Hyundai Motor Group's Development of the Fuel Cell Electric Vehicle

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Agenda

1. Hyundai's ECO friendly strategy
2. FCEV development at Hyundai
3. The Global Approach to FCEVs
4. An OEMs Next steps: Validation and Production

1. Global Issues

- **Paradigm shift in automotive industry is demanded due to global warming & oil depletion**
  - Transportation part captures 21% of total energy consumption, 23% of GHG emission

Global Warming

▸ **Carbon Dioxide Increase**

- CO_2 concentration in air

: 280 ppm (before industrialization) → 379 ppm (present)

: Doubled CO_2 conc.→Temp. increase 2~4.5℃ (3.6~8.1F)

▸ **Climate Change & Natural Disaster**

- Water shortage, flood & extinction of species

Oil Depletion

▸ **Expected Peak Oil**

- Future limitations on oil discovery and production

▸ **Oil consumption increase in BRICS**

- Oil consumption annual growth rate ('00~'20)

: China 4.1%, India 3.8%

- Dubai oil's annual price increase rate: 6%

: Forecast over $200/bbl in 2029

Hyundai's Eco-friendly Vehicle Strategy

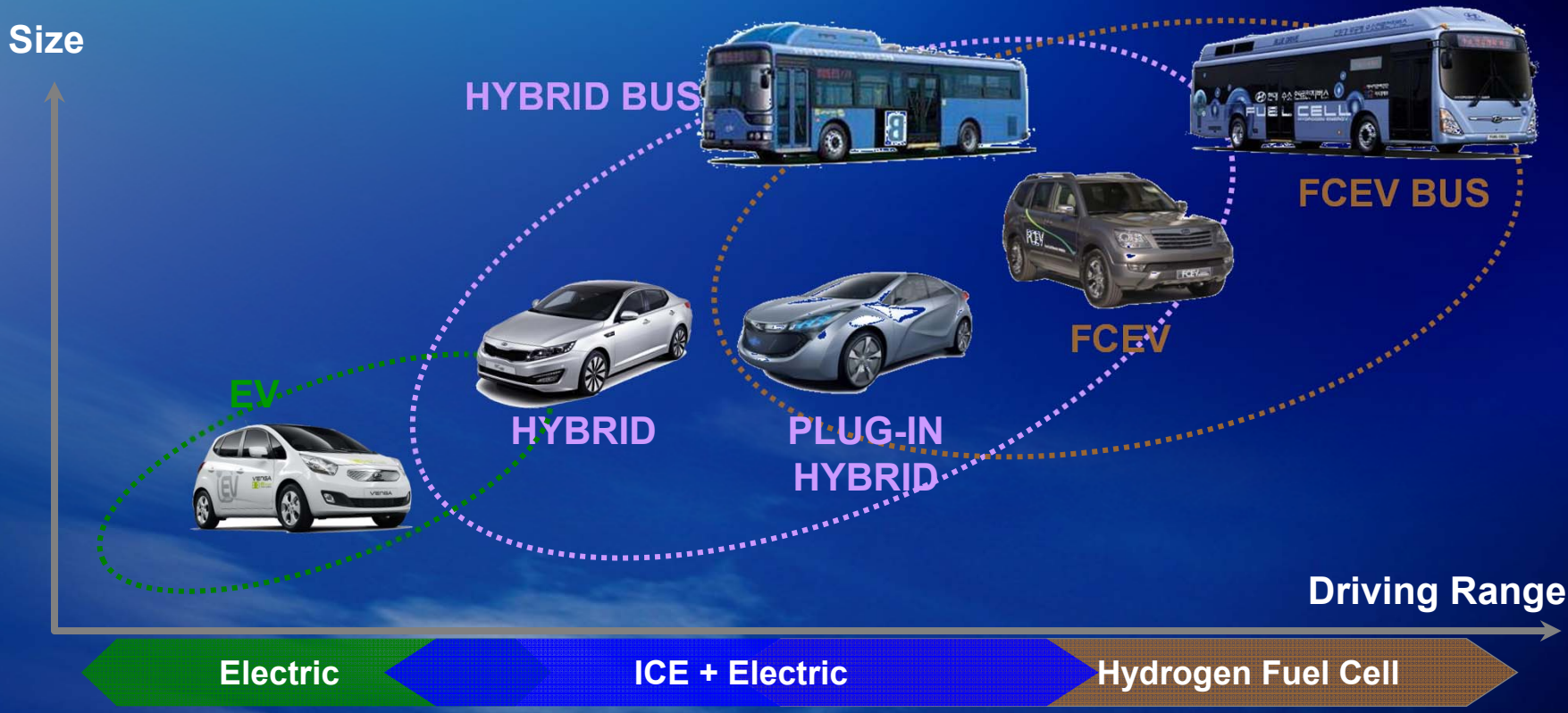
blue drive eco Dynamics

Preserving automobile mobility while creating a harmonious balance with our environment

Low CO_2 ICE	Bio Fuel	Hybrid	Plug-In	FCEV,EV
Continuous improvement of fuel economy	**Responding to regional diversity of fuel usage**	**Expanding line-up**	**Interim solution**	**Ultimate solutions**

Hyundai's Eco-friendly Vehicle Strategy

- Small vehicles for short driving range → EV
- Large vehicles for long driving range → Hydrogen FCEV



2. Fuel Cell Vehicle Development

Small Scale Production

• 2012 ~

Validation Program
(2009.12 ~ 2012.05)

- Tucson *iX* FCEV (100kW)

• 2008 ~ 2011

- Borrego FCEV (115 kW)
- FC-BUS Gen II (200kW)

Domestic Monitoring Program
(2006.08 ~ 2010.07)

• 2007

i-Blue Concept car

- Sportage FCEV-II (100 kW)
- FC-BUS II (200 kW)

US DOE Fleet Program
(2004.09 ~ 2009.12)

• 2006

- Sportage FCEV (80 kW In-house Stack)
- FC-BUS (160 kW In-house Stack)

Member of CaFCP
(2000.11 ~ Present)

• 2004 ~ 2005

- Sportage FCEV (80 kW)

• 2000 ~ 2002

- SantaFe FCEV (75 kW)
- Sportage (10kW)

Fuel Cell Vehicle Development

	80 kW Fuel Cell Vehicle (2006)	100 kW Fuel Cell Vehicle (2007)
Fuel Cell Power	80 kW	100 kW
Aux. Power	20kW – LiPB	Ultra-capacitor (10F)
Motor System	80 kW	100 kW
H_2 Tank	3.7 kg H_2 @ 350 bar (8.2 lb @ 5.1 kpsi)	3.7 kg H_2 @ 350 bar (8.2 lb @ 5.1 kpsi)
Fuel Economy	20.7 km/l (48.7 mpg)	27.2 km/l (64.0 mpg)
Driving Range	291 km (181 miles)	382 km (237 miles)
Acceleration (0 → 100kph)	16.2 sec	12.0 sec
Max. Speed	141 kph (88 mph)	155 kph (96 mph)

Fuel Cell Vehicle Development

FC Bus – 1st Generation (2006)

Fuel Cell Power	160 kW
Ultra-capacitor	Max. 240 kW
Motor System	240 kW
H_2 Tank	40kg H_2 @ 350 bar (88 lb @ 5.1 ksi)
Acceleration (0 →50kph)	14.2 sec
Max. Speed	72 kph (45 mph)

