UNITED STATES
DEPARTMENT OF TRANSPORTATION

Applications for the Environment: Real-Time Information Synthesis (AERIS) – Benefit-Cost Analysis

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On behalf of:
AERIS Program

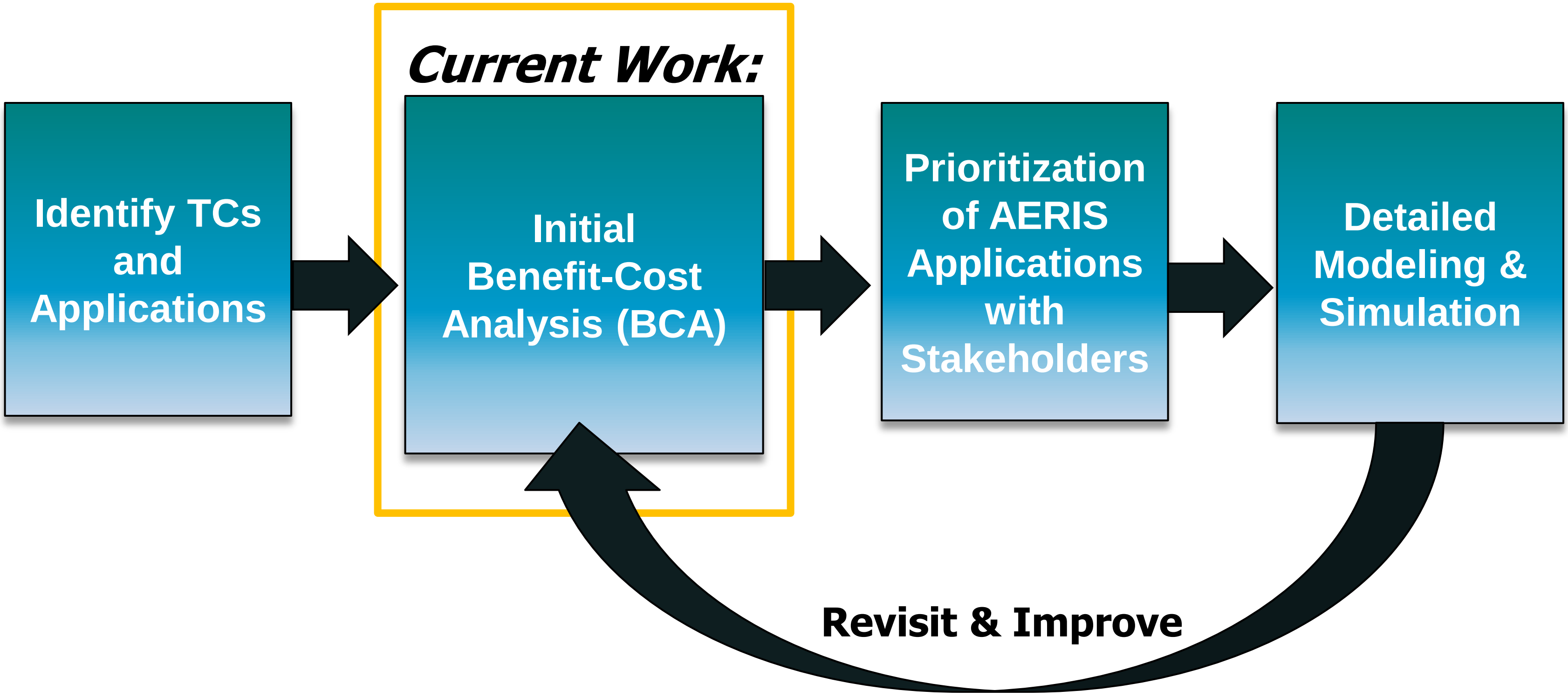
AERIS

Agenda

1. PURPOSE OF BENEFIT-COST ANALYSIS
2. OVERVIEW OF APPROACH
3. BASELINE ASSUMPTIONS
4. BENEFIT ANALYSIS
5. COST ANALYSIS
6. NATIONAL EXTRAPOLATION
7. RESULTS

Evaluation of AERIS Applications

Identify, evaluate, and prioritize applications that leverage connected vehicle technologies that have the potential of providing significant environmental benefits



Transformative Concepts and Applications

Transformative Concept	AERIS Application
Eco-Signal Operations	Eco-Traffic Signal Timing
	Eco-Freight Signal Priority
	Eco-Transit Signal Priority
	Eco-Approach and Departure at Signalized Intersections
	Connected Eco-Driving
Dynamic Eco-Lanes	Dynamic Eco-Lanes
	Eco-Speed Harmonization
	Eco-Cooperative Adaptive Cruise Control
	Eco-Ramp Metering
	Multi-Modal Traveler Information
Dynamic Low Emissions Zones	Dynamic Emissions Pricing
	Connected Eco-Driving
	Multi-Modal Traveler Information
Support AFV Operations	AFV Charging/Fueling
	AFV Engine Performance Optimization
Eco-Traveler Information	Dynamic Eco-Routing
	Flexible Eco-Transit Routing
	Dynamic Eco-Freight Routing
	Eco-Smart Parking
	Connected Eco-Driving
	Multi-Modal Traveler Information
Eco-Integrated Corridor Management	Eco-Integrated Corridor Management Decision Support System

Purpose of Benefit-Cost Analysis

- What magnitude of benefits can be expected from AERIS applications?
- What costs will be incurred by deploying these applications?
- Do the benefits outweigh the costs?
- Which applications provide the highest benefit to cost ratio?

Benefits vs. Costs

Key Assumptions & Scope

- Only *incremental* costs were evaluated; connected vehicle infrastructure is assumed to be in-place

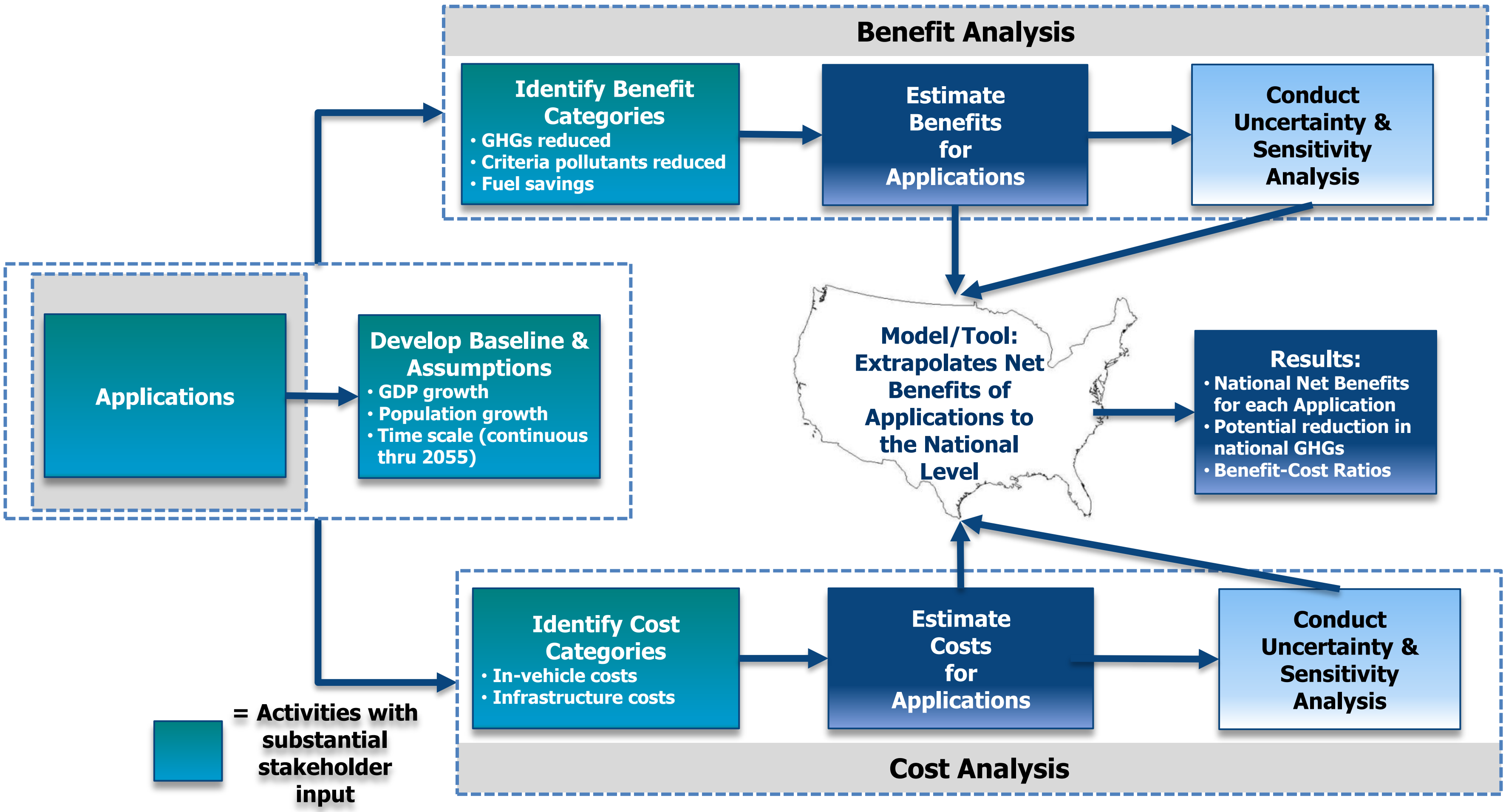
- Only *environmental* benefits were considered:
  - Greenhouse gas reductions
  - Criteria pollutant reductions
  - Fuel savings

- Costs and benefits data were derived from literature:
  - ITS Cost-Benefit Database
  - AERIS Broad Agency Announcement (BAA) Projects
  - Environmental Protection Agency Vehicle Emissions Factors

