Design and Economics of an Early Hydrogen Refueling Network for California

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Project ID #
AN 032

Overview

Timeline
(NextSTEPS program)

- Start: Jan. 1, 2011
- End: Dec 31, 2014
- 50% Complete

Budget

- Total project funding
  - DOE share: $240 K (4 years)
  - Contractor share: $ 0
- Funding received FY12: $60K
- Funding for FY13: $60K

Barriers

- Barriers addressed (from MYPP)
  - **Future Market Behavior**
  - **Inconsistent Data, Assumptions and Guidelines**
  - **Insufficient Suite of Models and Tools**
- Goal Addressed::
  - **Provide system-level analysis to support hydrogen and fuel cell technologies development**

Partners

- The work was conducted at UC Davis under the NextSTEPS research consortium, which has 23 government and industry sponsors, including USDOE
- UC Davis manages NextSTEPS (see supplemental slides)

OVERALL PROJECT GOAL: Provide system-level technical & economic analysis to support initial rollout of H2 and fuel cell technologies.

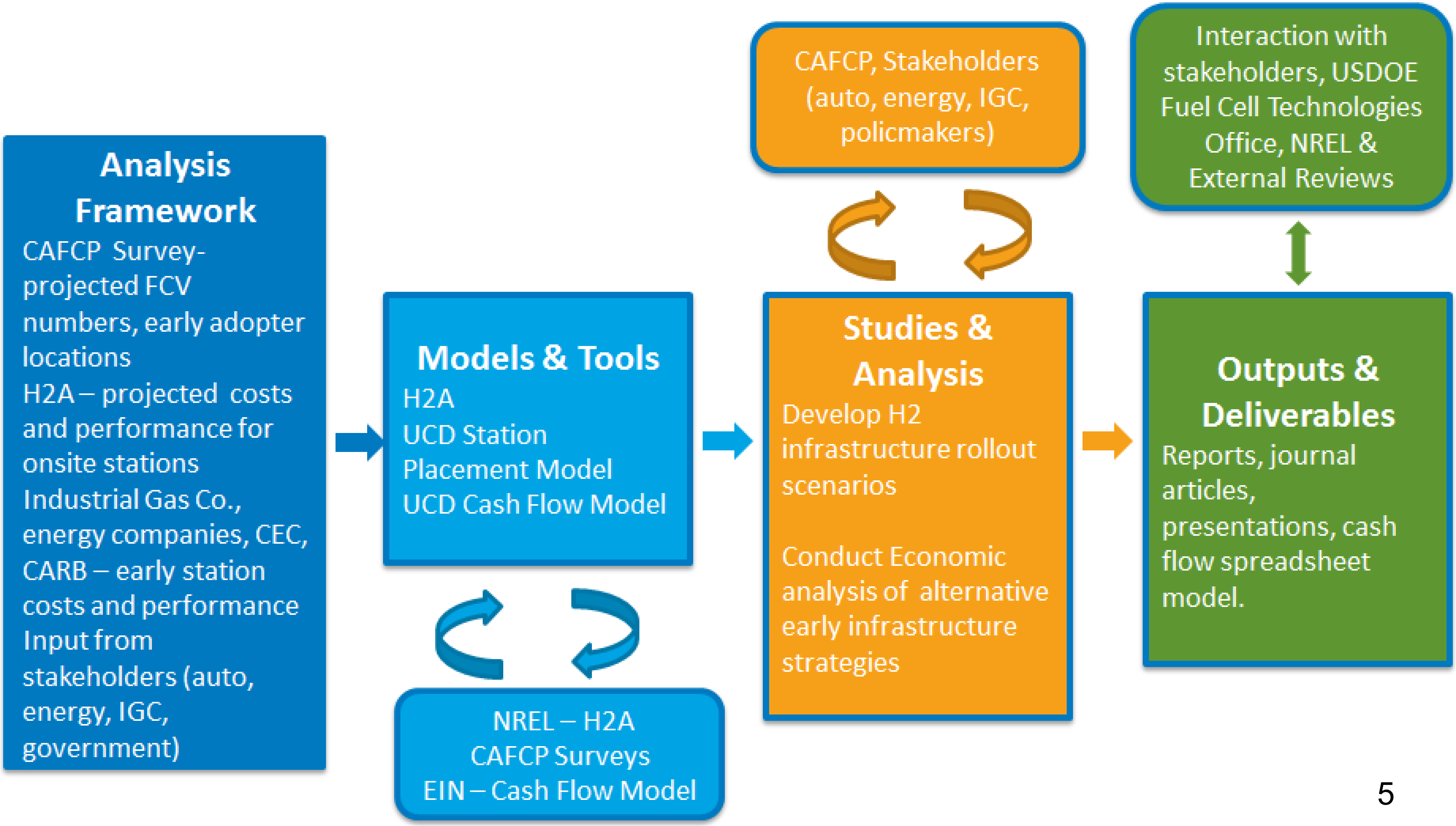
DOE BARRIERS (From Analysis Section MYPP)	AN 032 PROJECT GOALS
Future Market Behavior	Analyze strategies for early H2 fueling station placement, numbers and network development, to enable fuel accessibility for initial rollout of H2 fuel cell passenger cars.
Inconsistent Data Assumptions and Guidelines	Develop robust data on costs and performance for early stations and scenarios and strategies for deployment.
Insufficient Suite of Models and Tools	Conduct case studies for California, utilizing GIS-based analysis for station siting and consumer convenience and economics from perspective of the network, individual station owners and consumers (fuel cost).

