Evaluation of Powertrain Options and Component Sizing for MD and HD Applications on Real World Drive Cycles

2011 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review
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Sponsored by David Anderson

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U.S. Department of Energy
Energy Efficiency and Renewable Energy
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Project Overview

Timeline

- Start – October 2010
- End – September 2011
- 15% Complete

Barriers Addressed

- Evaluate the potential fuel efficiency gains for Medium & Heavy Duty vehicles
- Provide DOE R&D guidance

Budget

- FY 11
  - $200K (sizing algorithm)
  - $200K (real world drive cycles)

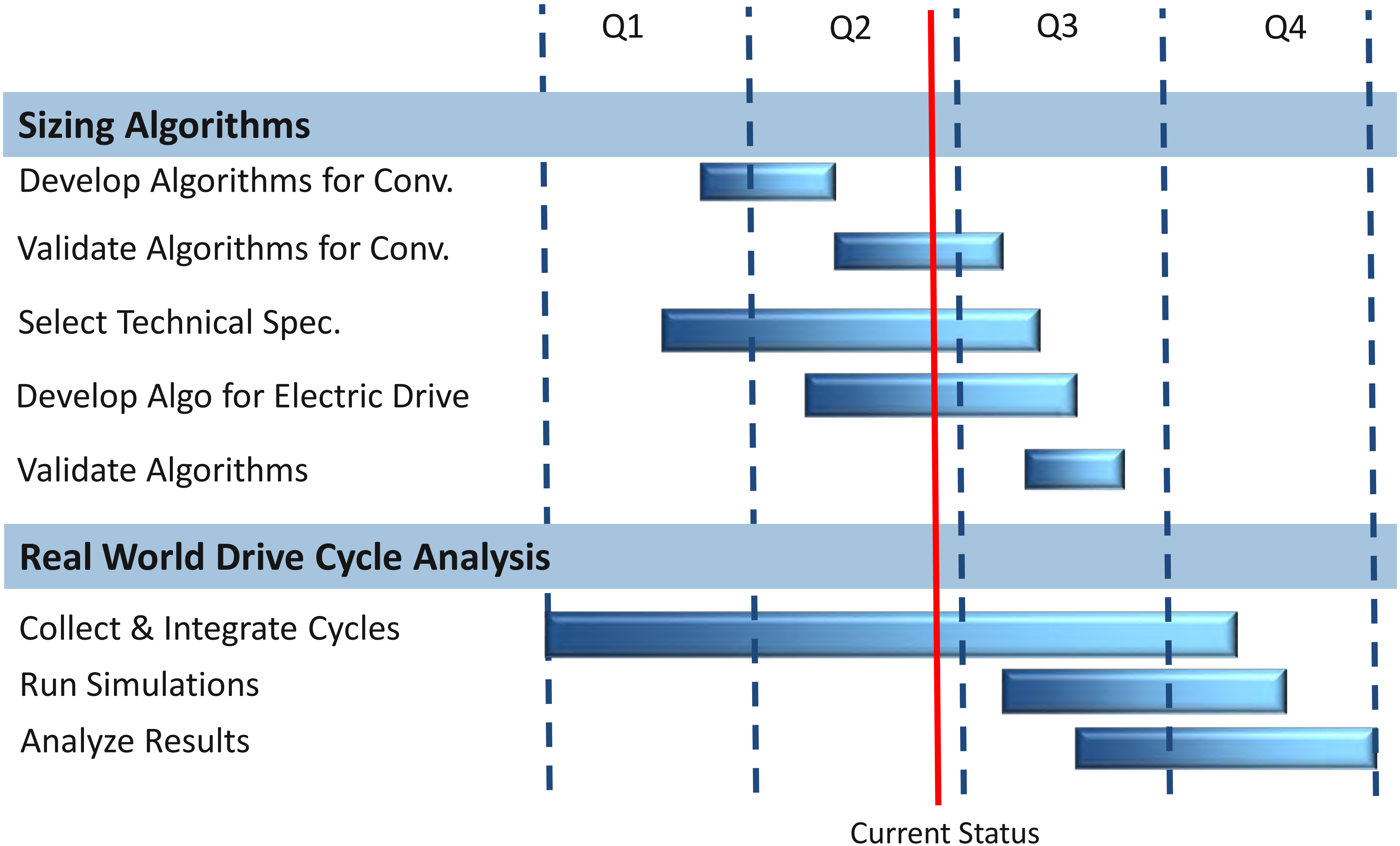
Partners

- OEMs (Navistar, Paccar, John Deere, Cummins…)
- NREL
- ORNL
- West Virginia University

