Advancing Energy Analysis at GM with the New VERDE Toolchain

Anamitra Bhattacharyya, GM

- Vehicle energy model co-simulation specialist
- Analysis tool development and co-simulation tool and method development
- Previous experience at Cummins and FEV
- M.S. in mechanical engineering from Wayne State University and a B.S. in mechanical engineering from VNIT India.

Nate Wilmot, GM

- Engineering manager of the Energy Model and Toolchain Development Team
- Advance GM's virtual capability in the vehicle energy and performance domain.
- 25+ years of automotive industry experience
- M.S. in mechanical engineering from the University of Michigan, a B.S. in mechanical engineering from Cornell University, and a B.A. in physics from Ithaca College.

MathWorks
AUTOMOTIVE CONFERENCE 2024
North America

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Nathan Wilmot
Engineering Group Manager

(he/him/his)

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Vehicle Energy Co-sim Specialist

(he/him/his)

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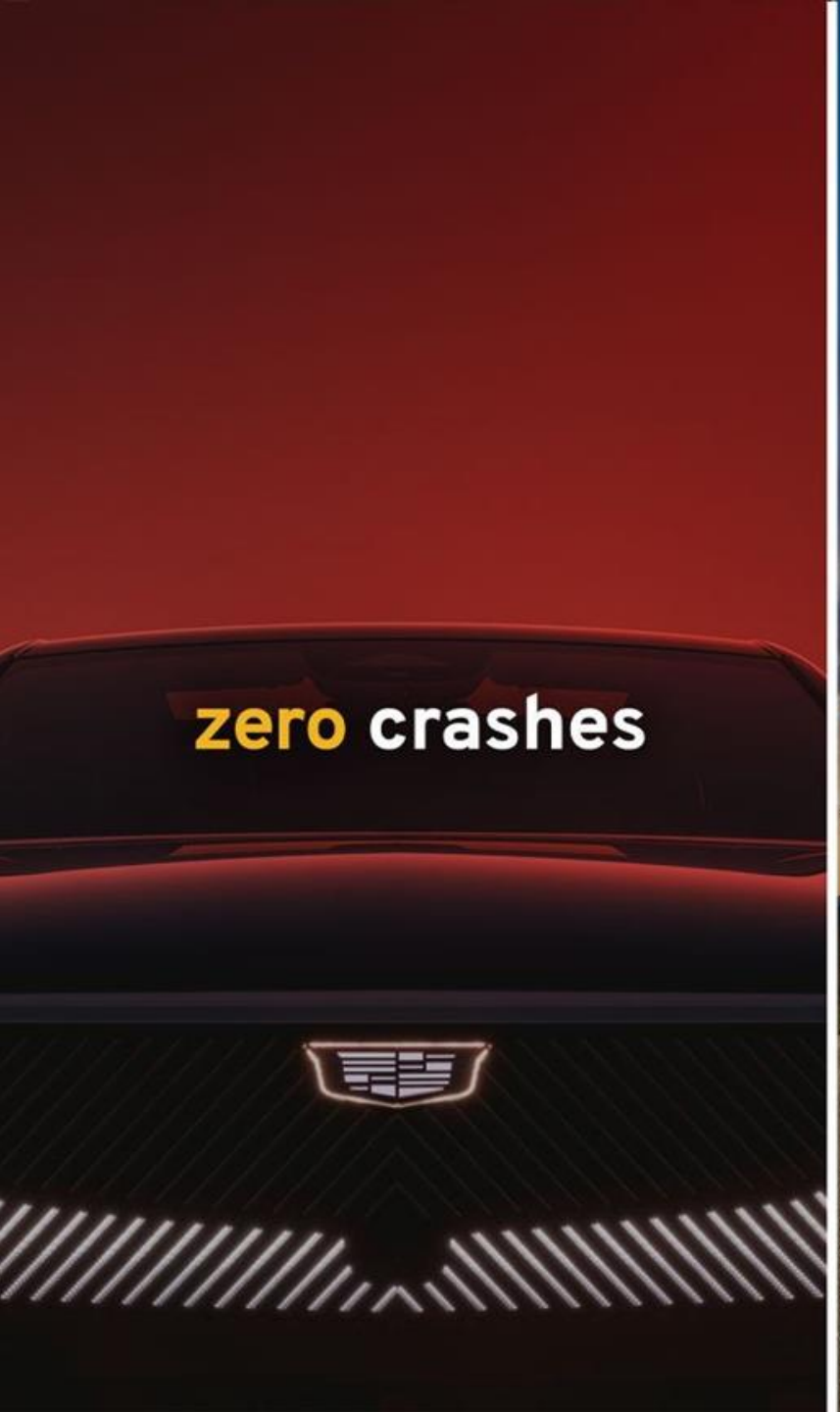
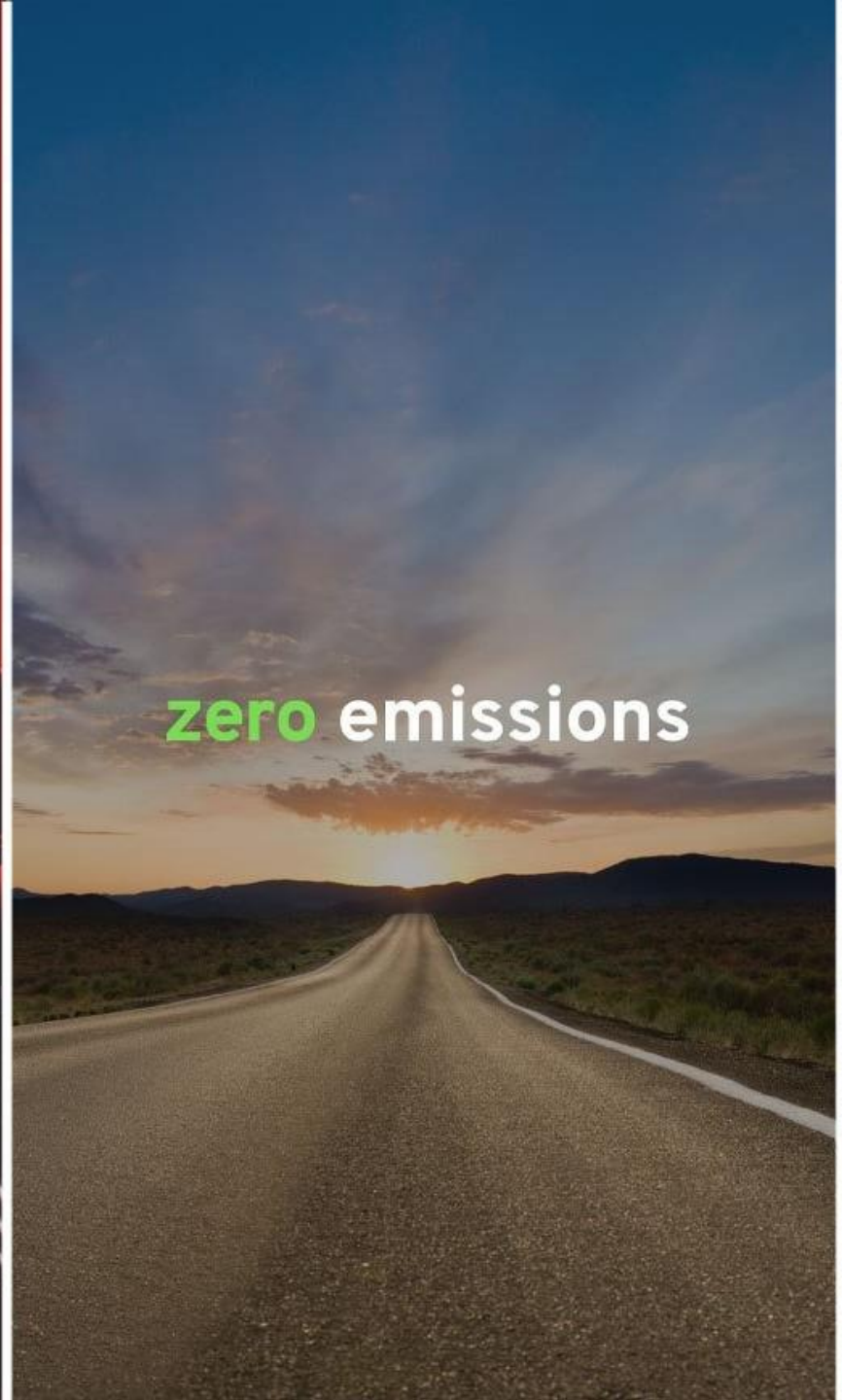
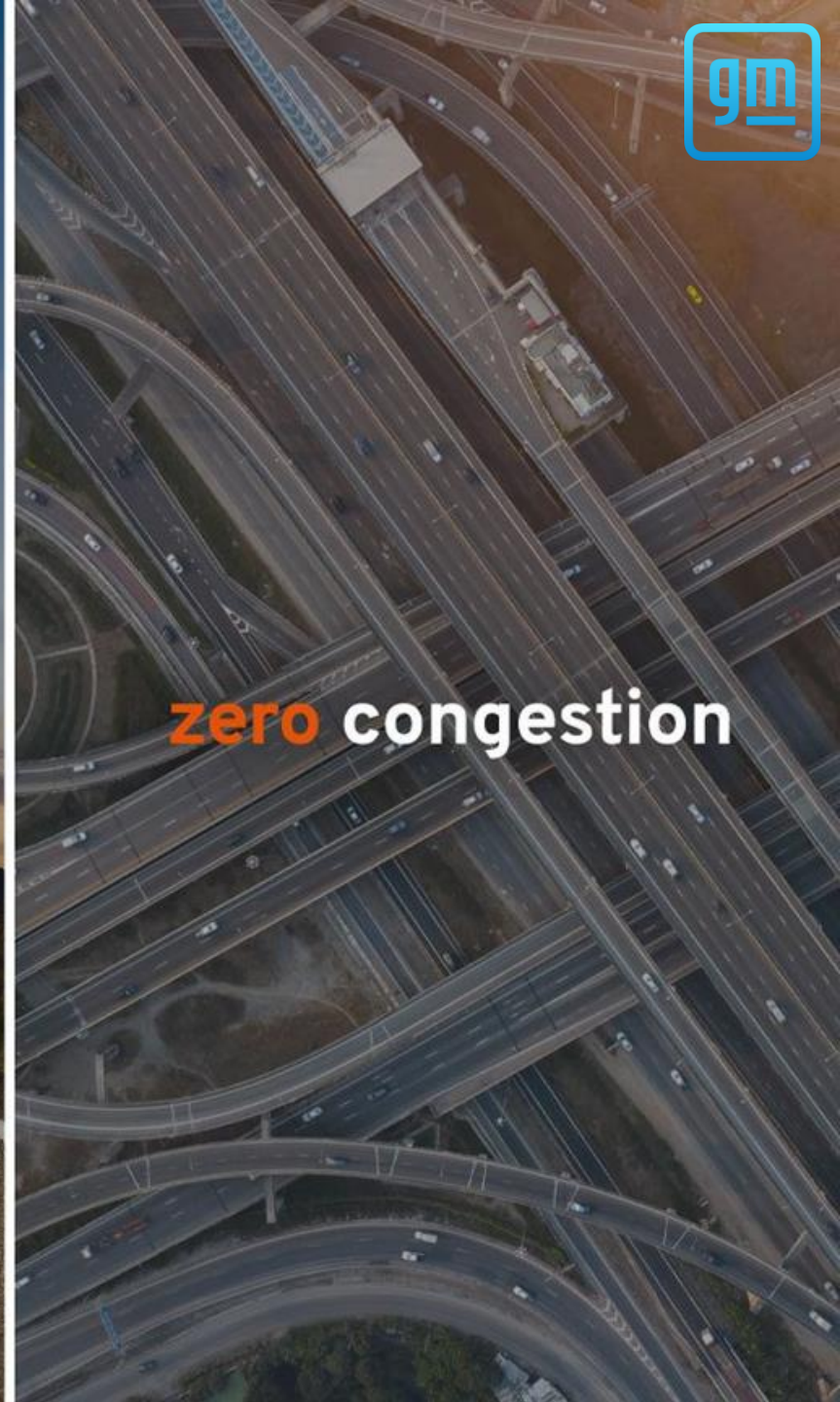
Agenda