Infrastructure Economic Analysis

- Estimate near term H2 station capital & operating costs
- Consider different infrastructure build-out scenarios over next decade based on cluster strategy
- Analyze economics from several perspectives
  - Station Network
  - Single station owner
  - Consumer (fuel cost)
- Find Cash flow and Break-even year (when can the station produce H2 competitively?)
- Estimate subsidies that might be needed to support early infrastructure
- Sensitivity studies to better understand uncertainties, risks

Project Overview

Design & Economics of Early H2 Refueling Network for California



Estimate Near Term Station Cost & Performance

Station costs based on interviews with energy and industrial gas company experts reflecting current and future costs.

- **Onsite Reformer 100-1000 kg/d**
- **Onsite electrolyzer 100-1000 kg/d**
- **LH2 truck delivery 100-1000 kg/d**
- **Compressed gas truck delivery 100-500 kg/d**

For onsite future stations, assume $0.5-2 million for site prep, permitting, engineering, utility installation, for green-field site before any fuel equipment goes in. H2 equipment costs are added to this.

For 2012-2014, equipment costs = 2 X H2A "current tech"

For 2015-2017, equipment costs = H2A "current tech"

Use IGC estimates for low-cost gas truck delivery options

Station Capital Cost Assumptions ($M)

	2009-2011	2012-2014	2015+
Mob. Refueler 100 kg/d	1.0	1.0	0.4
LH2 Truck Delivery			
100 kg/d	4.0	2.6	2.3
250 kg/d		2.7	2.3
400 kg/d		2.8	2.4
1000 kg/d		3.2	2.6
Onsite Reformer			
100 kg/d	3.5-4.0	3.3	2.6
250 kg/d		4.0	3.0
400 kg/d		4.8	3.4
1000 kg/d		7.8	4.9
Onsite Electrolyzer			
100 kg/d	-	3.2	2.6
250 kg/d		4.2	3.1
400 kg/d		5.3	3.6
1000 kg/d		9.3	5.6

Station O&M Cost Assumptions

Progess/Accomplishments

	Variable O&M	Fixed O&M
Mobile Refueler	**Compressed H2 supply** $20/kg H2	100 kg/d: 13 % cap.cost /y + $130,000/y (land rental)
LH2 Truck Delivery	**LH2 supply+ station LH2 pump/compression** $10/kg LH2 + 0.81 kWh/kg H2 x electricity price $/kWh	100 kg/d: 11 % cap.cost /y + $130,000/y (land rental) 250-1000 kg/d: 11% cap.cost /y + $360,000/y (land rental)
Onsite Reformer	**NG feed + station H2 compression** 0.156 MBTU NG/kg H2 x NG price $/MBTU + 3.08 kWh/kg H2 x elec price $/kWh	100 kg/d: 10 % cap.cost /y + $130,000/y (land rental) 250-1000 kg/d: 7% cap.cost /y + $360,000/y (land rental)
Onsite Electrolyzer	**Electrolyzer electricity + station H2 compression:** 55.2 kWh/kg H2 x elec price $/kWh	Same as onsite reformer

