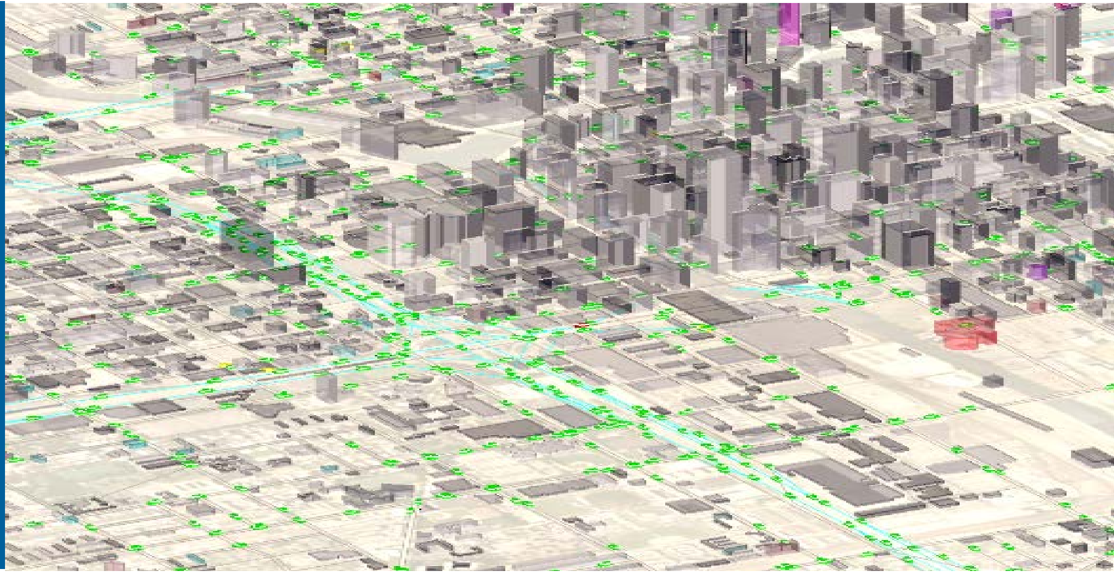
PROJECT ID # EEMS013

ANL CORE TOOLS SIMULATION



Phillip Sharer, Ram Vijayagopal, Paul Delaughter, Michael Juskiewicz, Sylvain Pagerit, Aymeric Rousseau

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9700 S Cass Ave
Lemont, IL

Annual Merit Review 2020, Washington DC

PROJECT OVERVIEW

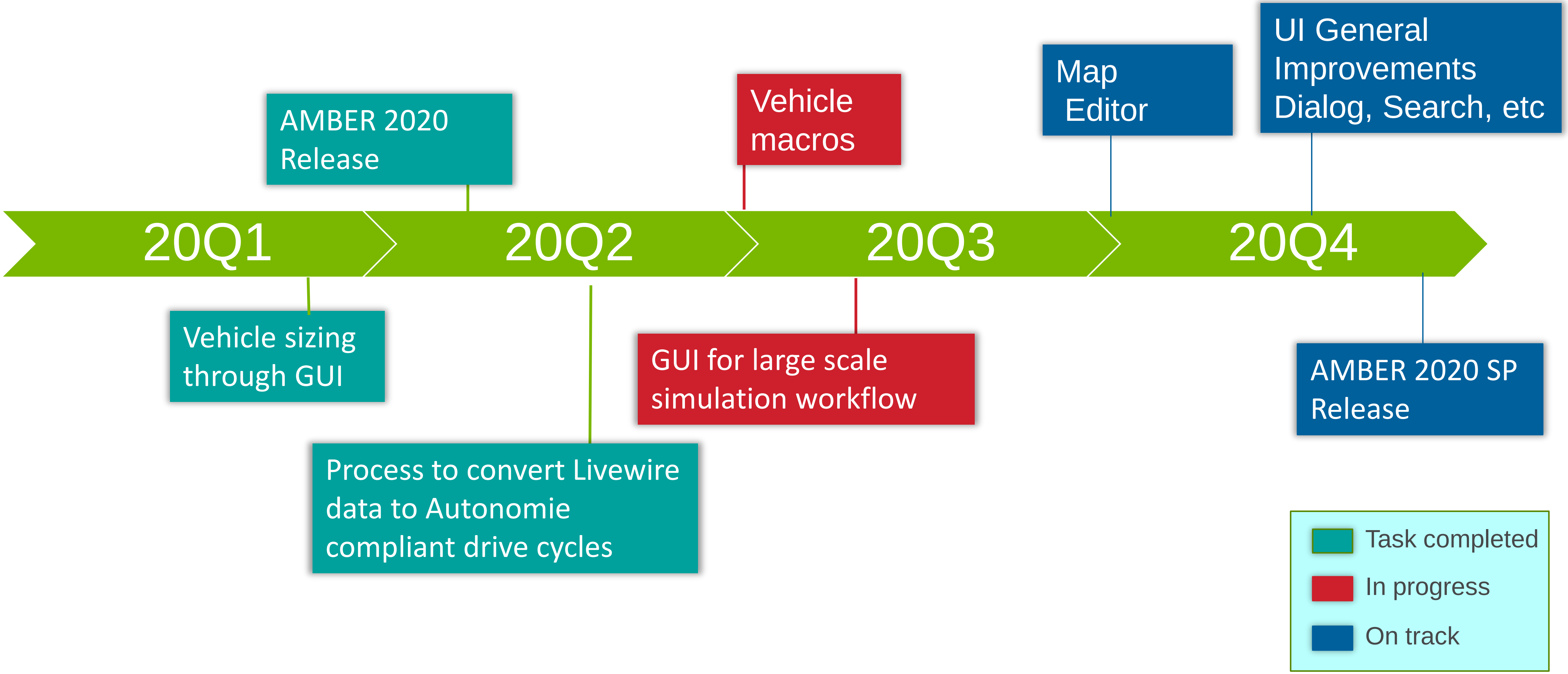
Timeline	Barriers
• Project start date : Oct. 2018 • Project end date : Sep. 2021 • Percent complete : 50%	• High uncertainty in technology deployment, functionality, usage, impact at system level • Computational models, design and simulation methodologies • Lack of data on individual behaviors relating to e-commerce and freight • Integration of disparate model frameworks
Budget	**Partners**
• Total funding: $3,750,000 • FY20 funding received : $1,250,000	• Argonne • Ford • US Drive Partnership • 21CTP Partnership

PROJECT RELEVANCE

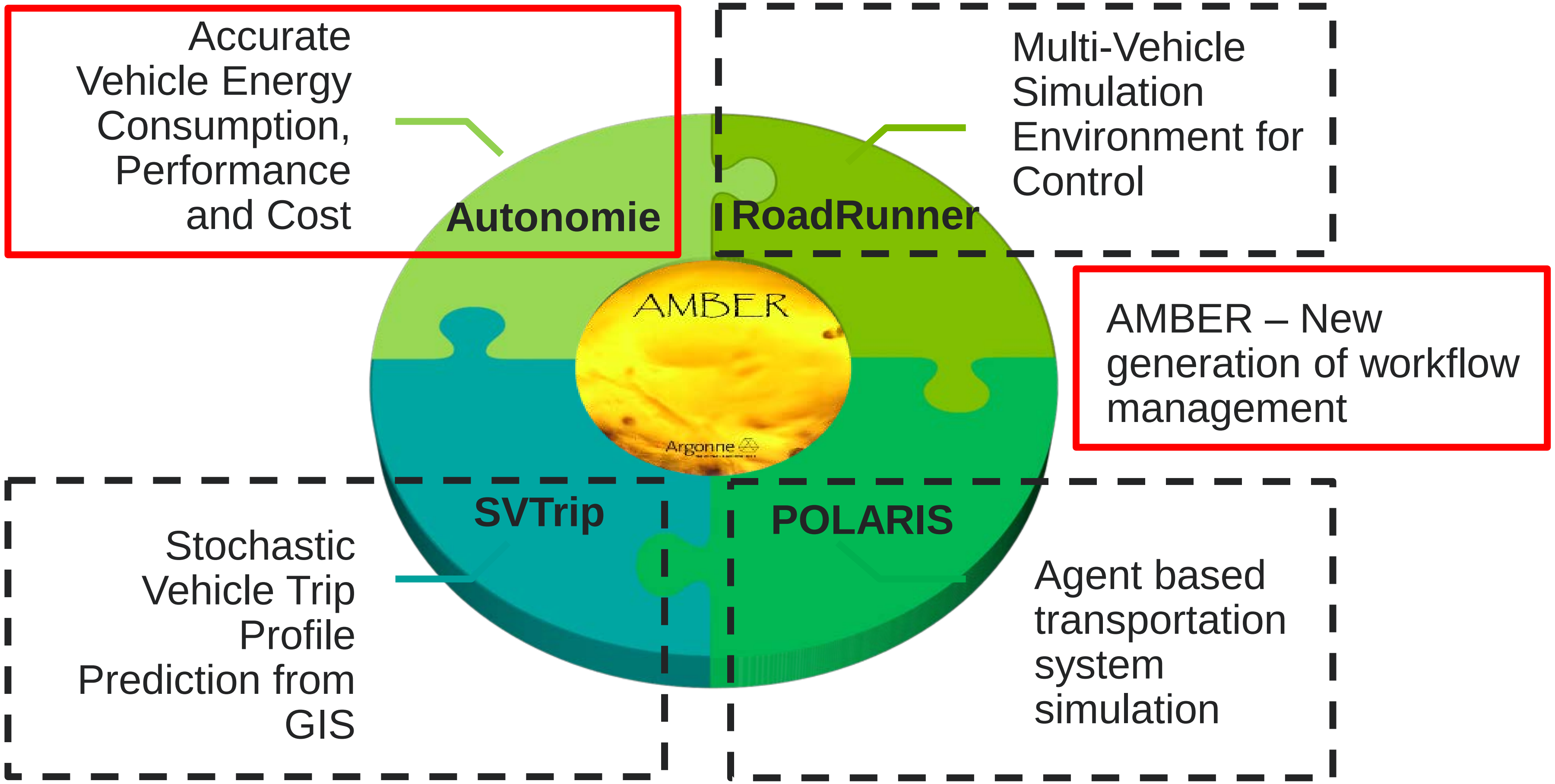
Argonne simulation tools and results are used to support a very large number of VTO projects as well as organizations throughout the world to define R&D targets, evaluate the benefits of advanced technologies, provide R&D guidance…