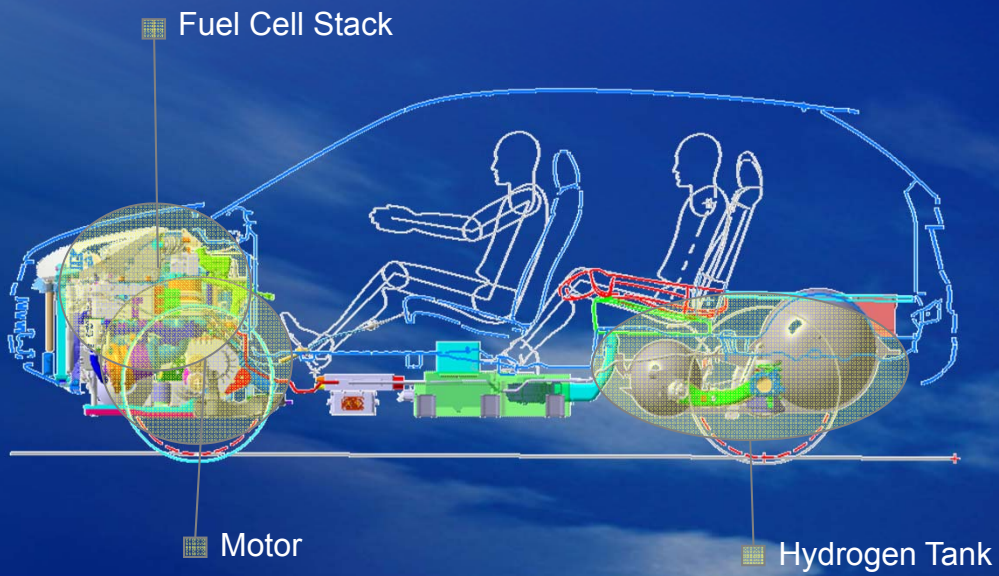
FC Bus – 2nd Generation (2009)

Fuel Cell Power	200 kW
Ultra-capacitor	Max. 400 kW
Motor System	300 kW
H_2 Tank	30kg H_2 @ 350 bar (66 lb @ 10.2 ksi)
Acceleration (0 →50kph)	8.4 sec
Max. Speed	104 kph (65 mph)

Fuel Cell Vehicle Development

Tucson iX Fuel Cell Vehicle (2012)

- Simpler module design of fuel cell system for volume production
- Drastic cost reduction by metallic bipolar plate, AC induction motor, and Li-ion battery
- Improved vehicle performance for fleet & general public customers

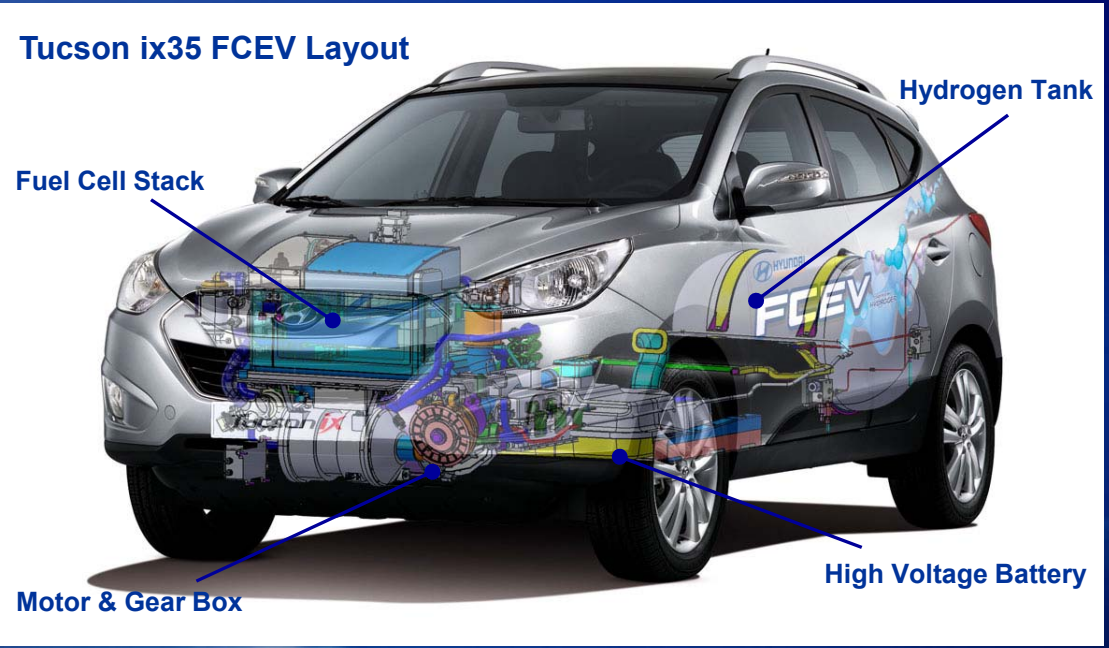


Fuel Cell Power	100 kW
Battery	34 kW
Motor System	AC Induction/100 kW
H_2 Tank	700 bar
Fuel Economy	30 km/L (73 mpg_{ge})
Driving Range	650 km (406 miles)
Acceleration (0 → 100kph)	12.9 sec
Max. Speed	160 km/h (100 mph)