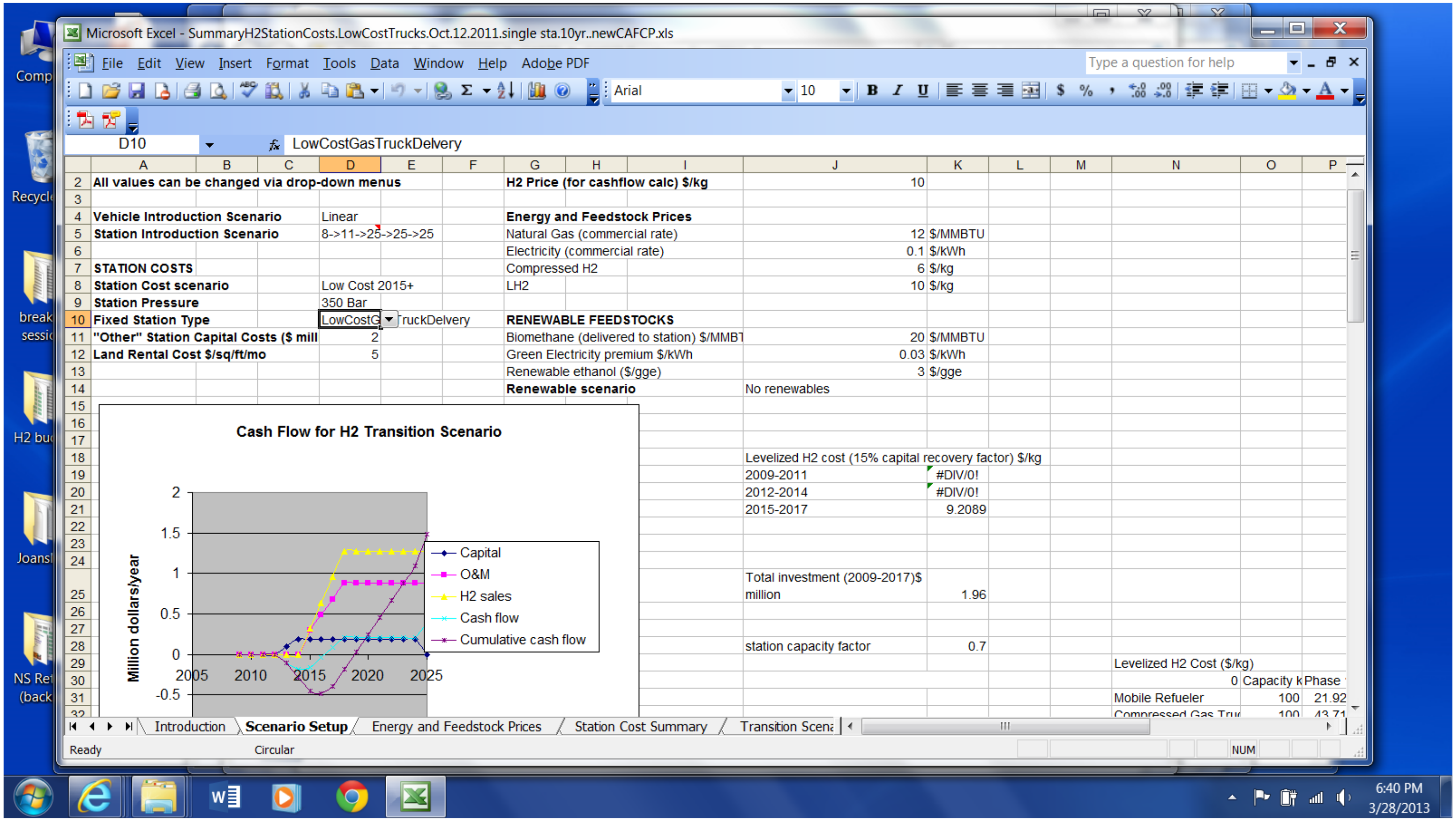
Compressed gas truck delivery

H2 Station Cost Assumptions: 700 bar dispensing.

Time frame	Capital Cost	Annual O&M cost $/yr
<u>Phase I (<2013)</u> 100 kg/d -> 170 kg/d 250 kg/d (has more ground storage)	$1 million $1.5 million	$100 K (fixed O&M) + 1 kWh/kgH2 x kg H2/yr x $/kWh (compression elec cost) + H2 price $/kg x kg H2/y (H2 cost delivered by truck)
<u>Phase 2 (2014)</u> 100 -> 170 kg/d 250 kg/d	$0.9 million $1.4 million	Same as above
<u>Phase 3 (2015+)</u> 100 -> 170 kg/d 250 kg/d 400 -> 500 kg/d	$0.5 million $0.9 million $1.5-2 million	Same as above

