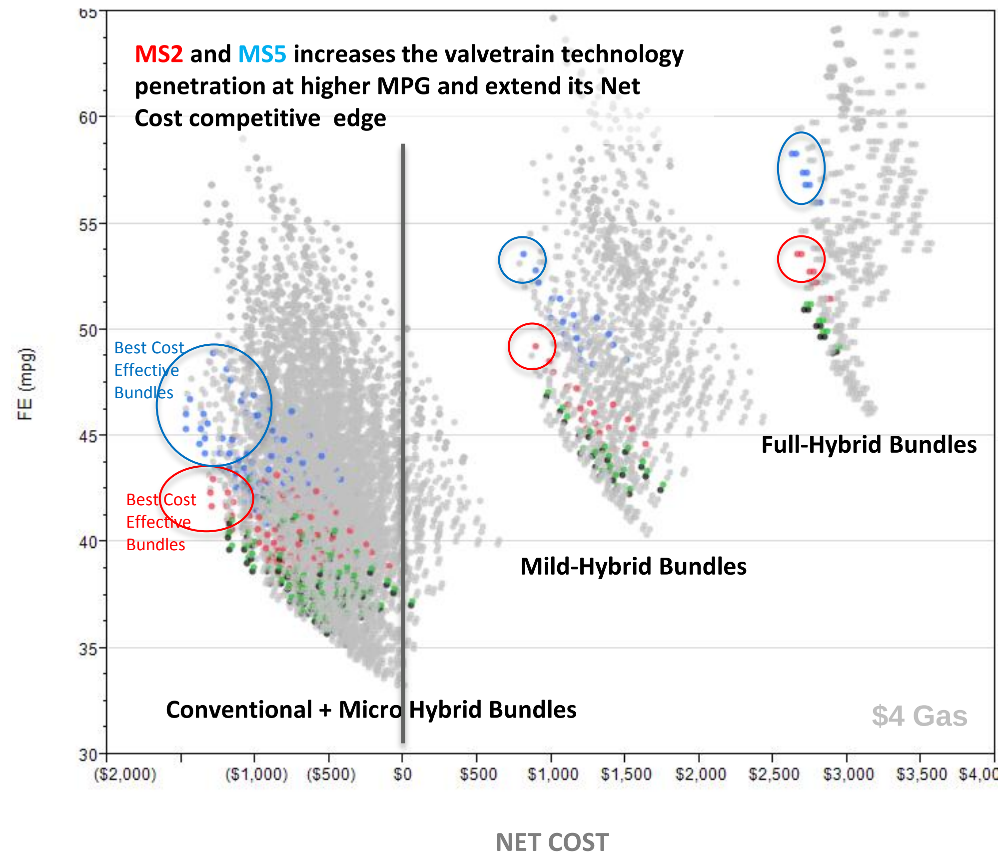
1. Adv. Valvetrain Technologies are highlighted



2. MS1 is added to the Adv. Valvetrain bundles



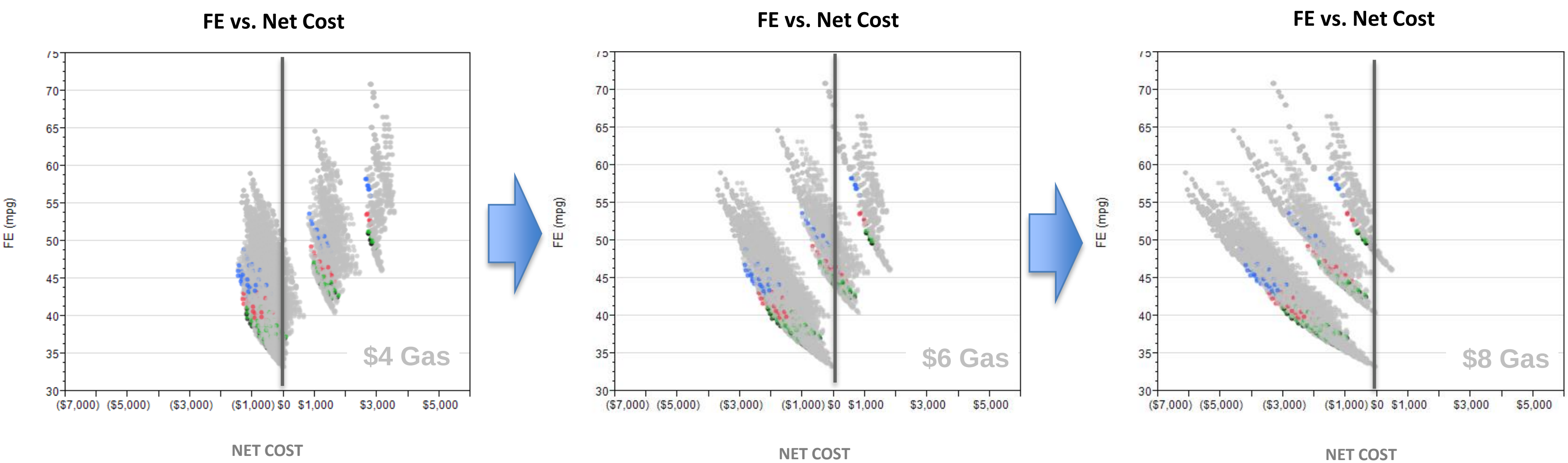
3. MS2 and MS5 are added to the Adv. Valvetrain bundles



Advanced Fuel Economy Technologies Save Consumers Money

DRIVEALUMINUM

- Fuel price increases stretch net cost (NC) clouds to the left (more negative) greater consumer "pay back."
- With increasing fuel price, more packages have increased consumer pay-back
- The example below illustrates materials substitution (MS) technologies in combination with advanced valve-train technologies.
- Independent of fuel price, the MS enhanced bundles stay on the efficient frontier



Above 44 MPG -

Significant Weight Reduction (> 20 %) <u>Integral</u> to All

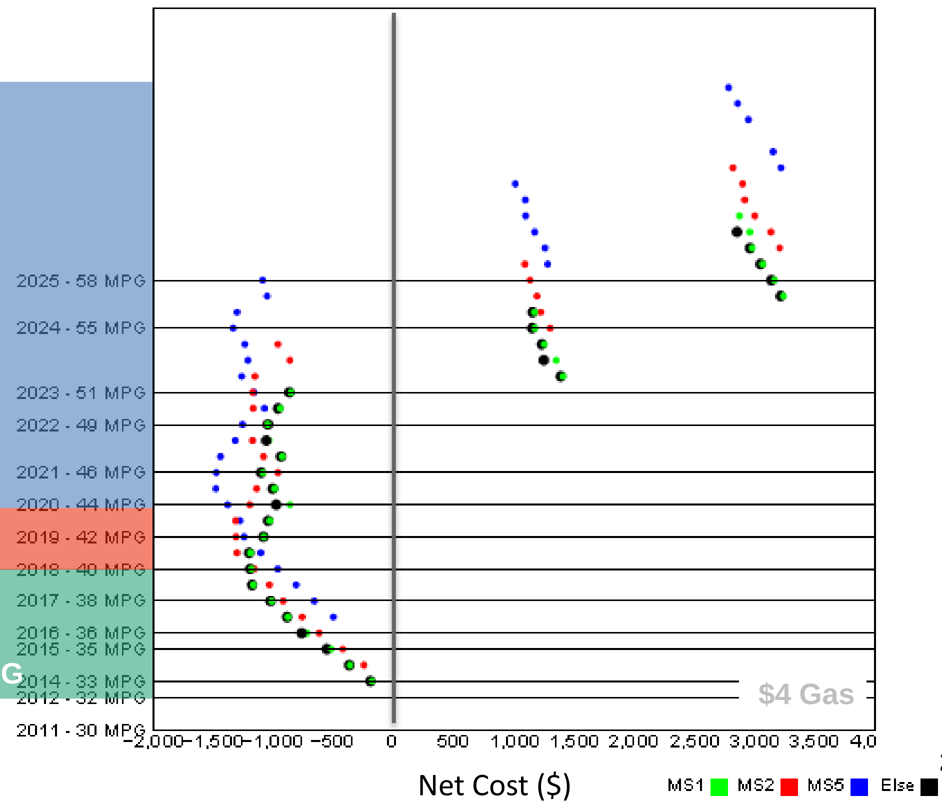
Cost-Efficient Technology Strategies

The efficient frontier for technologies containing no weight reduction (black), MS1 (green), MS2 (red) and MS5 (blue) were extracted from the point clouds. Regulatory targets for the base vehicle (footprint = 47 square feet) are shown for each year.

