ANL Vehicle Technologies Analysis Modeling Program

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Argonne National Laboratory

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Washington DC

Project ID: VAN017

Project Overview

Timeline	Barriers
• Project start date: 10/01/2015 • Project end date: 09/30/2018 • Percent complete: 58%	• Indicators and methodology for evaluating environmental sustainability • Evaluate energy and emission benefits of vehicle/fuel systems • Overcome inconsistent data, assumptions, and guidelines
Budget	**Partners**
• Total project funding: $4.5 M (100% DOE) • Funding received in FY 2016: $1.5M • Funding for FY 2017: $1.1 M (estimated)	• National labs: ORNL, NREL • Industries: OEMs and energy companies via USDRIVE • Agencies: EIA, EPA, DOT • Other org: UIC, Jacobs, ERG

Project Overall Objectives

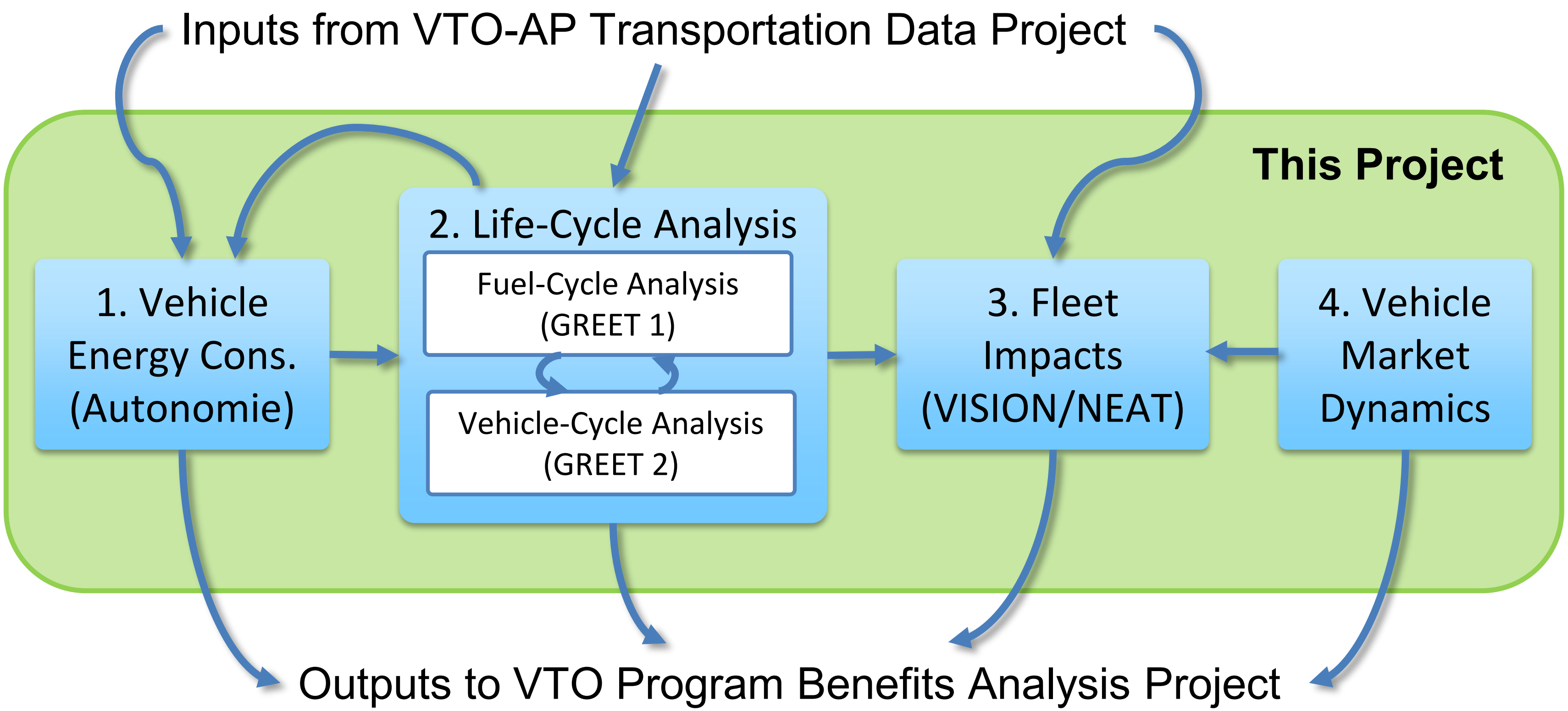
- Overcome inconsistent data, assumptions, and guidelines by developing transparent models
  - The **Autonomie** model: Dynamically quantify vehicle energy consumption and cost impacts of advanced vehicle technologies
  - The **GREET** life-cycle analysis (LCA) model: Holistically address energy and environmental impacts of vehicle/fuel systems with fuel cycle and vehicle cycle
  - The **VISION/NEAT** and **household-level** vehicle purchase/use models: Systematically assess energy and emission effects of vehicle technology deployment scenarios

- To develop indicators and methodology for environmental sustainability and evaluate energy and emission benefits of vehicle/fuel systems, the suite of models includes:
  - Energy use, especially related to petroleum reductions of advanced vehicle technologies and alternative transportation fuels
  - Greenhouse gas (GHG) emission impacts of vehicle/fuel systems
  - Air pollutant emission impacts (NOx, PM10, SOx, VOC, etc.)
  - Water consumption of different transportation fuels

Task Objectives

- ***Task 1:*** Leverage high-fidelity dynamic vehicle modeling with **Autonomie** to quantify energy and cost impacts of a wide range of technologies (vehicle, powertrain, component, control, cost, etc.) and vehicle classes (light duty to heavy duty)
- ***Task 2:*** LCA of vehicle/fuel systems with **GREET** covers the supply chain of a large number of fuel production pathways and vehicle manufacturing processes to generate LCA energy use, emission and water consumption results
- ***Task 3:*** Fleet-wide energy and emission assessment of advanced vehicle/fuel systems with **VISION/NEAT** by considering market potentials of vehicle technologies and fuels
- ***Task 4:*** **Market dynamics** modeling of household-level vehicle ownership provides improved projections of market shares and utilization of advanced vehicle technologies

Internal Linkage Among Project's Tasks and External Interaction with Other VTO-AP Analysis Efforts



Schedule/Milestones

Schedule/milestones are determined through:

- Quarterly updates to VTO-AP sponsors
- Semi-annual ANL visits by VTO-AP sponsors
- Regular meetings with key stakeholders via USDRIVE etc.
- Reviewer inputs from VTO Annual Merit Review

FY16
- Gather assumptions
- Build vehicle models
- Perform simulations

FY17
- Perform analysis
- Write report
- Share data

FY18
- Gather assumptions
- Build vehicle models
- Perform simulations

Task 1: VTO Energy and Cost Impact

FY16
- Annual update
- Auto connection to GREET
- Uncertainty modeling in VISION LD sector

FY17
- Annual update
- Uncertainty modeling in VISION MD/MD sectors

FY18
- Annual update
- Add criteria pollutants to VISION

Task 3: Fleet Impacts with VISION/NEAT

Schedule/Milestones (continued)

