Analysis of a “Cluster” Strategy for Introducing Hydrogen Fuel Cell Vehicles and Infrastructure in Southern California

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Focus: H2 Transition in Southern California

- UC Davis “H2 FCV Roadmap” project supported by Shell Hydrogen, Toyota, Chevron, Daimler, GM, and Honda
- Developed scenarios for H2 infrastructure and FCV rollout in So. Cal. w/stakeholder input (energy companies, automakers, CA policymakers)
  - 5 stakeholder workshops held at UC Davis (2009-2010)
  - Interviews with individual stakeholders
- UCD conducted transition analysis
- Recently updated to include new data

Rollout Strategies for H2 Infrastructure

- Analyze “cluster” strategy for introducing H2 vehicles and refueling infrastructure in So. California over the next decade, to satisfy ZEV regulation.
  - Station placement within the Los Angeles Basin
  - Convenience of the refueling network (travel time to stations)
  - Economics – capital and operating costs of stations; cost of H2 station build-out for different station scenarios. Transition costs for H2 to reach cost competitiveness with gasoline on cents/mile basis
  - Options for meeting 33% renewable H2 requirement

FCVs in LA Basin

Use projected FCV numbers based on CAFCP surveys

Vehicles and stations placed in 4 to 12 “clusters” identified by stakeholders as early market sites.

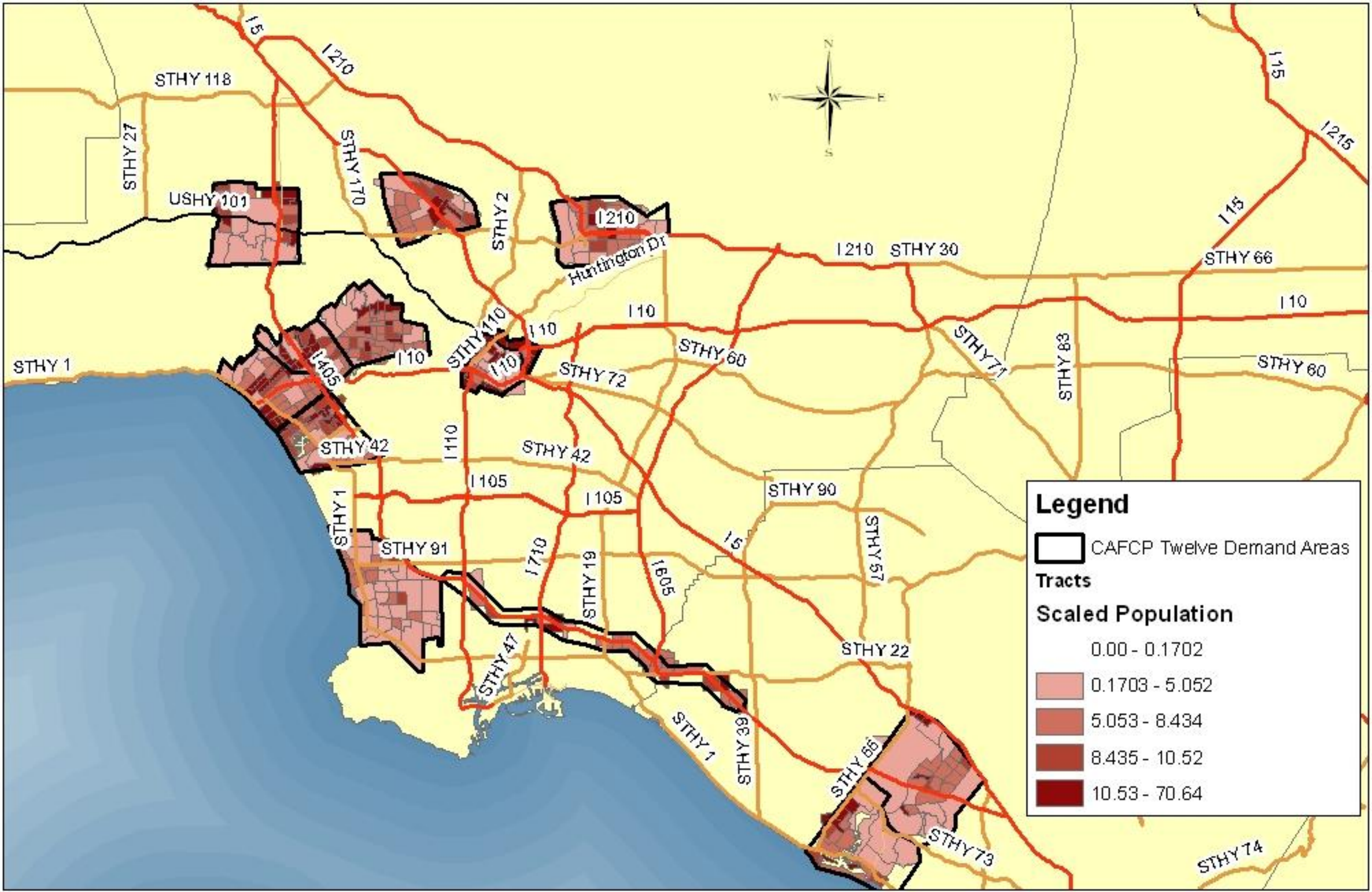
Some connector stations are added to facilitate travel throughout the LA Basin.

12 Clusters Identified by the CAFCP Survey

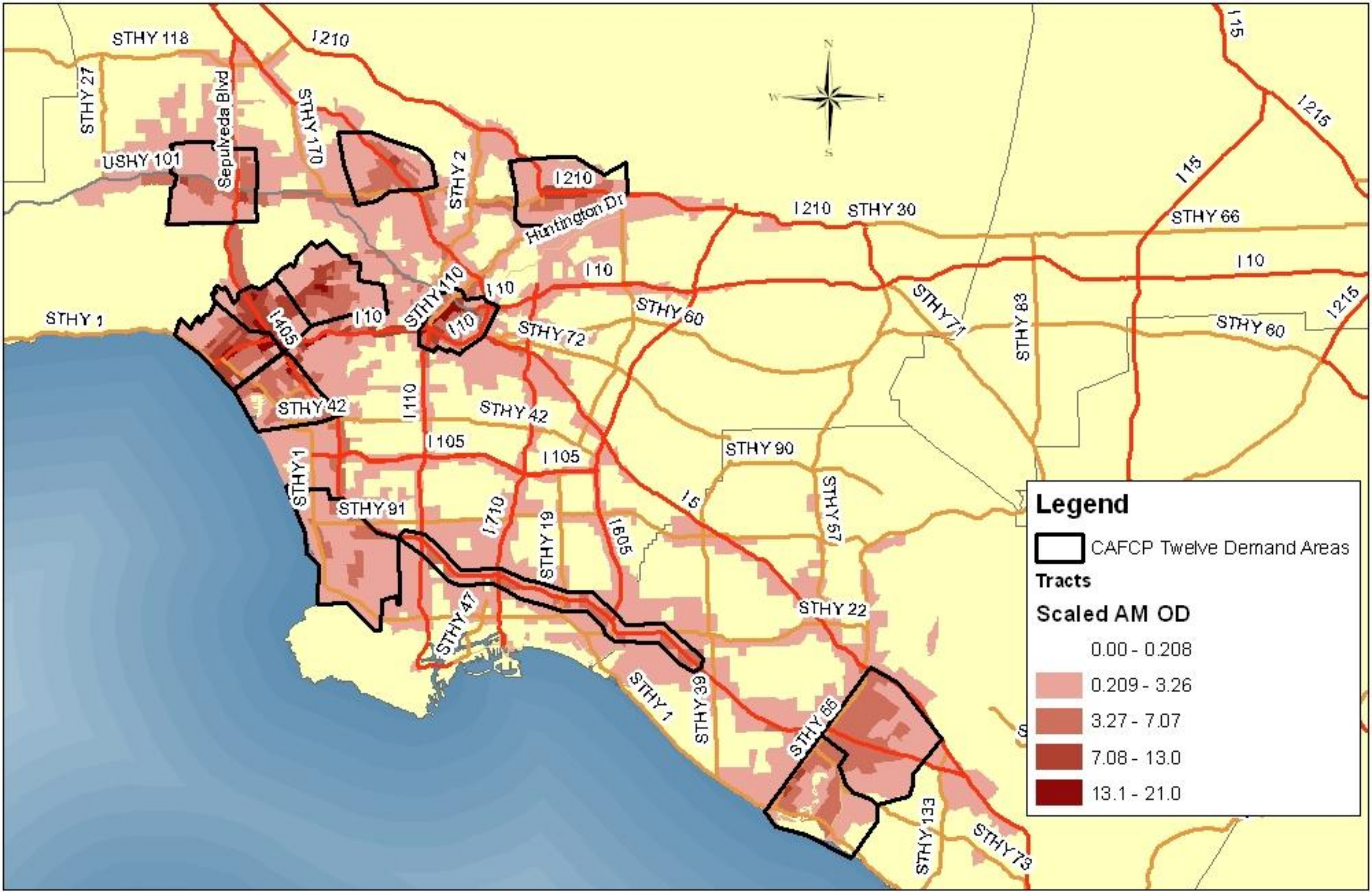
Two Ways to Measure Consumer Convenience

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

Analyzed the Population Distribution Within the 12 Clusters to Estimate Home to Station Times



Analyzed Traffic Whose Origins are in the 12 Clusters to Estimate Diversion Time

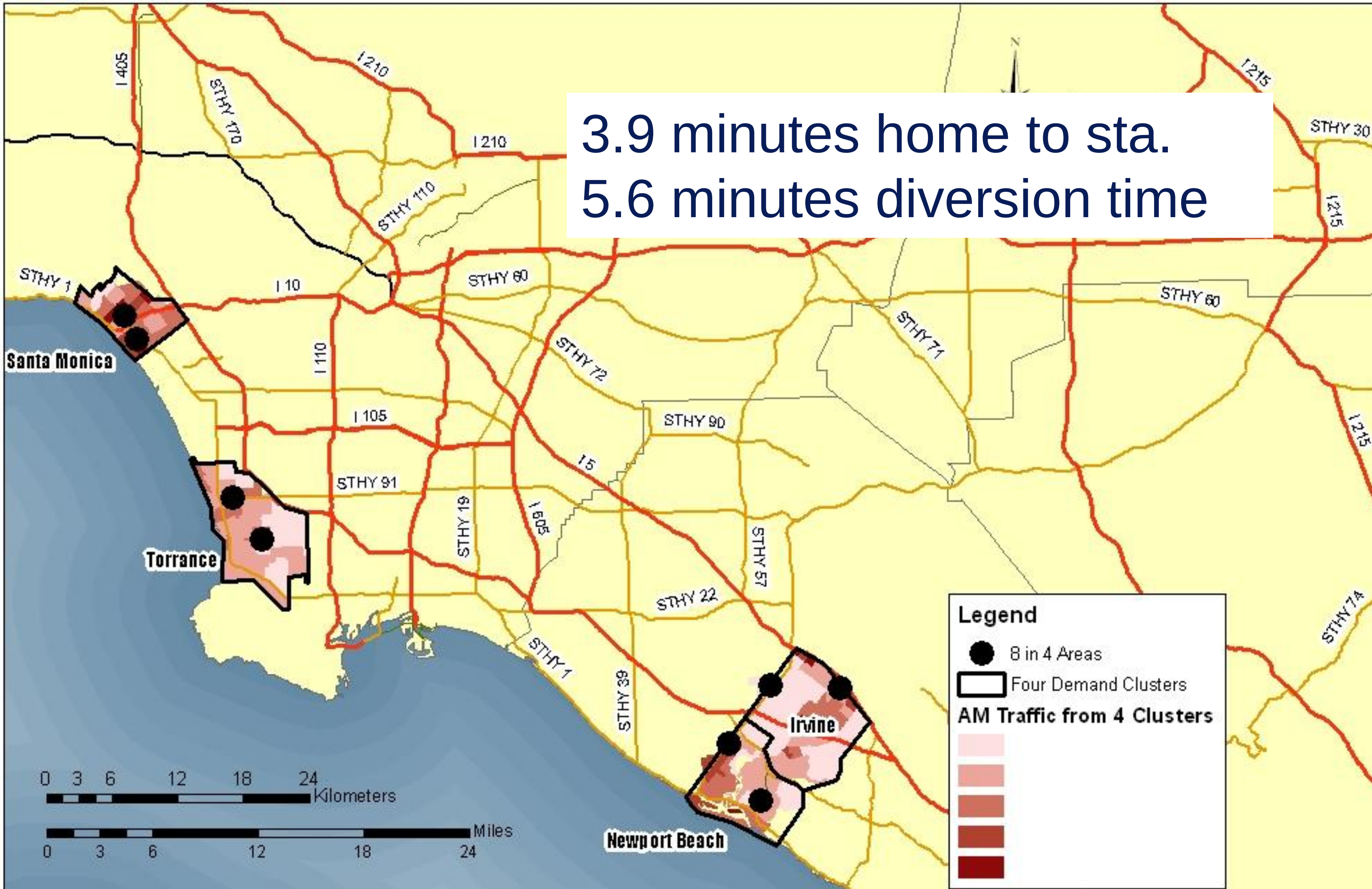


8 Station Example

4 Clusters – 2 Local Stations Per Cluster

3.9 minutes home to sta.

