SAND2019-4629PE

# ParaChoice Model

Project ID# van019

Date: 6/13/2019

2019 DOE
Vehicle Technologies
Office
Annual Merit Review

PRESENTED BY

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# Overview

**Timeline**

- Start date: FY14
- End date: Project continuation determined annually
- Percent Complete: FY19 50%*

**Budget**

- Total Project Funding:
  - DOE Share: $200K
  - Contractor Share: N/A
- Funding for FY 2017: $350k
- Funding for FY 2018: $200k

**Barriers and Technical Targets**

- Accelerate the development and adoption of sustainable transportation technologies by highlighting sensitivities and tradeoffs in the highly uncertain transportation sector.

**Partners: Interactions/ Collaborations**

- Argonne National Lab (ANL)
- National Renewable Energy Laboratory (NREL)
- Energetics
- Lawrence Berkeley National Lab (LBNL)
- University of California, Davis
- Nikola Motor Company
- Gillig Transit Bus Manufacturing

*As of 4/1/2019

# Relevance & Objective

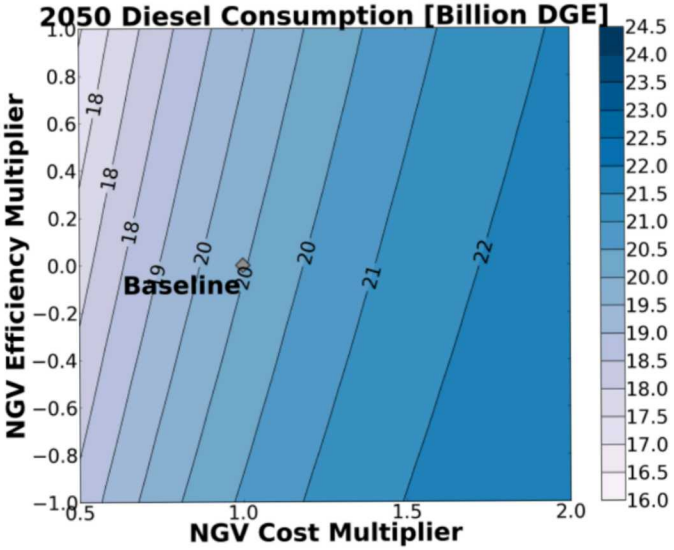
**Lifetime Project Goal:** Systems level analysis of the dynamics among the light-duty (LD) and heavy-duty (HD) fleets, fuels, infrastructure mix, and emissions

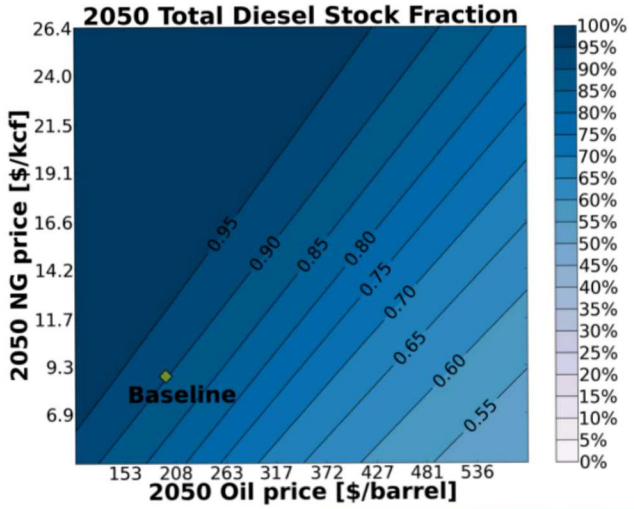
- Use parametric analysis to:
  - Identify trade spaces, tipping points & sensitivities
  - Understand & mitigate uncertainty introduced by data sources and assumptions

**HDV:** Evaluate the potential for Alternative Fuel Vehicles (AFVs) to increase freight hauling efficiency and reduce pollution

- Update model capability to handle Fuel Cell Electric, Battery Electric, Plugin Hybrid Electric Vehicles (FCEV, BEV, PHEV)
- Conduct a gaps analysis to identify and assess data sources and quality
  - To answer current ParaChoice analysis questions
  - Provide context and planning for future work

**LDV:** Participate in Benefits Analysis (BaSce)




ParaChoice provides decision & investment guidance despite significant uncertainty