MS 5 is firmly on the efficient frontier above 44 MPG

MS2 is on the efficient frontier below 43 MPG

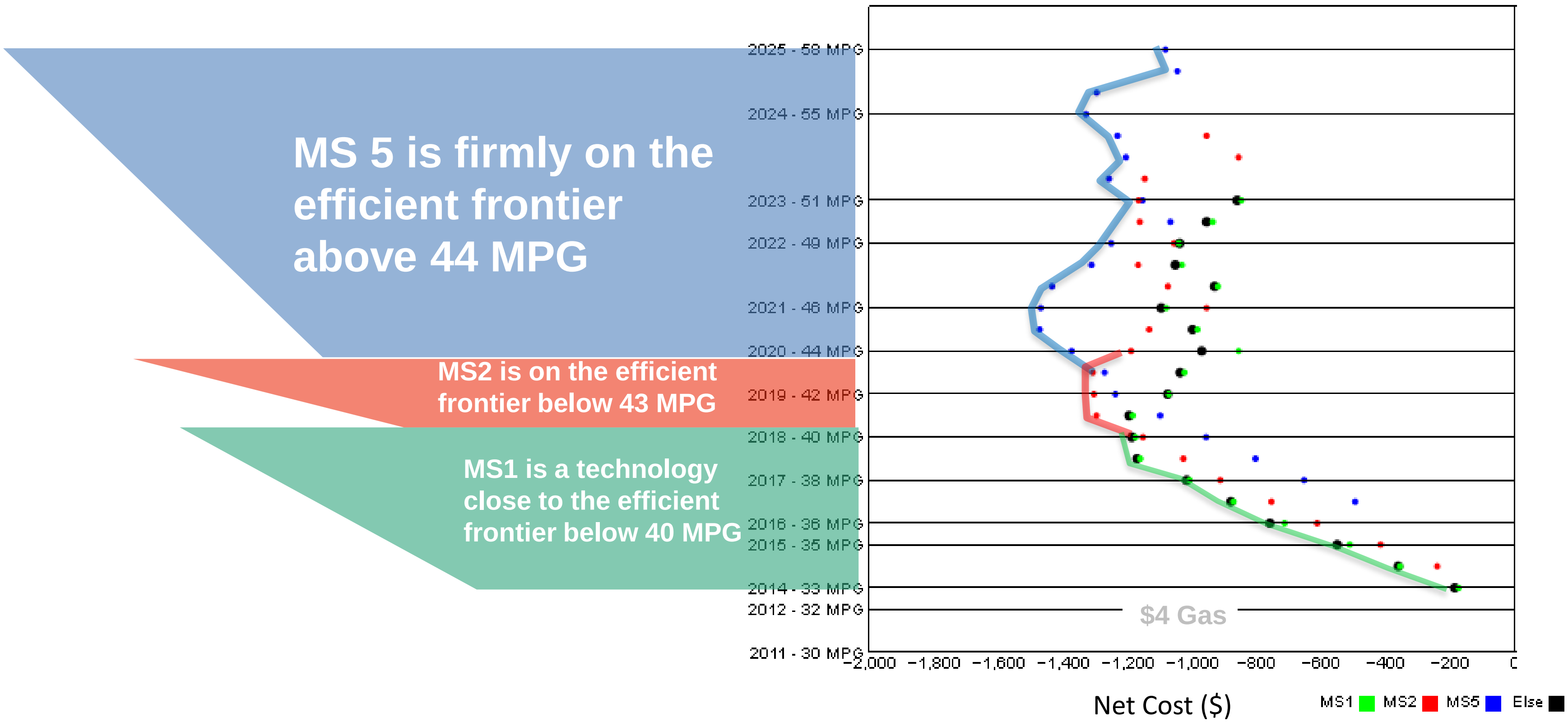
MS1 is a technology close to the efficient frontier below 40 MPG



Above 50 MPG -

Significant Weight Reduction (> 20 %) is Necessary

in Any Cost-Efficient Technology Strategy



Weight Reduction Allows Flexibility - Introduction of Alternative Fuel Economy Technologies

DRIVEALUMINUM

ENTRY YEAR FOR SELECTED TECHNOLOGIES:

	Gas $	LUB	EFR	DCP	CVVL	DVVLD	SGDI	CBRST	EGRB	DSLC	IATC	NAUTO	DCTAM	EPS	IACC	BISG	CISG	PSHEV	MHEV	AERO	ROLL
Else	4	2015	2014	2016	0	2017	2019	2018	2022	2021	2014	0	2014	2018	2021	2019	2023	2024	0	2012	2014
MS1	4	2012	0	2014	2018	2017	2019	0	2022	2021	2023	0	2015	2018	2018	2019	2023	2024	0	2014	2012
MS2	4	2014	0	2017	2019	2018	2020	2020	2023	2021	2015	0	2016	2019	2019	2020	2023	2025	0	2014	2015
MS5	4	2017	2019	2019	0	2021	2022	2021	2024	2023	2023	0	2017	2020	2021	2021	2025	2025	0	2016	2017

$4 - Gas Price

Legend: Color → Year

2012 → 2025

Example:

BISG Application Delay via MS level Adoption

	Gas $	BISG
Else	4	2019
MS1	4	2019
MS2	4	2020
MS5	4	2021

Summary:

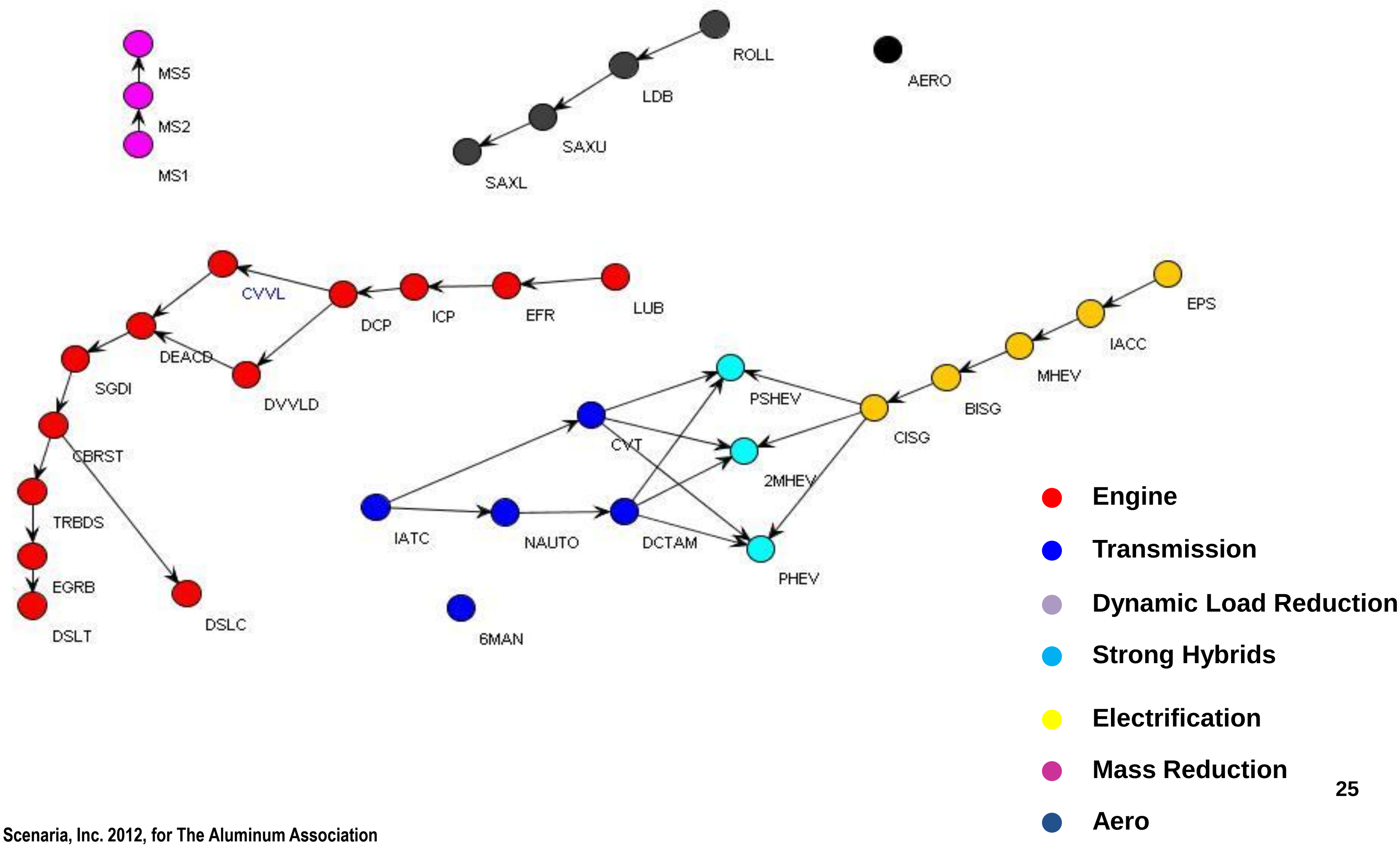
- **At $4/gal gas, weight reduction with aluminum gives automakers flexibility in when to introduce other often more expensive technologies as part of their approach to improving fuel economy.**
- **Example: For low friction engine lubrication (LUB), when no MS or only MS1 is included is introduced in 2012. When MS2 is selected, the entry year for LUB is 2014 and to 2016 for MS5.**
- **Weight reduction strategies allow manufacturers to efficiently manage capital and human resource commitments to alternative fuel economy improvement technologies.**

Appendices

- Appendix A – NHTSA Technologies and Trees (2011-2016)
- Appendix B - MS Sensitivity to Fuel Price & Tech Cost (Bubble Plots)
- Appendix C – Synergies in Technology Bundles (Point Clouds)
- Appendix D - MS Synergies with other Candidate Technologies per Fuel Price Range
- Appendix E – Fuel Price Effect on Payback

Appendix A

NHTSA Technologies and Trees (2011-2016)

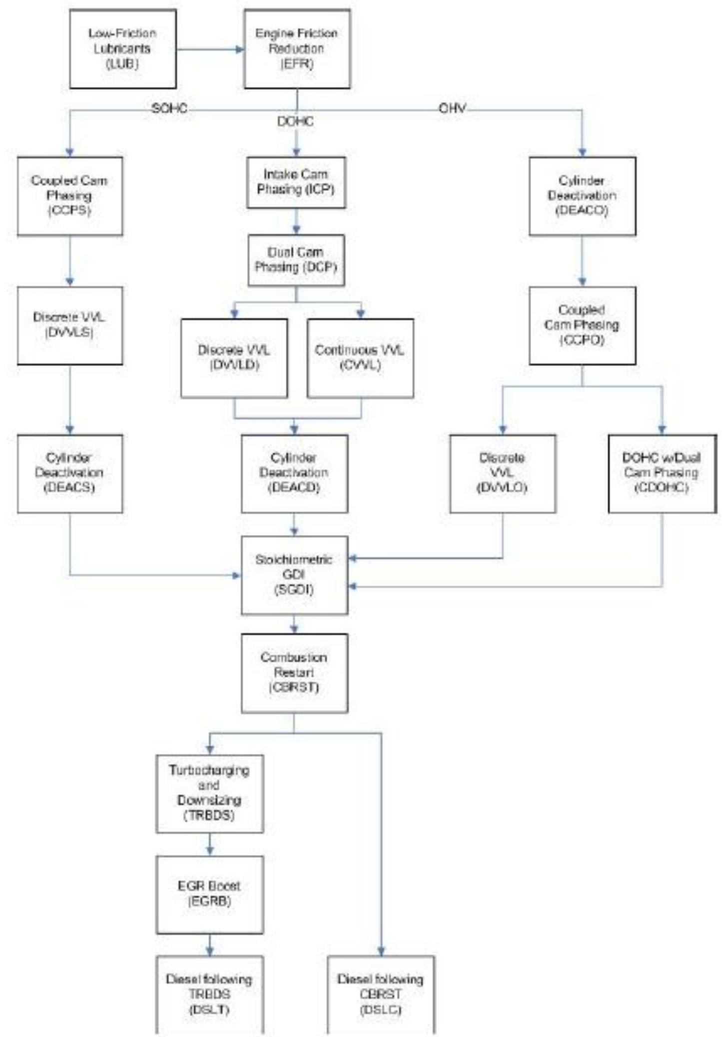


Appendix A (continued)

Technology Index and Definition

Technology Group	Group Members
Engine Technology Group (EngMod)	Low Friction Lubricants (LUB)
	Engine Friction Reduction (EFR)
	Variable Valve Timing type • VVT Coupled Cam Phasing on SOHC (CCPS) • VVT Couple Cam Phasing on OHV (CCPO) • VVT Intake Cam Phasing (ICP) • VVT Dual Cam Phasing (DCP)
	Cylinder Deactivation • on SOHC (DEACS) • on DOHC (DEACD) • on OHV (DEACO)
	Variable Value Lift & Timing • Discrete Variable Valve Lift [DVVL] on SOHC (DVVLS) • Discrete Variable Valve Lift [DVVL] on DOHC (DVVLD) • Continuously Variable Valve Lift (CVVL) • Discrete Variable Valve Lift [DVVL] on OHV (DVVLO)
	Conversion to DOHC with DCP (CDOHC)
	Stoichiometric Gasoline Direct Injection (SGDI)
	Combustion Restart (CBRST)
	Turbocharging and Downsizing (TRBDS)
	Exhaust Gas Recirculation [EGR] Boost (EGRB)
	Dieselization[3] (DSLC, DSLT)
Electrical Accessory Group (ELEC)	Electric Power Steering (EPS)
	Improved Accessories (IACC)
	12 Volt Micro-Hybrid (MHEV)
	Belt Mounted Starter Generator (BISG)
	Crank Mounted Integrated Starter Generator (CISG)
Transmission Technology Group (TrMod)	6-Speed Manual/Improved Internals (6MAN)
	Improved Auto. Transmission Controls/Externals (IATC)
	Continuously Variable Transmission (CVT)
	6/7/8 Speed Transmission With Improved Internals (NAUTO)
	Dual Clutch or Automated Manual Transmission (DCTAM)
Material Substitution Technology Group (MSM)	Mass Reduction 1.5% (MS1)
	Mass Reduction 3.5 – 8.5% (MS2)
Hybrid Technology Group (HEV)	Power Split Hybrid (PSHEV)
	2-Mode Hybrid (2MHEV)
	Plug-in Hybrid (PHEV)
Dynamic Load Reduction Technology Group (DLR)	Low Rolling Resistance Tires (ROLL)
	Low Drag Brakes (LDB)
	Secondary Axle Disconnect (SAXL)
Aerodynamic Reduction Technology Group (AERO)	Aerodynamic Drag Reduction (AERO)