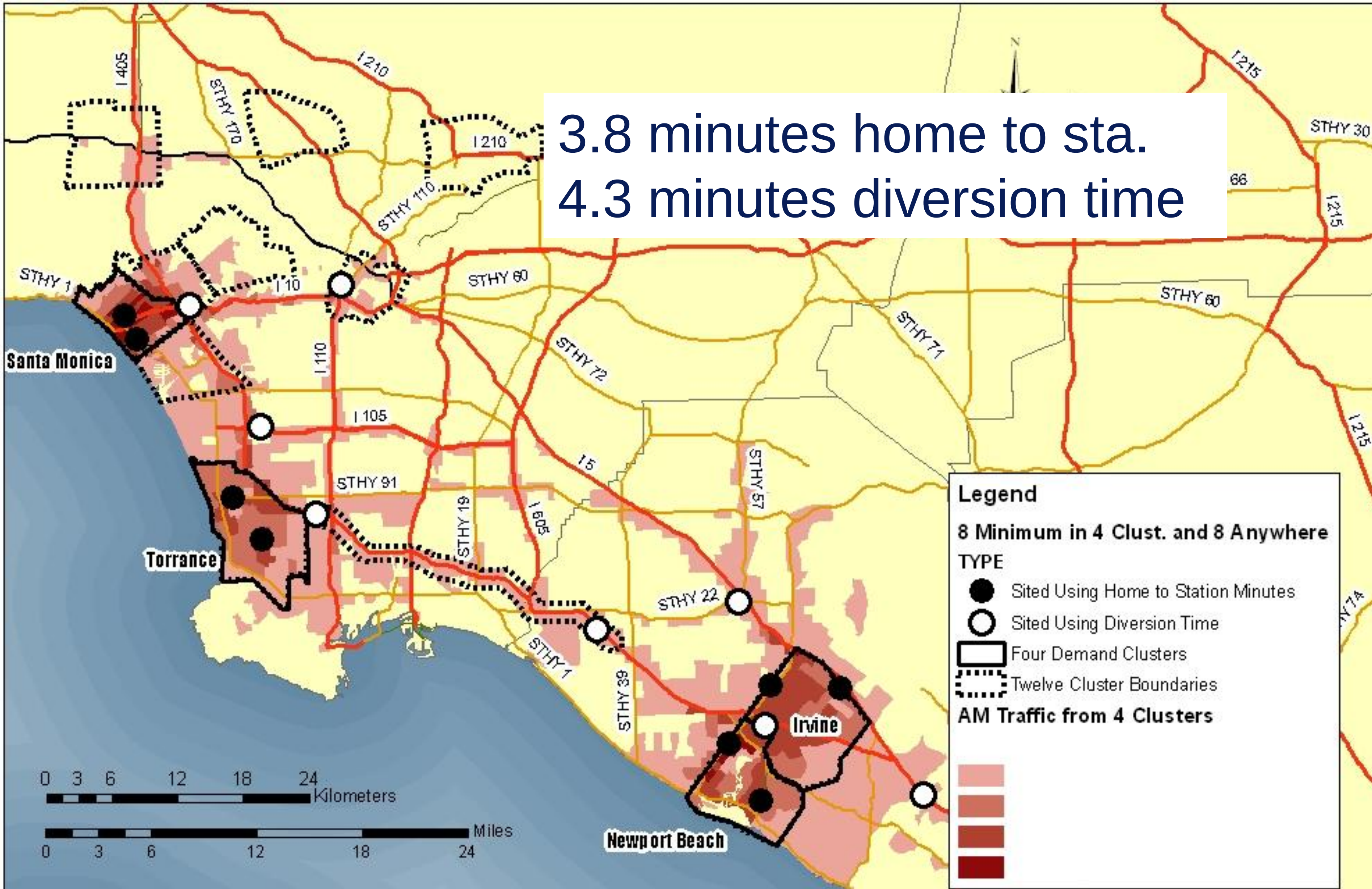
5.6 minutes diversion time



16 Station Example

Add 8 Connector Stations => Lower Diversion Time

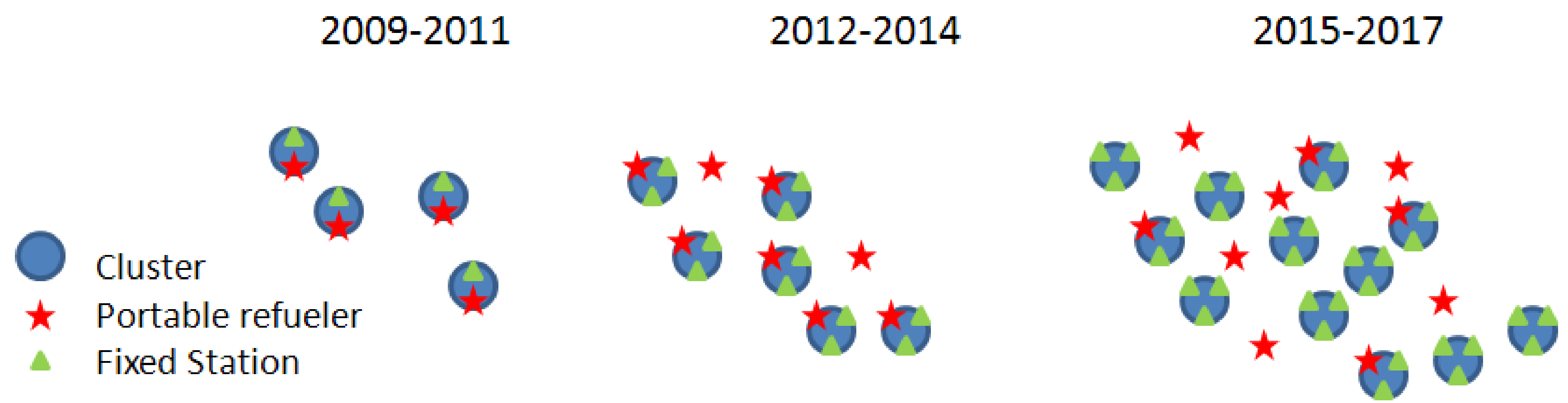
3.8 minutes home to sta.
4.3 minutes diversion time



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)

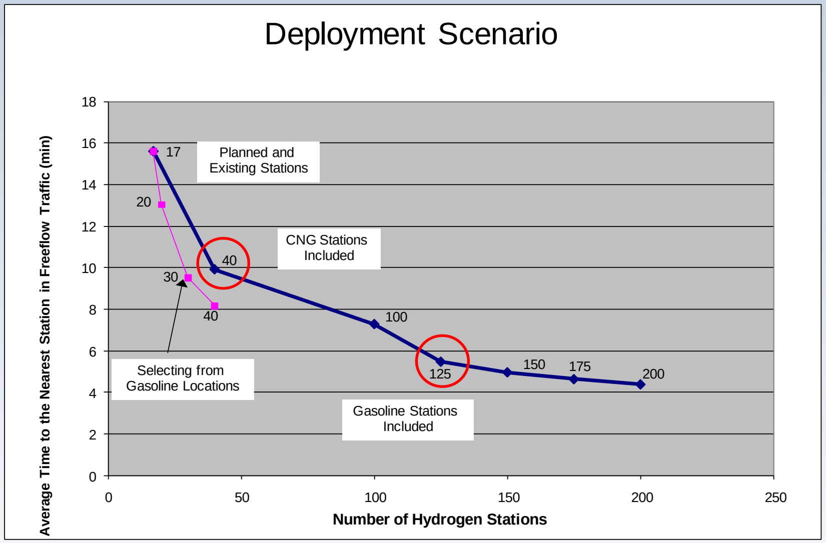


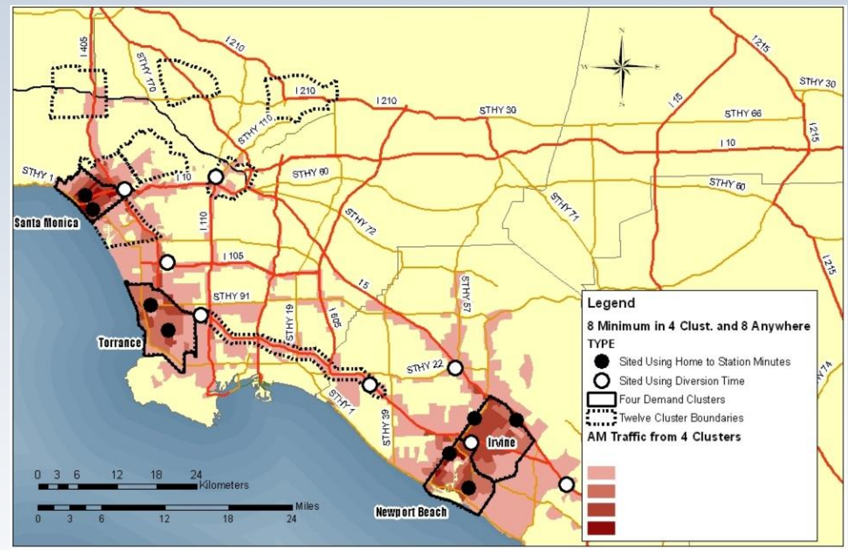
	636 FCVs	3442 FCVs	25,000 FCVs
# Stations	8	20	42
# clusters	4 (2 sta/cluster)	6 (3 sta/cluster)	12 (3 sta/cluster)
# connect.sta	0	2	6
Ave travel time	3.9 minutes	2.9 minutes	2.6 minutes
Diversion time	5.6 minutes	4.5 minutes	3.6 minutes

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

Vehicles placed by population

Cluster strategy: Co-locate early FCVs & H2 sta. in a few cities in region





H2 Pathways CA H2 Highway Network Study 2005:
Ave. travel time to 17 optimally placed stations in LA Basin

= 16 minutes

UCD H2 Rollout Study 2010:
Ave. travel time to 16 optimally placed stations in LA Basin

= 4 minutes

Nicholas, Michael A. and Joan M. Ogden (2010) An Analysis of Near-Term Hydrogen Vehicle Rollout Scenarios for Southern California. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-10-03.