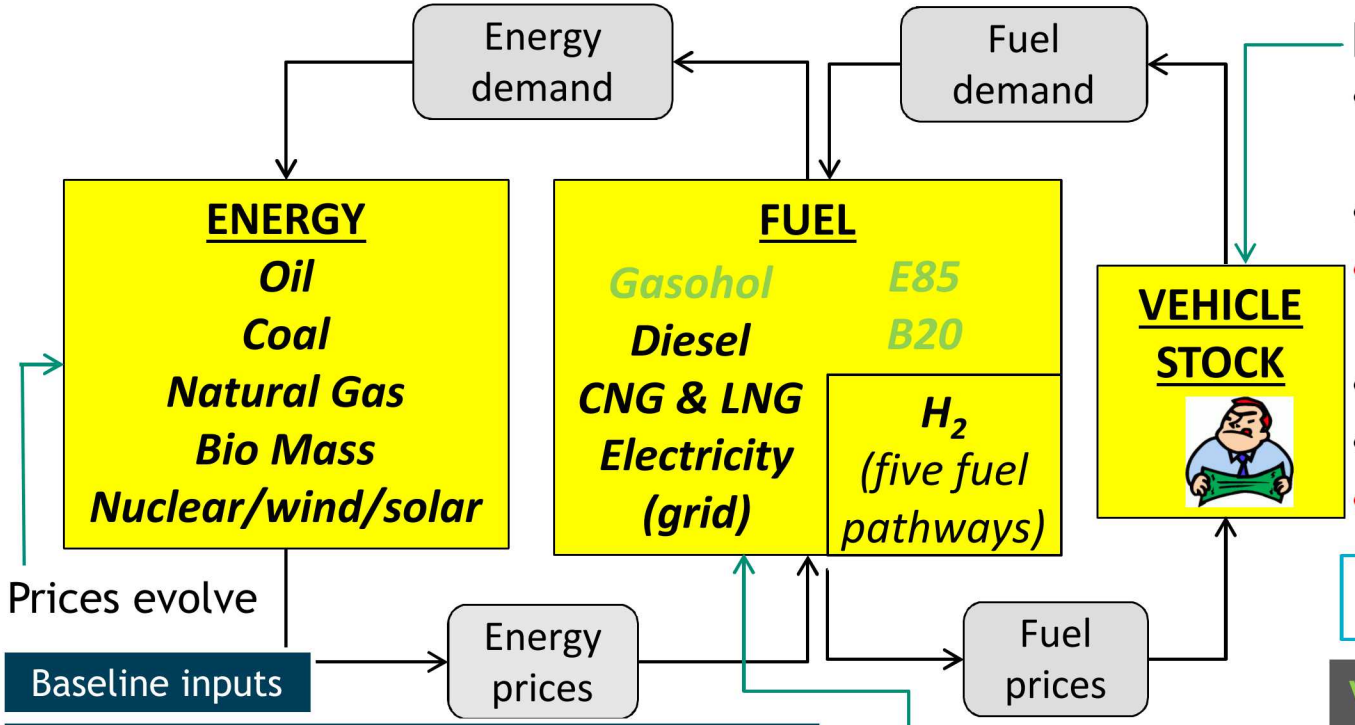
# Milestones

| Date | Milestone & Go/No-Go | Status |
|---|---|---|
| FY19 Q1 | **Milestone**: Identify and provide list of new expert personnel to execute project. | Complete |
| FY19 Q2 | **Milestone**: Update Project plan; submit new AOP; attend Analysis Summit | Complete |
| FY19 Q3 | **Milestone**: Presentation to HQ on the gaps analysis | On Track |
| FY19 Q4 | **Milestone**: Presentation to HQ to demonstrate ParaChoice HDV on example vehicle for multiple AEV powertrains | On Track |
| FY19 Q4 | **Go/No-Go Decision**: Provide to HQ a list of powertrains & associated data sources for HDV analysis | On Track |

Current team did not form until after the FY started. New AOP was drafted and deliverables are now on track

# Approach: ParaChoice – Underlying systems model between energy and LD or HD vehicles

Begins with today's energy, fuel, and vehicle stock and projects out to 2050. At each time step, vehicles compete for share in the stock based on value to consumers.




Parameters as $f(t)$:

- Veh. costs & efficiencies
- Model availability
- Infrastructure evolution
- Stock size
- Powertrain prevalence
- Emissions

Red = endogenous

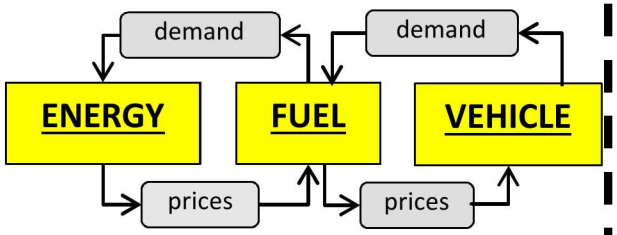
- Energy prices: AEO 2016
- Emissions: GREET
- Fleet segmentation: NHTS (LDV); Polk (HDV)
- VMT: FWHA, AFDC
- Vehicle price projections: Autonomie; National Petroleum Council (HDV)
- Fueling stations: AFDC
- Policies (by state): AFDC

Policy options as $f(t)$:
RFS, carbon taxes, $H_2$ production pathways, electric grid composition

Variety of Output Options, Including:

- Sales Fractions
- Vehicle Stock
- Emissions
- Fuel Consumption
- Trades & Sensitivities

# Approach: ParaChoice segments vehicles, fuels, & population to understand competition between powertrains & market niches




*Demographics* | *Vehicle* | *Geography*

**LDV Segmentation**

**Powertrain**
20 Powertrains

**Housing type**
With or w/o access to charging/ fueling

**Driver Intensity**
Low, Med, or High

**VMT Segmentation**

**Energy/Fuel Seg.**

**State**
48 CONUS + Washington, DC

**Density**
Urban
Suburban
Rural

**Size**
5 Sizes

**Age**
0-46 years

**HDV Segmentation**

**Powertrain**
CI
NG (LNG, CNG)
FC
HE (CI, CNG)
PHE (CI)
BE

**Refueling Type**
Gas Station
Truck Stop
Private

**Age**
0-18 years

**GVW**
Class 7 & 8

**Body Type**
Tractor Trailer
Straight Truck
Bus

**Vocation (Use)**
Construction
Food
General Freight
Lease/ Finance
Manufacturing
Natural Resources
Services
Wholesale/Retail
Bus/Transportation