- VERDE Introduction
- Tool Details and Execution
- VERDE Features and Use Cases
- What's Next


zero crashes


zero emissions


zero congestion

Energy Model and Toolchain Development Team

- Provide the analytical tools, virtual infrastructure, and user support to engineer efficient, capable, and exciting vehicles.
- Manage and advance the suite of tools used to predict, analyze, develop, validate core vehicle performance attributes such as:

Driving Range

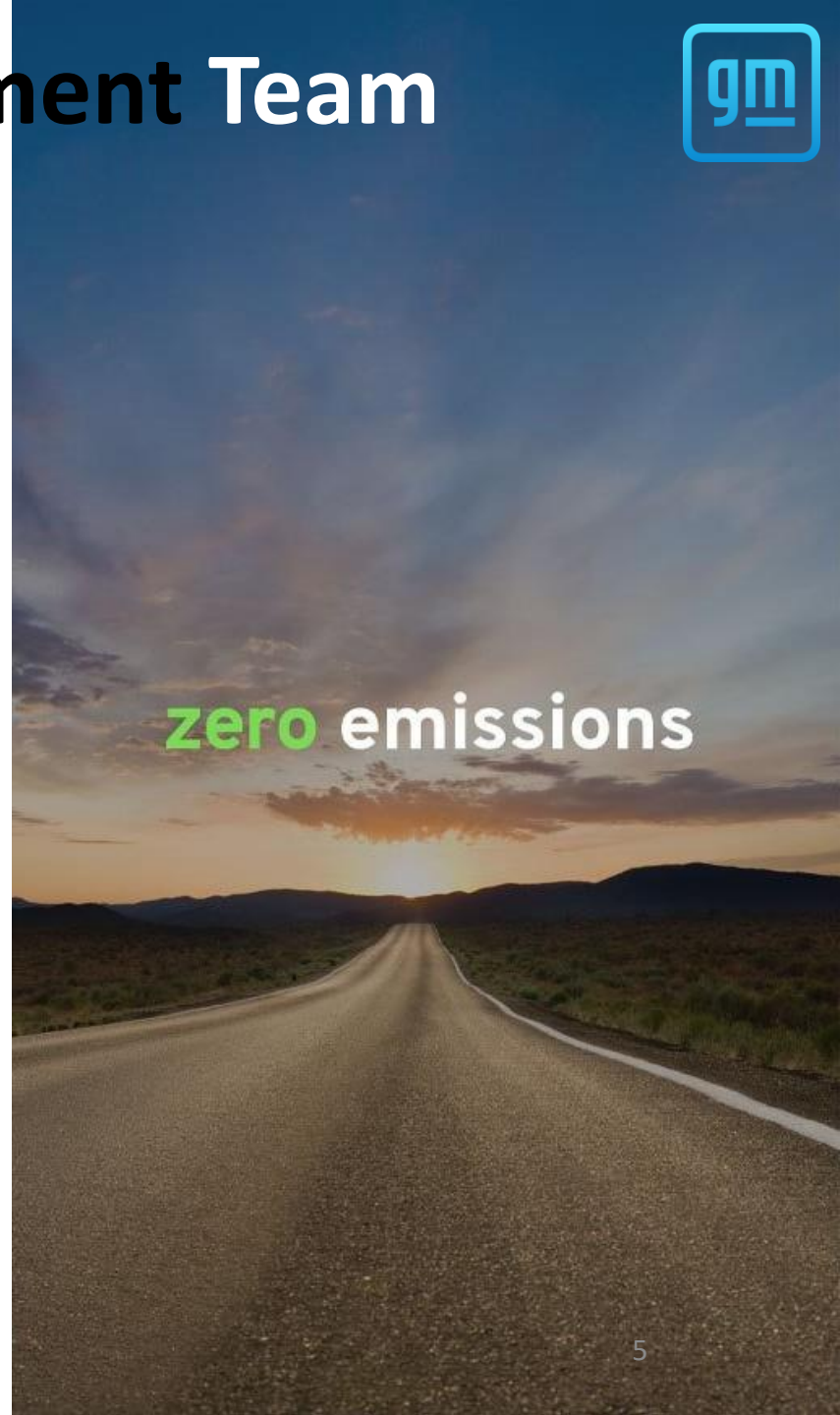
Fuel Efficiency

Drive Quality

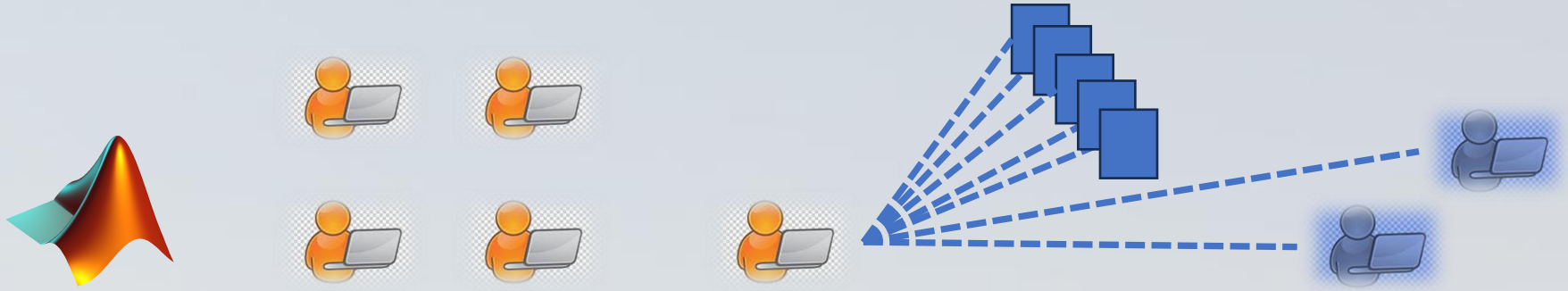
Longitudinal Acceleration

Grade Capability

Towing Performance



GM Vehicle Energy Modeling Journey



100% In-House Tools & Codes

MATLAB / Simulink

Single User & Individual Runs

Multiple Runs / DOE's

Started Co-Sim Connections

2000's | 2010's | 2020's

Capability & Efficiency

Global Users

Industry Standards

Modern Interfaces

Tool Connections

Rapid Evolving Space

Strategic Inflection Point

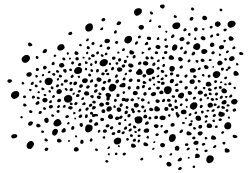
Growth

Stability

Decline

Biggest Challenges & Opportunities

- **Speed** – Reduce the time to learn, build and execute models
- **Scale** – Large DOEs & Optimization Studies
- **Data** – Inputs & Outputs managed, released, databased, ma
- **Accuracy** – High-level metric **AND** behavior alignn t
- **Fidelity** – Scalable & Modular to enable Coarse-Fine by Syste -System
- **Democratization** – Getting more team members able to generate meaningful results
- **Co-Simulation** – Leverage other tools; collaborate with other domains

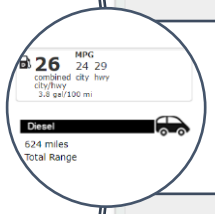






VERDE Introduction

VERDE (**V**ehicle **E**nergy and **R**ange **D**evelopment **E**nvironment) is a common tool used across GM from the earliest stages of a program framing through production and beyond.

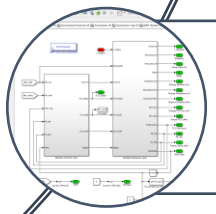
Forward driven model capable of representing almost any vehicle and propulsion configuration in any scenario of longitudinal motion.



Models Customer Facing Efficiency & Acceleration Performance

Feeds Global GHG and CO2 Strategy

Close to 400 Global Users – Multiple Domains



200k+ Simulink Blocks, 200+ Sub-Systems

Typical Simulation: ~ 500 discrete inputs (tables or values), ~250 output signals, ~270 calculated metrics

Why an In-House tool?

Why NOT use a pre-packaged COTS tool for this analysis?

- Not difficult to develop these models at the highest level
- Many people/teams do this, and do it well…

AVL

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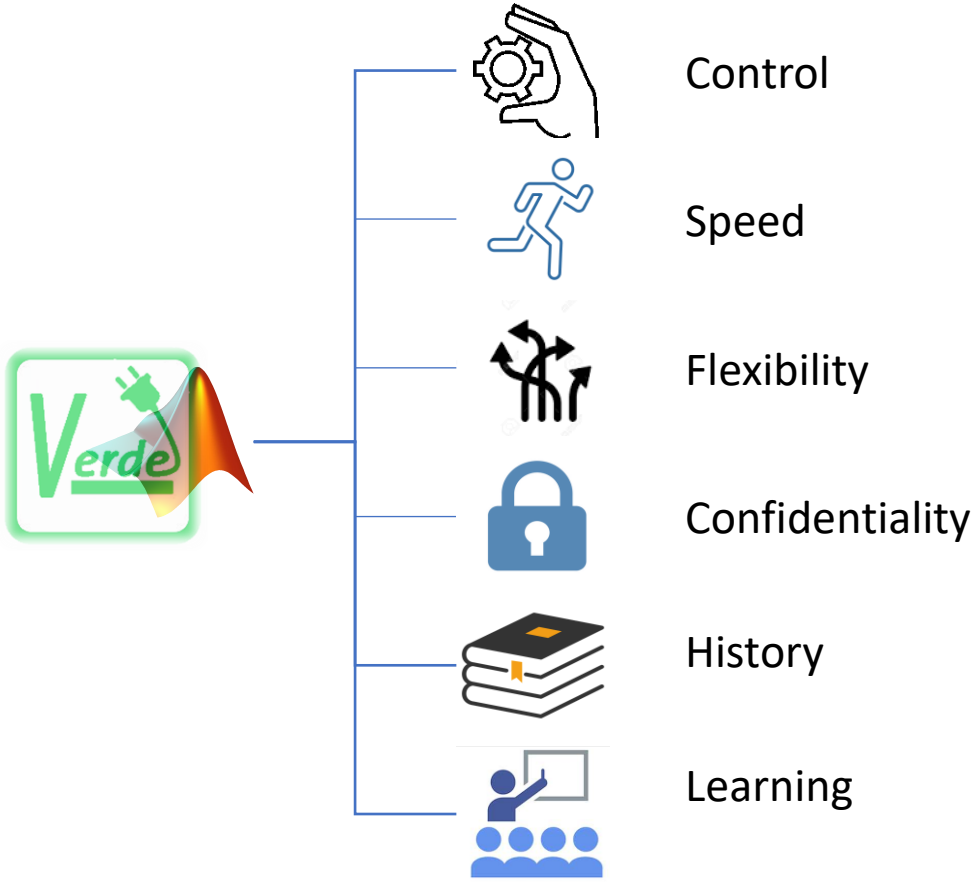
GAMMA TECHNOLOGIES