Fuel Cell Vehicle Development

Tucson iX Fuel Cell System (2012)

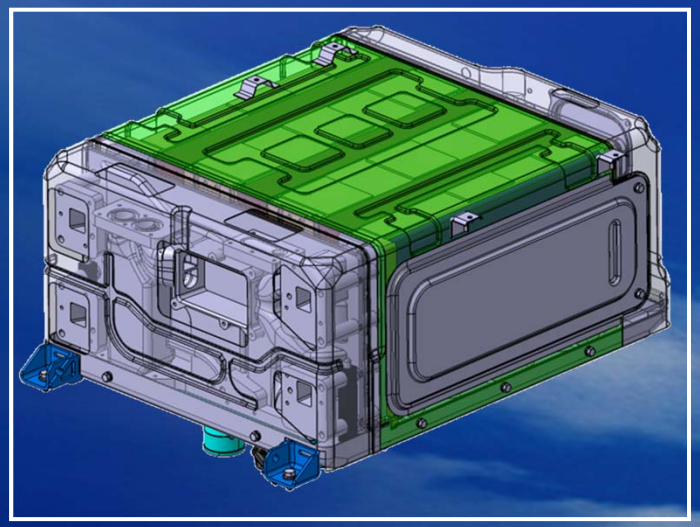
- Size reduction achieved through modularization
- System Power Density: > 640 W/L (DOE Target: 650 W/L)
- Gas/Gas Humidifier
- Cold Start Capability: -25 °C
- System max. Pressure: 1.45 bara