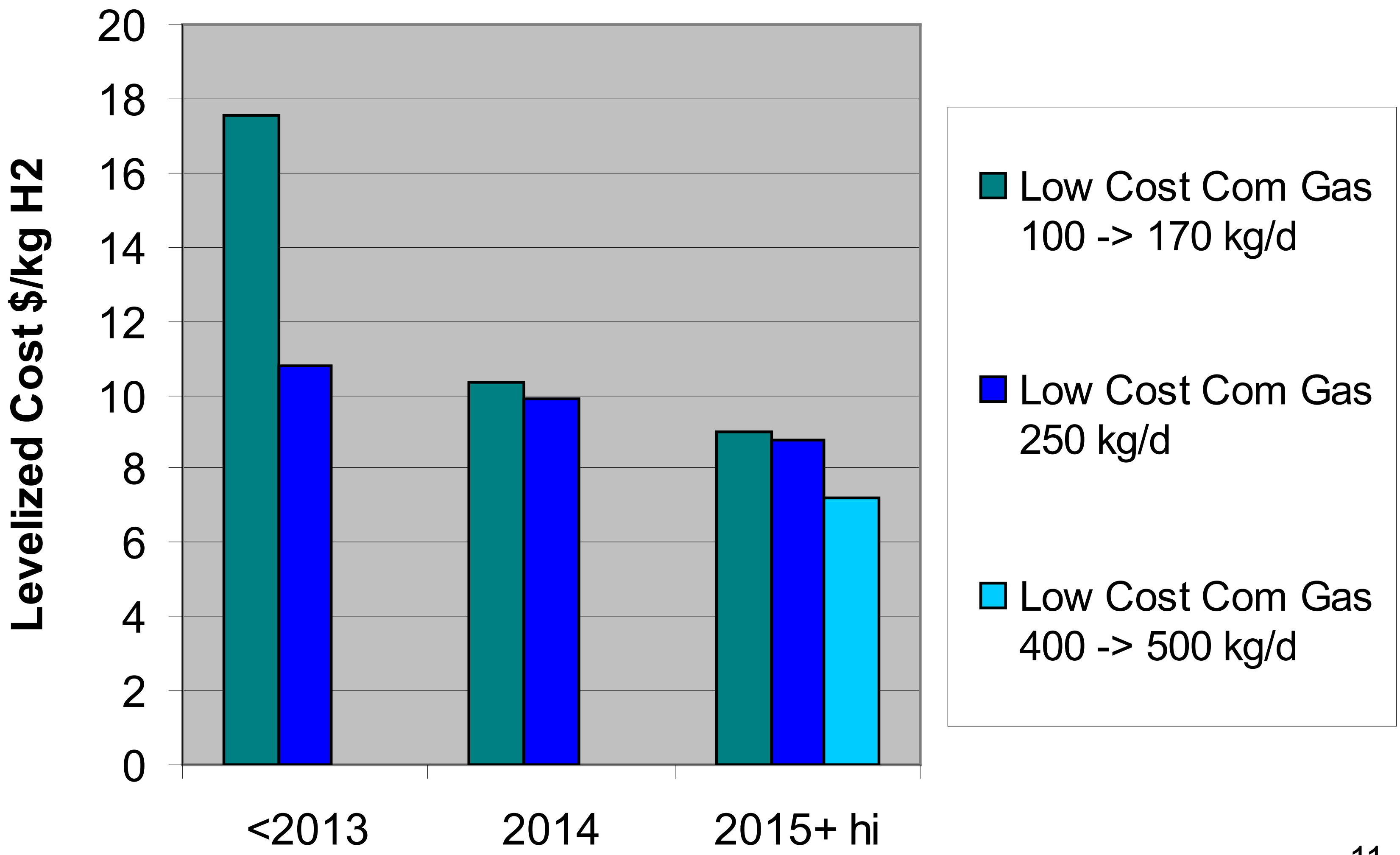
UCD Rollout Scenario Spreadsheet Model

Developed EXCEL based spreadsheet to model economics of different station types and explore costs of rollout strategies

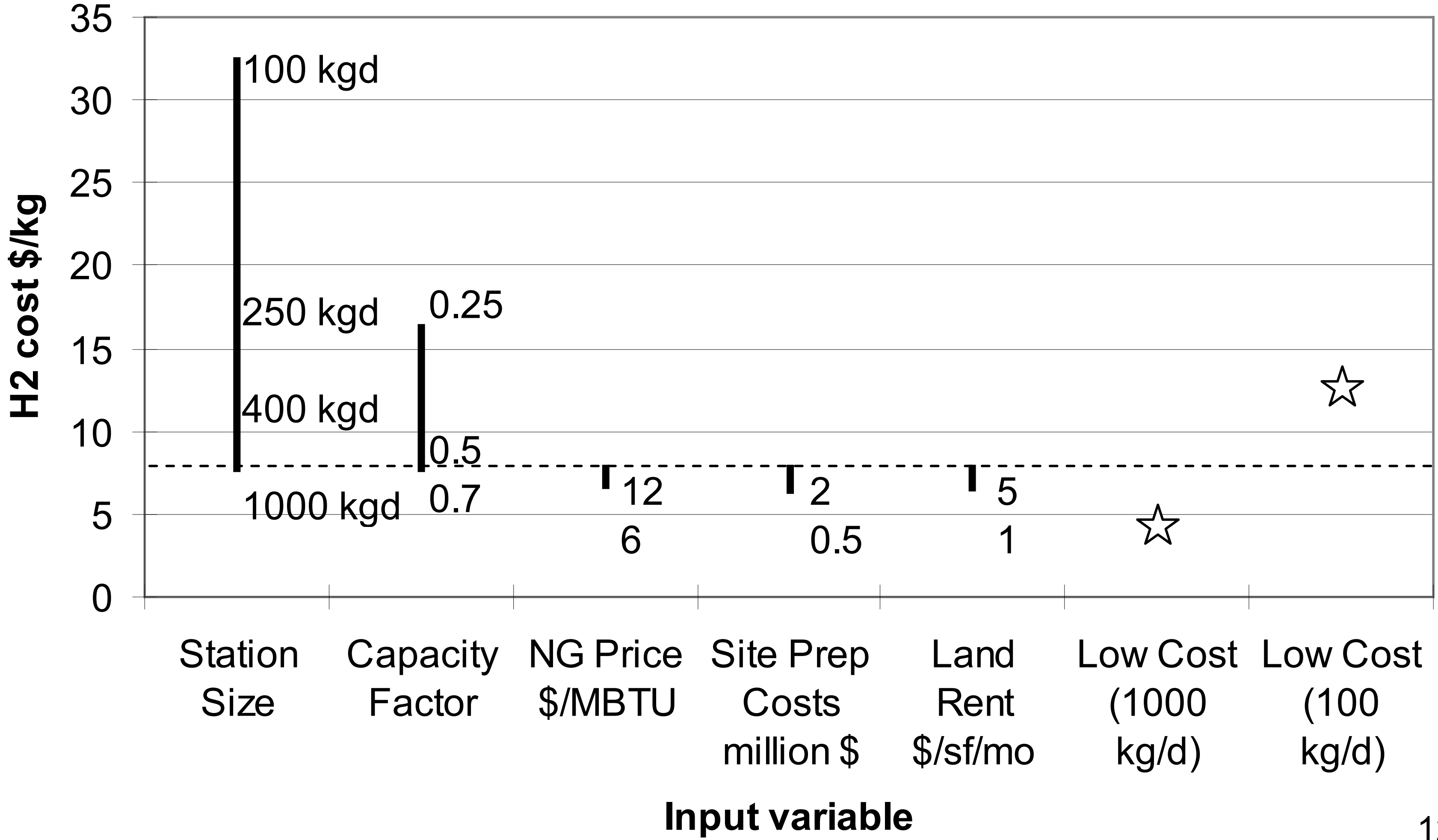


Estimated Delivered H_2 cost via Gas Truck \$/kg

(w/ 2015+ tech, H_2@\$7-9/kg ~cent/mi Gasoline @ \$4.3-5.6/gal)



