Project ID: SA065

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AGENT-BASED MODELING OF CONSUMER BEHAVIOR

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Overview

Timeline

Start date: Dec 2016

Update to previous work for DOE (2006-2010)

End date: Subject to DOE

Barriers

A: Future Market Behavior

B: Stove-piped/Siloed Analytical Capability

C: Inconsistent Data, Assumptions & Guidelines

D: Insufficient Suite of Models and Tools

Budget

FY17 Planned DOE funding: $110k

Total spent as of 3/26/2017: $31k (28%)

Partners/collaborators

Foundation based on work with Ford Motor Co., RCF Economic & Financial Consulting, and Synovate Motoresearch

Current Update: Data provided by a major OEM

Anticipate stakeholder input/review/vetting in FY18.

Relevance: Project Objectives

- Explore the role of **consumer choice** in the expansion and support of consumer-facing hydrogen refueling infrastructure.

- **Understand how the system works** rather than provide a single forecast of system development.
  - What role do consumer attitudes and behavioral characteristics play?
  - To what extent do social interactions influence purchasing behavior?
  - How do different offerings from OEMs affect consumer adoption?
  - How sensitive and to what extent is growth affected by policy makers?

- Consider in a complex adaptive system the **interactions** between:
  - Consumers of hydrogen fuel and fuel cell vehicles (FCVs)
  - Hydrogen fuel producers and suppliers
  - Manufacturers of FCVs

Work started December 2016.
No impact on addressing barriers and targets since last AMR to report.

Background for Current Work

- Prior work on the model (10+ years ago) was a pioneering effort that provided insights different from those possible with other methodologies

- ABM is a methodology that is increasingly being used in public and private applications across a variety of domains

- As ABM has gained exposure and become more widely used, the earlier DOE work is of increasing relevance. However:
  - Current model's data and assumptions are out of date
    - Then: no FCVs commercially available, now: Honda, Toyota, Hyundai in market
    - Then: very limited refueling network, now: ~30 stations operating in CA
    - Then: 350 bar storage limited vehicle range, now: almost all fueling at 700 bar
  - Computing technology has improved
  - Understanding of market has improved: model must be updated to consider smaller refueling stations

- The updated model will serve as a foundation for integrating revised consumer decision algorithms and exploring consumer and investor behavior.

Agent-Based Modeling of Consumer Behavior

Analysis Framework

- Complex adaptive systems
- Behavioral economics
- Stakeholder experience/data
- American Community Survey, NHTS, Synovate Motoresearch, and various other datasets

Models & Tools

- ParaChoice
- MA3T
- LAVE-TRANS
- LVCFlex
- Polaris
- VISION
- GREET
- H2A, HDSAM

National Labs

- LBNL (Consumer Behavior Framework)
- NREL (H2FIRST)

Stakeholder Analyses (CaFCP, OFCC, CCAT)

Studies & Analyses

- *"Modeling the Transition to a Hydrogen-Based Personal Transportation System"*
- *"Modeling Investment Strategies in the Transition to a Hydrogen Transportation Economy"*
- *"Analysis of Combined Hydrogen, Heat, and Power as a Bridge to a Hydrogen Transition"*

Stakeholders FCTO & External Reviewers

Outputs & Deliverables

- Update to DOE model
- Input to other consumer choice models
- Stakeholder workshops

Model Uses Agent-Based Modeling and Simulation

- Simulating the decisions and actions of individual players in the system, Agents:
  - are autonomous, have behaviors, make decisions
  - live in a dynamic environment and interact with one another
  - have no central authority
  - learn from experience

- Models from the bottom up: **system behavior emerges** from the interactions of individuals.
- Well-suited for our problem: thousands of players acting autonomously and interacting with one another.
- Useful tool to help understand micro-factors that in combination drive the macro outcome.
- Current model originated at Ford Motor Co., significantly enhanced in work with RCF Economic & Financial Consulting and subsequently for DOE.

