



Core Modeling & Decision Support Capabilities: FASTSim, RouteE, T3CO & OpenPATH

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National Renewable Energy Laboratory
Tuesday June 3, 2025

DOE Vehicle Technologies Office
2025 Annual Merit Review and Peer Evaluation Meeting

Tool Leads

FASTSim: Chad Baker

RouteE: Jake Holden

T3CO: Alicia Birky

OpenPATH: K. Shankari

EEMS112

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

- Project start: October 2024
- Project end: September 2027
- Percent complete: 20%

Budget

- Total project funding: \$1.125M/yr for FY25–FY27
 - DOE share: 100%
- \$925K received for FY25 so far

Barriers

- Improved model and data availability to support enhanced RD&D of advanced mobility solutions
- Quantify technology impacts
- High uncertainty and rapid changes in mobility technology and behaviors

Numerous Partners/Collaborators

- OEMs and suppliers, fleets, federal agencies
- Research partners at other labs, universities, state agencies, industry
- Mapping, logistics, and information providers
- MPOs, local agencies, mobility providers
- Livewire/TSDC for data dissemination (EEMS066)

Project Objectives and Relevance

- Support tools for quantifying energy, mobility, and cost impacts and for identifying strategies to achieve maximum impact
- Enable collaborations for implementing and deploying tools to realize real-world benefits
- Facilitate data collection to target advancements where most beneficial, and to directly measure their impacts when implemented
- Directly relevant to DOE goals of increasing efficiency, reducing costs, and improving mobility + energy security
- Extensive stakeholder collaboration and coordination helps to advance an array of energy- and cost-efficient transportation activities
 - Capabilities leveraged by many other projects within and beyond EEMS/VTO/DOE
 - Tools, analyses, and data outputs made broadly available
- Efforts span passenger and freight movements across LD + MDHD and pedestrian + micromobility modes



Overall Approach

- Maintain, update/enhance, and broaden the reach of core capabilities for streamlined vehicle energy + cost modeling, as well as mobility data collection + analysis (of existing and advanced tech)
- Provide a foundation for impactful lab research and for industry/practitioner collaborations leveraging core tools
- Deliver further value to current users through feature additions, and attract new users and collaborators to expand impact



FASTSim



RouteE



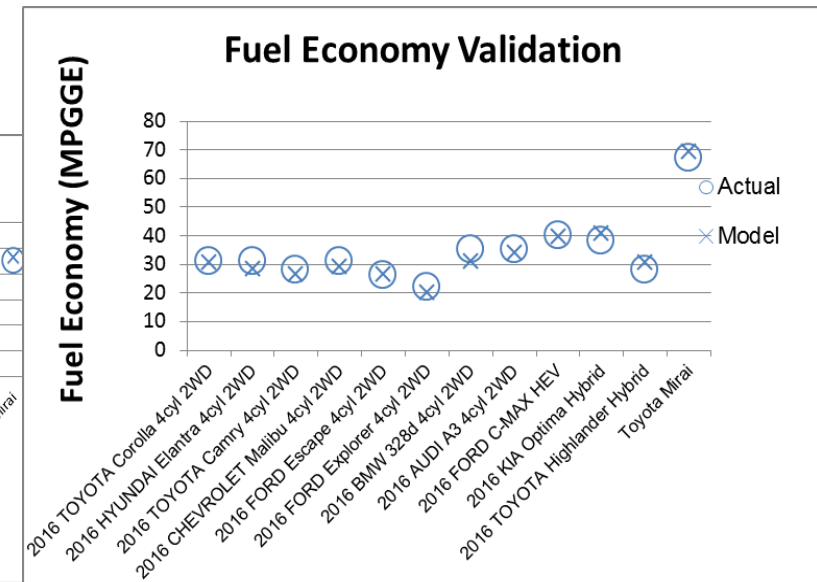
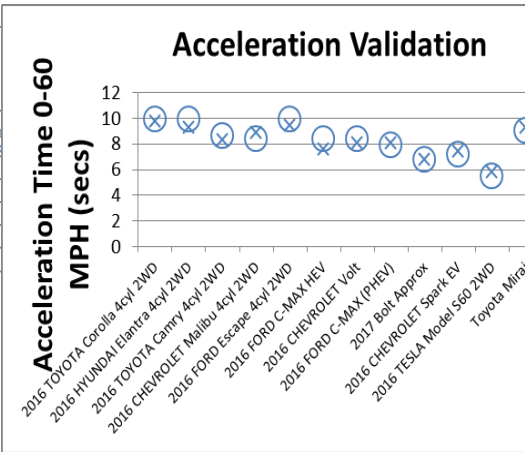
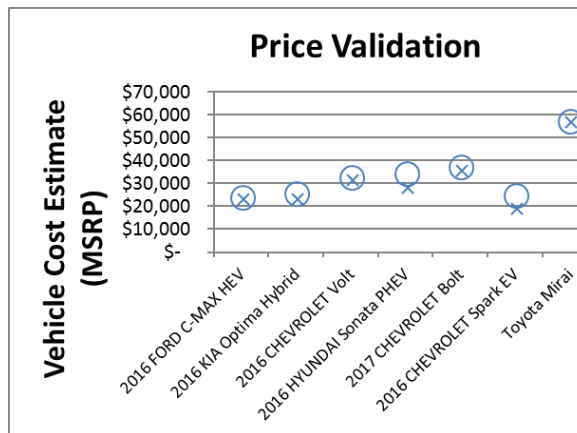
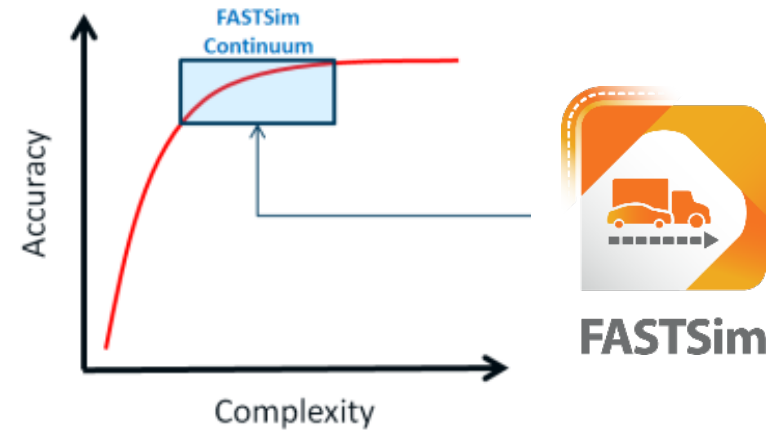
T3CO