**Fleet Size**
1-9; 10-99; 100-999; 1,000+

**Service Radius**
0-100; >100

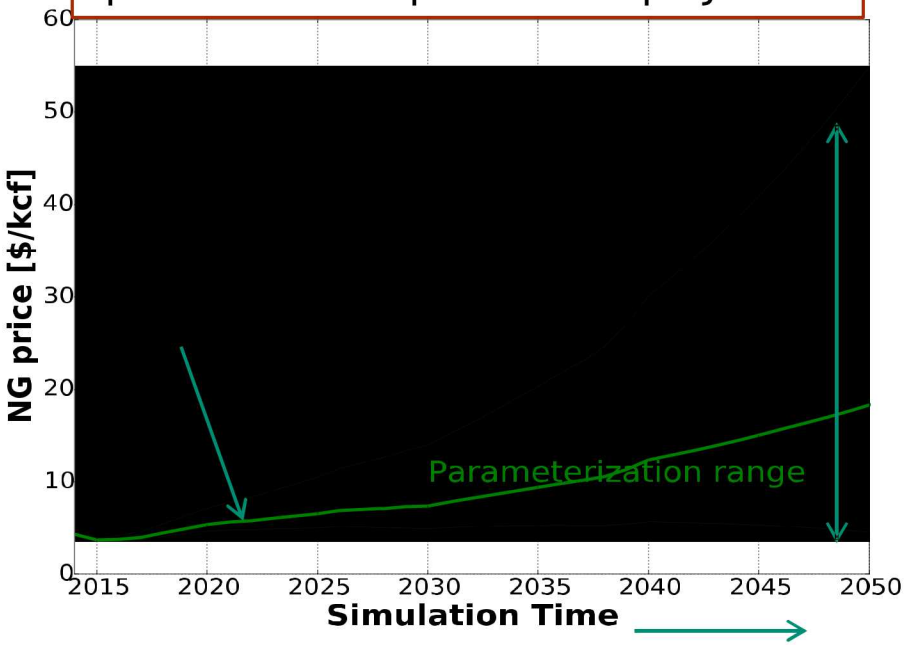
**State**
48 CONUS + Washington, DC

# Approach: Use parameterization to understand and mitigate uncertainty introduced by data sources and assumptions

***Uniqueness from other DOE models*:**
ParaChoice is designed to explore uncertainty & trade spaces, easily allowing identification of tipping points & sensitivities

- Core simulation is a system-level analysis of the ***dynamic***, economic relationship between energy, fuels, & vehicles with baseline values from trusted DOE sources. Technologies compete in the simulation, are allowed to flourish or fail in the marketplace.
- Simulation is run 1000s of times with varying inputs. This parametric analysis provides:
  - Perspectives in uncertain energy & technology futures
  - Sensitivities and tradeoffs between technology investments, market incentives, and modeling uncertainty
  - The set of conditions that must be true to reach performance goals

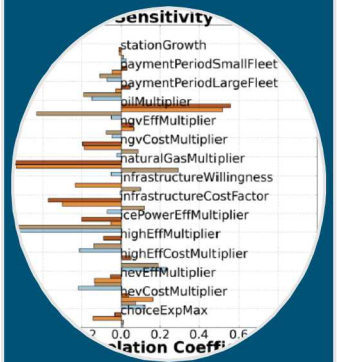
Example parameterization of natural gas prices with multiplier on AEO projection




- Vary two parameters at once- trade space analysis
- Vary many parameters- sensitivity analysis
- Parameterization ranges designed to explore plausible AND 'what if' regimes, covering all bases

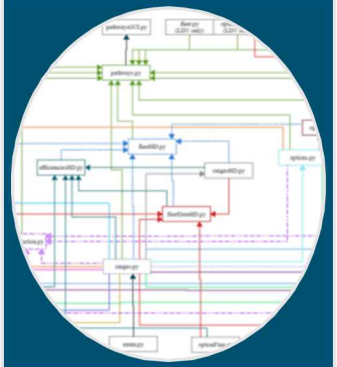
Modification and update of the legacy HDV ParaChoice model will extend these unique capabilities in the HDV segment.

# Approach: Updating model capability requires a thorough review and documentation of legacy code.




## Review Code ☑

- Understand functions and workflow of code
- Identify current analysis capabilities
- Generate plan for added capability(ies)

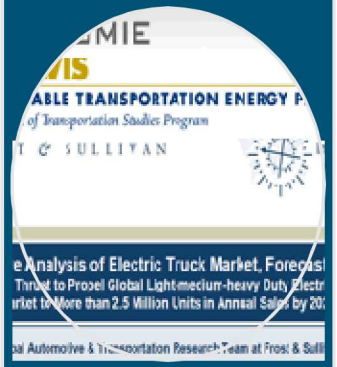


## Document Code ☑

- Generate detailed documentation of functions
- Generate graphic of code workflow

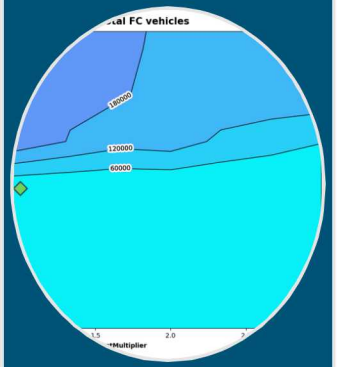
## Update Code

- Adapt code structure and functionalities based on defined deliverables




## Input Data

- Input updated data through gaps analysis, collaborations and market studies




## Show Capability

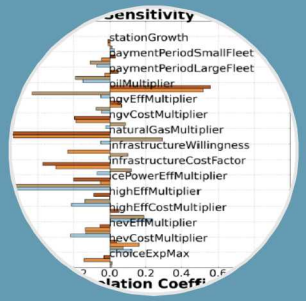
- Demonstrate HDV analysis capability based on defined deliverables

*FY19 progress*

# Approach: Gaps Analysis was a response to the recognition that the HDV space is complex and challenging.

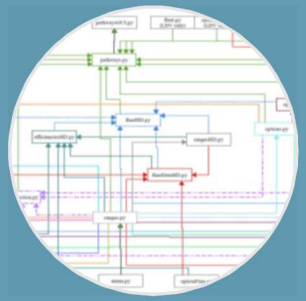
Engage deeply with new HDV material as an onboarding and planning exercise. Take a systems analysis approach to assessment of data availability.