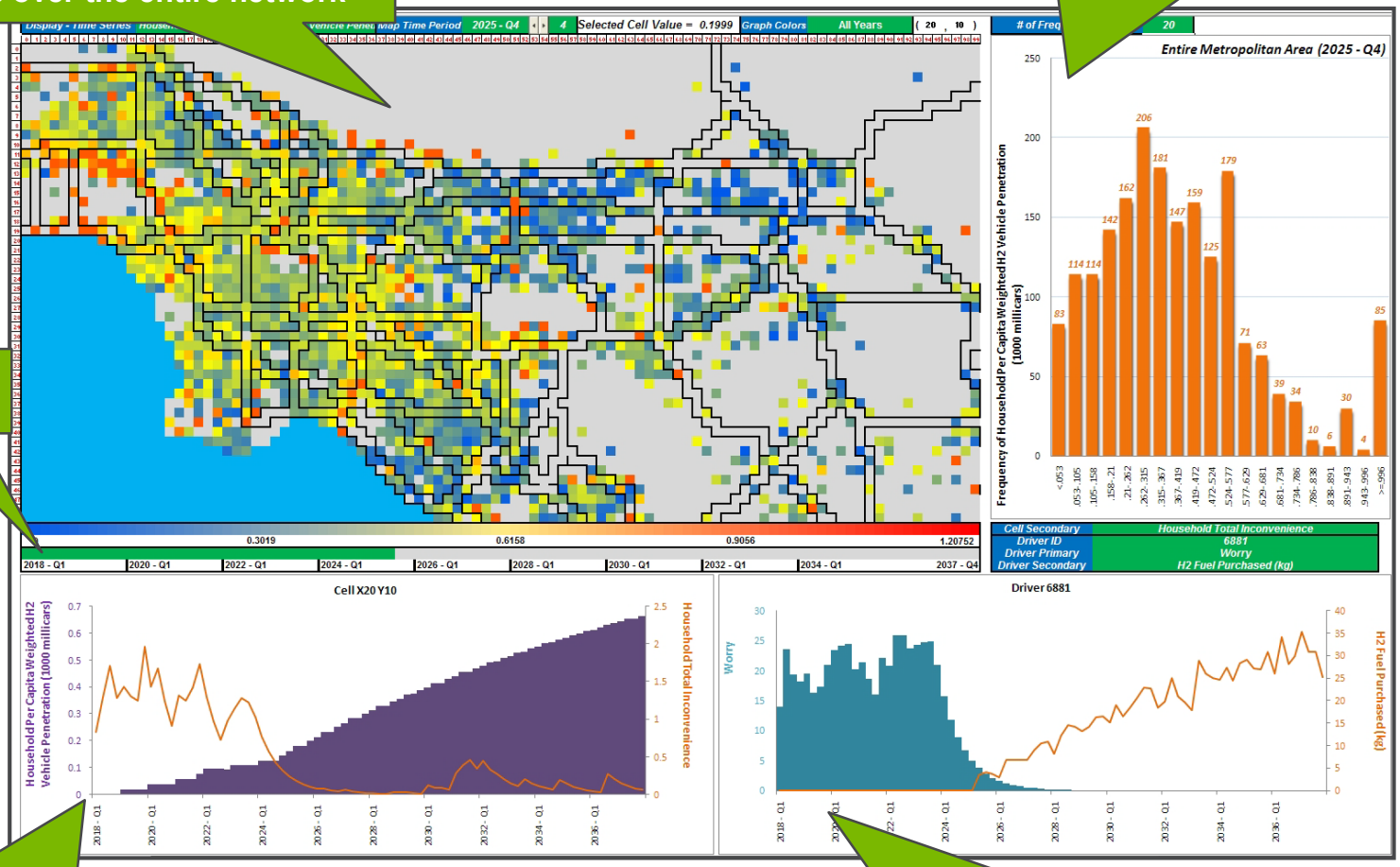
What Kind of Information Can ABMS Show Us?

This is an example interface for illustrative purposes only; data values are irrelevant and not representative of current model output.