OpenPATH

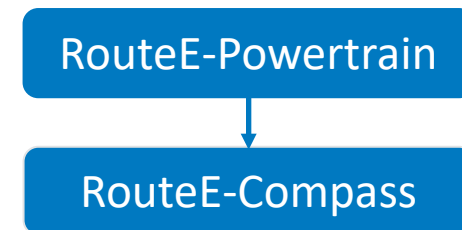
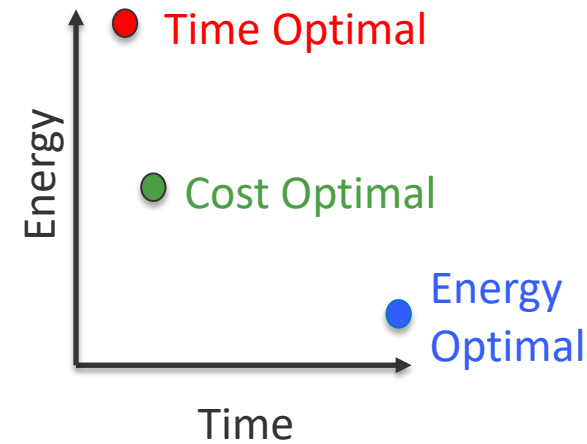
Approach: Vehicle Powertrain Modeling in FASTSim

- **FASTSim's balance of accuracy vs. complexity**
 - Model captures most important factors influencing vehicle energy use, performance, and cost
 - Useful for evaluating tech improvement impacts
- **Well validated and widely accepted**
 - Simplest version with generic components gives good large-scale agreement
 - Complexity can be added to capture a range of real-world considerations

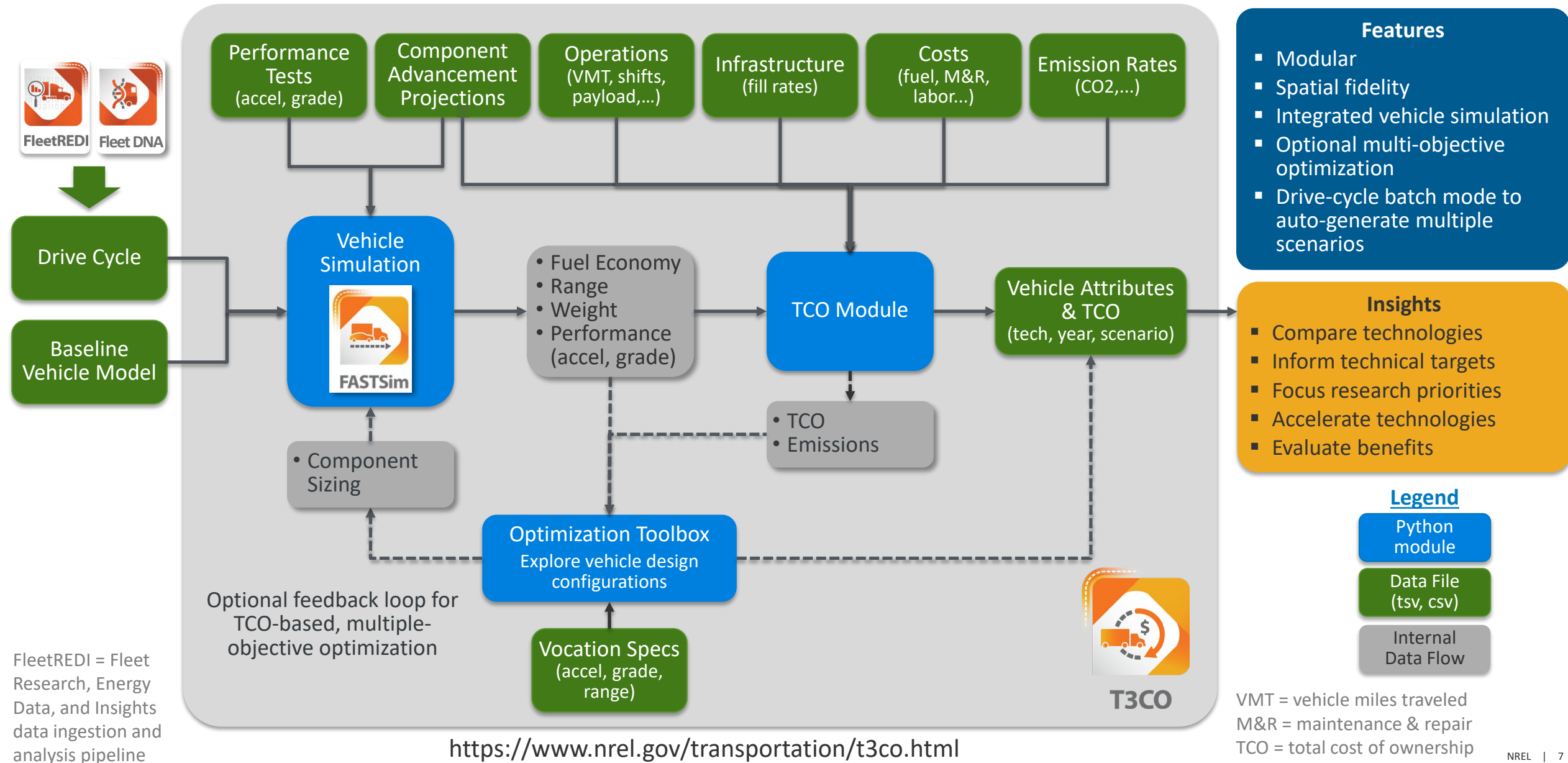


Approach: RouteE – Route Energy Prediction Model

- **RouteE-Powertrain** – predicts energy use for diverse vehicle and powertrain types over prospective driving routes **in the absence of high-frequency drive cycle data**
- **RouteE-Compass** – an **energy-aware routing and navigation** platform that allows users to co-optimize travel time, energy consumption and economic cost for individual **vehicles, fleets, or entire transportation networks**
 - Allows fleets to **minimize operating costs** by selecting routes that **reduce energy use without compromising travel time or service reliability**



