NREL
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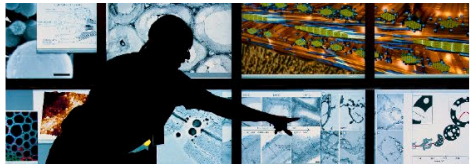
National FCEV and Hydrogen Fueling Station Scenarios

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DOE Hydrogen and Fuel Cells Program
2016 Annual Merit Review and Peer Evaluation Meeting

June 9, 2016

Project ID # SA061

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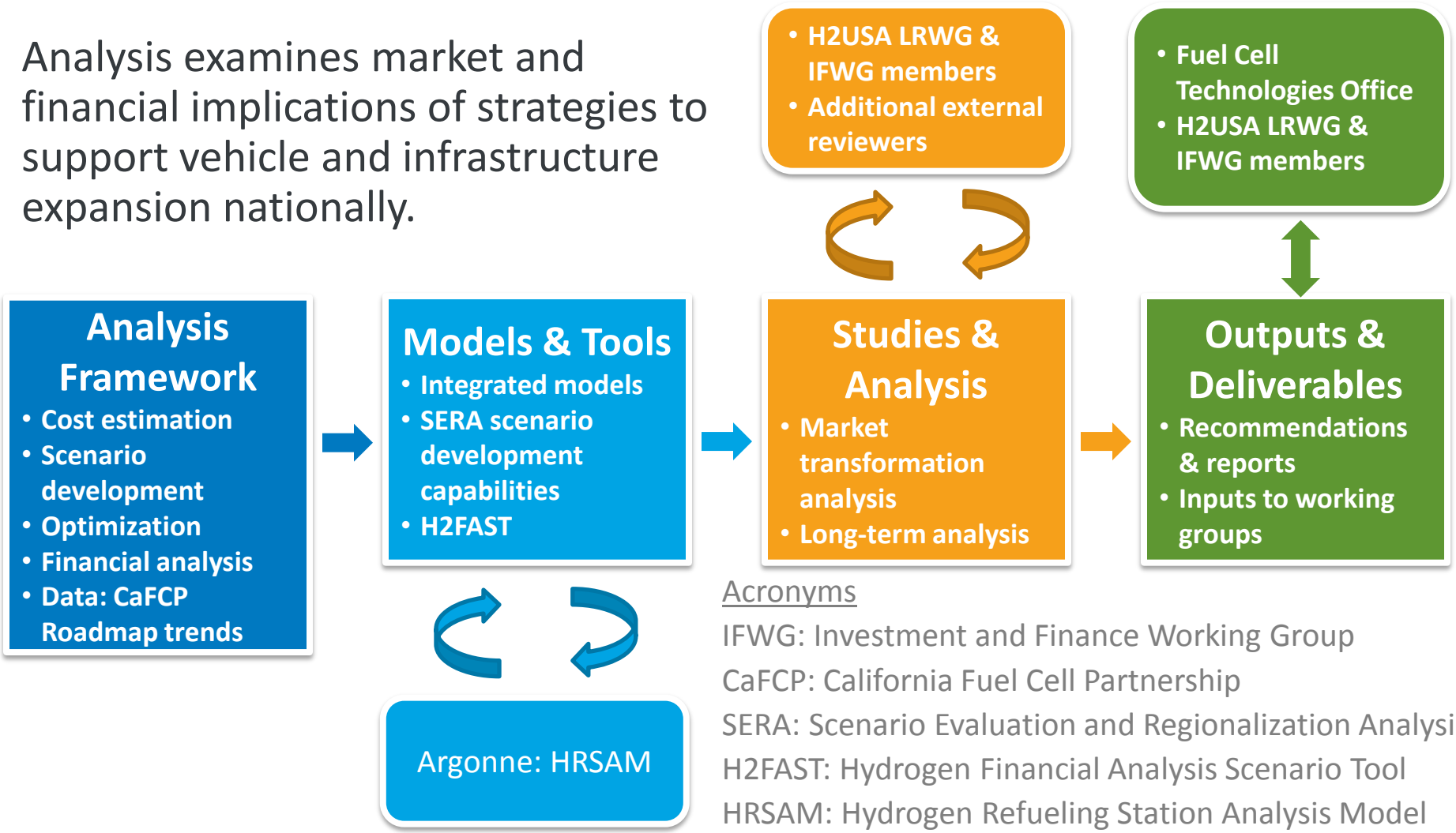
Overview

Timeline	Barriers
Start: September, 2014 End: September, 2016* * Annual project direction determined by DOE	**4.5 A. Future Market Behavior:** • Scenarios to understand vehicle-fuel interactions **4.5 C. Inconsistent Data and Assumptions** • Integrated scenario analysis enforces consistency in assumptions **4.5 E. Unplanned Studies and Analysis** • Response to H2USA public-private partnership and infrastructure deployment goals
Budget	**Partners**
Total project funding: $300K Funding received in FY16: $150K	• H2USA Investment and Finance Working Group • H2USA Location Roadmap Working Group • Lexidyne LLC • Multiple external and internal subject expert reviewers (NREL, national laboratories, government, industry, academia)

Relevance

Integrated scenario analysis assesses interactions among fuel cell electric vehicle (FCEV) adoption, infrastructure requirements, and investment.

Analysis examines market and financial implications of strategies to support vehicle and infrastructure expansion nationally.



Acronyms

IFWG: Investment and Finance Working Group
CaFCP: California Fuel Cell Partnership
SERA: Scenario Evaluation and Regionalization Analysis
H2FAST: Hydrogen Financial Analysis Scenario Tool
HRSAM: Hydrogen Refueling Station Analysis Model
LRWG: Location Roadmap Working Group

Relevance

The national scenarios effort directly addresses objectives for stakeholder-engaged scenario development/analysis.

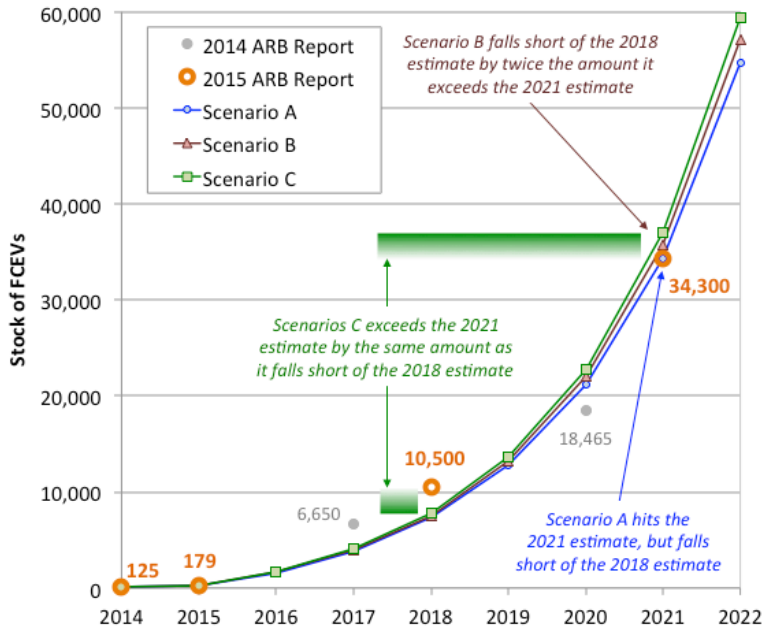
- **Objectives**
  - Develop and analyze self-consistent national FCEV scenarios that accurately represent early market trends, but that also explore long-term possibilities for FCEV adoption.
    - Stakeholders are engaged to further the acceptance, usefulness, and dissemination of these scenarios.
  - "Work with industry and other stakeholders to assess and identify infrastructure scenarios and options for both long term transportation needs and early market opportunities for hydrogen and fuel cells." [MYPP 4.2]
- **Impacts on FCTO goals and barriers during reporting period**
  - Enhanced analysis of "vehicle supply interaction with fuels supply and the requirements to meet demand," including the analysis of future hydrogen fueling market behavior for "various hydrogen fuel and vehicle scenarios." [MYPP 4.5 A]
  - Provided analytical capabilities to H2USA partnership and FCTO in the form of analyses, briefings, workshops, and reports. [MYPP 4.5 E]

Approach

The scenarios embody high levels of self-consistency and quantify key variabilities in the evolution of FCEV adoption.

- Match published early market plans and forecasts
- High level of self-consistency between vehicles, stations, and finances
- Varied staging of ZEV and non-ZEV states
- Varied market penetration for FCEVs
- Varied station utilization and financial metrics

Calibrating to the CARB'15 Report



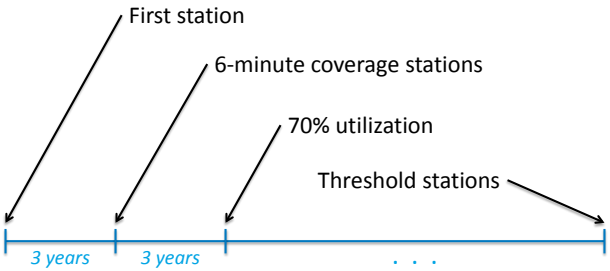
We have calibrated the initial conditions of logistic growth to the survey results from the CARB June 2015 report

These trends are used to project both stock & sales within and beyond CA

Approach

The scenarios' inputs and algorithms capture historical experience and near-term plans.