Gain an overview of conditions and outcomes over the entire network

View distributions over the entire geographic area for one point in time

Step through time



Drill-down to detailed information for a precise location

Drill-down to an individual consumer's experience over time

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Consumer (Driver) Agents

- Some consumers start with hydrogen vehicles based on sales data

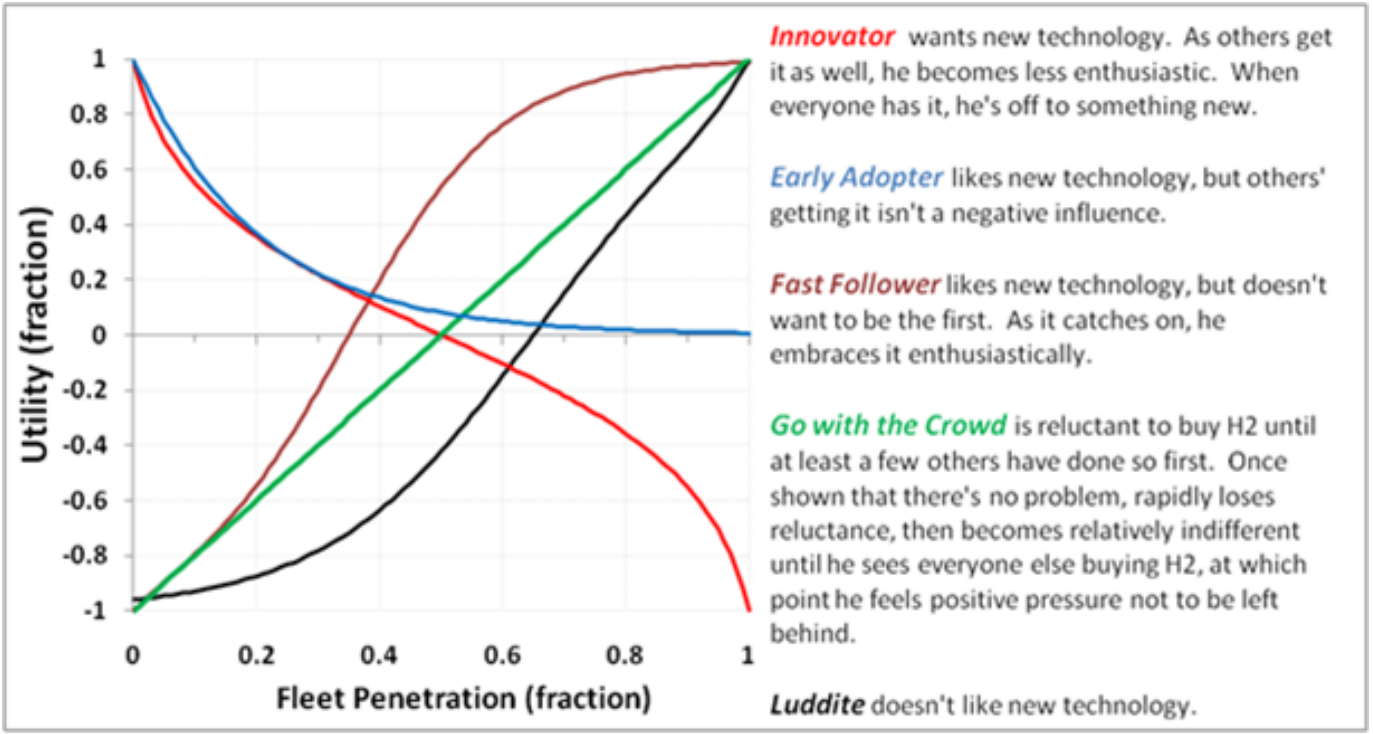
- Consumers make many simulated trips
  - Modeled trip statistics are calibrated to available research
  - Consumers note exposure to the available fueling infrastructure
  - May experience different types of refueling “inconvenience” and/or “worry”

- Vehicle purchase decisions are scheduled according to available statistics
  - High income consumers purchase vehicles more frequently
  - Newer vehicles are driven more miles per year
  - Low income consumers primarily purchase used vehicles

Consumer (Driver) Agents (cont'd)

- Vehicle Purchase Utility Function of consumer agent considers:
  - Vehicle sticker price
  - Operational savings
  - Inconvenience
  - Worry
  - Individual personality
  - Social influence

All are cast in terms of present-value dollars; intent is to simulate intuitive weighing of many different factors



Investor and OEM Agents

- Infrastructure Investor Agents
  - Attempt to assess sales potential of candidate locations, and build if expected ROI meets goals
  - Use observations of traffic volumes, known historical sales, and cannibalization effects
  - Project growth using various methods
  - Expect expansion by competitors
  - Operate within budgetary limits

