## PROJECT OVERVIEW

### Timeline
- **Project start date**: Oct. 2018
- **Project end date**: Sep. 2021
- **Percent complete**: 90%

### Barriers
- High uncertainty in technology deployment, functionality, usage, impact at system level
- Computational models, design and simulation methodologies
- Lack of data on individual behaviors relating to e-commerce and freight
- Integration of disparate model frameworks

### Budget
- **Total funding**: $3,750,000
- **FY21 funding received**: $1,250,000

### Partners
- AMBER and Autonomie users, both within and outside Argonne (e.g., Ford, Hyundai, Toyota…)
- US Government-Industry Partnerships (US Drive, 21CTP)
PROJECT RELEVANCE
Support the DOE Vehicle Technologies Office (VTO) system simulations, more specifically the Energy Efficiency Mobility Systems (EEMS) program

Stakeholders Engagement & Deployment
Collect users feedback including issues and new requirements, deploy tools to stakeholders based on their needs

Model-Based System Engineering
AMBER: Develop and maintain MBSE platform to estimate the impact of new technologies on mobility, energy, emission, cost, equity... from pure simulation to Vehicle-in-the-Loop.

Vehicle System Simulation
Autonomie: Maintain state-of-the-art vehicle energy consumption, performance and cost system simulation across vehicle classes, powertrains and component technologies.

System Simulation Workflows
Develop and maintain system simulation workflows designed to answer specific questions from individual component technology (e.g., new engine with single tool) to individual vehicles and large fleets.

>28 Projects were related to AMBER/Autonomie during AMR 2020
**PROJECT RELEVANCE**

Examples of Applications Supported by EEMS Core

<table>
<thead>
<tr>
<th>EEMS CORE</th>
<th>Goals / Initiatives</th>
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</thead>
<tbody>
<tr>
<td>• Technical support, tools maintenance, license management</td>
<td>• Stakeholder engagement</td>
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<tr>
<td>• AMBER development</td>
<td>• Autonomie, SVTrip, RoadRunner, POLARIS, Aeronomie deployments</td>
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</tbody>
</table>
| • AMBER workflows  
  • Large scale vehicle studies  
  • Compiled vehicles… | • Stakeholder engagement |
| • Autonomie development | • 100K+ simulations (HPC)  
  • Micro & Meso simulations |
| • Assign powertrains for MD/HDT | • Component technical targets for light duty (USDrive) and medium/heavy duty (21CTP) vehicles |
| | • VTO/HFTO technology benefits  
  • Component performance data, cost  
  • New powertrain sizing |
| | • Freight operational efficiency (SMART) |

**In support of**

SMART Mobility  
EEMS FOAs  
TI FOAs  
VTO Tech managers  
USDrive  
21CTP  
Stakeholders
MILESTONES

21Q1
- License API & Database Improvements
- Large Scale Simulation for Transportation System Energy Estimation

21Q2
- AMBER & Autonomie 2021 Releases
- Autonomie Express Compiled Only Version

21Q3
- Advanced Macros
- Data Analysis Improvements

21Q4
- Powertrain Sizing Improvements
- New BEV Architectures
- Total Cost of Ownership (TCO) and LCA (GREET)
- AMBER & Autonomie 2021 U1 Release
AMBER Framework Designed to Support Any System Simulation Workflows

Tools

SVTRIP

Stakeholder Inputs

Workflow Examples

Individual vehicle energy, cost and GHG (VAN023)

Energy-efficient control enabled by connectivity and automation (EEMS089)

SMART Mobility Workflow (EEMS093, VAN035)

and many more…
**APPROACH**

*Autonomie Continuously Collect Data and Inputs from as Many Sources as Possible*

**Objective**: Model any powertrain, component technology, control, test procedure... in the market (now and in the future) from light-duty vehicles to heavy duty trucks

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**Component Data**
- OEMs, suppliers, literature, DOE R&D, DOT/NHTSA...

**Vehicle Data**
- Argonne Advanced Mobility Technology Laboratory (AMTL), including DOT/NHTSA projects

**Vehicle Technical Specifications**
- Argonne Vehicle Technology Database (integrate 20+ data sources 1990-2020), A2MAC1...