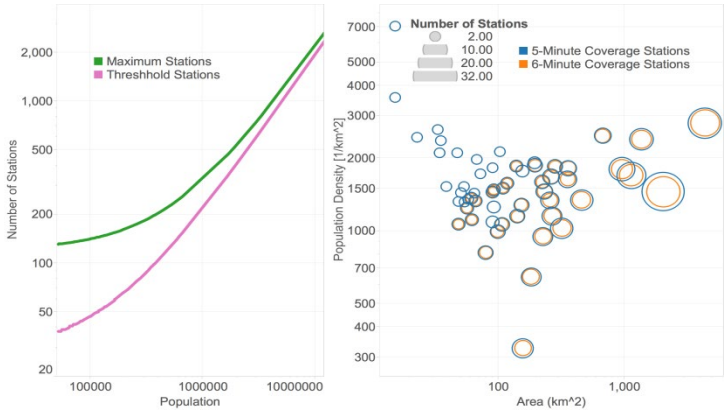
Timing of new stations



Cost of Stations

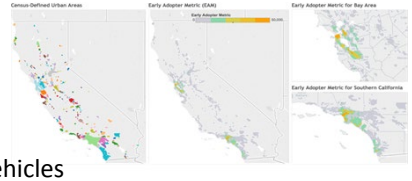
$$\text{capital cost in \$} = (\$4{,}175{,}244)\frac{\left(\frac{\text{capacity in kg/day}}{460\ \text{kg/day}}\right)^{0.70700}}{\left(\frac{\text{cumulative capacity in kg/day}}{11{,}358\ \text{kg/day}}\right)^{0.20409}}$$

Stations needed for coverage



Early adopter metric

- **The early adopter metric (EAM) is based on ZIP-code-level vehicle registrations and IRS tax data.**
  - Nested weighting factors
    - 50% fraction of weighted "advanced vehicle" registrations
      - HEV = 1 advanced vehicle
      - PHEV = 1.5 advanced vehicles
      - BEV = 2 advanced vehicles
      - FCEV = 5 advanced vehicles
      - Other = 0 advanced vehicles
    - 25% fraction of registrations of luxury vehicles
    - 25% fraction of income tax returns with adjusted gross income (AGI) over $100k
  - Normalized so that the sum of EAM over the largest 100 urban areas is one million.



Station sizing

Let $D(t)$ be the demand at time t and let $d(t+1) = D(t+1) - D(t)$ be the incremental demand at time $t+1$. Define $d(t_0) = D(t)$, where t_0 is the initial year. The number of stations at year t is:

$$N(t+1) = N(t) + \beta\, N^*(t+1),$$

$$N(t_0) = N_0$$

where

$$N^*(t+1) = \frac{d(t+1)}{Q_{\text{ave}}(t)},$$

$$\beta = \alpha^{\left(\frac{Q_{\text{ave}}(t)}{Q_{\text{ave}}^{\max}} - 1\right)},$$

$$Q_{\text{ave}}(t) = \frac{D(t)}{N(t)}.$$

This algorithm results in a situation where the average station capacity is small in early years, but approaches the maximum size $Q_{\text{ave}}^{\max}$ as time progresses. Recommended values for the free parameters in this algorithm are $Q_{\text{ave}}^{\max} = 5000$ kg/day and $\alpha = 2.7$.

For each year t, build $n(t) = N(t) - N(t-1)$ stations.

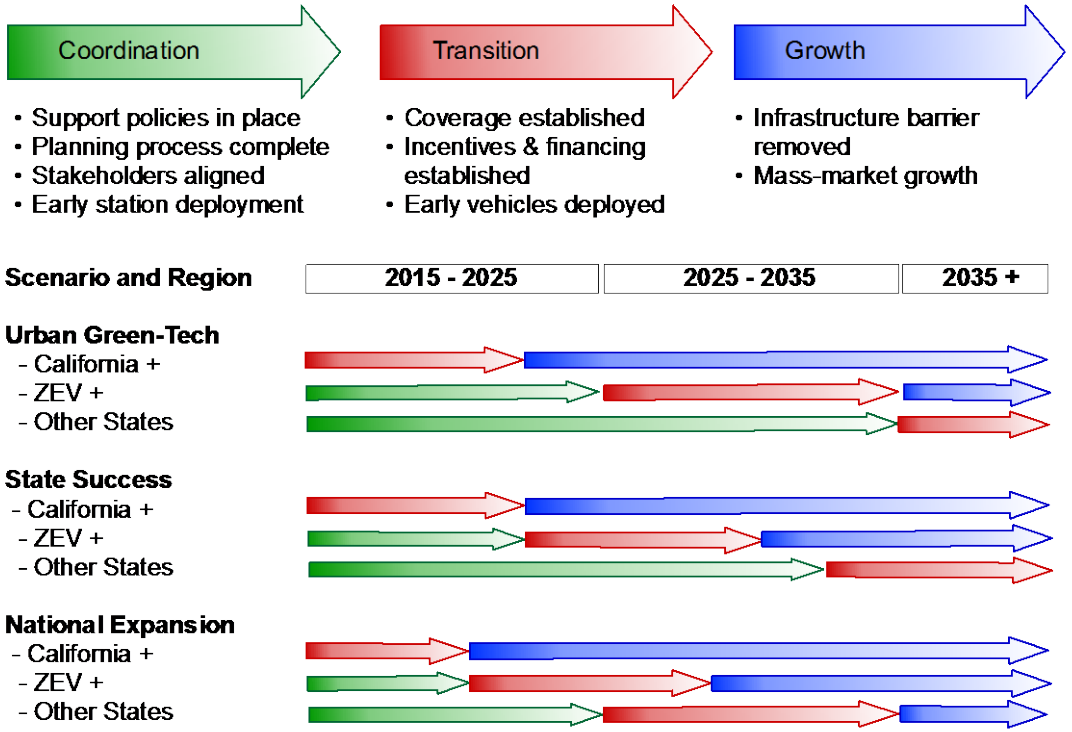
Approach

The scenarios frame emphases and time periods relevant to different stakeholder audiences.

Near-term (2015-2025)
- Early adopter markets
- California ramp-up period
- Coordination, planning and coverage in ZEV+

Mid-term (2025-2035)
- Early adopter markets (beyond California)
- Significant national coverage
- Broad state coalitions
- ZEV mandate is major influence

Long-term (2035+)
- Beyond early markets
- Many (most) states onboard
- Transition complete in some markets



Explanation of window sequences

Urban Green-Tech: Strong market growth in CA+ market achieved after transition period. Transition period for ZEV+ markets similar to CA state experience. Other states follow ZEV+.

State Success: Alignment and learning shortens ZEV+ Coordination period. Other states follow ZEV+. FCEVs make major contributions to ZEV Mandate and other goals.

National Expansion: Rapid success in CA+ markets spills over into ZEV+ and Other states. FCEV markets exceed ZEV mandate requirements and contribute to national goals.

Approach

The three scenarios are defined qualitatively in terms of market incentives and evolution.

Urban Green Tech	National FCEV adoption rates are relatively modest, and growth is restricted to the most promising urban markets with high concentrations of early adopters. Early adopters are consumers willing to pay a premium for green vehicles or high-tech vehicles. These consumers tend to be concentrated in large urban areas along the West and East Coast, and in a select number of additional urban markets. The neighbor effect is strong in this scenario, and the development of station networks in response to early adopter demand results in an increase in local market share across other consumer segments, including fast followers and mainstream consumers. The result is relatively deep pockets of FCEV adoption in major urban areas, with station coverage along highway corridors linking clusters of cities.
State Success	Strong national market growth is achieved due to the influence of state policies such as vehicle rebates and the ZEV Mandate. Early station networks tend to be limited to urban areas in these states, and only expand to other states after FCEVs have become a mainstream consumer product. Early adopters are still important in this scenario, but less so than in the Urban Green Tech scenario, and the neighbor effect has a modest influence on the expansion of markets geographically.
National Expansion	California continues to be a key early market for FCEVs, but additional growth is distributed across a broad range of markets, due to both the successful market adoption of FCEVs and aggressive investments in hydrogen station networks. Concentrations of early adopters help guide the placement of early coverage stations, but otherwise have little influence on larger market growth trends. Barriers to hydrogen infrastructure development are removed and overcome quickly, and rapid adoption of FCEVs occurs due to removal of information barriers in general rather than the neighbor effect. FCEV technology and cost improves quickly, and consumers purchase FCEVs as replacements for conventional vehicles with little concern over availability of stations.