- Met internal needs of organizing and prioritizing effort
- Meets VTO need by highlighting opportunities for future work in this and other programs.




## Identify HDV Analysis Questions

- Extend previously answered questions to new segments
- Asses LDV for analogous opportunities
- New questions as a result of an evolving market

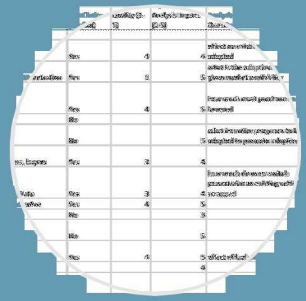


## Identify Data Needs

- Use ParaChoice as a framework
- Create a set of criteria to assess data for programmatic needs and quality


## Gather Data

- Prioritize data search on need/ expected analysis impact
- Search known data sources first
- Reach out to partners to help identify data sources.



## Perform Gaps Analysis

- Use data in new and updated analyses
- Support VTO by identifying new research opportunities for analysis portfolio

*FY19 progress*

# Accomplishments & Progress: ParaChoice Participation in the BaSce effort encourages interaction, collaboration and interdependence with other labs to meet VTO needs.

**TABLE B-5 LDV Market Penetration Estimates for the No Program and Program Success Cases from the ParaChoice Model**

| | No Program (%) | | | | Program Success (%) | | | |
|---|---|---|---|---|---|---|---|---|
| Drivetrain Type | 2025 | 2030 | 2040 | 2050 | 2025 | 2030 | 2040 | 2050 |
| SI Conv | 70.7 | 46.7 | 29.3 | 23.0 | 57.3 | 41.4 | 22.8 | 11.7 |
| CI Conv | 11.8 | 18.4 | 14.0 | 9.4 | 14.3 | 21.0 | 11.6 | 6.0 |
| HEV Gasoline | 15.8 | 25.3 | 18.4 | 12.1 | 25.6 | 24.6 | 14.9 | 8.4 |
| PHEV25 | 0.4 | 3.2 | 9.7 | 8.0 | 0.9 | 3.8 | 10.1 | 6.8 |
| PHEV50 | 0.1 | 1.1 | 3.2 | 2.8 | 0.5 | 2.0 | 5.0 | 3.5 |
| BEV100 | 1.0 | 4.0 | 14.4 | 21.5 | 1.1 | 4.3 | 9.1 | 7.5 |
| BEV200 | 0.1 | 0.7 | 3.5 | 4.6 | 0.2 | 1.2 | 4.3 | 3.6 |
| BEV300 | 0.0 | 0.0 | 0.2 | 0.7 | 0.0 | 0.0 | 0.5 | 1.1 |
| FCV | 0.1 | 0.5 | 7.3 | 17.8 | 0.2 | 1.7 | 21.7 | 51.3 |

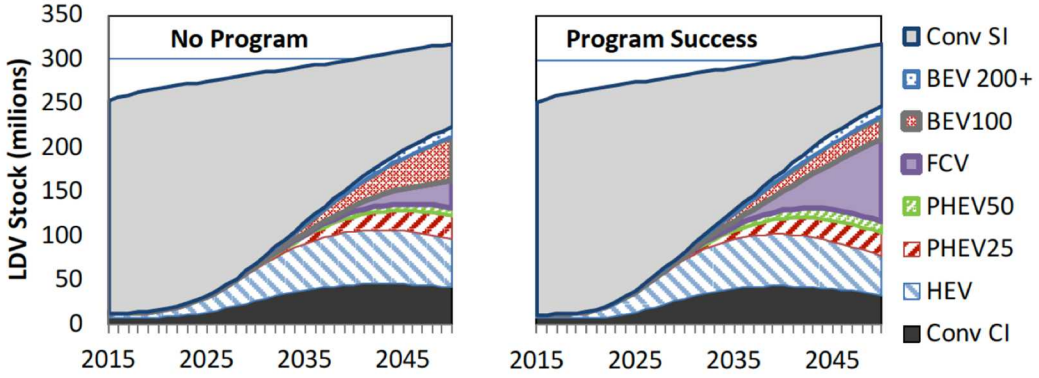



**FIGURE B-5 LDV Stock by Powertrain Type for the No Program (left) and Program Success (right) Cases Projected by the ParaChoice Model**

Participated in Benefits analysis for FY18

Parachoice's unique parametric execution provides a nuanced perspective to the choice modeling endeavor

**ParaChoice is an integrated part of the BaSce effort; receiving data from and providing data to other agencies models like:**

- **GREET**
- **Autonomie**
- **Vision**

Stephens, T.S., A. Birky, and D, Gohlke. 2017. *Vehicle Technologies and Fuel Cell Technologies Office Research and Development Programs: Prospective Benefits Assessment Report for Fiscal Year 2018.* Argonne National Laboratory, Argonne, IL, report ANL/ESD-17/22, November,

# Accomplishments & Progress: A rigorous review of the HDV code revealed opportunities for improvement and leveraging existing capabilities.