Task 2.1: GREET Water Consumption LCA

FY16
- Collect and analyze water consumption data

FY17
- Examine water availability and consumption by region
- Develop regional water stress indices

FY18
- Evaluate impacts of large scale energy systems
- Examine regional differences

Task 2.2: Vehicle Cycle Analysis (GREET2)

FY16
- Collect and analyze vehicle materials/ manufacturing data

FY17
- Analyze critical LCA issues related to vehicle lightweighting

FY18
- Develop PDFs
- Conduct uncertainty analysis

Task 2.3: GREET Development in the .net Platform

FY16
- Develop regional analysis capabilities
- Expand HDV and rail

FY17
- Update fuel economy and vehicle materials
- Develop user tutorials

FY18
- Incorporate additional vehicle classes
- Include stochastic simulations

Task 2.4: Market Dynamics Modeling

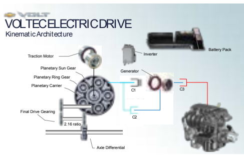
FY16
- Identify data sources
- Review literature

FY17
- Develop holdings model
- Develop initial transaction model

FY18
- Finalize models
- Document model and model projections

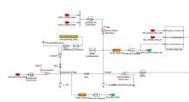
Autonomie Vehicle Energy Consumption and Performance Approach

Vehicle Powertrain



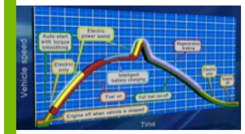
i.e. GM Voltec Development

Component Models



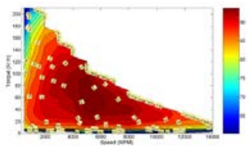
i.e. Advanced Transmission (e.g. DCT)

Vehicle Control



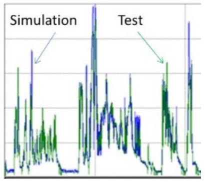
Integrate advanced control algorithms such as instantaneous optimization or route based control

Component Benchmarking



Vehicle Energy & Cost

Validation

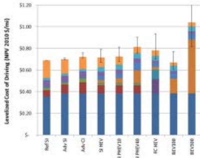


Standard Procedures

Large Scale Simulation

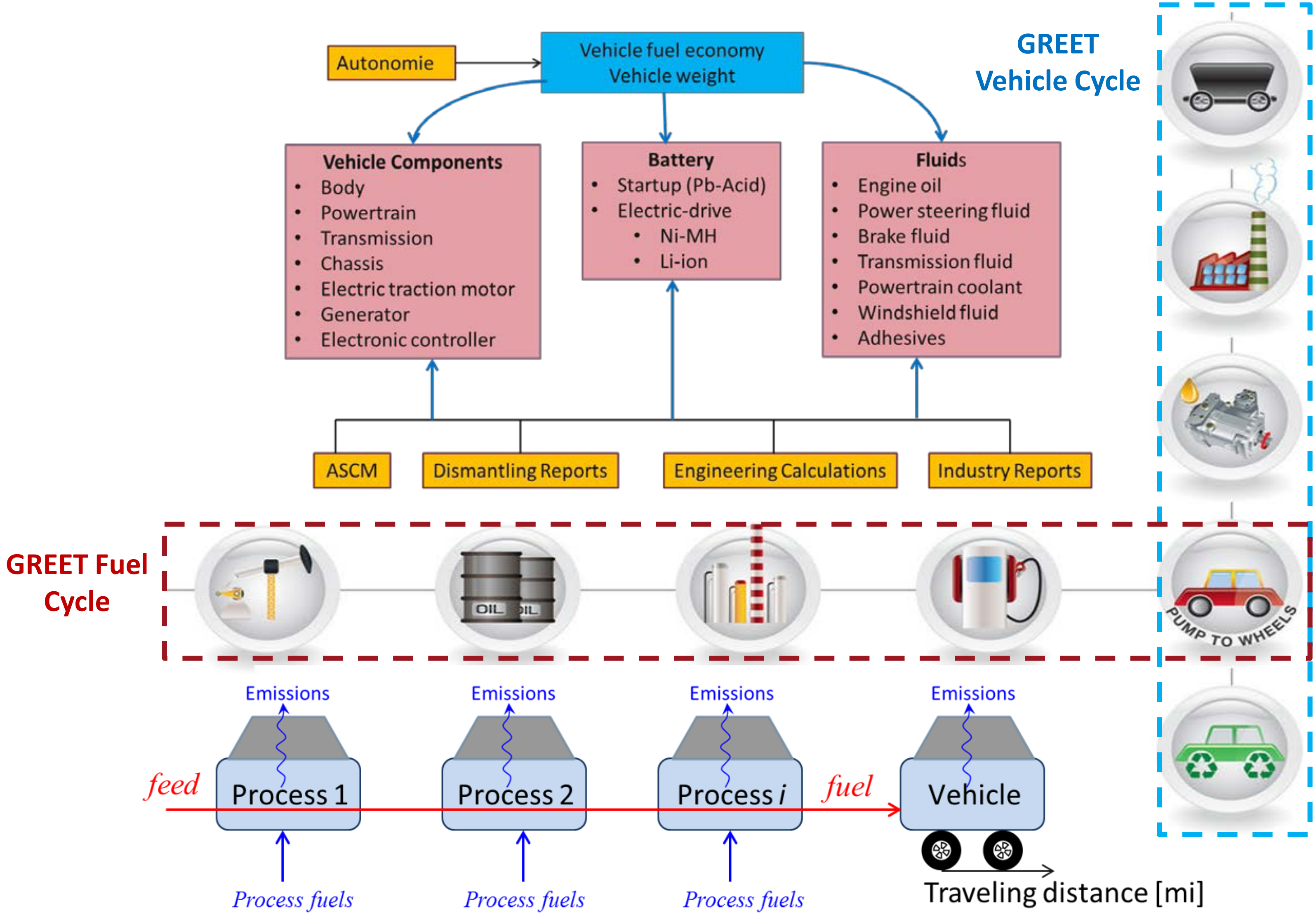
Numerous processes, including vehicle sizing algorithms, distributed computing, parametric study, SOC correction… are used to evaluate a large number of options

Levelized Cost of Driving



Integrate LCD calculations to evaluate the technology benefits using $/mile

Approach of GREET Life Cycle Analysis



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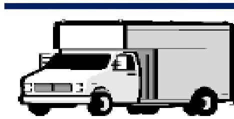
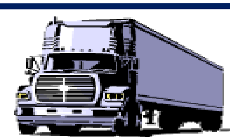
Approach of VISION/NEAT Fleet Impact Modeling

Major Inputs (User defined)
- Market share
- Fuel efficiency
- Travel volume
- Economic factors

Internal Calculations
- Vehicle stock
- VMT per vehicle
- VMT per technology
- Emission and energy rate

Major Outputs
- Energy use and GHG emissions by vehicle tech, vehicle type and fuel type