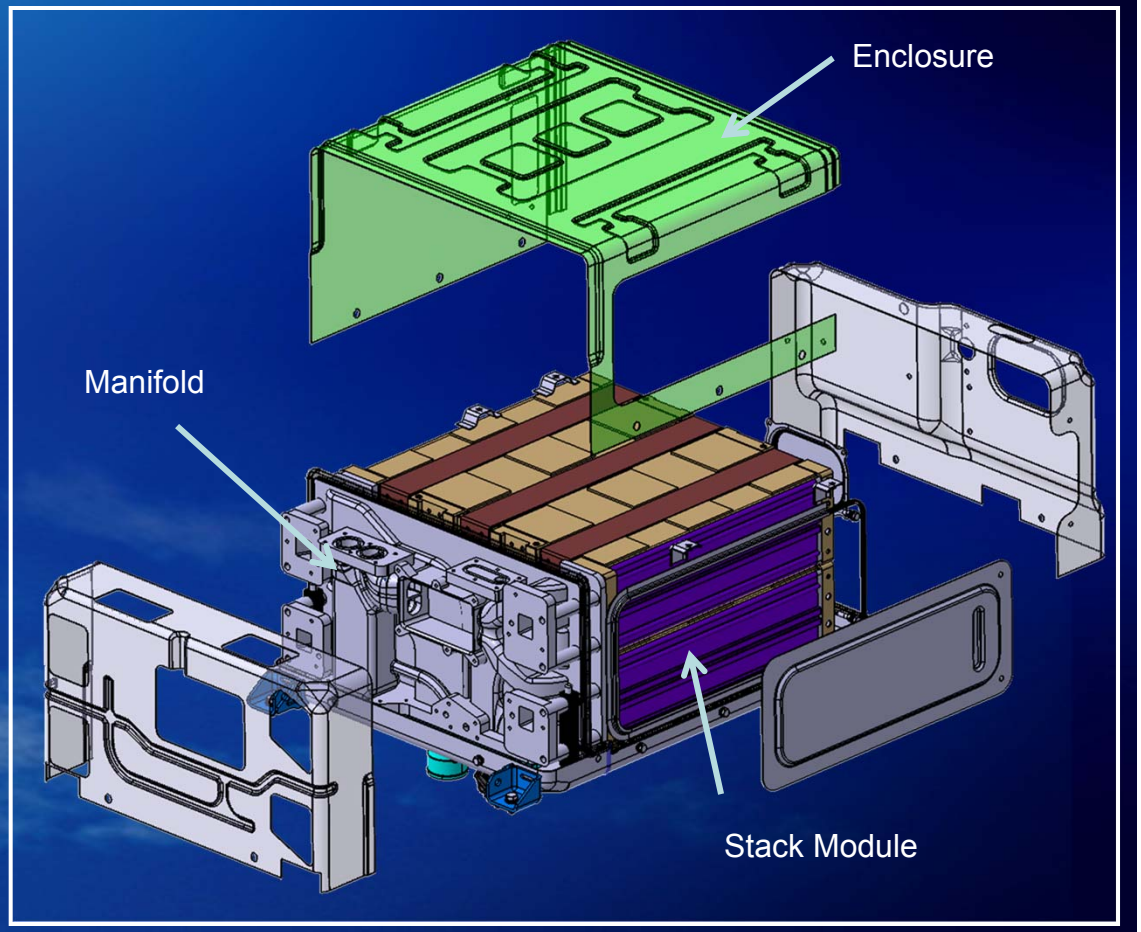


Fuel Cell Vehicle Development