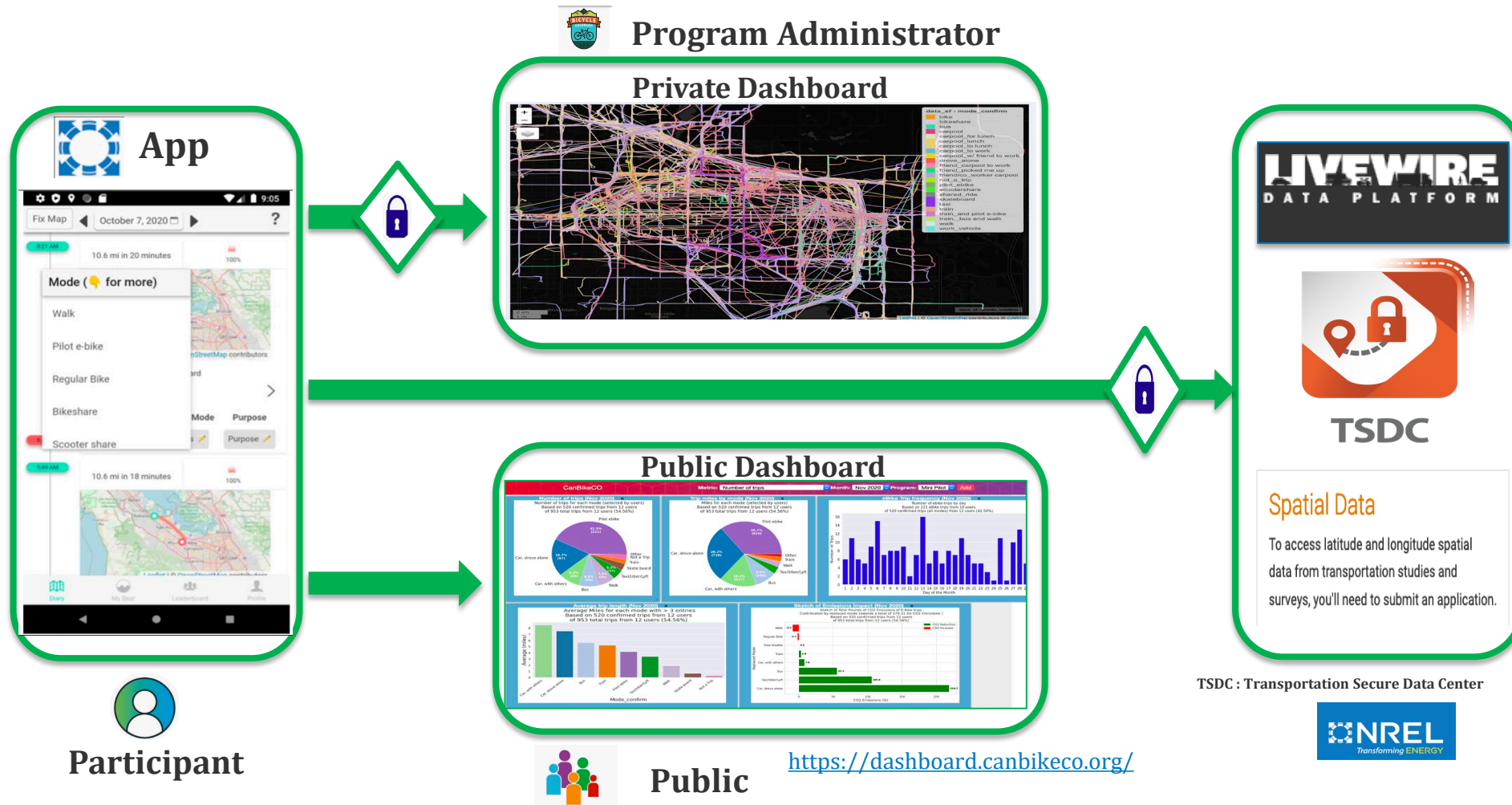
Approach: Transportation Technology Total Cost of Ownership (T3CO) Modeling Flow



Approach: Instrumenting Human Mobility with OpenPATH



OpenPATH



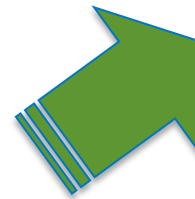
Approach: OpenPATH Helps Include Hard-to-Reach Groups in Analysis and Decision-Making

From inadequate status quo...

Alternatives fall short



- City council and town hall meetings struggle to reach busy residents
- Online surveys are overly simplistic and prone to reporting error



To enabling improved representation...

Speak through behavior

- Partner in communities
- Capture unusual hours and modes
- Provide for privacy and transparency



OpenPATH

“If you cannot measure it, you cannot improve it”

FY25 Milestones

Description	Due	Status
Implement battery thermal model and controls for HEV and BEV in fastsim-3.	12/31/24	Complete
Provide T3CO results visualization template in Python.	12/31/24	Complete
Implement at least 2 high priority bug fixes and at least 1 high priority incremental update to OpenPATH, as determined by deployer feedback. An example of an incremental update would be supporting bulk downloads in the admin dashboard.	3/31/25	Complete
Implement thermally sensitive RouteE-Powertrain models for BEVs. To include incorporation of the FASTSim battery thermal models for BEVs to accurately estimate energy rate and range impacts due to ambient temperature when validated against on-road energy consumption data for at least 3 different BEV models.	6/30/24	On track
Prepare a paper documenting T3CO opportunity cost methodologies for submission to a peer-reviewed journal and/or conference venue.	6/30/24	On track
Prepare a paper showing impact of ambient temperature and pre-trip conditioning on BEV range, including a sweep of thermal management control parameters to highlight the importance of thermal management in improving BEV range.	6/30/24	On track
Summarize OpenPATH O&M activities, with a focus on deployments and the incremental updates to support them. To include: <ul style="list-style-type: none"> - Summary of newly signed MOUs - Highlights of unique/unusual use cases in the newly signed MOUs, representing a diversity of applications 	9/30/24	On track