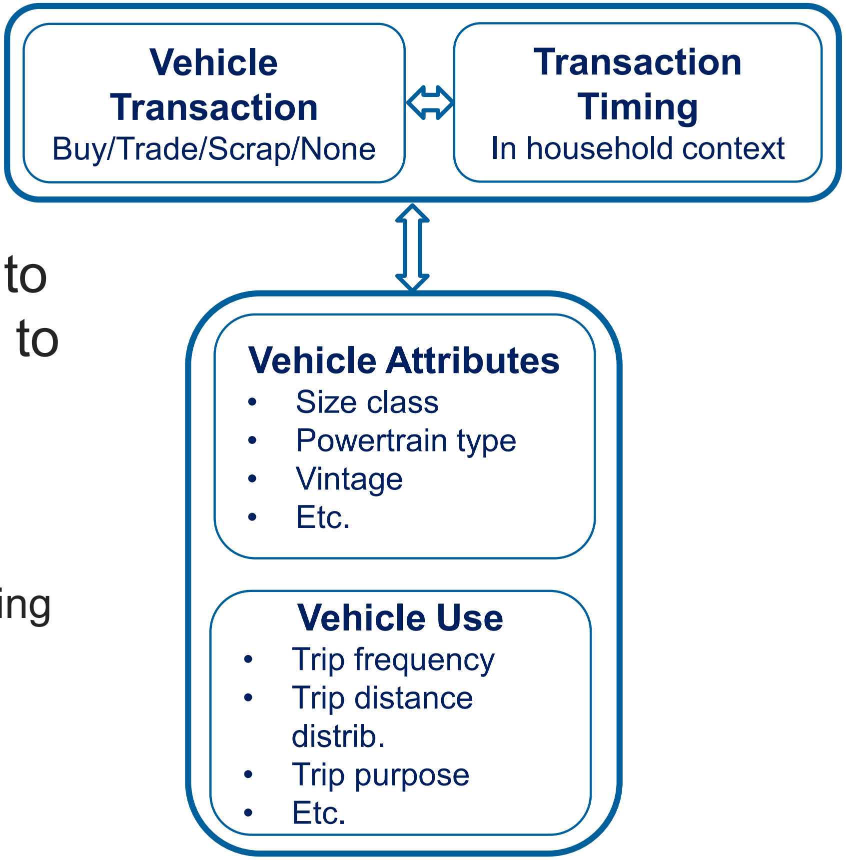
Vehicles	Technology & Fuel
 Cars  Light Trucks	4 ICEVs (gasoline, diesel E85, CNG) 3 HEVs (gasoline, diesel, E85) 3 PHEVs (2 gasoline types, diesel) 2 EVs 1 FCEV
 Class 3-6 Trucks	Gasoline ICEV, diesel ICEV, CNG ICEV, diesel HEV
 Class 7-8 Single Unit Trucks	Gasoline ICEV, diesel ICEV, CNG ICEV, diesel HEV
 Class 7-8 Combination Trucks	Diesel ICEV and LNG ICEV

Fuel Pathways

- Crude oil to gasoline and diesel
- Natural gas To CNG, LNG, F-T diesel
- Soybeans to biodiesel
- Corn, sugarcane, Switchgrass, etc. to ethanol
- Coal, nuclear, Renewables, etc. to electricity
- NG, coal, Biomass, etc. to H2

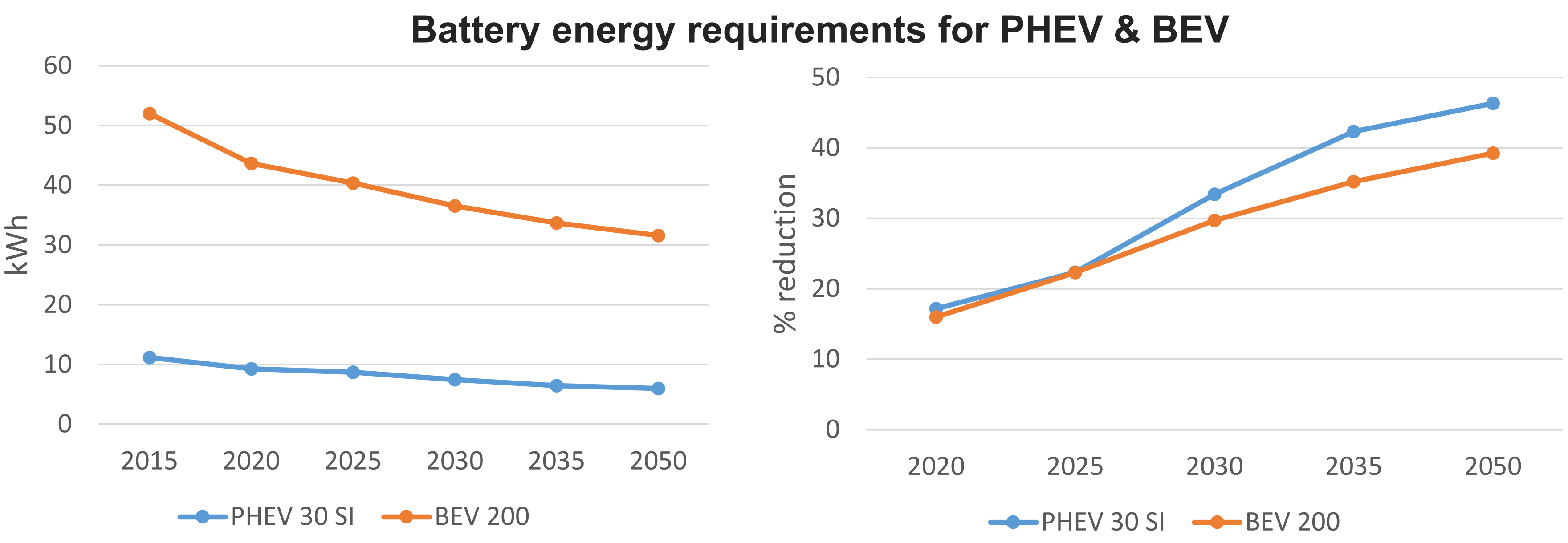
Approach of Household Vehicle Ownership Modeling

- Dynamic vehicle ownership model
  - Vehicle transactions depend on the utility derived from the household vehicles within the household context
  - *Transaction timing* is the **central variable**
- Dynamic timing models can be linked to new or existing vehicle choice models to better represent market dynamics
- Based on longitudinal vehicle transaction data from various regions
  - Supplemented with small-scale survey focusing on new vehicle technology
- Two model components:
  - Baseline holdings model gives current household vehicle stock
  - Transaction decision model gives future changes in vehicle holdings (buy, trade, scrap, none



Impact of VTO Targets on Battery Requirements Report Released

- The goal of this analysis is to provide key figures and trends related to the battery
- The main dimensions reviewed include power requirements, energy requirements, power to energy (P/E) ratio, weight, and cost. We look at how those dimensions evolve over time, across vehicle platforms, and across vehicle powertrain (PWT) options..