- During the 2019 AMR, 28+ projects were related to Autonomie:
  - Provided inputs to Autonomie:
    E.g. New data from SMART Consortium, vehicle testing…
  - Used Autonomie to perform studies:
    E.g. Advanced technology impacts (e.g., CAVs, Co-Optima)
  - Used Autonomie results to perform further studies / analysis:
    E.g. VTO Benefit Energy Impact, US Drive…
- Autonomie was also used to support ARPA-E NEXTCAR, FCTO, DOT and DOD

MILESTONES


AMBER 2020 Release
Vehicle macros
Map Editor
UI General Improvements Dialog, Search, etc
20Q1
20Q2
20Q3
20Q4
Vehicle sizing through GUI
GUI for large scale simulation workflow
AMBER 2020 SP Release
Process to convert Livewire data to Autonomie compliant drive cycles
Task completed
In progress
On track

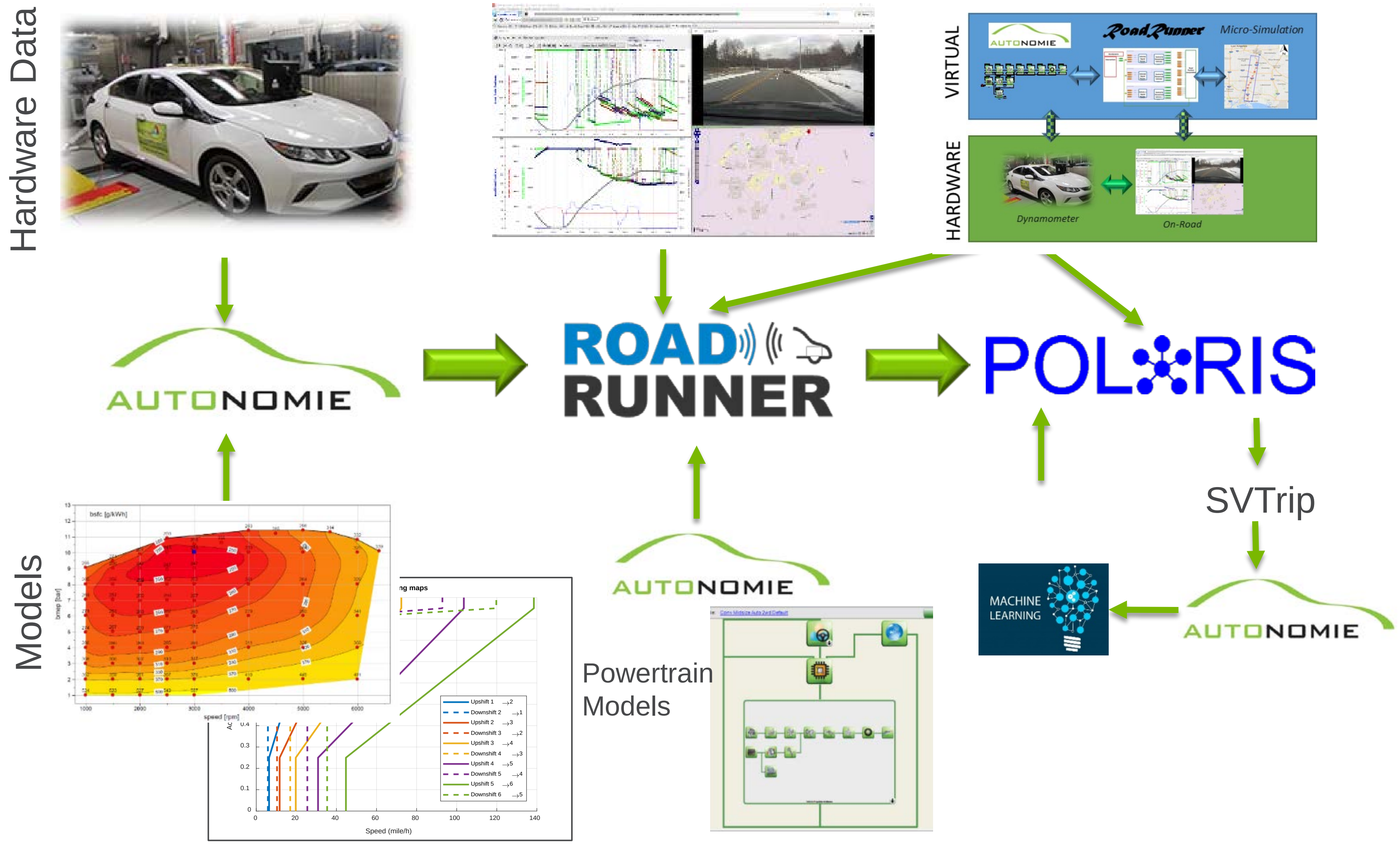
APPROACH – AMBER WORKFLOW MANAGER



EEMS013 (This project)

EEMS058 (SMART Mobility Consortium Tools and Process Development)

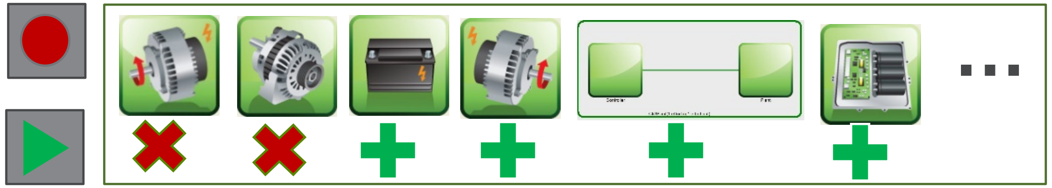
APPROACH - TOOLS ARE PART OF AN INTEGRATED ENVIRONMENT