SENSITIVITY STUDY: Delivered H_2 Cost via Onsite SMR $/kg
(Vary station size, cap. factor, NG price, site prep, land costs)
(w/2015+ tech, H_2@$5-8/kg ≥cent/mi~Gasoline @ $3-5/gal)



Transition Analysis: Use 2010 CAFCP estimates for FCVs in fleet in Southern California

YEAR	#FCVs in fleet
2011	197
2012	240
2013	347
2014	1161
2015-2017	34,320

Assumption: FCV average H2 usage 0.7 kg/d

Rollout Scenario Schedule

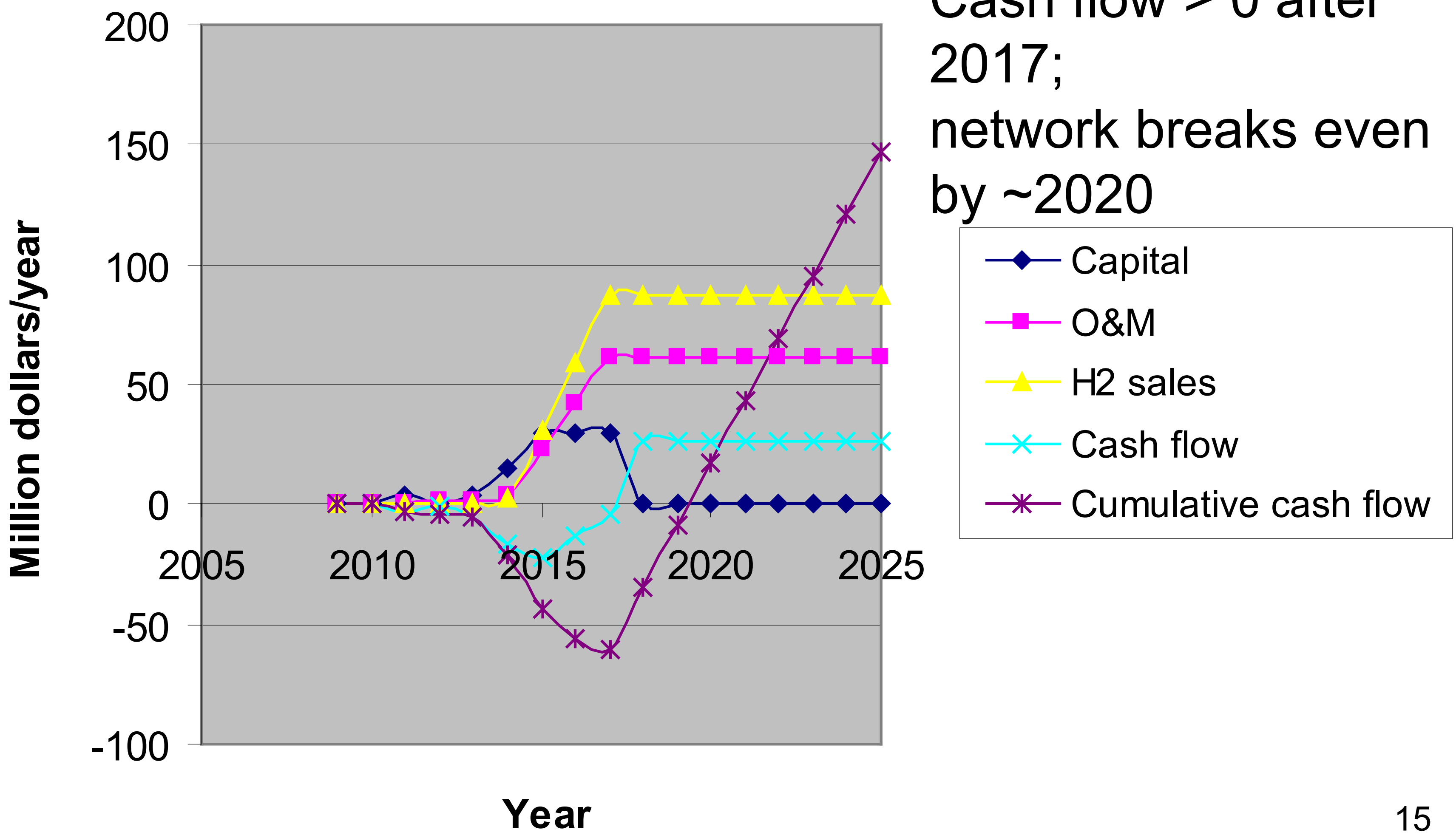
(New stations added per year by station type and size)

78 sta. total in 2017, supply H_2 to 34,00 FCVs in SoCal.