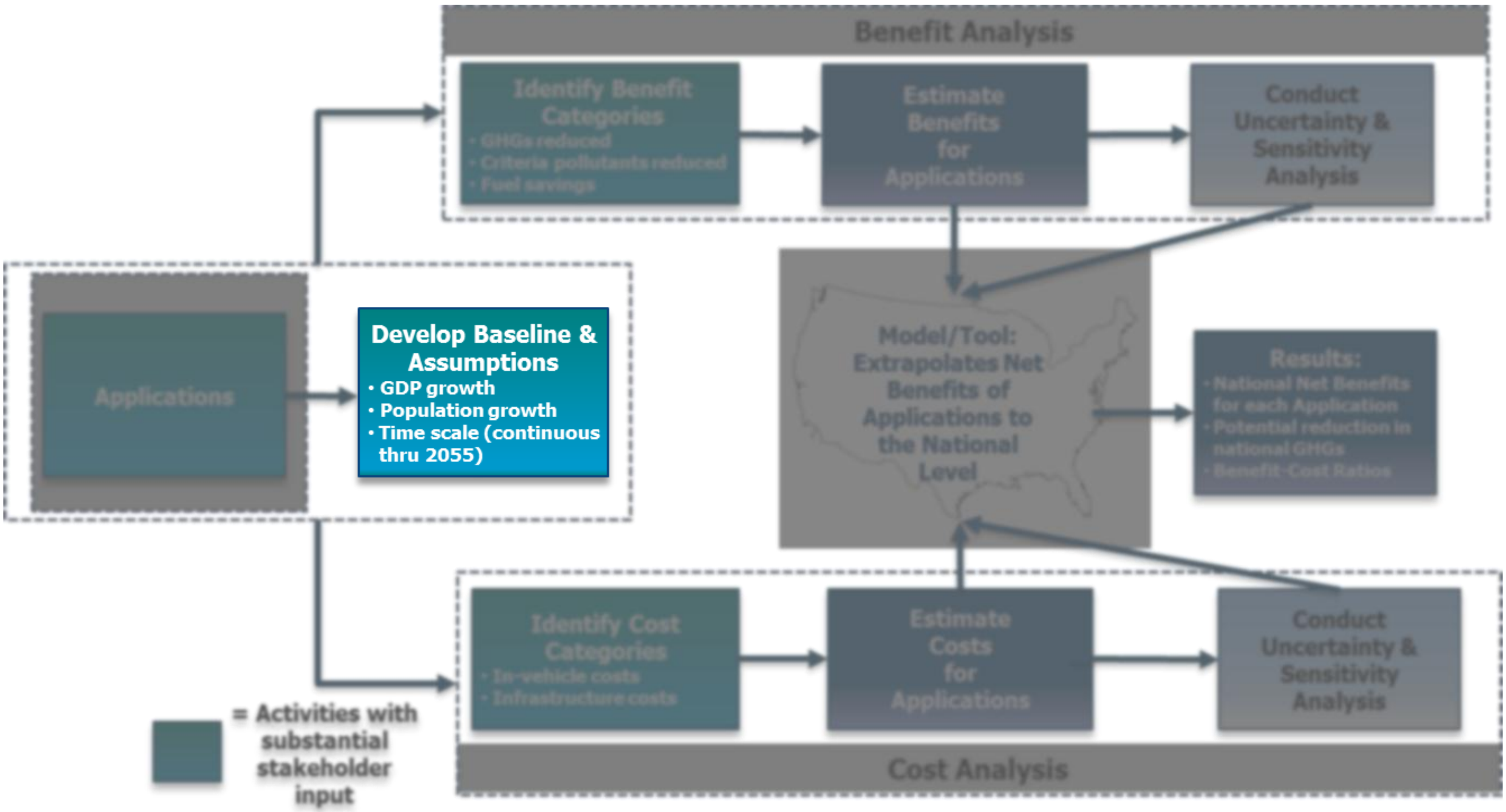
In most cases, the AERIS team made the most conservative assumptions

AERIS BCA Summary Approach

Systematic approach to project nationwide benefits and costs



Baseline Development



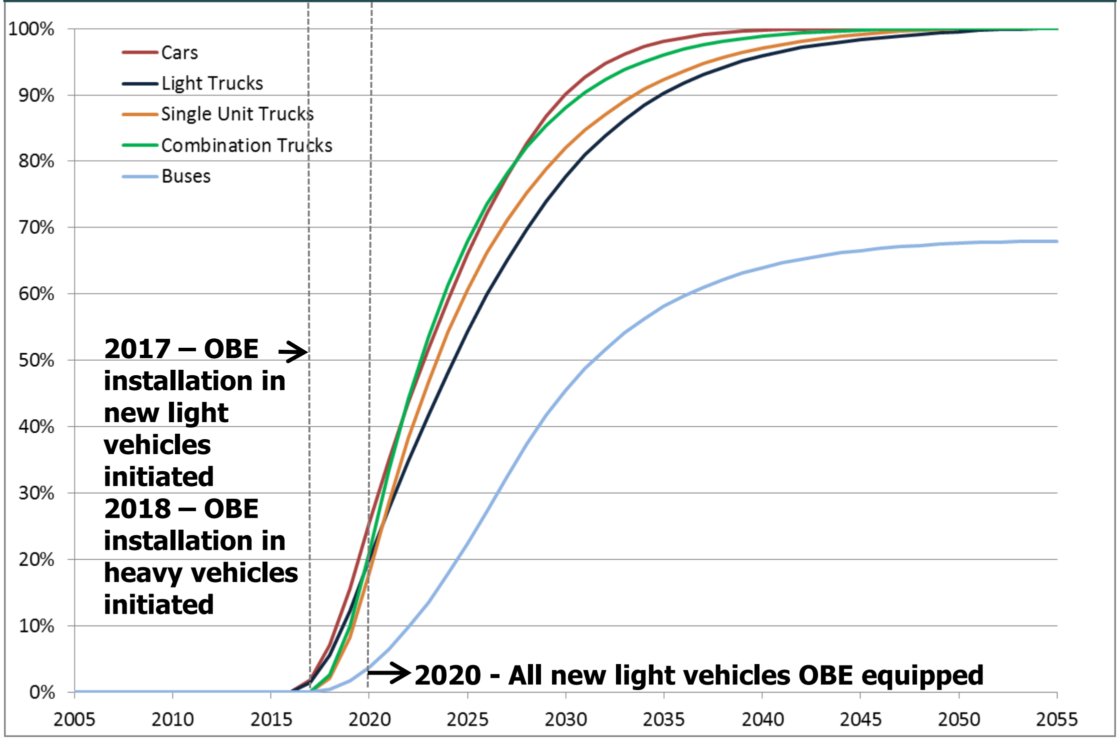
Baseline Assumptions

- On-Board Equipment (OBE) Deployment Rate
- Roadside Equipment (RSE) Deployment Rate
- AERIS Application Deployment Rate
- AERIS Application Compliance Rate
  - Driver Compliance
  - Agency (or Jurisdiction) Compliance
- Other Key Variables
  - Fuel Price
  - Vehicle Miles Travelled

On-Board Equipment (OBE) Deployment Rate

Vehicle Class	Phase-In Start	Phase-In Duration	Installed at Maturity	Source
Cars	2017	3	100%	Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis Version 2.3 (Draft); US DOT ITSJPO; Prepared by Volpe National Transportation Systems Center; May 8, 2008.
Light Trucks	2017	3	100%	
Single Unit Trucks	2018	3	100%	
Combination Trucks	2018	3	100%	
Buses	2018	10	68%	Automatic Vehicle Locator deployment used to estimate. Source - DOT RITA ITS, "Transit Management Deployment Statistics", April 2011

Percentage of Fleet with OBE



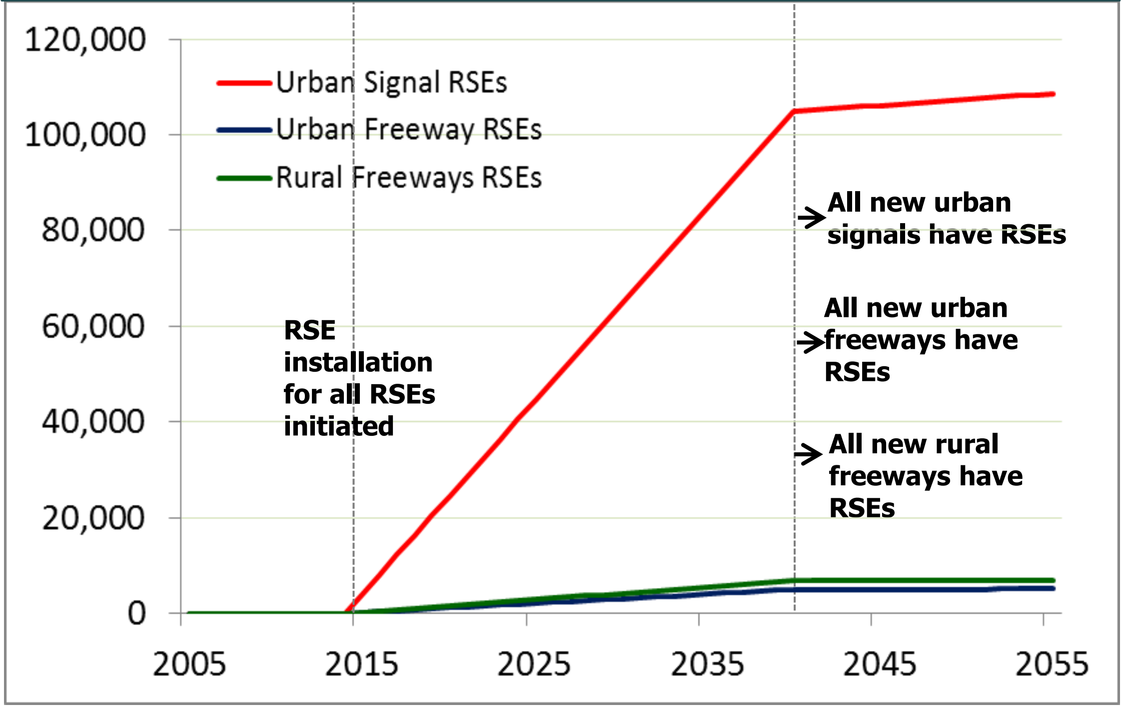
Key Assumptions

- OBE is in-vehicle equipment that enables vehicle to be connected to other vehicles and infrastructure.
- Deployment assumes 2013 NHTSA decision with 2 years for rule-making and 2 years for litigation.
- Assumes manufacturers are required to initiate phase-in of OBEs in 2017 and by 2020, all new light duty vehicles must have OBE.
- Assumes buses not required to install OBEs. Deployment is based on trend of Automatic Vehicle Location (AVL) equipment.
- After-market OBE retrofits are not considered (for initial BCA).
- Fleet turnover model uses assumptions to estimate the number of vehicles (by type) on the road each year with OBEs.