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

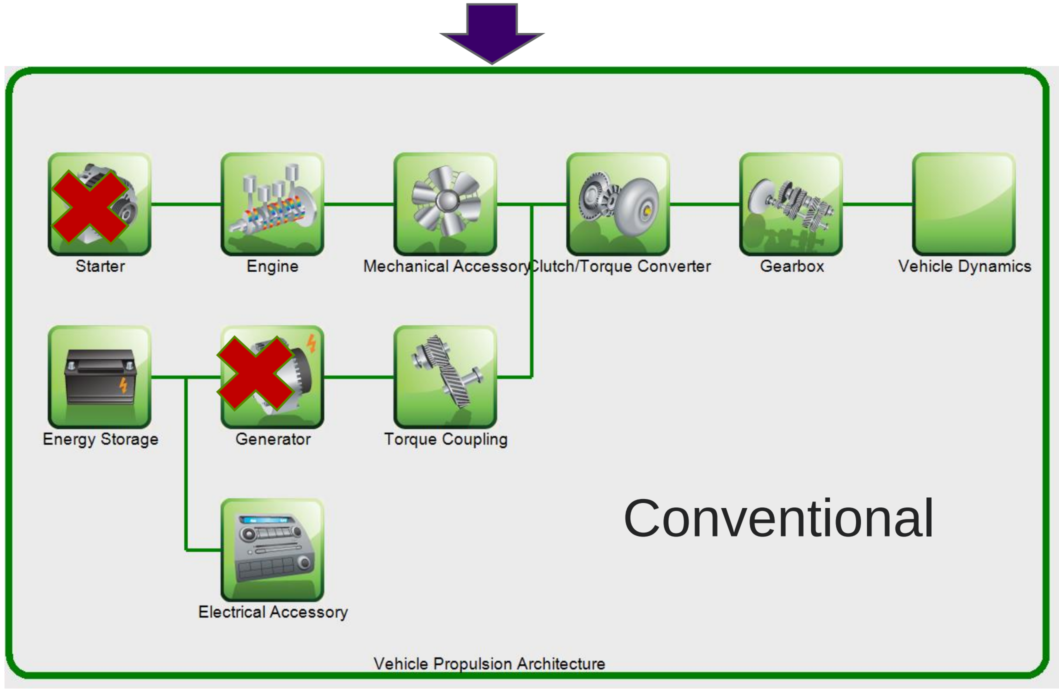
REUSE PART OF A VEHICLE TO CREATE A NEW ONE FROM 2 HOURS DOWN TO 5 SECONDS

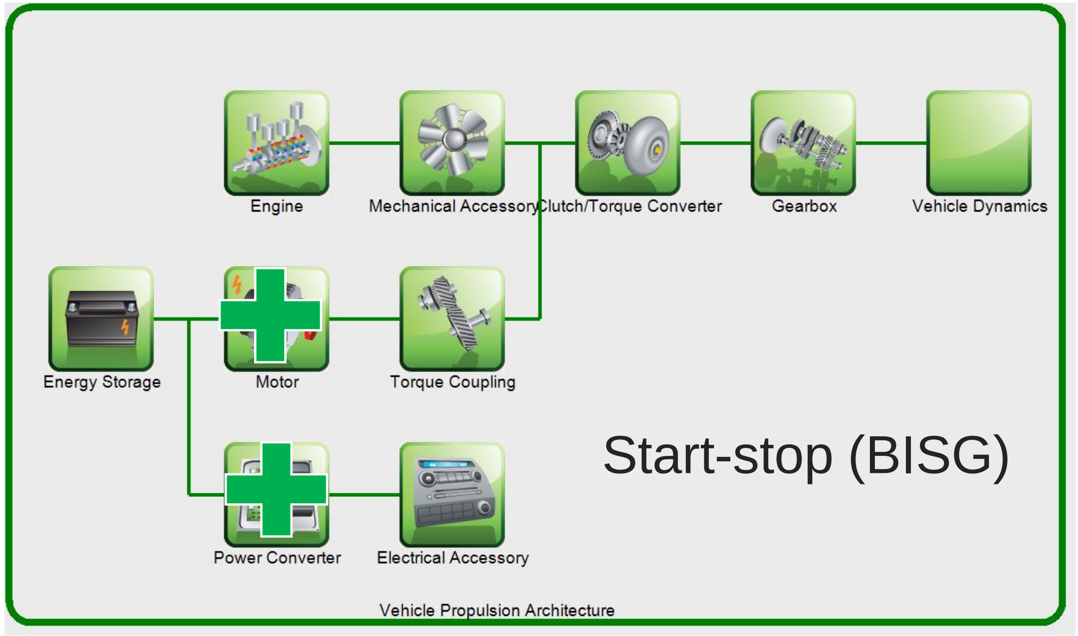
ALL changes in the interface are recordable



20+ Changes

1. PI Driver to Human Driver for **RoadRunner**
2. Manual to Autonomic
3. Gasoline to Diesel
4. Conventional to BISG
5. Two wheel drive to Four wheel drive
6. …





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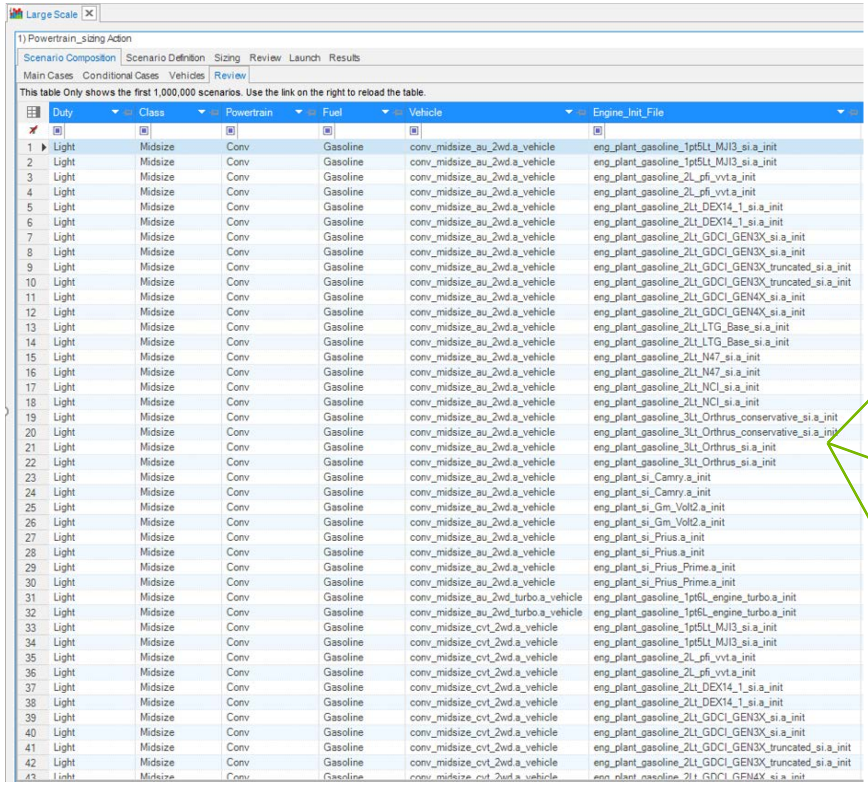
CUSTOMIZE AND RUN MILLIONS OF SIMULATIONS DIRECTLY FROM AMBER



	Duty	Class	Powertrain	Fuel	Vehicle	Engine_Init_File
1	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_1pt5Lt_MJI3_si.a_init
2	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_1pt5Lt_MJI3_si.a_init
3	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2L_pfi_vvt.a_init
4	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2L_pfi_vvt.a_init
5	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_DEX14_1_si.a_init
6	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_DEX14_1_si.a_init
7	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_si.a_init
8	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_si.a_init
9	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_truncated_si.a_init
10	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_truncated_si.a_init
11	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN4X_si.a_init
12	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN4X_si.a_init
13	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_LTG_Base_si.a_init
14	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_LTG_Base_si.a_init
15	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_N47_si.a_init
16	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_N47_si.a_init
17	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_NCI_si.a_init
18	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_2Lt_NCI_si.a_init
19	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_3Lt_Orthrus_conservative_si.a_init
20	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_3Lt_Orthrus_conservative_si.a_init
21	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_3Lt_Orthrus_si.a_init
22	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_gasoline_3Lt_Orthrus_si.a_init
23	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd.a_vehicle	eng_plant_si_Camry.a_init
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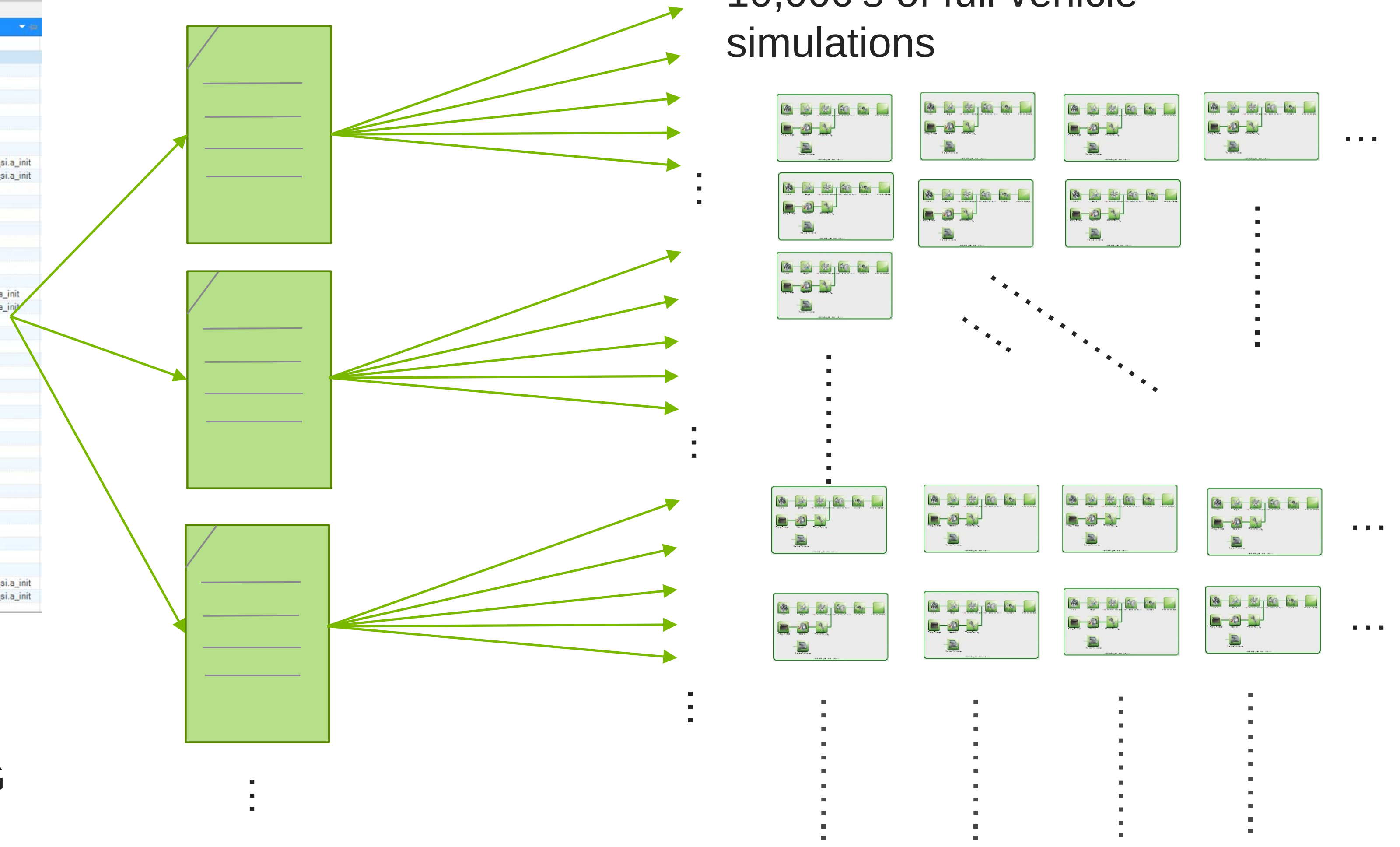
31	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd_turbo.a_vehicle	eng_plant_gasoline_1pt6L_engine_turbo.a_init
32	Light	Midsize	Conv	Gasoline	conv_midsize_au_2wd_turbo.a_vehicle	eng_plant_gasoline_1pt6L_engine_turbo.a_init
33	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_1pt5Lt_MJI3_si.a_init
34	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_1pt5Lt_MJI3_si.a_init
35	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2L_pfi_vvt.a_init
36	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2L_pfi_vvt.a_init
37	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_DEX14_1_si.a_init
38	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_DEX14_1_si.a_init
39	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_si.a_init
40	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_si.a_init
41	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_truncated_si.a_init
42	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN3X_truncated_si.a_init
43	Light	Midsize	Conv	Gasoline	conv_midsize_cvt_2wd.a_vehicle	eng_plant_gasoline_2Lt_GDCI_GEN4X_si.a_init