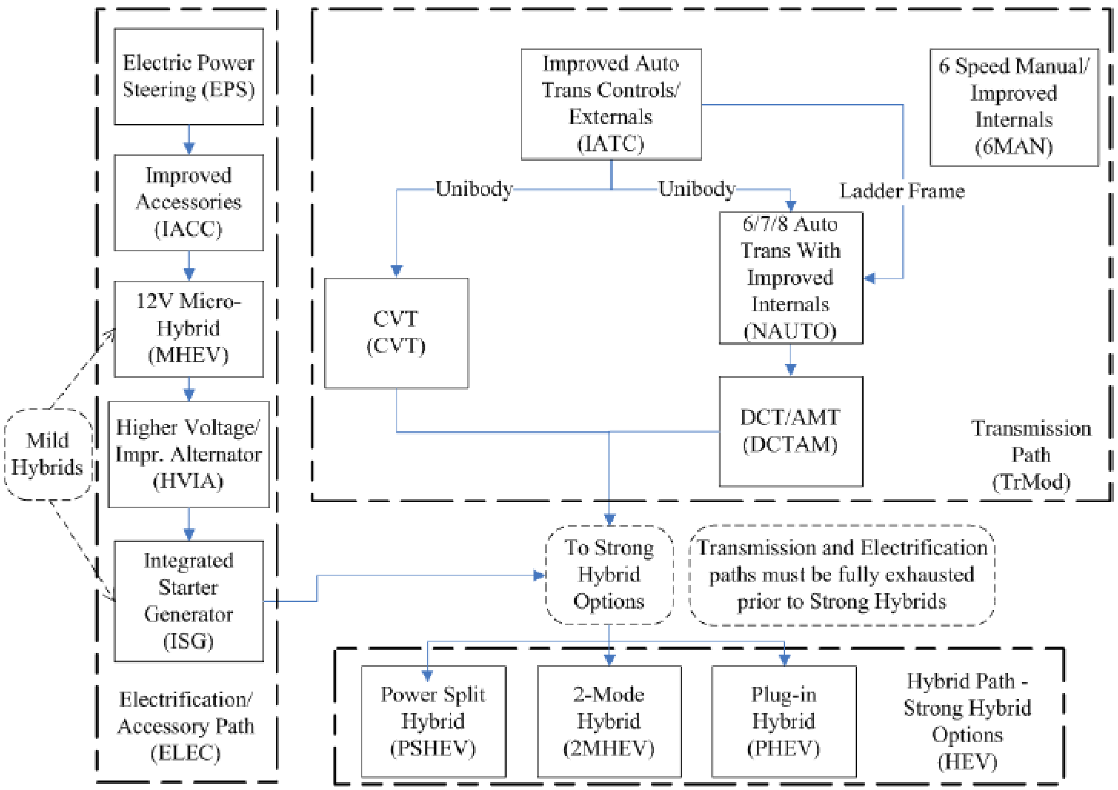
Engine Tech Tree



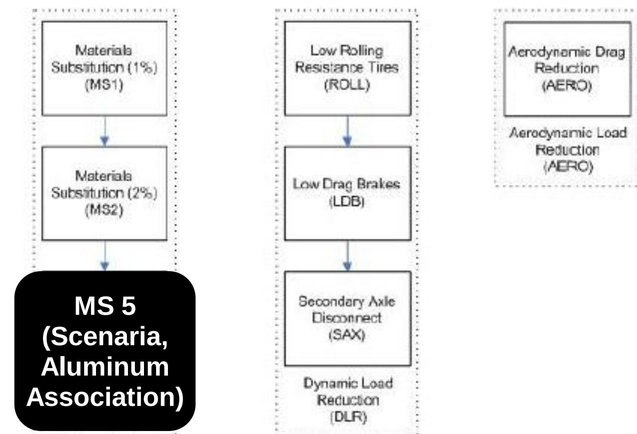
Appendix A (continued)

NHTSA Technologies and Trees (2011-2016)