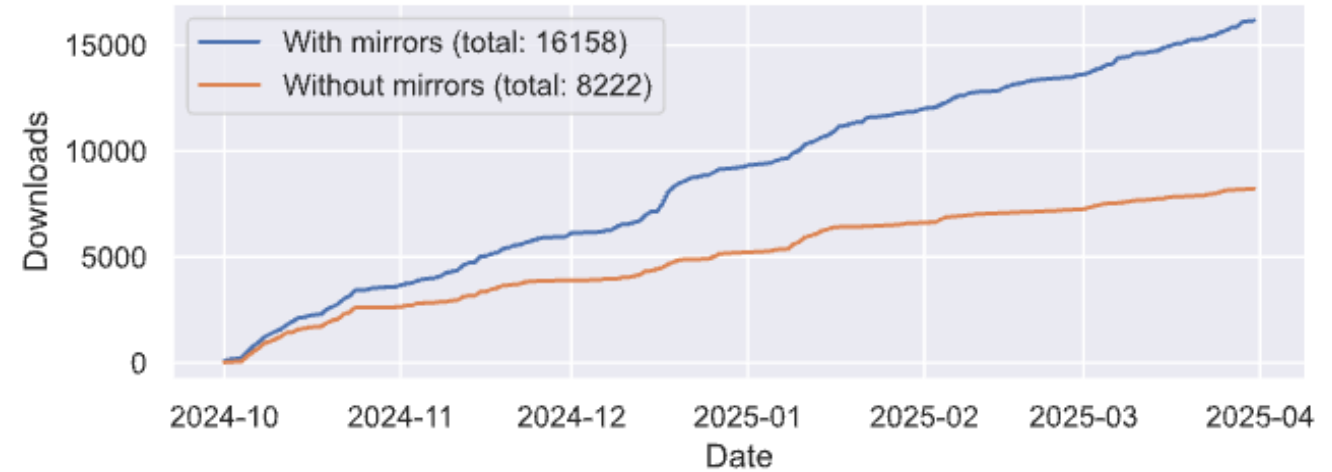
Tool Enhancement Accomplishments

FASTSim

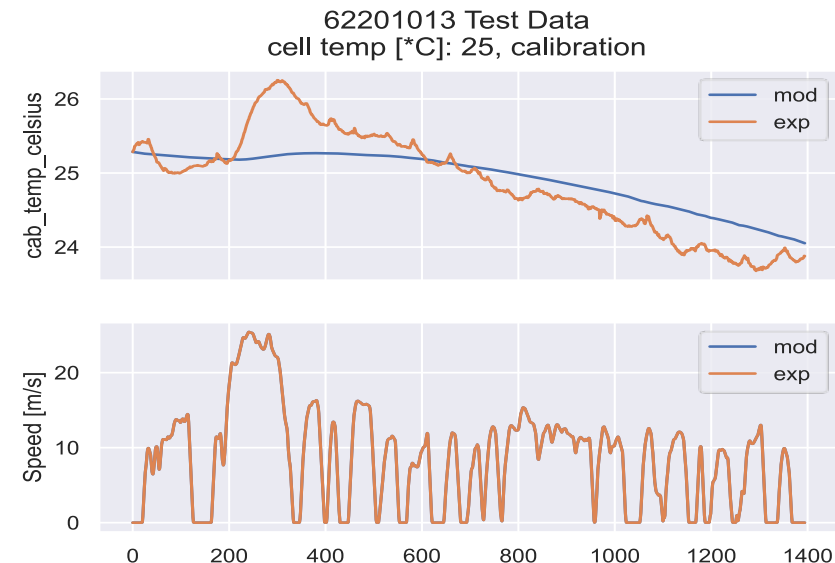
- Maintain fastsim-2 while completing fastsim-3 & supporting transition to it as the new default version
 - New version more modular, flexible, hierarchical and object-oriented; ~10x faster
 - ~60% reduction in RAM usage → greater HPC scalability
- Implemented thermal models and controls BEVs, PHEVs and HEVs with myriad configurations
 - Heat cabin with engine waste heat, resistance heater, or heat pump
 - Cool cabin with HVAC system
 - Heat battery with resistance heater, heat pump or nothing (i.e., passive thermal management)
 - Cool battery with HVAC system + coolant loop or nothing (i.e., passive thermal management)
- On-going tracking of [FASTSim-supported publications](#); >180 identified so far

HPC = high-performance computing; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; HEV = hybrid electric vehicle; HVAC = heating, ventilation, and air conditioning

Cumulative downloads via PyPI (previous 6 months only)



Thermal Model vs Experimental Cabin Temp [C]



Tool Enhancement Accomplishments



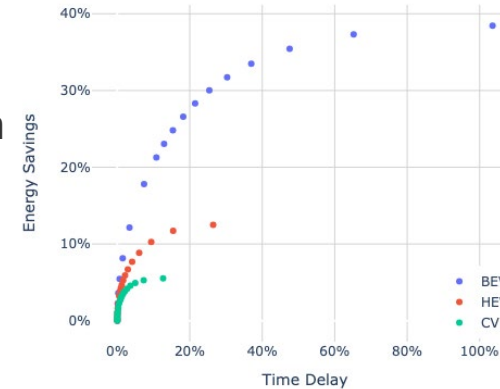
RouteE



T3CO

- **RouteE**

- Significant performance updates to enable large scale analysis (billions of queries)
- Continued refinement of tool usability and stability through integration with other projects
- Development of new reinforcement learning approach to minimize fleet real-time routing operational costs
- Large scale national opportunity analysis to discover the quantity of energy savings available with realistic energy-aware routing



Energy Savings by PT Type		
Average Travel Time Delay	5-10%	10-20%
CV	5%	6%
HEV	8-10%	10-12%
BEV	12-20%	22-28%

Sample results from national opportunity analysis showcasing broad potential energy savings from energy-aware routing

- **T3CO**

- Released as open source
- Enhanced user-friendliness through T3CO-Charts for results visualization and T3CO-Go html GUI to edit inputs, run the model, and visualize results
- Added Quick Start user guide to online documentation
- Completed API to enable integration with other tools
- Developed beta version that enables decoupling from FASTSim and includes new features requested by users: annualized cash flows and cumulative TCO, separation of on- and off-shift fueling/charging price, financing and leasing costs