Define the study not the vehicles.

- Search and filter runs
- Run only a subset (e.g. run all BISG diesels with a 8spd DCT)

1000’s of large scale run files

Large scale run files define 10,000’s of full vehicle simulations



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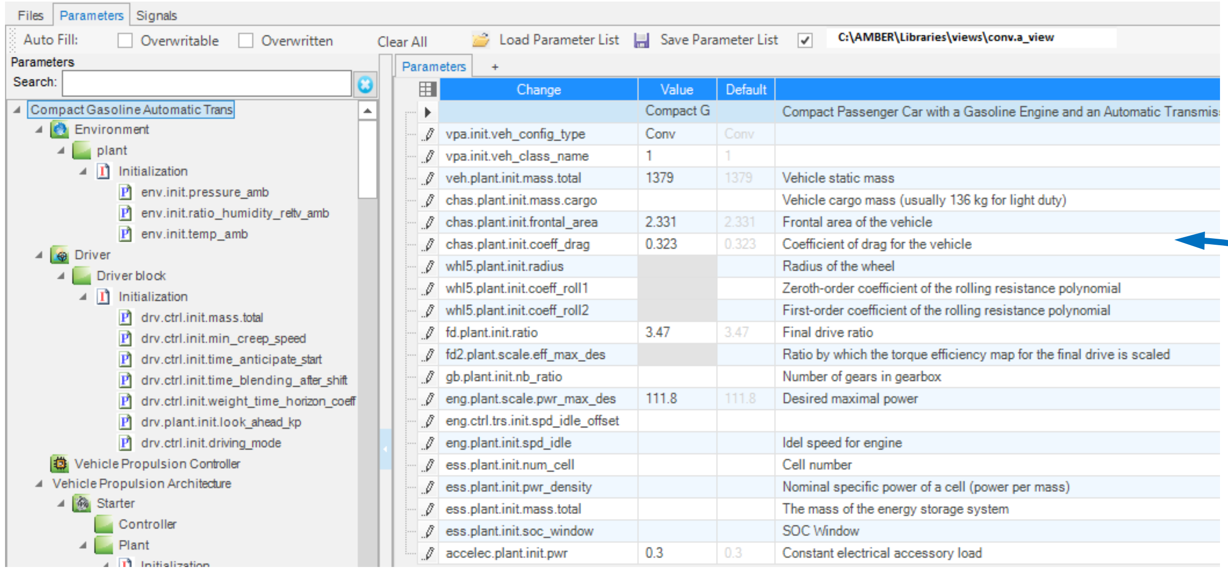
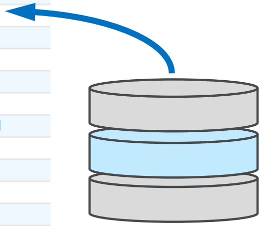
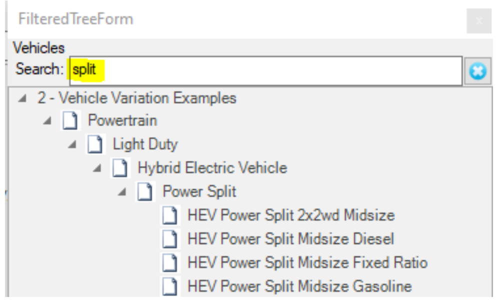
WORK FASTER AND BETTER WITH IMPROVEMENTS THROUGHOUT THE USER INTERFACE

- Based on user feedback
  - Redesigned dialogs
    - Searchable
    - Informative
    - Visual
  - Additional tool tips
  - Preloading editors with user defined favorites
    - Edit a Vehicle
    - Run a Vehicle
    - Import Test Data
  - More interactive suggestions about files, parameters, buses to guide users when modifying vehicles

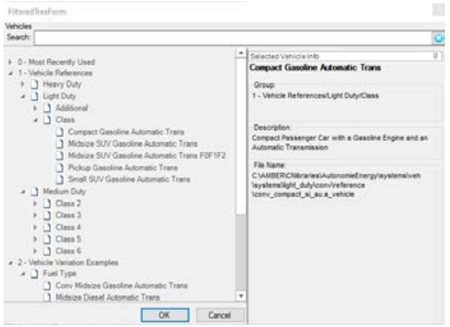




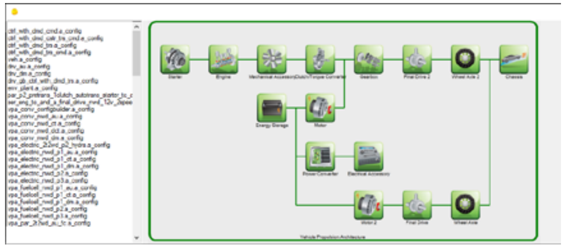
Find files faster with search



More informative dialogs



See configurations before selection



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USE CASE:

EVALUATE THE REAL WORLD FUEL ECONOMY IMPACT OF HEAVY DUTY POWERTRAIN ELECTRIFICATION

USE LIVEWIRE DATA IN AUTONOMIE (FLEETDNA → LIVEWIRE → AUTONOMIE)

- Use real world drive cycles shared through Livewire
- Quantify real world benefits of electrified powertrains using Autonomie
- Share the platform independent models and cycles for wider usage.