Report available under http://www.autonomie.net/publications/battery_requirements_report.html

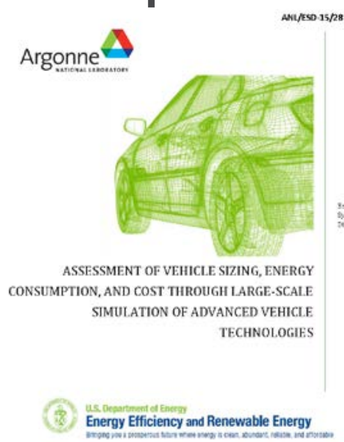
VTO Targets Impact on Energy Consumption and Cost for Light, Medium and Heavy Duty Vehicles

- The benefits were updated for **light duty vehicles**, including new/updated component assumptions, updated vehicle control strategies

- New vehicle models have been developed for **medium and heavy duty** for 13 different classes leveraging available data from recent regulations

- Developed a new **cost benefit analysis tool (BEAN)** to quantify the economic viability of technologies

Reports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ASSESSMENT OF VEHICLE SIZING, ENERGY CONSUMPTION, AND COST THROUGH LARGE-SCALE SIMULATION OF ADVANCED VEHICLE TECHNOLOGIES

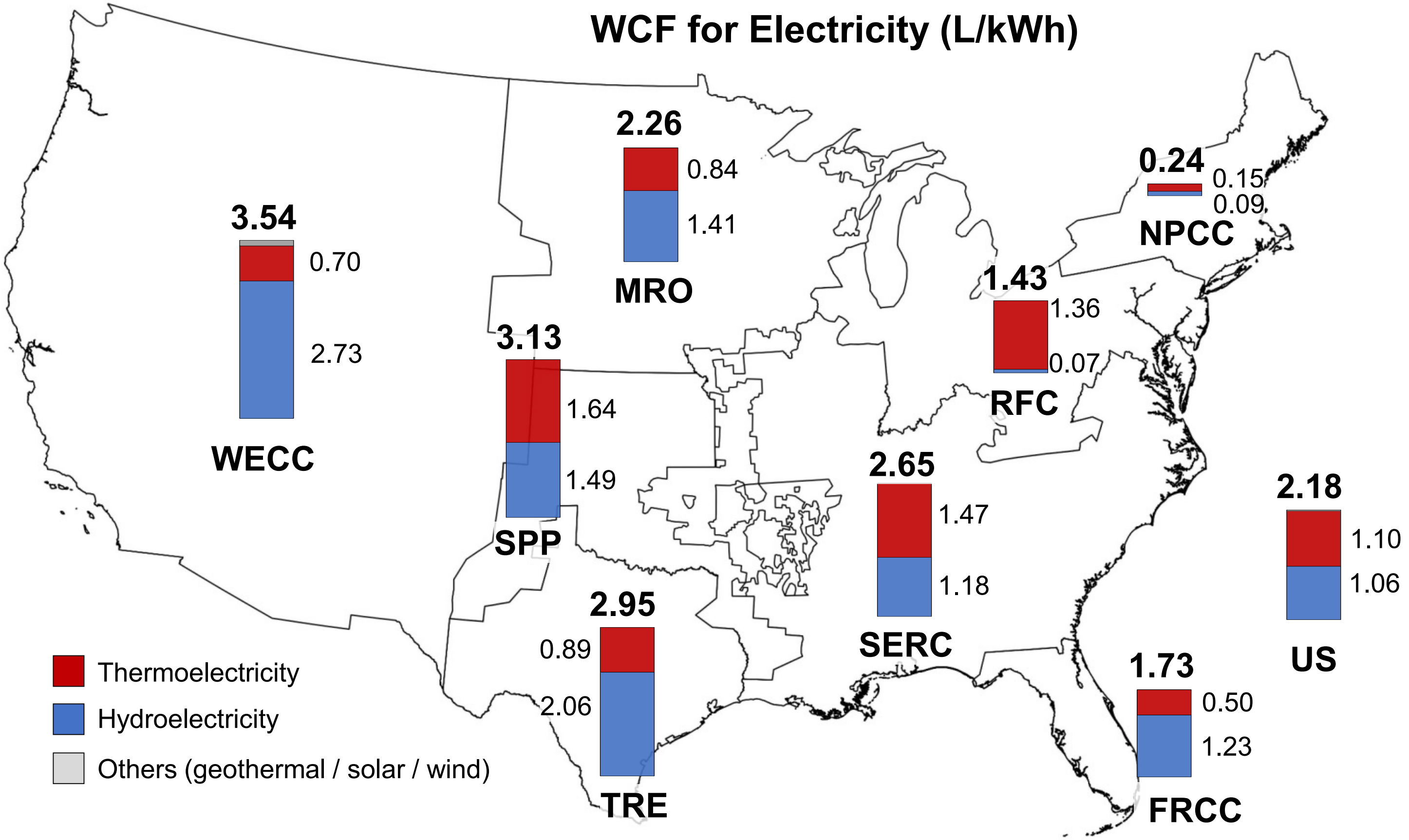
U.S. Department of Energy
Energy Efficiency and Renewable Energy

usage

- VTO Benefits
- EV Everywhere analysis
- USDRIVE C2G (Cradle to Grave) Working group
- GHG (GREET)
- Market penetration tools (MA3T, LAVE-Trans, LVCFlex, ParaChoice, ADOPT)
- BLAST-V (NREL)
- DOE Advanced Tech Modeling runs with NEMS
- Multiple research organizations (IEA, AVERE, NorthWestern Univ…)
- …

(1) New report under development. Previous reports available under at http://www.autonomie.net/publications/fuel_economy_report.html

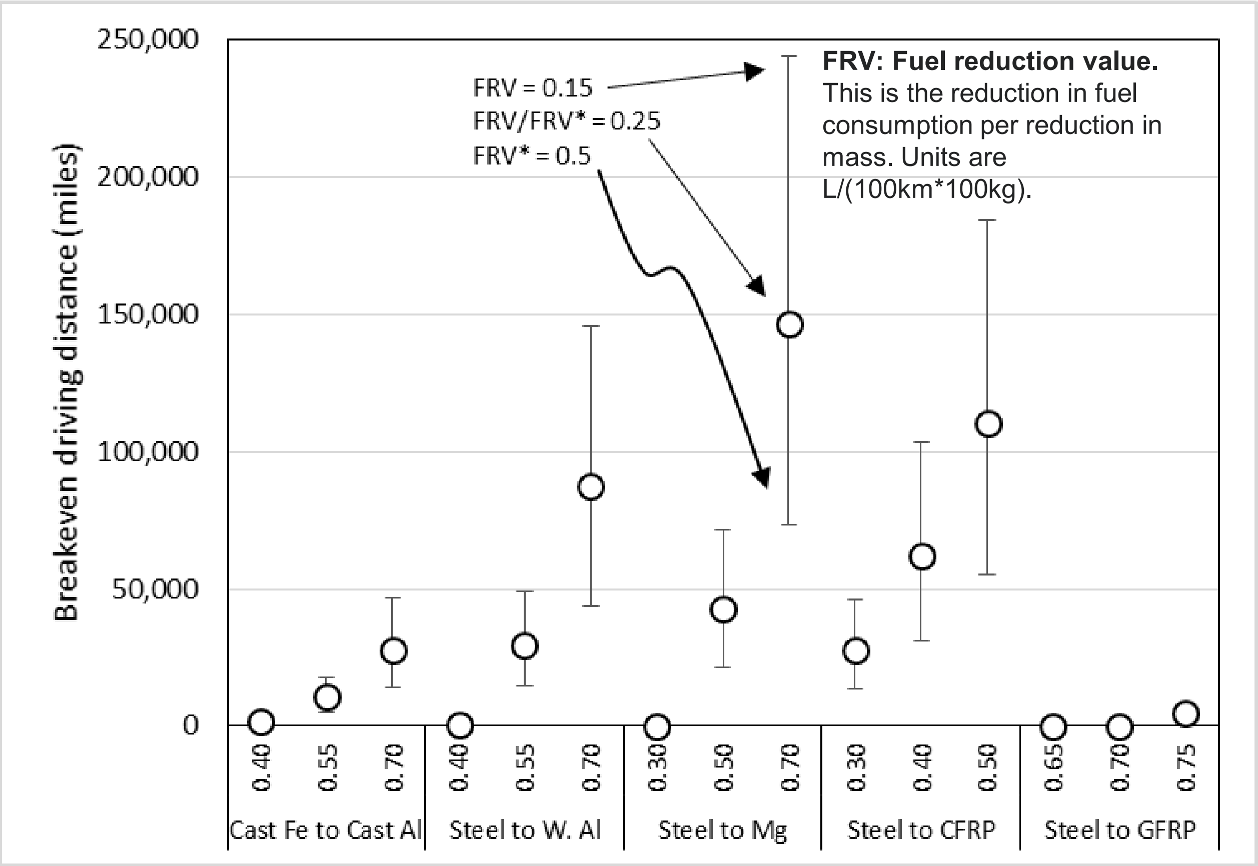
GREET LCA: Water Consumption for Thermal and Hydro Electricity Generation by Region