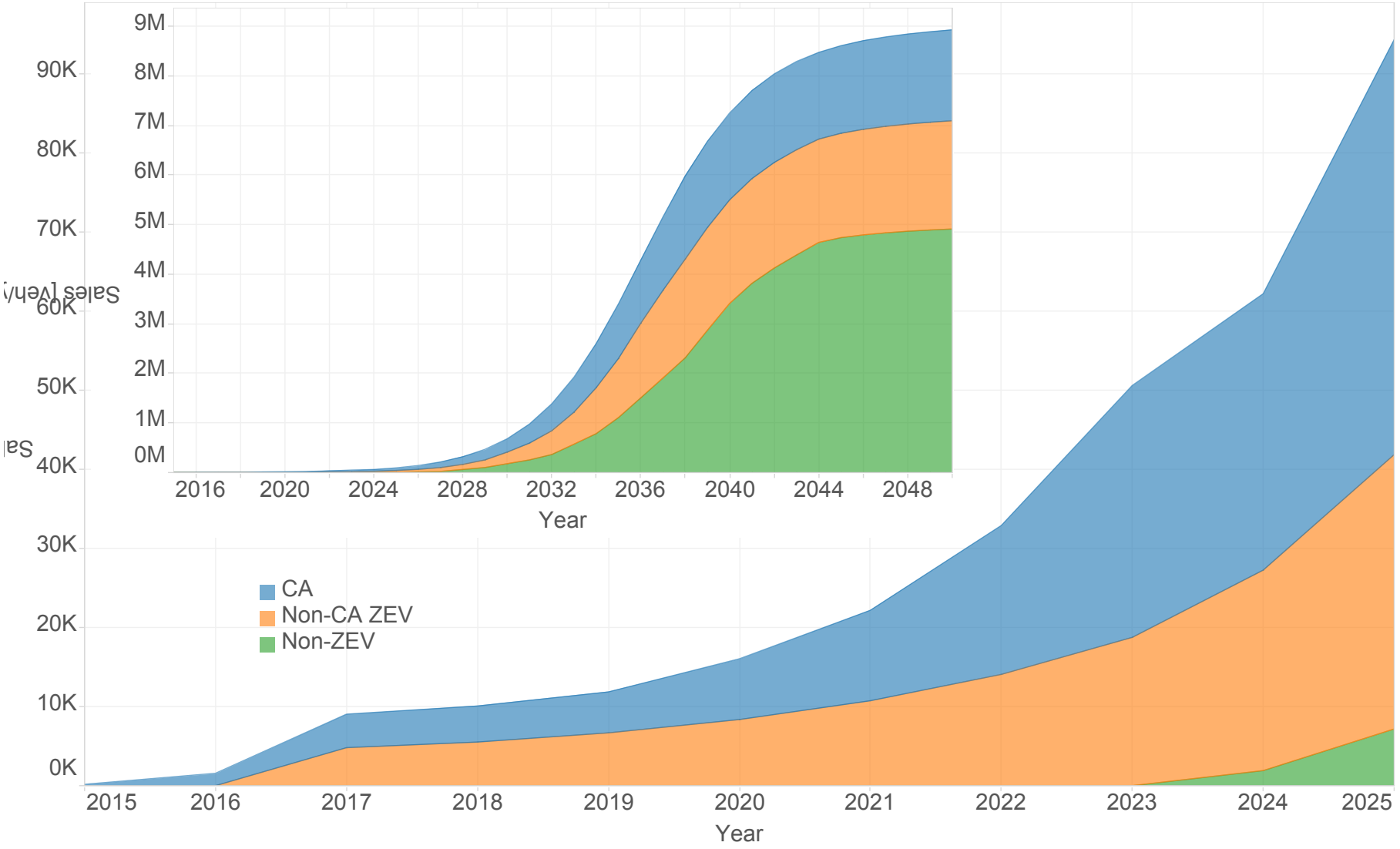
Approach

Milestones have been completed on time or are on schedule for completion on time.

- **FY2015: Annual Milestone (Regular), 9/30/2015**
  - "Presentation to DOE on updated scenario development activities."
  - *Status:* completed on schedule
- **FY2016: Annual Milestone (Regular), 9/29/2016**
  - "Presentation to DOE on updated scenario development activities. . . . The scenario analysis will result in 3 scenarios that combine and capture all relevant feedback collected from the H2USA WG (and other stakeholders) to convey key dynamics associated with FCEV and HRS rollout/market introduction strategies. The scenarios will include detailed infrastructure development and costs, with at least 3 planning input parameters (including local clustering, regional variations in market growth, and initial coverage requirements)."
  - *Status:* ahead of schedule
- **The related H2USA report "National Hydrogen Scenarios: How many stations, where and when?" is in its final stages of review and approval.**

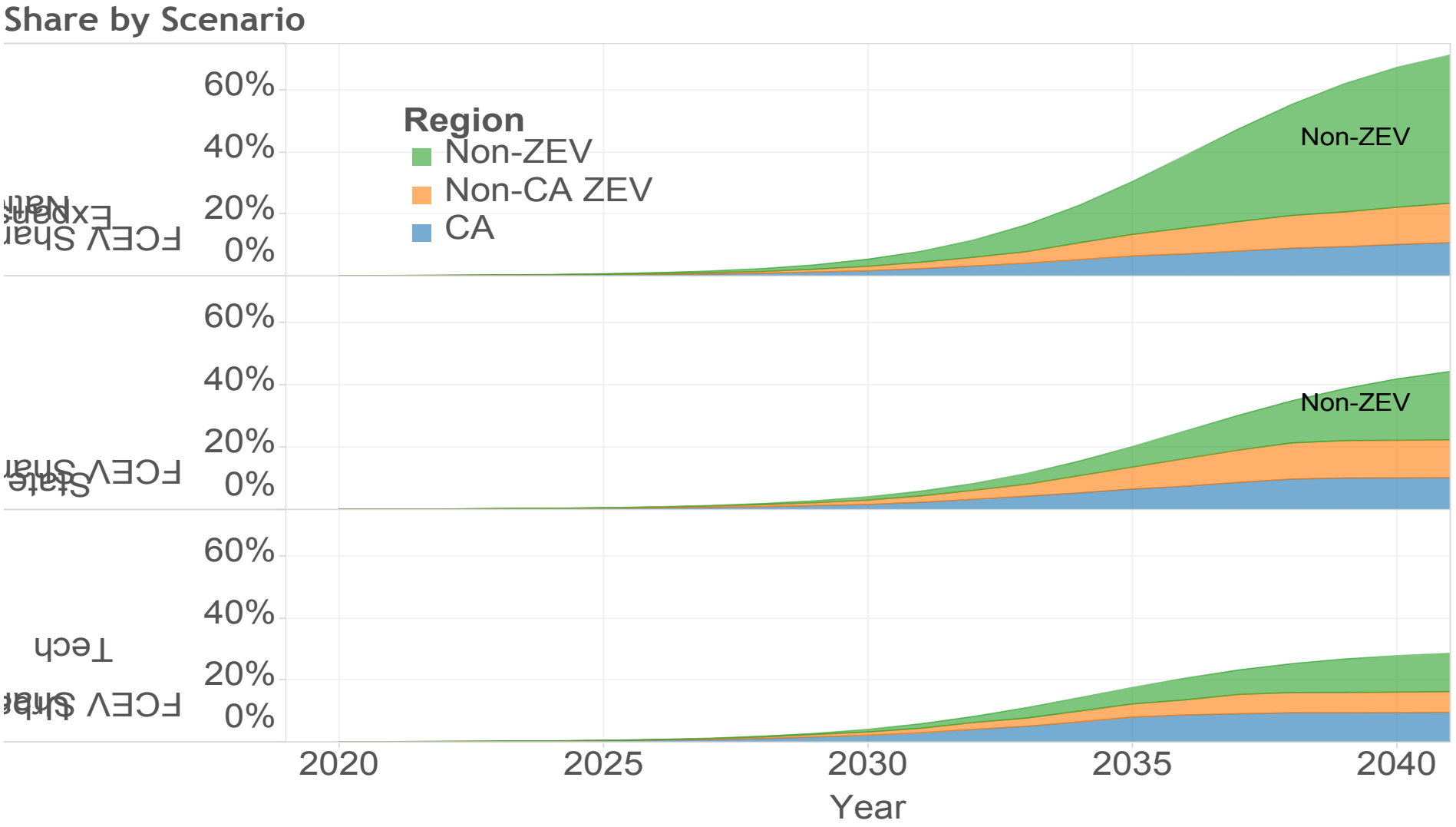
Accomplishments and Progress

The early market portion of the "State Success" scenario matches published forecasts for California and ZEV states.