NREL

- **Real World Data**
- Drive cycles for multiple types of trucks
- Test weight estimates

Livewire

Argonne

- **Vehicle Simulation**
- Vehicle models
- Drive cycles formatted to daily work trips
- Energy consumption estimates on real world use cases

Autonomie

Argonne

- **Data Dissemination**
- Compiled vehicle models that can run as an executable file
- Daily drive cycles formatted for vehicle simulation*

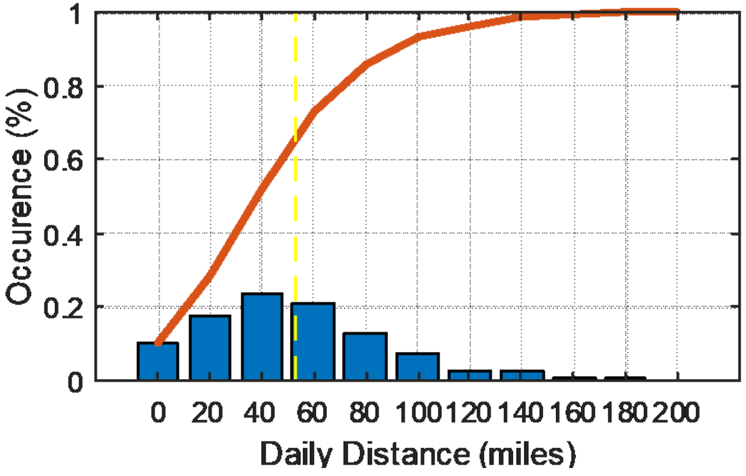
Globus

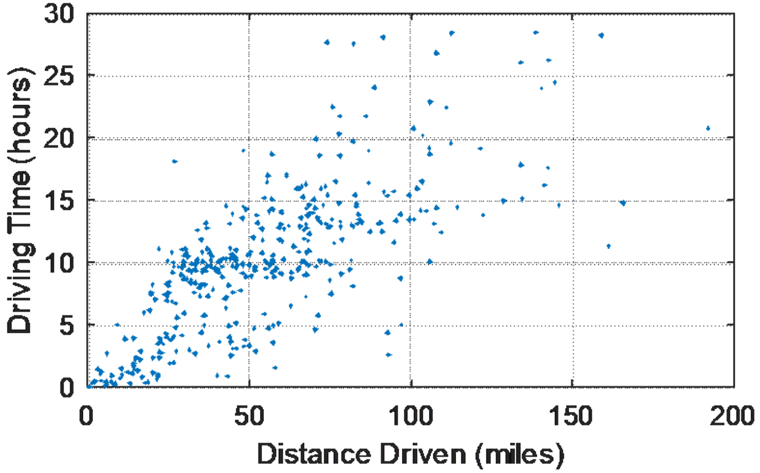
REAL WORLD DRIVE CYCLES (RWDC) INFORMATION USED TO IMPROVE VEHICLE REQUIREMENTS

Range, Payload estimates, Downtime available for Recharging/Refueling

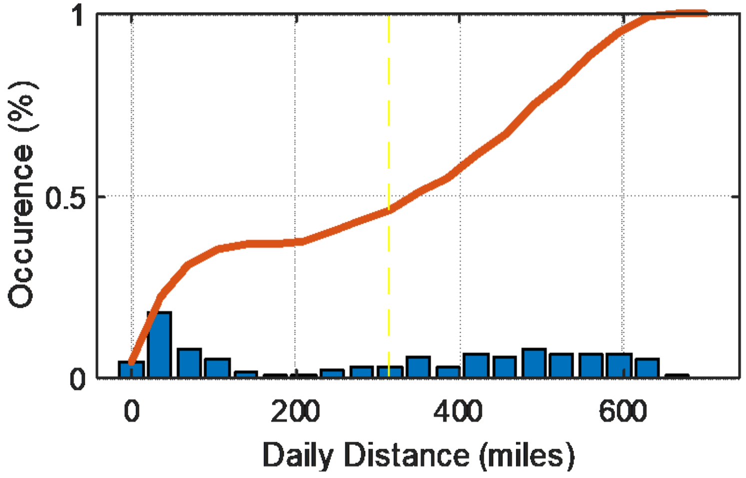
- RWDC was collected from fleets across US by NREL. This data is shared through Livewire
- Daily driving range –Multi shift operations can have some work days extending beyond 24 hours. Downtime available between trips will guide charging or refueling rates needed for vocations
- Other information
  - Cruising speed requirements
  - Payload estimates,
    - Test weight estimated by NREL
    - Vehicle curb weight is known
    - Location & duration of stops could identify the opportunities for charging or refuelling.

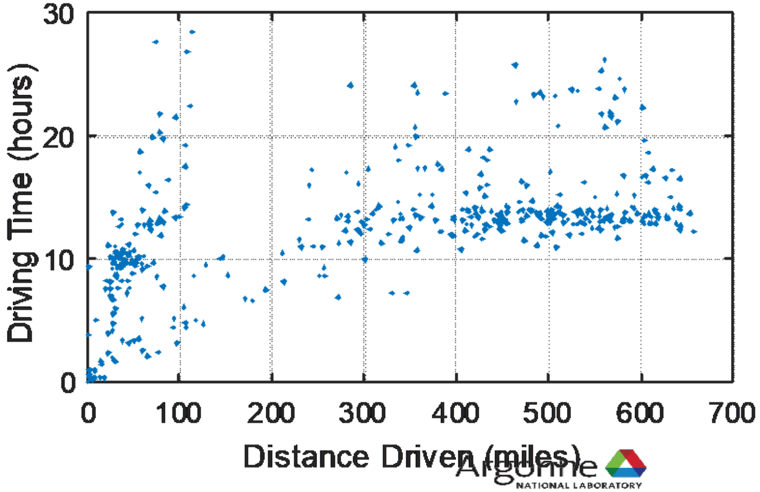
Class 6 Delivery (CERC)





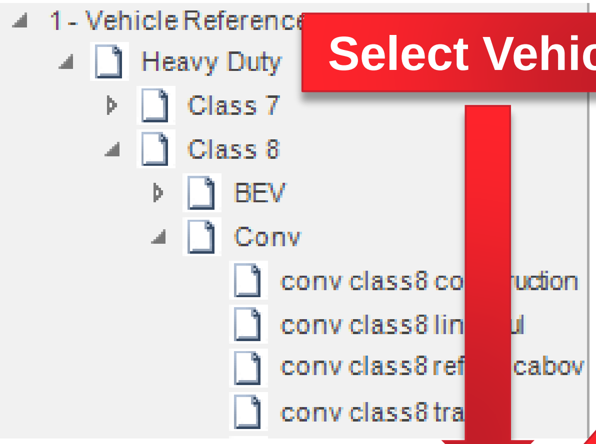
Class 8 Regional (Livewire)





More info on RWDC data is at www.nrel.gov/fleetdna

POWERTRAIN SIZING PROCESS FULLY INTEGRATED



Select Vehicle

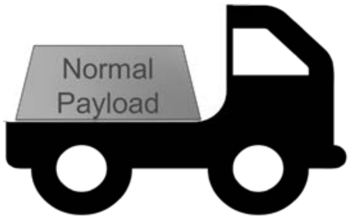
Tech Specs.

Default	
size_HD_vehicle.	Sizing Algorithm
	Powertrain
13.33	0-30mph Acceleration Speed
14	0-30mph Acceleration Time
26.6667	0-60mph Acceleration Speed
50	0-60mph Acceleration Time 2
31.2	Target Cruising Speed
35	Target Max Speed
16.54	Target Grade Speed
6	Percent Grade
400	Battery Pack Voltage

Sizing

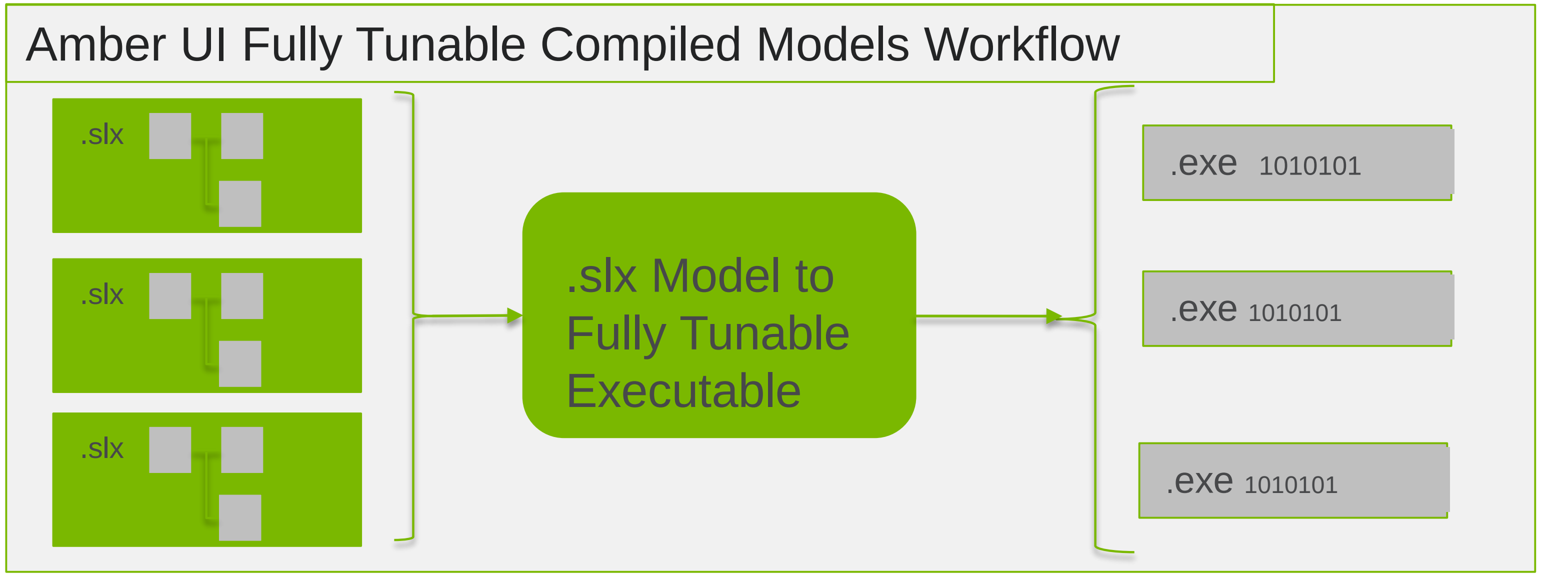
- Performance tests @ max
  Gross Vehicle Weight Rating (GVWR)
  - Cruising speed
  - Sustainable Grade @ 65mph
  - Sustainable speed at 6% Grade climb for 11 miles
  - Launch @ 15% grade
  - Acceleration & Passing
    - 0-30mph & 0-60mph
  - All Electric/Driving Range