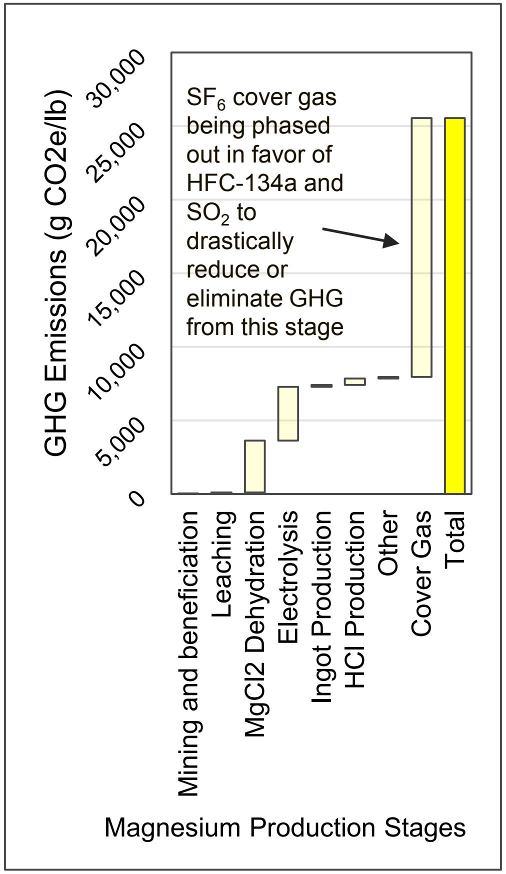


Power Generation Share

NERC	WECC	MRO	SPP	TRE	NPCC	RFC	SERC	FRCC	US
Thermoelectricity	66%	77%	82%	90%	83%	96%	96%	98%	87%
Hydropower	22%	5.2%	1.8%	0.2%	13%	1.1%	3.4%	0.7%	6.3%

Vehicle Lightweighting: Breakeven Analysis



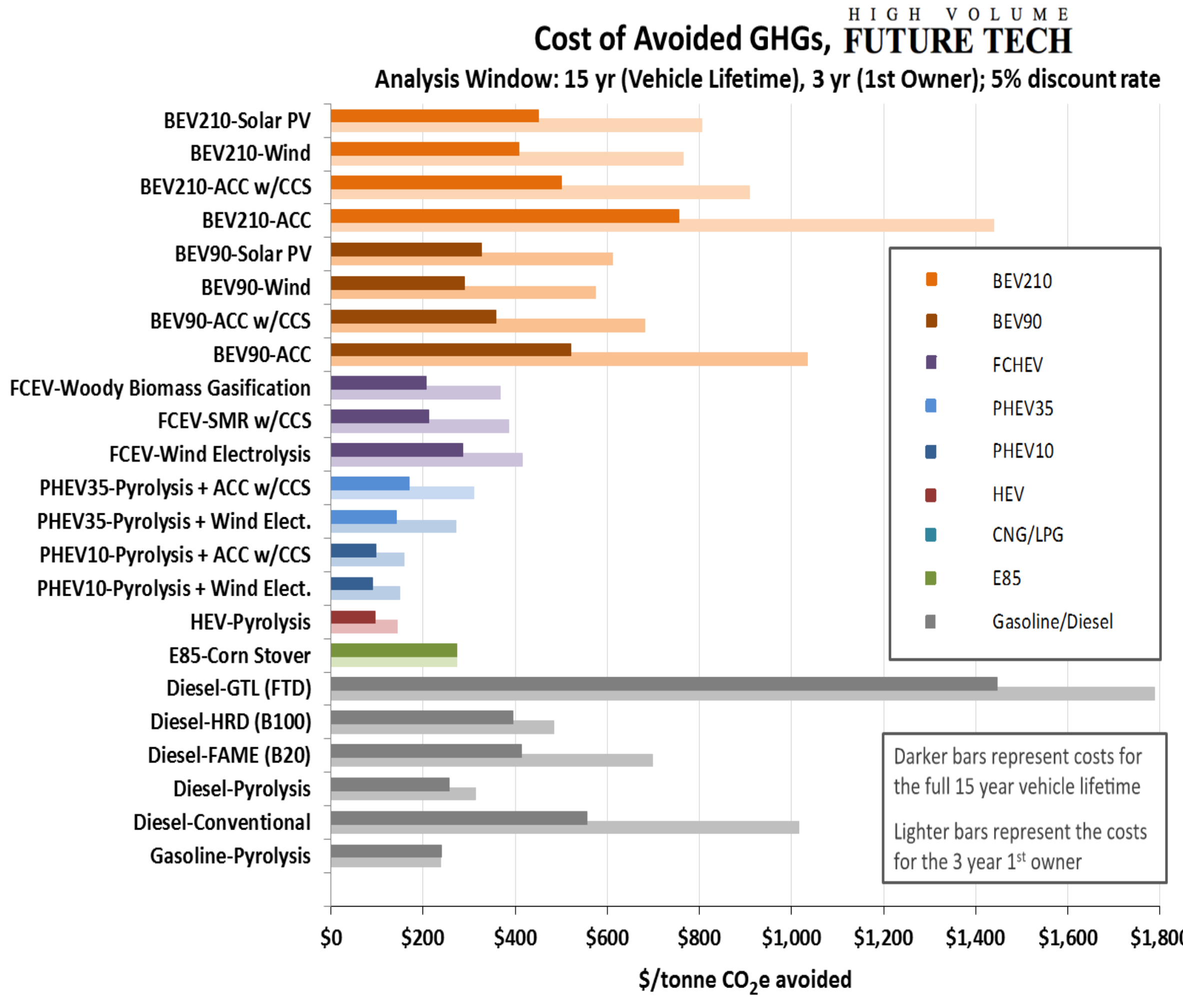


Material substitution ratios strongly influence driving distance required to achieve breakeven life-cycle GHG emissions