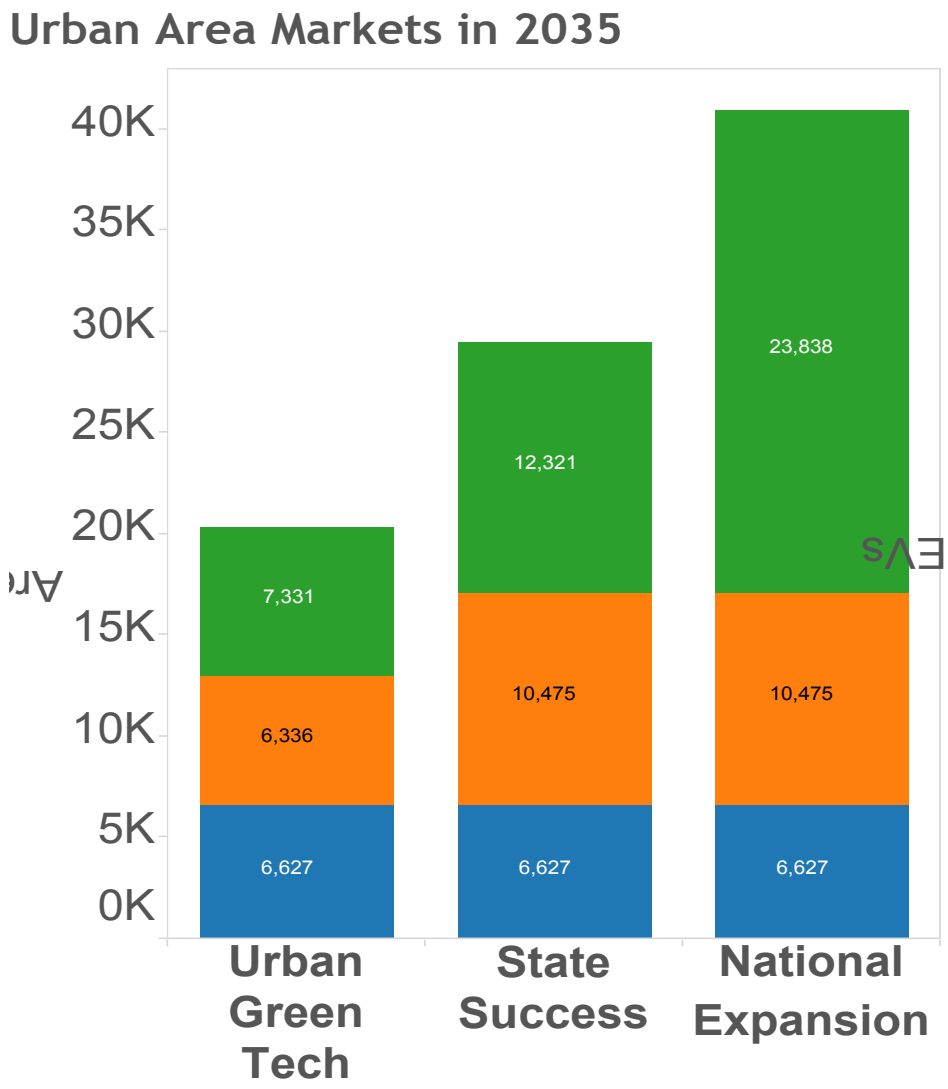
Accomplishments and Progress

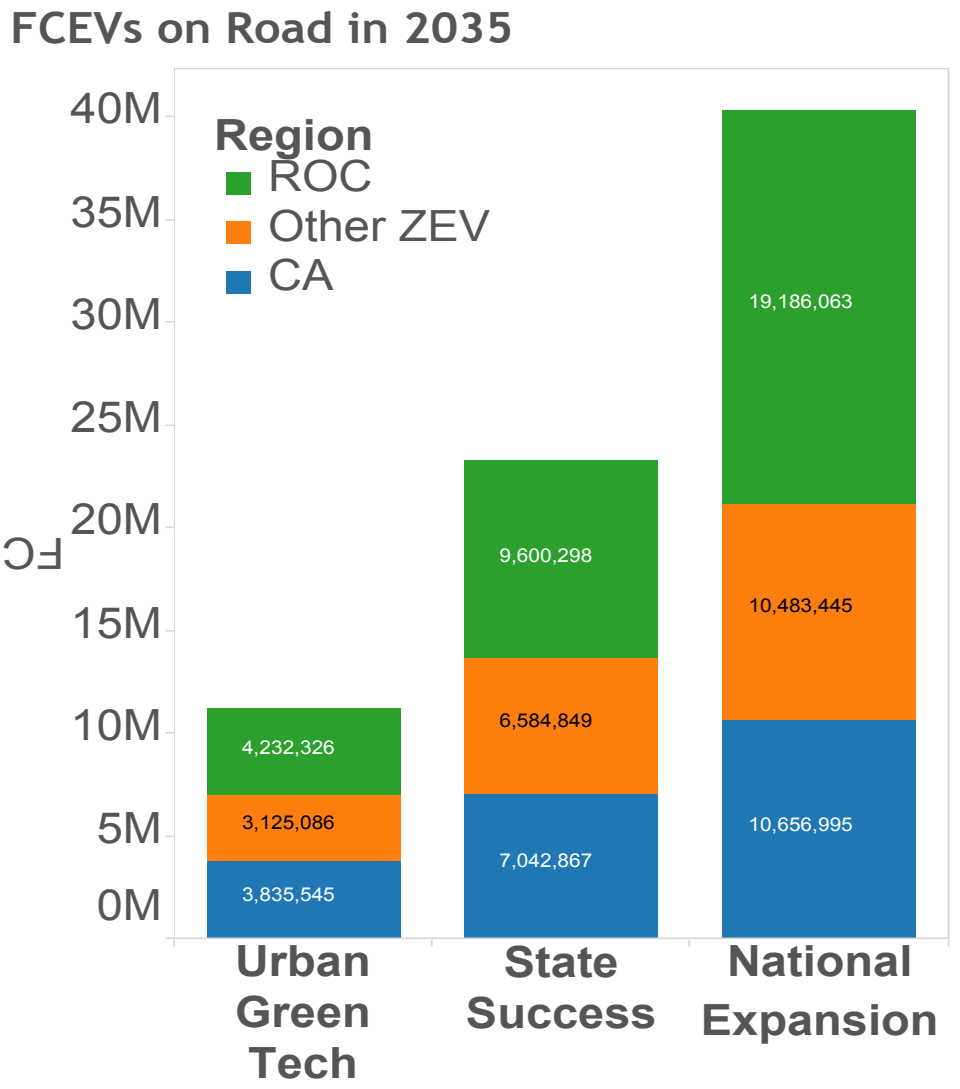
The three scenarios achieve different overall FCEV market shares.



Accomplishments and Progress

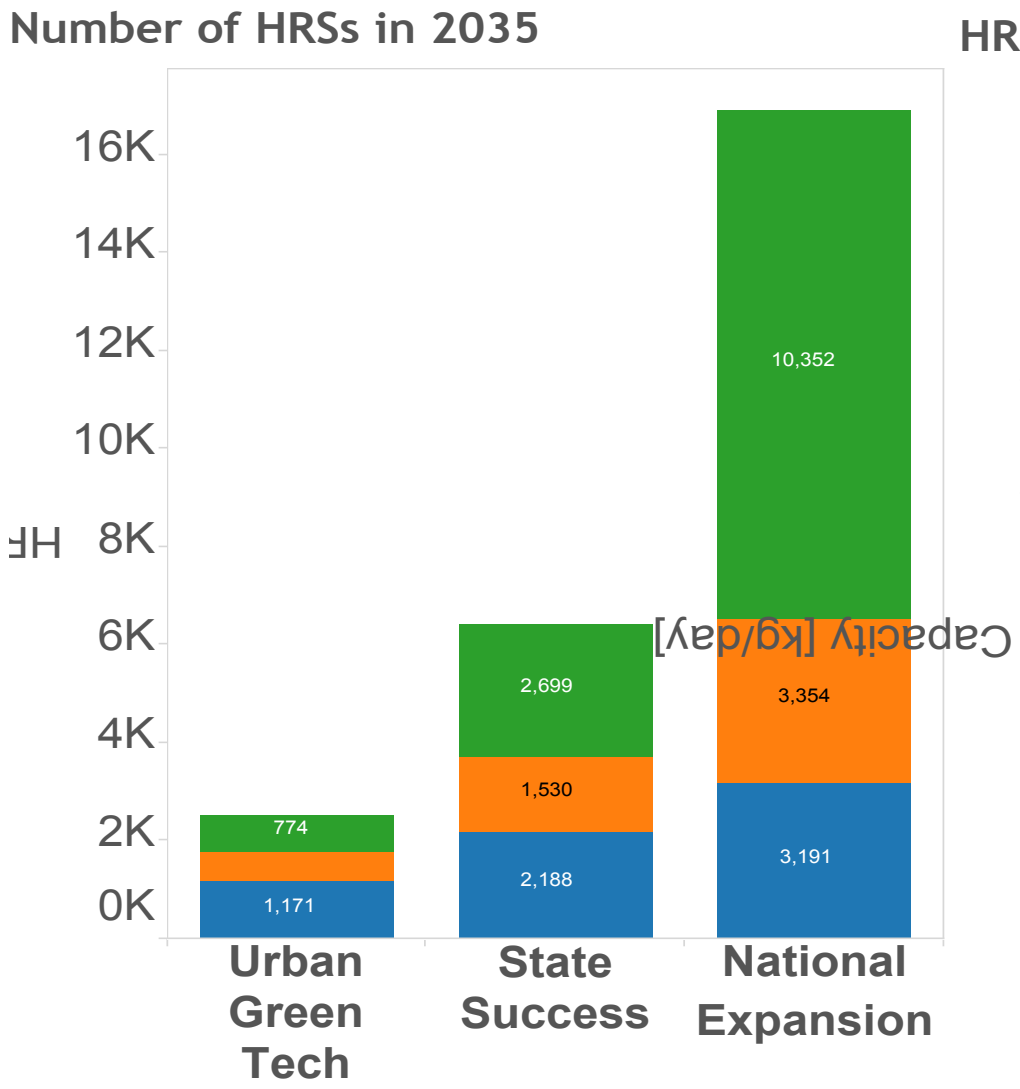
All three scenarios show substantial FCEV market growth by 2035.