Road Side Equipment (RSE) Deployment Rate

RSE Location	Phase-In Start	Phase-In Years	Installed at Maturity	Source
Urban Freeway	2015	25	2 per 10 miles (one in each direction)	Started with Volpe Center Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis Version 2.3 (Draft) assumptions; based on internal AERIS team meeting, made RSE deployment more conservative ; based on JPO June 20th brief further revised down deployment.
Rural Freeway	2015	25	2 per 10 miles (one in each direction)	
Urban Signal	2015	25	1/3 of signals	

Number of RSEs (by type)



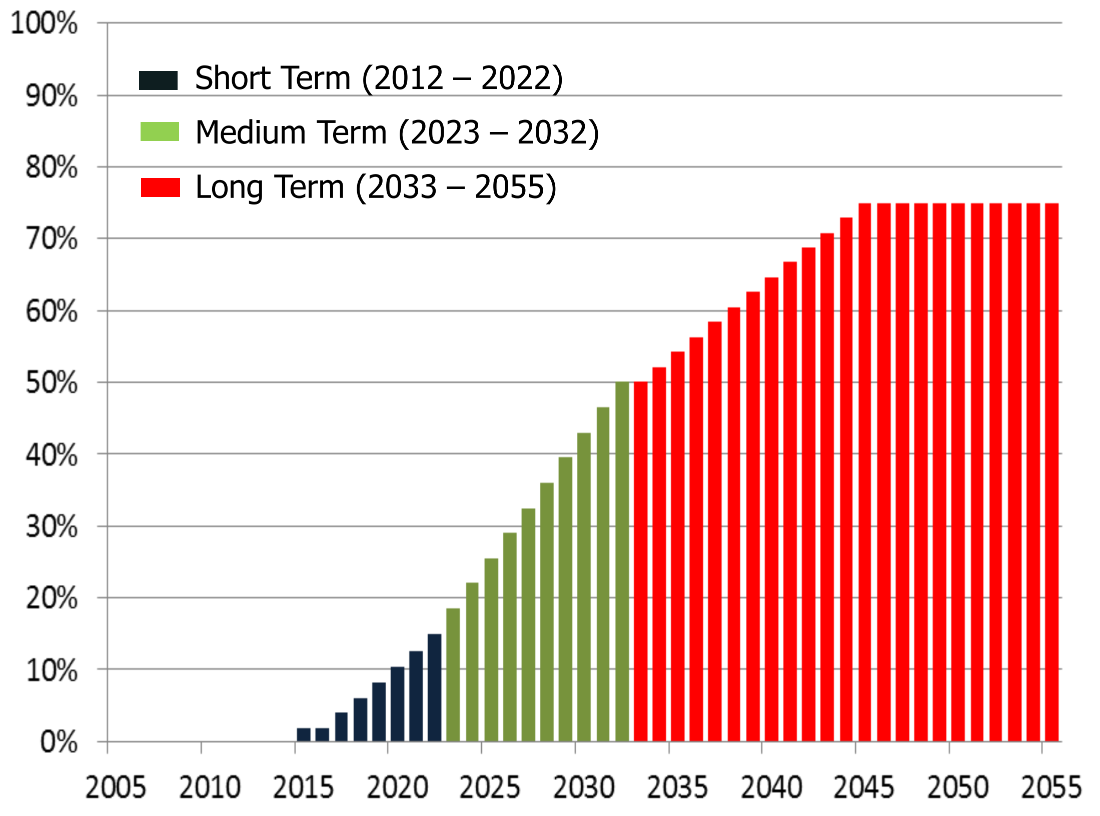
Key Assumptions

- RSE is equipment on road or at traffic signal that enables information to be passed to OBEs.
- Deployment assumes no readily available federal funding for RSEs.
- RSEs are needed to enable DSRC communication. AERIS applications that are not signal based do not rely on RSEs; rather they utilize cellular communication.
- RSE number based on freeway road miles and number of traffic signals.
- At full deployment, 30% of urban traffic signals will have an RSE.
- At full deployment, urban and rural freeways will have 2 RSEs every 10 miles (one for each direction).

AERIS Application Deployment Rate

Application	Short	Medium	Long	Source
All Applications	15%	50%	75%	AERIS team
Short Term = 2015 – 2022	Medium Term = 2023 – 2032		Long Term = 2033 - 2055	

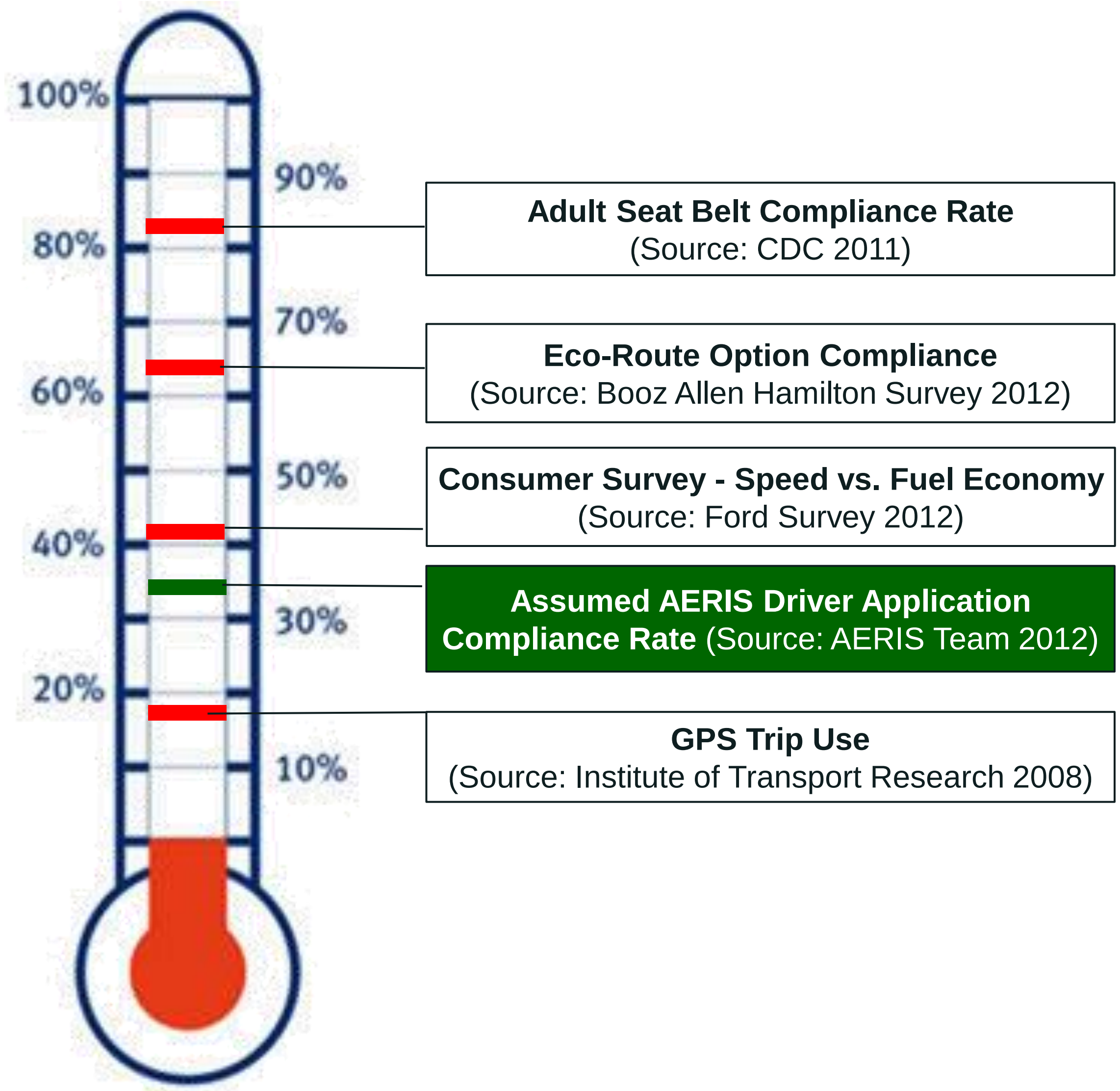
Application Deployment Rate (%)



Key Assumptions

- AERIS application benefits will only be realized if connected vehicle system is in-place.
- All AERIS applications are deployed at the same rate. This assumption may be revised in future iterations when more information becomes available.
- In the short term, 15% of the available connected vehicle system will have AERIS applications.
- In the medium term, 50% of available connected vehicles system will have AERIS applications and 75% in the long term.
- Application deployment doesn't reach 100%, even in the long-term.
- Traffic signal-based applications are only deployed in urban areas (RSEs are only deployed at urban traffic signals).