COTS: **C**ommercial **O**ff **T**he **S**helf

Strategic Advantages:



Tool Details and Execution

Advancing Energy Analysis at GM with the new VERDE Tool Chain

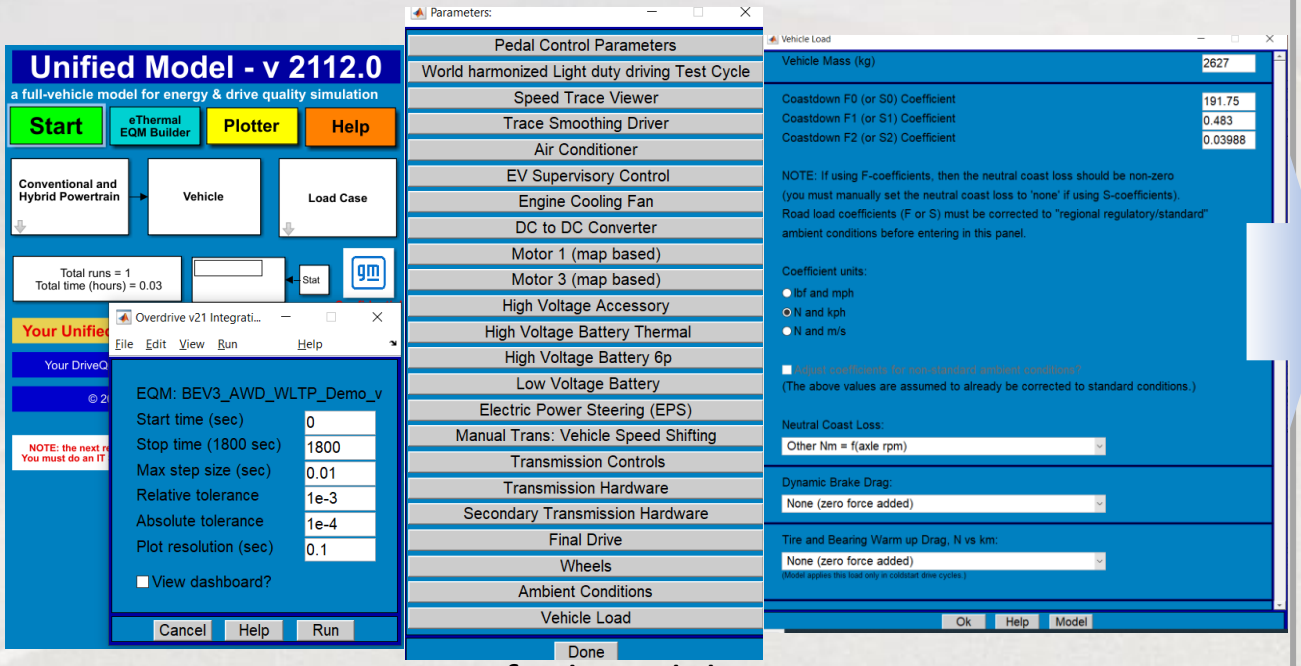
VERDE GUI

Legacy GUI: based on GM custom MATLAB toolbox

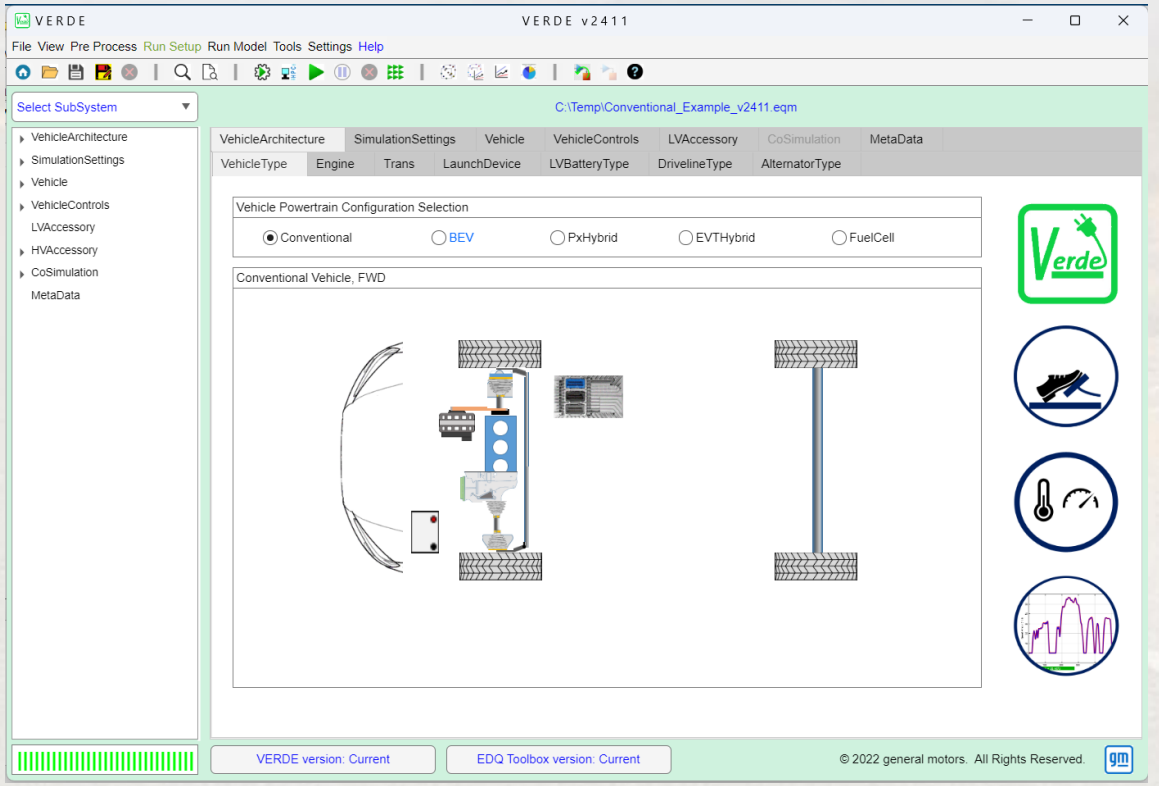
- Needs Simulink model to be loaded
- Complex and layered navigation
- Difficult to onboard new users
- Difficult to add advanced features

VERDE GUI: based on MATLAB App Designer

- GUI can function independent of the model
- GUI is easy to navigate
- GUI is Intuitive and integrates many help features
- Supports several advanced features related to data import, tools integration etc.



Unified Model

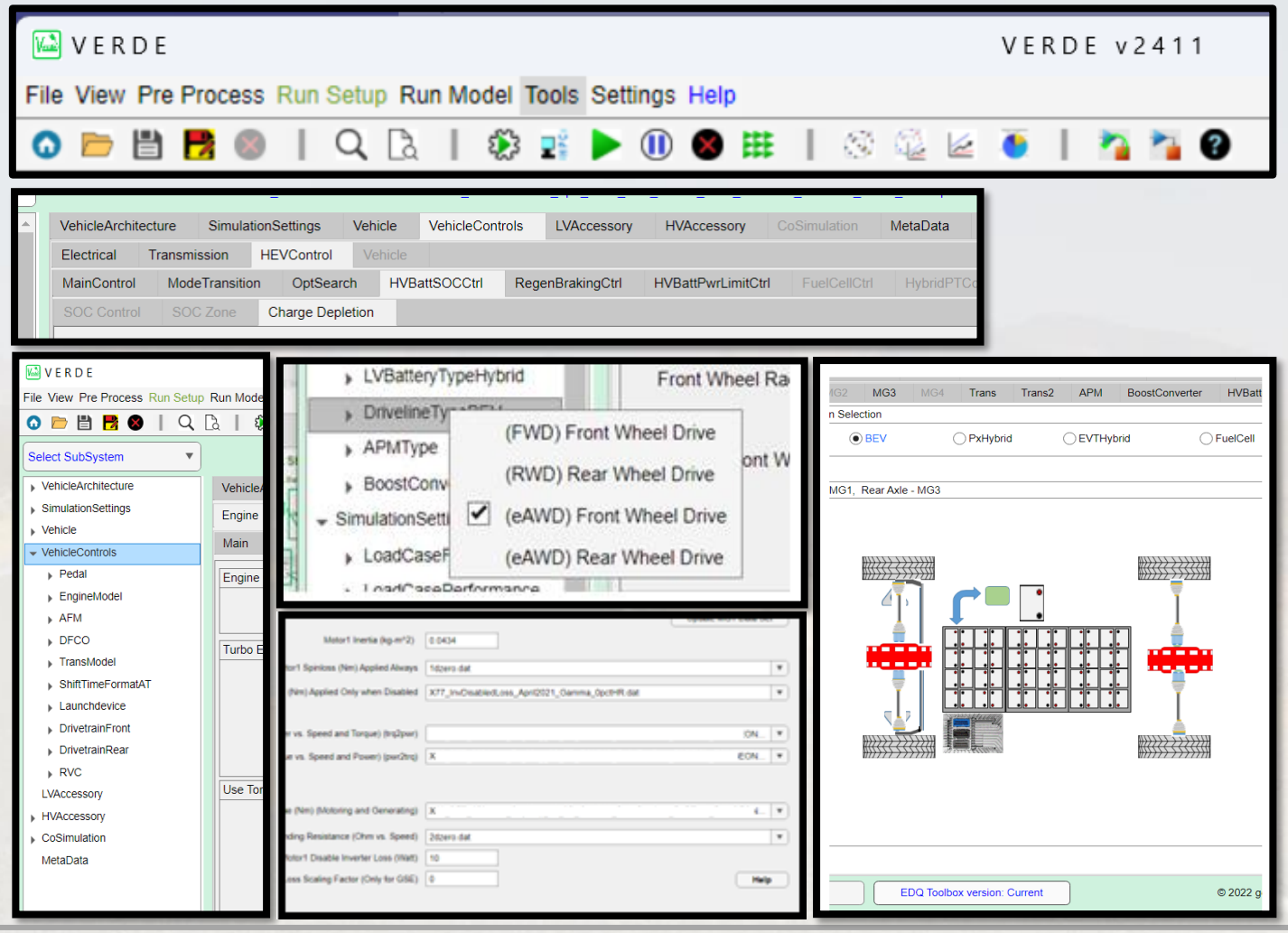


VERDE GUI Features

Provides several user-friendly features

- Ribbon with buttons
- Intuitive navigation
  - ➢ Multilayer Tabs
  - ➢ Dynamic tree options
  - ➢ Interactive system graphics
- Dynamic model configuration
  - ➢ Right click tree node options
- Parameter selection from GUI

and more..