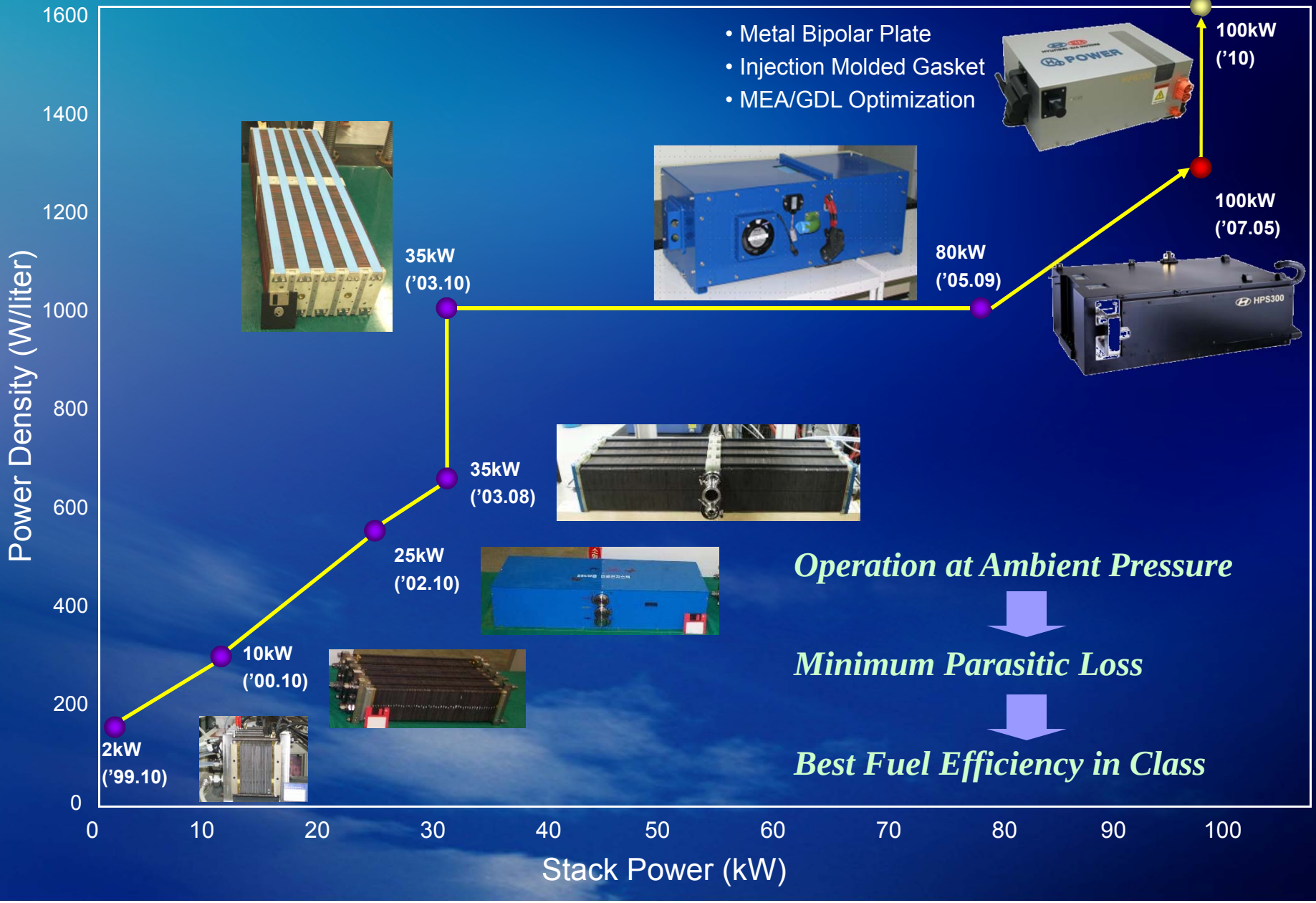
Tucson iX Fuel Cell Stack (2012)