**Driving Cycles / Test Procedure**
- SAE, OEMs, Suppliers, NREL TSDC/FleetDNA...

**Stakeholder Inputs**
- Issues, new GUI features, new workflows, new vehicles...
TECHNICAL ACCOMPLISHMENTS AND PROGRESS
STAKEHOLDER INPUTS DROVE CAPABILITIES AND IMPROVEMENTS

140+ New Features and Enhancements Added Based on User Feedback

Both government and commercial users requested a way to edit 2D and 3D maps directly from the UI.

Users asked for a more dynamic visual representation of changes to cycle options, like # of repetition, scaling, grade...
### AUTONOMIE EXPRESS – A NEW, FASTER VERSION WITH A LARGE NUMBER OF PRE-DEFINED VEHICLES

Increase Tool Adoption by Targeting Users (vs Developers)

<table>
<thead>
<tr>
<th>Source Code</th>
<th>Full code access (component models, controls, data...)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Models</td>
<td>100+ full vehicle models with controls provided with unlimited ability to create new ones</td>
</tr>
<tr>
<td>Licensing</td>
<td>Free (US Gov funded projects, teaching) Paid license for commercial use Requires Matlab/Simulink/StateFlow</td>
</tr>
<tr>
<td>Applications</td>
<td>For developers: impact of new powertrains, models, controls, develop new workflows...</td>
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<tr>
<td></td>
<td>Compiled vehicle models, access limited to component data</td>
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<tr>
<td></td>
<td>1500+ vehicle models (and growing fast – VAN023) 10X faster</td>
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<tr>
<td></td>
<td>Only requires Matlab</td>
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<td></td>
<td>For users: simulate existing vehicles on existing workflows (e.g., energy with micro-simulation tools)</td>
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</tbody>
</table>

Request Autonomie or Autonomie EXPRESS under

- [https://vms.es.anl.gov/LicenseRequest/NonGovernmentAutonomie](https://vms.es.anl.gov/LicenseRequest/NonGovernmentAutonomie)
- [https://vms.es.anl.gov/LicenseRequest/GovernmentAutonomie](https://vms.es.anl.gov/LicenseRequest/GovernmentAutonomie)
NEW WORKFLOW DESIGNED TO ESTIMATE ENERGY, COST FROM MICRO-SIMULATION TOOLS

Most Commonly Used Tools Integrated

**Micro-simulation Tools**

- SUMO
- VISSIM
- PTV
- amsun

**Workflow**

- Assign Autonomie EXPRESS models to individual micro-simulation vehicles
- Simulate using individual vehicle speeds from micro-simulation

**Five Timeframes** (2020, 2025, 2030, 2035, 2040)

- 20+ vehicle classes from light-duty to medium and heavy duty

- Multiple Powertrains (conv, ISG, HEV, PHEV, BEV, FCEV)

- Technology Uncertainties

- 1000s of vehicle models
AUTONOMIE UPDATED TO EVALUATE NEW & EMERGING TECHNOLOGIES

Component Data
New transmission (F150), torque converter (SwRI), fuel cell (Mirai), MD/HD engines (EPA, SwRI)...

Powertrain Configuration
New BEV architecture for MD/HDT with multiple gears, new fuel cell (Range extender)...

Control
Improved robustness to grade noise, traction limit controls updated with grade dependent weight transfer to driven wheels

Powertrain Sizing
BEV/PHEV/FCEV range algorithm updated to include SAE J1634, CNG & EREV sizing algorithms added. Initiated merging of passenger vehicle and MD/HD truck algorithms

Driving Cycles
New heavy duty representative real world drive cycles added to Autonomie, including vocation specific cycles from NREL FleetDNA, updated EPA weighting factors, created “Autonomie ready” cycles from FleetNDA & TSDC

Post-processing
Added new powertrain efficiency calculations, improved QA/QC...
MATCHING POWERTRAIN TO MEDIUM/HEAVY DUTY APPLICATIONS