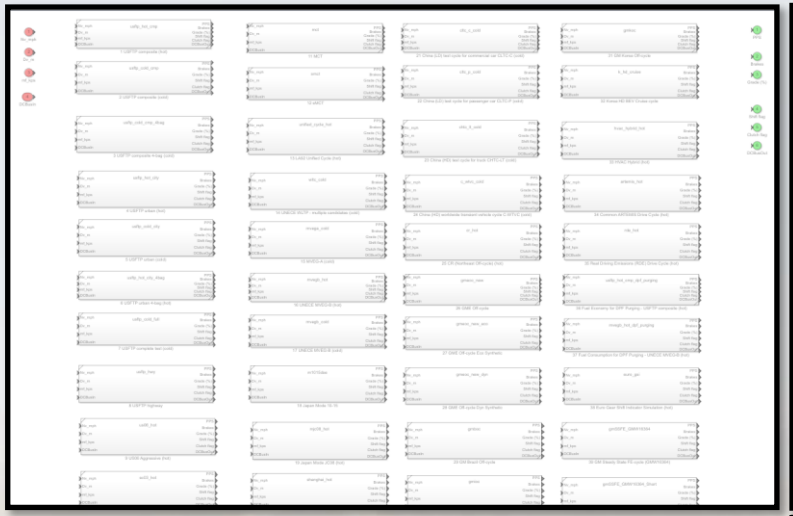
MATLAB® App Designer

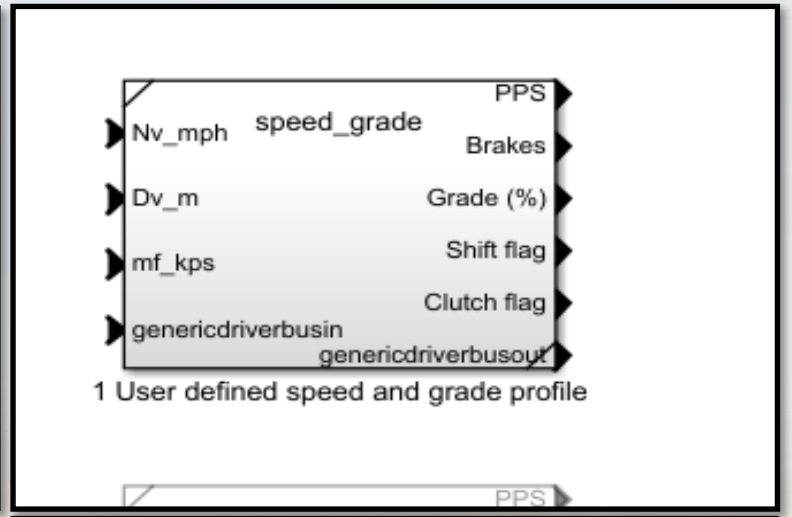
VERDE Model

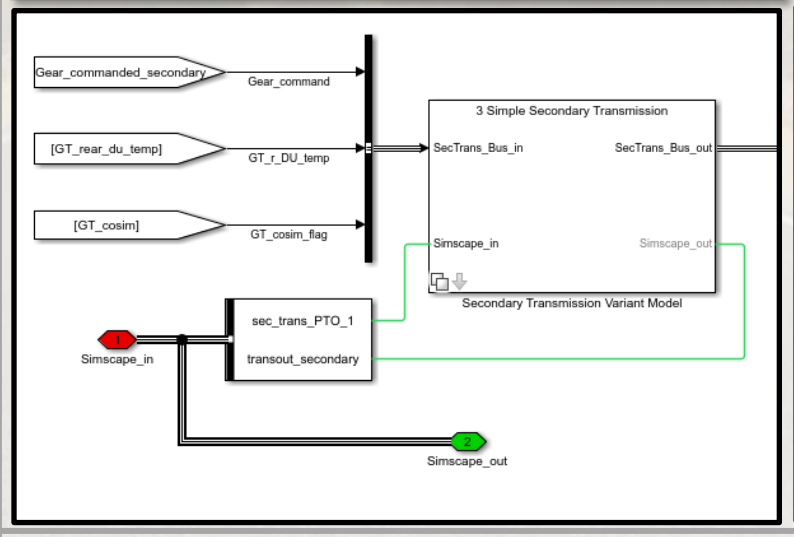
VERDE GUI interacts with Simulink models to set up and run the simulations

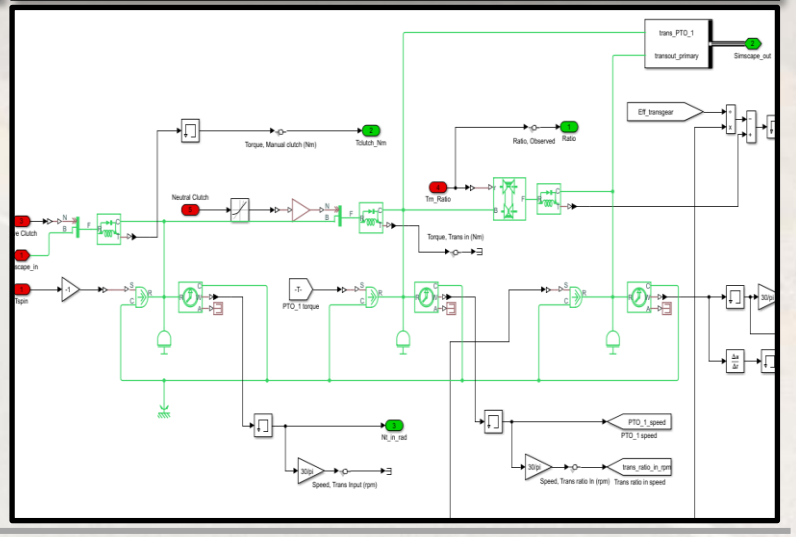
- Simulink variants
- Reference subsystems and models
- Bus architecture
- Simscape toolbox
- Auto configurable from GUI
- Complexity
  - ➢ More than 2000 parameters
  - ➢ Around 100 variants
  - ➢ Over 200,000 blocks

and more..









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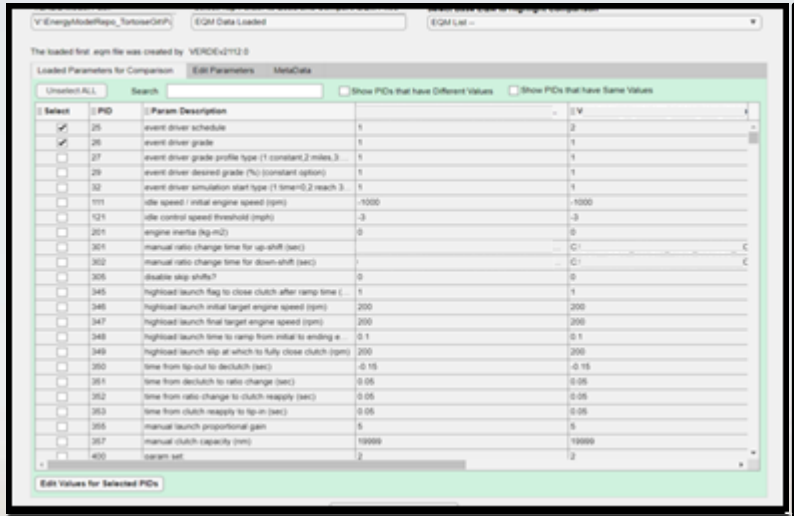
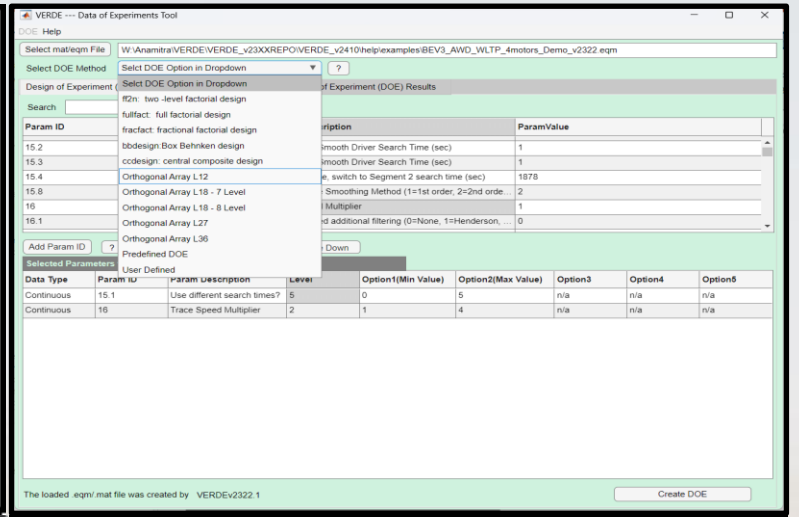
Supporting Tools, Pre-Processing

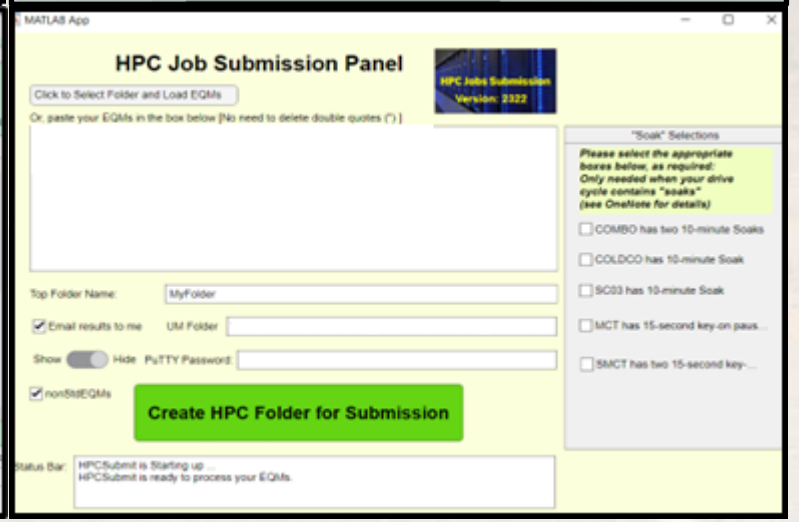
Energy Tool-Chain features following pre-processing capability

- Compare and edit one or more models
- Set up and run DOE using a seed model
- Manage input data from Database
- Submit and retrieve jobs from HPC (with / without DOE)

etc..