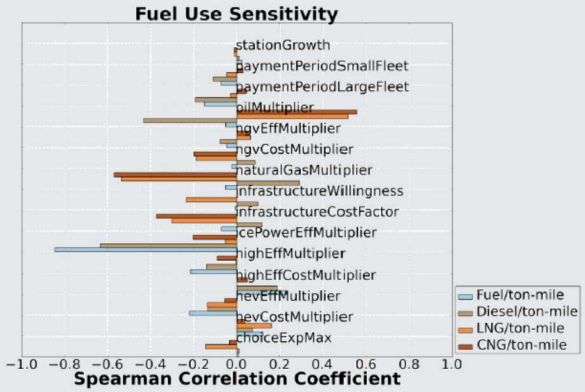
## Review Code ☑

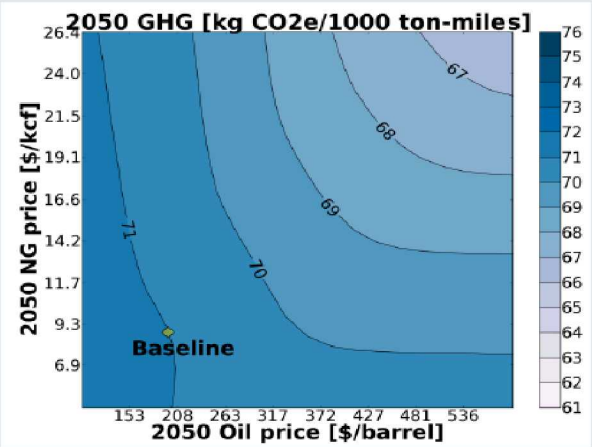
Technical capability

- Multidimensional analysis along multiple parsing parameters
  - Powertrain, vocation, fuel type, etc.
- Highly adaptable input deck, supporting a variety of analysis questions
- Massively parallel Monte Carlo analysis, supported by Sandia's HPC clusters
  - Sensitivity and trade space analyses

Legacy analysis capability (documented in SAND2014-4448)

- Choice simulation for CI, and NG based on verifiable information from databases (.gov and .com sources), secondary model outputs (GREET), as well data shares from collaborations
- Investigates effects of vehicle stock, and associated emissions and petroleum consumption due to:
  - Technology cost
  - Fuel efficiency
  - Infrastructure availability
  - Fuel costs
  - Financing options



# Accomplishments & Progress: Thorough documentation of the code support the update process while mitigating the risk of unintended consequences

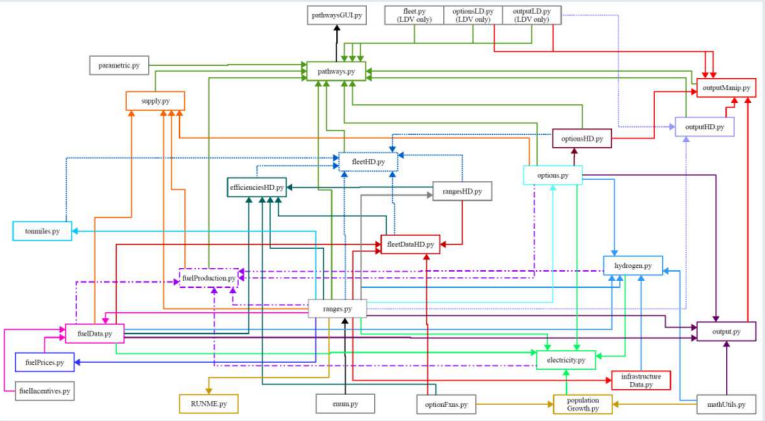
## Document Code ☑

### Motivation

- Legacy HDV code was documented at a high level

### Output

- Generated a detailed workflow graphics of model, showing dependencies among modules
- Generated accompanying database with explicit descriptions of functions and direction of data flow




## Update Code (in progress)

### Completed

- Updated ton-mileage and existing vehicle stock based on parsing by service radius
- Added disaggregation between transit bus and school bus vocations
- Increased data input functionality
- Generalized update-plan and priorities list including:
  - Functionality to read Autonomie data for efficiency and purchase prices of identified powertrains
  - Fueling infrastructure of alternative fuels as relevant to HDV

# Accomplishments & Progress: Gaps Analysis is an opportunity to systematically create a data informed extended development plan

## Identify HDV Analysis Questions (in progress)

Reviewed previous LDV and HDV ParaChoice analyses

Attended TRB, and VTO Analysis summit to find ideas for new analysis.

We looked to industry to understand some of their concerns.

Some Example Questions:

- What is the effect of vehicle availability on sales?
- What effect does end-of-life salvage value have on vehicle adoption?
- What powertrains should be considered in the analysis?
- How does infrastructure funding affect adoption?
- Effects of higher charging powers?

The Gaps Analysis is executed as a spreadsheet backed by a granular database

### Row Categories*

- Energy Sources
- Vehicles
- Fuel Production
- Infrastructure
- Consumers
- Economics

*Total of ~100 data types

### Column Headers

- Parameter
- In ParaChoice
- Data Quality
- Analysis Impact
- Analysis Question
- Citations
- Opportunities

**Fuels**

- Diesel Petroleum
- LNG Petroleum
- CNG petroleum
- Biodiesel
- Fisher-Tropsch
- Methane Reformation
- 5 H2 Pathways
- DME
- Electricity (Fossil)
- Electricity (Renewable)
- Electricity (Biomass)

**Powertrains**

- Conventional
- Biodiesel
- CNG
- LNG
- FC
- BE

**Vehicles (Class 7 & 8)**

- TT- Van Basic
- TT- Van refrigerated
- TT- Dump
- TT- Flatbed/stake/platform
- TT- Tank
- SUT- Van Basic
- SUT- Van Refrigerated
- SUT- Refuse
- SUT- Construction
- SUT- Dump
- SUT- Flatbed/platform/stake
- SUT- Tank
- Motorhome
- Bus- School
- Bus- Transit

# Accomplishments & Progress: The gaps analysis will visualize the short-term and long-term needs of HDV ParaChoice

- First version of gaps analysis focuses on approximately 100 sets of required data.
- Will allow developer to quickly sort/prioritize development based on a variety of factors.
- Can be used to clearly articulate to VTO what analyses could be enabled, what impact we expect they will have, and make suggestions how to get data for the analysis.