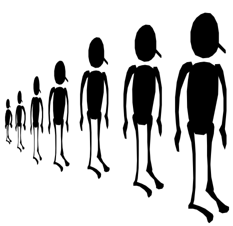
Compliance Rates: Driver & Agency

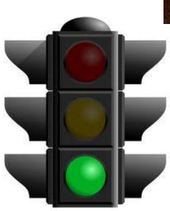


Key Assumptions

- Drivers are not likely to use applications 100% of the time.
- Similarly, agency's may not use applications optimized for the environment 100% of the time.
- The Driver and Agency Compliance Rates directly impact benefits generated.
- The AERIS Team used 33% for driver compliance rate for applications that drivers can choose to opt-in or use. *Four AERIS applications allow driver the ability to choose extent of usage.*
- The AERIS Team used 30% for agency compliance rate. *Seven AERIS applications can be turned on and off by agencies.*

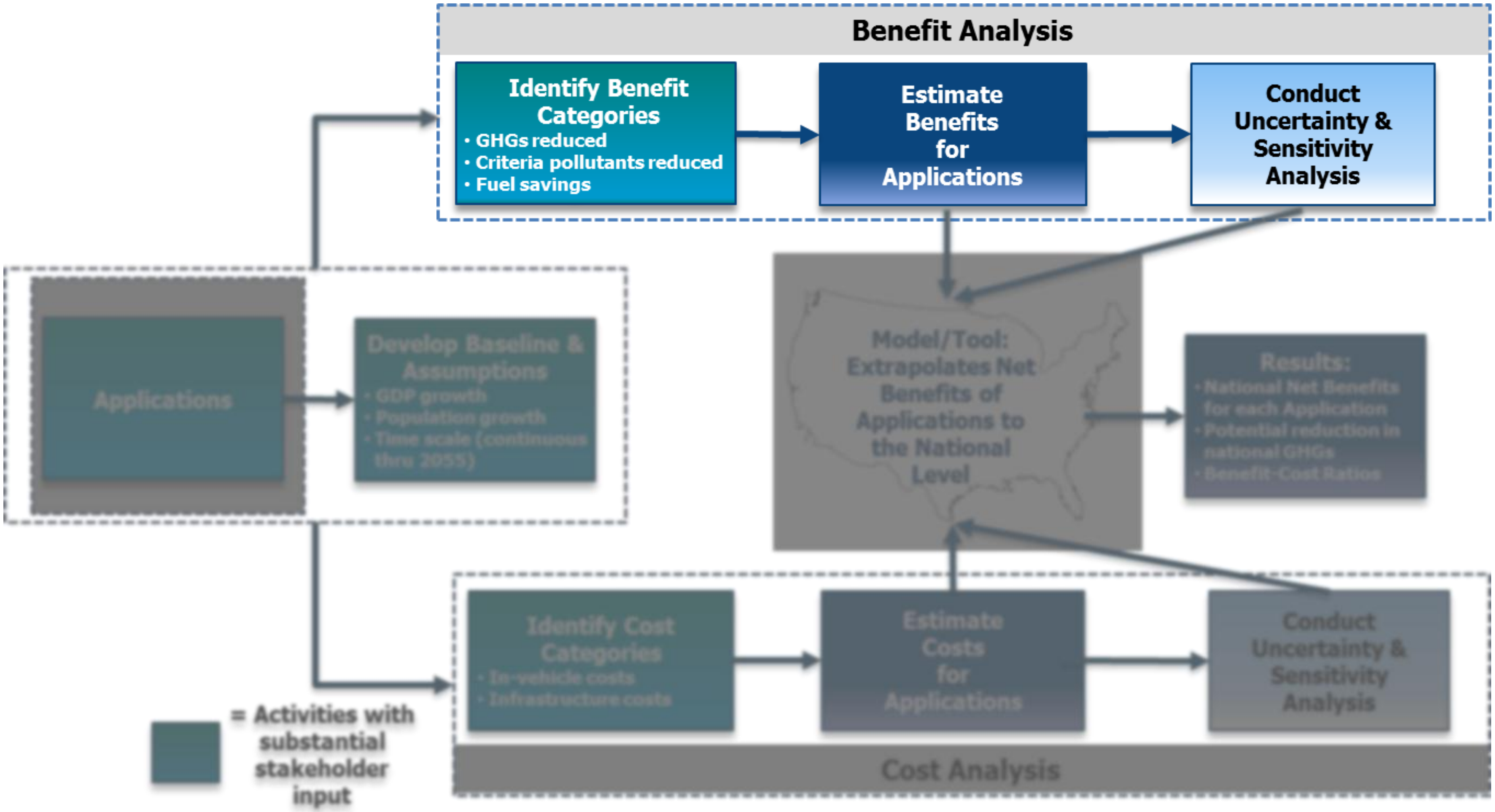
Other Key Variables





Variable	Impact on Model	Source
Fuel Price	Value of fuel savings in benefit estimate Impacts number of vehicle miles travelled	
Vehicle Miles Traveled	Many AERIS applications yield benefits per vehicle mile traveled	
Vehicle Fuel Efficiency (on-road)	As fuel efficiency increases, AERIS application benefits decrease	DOE EIA AEO 2011 Reference Case
Greenhouse Gas Emissions from Transportation	Reference point to measure impact of applications on baseline GHG emissions	
Population Growth	Impacts cost of outreach and education	
Miles (freeway, arterial, local)		FHWA Highway Statistics 2007
Traffic Signals		

Benefit Analysis



Benefit Analysis Approach

Data Collection

1) An extensive literature review was conducted
2) Case studies, or other sources, were collected and the environmental benefit estimates were assessed

Data Normalization

1) Reported benefits data were normalized to derive an absolute value on a per unit basis (i.e. grams per VMT or gallons per vehicle)

Monetization

1) Unit benefits were monetized utilizing EPA, DOT, or DOE data on the value of reducing emissions or fuel savings (projected values change over time)

Nationwide Extrapolation

1) Monetized unit benefits are multiplied by # of units per representative area taking into account the application adoption rate
2) Annual national monetized benefits are aggregated

Results

Benefits will be available for any year or as Net Present Value

Results are comparable between applications for purposes of ranking the relative merits of applications

Derivation of Benefit Estimates from Literature

Extensive Analysis of Benefit Estimates Available in the Literature

Application	Benefits Reported	Source
Eco-Transit Signal Priority	Reduced transit delay up to 40% (not clear what the wait time for other traffic is); Second study reduction of 15% (3 minutes) in running time; in LA - bus running time was reduced by 25%.	Transit Signal Priority (TSP): A Planning and Implementation Handbook; May 2005
	Fuel consumption decreased by 3.6%, NOx were reduced by 4.9%, CO decreased by 1.8%, HC declined by 1.2 %, and PM decreased by 1.0%.	The Benefits of a Pilot Implementation of Public Transport Signal Priorities and Real-Time Passenger Information; Lehtonen, Mikko and Risto Kulmala; Paper presented at the 81st Annual Transportation Research Board Meeting; Washington, DC; 13-17 January 2002.
	Fuel consumption increased from 0.3 % to 2.9%; HC emissions ranged from a decrease of 0.3% to an increase of 0.7%; CO decreased between 0.6 percent and 1.0 percent; NOx emissions increased between 0.18% and 1.1%	Evaluation of Transit Signal Priority Benefits Along A Fixed-Time Signalized Arterial; Dion, Francois, et al.; Paper presented at the 81st Annual Transportation Research Board Meeting. Washington, District of Columbia; 13-17 January 2002
	TSP studies reported that bus emissions were reduced up to 30%, non-transit vehicle emissions increased up to 11%.	Transport Research Laboratory. (1999). Monitoring and Evaluation of a Public Transport Priority Scheme in Southampton. Publication Report No. 413, University of Southampton and University of Portsmouth.
Eco-Adaptive Cruise Control	Fuel reductions up to 10% and CO2 and NOx reductions of 3%. PM increased by 3% in one pilot.	Mahmod, M. et el. (2009). Modeling reduced traffic emissions in urban areas.TRB 2010 Annual Meeting. Washington, DC: TRB.
	Simulated results of one ICC vehicle in a line of 10 manually operated vehicles yielded CO reduction from 18.4% to 60.6%, CO2 reduction from 8.1% to 60.6%, NOx 13.1% to 1.5%, HC from 15.5% to 55.4%, fuel consumption 8.5% to 28.5%.	Evaluation of the Environmental Effects of Intelligent Cruise Control (ICC) Vehicles; Bose, A. and P. Ioannou; Paper presented at the 80th Annual Transportation Research Board Meeting. Washington, District of Columbia; 7-11 January 2001
	27% savings in fuel consumption.	Eco-Driving Application Development and Testing; Hesham A. Rakha

Key Sources

- Government reports including: DOT and National Academies
- Scholarly journals from: University and other sources of private transportation research.
- AERIS Broad Agency Announcement Reports
- ITS Cost-Benefit Database
- Examples include:
  - Georgia Regional Transportation Authority. *Atlanta Smart Corridor Project Evaluation Report; TransCore for the Georgia Regional Transportation Authority.* June 2010.
  - Department of Transportation, Federal Transit Administration. *Transit Signal Priority (TSP): A Planning and Implementation Handbook.* May 2005.
  - Wang, Z., & Walton, C. M. *An Investigation on the Environmental Benefits of a Variable Speed Control Strategy.* National Technical Information Service. 2006.

Normalization of Benefit Data

Benefits Reported*	Conversion
1) Benefits reported as %.	1) Used project parameters and outside information…i.e. average idling emissions.
2) Benefits reported at project level.	2) Used project parameters to estimate for a unit…such as grams per mile.
3) Benefits not reported for all benefit categories.	3) Used EPA's average vehicle emission/fuel factors …i.e. 1 gallon of fuel saved is equivalent to 8,849 grams CO_2.

Application	Unit Basis (Annual)
Eco-Traffic Signal Timing	Per Intersection Crossing
Eco-Freight Signal Priority	Per Intersection Crossing
Eco-Transit Signal Priority	Per Bus /Region
Connected Eco-Driving	Per Intersection Crossing
Eco-Speed Harmonization	Per Vehicle Mile Travelled
Eco-Ramp Metering	Per Freeway Mile /Vehicle
Eco-Adaptive Cruise Control	Per Vehicle/VMT
Dynamic Emission Pricing	Per Vehicle/VMT
Eco-Smart Parking	Per Vehicle/Parking Space
AFV Charging/Fueling Info	Per Vehicle/VMT
AFV Engine Performance Opt	Per Vehicle/VMT
Dynamic Eco-Routing	Per Vehicle/VMT
Flexible Eco-Transit Routing	Per Bus/VMT
Eco-Approach & Departure at Signalized Intersections	Per Intersection Crossing
Multi-Modal Traveler Info	Per VMT
Eco-Network Decision Sup	Per VMT