Economic Analysis (2010 report):

Station Capital Cost Assumptions

- H2 station costs (2009-2011) based on interviews with energy company experts reflecting today's costs.
- For future fixed stations, assume $2 million for site prep, permitting, engineering, utility installation, for a green-field site before any fuel equipment goes in. H2 equipment costs are added to this.
- For 2012-2014, equipment costs = 2X H2A "current tech"
  - Rationale: H2A is based on 500 units per year. If we reduce this by a factor of ~50-100 to reflect 2012-2014 production of stations (5-10 stations per year), the equipment cost should be about 2 times the H2A estimate.
- For 2015-2017, analyze two cost cases:
  - 1) **Low Cost**: assume that the H2A current equipment costs are appropriate (we are building 100 stations/yr in LA and elsewhere, if FCVs are "taking off")
  - 2) **High Cost**: Costs are the same as in 2012-2014

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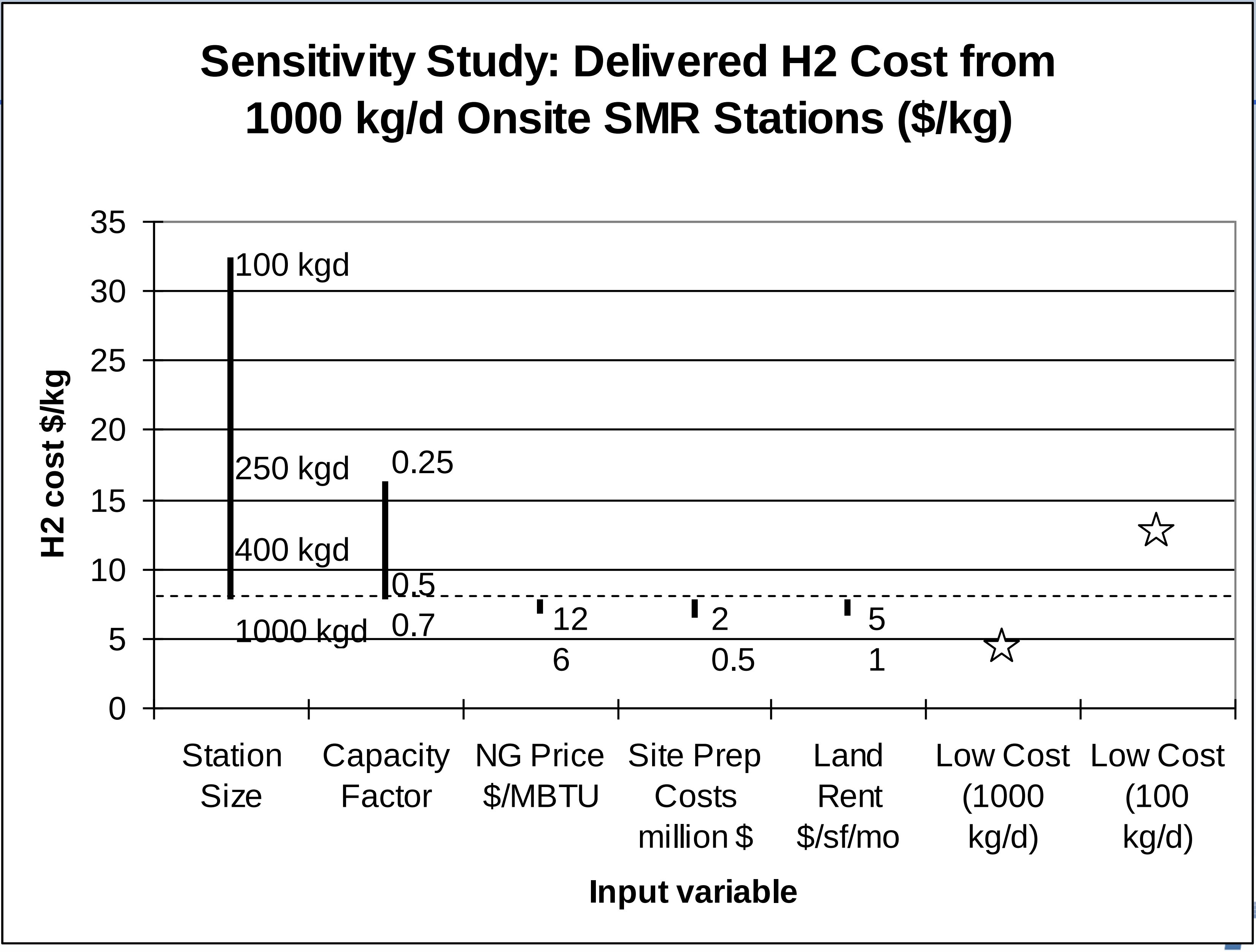
Sensitivity Study: Delivered H2 Cost from
1000 kg/d Onsite SMR Stations ($/kg)
H2 cost $/kg
35
30
25
20
15
10
5
0
100 kgd
250 kgd
400 kgd
1000 kgd
0.25
0.5
0.7
12
6
2
0.5
5
1
Station Size
Capacity Factor
NG Price $/MBTU
Site Prep Costs million $
Land Rent $/sf/mo
Low Cost (1000 kg/d)
Low Cost (100 kg/d)
Input variable
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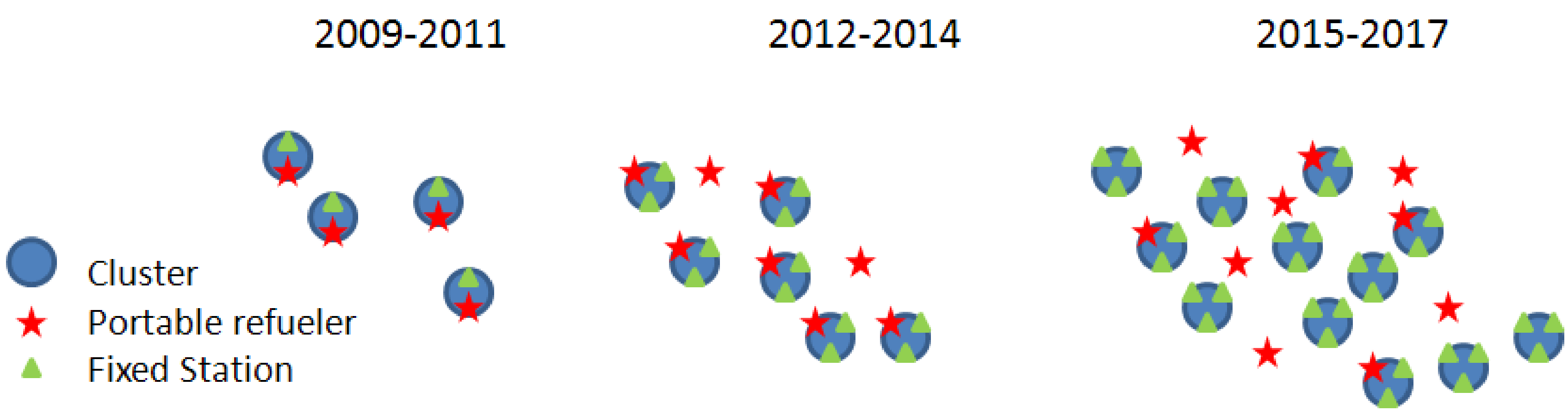
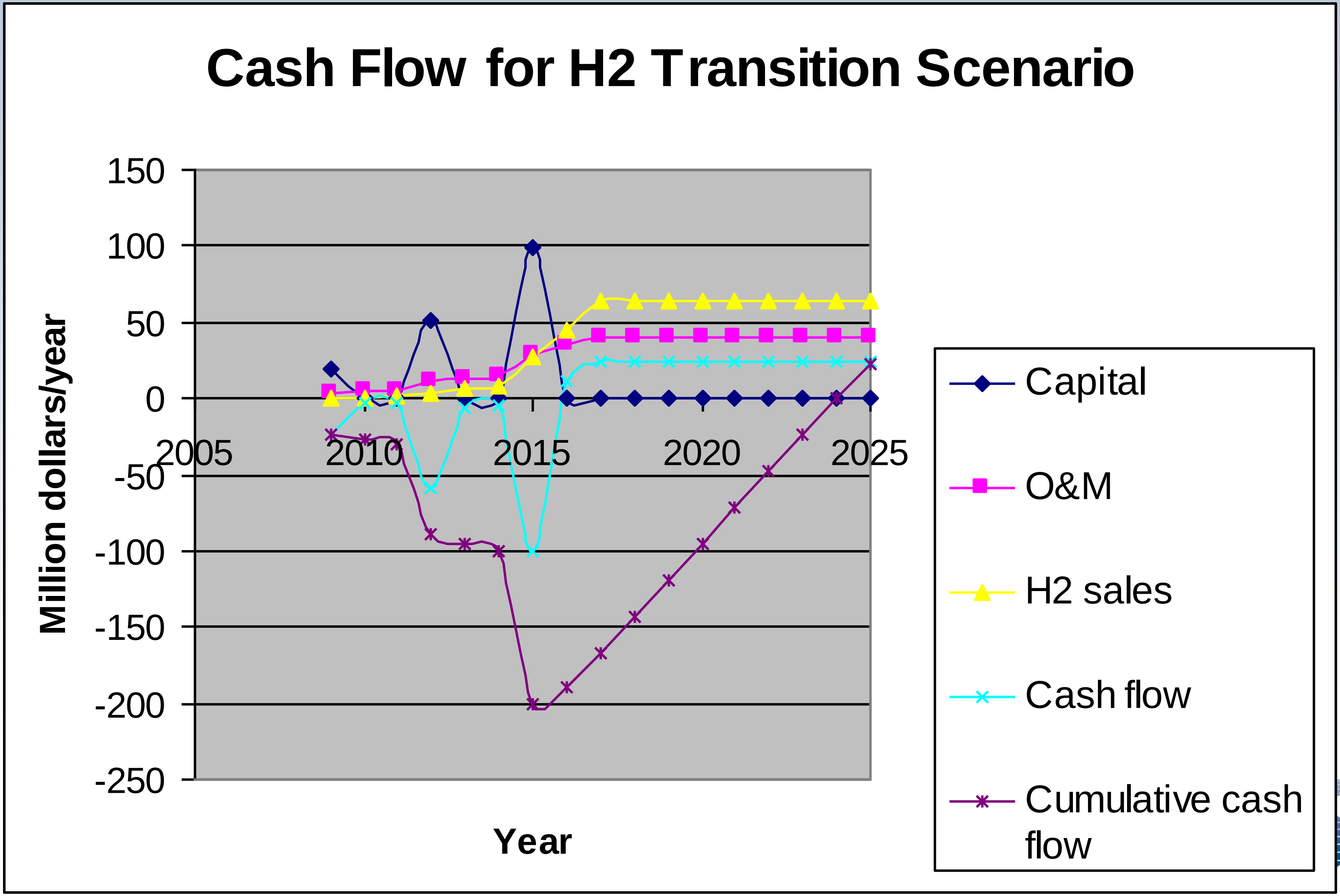
TRANSITION SCENARIO



	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
Station Mix	4 Portable refuelers 4 SMRs (100 kg/d)	8 Portable Refuelers 12 SMRS (250 kg/d)	10 Portable refuelers 12 SMRs (250 kg/d) 20 SMRs (1000 kg/d)
Capital Cost	$20Million	$52 Million	$98 Million
O&M Cost	3-5$Million/y	11-14 $Million/y	30-40 $Million/y
Ave travel time	3.9 minutes	2.9 minutes	2.6 minutes
Diversion time	5.6 minutes	4.5 minutes	3.6 minutes