Analysis



- Fuel economy tests @ regular load
  - EPA regulatory cycles
  - Real World Cycles (Livewire, FleetDNA, CERC)
- Total Cost of Ownership (TCO)
  - Component Cost:
    - DOE targets
    - Other sources (actual, ML etc)

FULLY TUNABLE COMPILED MODELS ALLOW RAPID EVALUATION OF HUNDREDS OF REAL WORLD CYCLES



The ability to run compiled (.exe) models enables:

- Faster simulations (min to sec)
- Cost savings (no 3rd party licenses)
- Scale up on HPC
- Deployment to larger number of users

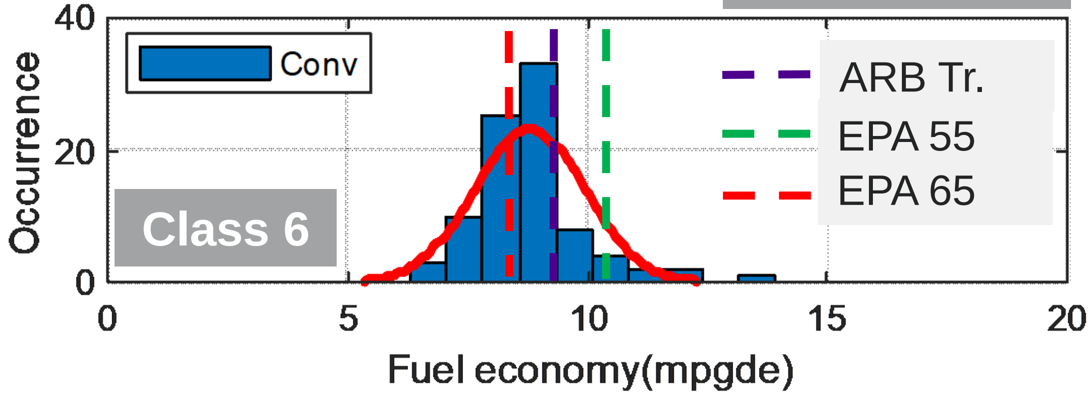
- Necessary inputs and outputs have been identified for compiled models
- Post-processing scripts are been developed to analyze the output
- Matlab tables, plots and tableau dashboards have been developed to analyze and visualize simulation results

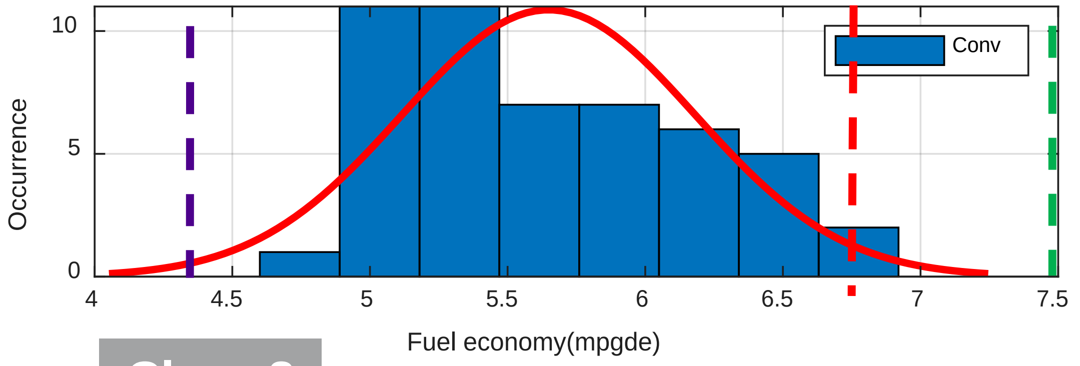
REAL WORLD FUEL ECONOMY EVALUATION OF VEHICLES

Regulatory cycles are fairly good representation of real world cycles.

- Class 6 cycles are from CERC Project (Cummins)
- Class 8 cycles are from Livewire for Sanger, TX
  - Two more locations were processed.
- EPA weighs the regulatory cycles according to use cases: Urban, Multipurpose, Regional
- RWDC characteristics help identify the appropriate weighing factors.
  - Class 6 Delivery is more multi-purpose, than Urban (in terms of driving behavior)
  - Class 8 runs in Texas yields lower mpg values due to the speeds >70mph. More locations are being evaluated.
- Q: Can we use regulatory cycles?
  - Prima facie, we see that the EPA weighting works well for conventional vehicles.
  - Weighing method needs to be determined for each vocation

Preliminary results





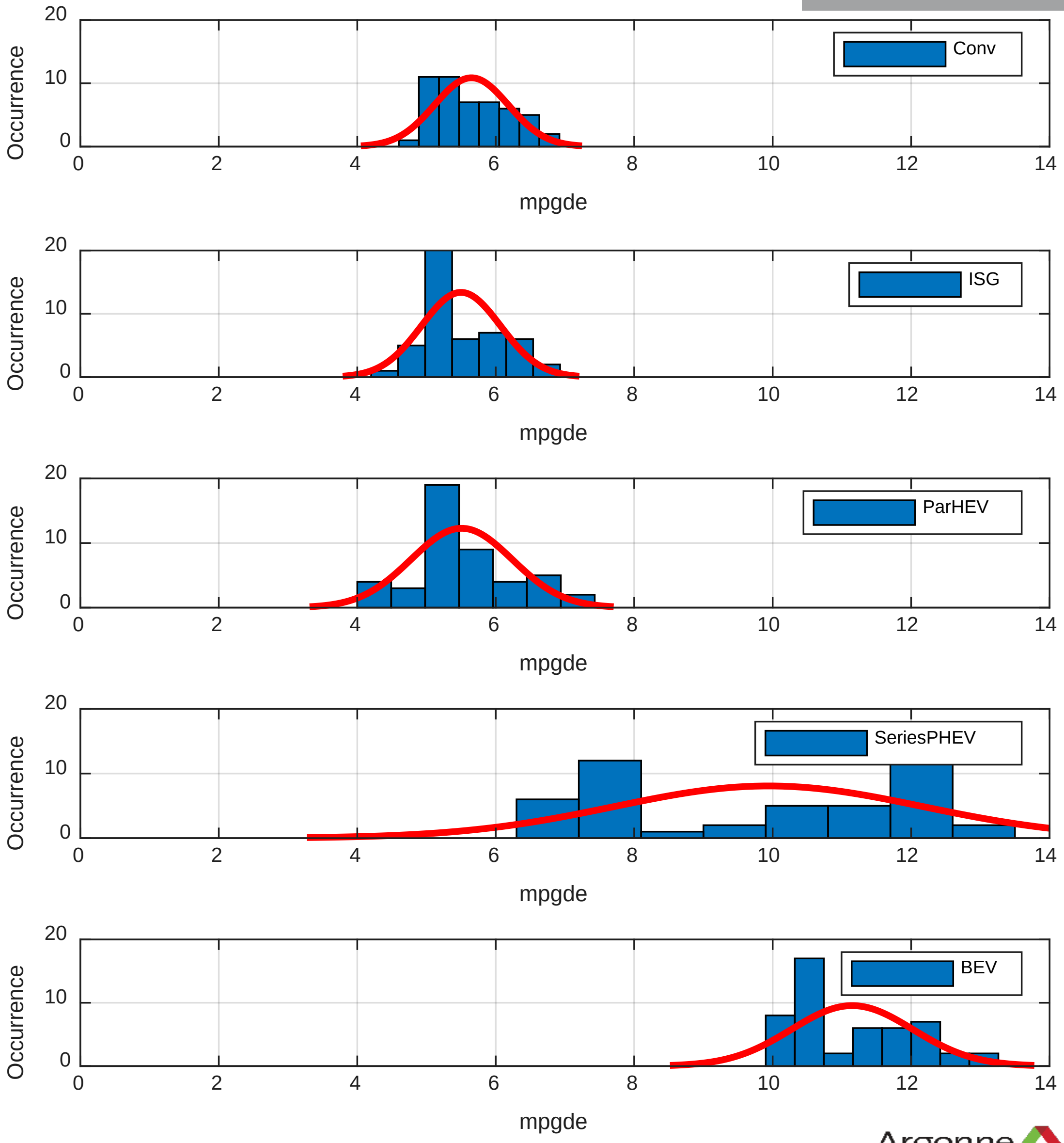
Class 8

POWERTRAIN SPECIFIC FUEL ECONOMY IMPROVEMENTS ON REAL WORLD CYCLES (CLASS 8 SLEEPER)

Preliminary results.