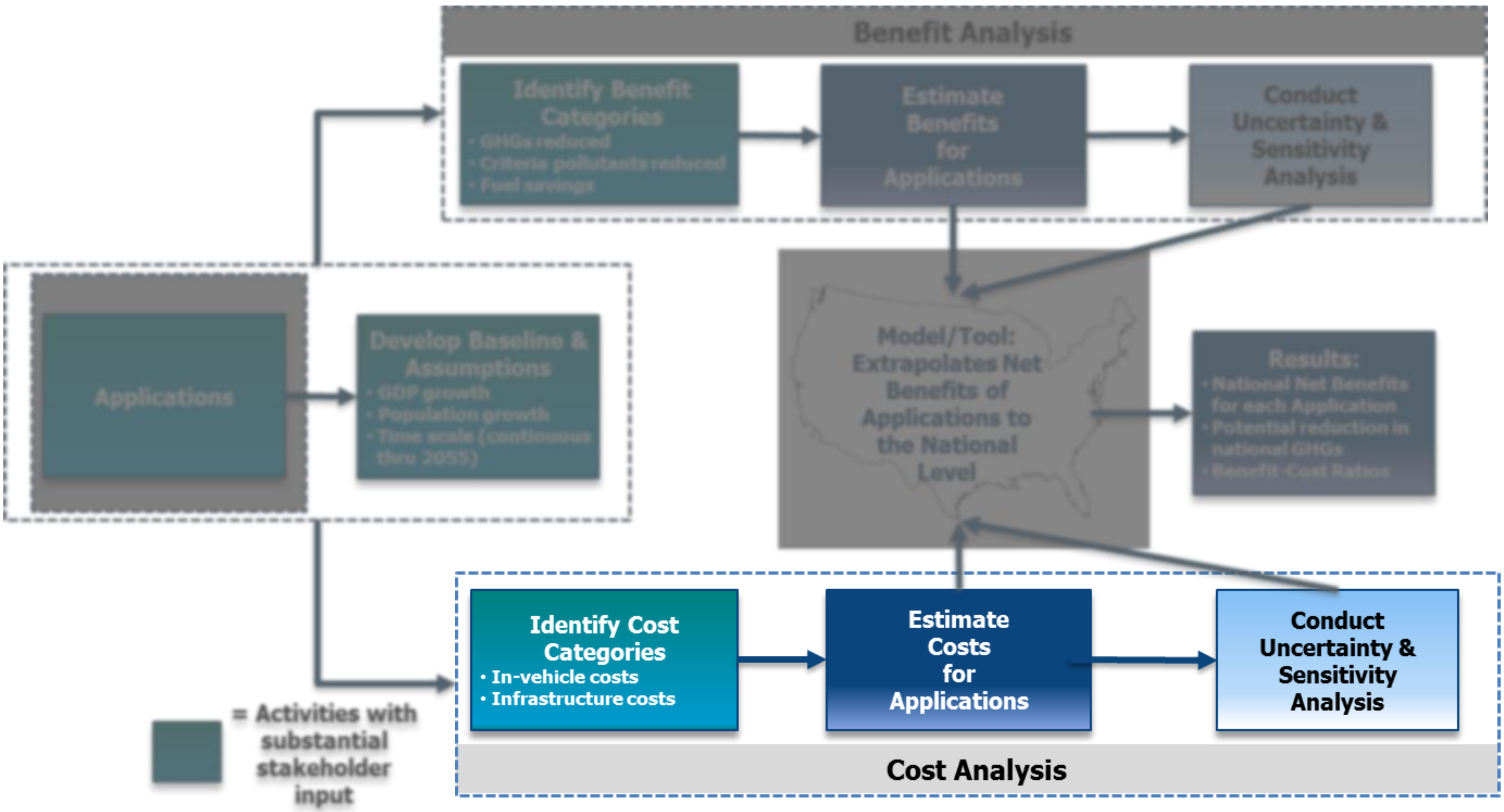
*Benefits derived from case studies may introduce optimism bias; to the extent that this is the case, results may be overly optimistic.

Monetization of Benefit Data

Benefit Category	Valuation		
	Technique	$/Unit*	Source of Information
GHGs (CO_2)	Social Cost of Carbon	$0.00007 per gram	Interagency Working Group as reported in DOT NHTSA Preliminary Regulatory Impact Analysis
Criteria Pollutants			
Particulate Matter	Contingent Valuation	$0.2292 per gram	EPA Regulatory Impact Analysis; Final Rule-making to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and CAFE Standards
Hydrocarbons	Societal Benefits	$0.008271 per gram	NHTSA Office of Regulatory Analysis and Evaluation, National Center for Statistics and Analysis; Lifetime Monetized Societal Impacts
CO	Contingent Valuation	$0.00416 per gram	EPA Regulatory Impact Analysis; Final Rule-making to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and CAFE Standards
NOx	Contingent Valuation	$0.0248 per gram	EPA Regulatory Impact Analysis; Final Rule-making to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and CAFE Standards
Fuel	Price-based Derivation	$2.92 per gallon	DOE EIA AEO 2011 Reference Case

*The monetary value displayed is the 2012 value; in the model, the monetary value changes over time in accordance with the source information's predicted values by year.

Cost Analysis



Cost Analysis Approach

Cost Element Identification

1) The necessary functionality of all applications were assessed
2) The cost elements required to enable development, installation, operation, and management for a given functionality were identified

Data Collection

1) Cost data were collected to estimate the individual cost elements
2) Case studies, or other sources, were collected and reported costs were assessed

Crosswalk & Normalization

1) Cost elements were associated with each application
2) Additional data were used to tailor cost element estimates for each application as needed
3) Costs were normalized to derive a per unit value

Nationwide Extrapolation

1) Unit costs were multiplied by the number of national units taking into account the application adoption rate
2) Costs were aggregated

Results

Costs are specified for each year of the analysis and/or as Net Present Value

Cost Element Identification

Category	Cost Element
Baseline	Roadside Equipment (RSE) units On-Board Equipment (OBE) units Telecom Backhaul The Connected Vehicle Core System Traffic Signal Systems
Infrastructure	Closed Circuit Television (CCTV) Cameras Static Road Signs Dynamic Message Signs (DMS) Environmental Sensors
In-Vehicle	On-Board Equipment, (marginal costs to integrate application)
Operation and Maintenance	System Integration & Back Office Online Presence Application Development Education & Outreach Telecom Backhaul, (marginal costs to process environmental data) Non-DSRC communication (i.e. cellular)

These costs are not included in BCA; as it is assumed that connected vehicle infrastructure exists

These costs are attributed to AERIS applications; Only *incremental* costs to install and operate AERIS applications above and beyond those costs in the baseline

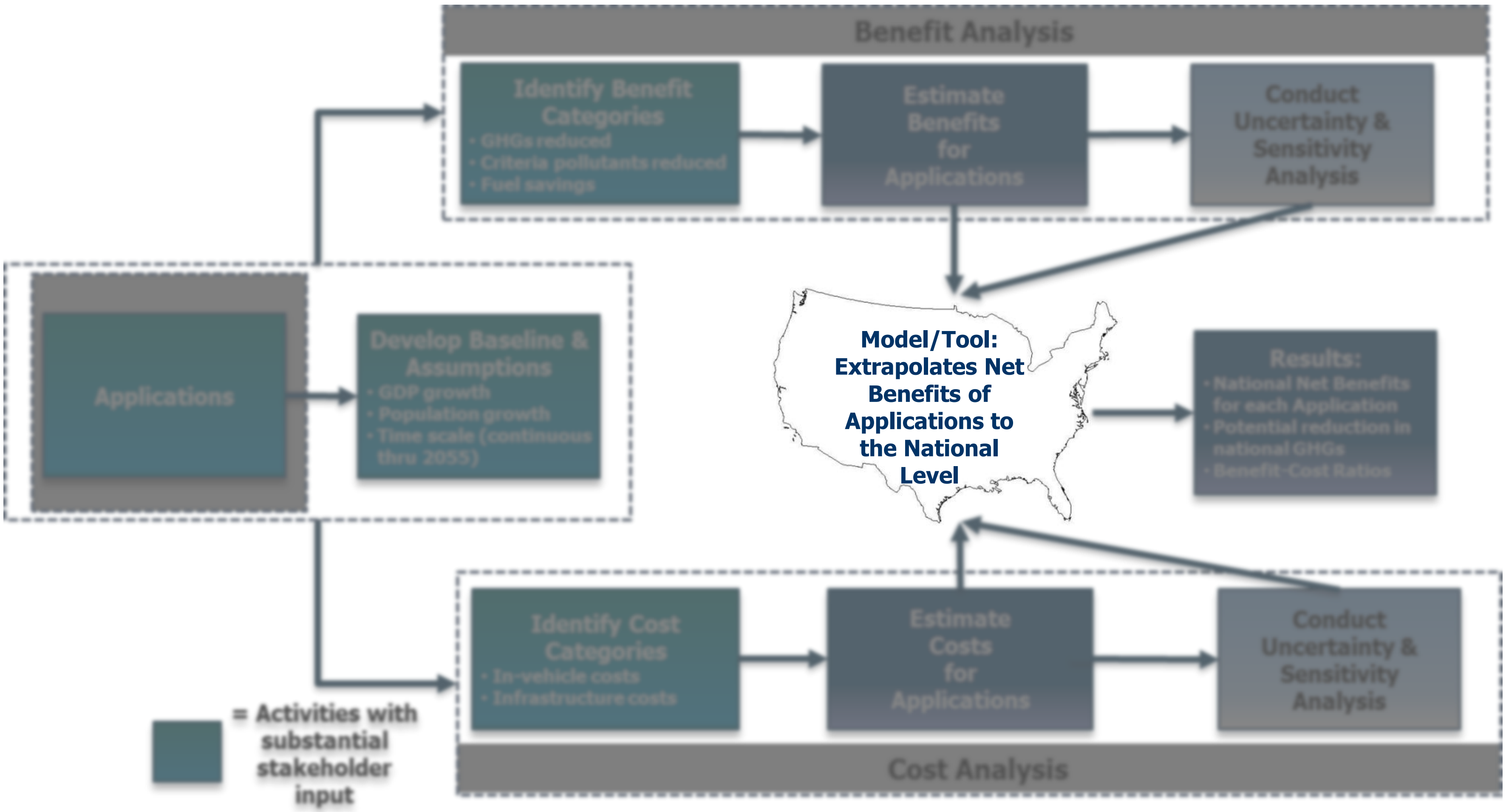
Derivation of Cost Estimates from Literature

Unit Costs					
Cost Element	**Unit**	**Cap. Cost**	**O&M Cost**	**Life (years)**	**Source**
Application Development	One-time, Nationwide	$10M	-	35	"Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis", Volpe Center, 2008 (VII BCA 2008).
OBE Incremental Cost	Per OBE	-	$0.10	-	VII BCA 2008.
Incremental Telecom Backhaul	Per kbps, Per RSE	-	$7.30	-	"Vehicle-Infrastructure Integration (VII) Communications Analysis", July 2006.
Non-DSRC Communication	Per OBE	-	$0.60	-	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Education, Outreach	Per Capita	-	$0.045	-	"Guidance for Implementation of the AASHTO Strategic Highway Safety Plan", NCHRP.
Online Presence	Per Area	$333K	$176K	15	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Systems Integration & Back Office	Per Area		$314,944		Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Closed Circuit TV Cameras	Each	$7K	$500	10	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Ramp Meters	Per Ramp	$169,800	$3,780	25	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Roadside Message Sign	Per Sign	$116	-	7	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Variable Speed Limit Sign	Per Sign	$3,500	$350	14	Compilation of studies found at: http://www.benefitcost.its.dot.gov.
Large Dynamic Message Sign	Per Sign	$82,000	$4,150	10	Compilation of studies found at: http://www.benefitcost.its.dot.gov.