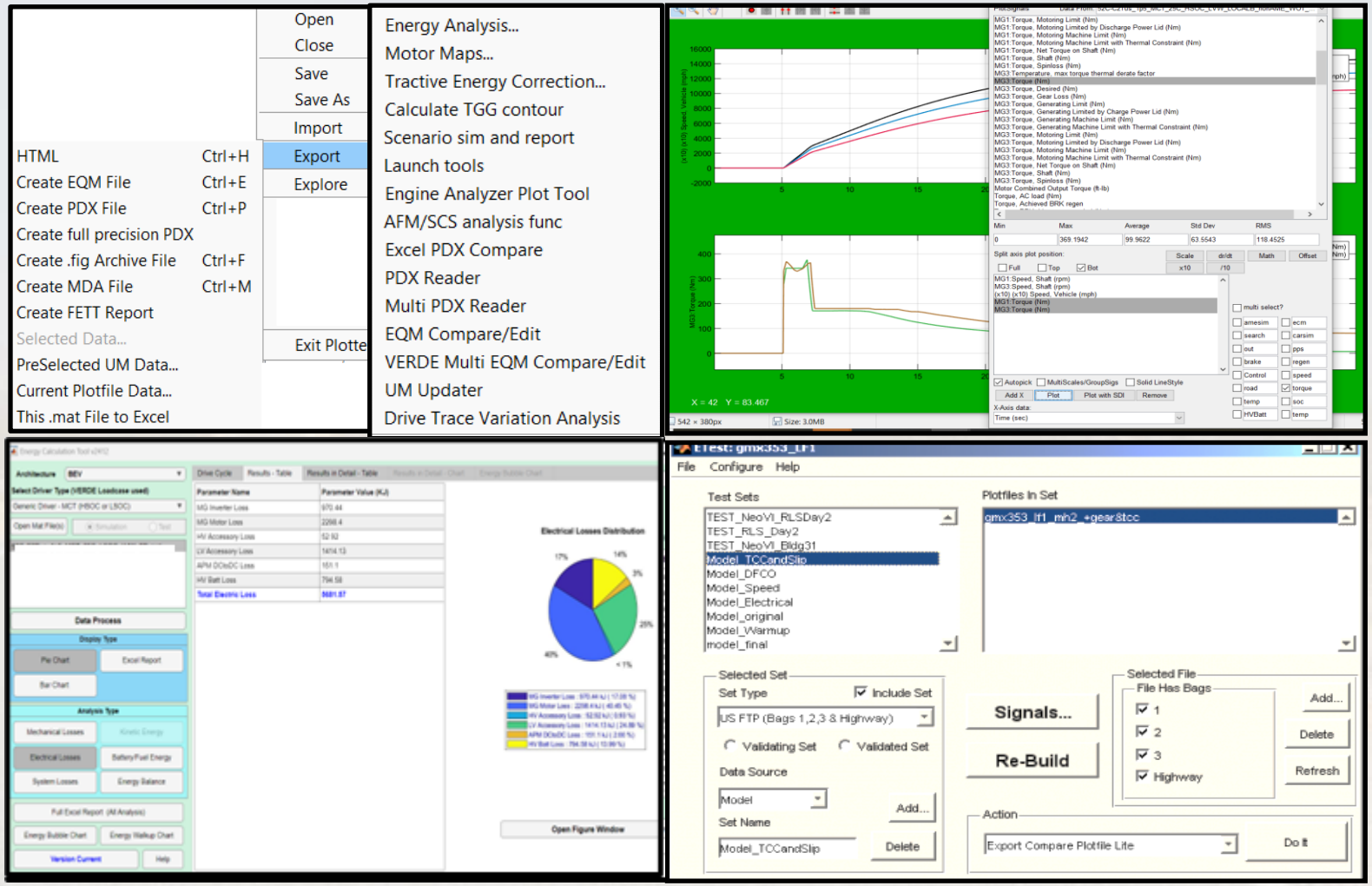


Supporting Tools, Post-Processing

Energy Tool-Chain features following post-processing capability

- Model results post-processing
  - ➢ Plot time history
  - ➢ Export model results
  - ➢ Use various post processing tools, ex. perform Energy Balance Analysis
- Automated model correlation tool
  - ➢ Common logic is used between test data and simulation results

etc..



MATLAB® App Designer

Executing a VERDE Model

Supported architectures and Standard Process

EV

ICE

Hybrid

Fuel Cell

Learning & Training

Model Definition File

Update Architecture

(FWD) Front Wheel Drive
(RWD) Rear Wheel Drive
(AWD/4WD) All Wheel Drive - Transverse
(AWD/4WD) All Wheel Drive - Longitudinal

Import from Database

Update Control

Simulation Settings

Run Model

HPC

Post Process

Electrical Losses Distribution

Analysis & Reporting

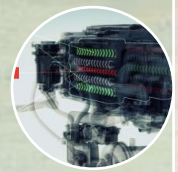
Closed loop learning

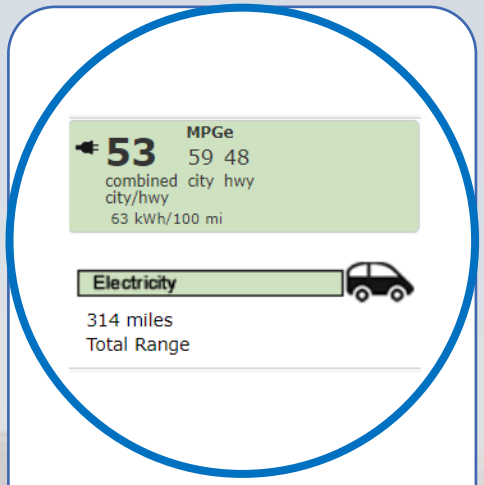
Model Prediction Standalone Use


EV

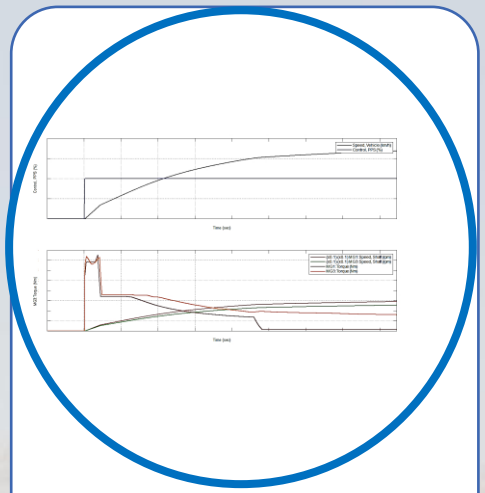

ICE


Hybrid

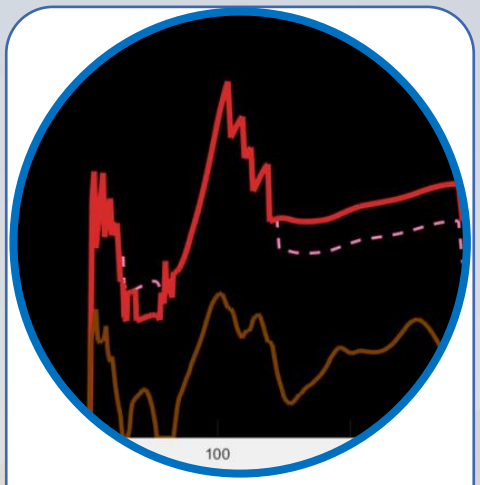

Fuel Cell



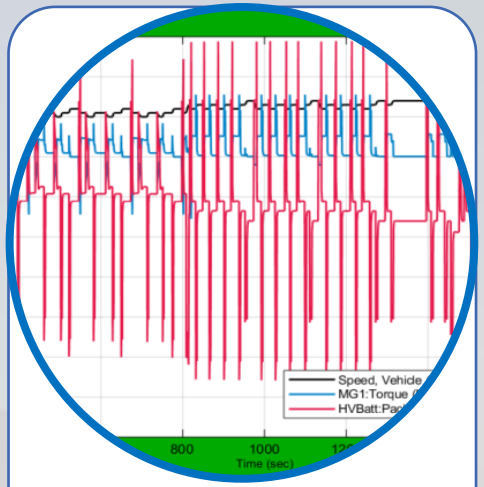
EV Range / ICE Fuel Economy



Performance and capability



Drive Quality



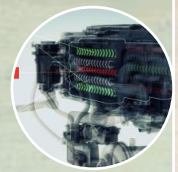
Profile generation for subsystems

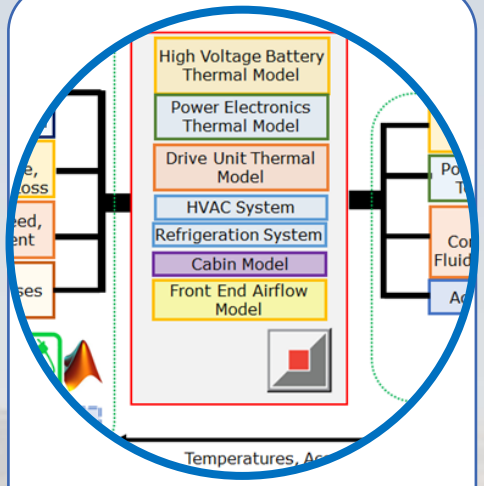
Model Prediction, Tool Connection

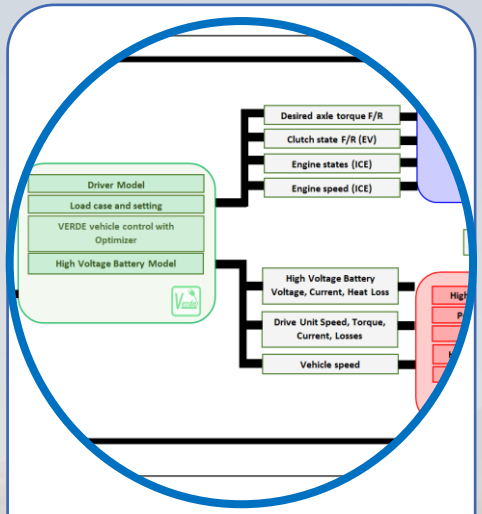

EV

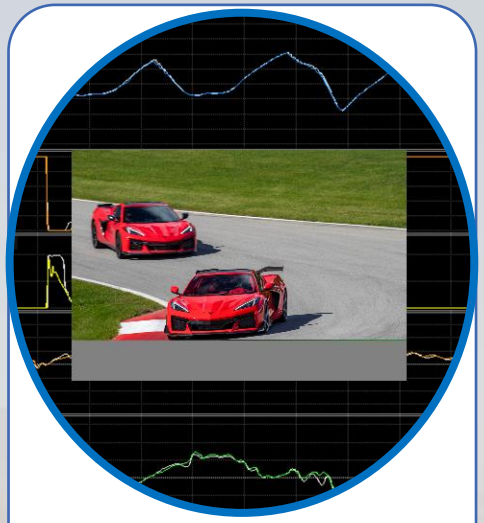

ICE


Hybrid


Fuel Cell







Thermal

NVH with DIL

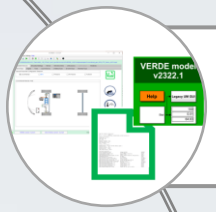
Driveline Dynamics

Lap Time Simulation

VERDE Features and Use Cases

Advancing Energy Analysis at GM with the new VERDE Tool Chain

VERDE Features



Semi coupled Tool and GUI: flexibility to support multiple vehicle architectures

Co-Simulation: EV and ICE thermal prediction, vehicle and driveline dynamics, Lap Time predictions
NVH simulation, DIL etc.