Transmission and Electrification Trees

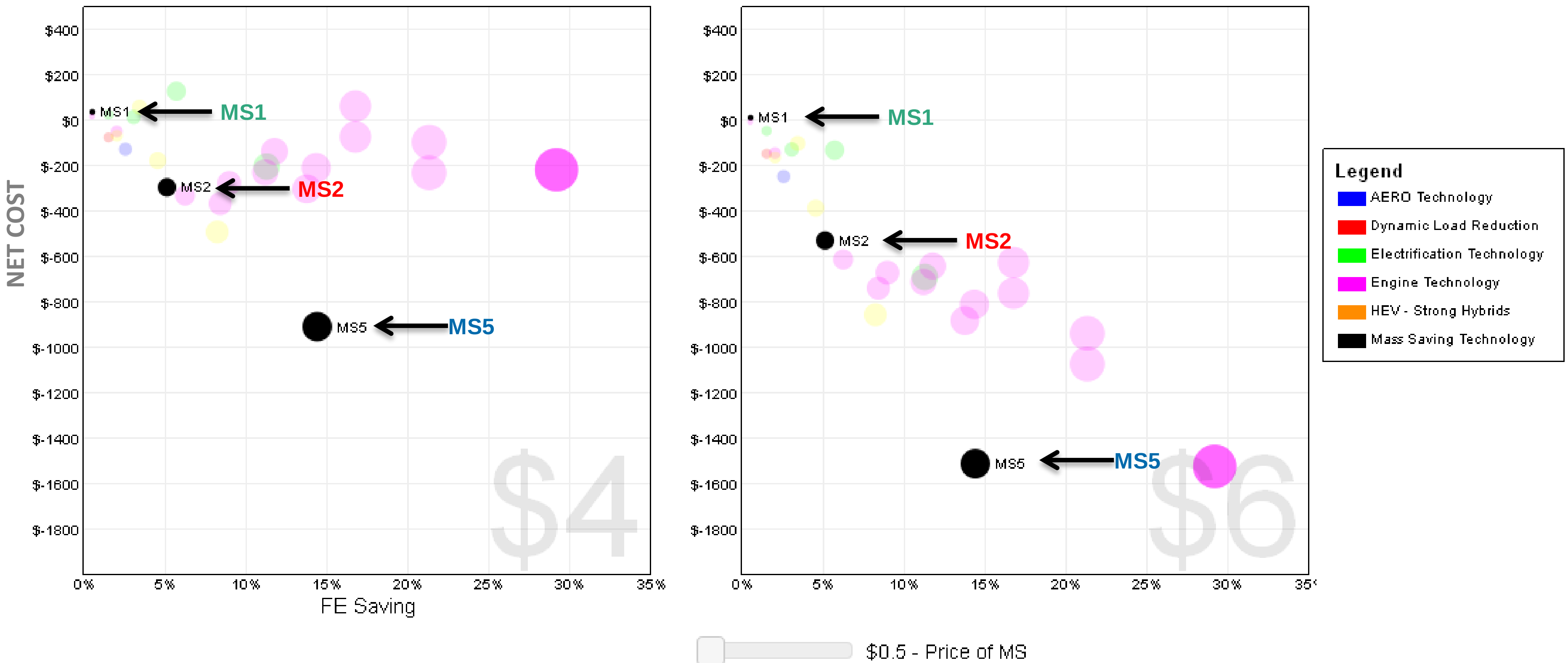


Mass, Dynamic Load and Aero Trees



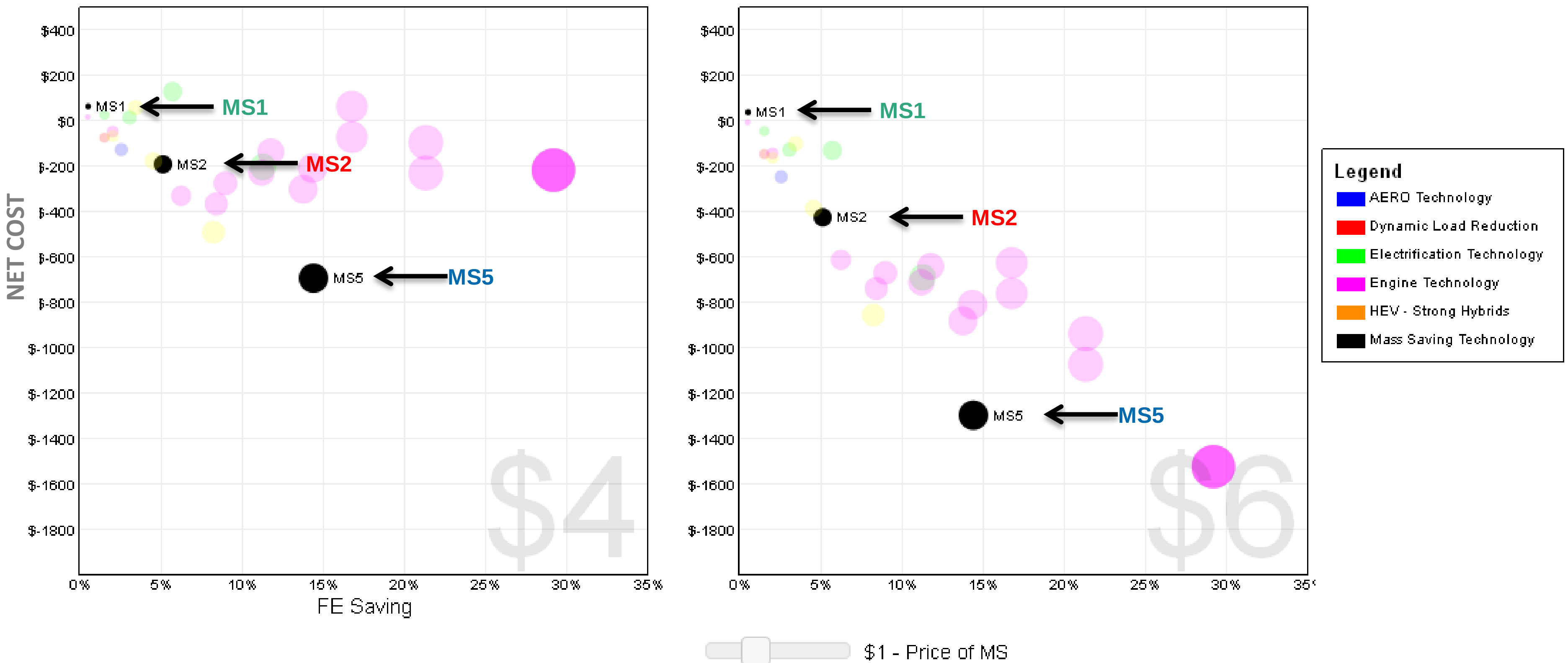
Appendix B

MS Sensitivity to $4-$6 Fuel Price at TC **$0.5/lb**



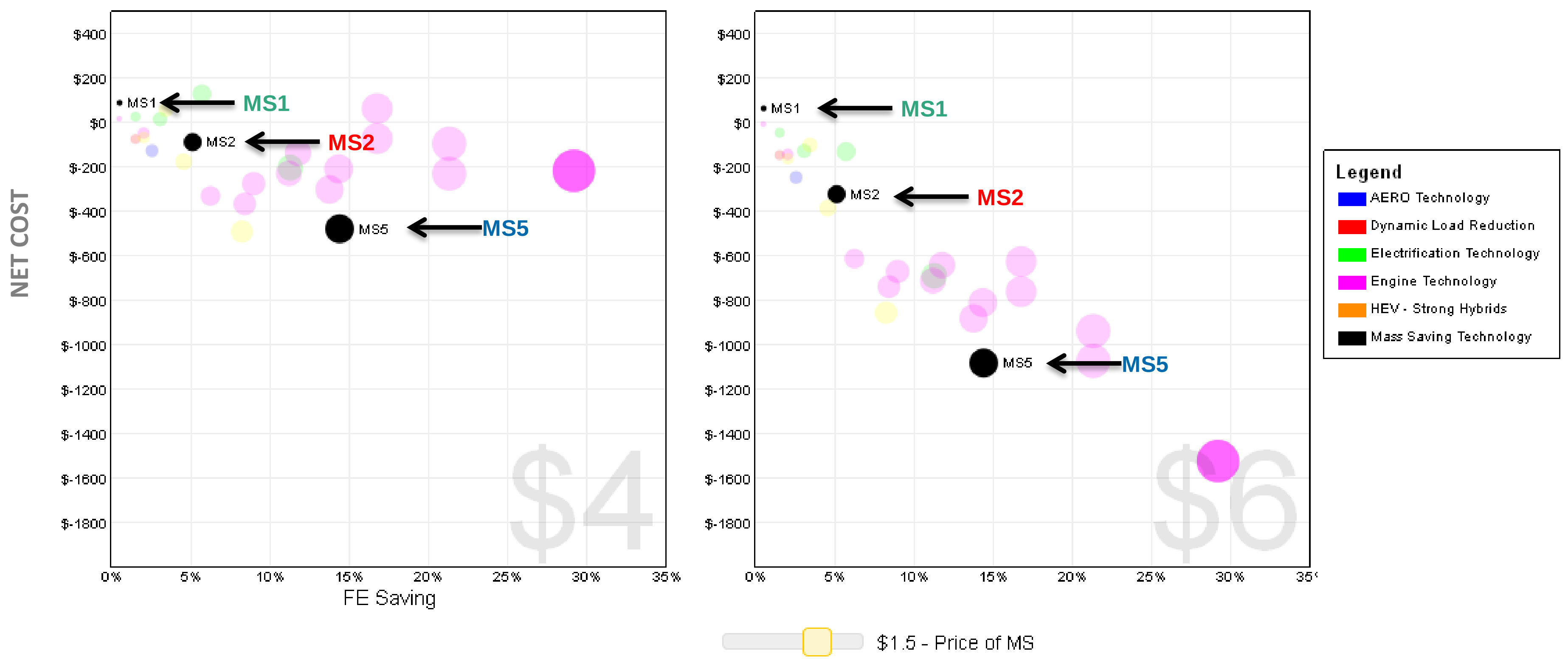
Appendix B

MS Sensitivity to $4-$6 Fuel Price at TC **$1.0/lb**



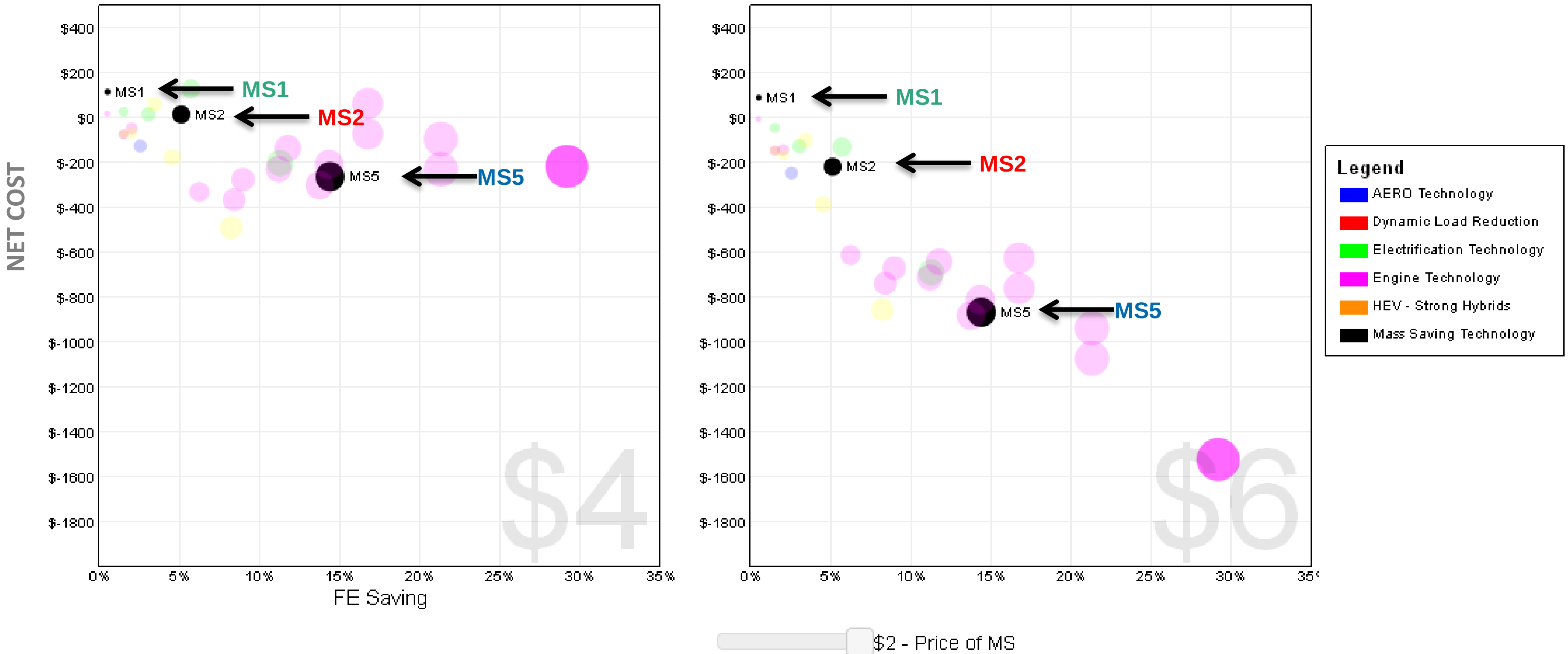
Appendix B

MS Sensitivity to $4-$6 Fuel Price at TC **$1.5/lb**



Appendix B

MS Sensitivity to $4-$6 Fuel Price at TC **$2.0/lb**