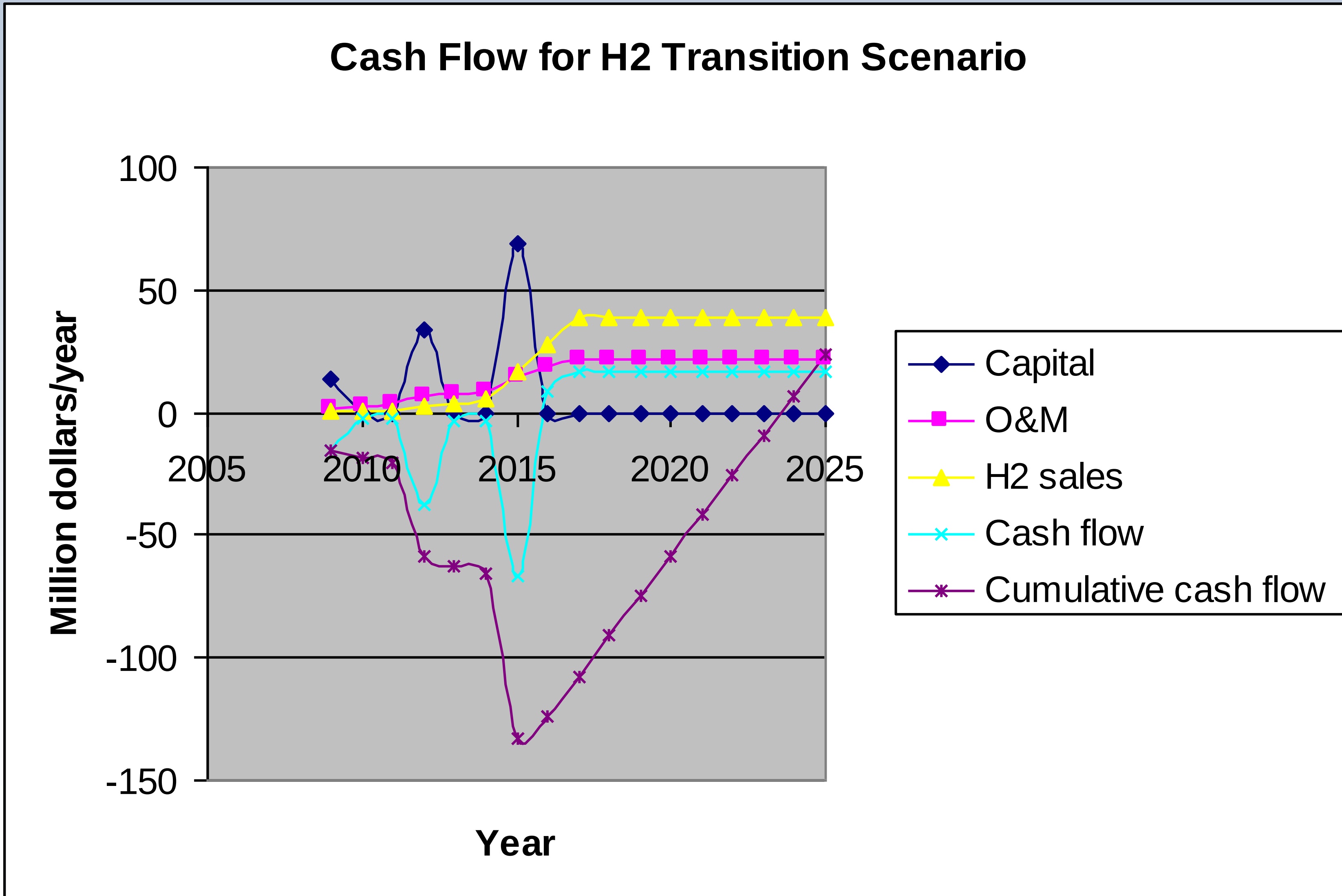
Cash Flow (H2 sold @ $10/kg)

($2 million site prep., $5/sf/mo land rent, NG=$12/MBTU)



Cash Flow (H2 sold @ $6/kg)

($0.5 million site prep., $1/sf/mo land rent, NG=$6/MBTU, low 2015-2017 station costs)



RESULTS: TRANSITION ANALYSIS

Capital investment ~$120-170 million to build 42 stations through 2015, serving 25,000 FCVs. Initially, cash flow is negative (due to initial capital expenditures to build the stations). With growing demand, cash flow becomes positive after 2015.

By 2020-2025, the total investment can be recouped, if H2 from these early stations is sold @$6-10/kg.

Entre to a "Business Case" Beyond 2017. Once the hydrogen demand is sufficient to support fully utilized 1000 kg/day stations (probably starting after 2017), hydrogen could be produced at $5-7/kg, (competitive on a fuel cost per mile basis with gasoline at $3-4.3/gallon, comparing a gasoline hybrid and a fuel cell vehicle.)

2011 UCD Case Study: Low Cost Gaseous H2 Truck Delivery

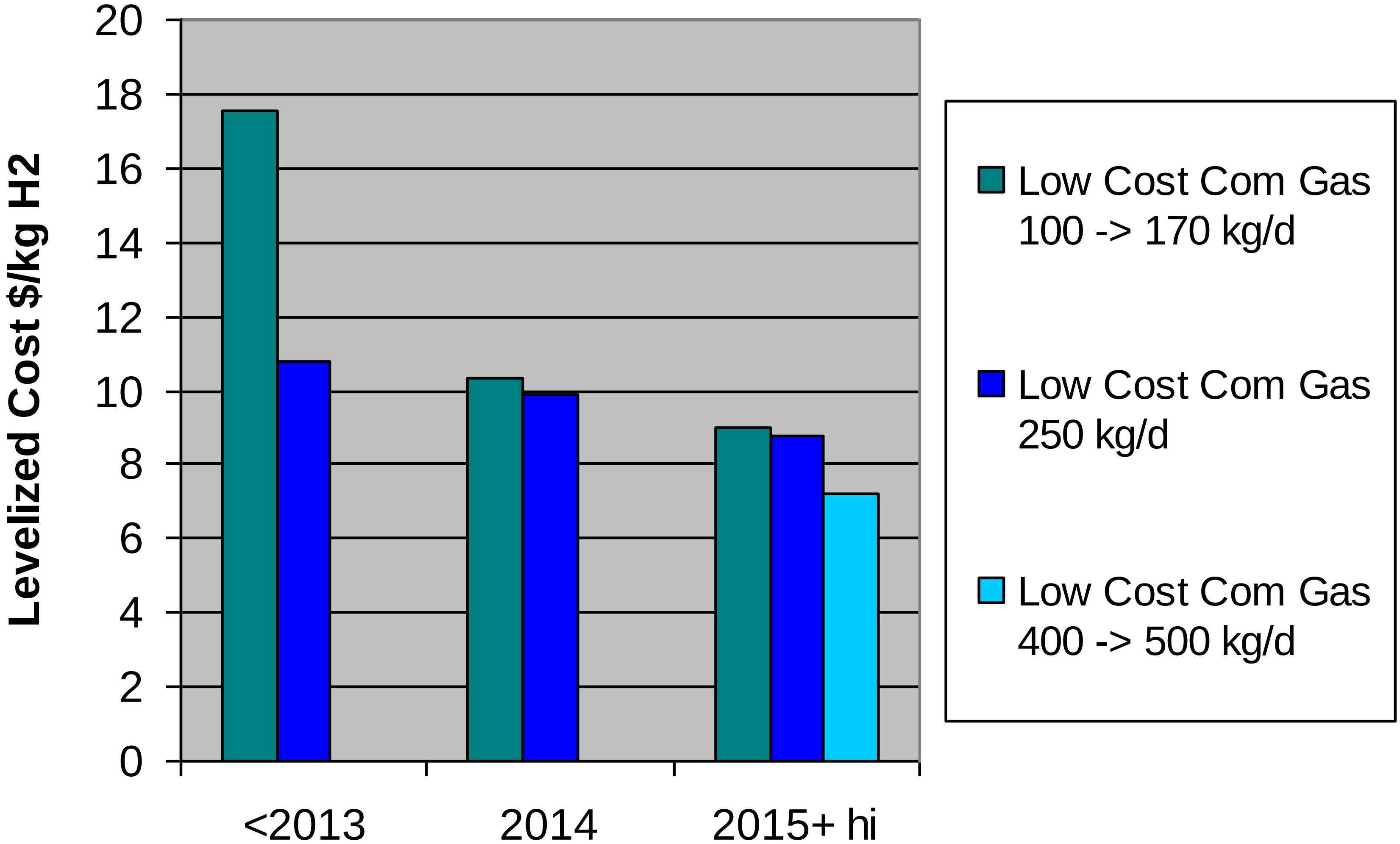
- Update FCV numbers from CAFCP 2010 survey
- Examine strategy of many small low cost stations based on gaseous truck delivery of low cost H2
- Reduce initial capital costs

Station Cost Assumptions: UPDATED 9/15/11

Low Cost Compressed gas truck delivery for 700 bar dispensing.

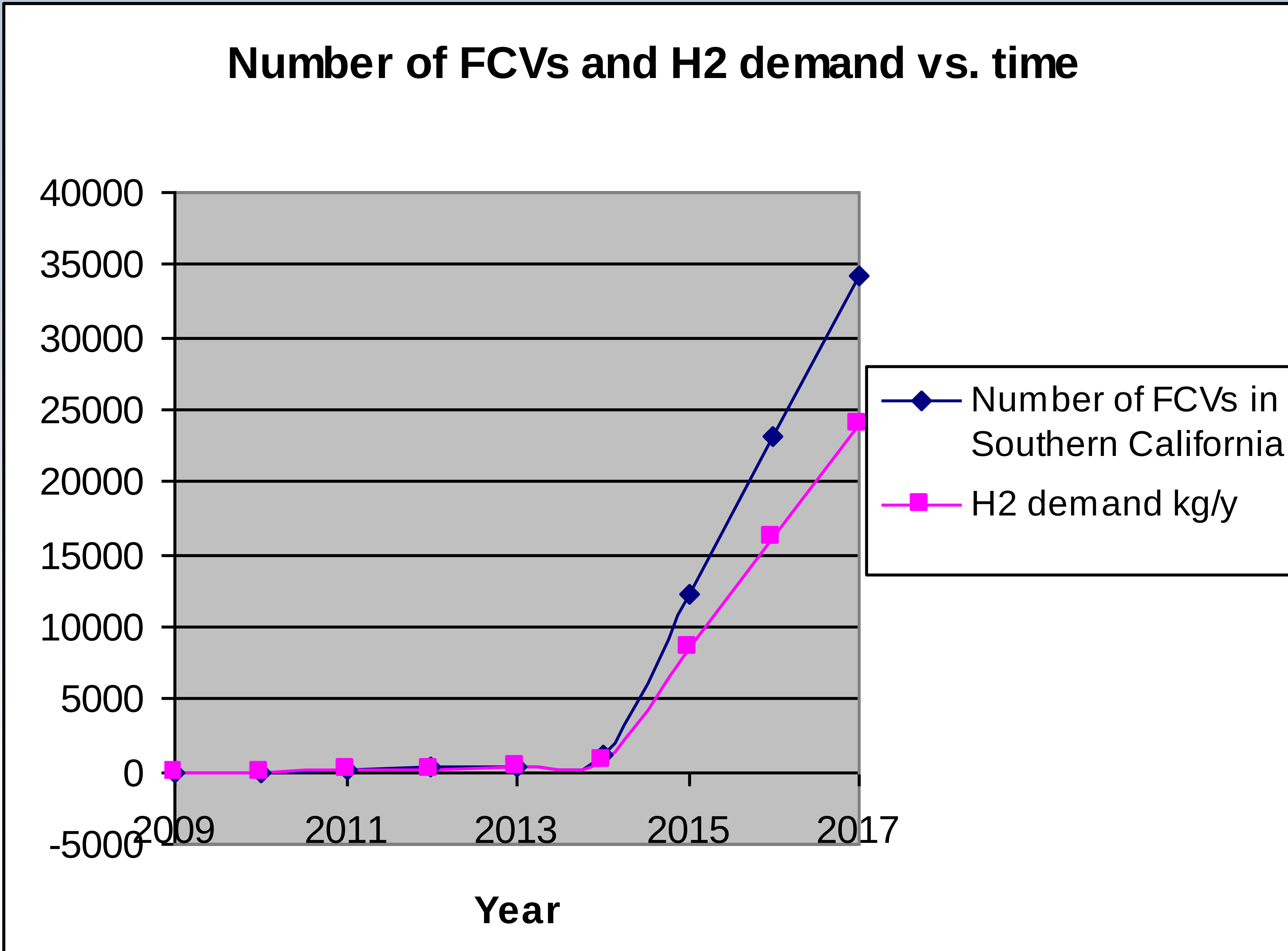
Time frame	Capital Cost	Annual O&M cost $/yr
Phase I (<2013) 100 kg/d -> 170 kg/d 250 kg/d (has more ground storage)	\$1 million \$1.5 million	\$100 K (fixed O&M) + 1 kWh/kgH2 x kg H2/yr x \$/kWh (compression elec cost) + H2 price \$/kg x kg H2/y (H2 cost delivered by truck)
Phase 2 (2014) 100 kg/d 250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