→ ***longer distance reflects greater GHG from material substitution***

GREET LCA: Cradle-To-Grave (C2G) Analysis of Vehicle/Fuel Pathways

- Current and future (2030) vehicle-fuel pathways
  - GHG emissions
  - Levelized cost of driving for each pathway (at volume)
  - Cost of avoided GHG emissions relative to a conventional gasoline vehicle
  - Technology readiness level (TRL) assessment
- Fuel cycle and vehicle cycle
- Report published June 2016; revised September 2016



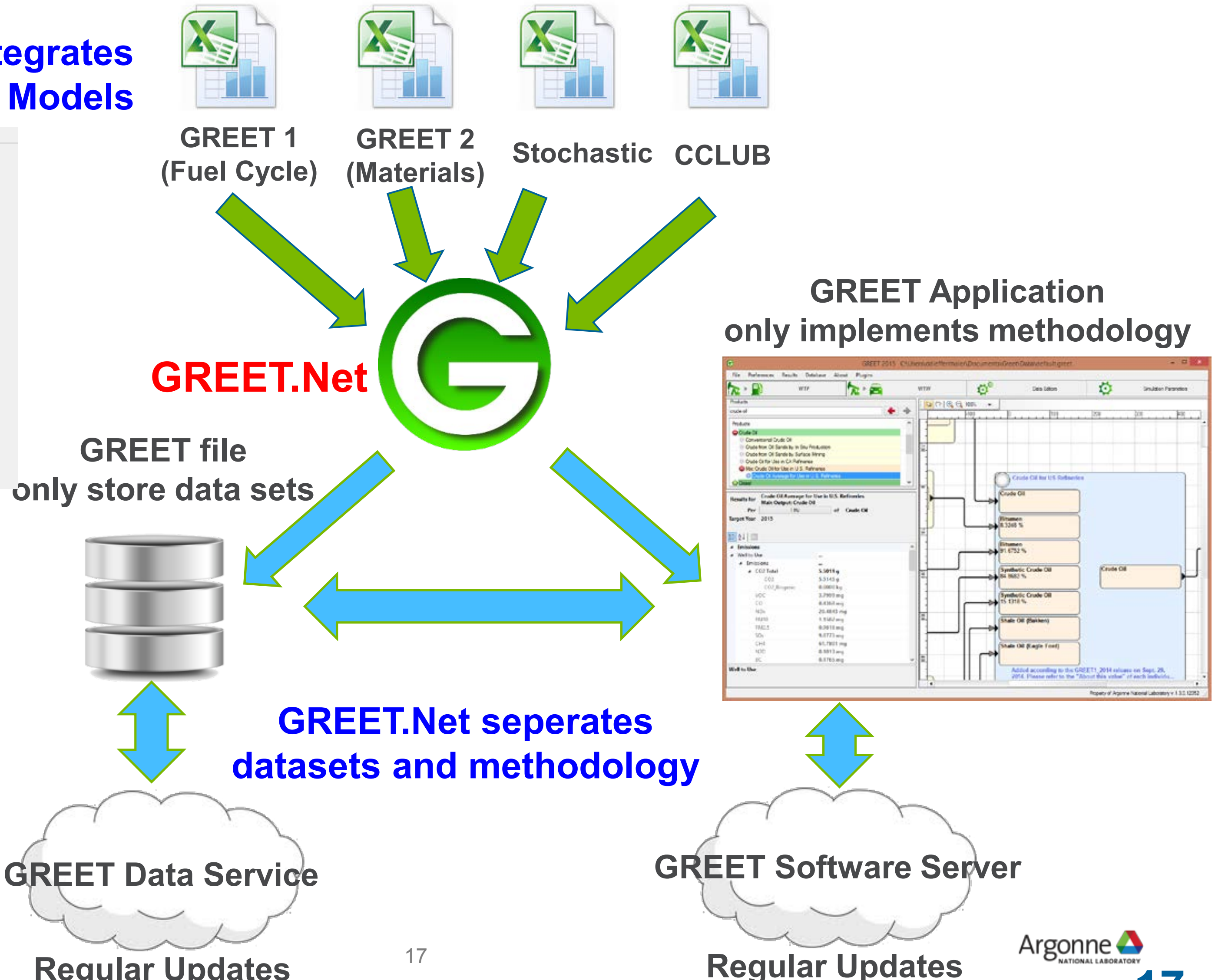
https://greet.es.anl.gov/publication-c2g-2016-report

GREET LCA: GREET.net – A Dynamic LCA Platform for Fuel and Vehicle Cycles

GREET.Net reliably integrates all databases in Excel Models

General Statistics	
Number of pathways	925
Number of processes	1442
Number of stationary processes	1146
Number of transportation processes	296
Number of modes	11
Number of gases	27
Numbrer of resources	466
Number of technologies	328
Number of parameters	64927
Number of mixes	106