- OEM Agent
  - Controls vehicle supply and price based on production capacity and sales volume

Activity Context

Technical work lays an essential foundation for subsequent activity

December 2016 – 2017 AMR

- Model refresh to 64-bit platform
- Data and assumptions update
- Spatial scope and resolution increase

Remainder of FY 17

- Simulate smaller-scale refueling stations with truck delivery

FY 18+

- Consumer decision science
- Different vehicle types and categories
- Collaboration and vetting with stakeholders
- Conduct analyses

Work started December 2016.
No previous accomplishments to report.
No previous AMR comments to address.

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Model Refresh and Data Update

The model has many input parameters and assumptions. We have conducted research to update these with the latest available information.

- Investor-related parameters:
  - Length of planning horizon
  - Fueling station capital cost
  - Fraction of station capital cost financed
  - Interest rate for debt service
  - Discount rate
  - Fueling station salvage value
  - Annual station maintenance costs
  - Fueling station capacity
  - Variable cost to produce fuel
  - Cost of extra fuel when over capacity
  - Selling price of fuel
  - Fuel production and sales taxes
- Vehicle-related parameters:
  - Vehicle price
  - Fuel tank capacity
  - Fuel consumption rate
  - Fleet age distribution
  - Fleet VMT distribution
- Consumer/behavioral-related parameters:
  - Present value of (dis)incentives
  - Driver VMT
  - “Neighborhood” refueling radius
  - “Inconvenience” trip costs

Sources: H2A, VISION, Edmunds, HDSAM, H2FIRST, GREET, Autonomie, D. Greene, E. Martin, J. E. Kang, W. W. Recker

Model Refresh and Data Update

Parameter or Set of Parameters	Data Update (FY17)	Modeling/Sensitivity (FY18)
Investor planning horizon	○	●
Fueling station capital & O&M cost	○	●
Station salvage value	○	
Station debt financing	○	●
Station capacity, delivery option [A]	○ ●	●
Augmenting station capacity	○ ●	●
H2 price (production, tax, retail, etc.)	○ ●	●
FC vehicle purchase price	○ ●	●
FC vehicle tank capacity, mi/kg, etc.	○ ●	●
FC vehicle age, VMT distribution	○	●
FCV driver VMT	○	●
FCV driver fueling preferences	○	
FCV driver worry	○	

○ = Updates with more recent, more complete and/or more robust research/reports.
● = Updates with observed data.
A = New parameter added.

Model Refresh and Data Update

Information characterizing certain behavior-related aspects of the model has been challenging to find and may not even exist. For example:

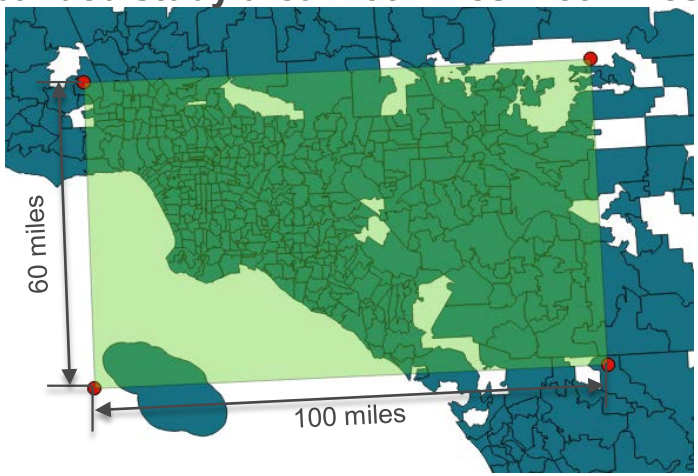
- Rate of decay in operational memory for recent on-road experiences and exposure
- Experience-based costs and how they affect vehicle technology selection
- Preferences when selecting different types and locations of fueling locations
- Preferences for when to refuel (remaining tank level)
- Characterization and extent of social influence on vehicle selection
- Characterization and effect of “green” consumer personality traits on vehicle selection

When specific data relating to these behavioral attributes cannot be found, sensitivity analyses are used to characterize the influence of the attribute.