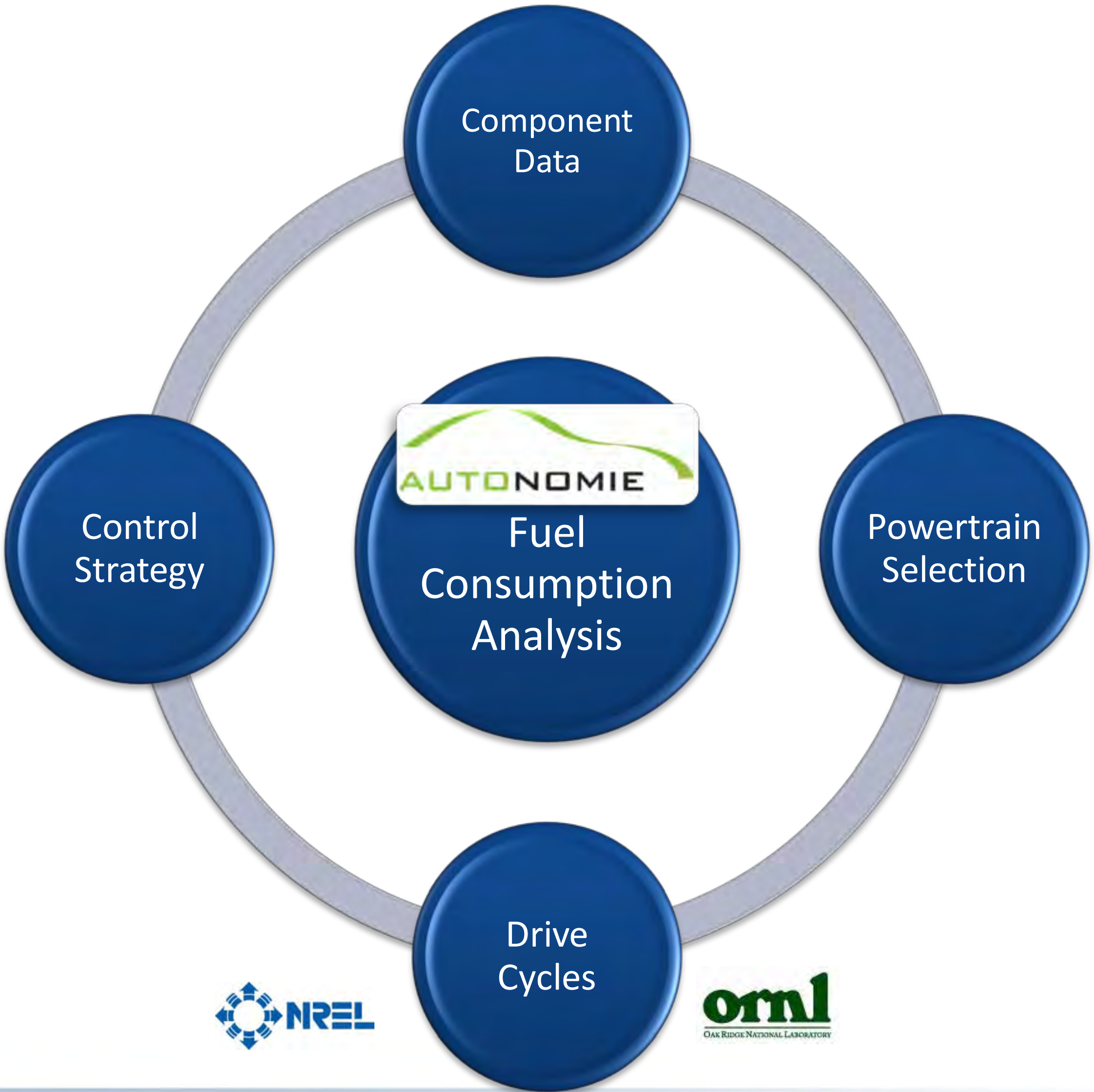
Objectives

- Evaluate benefits of DOE technology for medium and heavy duty vehicles
- Due to the large number of technologies and applications, sizing algorithms are necessary to quickly determine the fuel displacement potential and provide guidance for DOE R&D
- Evaluate the impact of component sizing on Real World Drive Cycles fuel consumption
- Evaluate the benefits of powertrain technologies on Real World Drive Cycles fuel consumption