Cost Element Associated with each Application

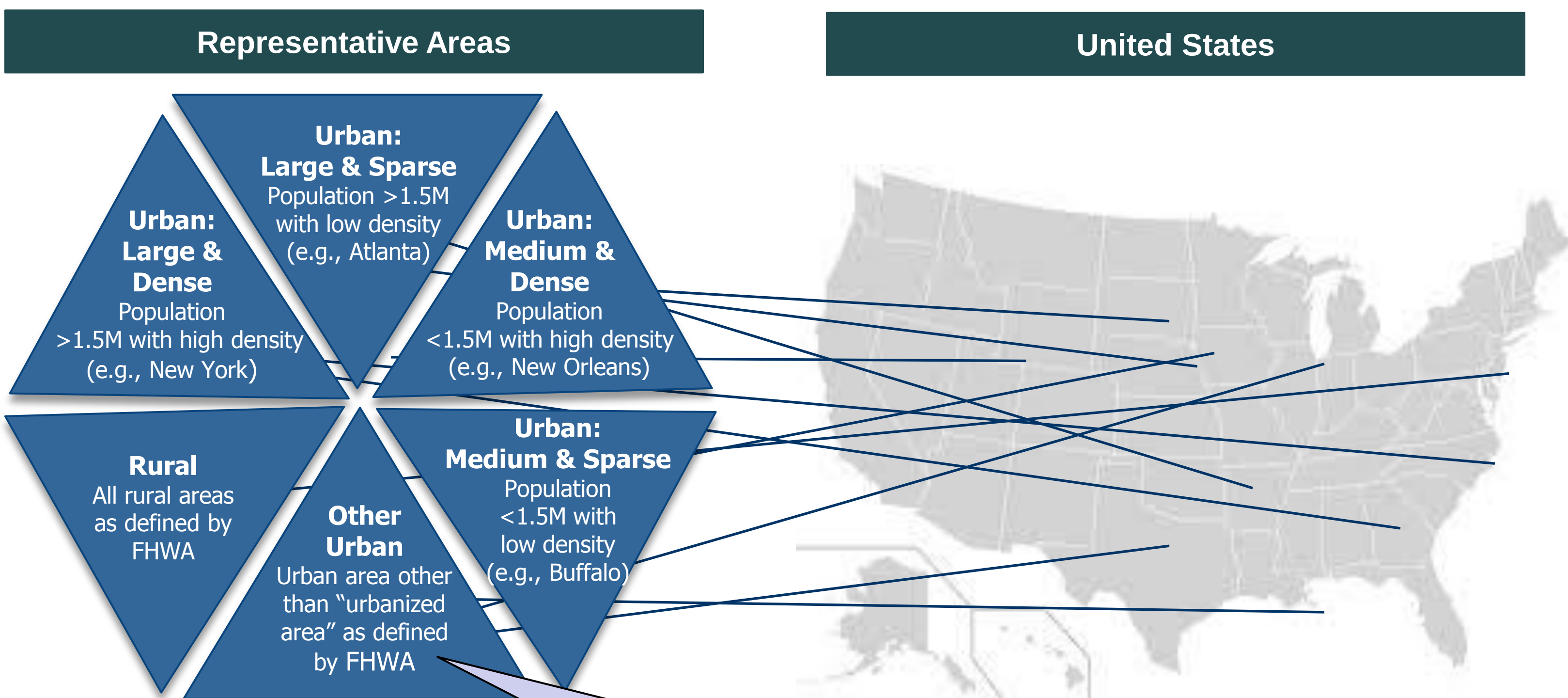
Applications	Cost Elements											
	Incr. Telecom Backhaul	Incr. non-DSRC	Closed Circuit TV Cameras	Ramp Meters	Roadside Message Sign	Variable Speed Limit Sign	Large Dynamic Message Sign	Incr. Sys. Integration & Back Office	Online Presence	Application Development	Education & Outreach	Incremental OBE Cost
Eco-Traffic Signal Timing	X	X						X		X	X	X
Eco-Freight Signal Priority	X	X						X		X	X	X
Eco-Transit Signal Priority	X	X						X		X	X	X
Connected Eco-Driving		X						X		X	X	X
Eco-Speed Harmonization		X				X		X		X	X	X
Eco-Cooperative Adaptive Cruise Control		X						X		X	X	X
Dynamic Emissions Pricing		X	X			X		X	X	X	X	X
Eco-Smart Parking		X			X			X	X	X	X	X
AFV Charging/Fueling Information		X			X			X	X	X	X	X
AFV Engine Performance Optimization		X						X		X	X	X
Dynamic Eco-Routing		X						X		X	X	X
Flexible Eco-Transit Routing		X						X	X	X	X	X
Eco-Approach and Departure to Signalized Intersections	X	X						X		X	X	X
Multi-Modal Traveler Information		X					X	X	X	X	X	X
Eco-Network Decision Support System		X						X		X	X	X
Eco-Ramp Metering		X		X				X		X	X	X

Extrapolation



National Extrapolation Tool

- **What:** Model/Tool that extrapolates unit costs and benefits to the National Level.
- **Why:** National driving behavior and transportation infrastructure are heterogeneous.
- **How:** Six “Representative Areas” were used to capture major geographical differences.



Source for urban and rural area statistics: FHWA

Key variables are estimated for each representative area in the model

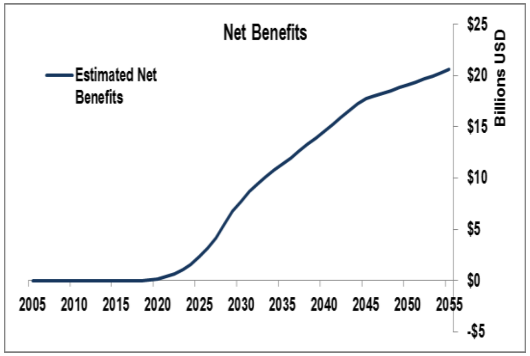
Nationwide Extrapolation of Unit Benefits

Monetized Unit Results → **Multiplied By** → **Number of Units in Each Representative Area** → **Yields** → **Nationwide Results for each Application**

Benefits (per unit annually)	
CO_2	$
PM	$
HC	$
CO	$
NOx	$
Fuel	$

Representative Area*	Benefit Realization Factors*				# of Areas (in the U.S.)
	Signals	Vehicles	VMT	Deploy-ment Rate	
Large & Dense	#	#	#	#	#
Large & Sparse	#	#	#	#	#
Medium & Dense	#	#	#	#	#
Medium & Sparse	#	#	#	#	#
Other Urban	#	#	#	#	#
Rural	#	#	#	#	#

*Benefit realization factors vary based on the unit basis of individual applications



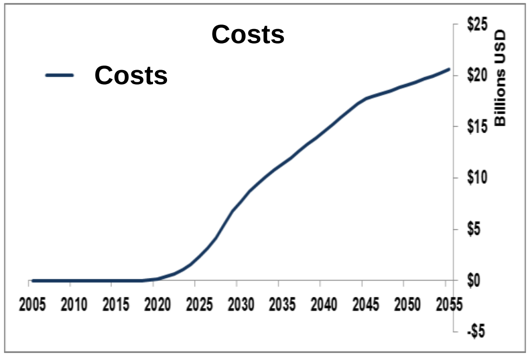
Nationwide Extrapolation of Unit Costs

Unit Costs → **Multiplied By** → **Number of Units in Each Representative Area** → **Yields** → **Nationwide Results for each Application**