Example

| Categories | Data Required | Parameter | ParaChoice (Yes/No) | Quality (1-5) | Analysis Impact (1-5) | Analysis Affected/ Use (Analysis Question) | Citations/ Sources | Opportunities (Our Analyses) |
|---|---|---|---|---|---|---|---|---|
| Vehicle | | | | | | | | |
| | Current & Historical Stock (Vehicle Counts) | vehicles | Yes | 4 | 4 | effect on existing fleet as AFV are adopted | Polk | |
| | Current and Projected Model Availability | marketPenetration | Yes | 1 | 5 | what is the adoption saturation given market availability | | |
| | Purchase Costs | Cv | Yes | 4 | 5 | how much must purchase cost be lowered | AFDC, publicsolutionsgroup .com, autonomie | |
| | Manufactuing Costs | | No | | | | | |
| | Purchase Incentives (National & Regional) | | No | | 5 | what incentive programs to be adopted to promote adoption | | |
| | Initial and Resale Purchase Data | sellers, buyers | Yes | 3 | 4 | | | |
| | Operating Life & Scrap Rates | scrapRate | Yes | 3 | 4 | how much do users switch powertrains as existing vehicles are scrapped | | |
| | Dive Cycle (Ton-Miles) | tonmilesAve | Yes | 4 | 5 | | FHWA, Polk | |
| | Depreciation Data | | No | | 3 | | | |
| | TCO for one time and annualized costs | | No | | 5 | | | |
| | Fuel Efficiency | consump | Yes | 4 | 5 | effect of fuel price on adoption | EIA, FHWA, autonomie | |
| | Use, Vocation, VMT Data | | | | 4 | | | |
| | Exemplar Vehicles for Disaggreagation | | | | | | | |

# Responses to 2017 AMR Reviewer Comments

| Comments from FY17 AMR | Responses |
| --- | --- |
| The reviewer was specifically concerned about the inclusion of several "free" utility parameters (e.g., model availability and alternative specific constants) in the nested logistic regression (logit) model. | Added Data needs to Gaps analysis to support answering these questions at a future date. |
| The reviewer commented that the project has no university collaborators or technical critiques by academic researchers. | Re-engaged with UC Davis STEPS/ ITS Programs. Leveraging having 2 Alumni as team members |
| The reviewer noted that the research into which alternative technologies could gain market penetration in the heavy-duty sector could fill a current research gap. | Adding FCV, BEV, and PHEV to HDV model to better project market penetration in HDV space |

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

# Partnerships/Collaborations/Interactions

## Recent

Argonne – Provides data for BaSce analysis. Provides data for powertrains, efficiency and costs

Nikola – Provide context on performance of their electric and fuel cell electric vehicles under development.

NREL – HDV Drive Cycle Data

Energetics, Lawrence Berkeley National Labs – Support as part of VTO analysis portfolio

UC Davis – STEPS symposium, renewed interactions with UC Davis including peer review of publications

Fuel Cells Technologies Office – Provides Joint Funding for this effort

## Previous

Incorporation of real-world driving cycles in collaboration with:
Ford Motor Company, General Electric, American Gas Association

Model input and review from:
ANL, ORNL, NREL, Energetics

Technical critiques on modeling and analysis:
DOE, DOT

Workshop Organizing Committee:
Toyota, American Gas Association, DOE

# Remaining Challenges and Barriers

Uncertainty in AFV Market: There are significant limitations in data availability for new powertrains/fuels/ infrastructure. Some vehicles/powertrains that we are interested in investigating are still in the prototype phase and have no practical real-world data. The transportation community is currently investing heavily in new materials, processes, energy pathways and general technology. The adoption of new technology can take on the order of a decade, ParaChoice projects out 30+ years. We recognize that uncertainty grows inherently further in the projections.

# Proposed Future Work- We will continue to develop the capabilities of ParaChoice in LDV & HDV

## Ongoing

FY19 – [Q3 Milestone] Present Gaps analysis to VTO HQ. Highlight opportunities for new and expanding research.

FY19 – [Q4 Milestone] Demonstrate ParaChoice HDV projection capabilities on an example vehicle with multiple powertrain/fuel options

FY19 – Continue adding capabilities (E.G. Powertrains, Fuels, and Infrastructure) to ParaChoice HDV.

## Planned

FY20 – Finish initial HDV updates of Powertrains, Fuels, and Infrastructure

FY20 – Participate in TCO working group

FY20 – Participate in BaSce LDV & HDV

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

# Summary

ParaChoice Team experienced substantive turnover at beginning of FY19

Turnover required an overhaul of FY19 AOP and onboarding effort for new team

LDV participation in BaSce continues, on track

A Gaps analysis has been engaged for the HDV work to assess near and long term data needs and to inform future analysis planning

Significant updates to HDV code planned including addition of 3 new ”fuels”, and added sophistication to handling of HDV segmentation

# Technical Backup Slides

Approach: At every time step, simulation assesses generalized vehicle costs for each vehicle. Choice function assigns sales based on these costs and updates stock.