In future, these data may be obtained from consumer decision science research, and/or stakeholder collaboration.

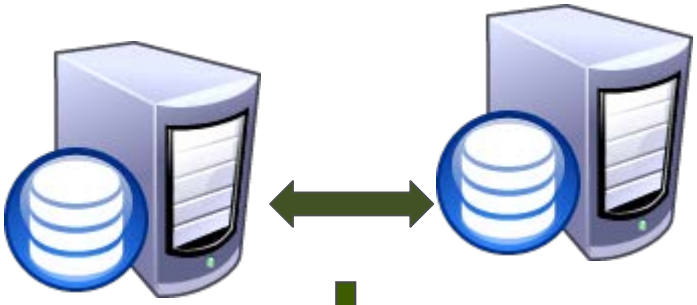
Spatial Data Update

Expanded study area: 100 miles X 60 miles



Updated national/state-level data: fleet age, vehicle travel, etc.

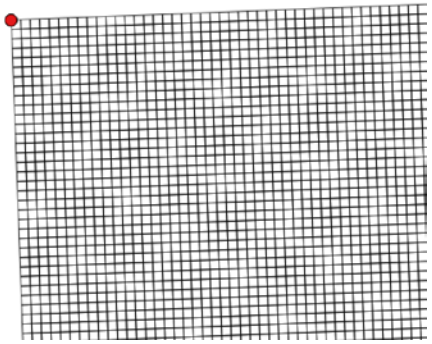
Updated ZIP Code-level data: income, jobs, population density, etc.