#New Sta	2011	2012	2013	2014	2015	2016	2017
Mobile Refueler	4	0	0	0	0	0	0
Compressed Gas Truck Delivery (for different station sizes)							
170 kg/d	0	0	4	0	0	0	0
250 kg/d	0	0	0	10	0	0	0
500 kg/d	0	0	0	0	20	20	20
Total sta. capacity (kg/d)	400	400	1080	3580	11580	21580	31580
# FCVs in fleet	197	240	347	1161	12106	23213	34320
H_2 demand kg/d	137	168	250	800	8500	16000	24000

CASH FLOW for 78 STATION NETWORK: Deliver compressed H2 @$6/kg, H2 sold @ $10/kg; Network Capital invest.=$113 M

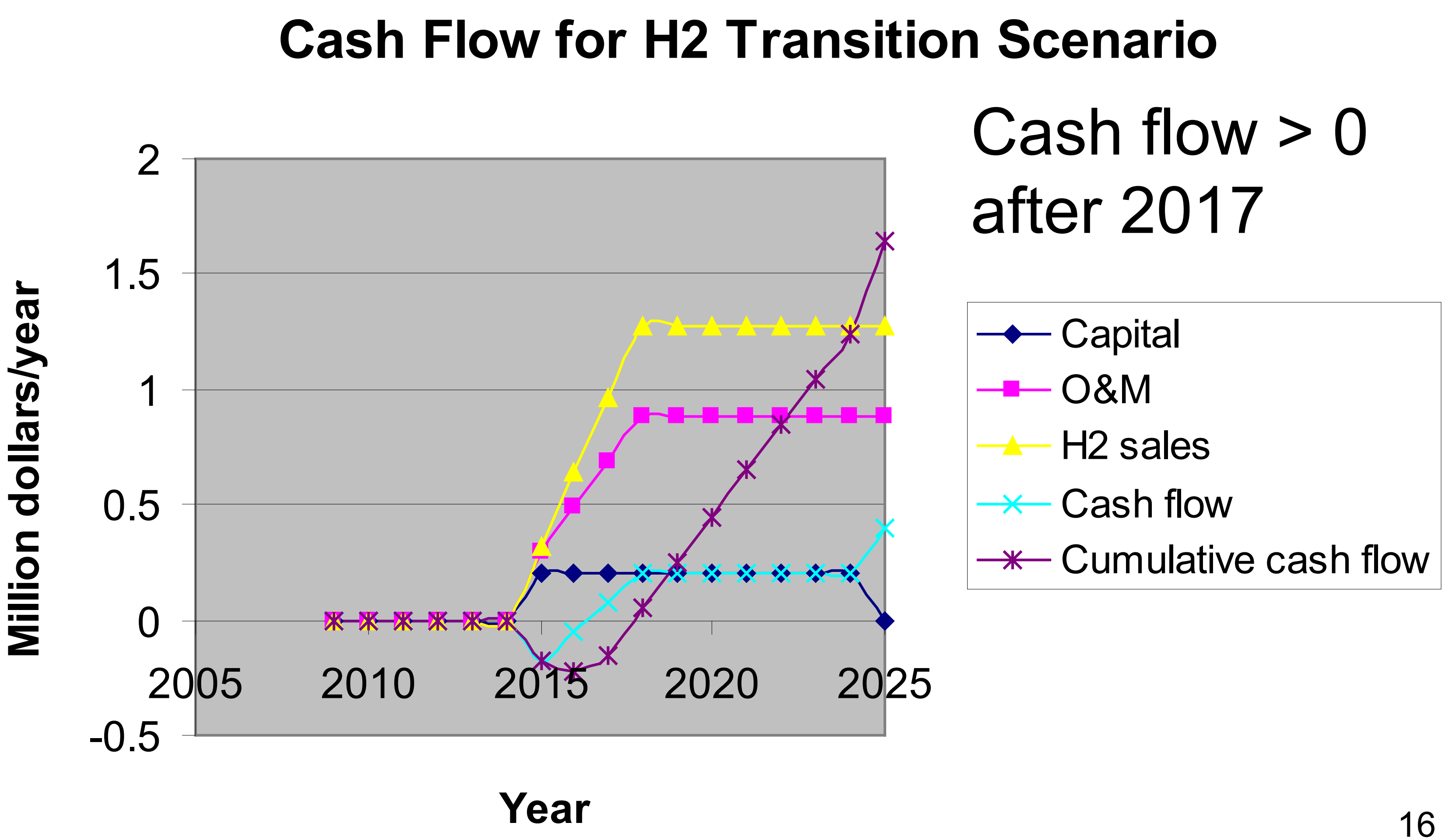
Cash flow > 0 after 2017;
network breaks even by ~2020



CASH FLOW: SINGLE 500 kg/d sta, Deliver compressed H2 @$6/kg, H2 sell @ $10/kg; Station capital cost $1.5 million, 10 yr loan @ 5.5% interest

Progess/Accomplishments

<u>Support needed until cash flow >0, ~$600K</u>



Summary Results

PROJECT GOALS:

Assess alternative strategies for introducing fuel cell vehicles and H2 infrastructure in So. Cal. over the next decade to satisfy the ZEV regulation. Consider station placement, number, size and type of stations.