Tool Application Accomplishments



FASTSim

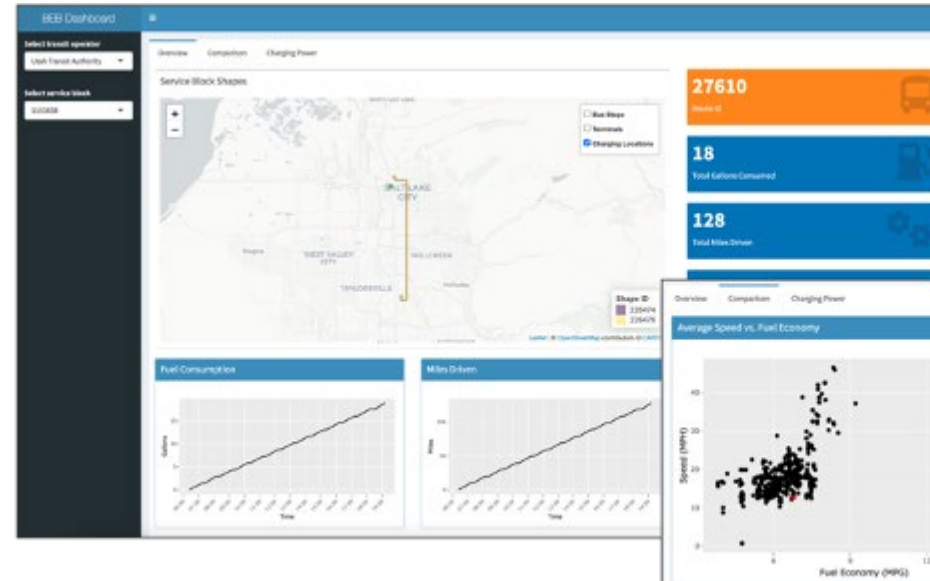


RouteE

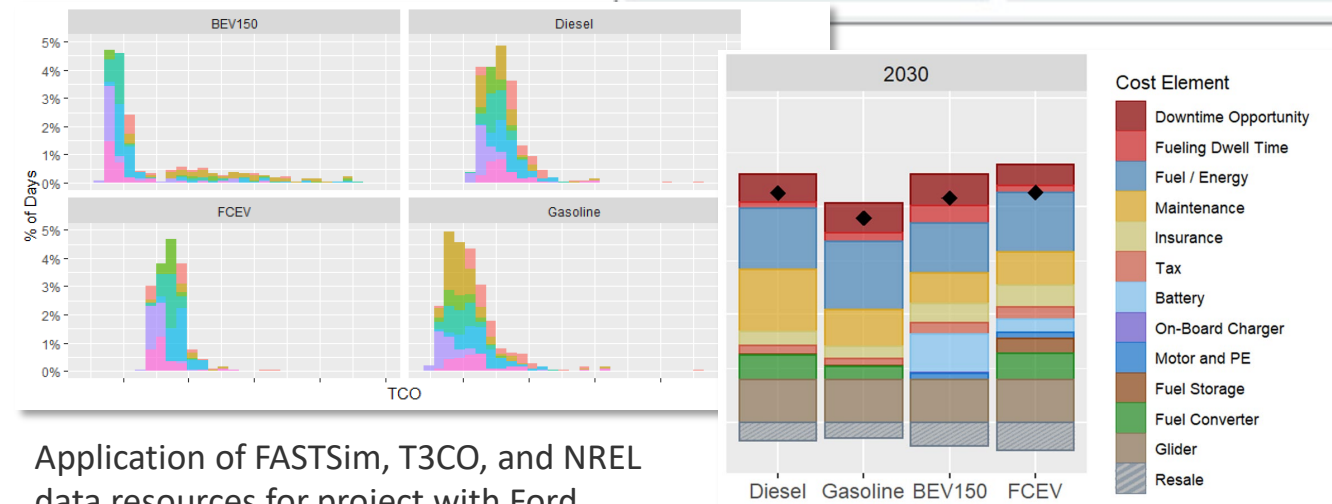


T3CO

- EEMS examples
 - BEAM CORE (EEMS092 & EEMS145)
 - Cooperative Driving Automation (EEMS119)
 - Xtelligent Cooperative Traffic Signal Network (EEMS121)
 - Energy in Traffic Signal Performance Measures (EEMS125)
 - Transit bus electrification (EEMS135)
 - Co-Optimization of Vehicles and Routes
- Broader VTO/DOE examples
 - SuperTruck 3 (ELT327)
 - Incorporating Battery Life Modeling into TCO (BAT561)
 - EVs@Scale Consortium, including VGI Toolkit
 - School bus electrification
 - ARPA-E INFORMES - INTERMODAL



Dashboard screenshots from RouteE applied to transit bus electrification project with Utah State University



Application of FASTSim, T3CO, and NREL data resources for project with Ford



Tool Application Accomplishments: Google Maps Expanding Eco-Routing to the World

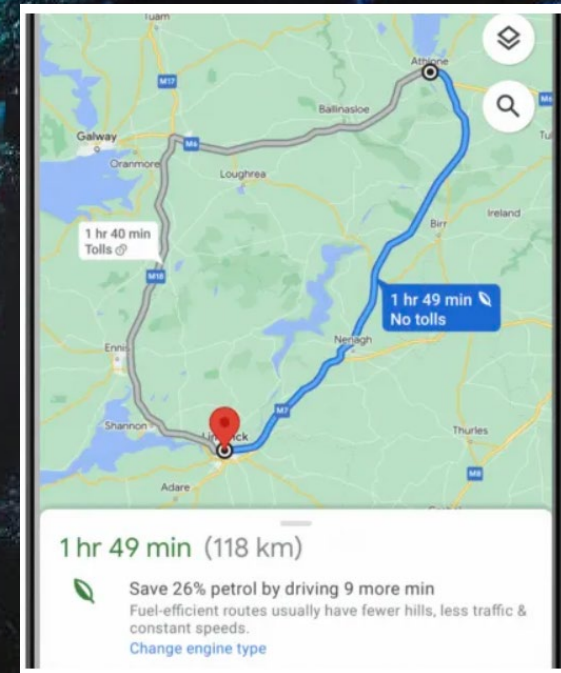


Photo from iStock 1166624542

THE BACKSTORY

Google began partnering in 2021 to integrate NREL's FASTSim model and RouteE methodology to inform eco-routing in the U.S.



FASTSim

THE LATEST

Continued collaboration has added more vehicle and powertrain types and expanded eco-friendly routing across the globe.



RouteE

WHY IT MATTERS

Eco-routing provides fuel cost savings and reduces emissions—equal to taking 650K gas cars off the road for an entire year.

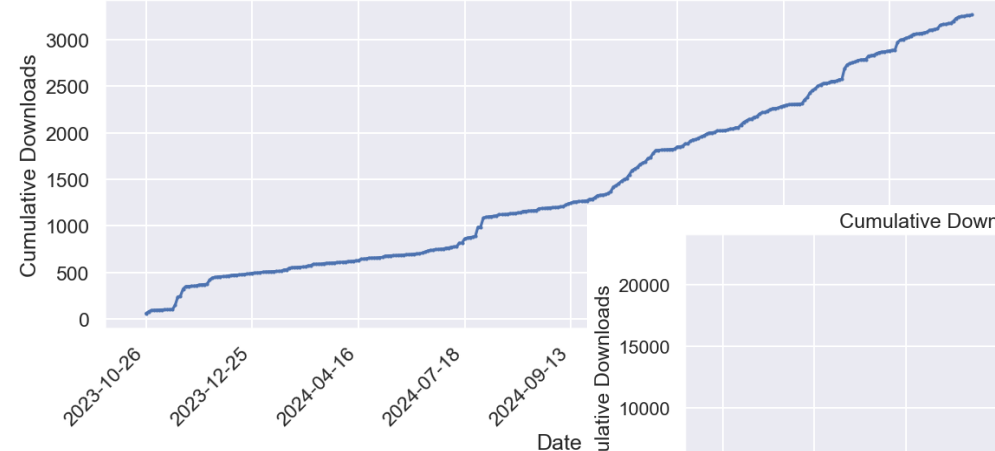
Further dramatic growth in benefits expected as the feature and enhancements expand to Google Maps' 1 billion global users.