Levelized H2 Cost < $10/kg



Transition Study: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

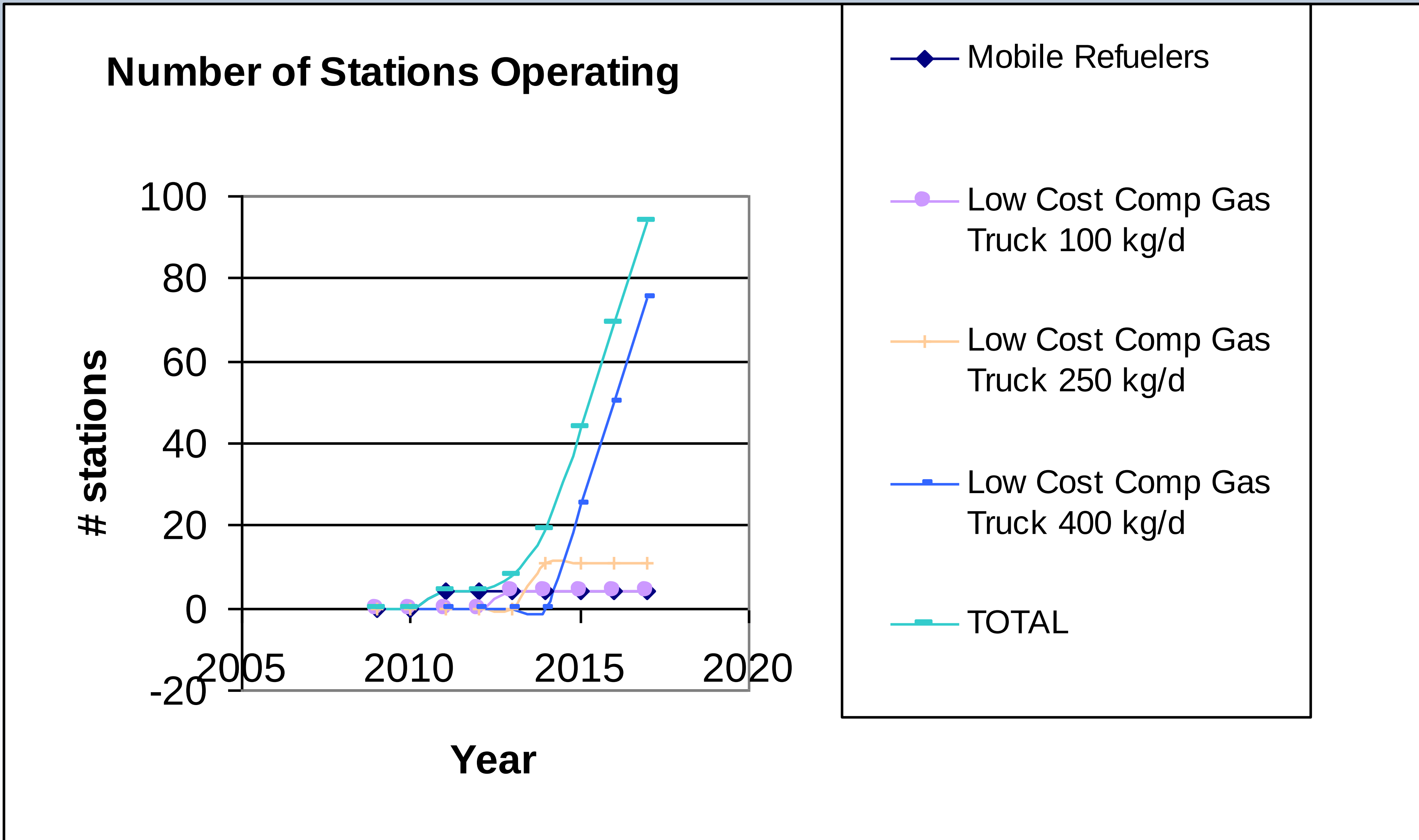


Number of FCVs and H2 demand vs. time
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
2009
2011
2013
2015
2017
Year
Number of FCVs in Southern California
H2 demand kg/y

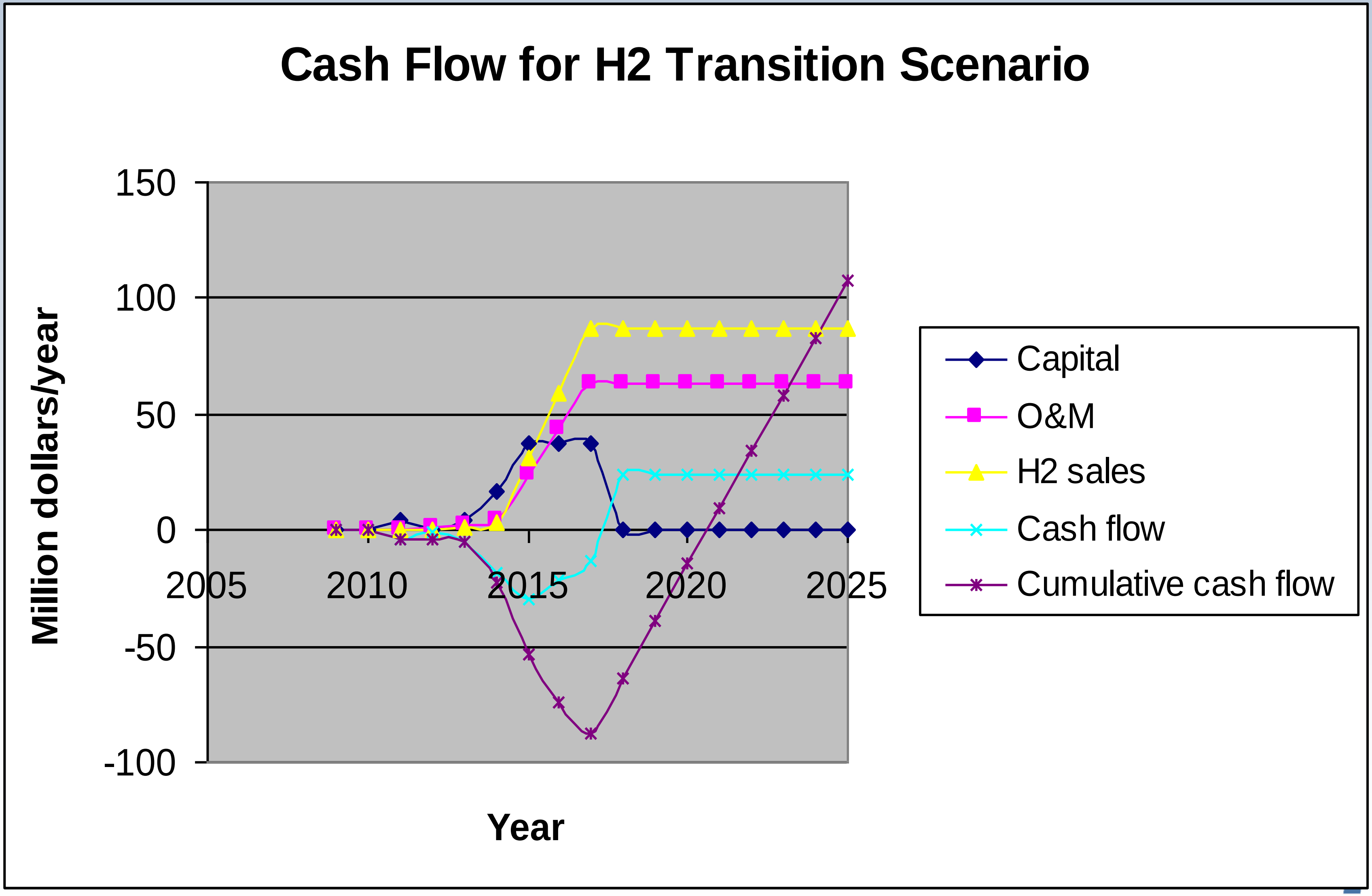
New stations added vs. year (94 total in 2017)

#New Sta	2011	2012	2013	2014	2015	2016	2017
Mobile Refueler	4	0	0	0	0	0	0
Compressed Gas Truck Delivery							
100 kg/d	0	0	4	0	0	0	0
250 kg/d	0	0	0	11	0	0	0
400 kg/d	0	0	0	0	25	25	25
Total sta. capacity (kg/y)	400	400	800	3550	13550	23550	33550
# FCVs in fleet	197	240	347	1161	12106	23213	34320
H2 demand (kg/y)	137	168	250	800	8500	16000	24000

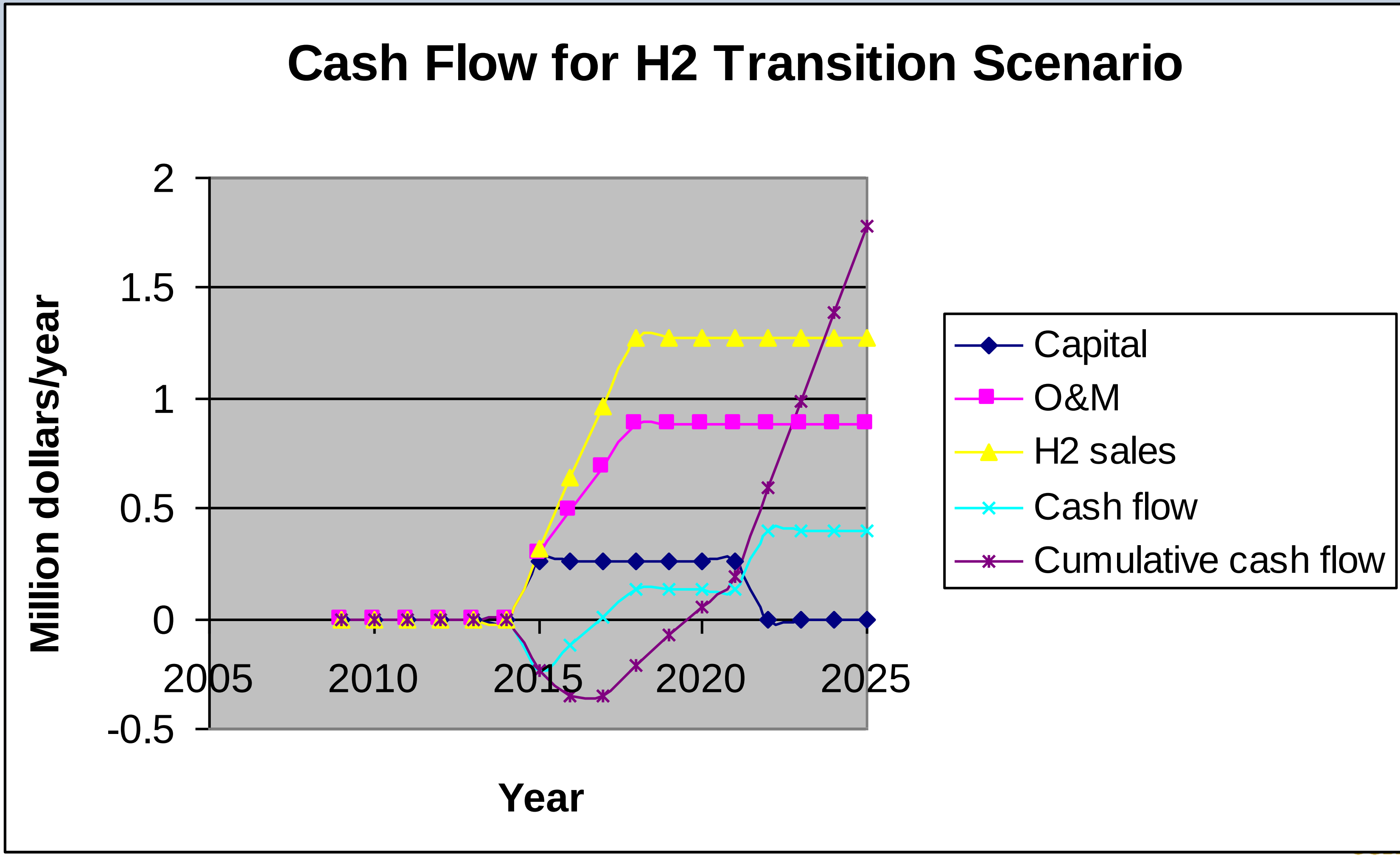
New stations added vs. year (94 total in 2017)



Cash Flow: Delivered compressed H2 @$6/kg, H2 selling price $10/kg. Sta. cap invest.=$137 million



CASH FLOW: SINGLE 400 -> 500 KG/D STATION. Delivered compressed H2 @$6/kg, H2 selling price $10/kg. $1.5 million capital cost. Ramp up demand to 500 kg/d output over 4 years. 5.5% 7 year loan.