- Max. Power: 100 kW
- Power Density: 1.65 kW/L
- Operating Voltage: 250~450V
- Cold Start Ability: -30 °C
- Max. Air Pressure: 1.35 bara
- Separator: Metal





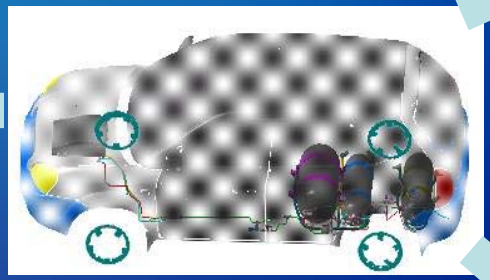
Fuel Cell Stack Development



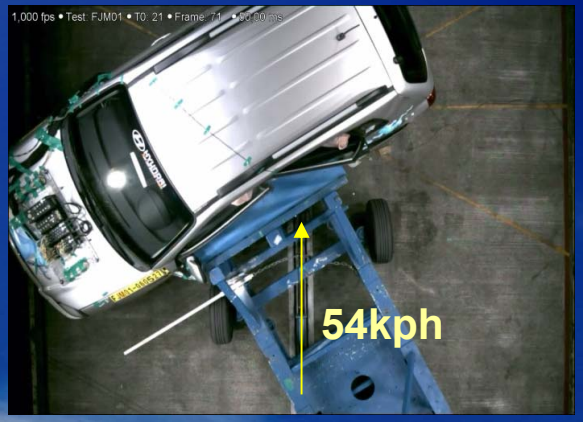
Fuel Cell Vehicle Tests

Collision Tests

Front crash test
(Frontal rigid barrier)



Rear crash test
(Rear rigid barrier)



Side impact crash test
(Side deformable barrier)

Rear-offset crash test
(Rear deformable barrier)

The hydrogen tank is protected from collisions!

Fuel Cell Vehicle Tests

Freeze Capability Tests

@ -20°C (-4°F)
in Environmental Chamber

on Taebak Mountains
(Jan., 2011)

Hydrogen Safety Tests

Fire Tests

	Gasoline Vehicle	FCEV with Type 3 Tanks
Test Condition	• Fire initiated from the ashtray	
Result	• Fuel tank exploded after 40 minute.	• PRD activated after 22 minutes.