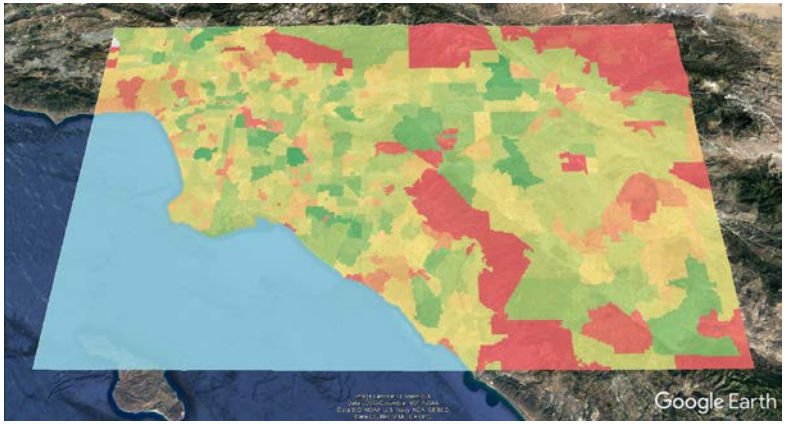
Select ZIP Codes

Join by population density

Apportion study area into higher-resolution grid



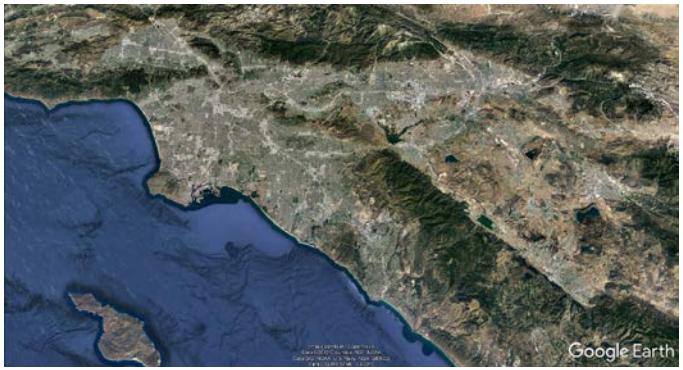
Populate data to individual cells

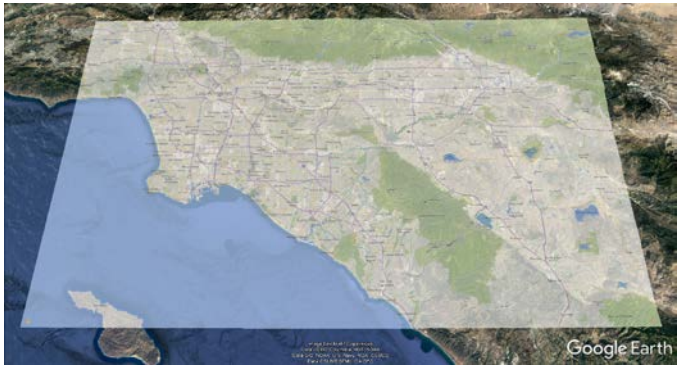


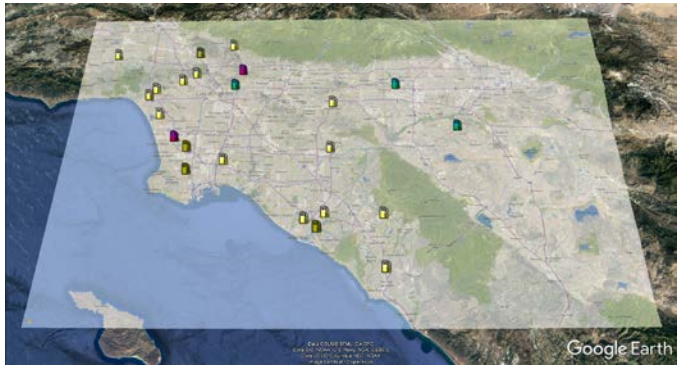
ZIP Code-segmented data within study area

Computing Enhancement and Spatial Resolution Increase

- Upgrade model to 64-bit platform; new hardware enables computationally demanding tasks
  - More agents
  - Finer time scale
  - Higher resolution space
  - More sophisticated algorithms
- Increase geographic scope and resolution
  - Larger study area in refresh
  - New driver agents created reflecting latest available data (home locations, income levels, workplace locations)
  - Arterial roads now explicitly modeled (previously only expressways)
  - More realistic trip routing and travel patterns
  - More precise locations for seed drivers and stations, using updated data
  - Additional potential refueling locations for investors to consider and consumers to utilize







Collaboration Opportunities

- The beginning of this multi-year project has been a lab-focused technical refresh of the model:
  - Collaborating with a major OEM to use owner location data for seeding initial model conditions. Model results will be shared with the OEM.
  - Using CaFCP data and ARB analyses to seed initial refueling station locations.

- As we move into later phases (end of FY 17 to FY 18) collaboration needs and opportunities will become more significant.
  - Anticipate collaborating with First Element, Shell, Honda, Hyundai, Toyota, Linde, Air Liquide and others who are building stations and selling vehicles. Informal discussions have been held with several of these potential partners.
  - Collaboration will help guide algorithm development, further refine data and assumptions, and calibrate model behavior.

Proposed Future Work

- Remainder of this year:
  - Continue model refinements related to expanded geographic scope and higher resolution
  - Add new capability to model smaller-scale refueling stations utilizing tube trailer delivery

- Current technical refresh work lays a foundation for new capabilities and analyses beyond this year:
  - Integrate state-of-the-art consumer decision science algorithms
  - Represent different vehicle categories
  - Allow consumers to choose between different hydrogen vehicle types
  - Model additional vehicle adoption methods (leases, rentals, fleets)

- Perform and report analyses
  - Broaden informative strategies to foster technology adoption
  - Inform stakeholder ROI
  - Expand lessons beyond the particular geography of Los Angeles

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

Summary

- **Relevance**
  - Explore the role of consumer choice in hydrogen technology adoption and infrastructure expansion. Understand how the entire system might evolve through the decisions and behavior of individual actors.
  - Update and extend existing model with new data and lessons learned from vehicle and station providers in Southern CA (SCA) market. Provide insight to other FCTO analyses.

- **Approach**
  - Agent-Based Modeling and Simulation

- **Accomplishments and Progress** *(work started December 2016)*
  - Model refresh and data update
  - Technical enhancements to take advantage of advanced computing hardware

- **Collaborations**
  - Current work is lab-focused model update and technical enhancement.
  - Collaboration in later phases likely to include data for seed locations and algorithms; vetting of assumptions and findings.

- **Future Work** *(subject to funding)*
  - Update consumer decision science algorithms
  - Vet assumptions and results with OEMs and station providers active in the SCA market.
  - Incorporate additional vehicle categories and types
  - Model analyses, insights applicable beyond SCA

Thank You!

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