Analyze infrastructure economics from multiple perspectives: network, station owner, consumer.

KEY RESULTS:

60-80 H2 stations needed to support 34,000 FCVs in So. Cal c.2018

Capital cost to build network $110-160 million

500 kg/d station shows positive cash flow in 2-4 years, assuming rapid market growth; network breaks even in 5-7 years

Delivered H2 cost: Early 100 kg/d truck-delivery sta. H2 <$10/kg, later 500 kg/d truck (H2 ~$7-9/kg) or 1000 kg/d onsite SMR ($5-8/kg)

Subsidy: Capital+O&M for 18 small stations (100-250 kg/d) & support for 60 500 kg/d stations until cash flow>0 costs $50-$70 million

Collaborations/Interactions

- California Fuel Cell Partnership: *provided survey data for future FCV projections; infrastructure working group discussions*
- Air Products and Chemicals, Inc., Linde, Praxair*: information on near term H2 station performance and cost.*
- NREL (Marc Melaina, Brian Bush): *H2A model*
- California Air Resources Board (Joshua Cunningham) *discussions on ZEV projections, rollout strategies*
- California Energy Commission (Jim McKinney, Tim Olson) *discussions of strategies for introducing hydrogen and other fuels*
- Members of UC Davis H2 Rollout Study (Shell, Chevron, Toyota, Honda, Daimler, GM, CARB) *scenario development*
- Energy Independence Now: *model comparisons, many discussions*
- University of California, Irvine (Tim Brown, Shane Stevens-Romero); University of California, Berkeley (Tim Lipman) *discussions on rollout strategies*
- 23 Sponsors of NextSTEPS Research Program (see supplemental slides) *for partial support*

Proposed Future Work

- Tri-generation strategies for early H_2 infrastructure (residential & commercial bldg.)
- Implications of low cost, plentiful natural gas for H_2 production
- Green H_2 studies (California, US); Potential role of H_2 in low-C energy future
- H_2 Infrastructure Build out Comparison US regions, other countries
- Social costs, materials, land, water issues for H_2, other fuel/vehicle pathways

Project Summary

- **Relevance**: *Provide system-level techno-economic analysis to support rollout of H2 and fuel cell vehicle technologies.*
- **Approach**: *Analyze rollout strategies for fuel cell vehicles and H2 infrastructure in So. Cal. over next decade, to satisfy ZEV regulation. Station placement, number, size, type of stations, infrastructure economics.*
- **Technical Accomplishments and Progress**: *developed models, publications (journal papers, reports, presentations, spreadsheet model).*
- **Collaboration:** *Input/discussion w/ stakeholders (auto, energy, industrial gas, state agencies, national labs)*
- **Proposed Future Research**: *Examine the potential role of residential and commercial tri-generation systems (CHHP) in early infrastructure.*

Technical Back-Up Slides

ECONOMIC ANALYSIS OF H_2 FCV ROLLOUT STRATEGIES

Approach

H2 INFRASTRUCTURE SHOULD OFFER

COVERAGE: enough stations, located to make fuel accessible to early FCVs

CAPACITY meet H2 demand as FCV fleet grows

CASH FLOW: positive cash flow for individual station owners and network-wide supply within a few years

COMPETITIVENESS: H2 fuel cost to consumers

COORDINATE FCV PLACEMENT + H2 INFRASTRUCTURE BUILD-OUT, GEOGRAPHICALLY AND OVER TIME

Finding: Cluster Strategy" co-locating early FCVs and H2 stations in a few cities (Santa Monica, Irvine, etc.) within a larger region (LA Basin) enables good fuel accessibility with a sparse network.

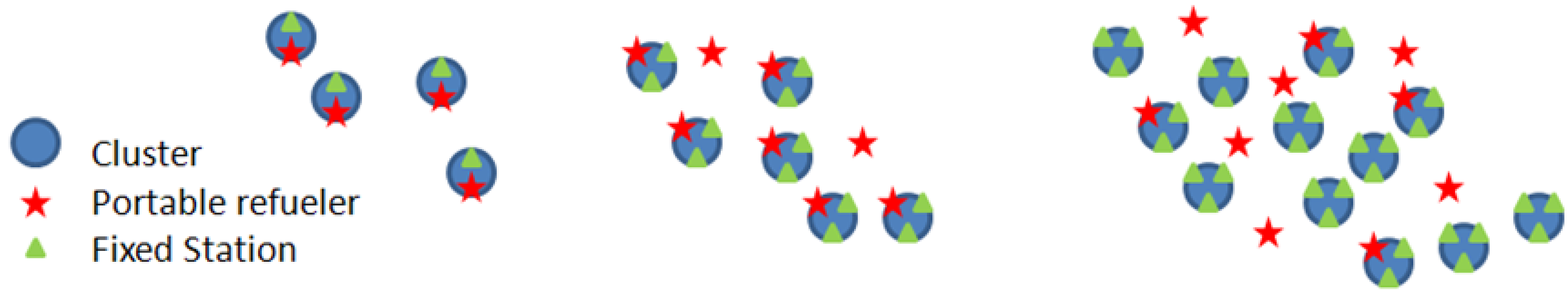
CLUSTER STRATEGY FORMS BASIS OF OUR ECONOMIC ANALYSIS.