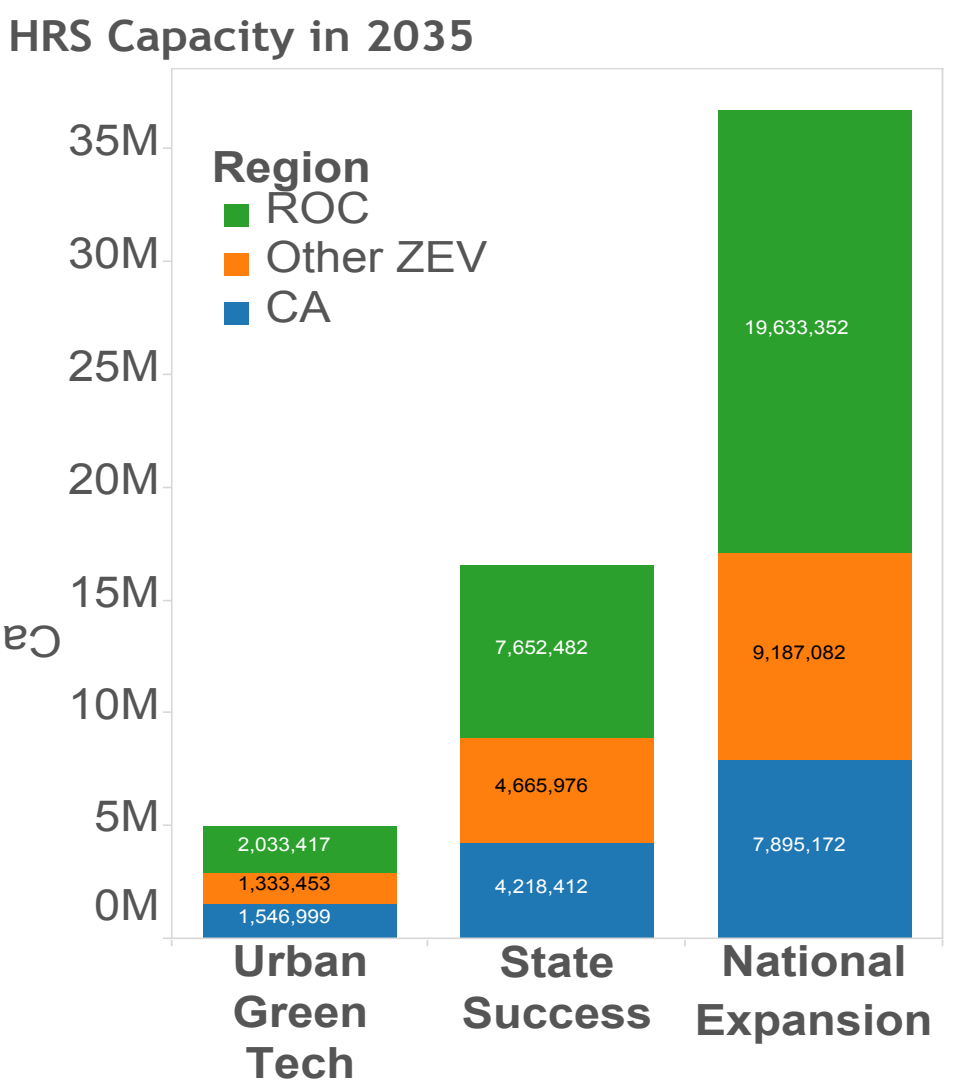




Accomplishments and Progress

The more aggressive scenarios have substantially greater numbers of stations.