https://greet.es.anl.gov/



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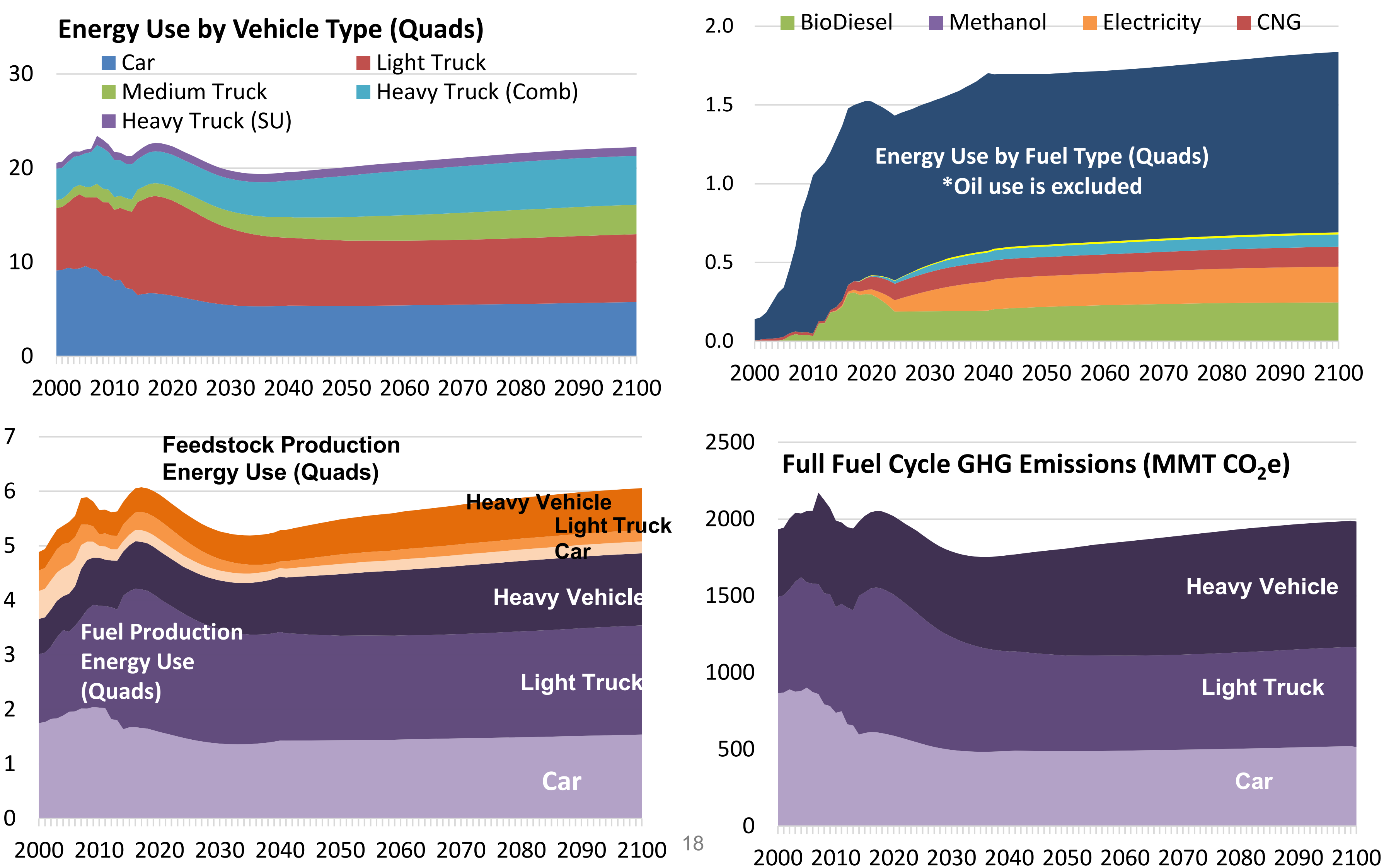
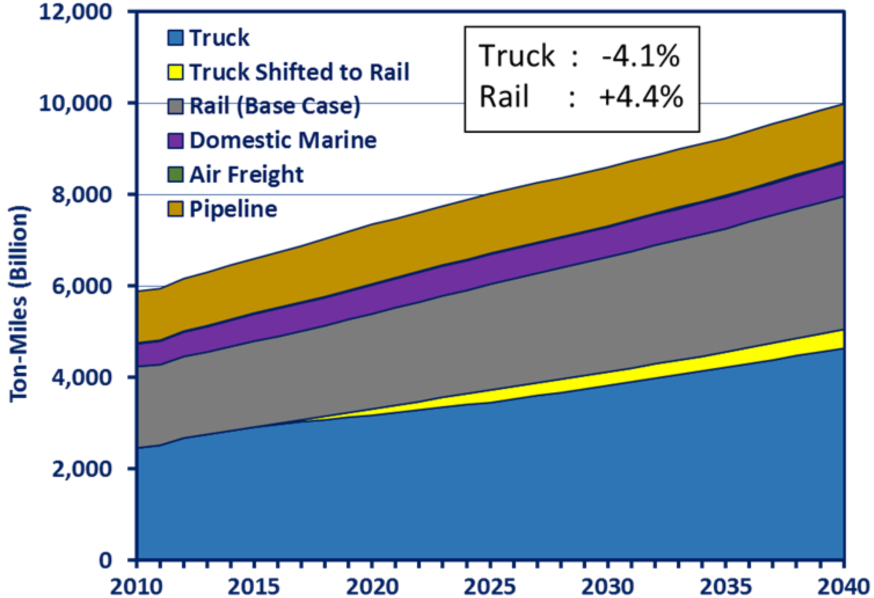
VISION/NEAT: Long-Term Base Case for LDVs and HDVs by Fuel and Vehicle Type (Calibrated to AEO 2016 Ref. Case)



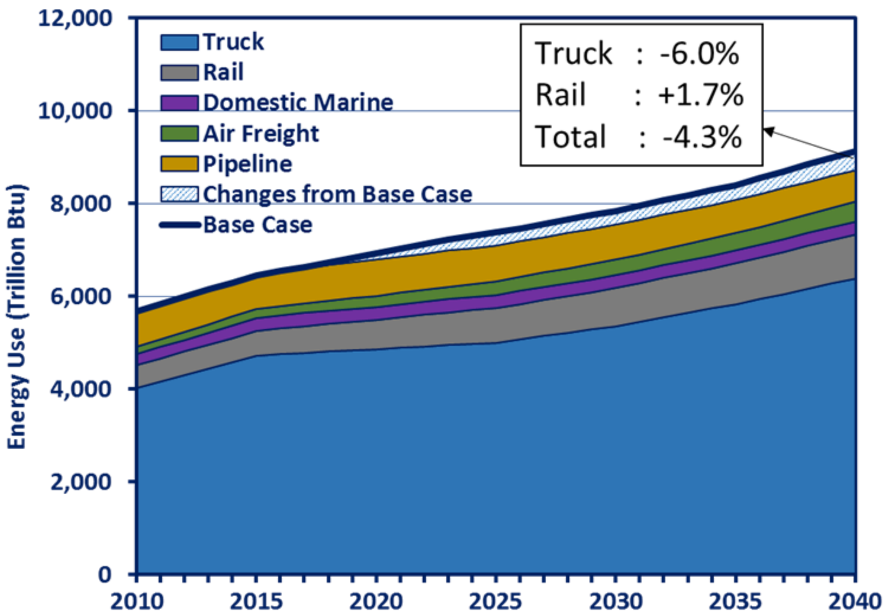
VISION/NEAT: Potential Energy and GHG Emissions Reduction Due to Freight Mode Shift

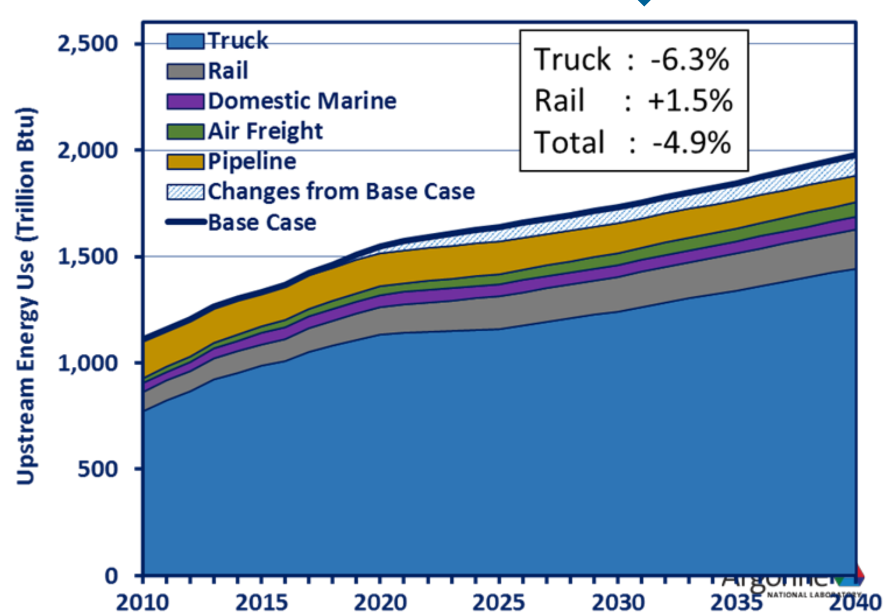


Slight increase in total ton-miles due to longer rail average length of haul (than truck)