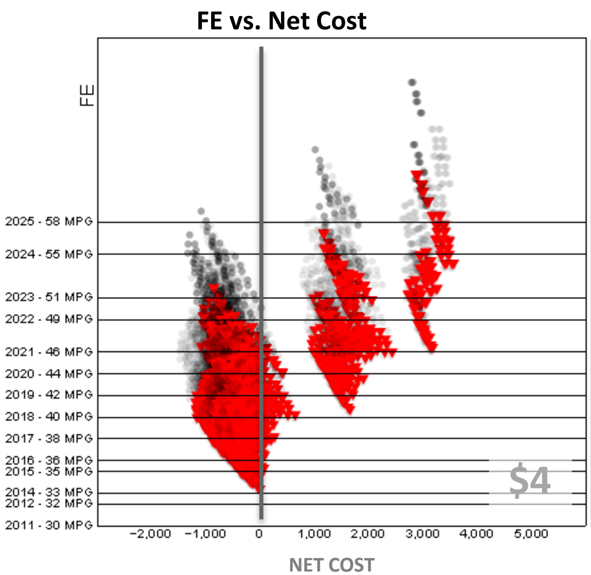


Appendix C

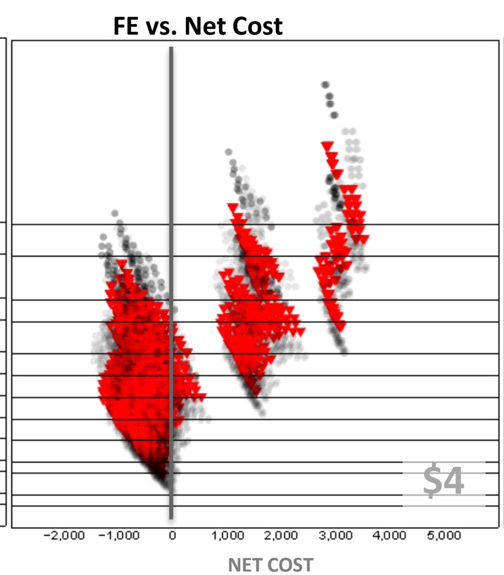
MS (FE / Effective Cost)

Point Cloud Summary:

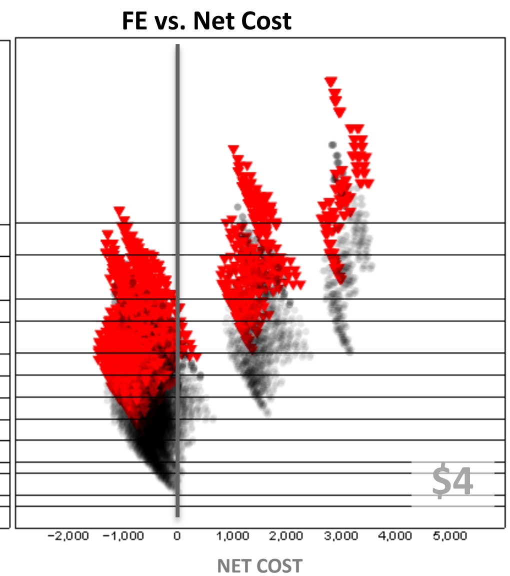
- Net Cost is the criteria
- All MS technologies are effective candidates for bundling / packaging with other techs
- MS1 is a competitive choice for targets of 40 MPG or less
- MS2 is a value-added choice for targets 41-43 MPG
- MS5 is a very good bundle candidate for targets above 44 MPG