## VEHICLE STOCK

| Vehicle | Generalized Vehicle Cost | | Percent of Sales |
|---|---|---|---|
| Conv. SI | $X /year | | A % |
| FCEV | $Y /year | | B % |
| PHEV40 | $Z /year | | C % |
| ... And 17 more | | | |

Given:
- Input attribute(s)
- Fixed set of 2+ output choices

**Nested Multinomial Logit Function**

Outputs:
- Probability distribution

### Generalized Vehicle Cost

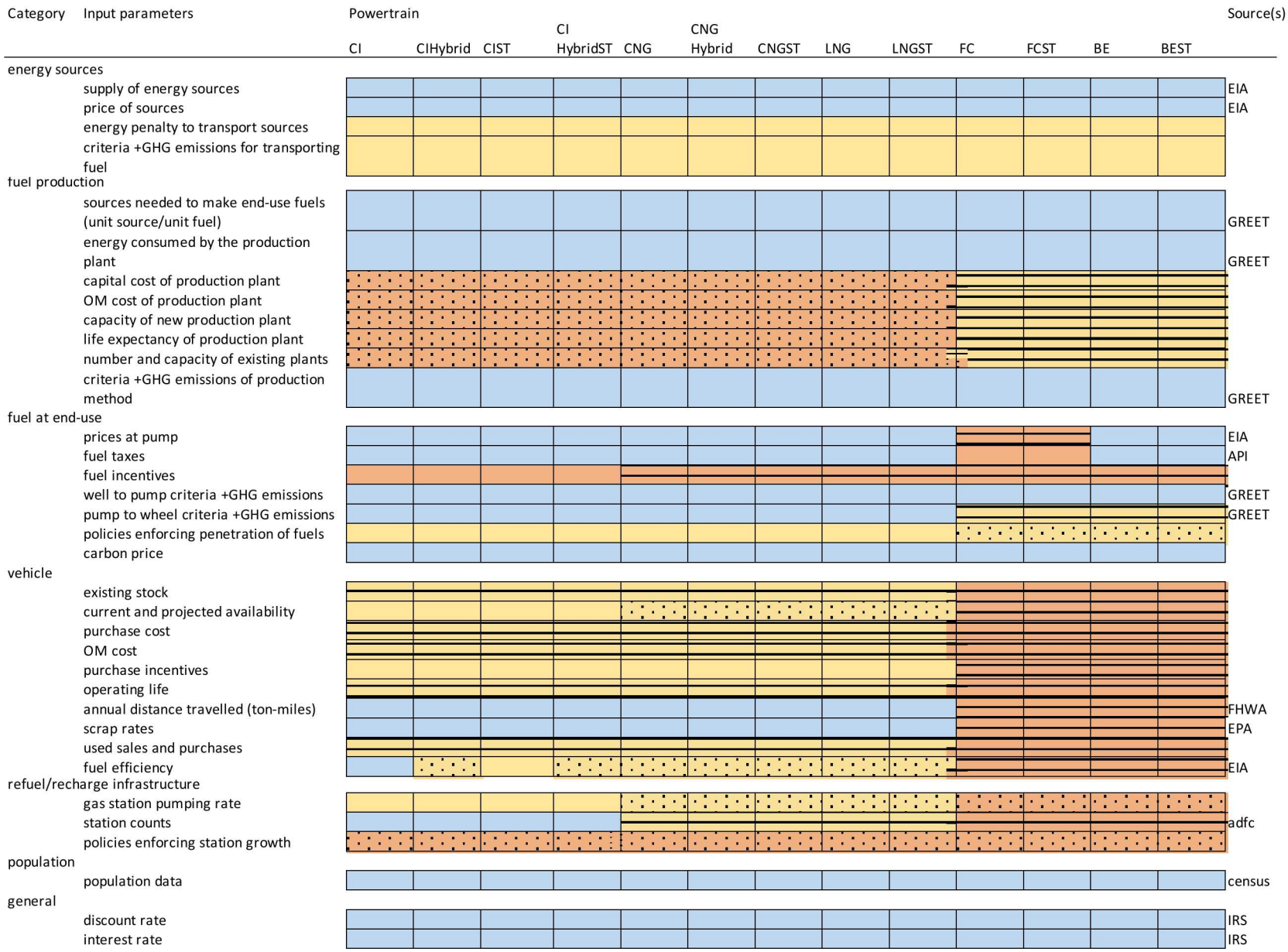
**Upfront Costs Amortized Over "Required Payback Period"**
- Purchase price
- One time incentives
- One time penalties *(Infrastructure penalty)*

**Recurring Costs**
- Fuel cost
- Annual incentives
- Annualized penalties *(Range penalty)*

## Slide 21

**NR8** Consider putting another box at the bottom that are costs outside the scope of the model (resale value for example)
Nealer, Rachael, 5/1/2017

# An assessment of the current state of the HDV code. Input parameters for Powertrains are for data availability, quality, and importance.