Mode shift reduced annual total freight energy consumption by 4.4% in 2040

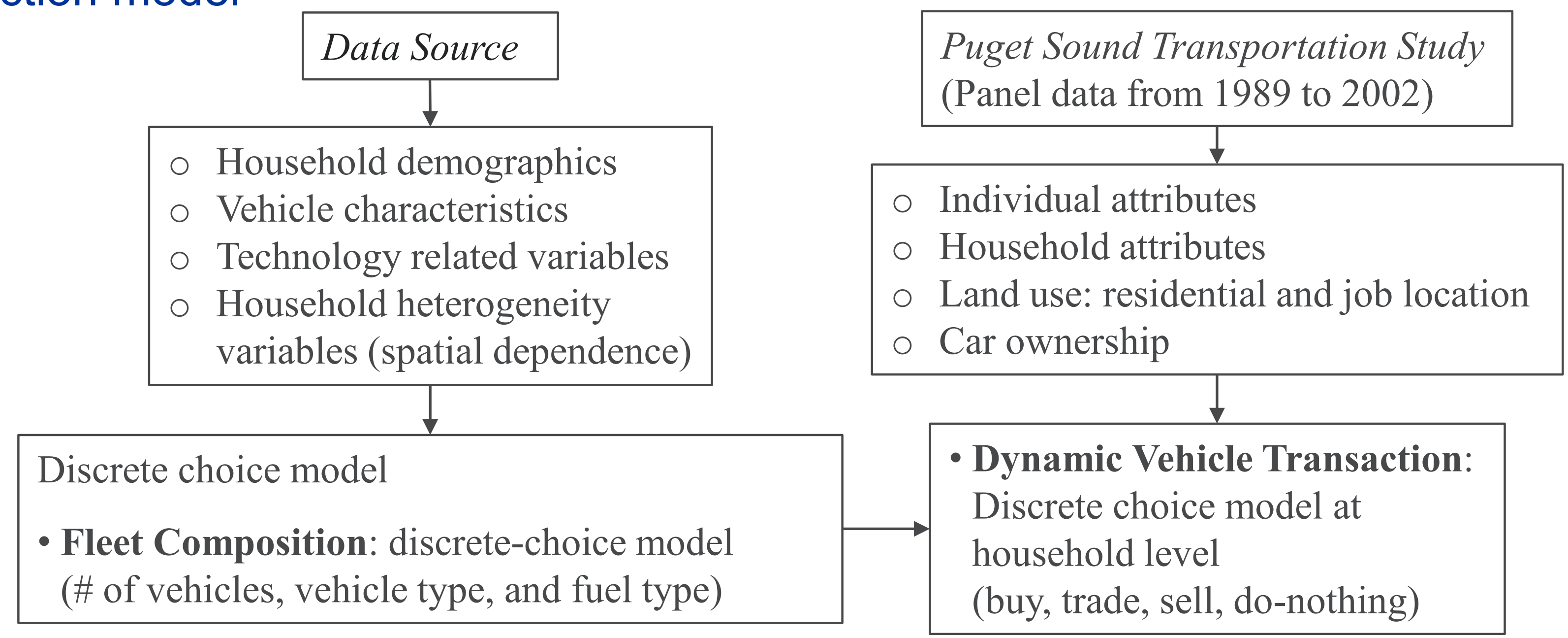
Upstream energy use could be reduced by 5% in 2040 due to lower energy intensity per ton-mile and less bio-diesel usage in rail compared to truck





Market Dynamics Modeling: Vehicle Holdings Model Framework Defined and Fit to Available Data

- Fleet composition (number of vehicles, vehicle type, and fuel type) are estimated using discrete choice model.
- The output of the fleet composition model is the input of dynamic vehicle transaction model



- Multiple data sources have been reviewed (surveys, state and regional transportation planning and energy organizations, etc.)

External Collaboration

- USCAR via USDRIVE for Autonomie and GREET
  - Inputs on vehicle technology options and fuel pathway choices
  - Verification of key parameters by member companies
- National lab partners for Autonomie, GREET, VISION/NEAT
  - NREL: TEA outputs processed for inputs to GREET for fuel production pathways
  - ORNL: Electric machine performance maps for Autonomie; transportation energy data book provides inputs for VISION/NEAT
- Universities
  - University of Illinois at Chicago (UIC): Household vehicle ownership modeling
- Other government agencies
  - EIA: GREET and VISION/NEAT, annual updates with AEO and other publications/databases
  - EPA: Power plant emissions and renewable fuel standard pathway development
  - DOT: FRA – GREET rail module; FAA – aviation fuels
- Research organizations
  - Jacobs Consultancy: detailed petroleum refinery LP modeling for energy, emissions and water
  - Eastern Research Group: criteria air pollutant emissions of petroleum refineries

Remaining Challenges and Barriers

- Data availability and quality: challenges for all models
  - Collaboration with various organizations
  - Modeling and simulations to produce needed inputs
- Modeling methodologies
  - Autonomie: Inclusion of latest powertrain and component technologies
  - GREET: System boundary expansion and modeling of indirect effects via economics; regionality of air pollutant emissions and water consumption
  - VISION/NEAT: Uncertainty analysis of key parameters
- Technology/market dynamics over time
  - Need to address technology improvements and market changes as time progresses
- Metrics of modeling results
  - Energy, emissions, water, costs so far
  - Only a subset of issues for performance of technologies/systems
- Interpretation of results
  - Users sometime have tendency to interpret results beyond modeling scope

Planned/Proposed Additional Work

- **Autonomie**
  - Include latest component and powertrain technologies (i.e., new GM xEV configurations)
  - Expand the current process to medium and heavy duty vehicle classes
  - Deploy post-processing tools to facilitate results analysis by 3rd parties
- **GREET**
  - Regional resolution of criteria air pollutant emissions and water consumption for feedstocks, fuels and vehicle materials
  - Address LCA system boundary issues to adequately address co-products and material recycling
  - Analyze critical LCA issues related to vehicle lightweighting such as material replacement ratios and fuel reduction values
  - Develop stochastic capabilities for environmental metrics in GREET.net
- **VISION/NEAT**
  - Annual update to match AEO reference case projections
  - Add criteria pollutant emissions into VISION
- **Household vehicle ownership modeling**
  - Refine model as additional data become available (new NHTS and other)

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

Summary

- Objective of this project is to develop modeling capabilities for VTO-AP to estimate energy, environmental, and cost effects of advanced vehicle technologies and alternative fuels

- Main products of this project include a suite of widely accepted/used models (GREET, Autonomie, VISION/NEAT) to address key barriers in analyzing energy, environmental, costs of vehicle/fuel systems

- Model development efforts of this project are
  - Highly leveraged with ANL's efforts for other EERE programs, other VTO programs, and other VTO-AP efforts
  - Executed by ANL top-of-field experts

- Key factor for project success is the continuing interactions with DOE sponsors, other national labs, OEMs, energy companies, and universities during project