Preliminary Conclusions

- An early strategy with many small low cost stations can yield H2 costs of <$10/kg. The levelized H2 cost comes down with sta.size, the overall capital investment for 94 stations is $137 million.

- If the difference

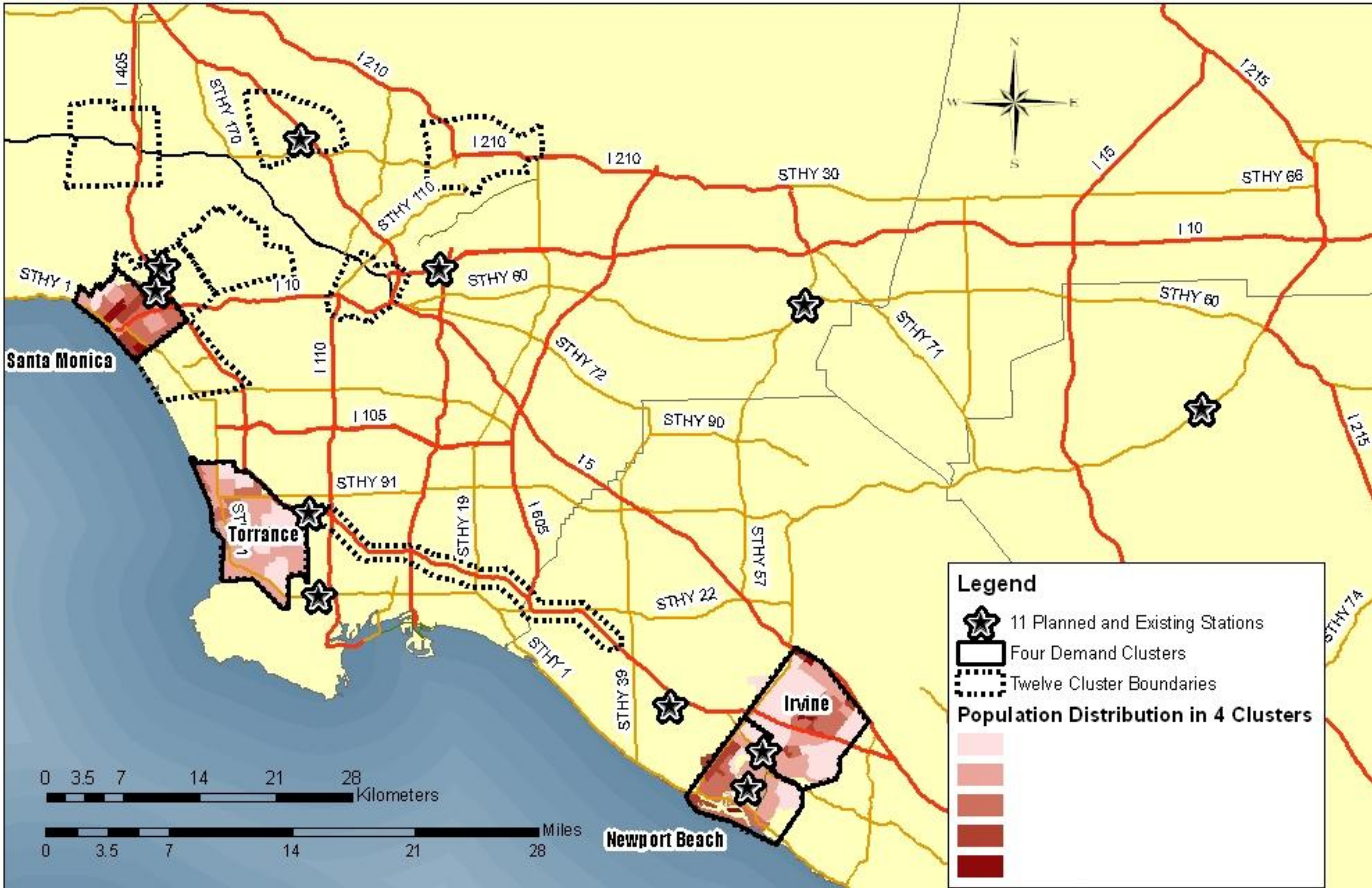
(H2 selling price) – (truck delivered H2 cost) ~ $4/kg, the network breaks even in <10 years.

Proposed Study

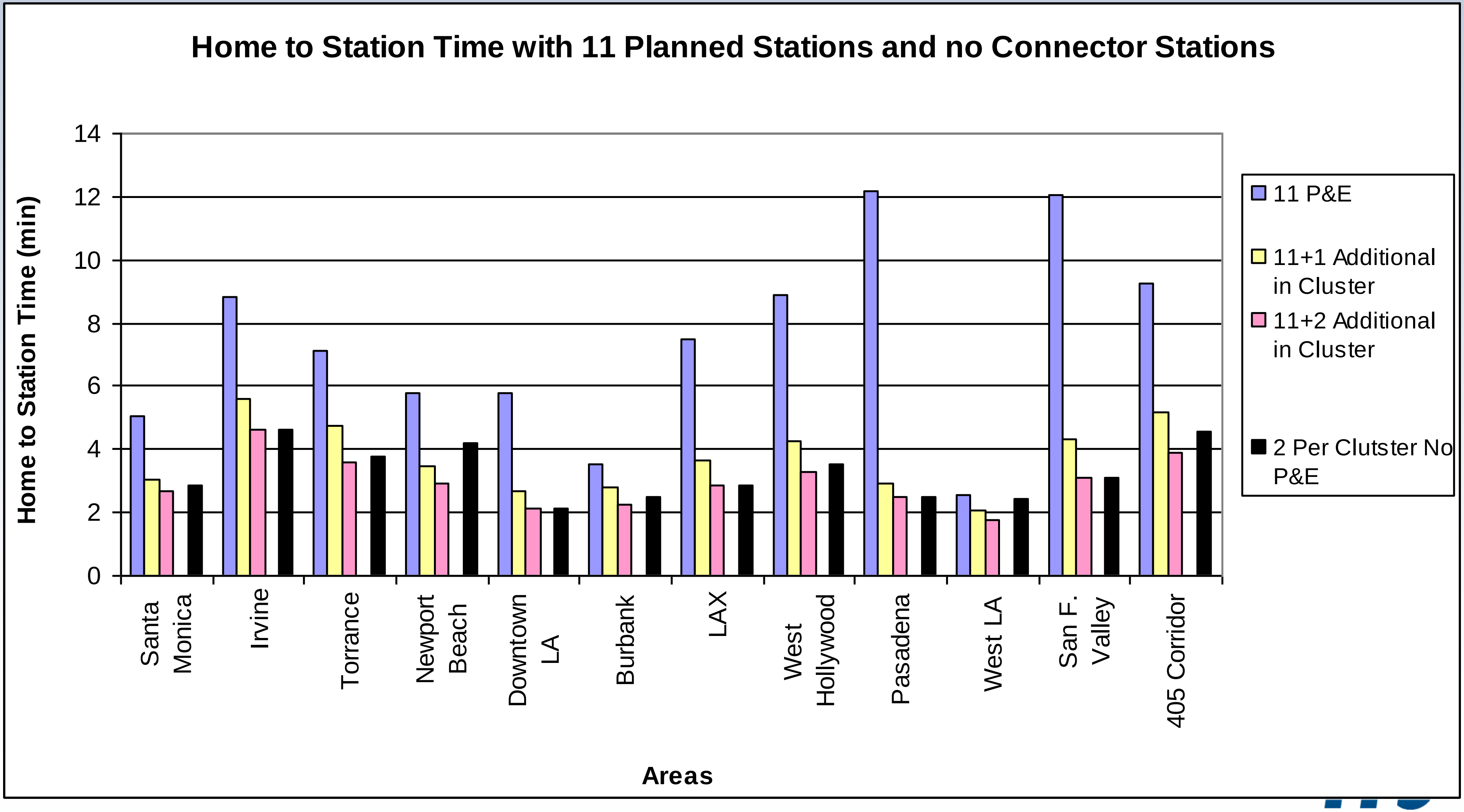
- Look at build-up of station network in clusters (including consideration of existing stations)
- Analyze Costs over time based on advanced truck delivery options over time.
  - Network of stations
  - Single station
- Benchmark with other models

extras

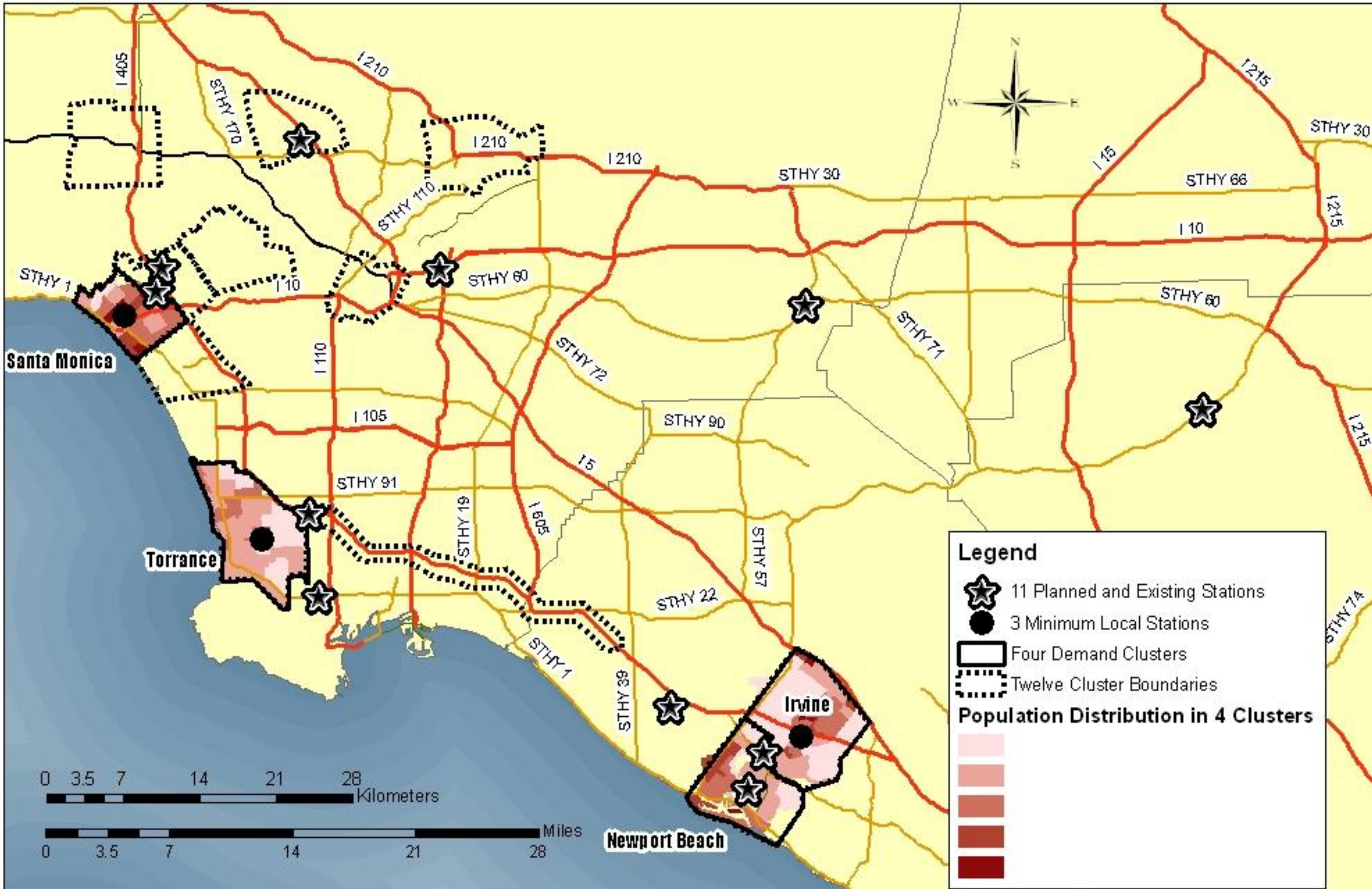
Integrating Existing Stations Into the Network