Milestones


Q1
Q2
Q3
Q4
Sizing Algorithms
Develop Algorithms for Conv.
Validate Algorithms for Conv.
Select Technical Spec.
Develop Algo for Electric Drive
Validate Algorithms
Real World Drive Cycle Analysis
Collect & Integrate Cycles
Run Simulations
Analyze Results
Current Status

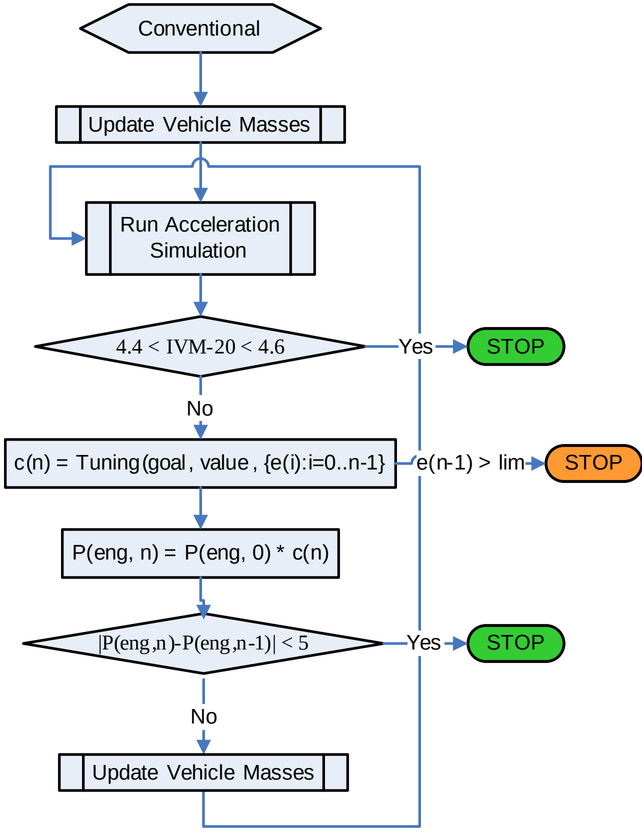
Approach
Work Directly with Companies, Nat. Labs, Universities



Technical Accomplishments

Sizing Algorithms Development

- Develop algorithms from “bottoms-up” (i.e., each component has its own specifications)
- Gather weight and performance information for different components for each vehicle class
- Include specific constraints for each application



Example: Conventional Vehicle

Technical Accomplishments

Sizing Algorithms Validation

Blue Bird Vision

	Reference	Sized	Error (%)
General information			
GVWR (lbs)	29000	class 6	
SLW (lbs)	23250	23296	0.20
Seat	27		
Engine			
Model	Cummins ISB		
Fuel Type	Diesel		
Displacement	6.7 l		
Power (W)	**178968**	**179355**	**0.22**

Blue Bird All American

	Reference	Sized	error (%)
General information			
GVWR (lbs)	31300	class 7	
SLW (lbs)	26800	26874	0.28
Seat	34		
Engine			
Model	Caterpillar 3126		
Fuel Type	Diesel		
Displacement	7.2 l		
Power (W)	**201339**	**202057**	**0.36**

Daimler SLF 200/35’

	Reference	Sized	error (%)
General information			
GVWR (lbs)	28580	class 6	
SLW (lbs)	24770	24859	0.36
Seat	32		
Engine			
Model	Mercedez-Benz		
Fuel Type	Diesel		
Displacement	6.7 l		
Power (W)	**208796**	**212938**	**1.98**