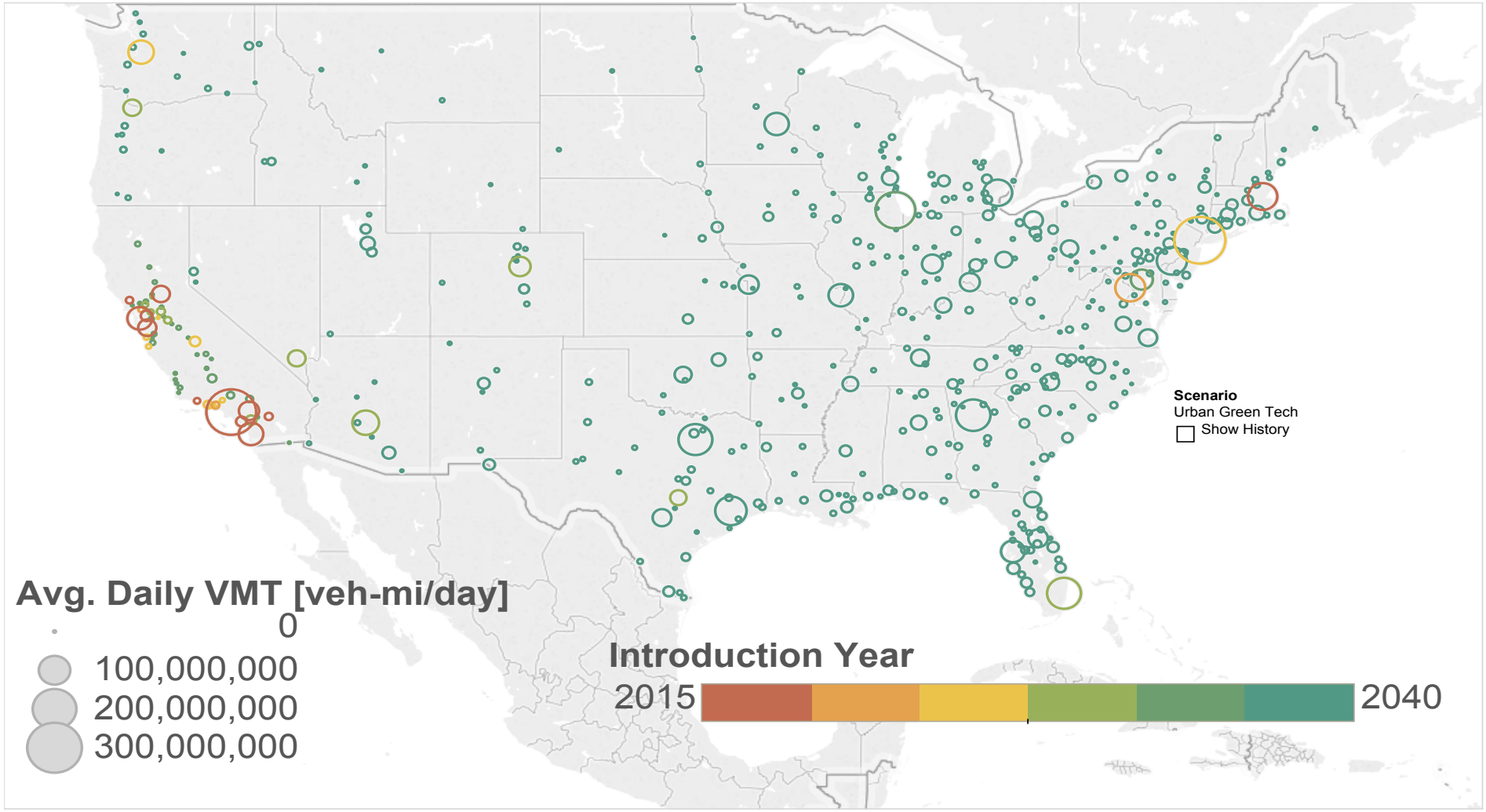




Accomplishments and Progress

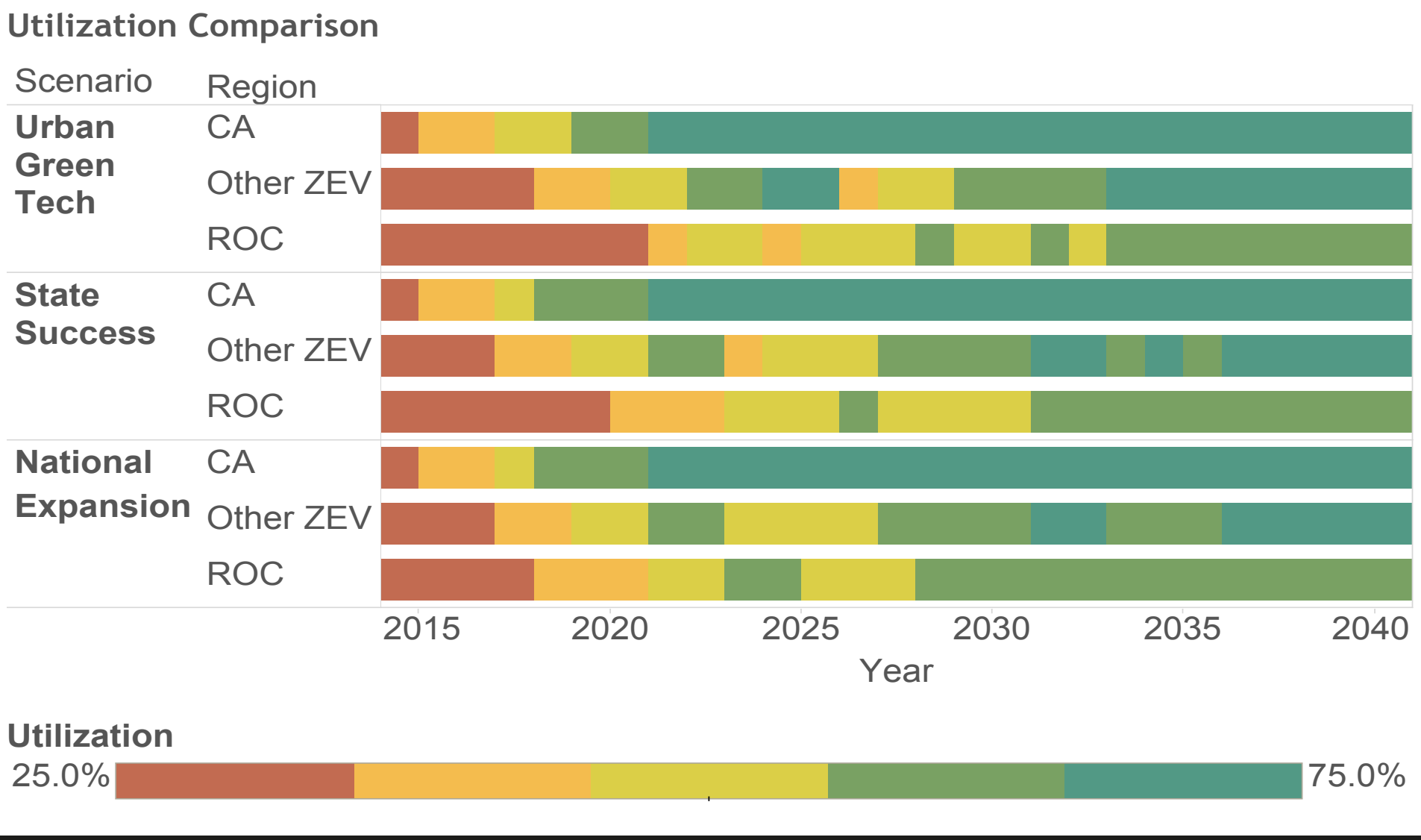
The Urban Green Tech scenario emphasizes FCEV sales in urban areas for likely early adoption.

Introduction Map - Urban Green Tech



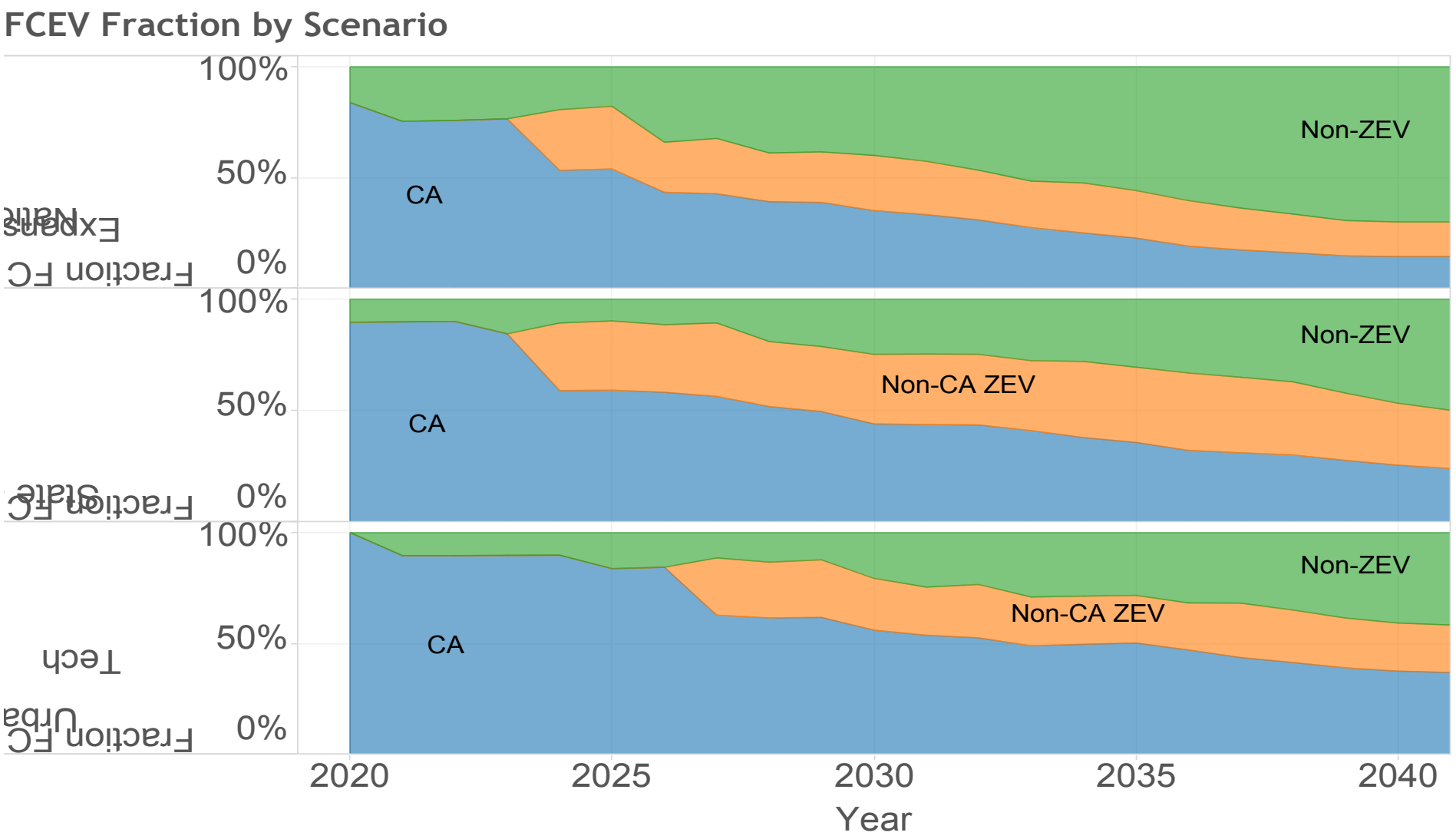
Accomplishments and Progress

Overall average station utilization becomes favorable in stages over time and geographically, varying by scenario.



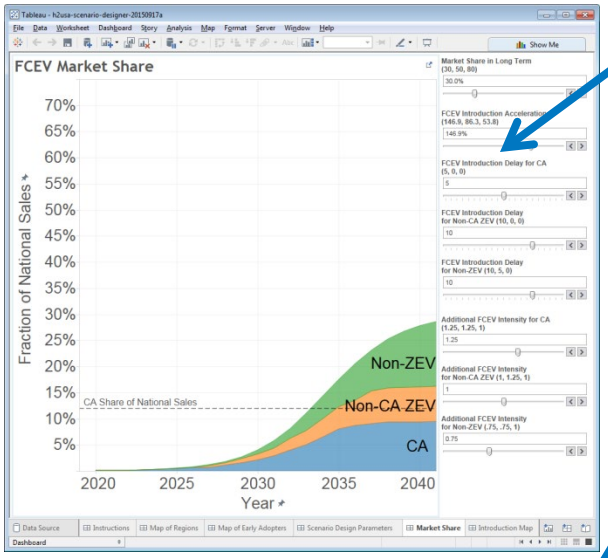
Accomplishments and Progress

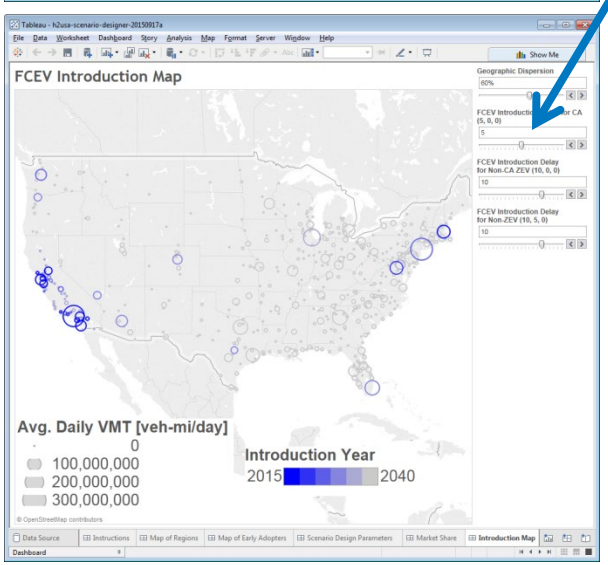
The three scenarios embody different geographic emphases on sales of FCEVs.