Tool Application Accomplishments

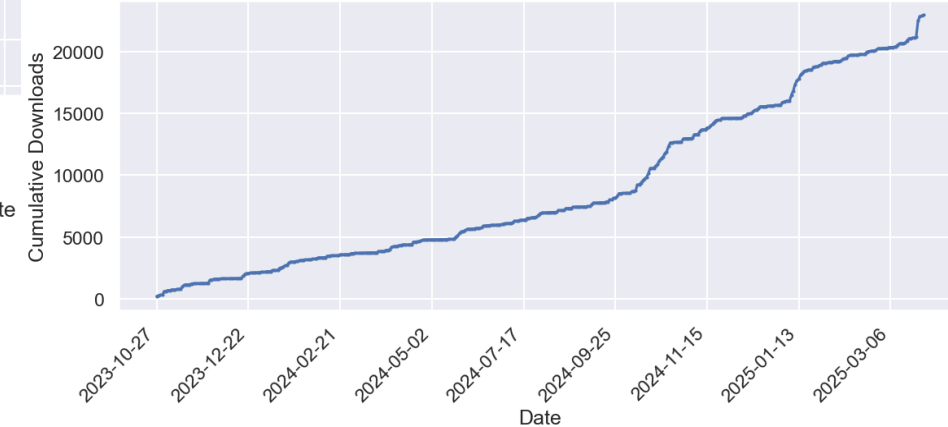


- Industry examples
 - Eco-routing (multiple)
 - Informing fleet electrification opportunities/strategy, GHG emissions standards, and operating cost savings
 - Off-cycle tech benefits evaluation
 - Large-scale analyses of info-rich controls, GHG emissions, and TCO scenarios
- Thousands of users from range of organizations
 - Growing base of active and interested users for each tool

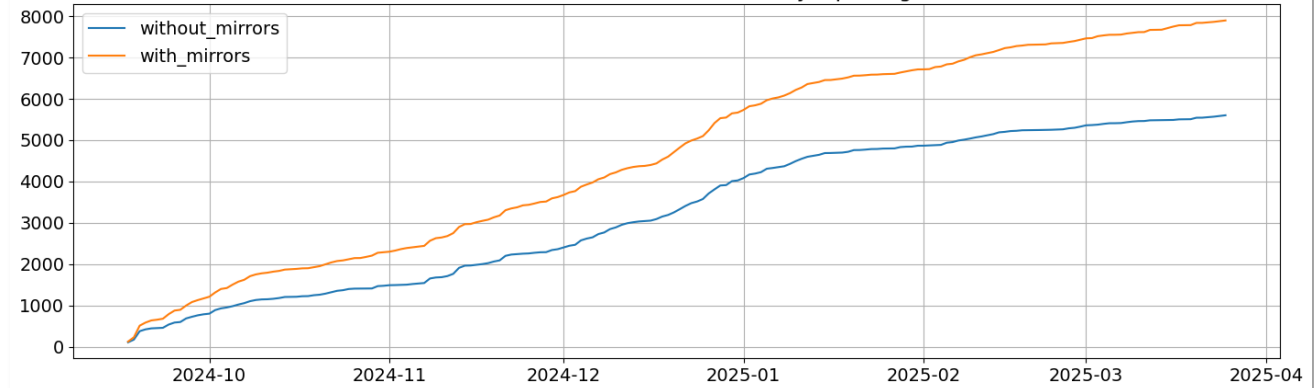
Cumulative Downloads Over Time For nrel.routee.powertrain



Cumulative Downloads Over Time For nrel.routee.compass



Cumulative Downloads for 't3co' PyPI package



Accomplishments: Growth in users and programs



Reached the 1k+ download milestone on android
<https://play.google.com/store/apps/details?id=gov.nrel.cims.openpath>



40 non-test deployments so far

```
$ ls -1 configs | egrep -v  
"stage|emulator|test" | wc -l  
40
```

NREL OpenPATH

National Renewable Energy Laboratory

4.3★
10 reviews

1K+
Downloads

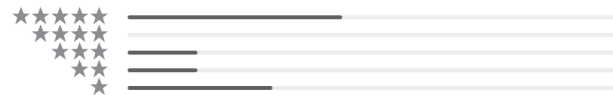
E
Everyone ⓘ

iOS does not publish such metrics on the app store,
but the number of reviews is around the same,
indicating a relatively similar install base