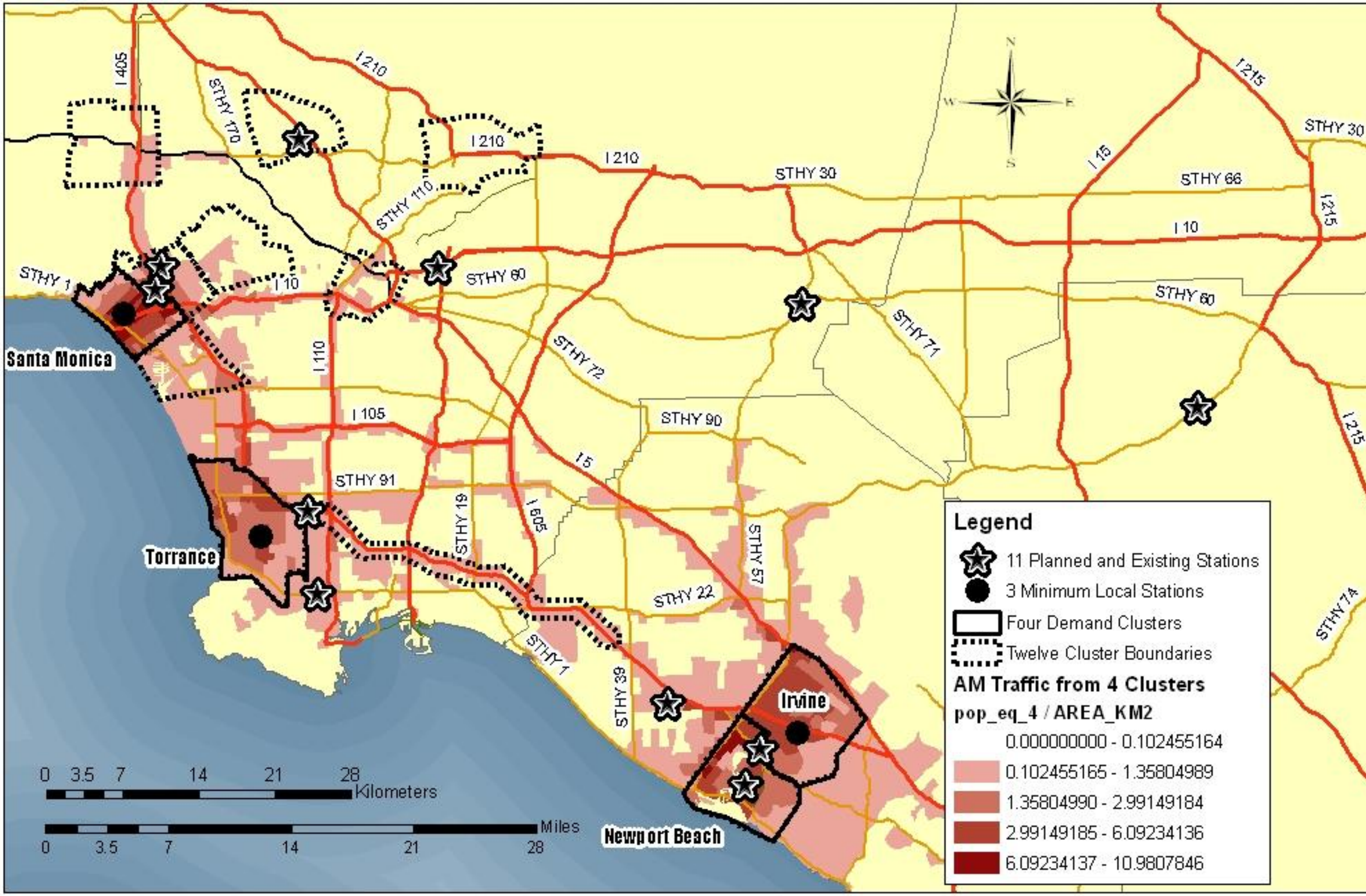
Existing Stations Home to Station Time



Add Three "Minimum" Local Stations



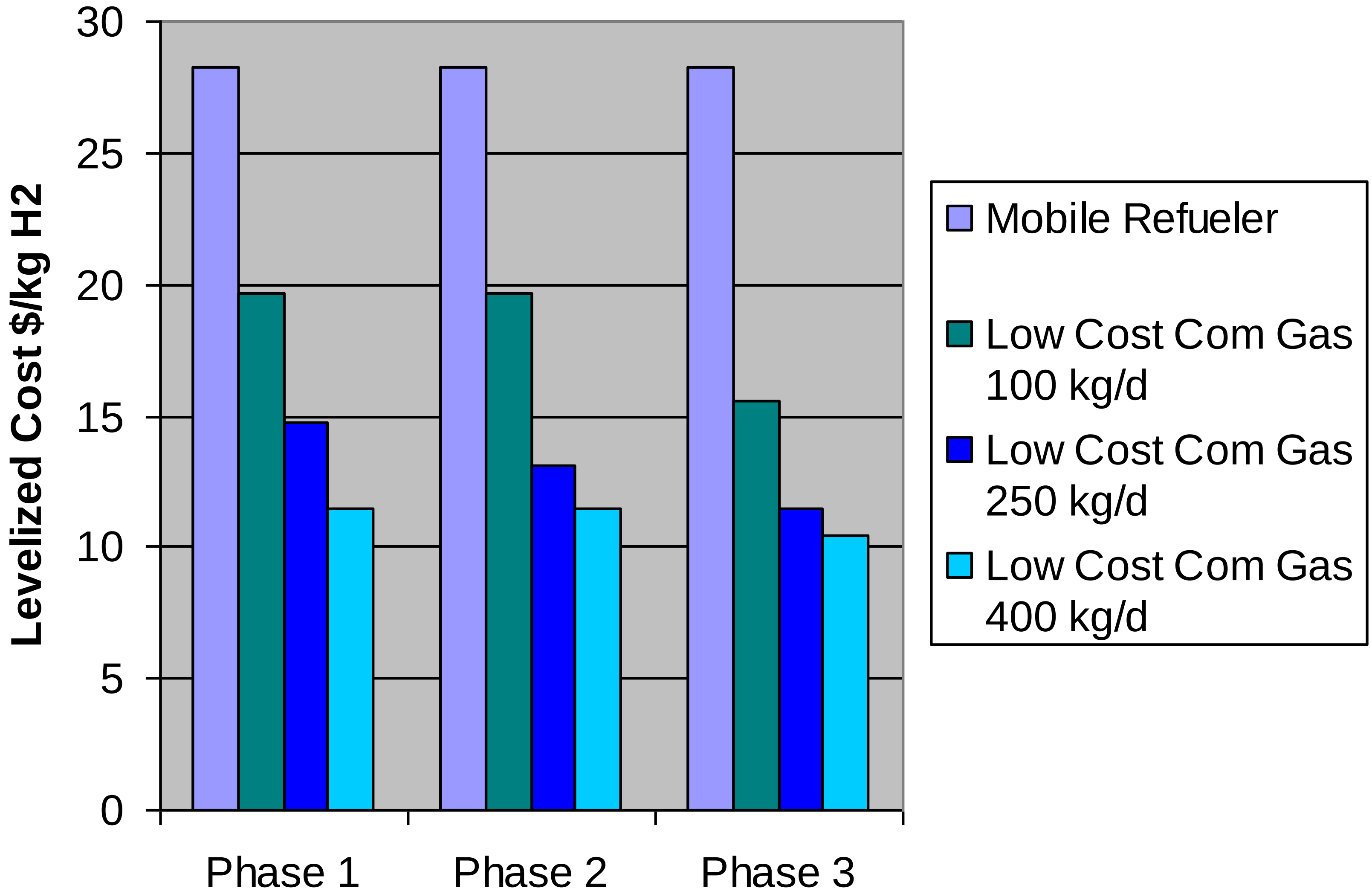
Existing Stations Can Serve as Connector Stations



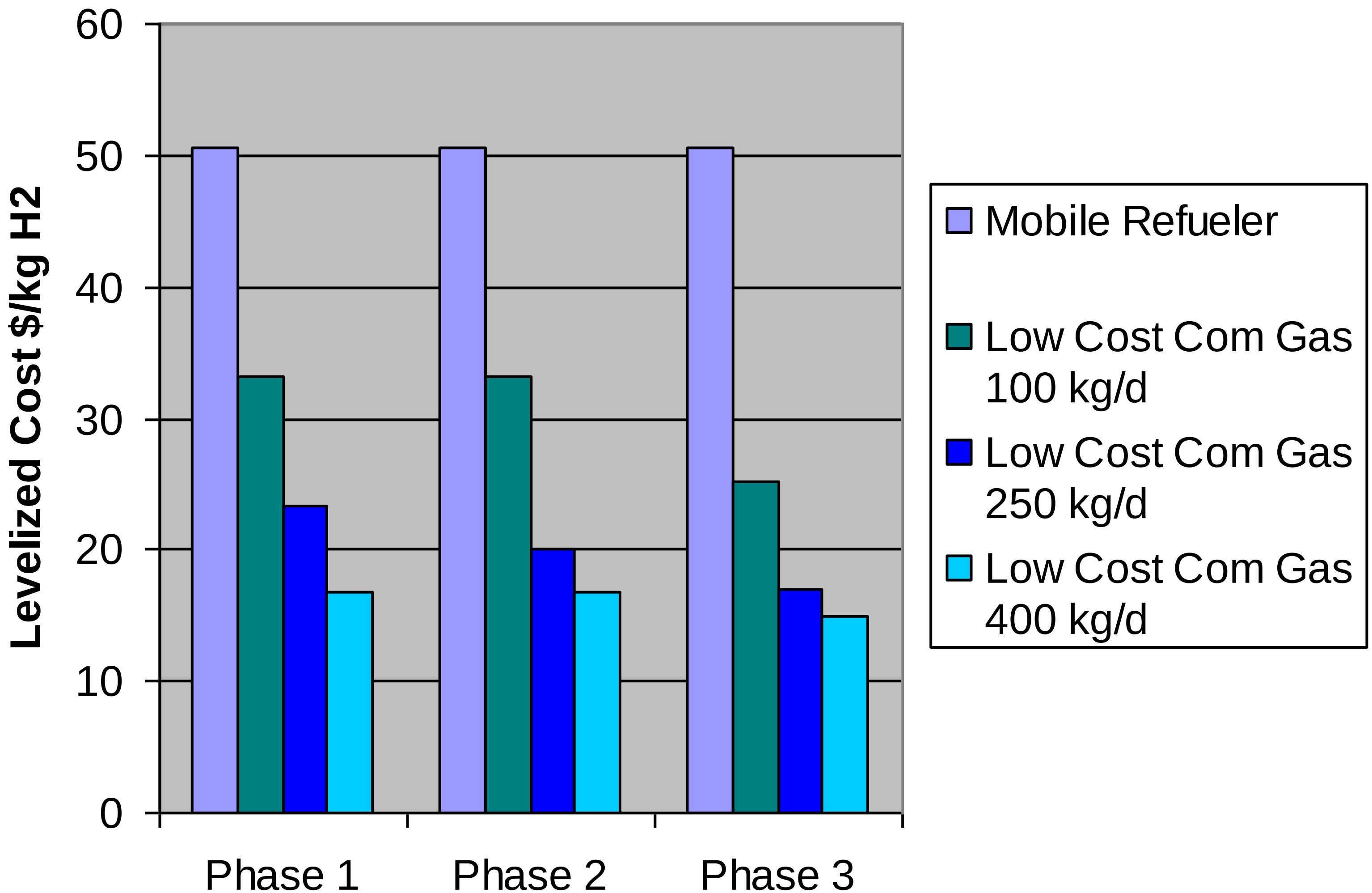
Effect of Planned and Existing Stations in Scenarios

- Network of 11 planned and existing (P&E) stations generally well placed, but some are not in clusters
- In most cases:
  - Home-to-station travel time with P&E station network is signif. greater than w/ cluster strategy (2 sta/cluster)
  - Need to add 1 or 2 stations per cluster to planned and existing network to get comparable accessibility.
- Highlights the question: Should the customers follow the existing stations or should the stations follow the customers?
- Those stations not in clusters still reduce diversion time