Vehicle-Route Recommender Critical for SMART (EEMS093)

Candidate Powertrains

Fixed Routes

Candidate Powertrains

Optimum powertrain assignment (lowest TCO) for each route subject to operational constraints of the fleet

Rating for each Individual Route

Inputs and Constraints

Vehicle Price

$/gallon

$/kwh

Charging constraints

Queuing

Exogenous variables

POLARIS

Recommended Model
NEW DEPLOYMENT INFRASTRUCTURE AND LICENSE MANAGEMENT

Required to Manage Increasing Number of Tools and Workflows

Integrated Source Control

Automated Release Generation

NEW LICENSE MANAGEMENT FEATURES

1) Updated FlexNet API
2) Get packages from license server (Ford)
3) Heartbeat to ensure active communication with FlexNet API
4) Activation support for multiple MAC addresses and hard drive volume serial number
RESPONSES TO PREVIOUS YEAR REVIEWERS’ COMMENTS

- **Question : Approach to performing the work**
  - 2/3 of reviewers positively rated the project approach
  - One reviewer expressed concerned about the simulation uncertainties and real world representations:
    - **Response**: Extensive vehicle testing and validations have been performed over the last 20+ years, and new ones added every year, including validation work for multiple DOE, DOT projects and OEMs. Results from the large scale studies are peer reviewed by independent experts...

- **Question : Technical Accomplishment and Progress toward project goals**
  - 2/3 of reviewers reported very good project milestones reached
  - One reviewer requested more information on how the simulation time can be down to 5s per simulation for large scale studies when setting each simulation in the GUI may take more time:
    - **Response**: In large scale studies, most simulations are a combination of vehicles and cycle scenarios. The new AMBER GUI simplifies the selection of those vehicles and cycles, and automate all their combinations, before running the simulations with compiled vehicles, speeding up the process by several order of magnitudes compared to previous tools.

- **Question : Proposed Future Research**
  - 2/3 of reviewers reported the current plan was good and relevant.
  - One reviewer requested a list with priorities, especially for MD & HD:
    - **Response**: Our list of priorities continuously evolves based on stakeholders inputs and DOE study needs. Current priorities: new powertrain configuration and sizing as well as component data and TCO.
COLLABORATION AND COORDINATION
Core Tools Used Across Companies and R&D Organizations

Total Number of Licenses (659)

- Commercial: 27%
- Commercial Consulting: 15%
- Ecocar Competition: 17%
- Government: 7%
- University/Not-for-Profit: 3%
- Teaching: 33%

License Requests (FY21)

- Commercial
- Educational & Non-profit
- Government
- Teaching

Projects Supported
US DOE (VTO, HFTO), US DOT, US DOD, FOAs, SPPs...

Worldwide Usage

- Total Number of Licenses: 659
- License Requests (FY21)
- Technical Support Requests (FY21)

Programs Supported

- SuperTruck
- ECOCAR Challenge
COLLABORATION AND COORDINATION

Core Tools Tightly Integrated Across Multiple Projects, Government Agencies

- Component data, cost
  - Powertrain sizing, control, large scale simulation...
  - VAN038
  - Total Cost of Ownership
  - VAN023
  - Individual Vehicle models
  - VAN023
  - VTO benefits (cycles), targets
  - USDrive, 21CTP, VTO

- Powertrain sel. algo. for MD/HD
  - This Project
  - EEMS093

- VTO Benefits (Transp. System)
  - VAN035
  - EEMS093

- SMART Workflow
  - Workflows
  - SMART Workflow Deployment
  - This Project

- Technical Targets
  - Workflow Manager (AMBER)

- DOT/NHTSA

- Maintenance / Tech. Support
  - This Project
REMAINING CHALLENGES AND BARRIERS OF THIS PROJECT