	CNG Tank (150 bar/2.2 kpsi)	Hydrogen Tank (350 bar/5.1 kpsi)
Test Condition	• Fire Source: LPG gas	
Result	• PRD activated: CNG vent • Max. flame height: 11 m (36 ft)	• PRD activated: H_2 vent • Max. flame height: 8 m (26 ft)

Facilities for Fuel Cell System Development

FC System Test Bench (Bread Board)

FC Stack Test Station (100 kW Class)

Facilities for Fuel Cell System Development

Motor Test Equipment (100 kW Class)

Motor Test Equipment (250 kW Class)

Fuel Cell Stack Development

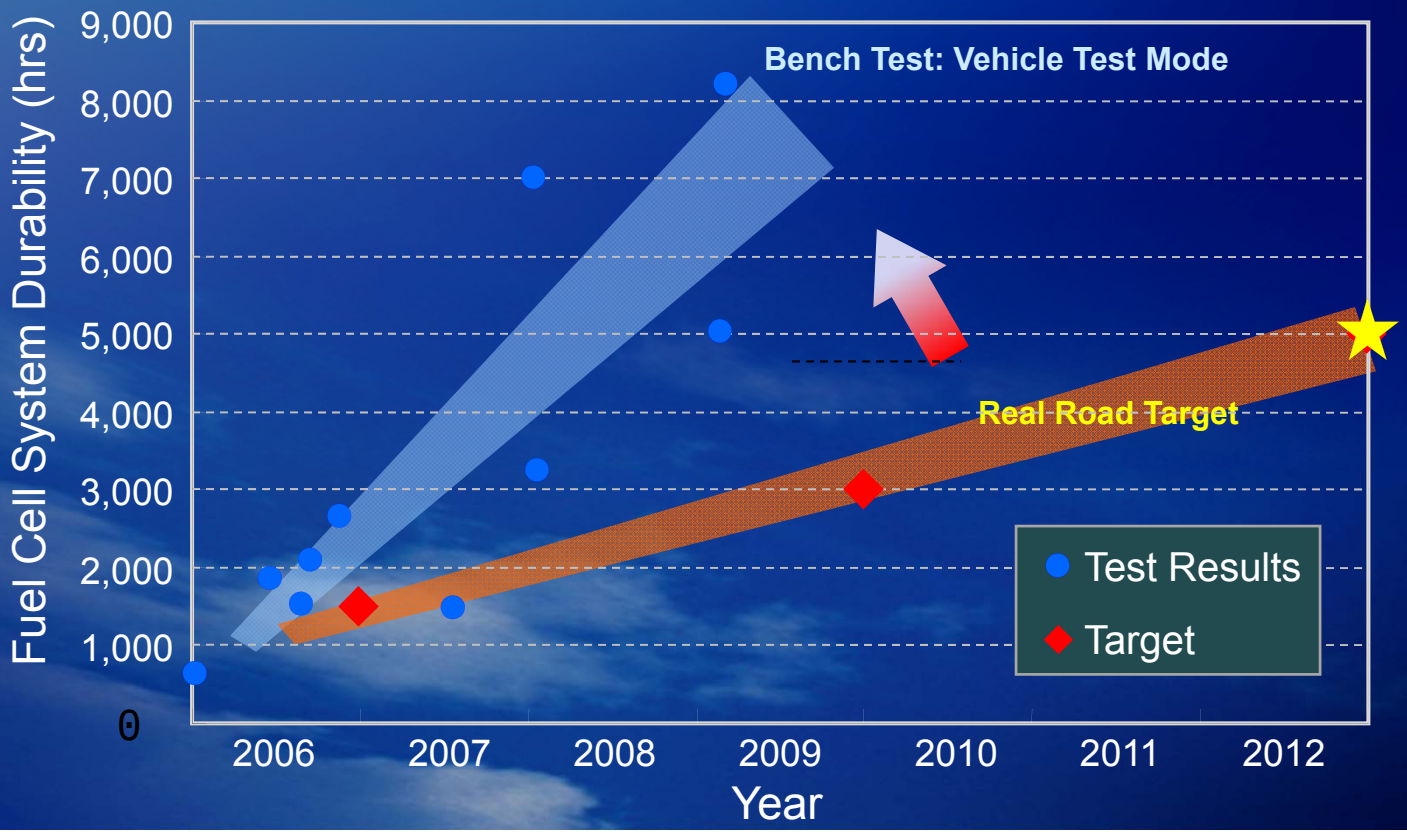
Durability

Durability = func. (Operation parameters, driving mode, environmental effects)