Modularity: ability to extract, compile, share systems or sub-systems

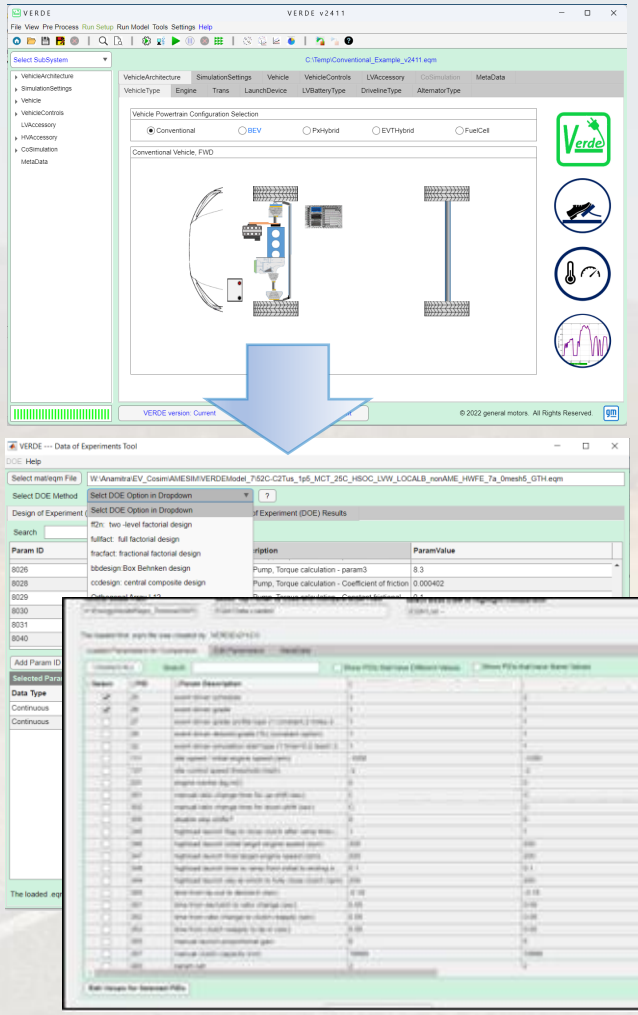
Large Scale Studies: Leverage High Performance Computing

InSPIRE: Enterprise-wide data management system to support model input and output data

Semi Coupled GUI and Tool

VERDE & Supporting GUI

MATLAB App Designer



Model Setup File(s)

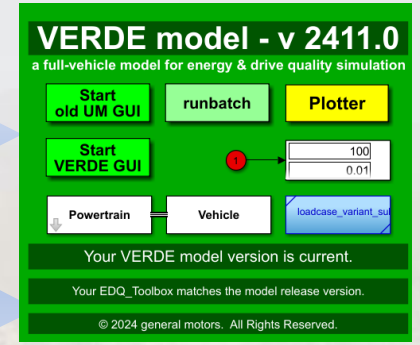
Individual

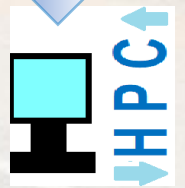
DOE

Batch

VERDE Model

SIMULINK Simscape





Co-Simulation Framework and COTS Tools

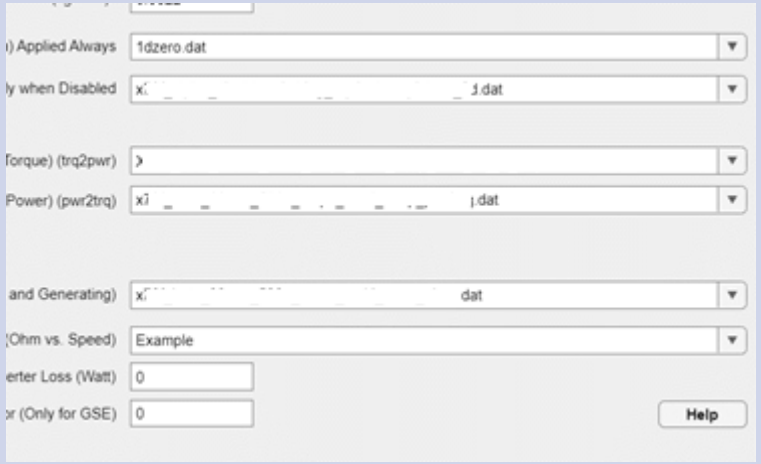
- Supports direct co-simulation
  - Thermal systems model for EV
  - Lap time Simulation
  - Vehicle and driveline dynamics
  - ICE thermal performance and emissions
- Supports Virtual HIL
  - Enables co-simulation with production control
- Supports FMI 2.0
  - GT Thermal, AMESIM, HV Battery etc.
- Modular design and extracted subsystems
  - Standalone module can be integrated with
    - Vehicle dynamics simulation
    - Lap time simulation / CarSim
- Supports Driver In Loop, can run real time

VERDE and Database

- VERDE input data can be accessed from a database
- VERDE simulation result metrics are stored in a database for further analytics and reporting

Past: Local/Network Data

- User managed input data with varied sources
- Each input data file needs to be selected individually



New: InSPIRE

- **In**novative **S**imulation **P**arameter **I**nputs and **R**esults **E**nvironment
- Relational *PostgreSQL database* application.
- Stores simulation *input* data used to parameterize models and simulation *results*.
- Data stored and imported as group/set of data
- Enables Automation, Reporting, Analytics and Traceability

VERDE Tool Use, Flexibility Example

Vehicle architecture → Drive scenario → Control and calibration → Co-simulation

- Conventional
- BEV
- PxHybrid
- EVTHybrid
- FuelCell

EV

ICE

Hybrid

Fuel Cell

- VehicleArchitecture
  - VehicleType
  - RegionOfSales
  - MG1
  - MG2
  - MG3
  - MG4
  - TransmissionRPO
  - TranslossFormatMT
  - Trans2
  - HVBatteryType
  - SecondHVBatteryTy
  - LVBatteryTypeHybrid
  - DrivelineTypeBEV
  - APMType
  - BoostConverterType
- No MG1 Machine
- MG1 TrqPwr Map Based
- MG1 TrqPwr Map Based with Clutch
- MG1 Motor Loss Map and Detailed Inverter Loss Model
- MG1 Motor Loss Map and Detailed Inverter Loss with clutch Model
- HVBatt
- HVBatt
- External/3rd party Battery
- HVBatt
- VehicleType
- RegionOfSales
- EngineRPO
- MG1
- MG2
- MG3
- MG4
- TransmissionRPOHybrid
- HVBatteryType
- LVBatteryTypeHybrid
- DrivelineTypeBEV
- VehicleArchitecture
  - VehicleType
  - RegionOfSales
  - EngineRPO
  - TransmissionRPO
  - TranslossFormatRWDAT
  - TC
  - LVBatteryTypeConv
  - DrivelineType
  - AlternatorType
- (FWD) Front Wheel Drive
- (RWD) Rear Wheel Drive
- (AWD/4WD) All Wheel Drive - Transverse
- (AWD/4WD) All Wheel Drive - Longitudinal

Fuel Economy

- USFTP composite (hot)
- USFTP composite (cold)
- USFTP composite 4-bag (cold)
- USFTP urban (hot)
- USFTP urban (cold)
- USFTP urban 4-bag (hot)
- USFTP complete test (cold)
- USFTP highway
- US06 Aggressive (hot)
- SC03 Supplemental (hot)
- MCT
- sMCT
- LA92 Unified Cycle (hot)
- UNECE WLTP - multiple candidates (cold)
- MVEG-A (cold)
- UNECE MVEG-B (hot)
- UNECE MVEG-B (cold)
- Japan Mode 10-15
- Japan Mode JC08 (hot)

Performance

- WOT performance
- WOT passing performance (40-100, 60-100, 80-120 & 120-160 km/h)
- Passing performance, user defined start and stop speeds
- Blocked pedal run
- Part throttle metrics (automatic transmission
- Part throttle metrics (manual transmission)
- Per-gear traction force (manual transmission)
- Gradeability
- Top gear grade capability
- Elasticity
- Tip-in from coast or steady speed
- Noise passby (SAE J1470)
- Noise passby (ISO 362)
- NVH Simulator
- Reduced Power Mode Simulator (conventional vehicle)
- Reduced Power Mode Simulator (EV)
- Steady state (pps; speed; accel)
- Event based driver
- Coastdown

Generic

- User defined speed and grade profile
- Steady state fuel economy
- Torque Converter Power Sweep
- Multiple Block Pedal from speed (Jeff tool)
- External Driver
- CarSim / LTS Co-sim driver, 2022
- NVH Simulator (Driver in Loop)

- VehicleControls
  - EVControls
  - MG1_Ctrl
  - MG2_Ctrl
  - MG3_Ctrl
  - MG4_Ctrl
  - HVBatt
  - HVBatt2
  - TransModel
  - Trans2Model
  - DrivetrainFront
  - DrivetrainRear
  - SecondaryFD
  - RVCBEV
  - LVElecLoad
  - EngineWrapper
- VehicleControls
  - Pedal
  - EngineModel
  - AFM
  - DFCO
  - TransModel
  - ShiftTimeFormatAT
  - Launchdevice
  - DrivetrainFront
  - DrivetrainRear
  - RVC
- Fixed or Speed Progression
- Engine Power Series 11.11.26
- Axle Torque Series 11.15
- Hybrid Vehicle System(ARM)

- CoSimulation
  - BEVHeatCosim
  - Car_Sim
  - GMSIM
  - NVH_DIL
  - AMESIM
- No GMSIM
- GMSIM BEVHEAT (12V SIL)
- GMSIM BEVHEAT (non 12V SIL)
- GMSIM BEVHEAT Custom

- CoSimulation
  - GMSIM
  - iDIEST
  - ExtEng
- No Gas Cosim
- GMPT External Gas (
- GMPT External Gas (
- No Diesel Cosim
- GMPT External Diesel (
- GMPT External Diesel (

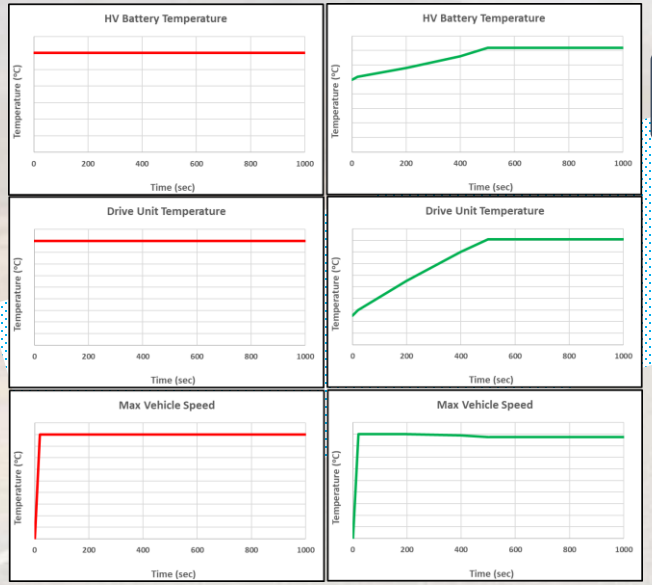
VERDE Tool Use, Fidelity Example

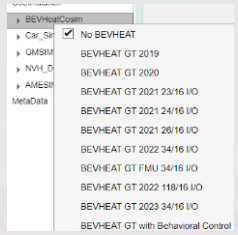
Model Fidelity
Behavioral Control
Constant / Time history