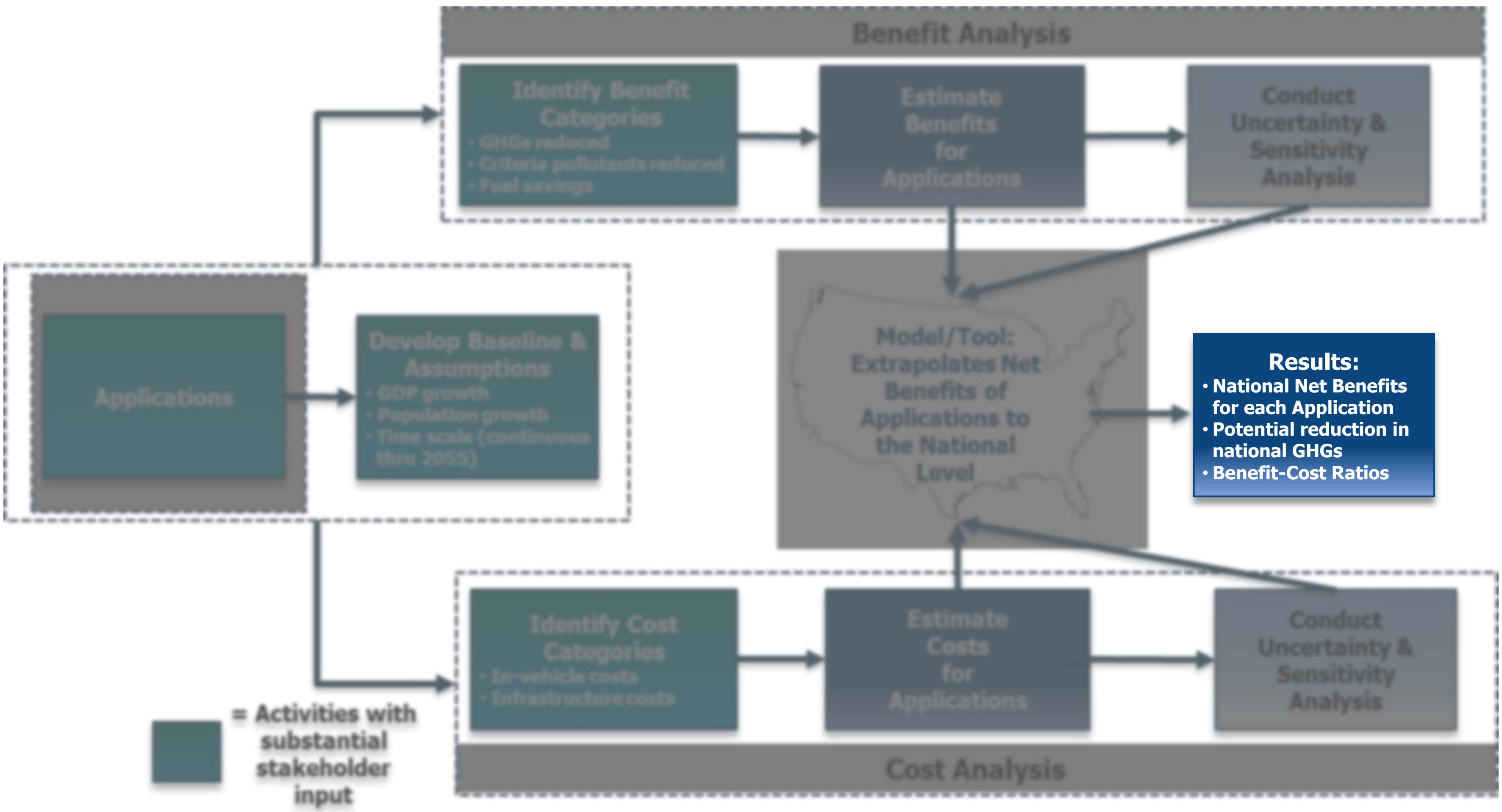
Costs (per unit annually)	
Application Development	$
OBE Incremental Cost	$
Incremental Telecom Backhaul	$
Non-DSRC Communication	$
Education, Outreach	$
Online Presence	$
Systems Integration & Back Office	$
Closed Circuit TV Cameras	$
Ramp Meters	$
Roadside Message Sign	$
Variable Speed Limit Sign	$
Large Dynamic Message Sign	$

Representative Area*	Cost Realization Factors*				# of Areas (in the U.S.)
	Signals	Vehicles	VMT	Deploy-ment Rate	
Large & Dense	#	#	#	#	#
Large & Sparse	#	#	#	#	#
Medium & Dense	#	#	#	#	#
Medium & Sparse	#	#	#	#	#
Other Urban	#	#	#	#	#
Rural	#	#	#	#	#

*Cost realization factors vary based on the unit basis of individual applications



Preliminary Results

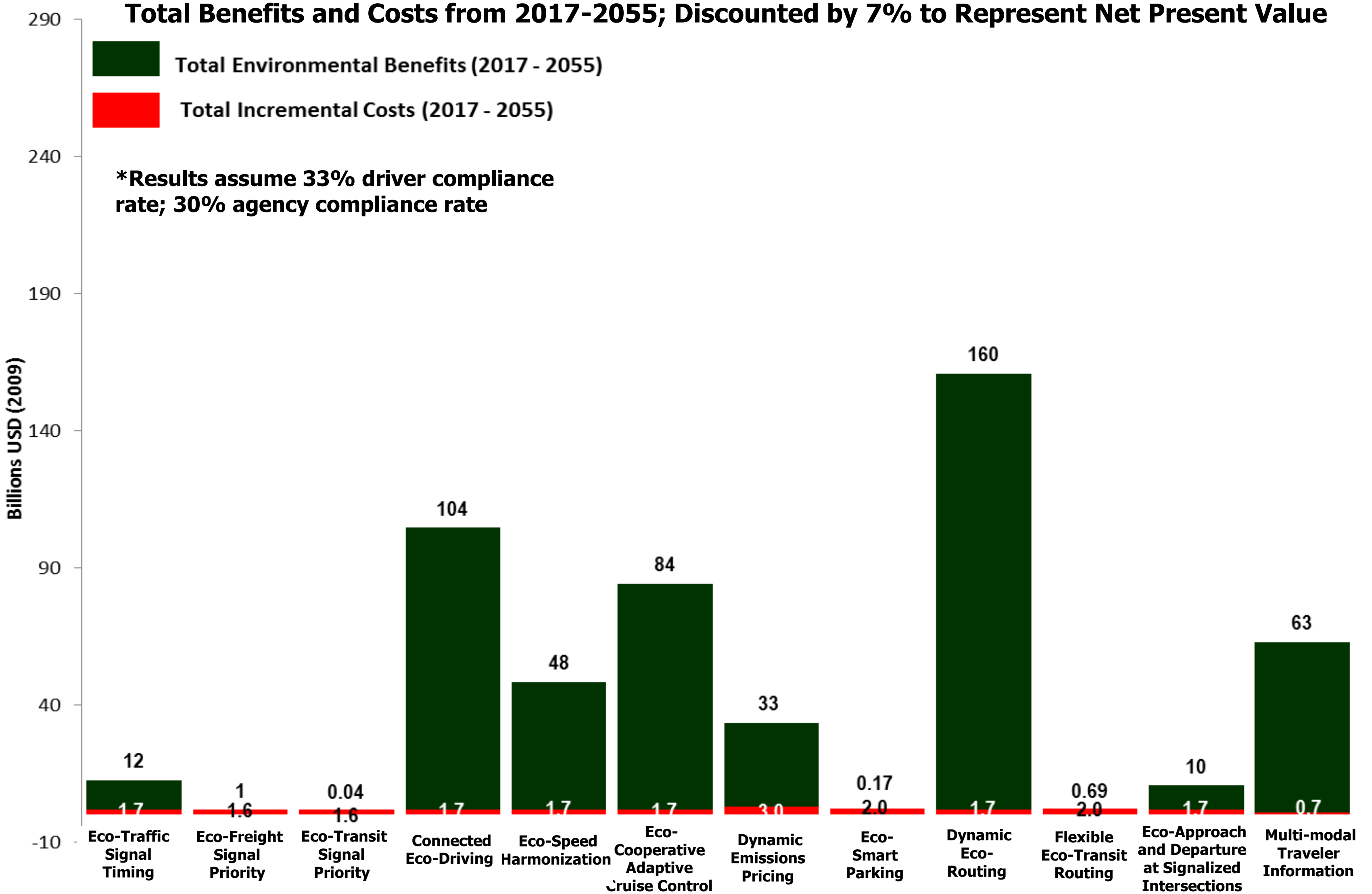


Preliminary Results Caveats

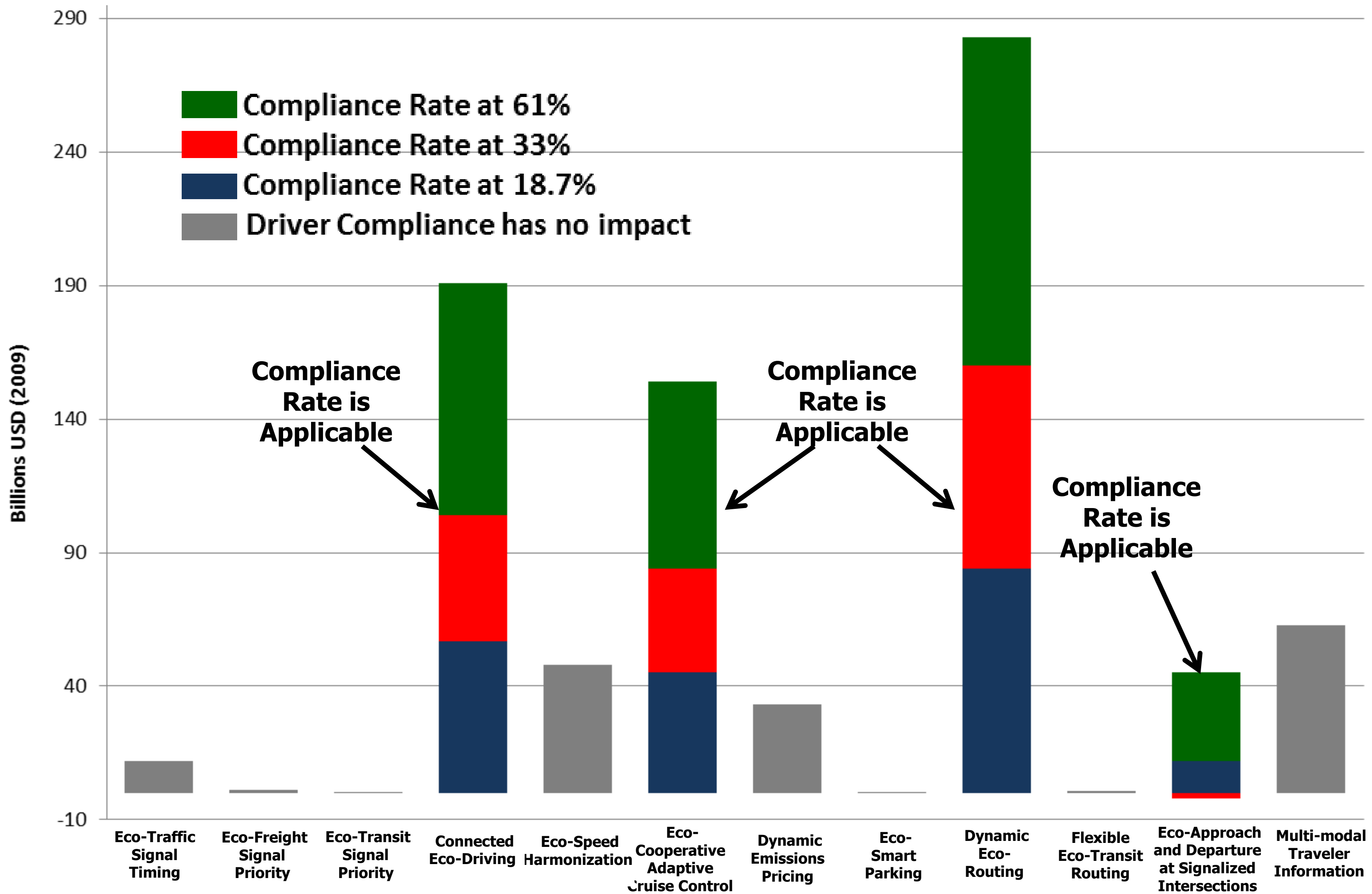
- **Net Benefits = Monetized Environmental Benefits – Costs**
- The results only consider *incremental* costs and *environmental* benefits
- Cumulative values for 2017-2055, discounted (7%), accounts for inflation and time value of money (Net Present Value)
- Values represent national deployment
- Applications evaluated individually, aggregation will change benefits and/or costs
- Benefit estimates derived from literature on similar, but not exact AERIS applications; modeling/simulation of AERIS applications will improve benefit estimates
- Not enough data was available to assess:
  - AFV Charging/Fueling Information
  - AFV Engine Performance Optimization
  - Dynamic Eco-Lanes
  - Eco-Network Decision Support System