# Modeling Approach – Disaggregation by geography, vehicle type, demographics, fuel

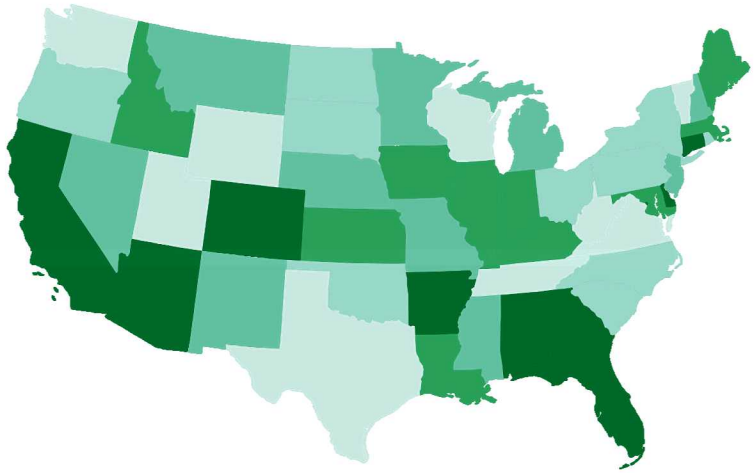
Vehicles
- Numbers, classes, drive-train mixes

Service demographics
- Ton-mileage

Fuels
- Costs, electricity mix, hydrogen production pathway, taxes & fees, alternative fuel infrastructure

Energy supply curves (as appropriate)
- Oil, coal, natural gas, renewable electricity

Policy
- Consumer subsidies and incentives



# Modeling Approach – Model inputs are taken from published sources when possible, and many are parameterized

**Energy sources**

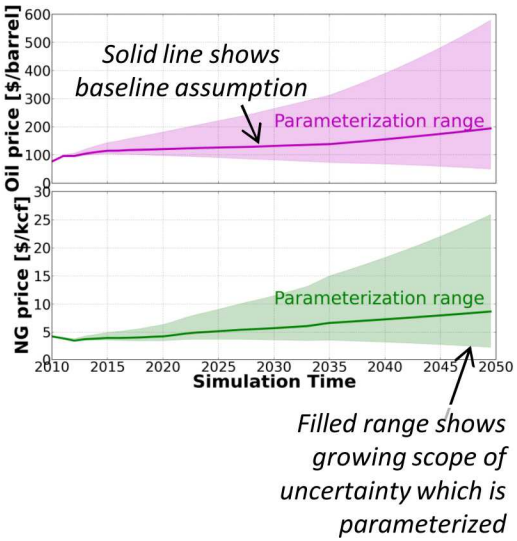
Oil: Global price EIA Annual Energy Outlook (2014)

Coal: National price EIA AEO (2014)

NG: Regional price EIA AEO (2014)

Biomass: State supply curves ORNL's Billion Ton Study

- Price corrected to match current feedstock markets




**Fuel conversion and distribution**

Conversion costs and GHG emissions derived from ANL GREET model

Electricity grid

- State-based electricity mix, allowed to evolve according to population growth and energy costs
- Intermittent and "always-on" sources assumed to supply base load first
- Vehicles assumed to be supplied by marginal mix

Hydrogen production

- Production cost based on least-cost pathway
- Production capacity allowed to evolve according to demand

# Modeling Approach – Model inputs are taken from published sources when possible, and many are parameterized

**Vehicle model**

Consumers do not change vehicle class

Ton-miles varies by model segmentation, but does not change over time

Vehicles segmented by fleet sizes with increasing payback period (larger fleets can tolerate longer payment periods)

Vehicle efficiency, and cost taken from EIA, EPA-NHTSA, AFDC, NPC & ANL Autonomie 2017 prototype model analysis

Consumer choice model is nested, multinomial logit type (like MA3T)

- Sale shares depend on amortized consumer utility cost = vehicle purchase price – subsidies + fuel operating costs + penalties (refuel time)

# Reviewer Only Slides

# Publications


Levinson, R. S., & West, T. H. (2018). **Impact of convenient away-from-home charging infrastructure**. *Transportation Research Part D 65,* pp. 288-299.

Levinson RS, Manley DK & West TH. (2016). History v. Simulation: An analysis of the drivers of alternative energy vehicle sales. *SAE, Int. J. Alt. Power 5(2)*

Askin AC, Barter GE, West TH & Manley DK. (2015). The heavy-duty vehicle future in the United States: A parametric analysis of technology and policy tradeoffs. *Energy Policy*, 81, 1-13.

Barter GE, Tamor MA, Manley DK & West TH (2015). Implications of modeling range and infrastructure barriers to battery electric vehicle adoption. *Transportation Research Letters*, 2502, 80-88

Peterson MB, Barter GE, West TH & Manley DK. (2014). A parametric study of light-duty natural gas vehicle competitiveness in the United States through 2050. *Applied Energy*, 125, 206–217.

Barter GE, Reichmuth D, West TH & Manley DK. (2013) The future adoption and benefit of electric vehicles: a parametric assessment. *SAE Int. J. Alt. Power*, 6(1).

Westbrook J, Barter GE, Manley DK & West TH. (2013). A parametric analysis of future ethanol use in the light-duty transportation sector: Can the US meet its Renewable Fuel Standard goals without an enforcement mechanism?. *Energy Policy*, 65, 419-431.

Barter GE, Reichmuth D, Westbrook J, Malczynski LA, West TH, Manley DK, Guzman KD, & Edwards DM. (2012). Parametric analysis of technology and policy tradeoffs for conventional and electric light-duty vehicles. *Energy Policy*, 46(0), 473 – 488.

# Critical Assumptions and Issues

Complete team turnover

- Every member of the ParaChoice team was replaced with minimal overlap at the beginning of the FY19. Team members replaced include Sandia PM, PI and contributors. Furthermore, the primary focus of the ParaChoice effort has shifted towards developing HDV capabilities. New team members and primary focus have required significant effort dedicated to ”onboarding”. As such, previously planned deliverables are delayed by 1-1.5 quarters. Current status is in-line with previous goals +1.5 quarters and no further delays are anticipated.