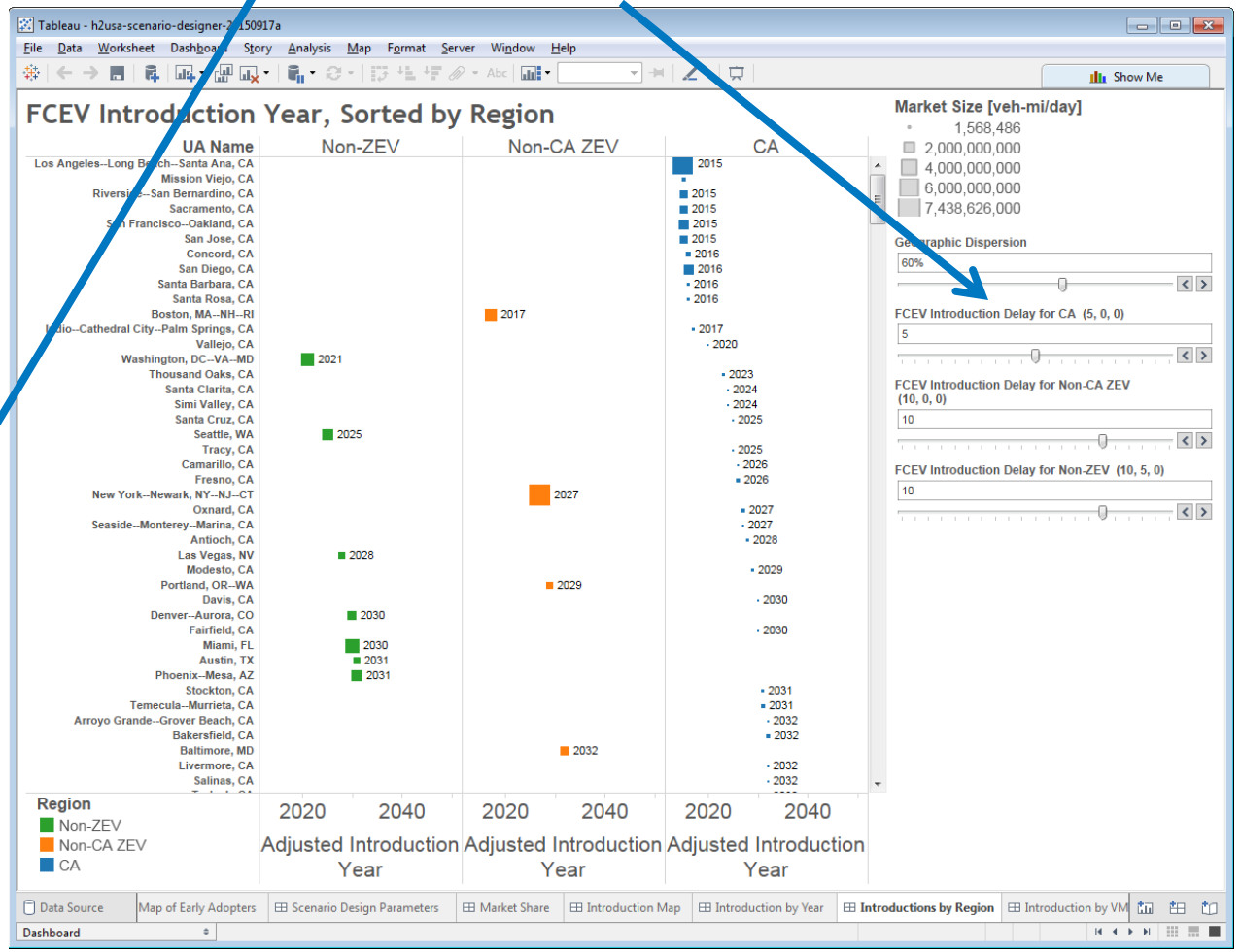
Accomplishments and Progress

An interactive scenario design and browsing tool has been delivered to stakeholders and demonstrated in workshops.



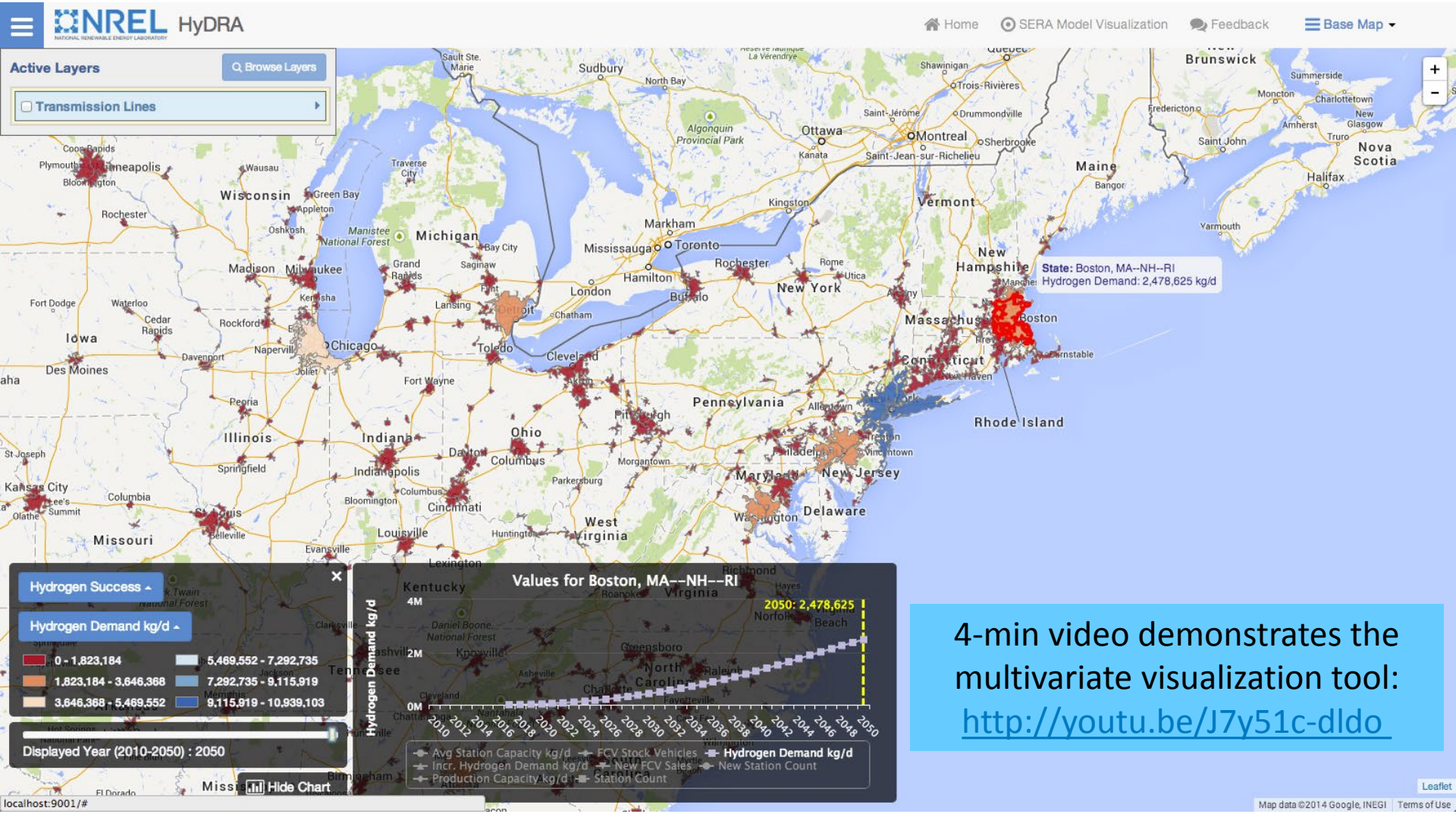


Users manipulate sliders and other widgets to change scenarios' aggressiveness, regional sequencing, and urban clustering.