Levelized H2 Cost, 50% Capacity Factor

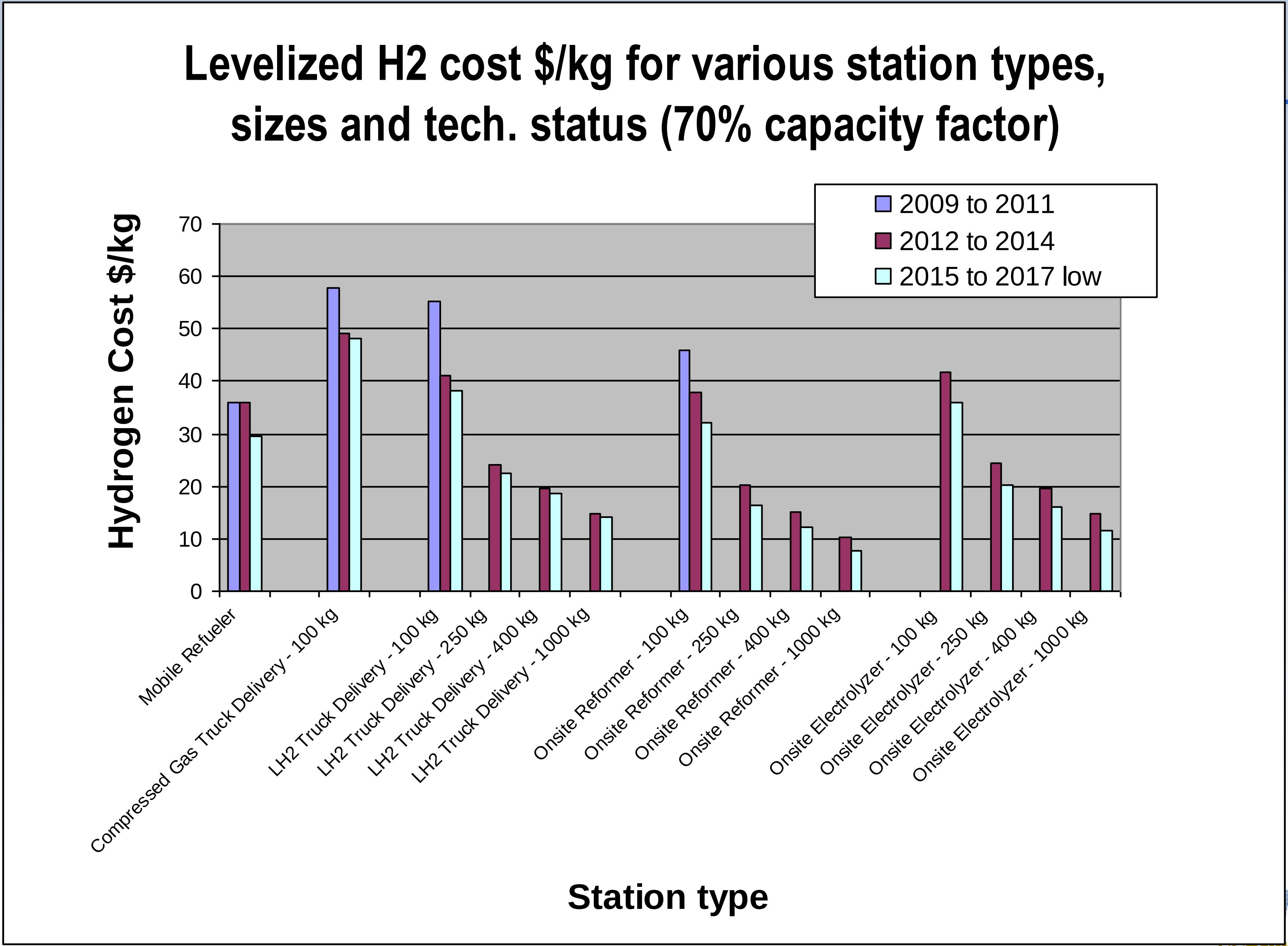


Levelized H2 Cost, 25% Capacity Factor



Transition Sensitivity Study

- The transition results are sensitive to the difference between the selling price of H2 at the pump and the cost of truck delivered H2.
- When H2 selling price – H2 delivered cost = $4/kg, breakeven happens within 10 years and the cumulative cash flow minimum is ~$80 million
- When H2 selling price – H2 delivered cost = $2/kg, breakeven takes substantially longer than 10 years and the cumulative cash flow minimum is ~$120 million



Levelized H2 cost $/kg for various station types, sizes and tech. status (70% capacity factor)
2009 to 2011
2012 to 2014
2015 to 2017 low
Hydrogen Cost $/kg
70
60
50
40
30
20
10
0
Mobile Refueler
Compressed Gas Truck Delivery - 100 kg
LH2 Truck Delivery - 100 kg
LH2 Truck Delivery - 250 kg
LH2 Truck Delivery - 400 kg
LH2 Truck Delivery - 1000 kg
Onsite Reformer - 100 kg
Onsite Reformer - 250 kg
Onsite Reformer - 400 kg
Onsite Reformer - 1000 kg
Onsite Electrolyzer - 100 kg
Onsite Electrolyzer - 250 kg
Onsite Electrolyzer - 400 kg
Onsite Electrolyzer - 1000 kg
Station type

Station Cost Assumptions: UPDATED 9/15/11

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Low Cost Compressed gas truck delivery for 700 bar dispensing.

Time frame	Capital Cost	Annual O&M cost $/yr
<u>Phase I (<2013)</u> 100 kg/d amount dispensed. Peak fueling period 8 cars per hour (40 kg/d) (COULD GO UP TO 175 kg/d for $1 million) 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 kg/d 250 kg/d	$0.9 million $1.4 million	Same as above
<u>Phase 3 (2015+)</u> 100 kg/d 250 kg/d 400 kg/d more like 500 kg/d DO NOT SHARE 400 kg/d #S, OK TO SAY IT IS POSSIBLE, ALSO TO HIGHER CAPACITIES.	$0.5 million $0.9 million $1.5 million OK TO DO A RANGE $1.5-2 million	Same as above

Expansion

- Can expand system over time by adding 20 hp -> 40 hp compressor, so the equipment.
- Start with 100 kg/d $1 million station., up to max for dispenser (8 cars per hour) 175 kg/d.
- Dispenser and storage is a unit for the station owner
- HP storage module and dispenser.7500 psia. What's in that module. Have ground storage for 700 bar requirement. Boost from trailer into intermediate ground storage for 700 bar.
- OEMs will moderate pressure at 400-450 bar. As delivery
- Eventually eliminate compression and need for ground storage.
- 230 kg of capacity on trailer. Know could go to 250kg on single module. Min trailer size is 20 foot length. Module is 10 foot. Could do two modules on 24 foot trailer, then could add a second 500 kg capacity on truck.
- Minimize distribution distances.
- 1000 kg, larger trailer and more modules. (38 foot for 3 modules)
- As 250kg ->500kg not that much extra footprint, although 3 modules would be more.
- Be flexible on capacity. From IGC perspective this.

Expansion -2

- Learning curve is flattened close to linear.
- $6/kg cost of hydrogen (might be reduced at large scale SMR H2 production.
- $1.3/kg production plus $1/kg truck delivery.
- $4/kg differential between. Goal is to come below $10/kg at station + profit
- When they do internal economic analysis with LH2,once you go beyond 200 miles LH2 attractive.
- They'd like to a scenario with lots of small stations to start with. If
- They have been active in H2 mobility. The business case in H2 mobility, once you build a large network in anticipation, if you go too large on stations the NPV to the station owner than any company would buy into.
- To start out markets with 80 kg and 220 kg stations.

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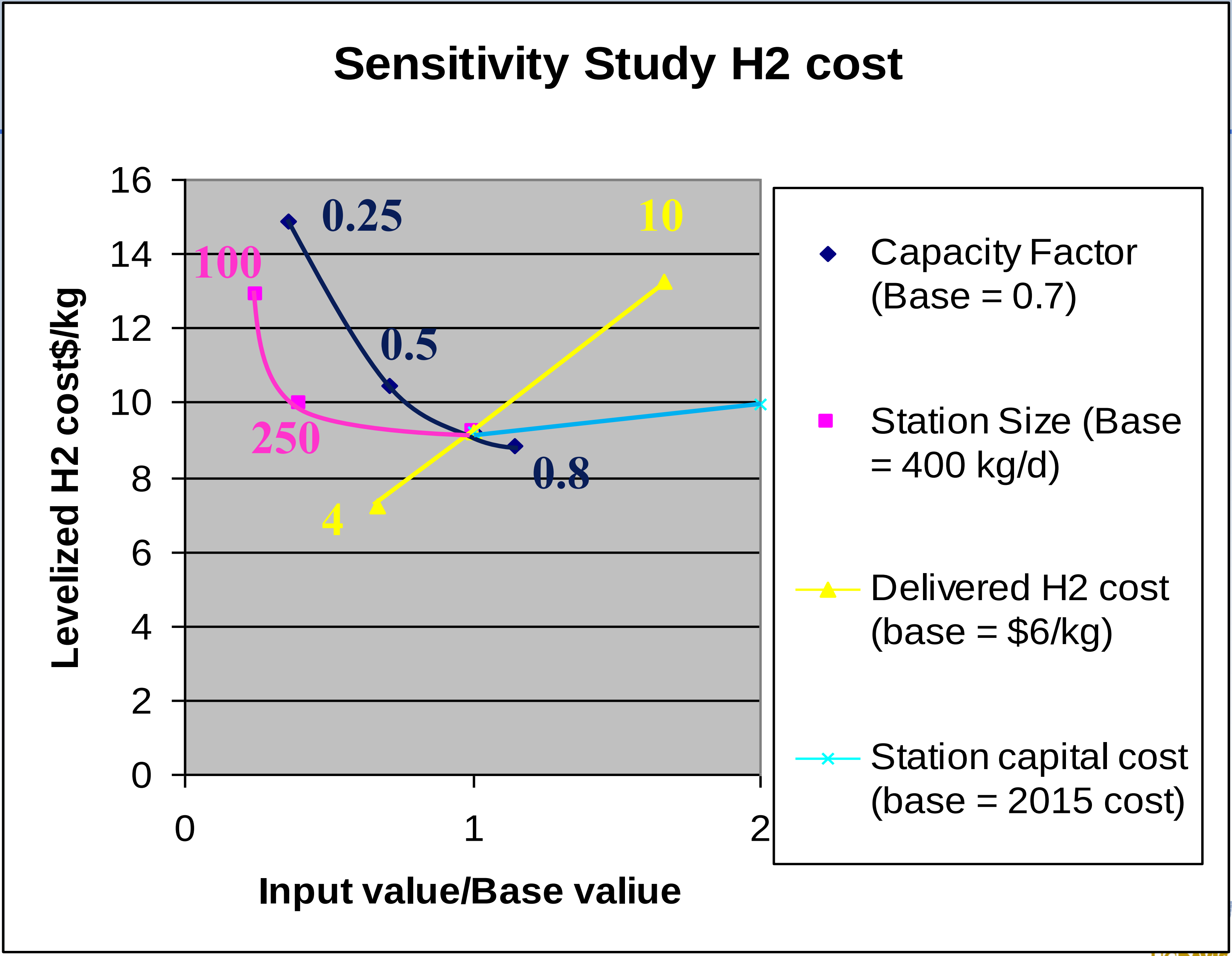
Sensitivity Study H2 cost
Levelized H2 cost$/kg
Input value/Base valiue
16
14
12
10
8
6
4
2
0
0
1
2
0.25
0.5
0.8
100
250
10
4
Capacity Factor (Base = 0.7)
Station Size (Base = 400 kg/d)
Delivered H2 cost (base = $6/kg)
Station capital cost (base = 2015 cost)

Station Cost Assumptions:
Low Cost Compressed gas truck delivery

Time frame	Capital Cost	Annual O&M cost $/yr
Phase I (<2013) 100 kg/d 250 kg/d	 $1 million $2 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)
Phase 2 (2014) 100 kg/d 250 kg/d	 $1 million $1.5 million	 Same as above
Phase 3 (2015+) 100 kg/d 250 kg/d 400 kg/d	 $0.5 million $1 million $1.5 million	 Same as above