Improvements are dependent on drive cycles

- Class 8 Sleeper data from Livewire*.
  - Integrated Starter Generator (ISG) & HEVs have limited advantages on highway driving, due to increase in curb weight.
  - Series PHEVs are heavier, but having 250 mile of Charge Depleting (CD) range helps in improving overall fuel economy
  - BEVs are sized for 500 mile range.
- Vehicles are tested with 38k lbs. of cargo mass
- NREL will provide data for more classes and vocations through Livewire



*Data from Sanger, TX

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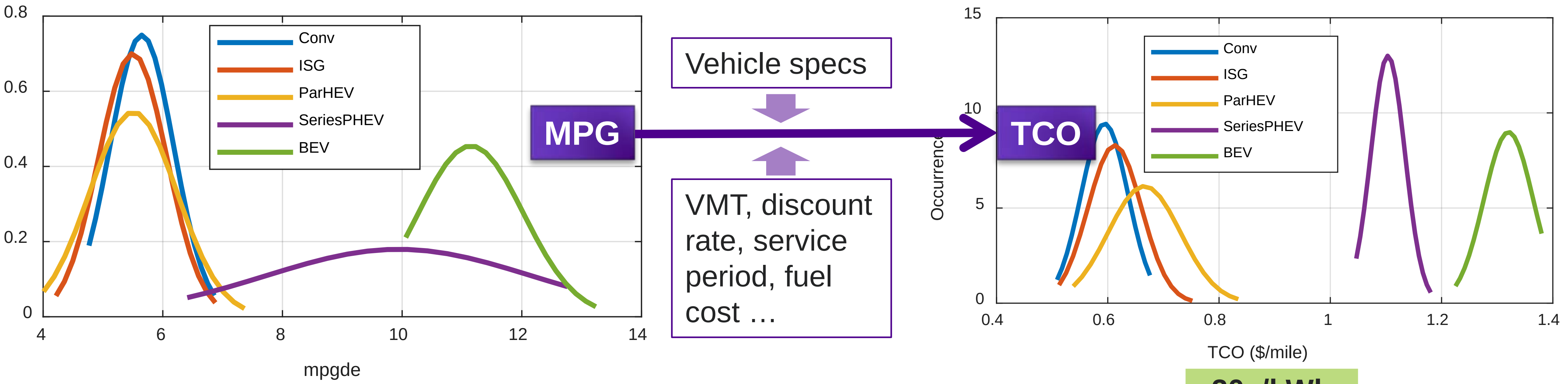
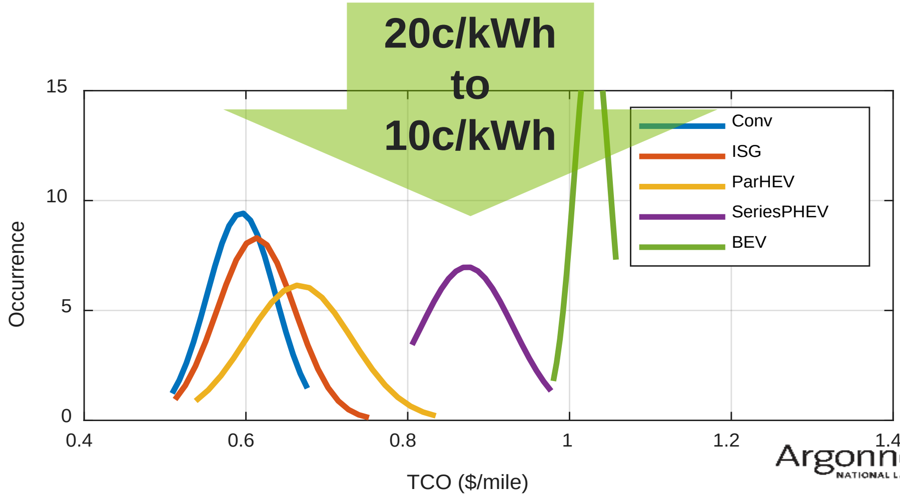
ESTIMATED POWERTRAIN SPECIFIC TCO FOR EACH DAILY DRIVE CYCLE / ROUTE

Cycle properties affecting the powertrain specific Total Cost of Ownership (TCO) are being investigated.





- Based on today’s vehicle price & fuel cost estimates, TCO is lowest for conventional vehicles.
- Further analysis will quantify the impact of technology progress & fuel costs on the powertrain choice
- Impact of battery cost changes and electricity prices will be quantified as well.

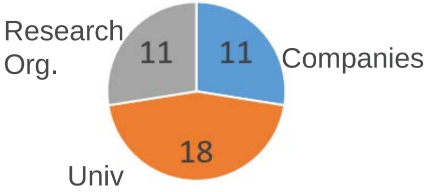
RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

- Comments from 2019 AMR
  - Overall, the reviewer stated that there is a good plan going forward. Developing workflows that do not require software licenses would be a huge benefit…
- Response
  - The compiled workflow & models will be freely distributed

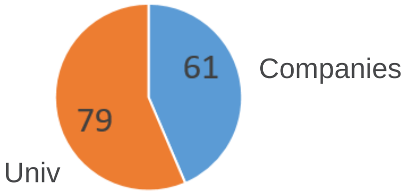
COLLABORATION AND COORDINATION

Users Overview (# of Institutions)

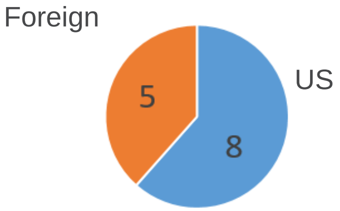
40 Government



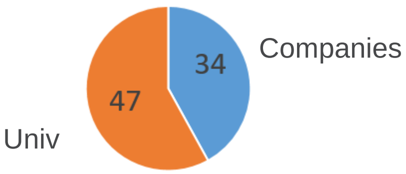
140 Paid Licenses Institutions



13 Classroom



81 New License Requests (Past 12 months)



Main Programs Supported

SuperTruck

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

GATE Graduate Automotive Technology Education

Co-Optimization of Fuels & Engines

EcoCAR3 Advanced Vehicle Technology Competition

CAFE Corporate Average Fuel Economy

arpa·e NEXTCAR

Current Project Partners

U.S. Department of Transportation National Highway Traffic Safety Administration

Volpe The National Transportation Systems Center

Federal Transit Administration

Clemson University

ORNL Oak Ridge National Laboratory

California PATH

City of Chicago

Connected Signals

Washington State University

Cummins

Rensselaer

NREL National Renewable Energy Laboratory

cta Chicago Transit Authority

Tsinghua University

Michigan

here

Carnegie Mellon University

Institut VeDeCoM

Illinois Institute of Technology

Argonne National Laboratory

REMAINING CHALLENGES AND BARRIERS OF THIS PROJECT

- The diversity of electrified powertrains is quickly increasing. Our goal is to develop full vehicle models for various types of powertrains. Prototype powertrain examples will be added based on feedback from DOE and industry
- Maintain latest versions of different tools (30+ software currently used)
- Access to latest component and vehicle test data is required to maintain state-of-the art models and controls

NEXT STEPS

- Continue to enhance AMBER functionalities based on users feedback and DOE needs
- Evaluate the benefits of advanced technologies across different vehicle classes, timeframes, uncertainties and scenarios (standards, real world…)
- Develop and deploy compiled tunable vehicle models of representative vehicles (license free)

PROPOSED FUTURE RESEARCH BEYOND THIS PROJECT

- Expand current workflows and add new ones to include additional tools, both commercially available and developed by US Government funding.
  - Eg. RoadRunner, SVTrip, Polaris
- Improve models with focus on medium and heavy duty (e.g. thermal models to include cooling system) and powertrain electrification (e.g., new architectures, specific MD/HD designs)

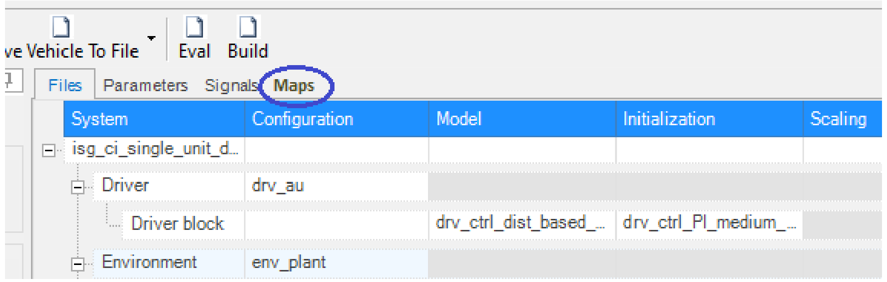
Any proposed future work is subject to change based on funding levels