Production Control

EV

Constant or profile from past

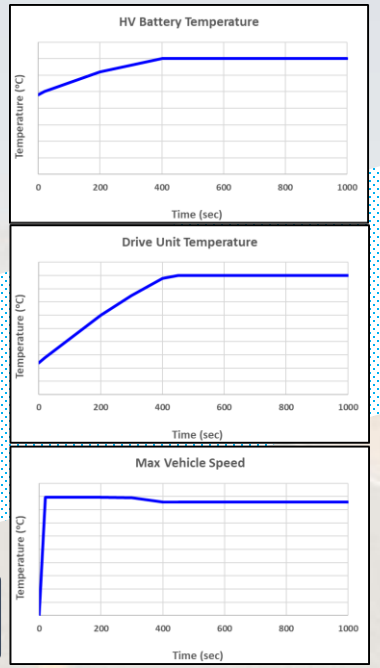


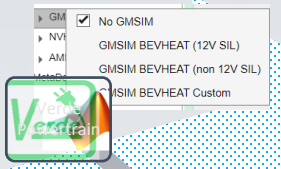


Cosim

Derate calibration

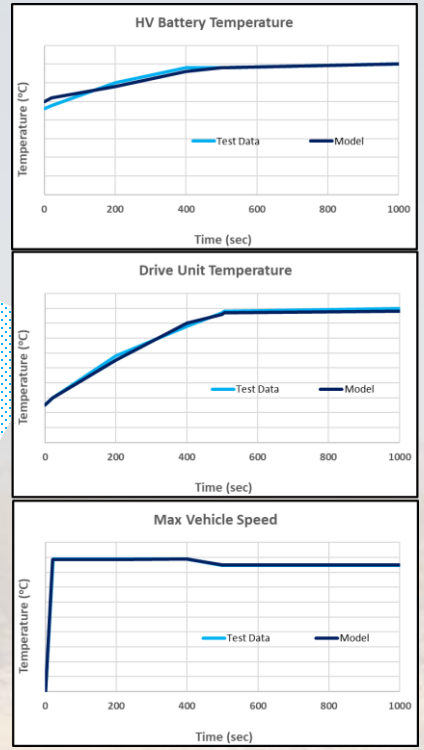
Behavioral control





Driver, HVBattery Model

Production control

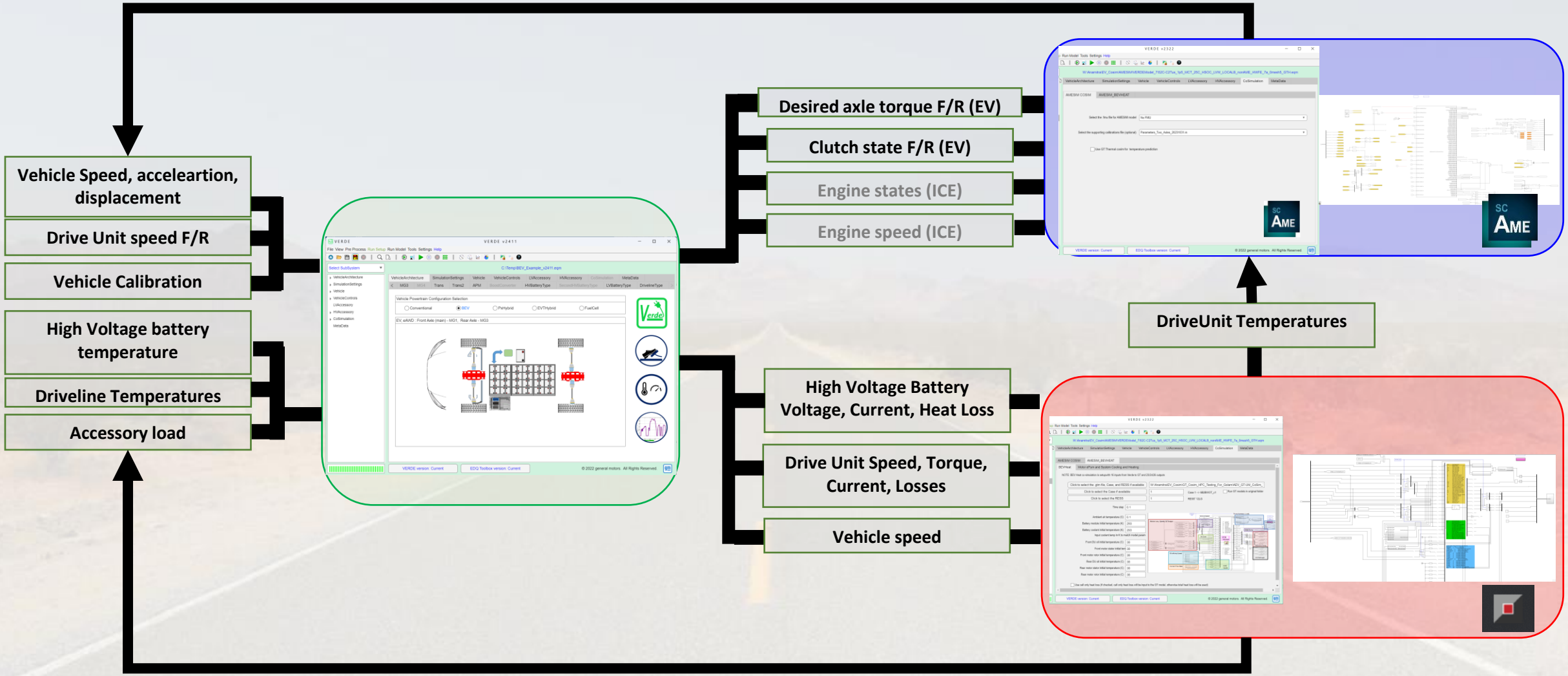


Program Framing

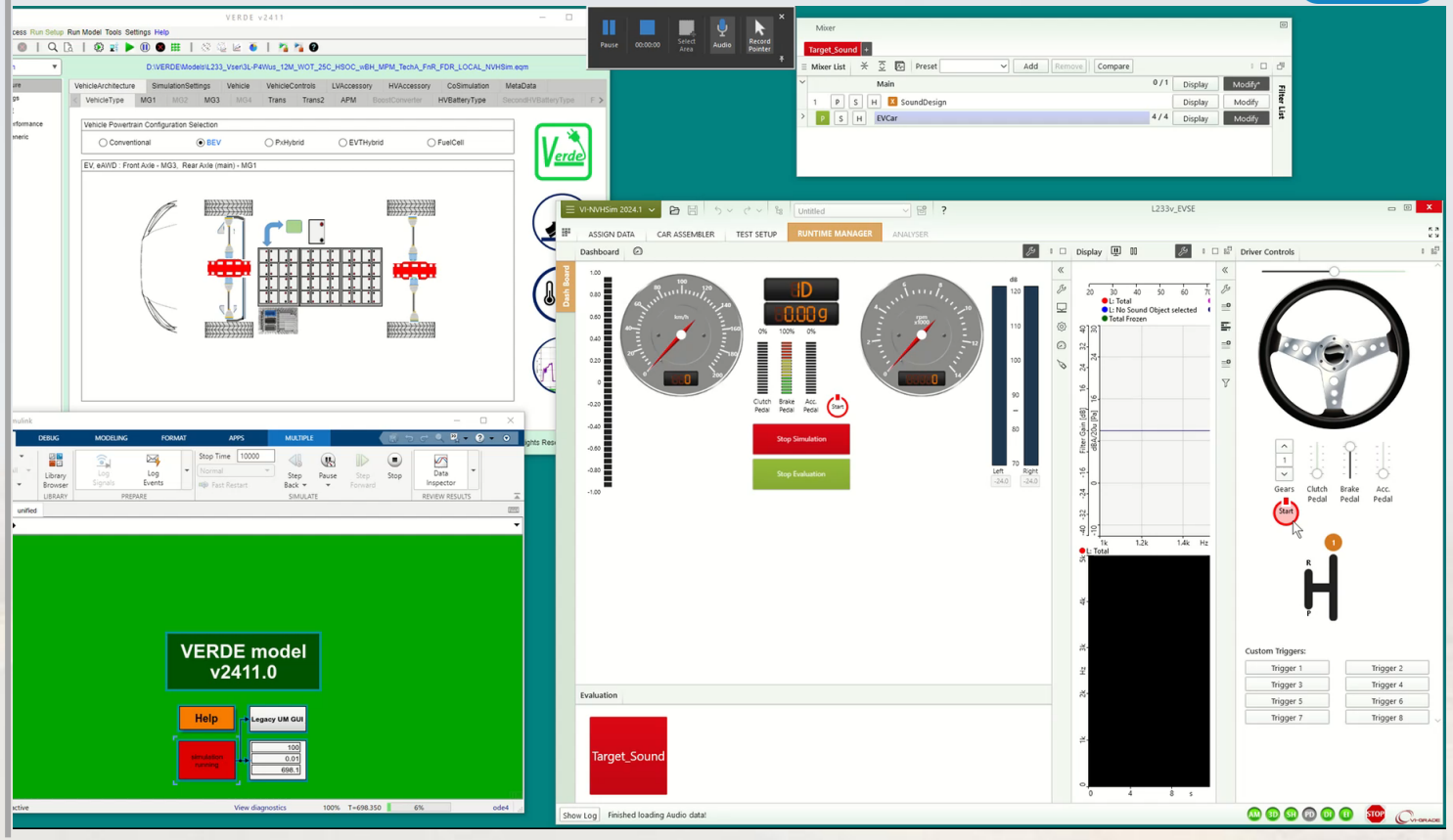
Development and Refinement

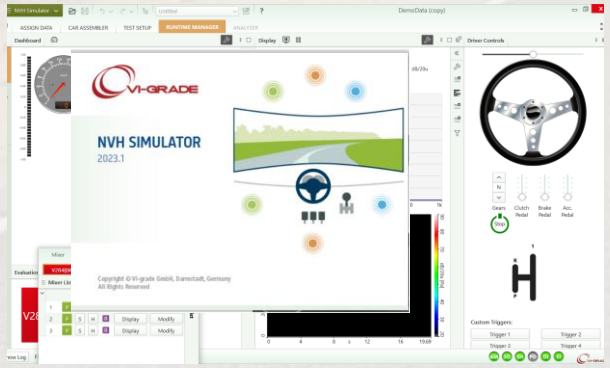
Production

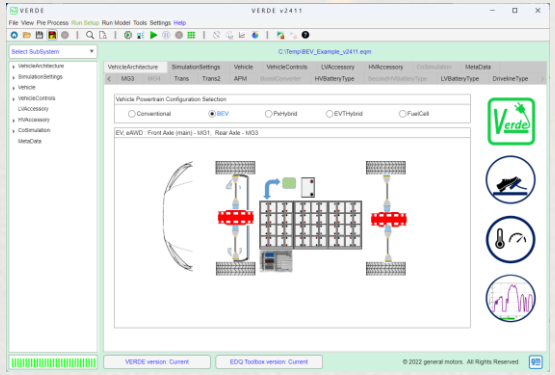
VERDE Tool Use, AMESIM Co-sim Example

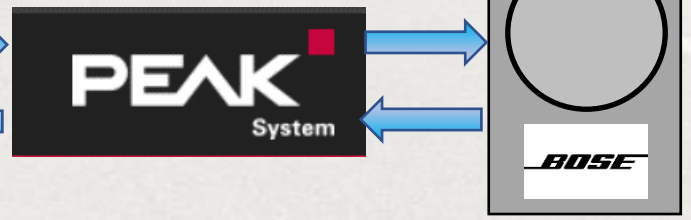


VERDE Tool Use, NVH Co-sim Example





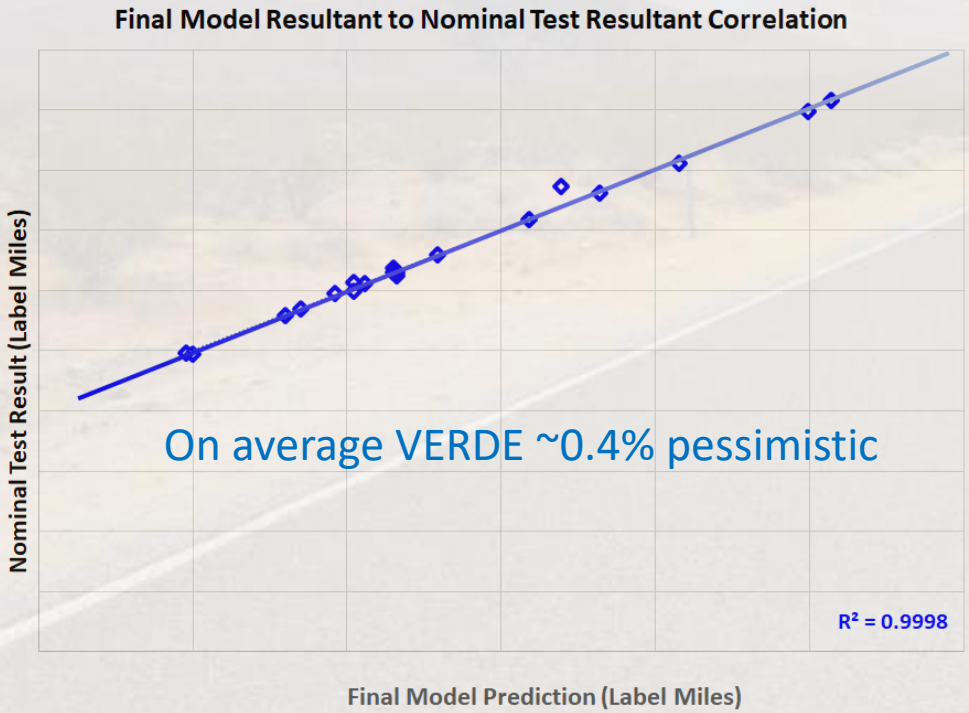


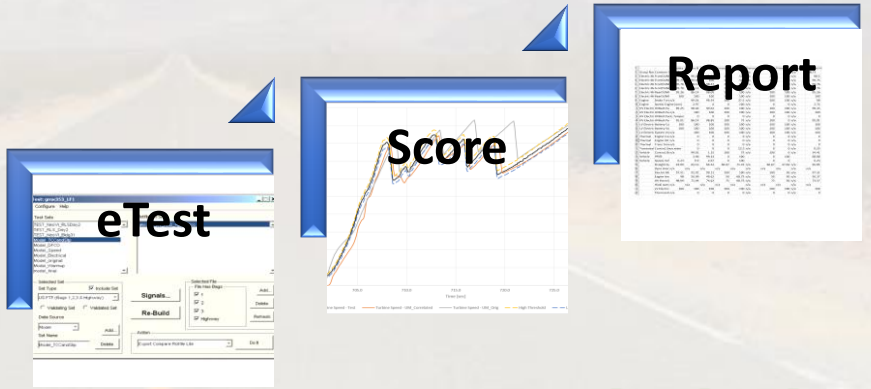


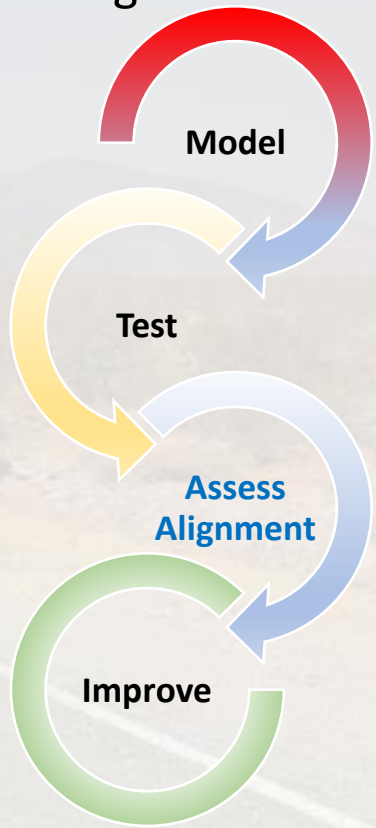
VERDE Model Closed Loop Learning

Main goals:

- Assess the ability of the tool to accurately generate METRICS AND BEHAVIORS
- Ensure generation of this information is easy and repeatable
- Use feedback to highlight model improvement needs and ACT on the learning



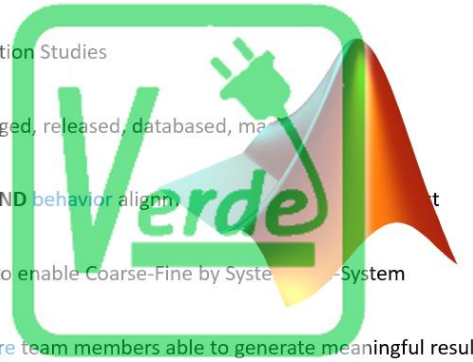




VERDE Transition Impact?

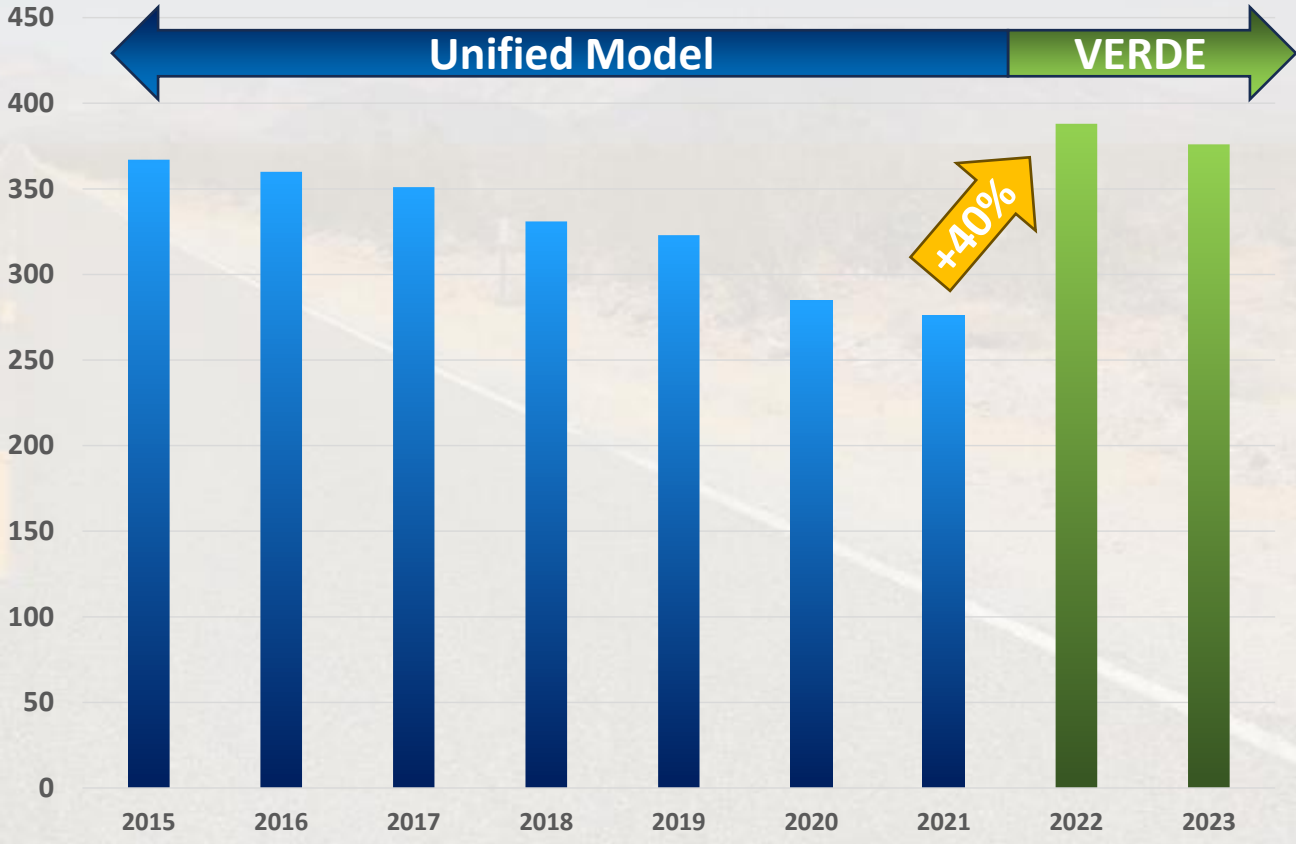
Biggest Challenges & Opportunities

- **Speed** – Reduce the time to learn, build and execute models
- **Scale** – Large DOEs & Optimization Studies
- **Data** – Inputs & Outputs managed, released, databased, ma
- **Accuracy** – High-level metric AND behavior alignm t
- **Fidelity** – Scalable & Modular to enable Coarse-Fine by Syste -System
- **Democratization** – Getting more team members able to generate meaningful results
- **Co-Simulation** – Leverage other tools; collaborate with other domains



6

Global Energy Toolchain Users



VERDE Tool Management Learnings