Application Results: Total Benefits and Costs

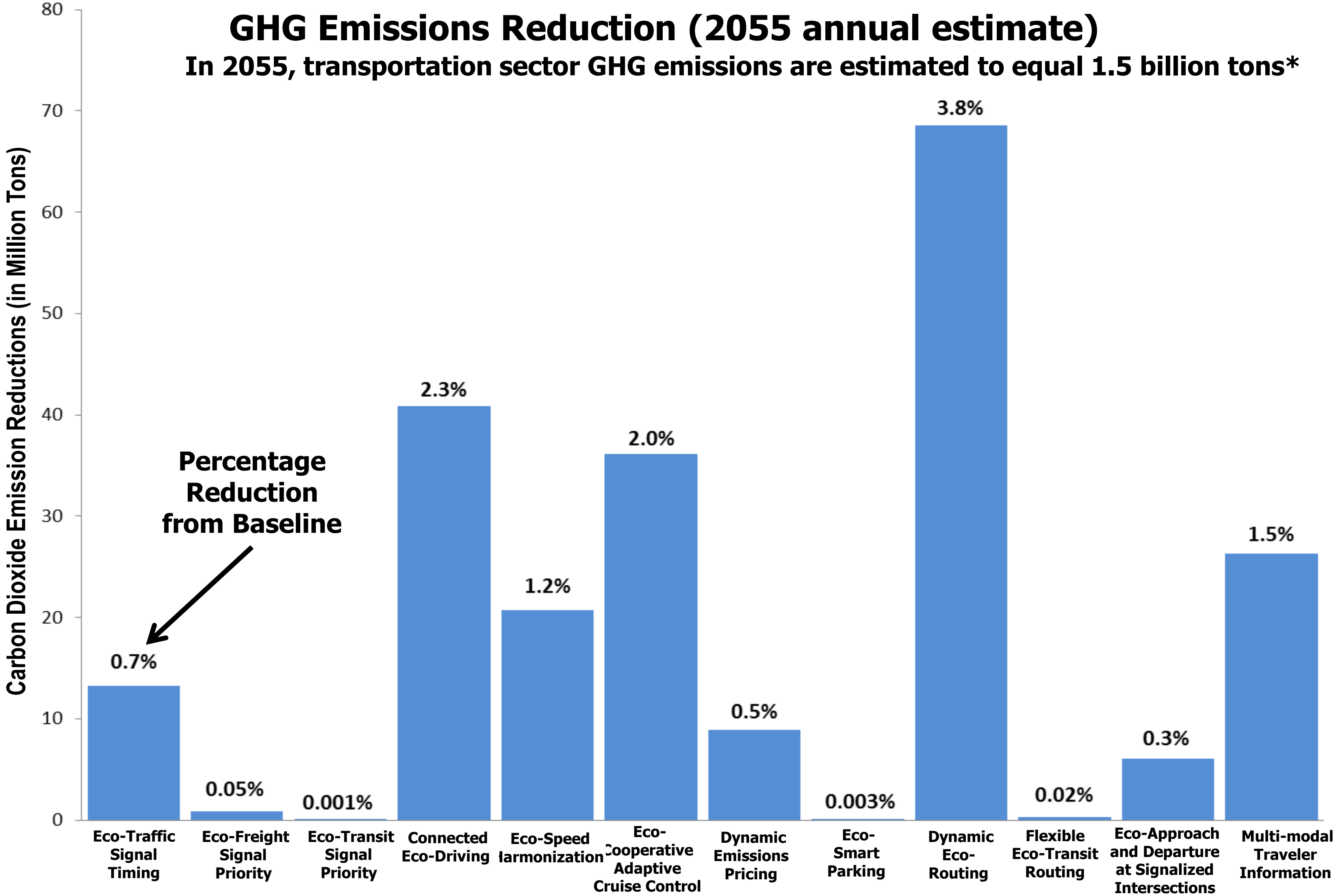
Total Benefits and Costs from 2017-2055; Discounted by 7% to Represent Net Present Value



Sensitivity to Assumptions: Driver Compliance Rate



Application Results: Annual GHG Reductions (2055)



*Source: DOE EIA AEO 2011 Reference Case, estimate includes car, truck, and transit vehicle emissions

Key Findings & Considerations

The initial BCA evaluates environmental benefits of the applications to compare the magnitude of their benefits; the results provide a number of key findings:

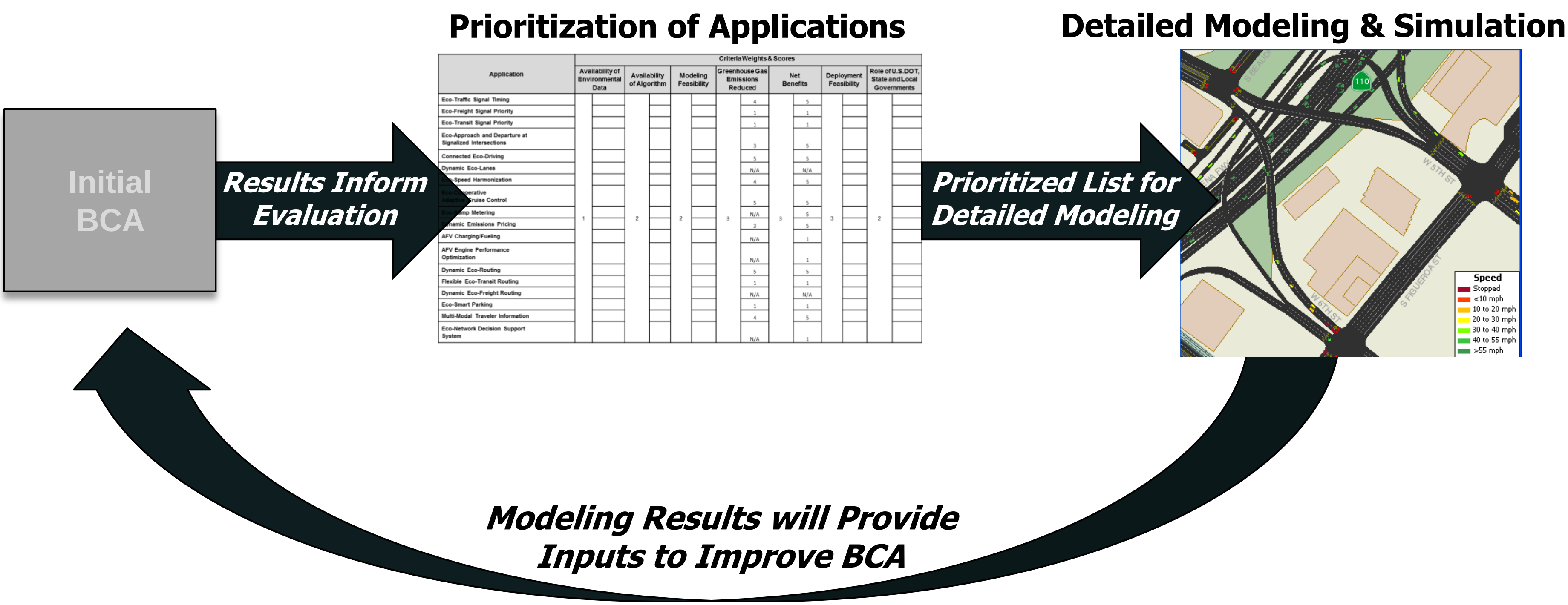
- Magnitude of benefits realized is very sensitive to the compliance rate
- Applications that generate benefits on a VMT basis have highest overall benefits
- Applications may have significant local/regional benefits; however, do not provide substantial nationwide benefits

Considerations raised by the BCA:

- The role of dedicated short range communication (DSRC) vs. cellular communication and the implications for deployment
- Agencies may not turn on applications all the time; e.g., eco-speed harmonization may be activated during code orange air quality days

Next Steps

The initial BCA evaluated the applications individually; detailed modeling and simulation will consider the synergies between applications as TCs and provide information on the cumulative GHG reductions of the program.



Application	Criteria Weights & Scores													
	Availability of Environmental Data		Availability of Algorithm		Modeling Feasibility		Greenhouse Gas Emissions Reduced		Net Benefits		Deployment Feasibility		Role of U.S.DOT, State and Local Governments	
Eco-Traffic Signal Timing								4		5				
Eco-Freight Signal Priority								1		1				
Eco-Transit Signal Priority								1		1				
Eco-Approach and Departure at Signalized Intersections								3		5				
Connected Eco-Driving								5		5				
Dynamic Eco-Lanes								N/A		N/A				
Eco-Speed Harmonization								4		5				
Eco-Cooperative Adaptive Cruise Control								5		5				
Eco-Ramp Metering	1		2		2		3	N/A	3	5	3		2	
Dynamic Emissions Pricing								3		5				
AFV Charging/Fueling								N/A		1				
AFV Engine Performance Optimization								N/A		1				
Dynamic Eco-Routing								5		5				
Flexible Eco-Transit Routing								1		1				
Dynamic Eco-Freight Routing								N/A		N/A				
Eco-Smart Parking								1		1				
Multi-Modal Traveler Information								4		5				
Eco-Network Decision Support System								N/A		1				

AERIS

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