- Maintain latest versions of different tools (25+ software currently used for development, version control, license management…)
- Manage increasing number of workflows
- Predict future stakeholder needs in terms of workflow
- Continue to access latest vehicle, component data to represent state-of-the-art technologies
- Access vehicle dynamometer testing to understand latest powertrain and component controls to validate our models
- Maintain and expand Argonne Vehicle Technology Database to understand current technology trends
- Develop full vehicle models, including control, of all combinations currently in the market or under development
PROPOSED NEXT STEPS*
Expand Workflow and Model Capabilities

**Autonomie Models**
- Continue to enhance models, data… to represent state-of-the-art
- Expand new transportation modes (off-road, rail, boats, micro-transit…)?
- Add new real world cycles (& deploy)
- MD/HDT validation (data source?)
- Powertrain thermal modeling
- Predictive vehicle design (learn from current vehicle designs)

**Autonomie Workflows**
- Build & deploy workflow to estimate individual component technology benefit including automated control calibration
- Workflows for users (e.g., compiled vehicles, AI/ML, online tool, MathWorks free)
- Predictive vehicle design (ML)
- Powertrain selection for specific routes (e.g., buses)
- Expand automated model development & validation

(*) Any proposed future work is subject to change based on funding levels
PROPOSED NEXT STEPS*

Expand Stakeholder Engagement & Deployment

Maintain Tools / Support Users
- AMBER, Autonomie (full, compiled, machine learning)
- Add SVTrip, RoadRunner, POLARIS, Aeronomie
- Track/address issues and new requirements
- Update 25+ software versions

Expand AMBER
- Expand APIs to support integration of additional 3rd party tools (e.g., xIL)
- New data analytics workflows (including larger datasets, videos…)
- Reduce XML complexity (i.e., reference) / coordinate w/ DOT
- HPC workflow

Deploy Models / Tools / Workflow
- Expand testing across all tools
- Expand training (specific version w/ videos, exercises).
- Select / manage deployed vehicles (2.5M+) and drive cycles

(*) Any proposed future work is subject to change based on funding levels
SUMMARY

Stakeholder Engagement & Deployment
AMBER, Technical support, software management

Model-Based System Engineering
Improved code structure, new license management, enhanced deployment infrastructure

Vehicle System Simulation
New data, models, control, powertrains, improved powertrain sizing

Supports
- 30+ VTO & HFTO projects
- 10+ US DOT & DOD projects
- Licensed to 275+ organizations with 650+ users

MBSE Workflows
New and improved workflows for vehicle energy consumption, performance and cost (e.g., compiled version, large scale simulation)
QUESTIONS?
SUPPORTING A GROWING USER BASE

- Licensing is critical to
  - Protecting our IP
  - Managing license data for us and for users
    - What type of license?
      - evaluation, government, commercial, education, etc
    - How many licenses?
    - When does their support end?

- Integrated new FlexNet API
- Created new license database in SQL Server
- Cleaned license data – 10 years of licensing information from Autonomie
- Speeding Adoption
  - Web tool development for Licensing, floating license generation
STAKEHOLDER INPUTS DROVE CAPABILITIES IMPROVEMENTS

140+ New Features and Enhancements added based on user feedbacks

Advanced users requested a more fine grained parameter options to optimize their simulation process

Added new tab to access advanced parameters

Provided access to the simulation solver options

Provided access to advanced parameters to optimize the model building process
MODERNIZING THE FRAMEWORK FOR EVEN LARGER STUDIES

- Running large scale studies is the backbone of our research
- REV13 to AMBER vehicle conversion and comparison
  - Identified changes to models, initialization data, vehicle architectures, …
  - Explored differences between REV13 and AMBER results
  - Developed sizing tests that run nightly and generate test reports
- Test-Driven development to assist in refactoring the sizing algorithms so that they run with AMBER APIs
DEPLOYING THE DOE ENERGY AND MOBILITY SIMULATION TOOLS

- Server and Cluster Improvements
  - Updated software
  - Increased Cores from 428 to 1028

- Jenkins Automation Server to run tests and package
  - Updated and maintained
  - Put a new server in production
  - Updated SVN server to support development
COLLABORATION AND COORDINATION

Core Tools Used Across Companies and R&D Organizations

Americas, 543

Europe, 20

Asia, 93

Africa, 3