- Core TEAM of highly capable tool developers that thrive in this space
- v2411.1
  - Clearly Defined and Consistent Tool Releases
  - Version and Change Management for tool developers
- Support the core tool with Pre-/Post- processing, data visualization, automated report generation, user facing efficiency and management tools
- Welcome and embrace cross-domain collaboration and alignment
- Learning & Training
  - Provide training, documentation, resources, and user support help desk
- Reach out to MathWorks team for technical support and understanding new features

Conclusions and Future Work

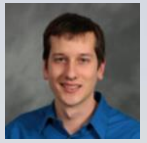
- Enhance controls integration at varying fidelity levels
  - Behavioral → Representative → Production
- Full database integration
  - Automated data updates and model construction
  - Data Mining inputs and outputs
- Model Accuracy & Precision Improvements
  - Driven by closed loop learning
- Co-Simulation
  - Keep updated with COTS tools (updates & new tools)
  - Reduce simulation build & run time
- Drive cross-enterprise alignment
  - Inputs/outputs, connections, workflows, data processing
- Integrate new functionality into VERDE ecosystem
  - Durability Modeling, Fast/Backwards Looking Models

Acknowledgements

GM Team


Adeel Ahmed


Golam Mortuza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Paul Mrozek


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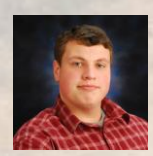
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CONFERENCE 2024
North America

Advancing Energy Analysis at GM with the New VERDE Tool Chain

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MathWorks