<u>Vehicle Technical Specification includes:</u>

- 0-20mph, 0-30mph, 0-40mph, 0-50mph
- Max grade at 1 mph, 25 mph and 50 mph

Transit Bus Example

Source Thomas D. Larson Pennsylvania Transportation Institute

Technical Accomplishments

Vehicle Technical Specifications Definition for Each Application

General information										
Bus manufacturer	Thomas Built®	Blue Bird	Orion	Champion Bus	New Flyer	Daimler	Nova Bus	New Flyer		
Model	SLF 200/30'	Vision	Orion VII	Defender	D40LF	229 SLF	60LFS Artic	DE 60 LFA		
GVWR	25350	29000	43000	16440	42540	26000	61729	66790		
CW		18180	28400	21630	29270	17390	41310	49460		
Seat	29	27	44	29	40	26	56			
Engine										
Model	Cummins ISB	Cummins ISB	Cummins ISC	Mercedes-Benz	Cummins ISM	Mercedes-Benz	Cummins ISL	Caterpillar C9		
Displacement	5.9 l	6.7 l	8.3 l		10.8 l	6.7 l	8.9 l	9.3 l	**Autonomie Requirements**	
Power	185 HP	240 HP	280	250	280	280	330 HP	285-350 HP	**Average**	StD
Acceleration										
0-10mph	3.17	3.16	4.57	4.74	5.34	4.99	5.34	4.57	**4.5**	0.9
0-20mph	5.72	6.16	8.77	7.85	9.13	8.62	10.29	7.97	**8.1**	1.5
0-30mph	10.76	10.18	13.67	11.53	13.78	13.83	16.63	13.37	**13.0**	2.1
0-40mph	17.95	16.46	23.07	17.06	22.23	22.15	28.72	23.46	**21.4**	4.1
0-50mph	31.68	25.84	37.08	24.46	37.08	36.09	51.99	41.49	**35.7**	8.8
Grade										
1 mph	19.8	18.6	13.5	13.3	12.9	13.3	12	14.8	**14.8**	2.9
25 mph	9.6	10.4	7.4	9.9	7.4	7.5	5.9	7.3	**8.2**	1.6
40 mph	4.8	6.3	4.3	7.9	4.5	4.6	3	3.7	**4.9**	1.5
50 mph	2.4	4	2.7	6.7	2.9	2.9	1.5	1.9	**3.1**	1.6

Transit Bus Example

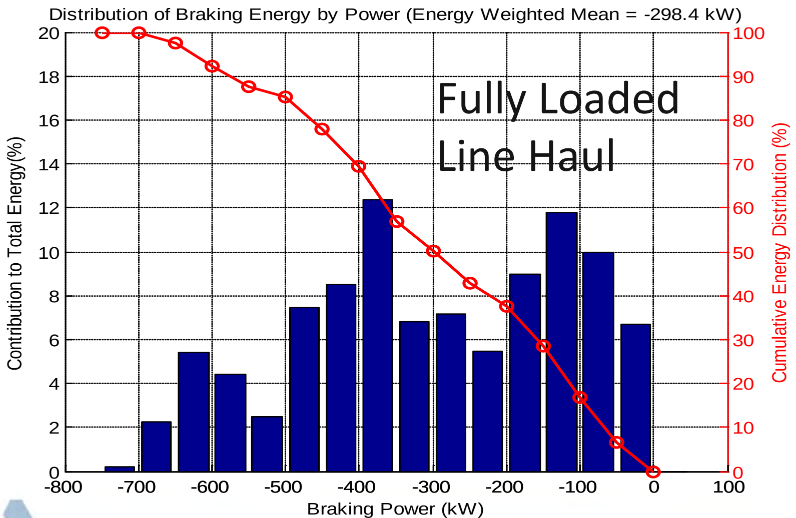
Source Thomas D. Larson Pennsylvania Transportation Institute

Technical Accomplishments

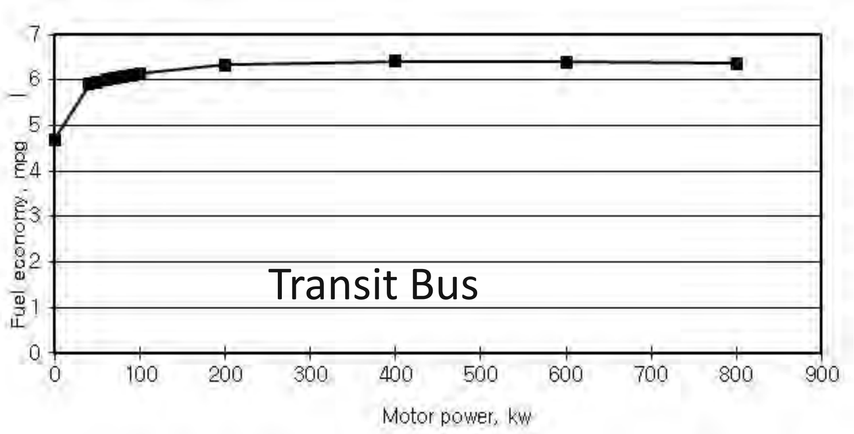
Sizing Algorithms Electric Drive Challenge

- Current vehicles are built on available hardware.
- How do we size the battery power and energy?
- What is the maximum pack voltage and its impact on configuration (i.e., series vs. parallel)?
- Can we downsize the engine? By how much?
- How do we select final drive ratios to ensure fair comparison with conventional?