MS1



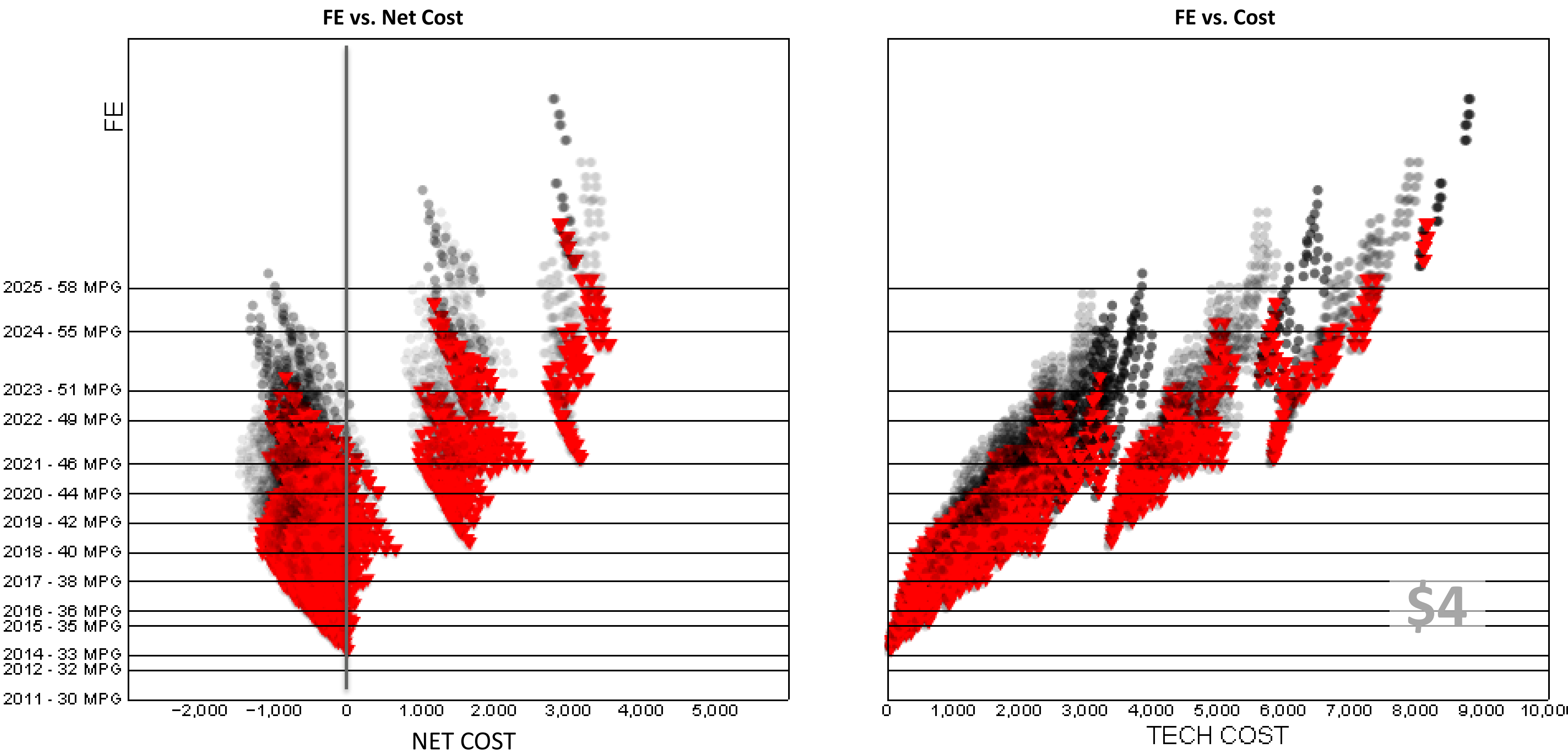
MS2



MS5

Appendix C

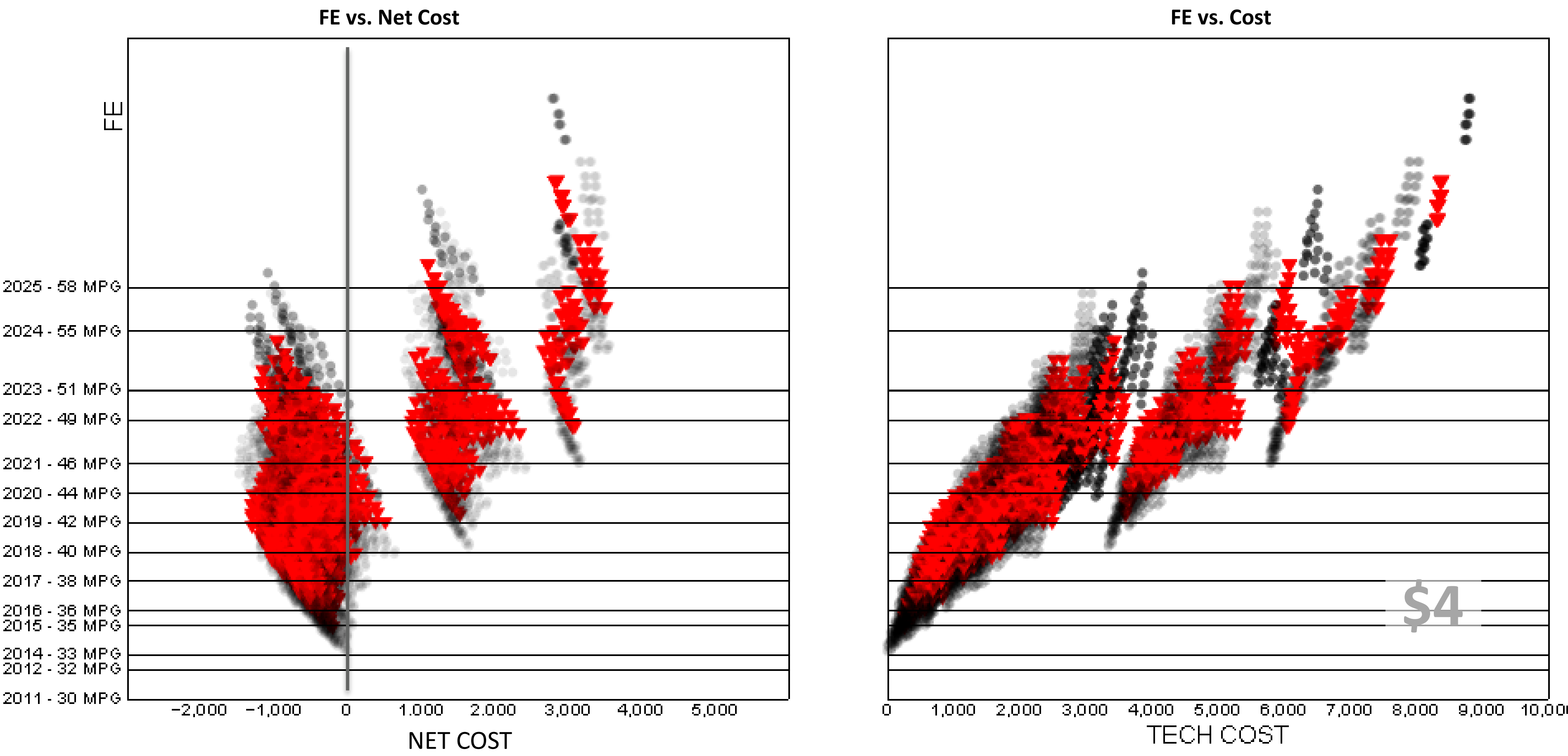
MS1 Synergy in Technology Bundles



Distribution of MS1

Appendix C

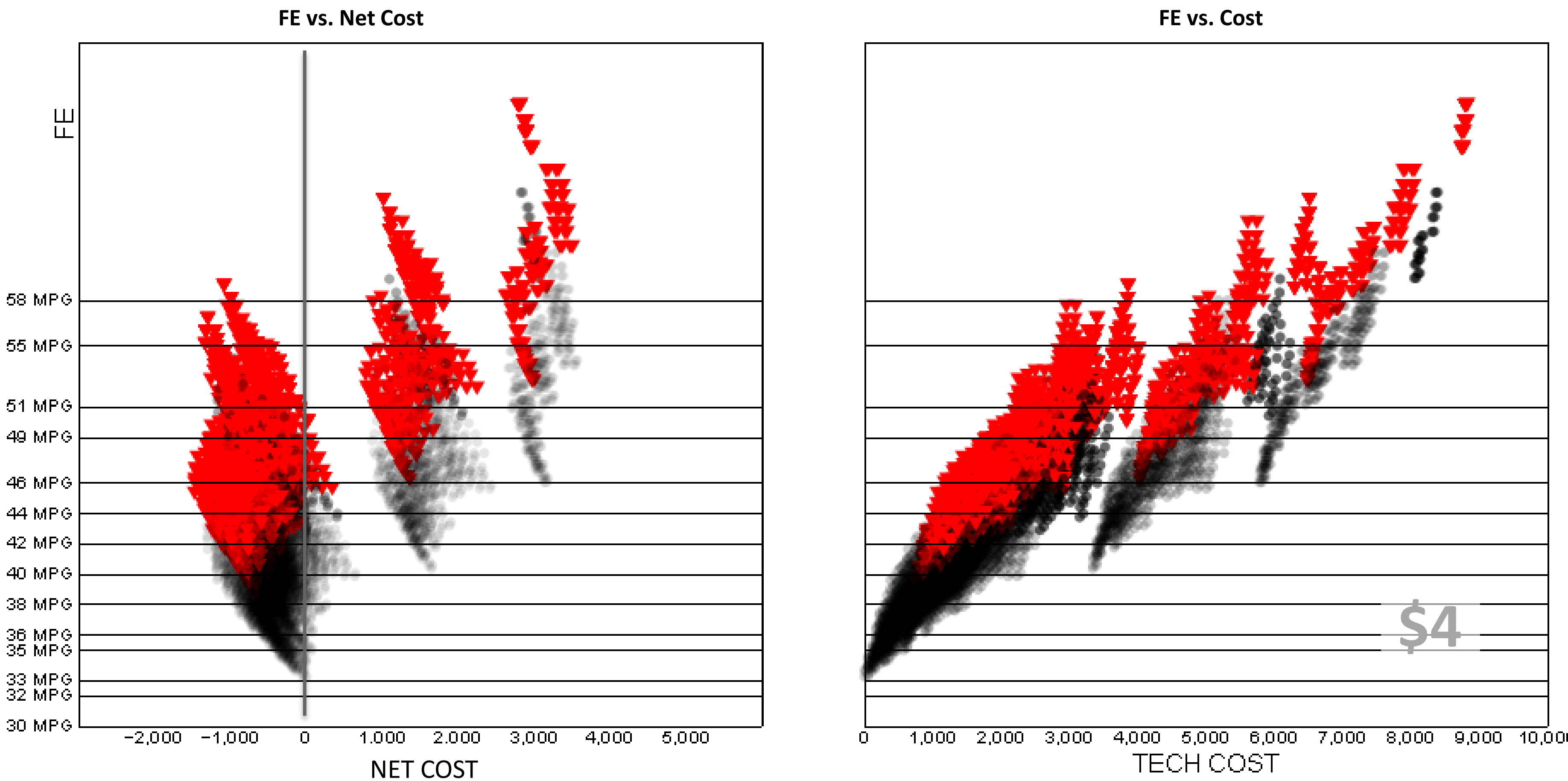
MS2 Synergy in Technology Bundles



Distribution of MS2

Appendix C

MS5 Synergy in Technology Bundles



Distribution of MS5

Appendix D

DRIVEALUMINUM

MS Synergies with other Candidate Technologies per Fuel Price Range for selected Technologies

ENTRY YEAR FOR SELECTED TECHNOLOGIES:

	Gas	LUB	EFR	DCP	CVVL	DVVLD	SGDI	CBRST	EGRB	DSLC	IATC	NAUTO	DCTAM	EPS	IACC	BISG	CISG	PSHEV	MHEV	AERO	ROLL
Else	3	2012	0	2016	0	2018	2019	2018	2022	2021	2023	0	2014	2017	2021	2019	2023	2024	0	2014	2012
MS1	3	2012	0	2014	2018	2018	2019	2019	2022	2021	2023	0	2015	2017	2018	2020	2023	2024	2019	2014	2012
MS2	3	2014	0	2017	2019	2019	2020	2020	2021	2022	2015	0	2016	2018	2019	2021	2023	2025	2020	2014	2015
MS5	3	2016	2019	2019	0	2021	2022	2021	2024	2023	2025	0	2017	2020	2021	2021	2025	2025	2022	2017	2016

$ 3 - Gas Price

	Gas	LUB	EFR	DCP	CVVL	DVVLD	SGDI	CBRST	EGRB	DSLC	IATC	NAUTO	DCTAM	EPS	IACC	BISG	CISG	PSHEV	MHEV	AERO	ROLL
Else	4	2015	2014	2016	0	2017	2019	2018	2022	2021	2014	0	2014	2018	2021	2019	2023	2024	0	2012	2014