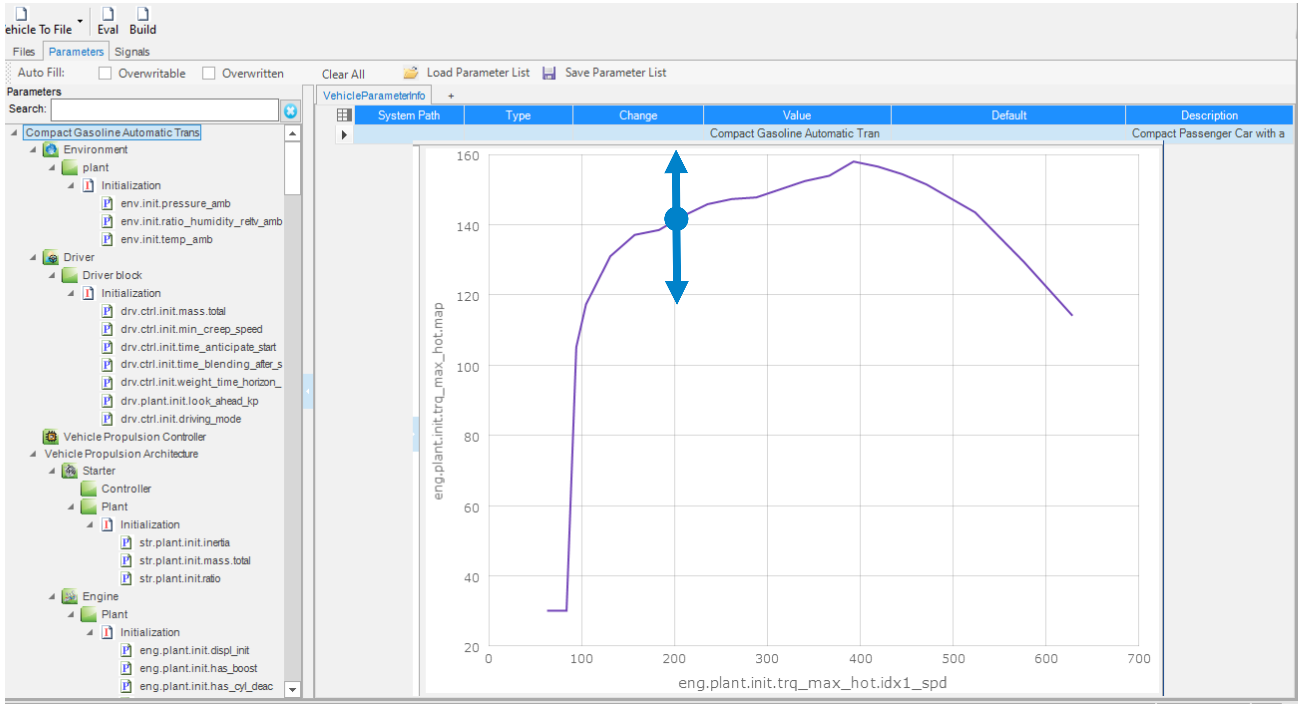
SUMMARY

- Autonomie is used widely across government, industry & academic organizations.
  - Autonomie 2020 is now released.
  - AMBER expands Autonomie capabilities (e.g., large scale simulation…).
- New functionalities have been added to support
  - Editing 2D maps and other model parameters through the GUI
  - Definition of macros for reproducing configuration and file changes in vehicles
  - Defining large scale simulations studies through the GUI
  - New MD & HD sizing processes with inputs from 21CTP

QUESTIONS?

EDIT PERFORMANCE AND CONTROLLER CALIBRATION MAPS IN THE UI - A LONG TIME USER REQUEST





- OEMs and DOE studies benefit from having parameterized maps
- Works with
  - Parametric studies
  - Optimization routines
- Control Designer workflow becomes possible

- 1D Maps can now be modified just like scalar quantities

ADDITIONAL VEHICLE SYSTEM SIMULATION IMPROVEMENTS IN AUTONOMIE

- New powertrains
  - Light Duty : Hybrid with dual clutch transmission (DCT) & integrated motor with an optional motor on rear axle (similar to hybrid version of Honda Jazz & Acura MDX).
  - Heavy duty electrified powertrain examples with 2 or more gears are under development.

- Model improvements
  - Improved shifting algorithms for HD vehicles (e.g., gear skipping)
  - HD control improvements for handling extreme grades, launch and creep situations.
  - Customizable cost and mass calculation functions for each component in AMBER.
  - Added the contribution of major aerodynamic improvement devices for HD Tractors
    - E.g. Boat tails, side skits, fairing, gap reducers etc. based on published information
  - Fully tunable, compiled vehicle models. APIs are developed for compiling and running the compiled models.

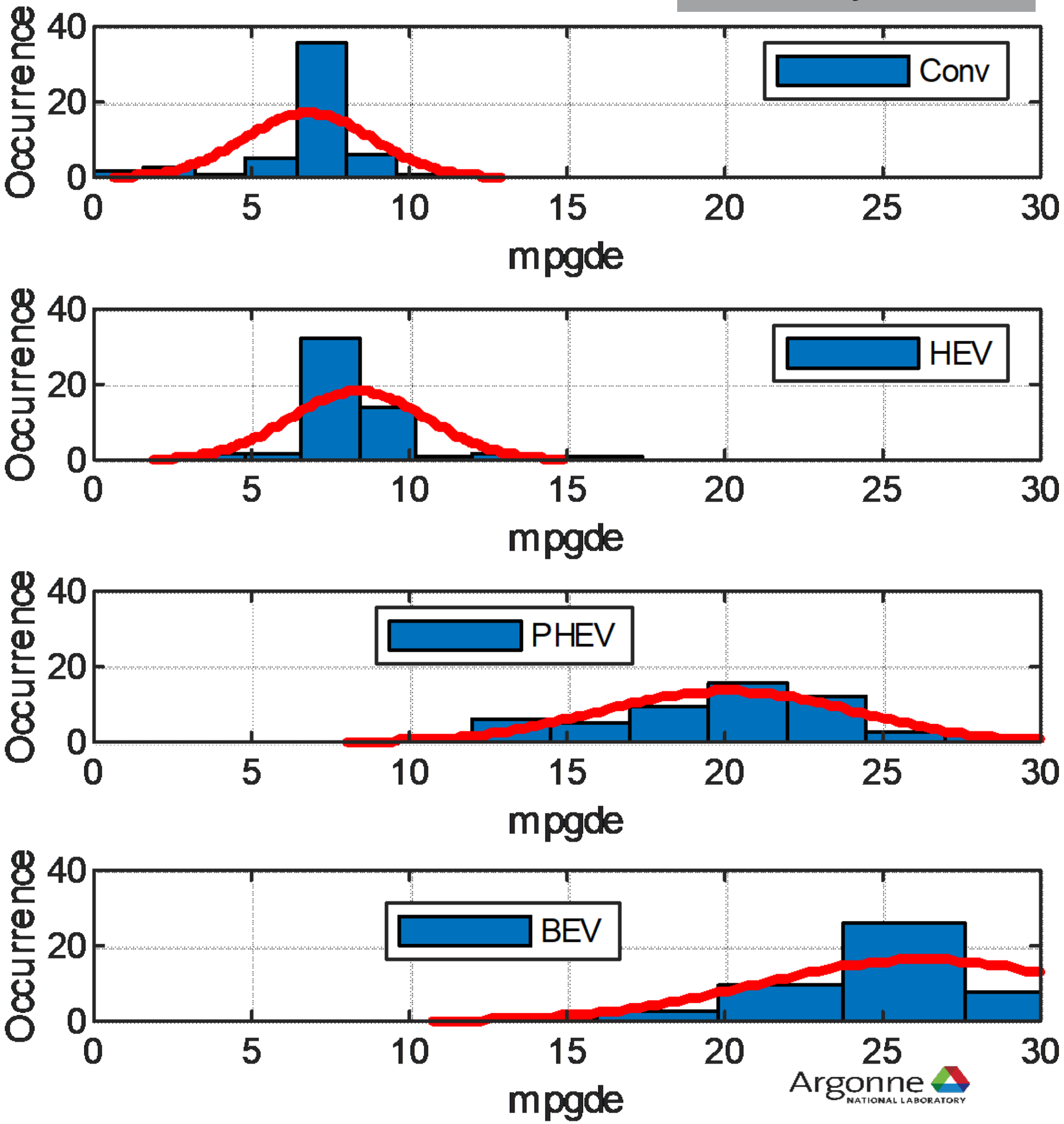
POWERTRAIN SPECIFIC IMPROVEMENTS (CLASS 6 DELIVERY)

Improvements are dependent on drive cycles.

Preliminary results.

- This data set for Class 6 vans have significant highway component.
  - HEVs do not show a big improvement over Conv for this data set.
  - PHEVs & BEVs show larger improvement in mpgde.
  - This includes both CD&CS operation of PHEVs. More than half of the cycles are drivable in all electric mode.

- Components are sized to meet the daily driving requirements.
  - Sizing logic was updated based on feedback from 21CTP*



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