Battery Power and Energy Selection



Motor Power Selection



Technical Accomplishments

Real World Drive Cycle Collection

Application	Source	Cycles #	Comments
Class 2B	EPA	110	Kansas City
	Chicago	600	Chicago
School Bus	NREL	17	Texas, North Caroline & Texas
	ORNL	16	Tennessee, includes grade
Transit Bus	NREL	12	King County Metro
Garbage Truck	New West	7	Includes Front, Rear and Side Loader with accessory information
Class 7 P&D	ORNL	24	Tennessee, includes grade
Utility Truck			Data requested
Line Haul			Data requested

Technical Accomplishments

Correlate Fuel Consumption Gains Based on Fleet Testing

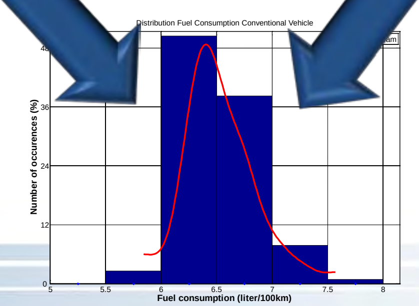
- Since no dynamometer testing is performed within DOE to support validation, Argonne has been collaborating with WVU & EPA to validate specific conventional models and is collaborating with OEM to validate MD HEV.
- Fleet testing reports will be used to correlate technology benefits

Fleet Test Reports

Develop Vehicles

AUTONOMIE

Fuel consumption comparison



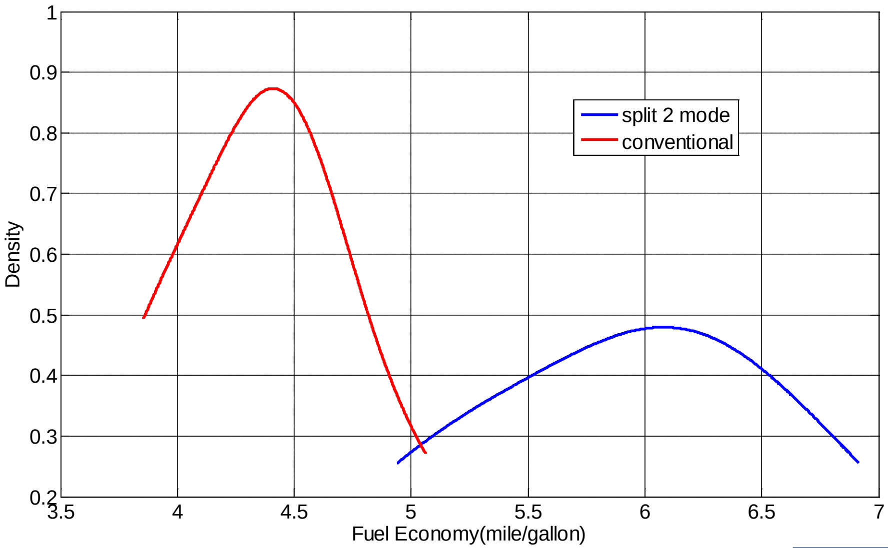
Correlate Results

Transit Bus Example

Technical Accomplishments

Fleet Testing Correlation

Example: Transit Bus King County Metro (NREL TP-540-40585).



- Vehicle from fleet modeled in Autonomie
- Average improvement from simulation consistent with fleet testing

- Need to refine correlation by adding cycles, understand reason behind efficiency improvements (modeled & non-modeled)

Vehicle	% Improvement over Conventional
Hybrid #1 Test	26.8
Hybrid #2 Test	50
Autonomie Simulation	35.7

Collaborations

- Due to the nature of DOE current funding for MD and HD applications, close relationship with truck manufacturers, suppliers, universities and national laboratory is required to collect:
  - Real world drive cycles
  - State-of-the-art component information
  - State-of-the-art vehicle information
  - Vehicle Technical Specifications
- Value of data obtained through partnerships valued at several million dollars

Future Activities

- Complete on-going activities
  - Continue to collect data & define VTS for several applications
  - Develop & validate sizing algorithms for electric drive vehicles
  - Continue to collect additional real world drive cycles (RWDC) for all applications considered
  - Evaluate fuel consumption benefits of advanced technologies on the RWDC
- Expand collaborations
  - Define potential technology improvements (i.e., lightweighting, engine, aero, tires…) and their impact on fuel efficiency
- Support future Medium and Heavy Duty labeling in Europe

Summary

- Automated sizing algorithms are being developed and validated for MD & HD applications to allow efficient evaluation of fuel efficiency improvement of several technologies
- Generic Vehicle Technical Specifications are being developed to represent an “average” for the application
- Real World Drive Cycles are being collected and implemented into Autonomie to evaluate benefits uncertainty
- Leveraged several millions of dollars of data from DOE and OEMs (component, vehicle and drive cycles)