Accomplishments and Progress

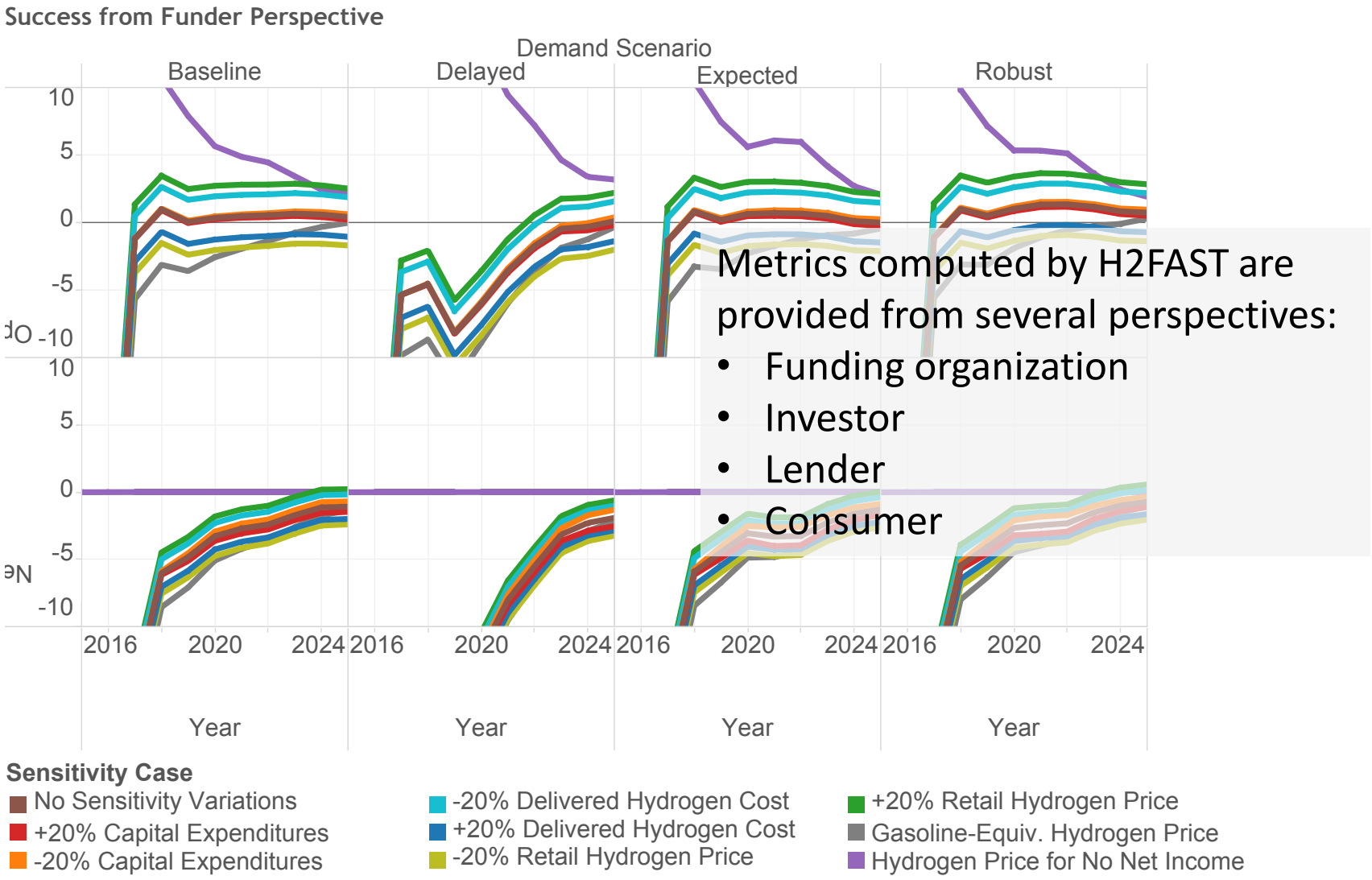
The Business Case Scenario tool (developed in FY2015) explores the full range of scenario outputs geographically over time.



4-min video demonstrates the multivariate visualization tool: http://youtu.be/J7y51c-dldo

Accomplishments and Progress

Financial metrics for different stakeholders summarize the business case for hydrogen refueling stations in scenarios.



Accomplishments and Progress:
Responses to Previous Year Reviewers' Comments

This project was not reviewed last year.

Collaborations

Industry, government, and academic stakeholders have informed and reviewed scenario development and analysis.

- Key stakeholders and subject matter expertise
  - H2USA Location Roadmap Working Group (LRWG)
  - H2USA Investment and Finance Working Group (IFWG)
  - California Energy Commission
  - California Air Resources Board
- Geospatial analytics
  - Lexidyne LLC

Remaining Barriers and Challenges

The early market conditions related to FCEVs continue to evolve.

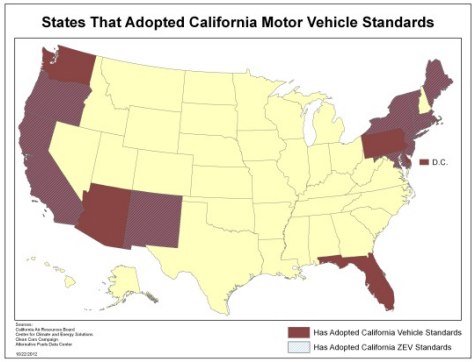
- **Ongoing developments affect national FCEV scenarios:**
  - hydrogen station costs
  - automaker plans
  - regional initiatives
  - energy prices
  - technology evolution
  - early market experience
- **The variety of stakeholder types necessitates presenting scenarios and analyses in multiple formats and from different perspectives.**

Proposed Future Work

We engage with stakeholders to improve analyses, update scenario definitions semiannually to adjust to conditions, and disseminate results.

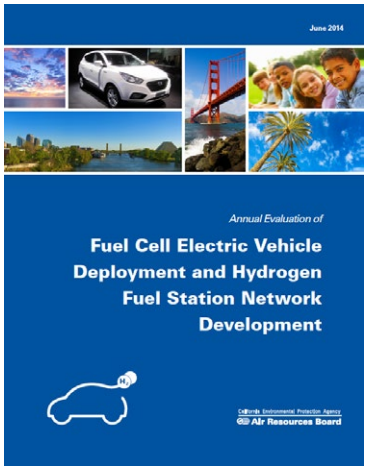
- Direct support for H2USA Working Group activities
- Integration of information relevant to financial analysis provided by various stakeholders engaged in deployment activities, including:
  - California Energy Commission (H2USA Member)
  - California Air Resources Board (H2USA Member)
  - Multi-State ZEV Action Plan (NESCAUM)

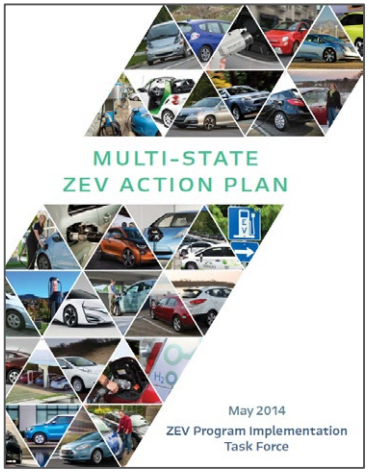
H_2USA



Municipal and state level plans can be incorporated into national scenarios

- Analysis framework can account for market factors or support mechanisms at any geographic scale (HOV lanes, etc.)
- Learning can be shared across markets





Summary

Objective	Develop and analyze self-consistent national FCEV scenarios that accurately represent early market trends, but that also explore long-term possibilities for FCEV adoption.
Relevance	Directly addresses MYPP objectives for stakeholder-engaged scenario development/analysis.
Approach	Create various scenarios grounded in empirical data, early market plans, and technical analysis.
Accomplishments	Developed and analyzed three distinct scenarios (plus additional sensitivity analysis) with detailed geographic, temporal, and financial information for vehicles, stations, and networks.
Collaborations	H2USA working groups and subject-matter experts.

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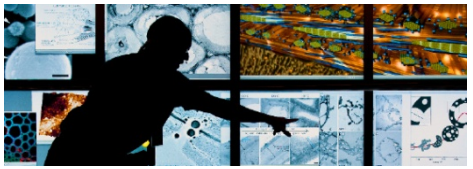

Reviewer-Only Slides

Critical Assumptions and Issues

1. There is not a sufficiently developed FCEV fueling market to assess the current retail price of hydrogen and its future trends.
2. Competition between FCEVs and other vehicles makes it difficult to draw boundaries around FCEV scenarios.
3. Not enough historical data have been available to gauge the details of how ZEV mandates will geographically and temporally affect the FCEV early market.

Publications and Presentations

- **Numerous presentations and several workshops for the H2USA location roadmap and infrastructure finance working groups (LRWG and IFWG).**
- **Draft H2USA report "National Hydrogen Scenarios: How many stations, where and when?"**