Ratings and Reviews

3.1 out of 5

7 Ratings



Word of mouth referrals

Ral-E-Bike
evaluation



NC Transit
Mode Shift
Program Evaluation

Harvard
Kenya study



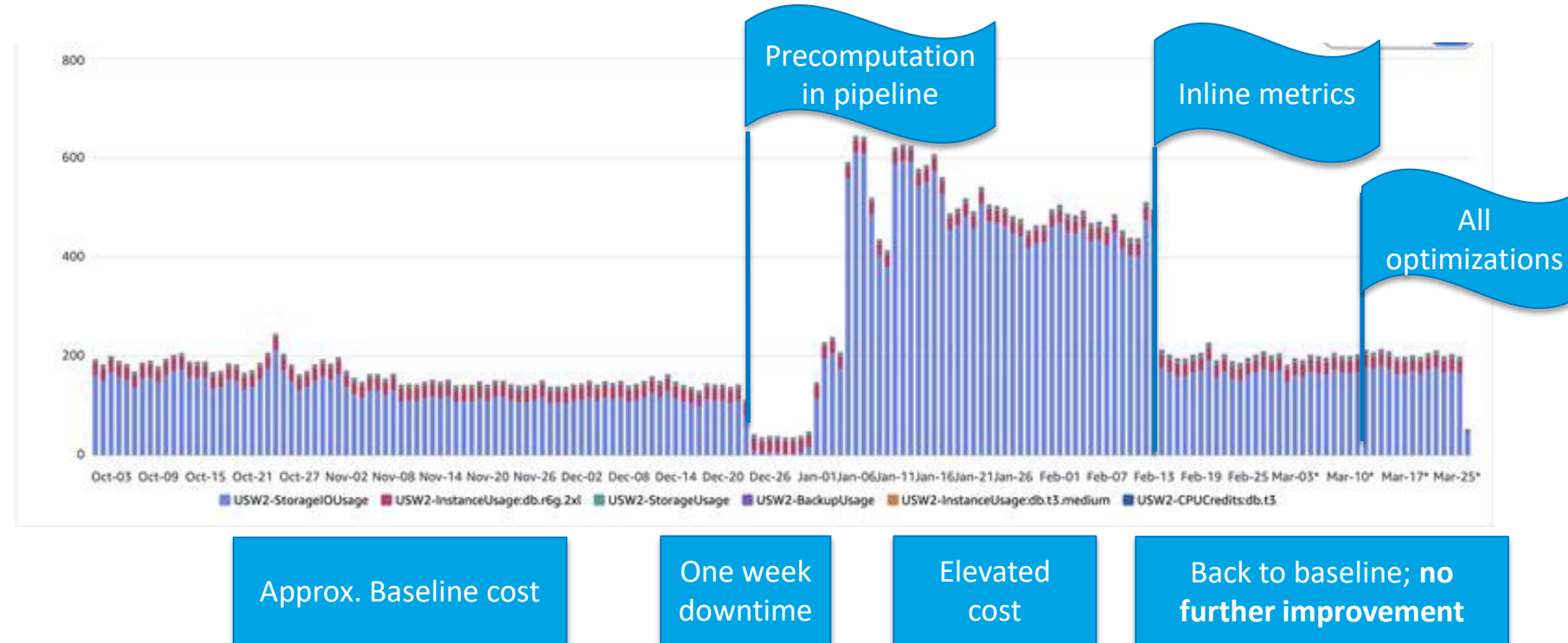
Harvard
Ghana study

DC Electric
Bicycle
Incentive
Program



godcgo
commute
program

Accomplishments: Addressing Scalability challenges



Ongoing changes to continue supporting deployments

Better code

Added additional instrumentation,
Working through bottlenecks

Better database

AWS DocumentDB -> self-hosted
MongoDB

Better processes

Streamlined decommissioning,
monitoring dormancy

Accomplishments: Co-design with program admins



Program admins



End-users

- Our “users” are our partners
- We provide a tool to facilitate study data collection, but they are the ones with the skills, resources, and local connections to recruit participants
- Resulting data also made available for legitimate research through the TSDC

Some examples of co-designing with our partners

Change onboarding to better support displaying a single QR code on a screen

Improved location permission flow

Making notifications optional

Suspending data collection to support before/after studies

Adding sensed and inferred modes to the public dashboard

Supporting visualization by sensed mode in the admin dashboard map




Allowing admins to create their own opcodes

Responses to Previous Year Reviewers' Comments

- Many complimentary comments—**thank you!**
 - “Maintenance, updating, and expansion of tools is not flashy, but it is vital to help make lots of work useful to a broad audience and to drive impacts”
 - “Technical accomplishments of the tools, in terms of capabilities added and use achieved is very strong; the team did excellent work”
 - “The list of partnerships and collaborations the team showed reads like an ideal wish list for any program of this type”
 - “It is an impressive effort to integrate toward a larger goal and to have the foresight to use the attributes that are most influential toward the goal while leaving some behind”
 - “Project showed excellent and appropriate collaboration, leading to a tangible impact”
- Encouragement to extend work/plans—**doing so**
 - “Continue work on this path, leveraging partnerships to get input on how to improve the tools and add useful data”
 - “Build upon current successes by establishing new collaborative applications for the tools”
 - “Maintain and expand partnerships”
- Suggestions to further increase impact and/or provide clarity
 - “The information as presented makes it difficult to know how functional the app under development is at this time.” – **The app is fully functional and has been published to the app and play stores. Slide 16 showcases that the app has been installed many thousands of times. It also indicates how we have had a steady flow of interested partners through word-of-mouth.**
 - “Need testing with users to refine in a co-design process” – **Slide 18 provides examples of how we are co-designing with our partners.**
 - “Further describe collaborations; Finding additional use cases and reaching out further; adding new features based on potential new use cases would be a plus” – **we continue to reach out and find additional use cases, some examples of such studies are highlighted on slides 13-16 and 20-21. However, given our available budget, we have our hands full keeping up with the current flow of potential partners, particularly given our scalability issues for OpenPATH.**
 - “Expand non-road data and analytical capabilities” – **We agree that this is an important area for growth; while this is not within this project’s currently funded scope, we have developed proposals to expand T3CO to non-road and collect operational data (or duty cycles) that would enable analysis; this would be straightforward to accomplish under a moderate level of support.**

Collaboration and Coordination

Numerous examples noted in application accomplishment slides; highlighting several:

	<u>Project Activities</u>		<u>Benefit to Various Collaborations</u>
	Performance updates/enhancements and on-going validation efforts	→	Further improved ease of use & tool stability to quantify energy impacts & strategies for maximum impact
FASTSim	Extensive thermal capability enhancements	→	Support for industry off-cycle benefits analyses and implementations
	Expanded vehicle coverage to include Transit Buses	→	Integration with Transit optimization software (NEXTBUS, FTA Bus Selection Tool)
RouteE	Public release		
	Integration with NREL tools	→	Improved TCO analysis support for 21CTP, SuperTruck3 (Ford), FTA Bus Selection Tool, Electric School Bus, and industry users
T3CO	Optional decoupling from FASTSim		



Google Maps



Posted tools also independently leveraged by thousands of users

FTA = Federal Transit Administration

Collaboration and Coordination

Numerous examples noted in application accomplishment slides; highlighting several:

Project Activities

Benefit to Various Collaborations

Admin dashboard improvements



Supports *self-serve* operations that allows us to support more deployments with the same effort

Improved server scalability



Supports larger deployments with the same computing resources

Improved onboarding



Reduces confusion while recruiting, allowing deployers to recruit more easily



First ever datasets from Puerto Rico and from Africa in the TSDC, collected by university partners