CLUSTER STRATEGY => GOOD FUELING CONVENIENCE W/ SPARSE EARLY NETWORK (<1% OF GASOLINE STATIONS)

METRICS: ***Ave. Travel time*** (home -> station)

Diversion time (time to nearest station for area-wide travel)

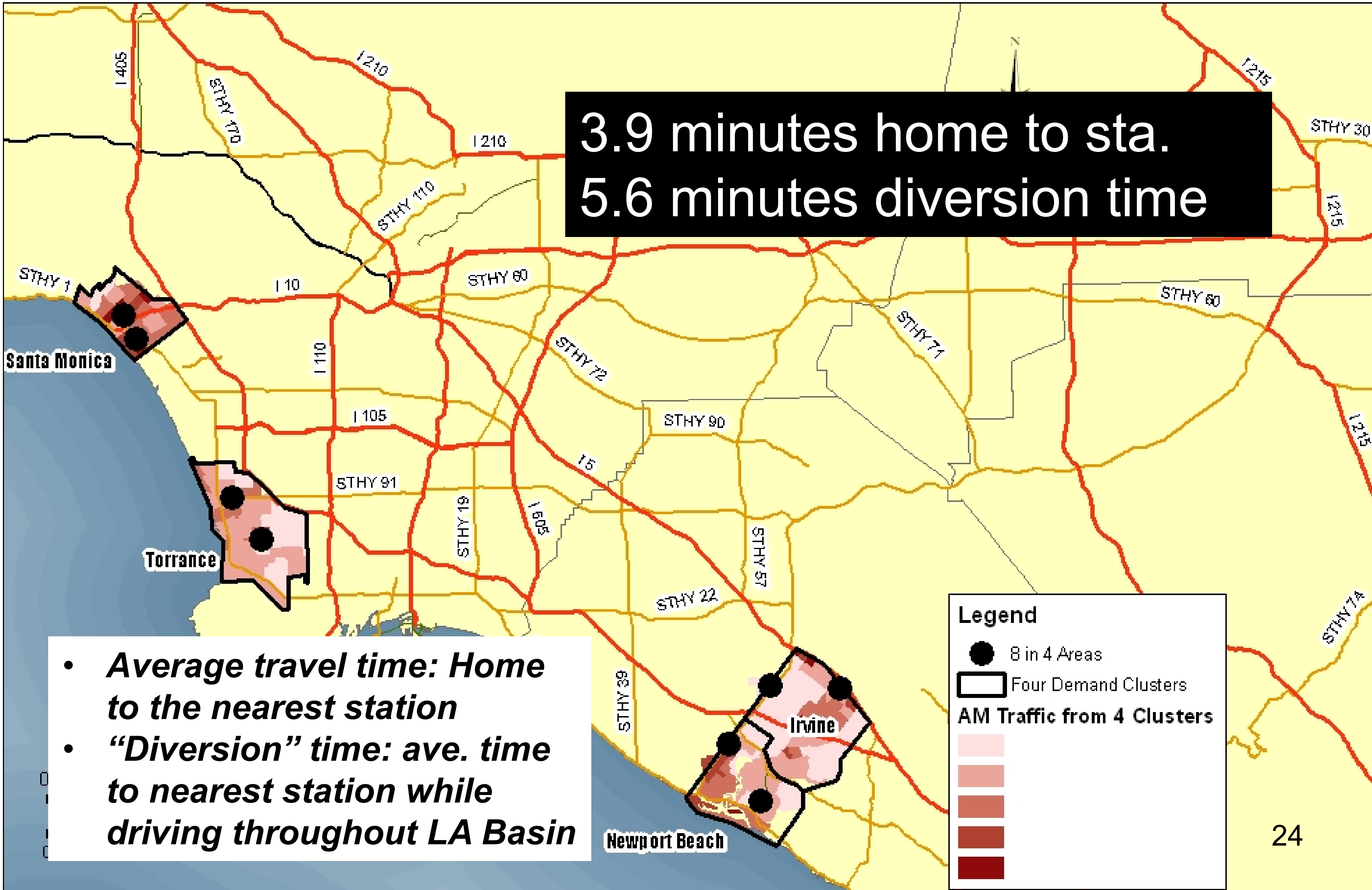
Phase 1 Phase 2 Phase 3



	636 FCVs	3442 FCVs	25,000 FCVs
# Stations	8	20	42
# clusters	4 (2 sta/cluster)	6 (3 sta/cluster)	12 (3 sta/cluster)
# connect.sta	0	2	6
Ave travel time	3.9 minutes	2.9 minutes	2.6 minutes
Diversion time	5.6 minutes	4.5 minutes	3.6 minutes

8 Station Network

4 Clusters – 2 Local Stations Per Cluster



3.9 minutes home to sta.
5.6 minutes diversion time

- ***Average travel time: Home to the nearest station***
- ***"Diversion" time: ave. time to nearest station while driving throughout LA Basin***

16 Station Network

Progess/Accomplishments

Add 8 Connector Stations => lower diversion time

3.8 minutes home to sta.
4.3 minutes diversion time