MS1	4	2012	0	2014	2018	2017	2019	0	2022	2021	2023	0	2015	2018	2018	2019	2023	2024	0	2014	2012
MS2	4	2014	0	2017	2019	2018	2020	2020	2023	2021	2015	0	2016	2019	2019	2020	2023	2025	0	2014	2015
MS5	4	2017	2019	2019	0	2021	2022	2021	2024	2023	2023	0	2017	2020	2021	2021	2025	2025	0	2016	2017

$ 4 - Gas Price

	Gas	LUB	EFR	DCP	CVVL	DVVLD	SGDI	CBRST	EGRB	DSLC	IATC	NAUTO	DCTAM	EPS	IACC	BISG	CISG	PSHEV	MHEV	AERO	ROLL
Else	6	2015	2014	2016	0	2018	2019	0	2024	2020	2014	0	2014	2016	2017	2018	2023	2024	0	2012	2014
MS1	6	2012	0	2014	0	2017	2019	0	2024	2020	2014	2019	2015	0	2018	2018	2023	2024	0	2014	2012
MS2	6	2014	0	2017	0	2019	0	2019	2025	2020	2015	0	2016	2017	2018	2020	2023	2025	0	2014	2015
MS5	6	2017	2019	2019	0	2020	0	2021	2025	2022	2017	0	2017	2020	2021	2021	2025	2025	0	2016	2018

$ 6 - Gas Price

Legend: Color → Year

2012 → 2025

Example:

BISG Application Delay via MS level Adoption ↓

	Gas$	BISG
Else	4	2019
MS1	4	2019
MS2	4	2020
MS5	4	2021

Appendix E

Fuel Price Effect on Technology Bundles Payback

$$Net\ Consumer\ Cost = Technology\ Cost\ - Fuel\ Consumption\ Savings$$

As Fuel price rises, the more expensive technologies with higher FE improvement impact start paying for themselves.