Remaining Challenges/Barriers → Proposed Future Work

- Limited test data available to calibrate vehicles with thermal components → implement 5-cycle label fuel economy calcs in fastsim-3 (only possible with thermal models) to validate scaling methodology for setting thermal parameters
- Features such as label fuel economy not yet implemented in fastsim-3 → Port these features from previous versions while maintaining performance gains
- Desirable to expand RouteE publication footprint → Work to put out additional RouteE papers (Compass Systems, National Opportunity Analysis, and Compass Fleet Optimization)
- Desire for continuous improvement and feature addition → Improve RouteE Powertrain model accuracy; expand scope of RouteE Compass routing to include charging station awareness for electric vehicles
- Achieve robust usability of T3CO with other simulation tools or data sources → Release v2.0 which includes the option to uncouple from FASTSim and supply required inputs from exogenous data sources or other modeling tools
- High user burden for T3CO vehicle and scenario inputs → Add use-case specific inputs and scenario inputs, with source documentation, to the T3CO Github repo
- OpenPATH scalability → Given the demand for OpenPATH, the increased sophistication of our partners, and our current funding levels, we anticipate that all our resources will be consumed in:
 - Improving server performance → so that we can support more users in parallel
 - App maintenance → adjusting to mandatory changes in the Android and iOS sensing APIs (e.g., Fitness → Health Connect)
 - Continue co-designing → implement features requested by partners
- Partnering critical to maximize impacts → Continue to support multiple deployments in parallel through co-design and improving self-service capabilities

Summary

- Project providing maintenance, updates, and enhancements to core capabilities supporting numerous EEMS/DOE and external efforts
- Tools plus data and research outputs made externally accessible
- Overall helping to advance transportation efficiency, emissions & cost reductions, and far-reaching mobility improvements.



FASTSim

www.nrel.gov/fastsim



RouteE

www.nrel.gov/routee



T3CO

www.nrel.gov/t3co



OpenPATH

www.nrel.gov/openpath



FleetREDI

www.fleetredi.nrel.gov



TSDC

www.nrel.gov/tsdc

livewire.energy.gov



Thank You

www.nrel.gov

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Technical Backup Slides

Further NREL Transportation Data and Tool Resources

Supporting a wide range of
transportation-related topics

See:

www.nrel.gov/transportation/data-tools.html

Energy Storage



Infrastructure



Vehicles and Mobility



Data Analytics



FY24 Milestones

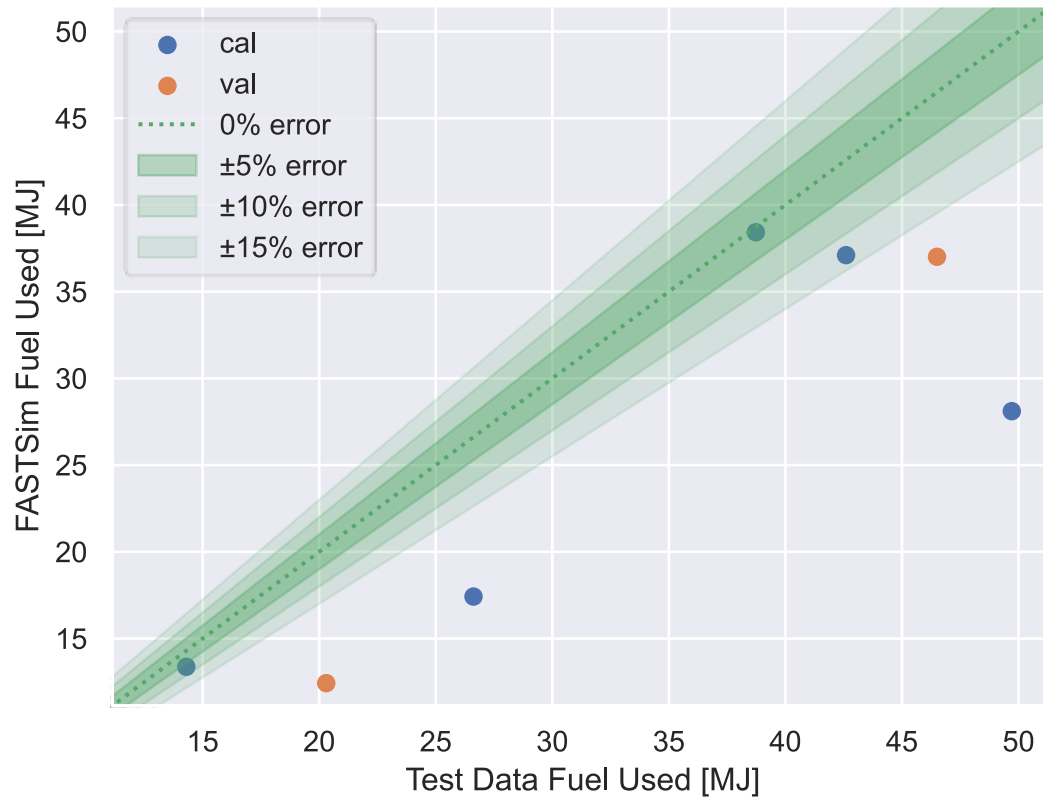
Description	Due	Status
Complete limited release of T3CO beta version to NREL and external project partners (such as 21CTP contacts) for testing, application, and feedback	12/31/23	Complete
Implement the top three OpenPATH feature enhancements requested by partners (split across the admin and public dashboards, depending on partner feedback)	3/31/24	Complete
Complete beta “FASTSim 3.0” with backwards compatibility and code updates enabling ~10x faster run time, modular and hierarchical model structure, up to 100x less memory usage, and improved maintainability and customizability	3/31/24	Complete
Implement updates to the RouteE web API to expose new RouteE-Powertrain and RouteE-Compass capabilities publicly to users with small scale problems or limited data, software, and computational expertise	6/30/24	Complete
Develop interface for T3CO to enable results visualization (graphs, etc.) and integration with other modeling tools, such as EVI-X and LIBRA	6/30/24	Complete
Improve the OpenPATH personal in-app dashboard to display energy consumed in addition to emissions generated. Improve emission calculation for electrified transport to be based on regional instead of national grid, to capture the impact of grid decarbonization	9/30/24	Complete
Complete full “FASTSim 3.0” update with streamlined vehicle model handling, improved battery efficiency modeling, and validated models (including conventional, HEV, and BEV powertrain types)	9/30/24	Complete
Complete analyses using enhanced RouteE-Powertrain and RouteE-Compass capabilities to calculate national eco-routing savings and to perform fleet planning and dispatch optimization	9/30/24	Complete

FASTSim Thermal Model Accuracy Improvements – 2021

Hyundai Sonata HEV



Model v. Test Data Without Thermal Effects



Model v. Test Data With Thermal Effects