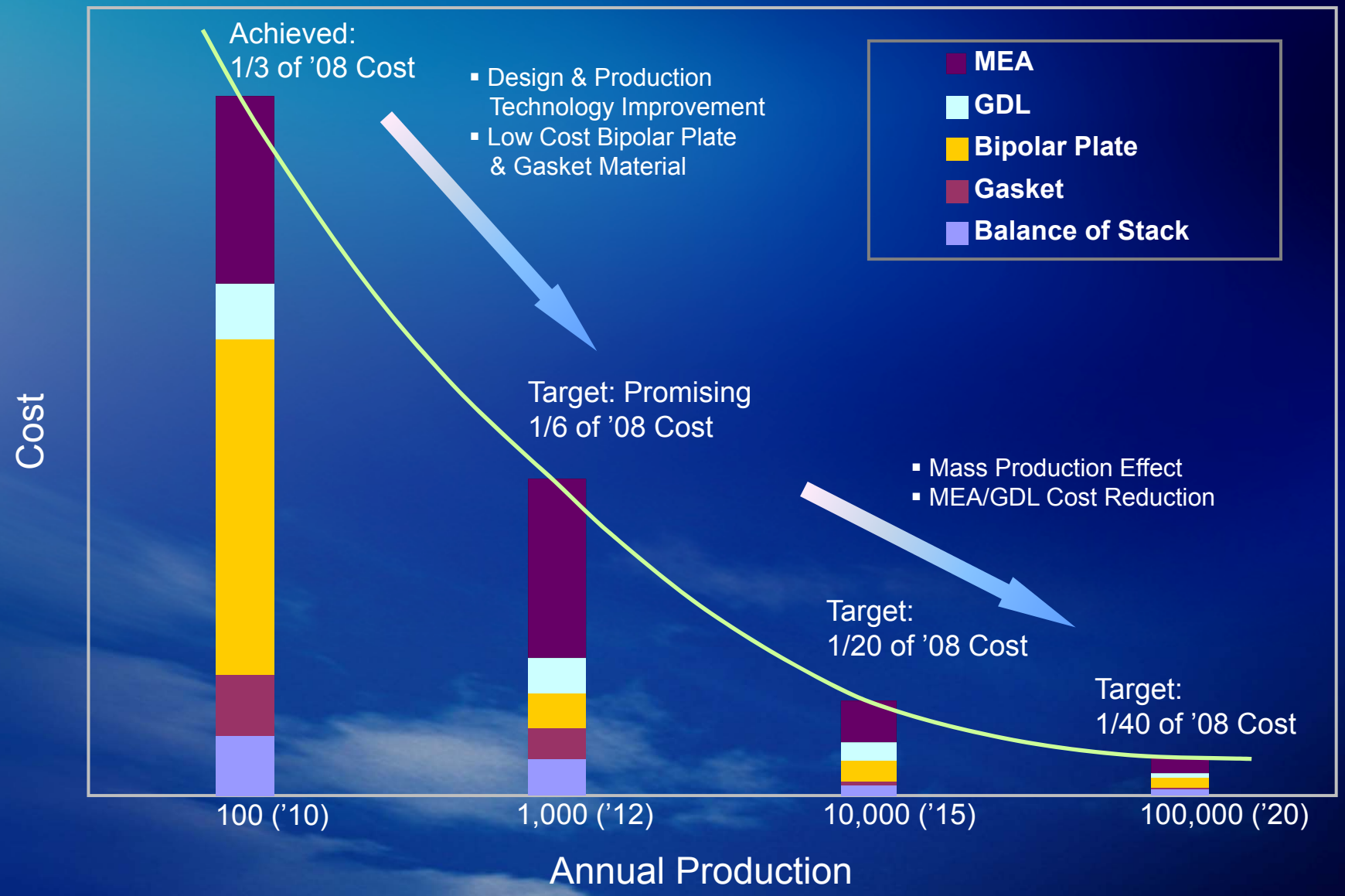
- Verification of degradation mechanism

  (Start-up / Shut-down / Cold start Up / High temperature operation)

- Development of new material (Catalyst / Membrane)

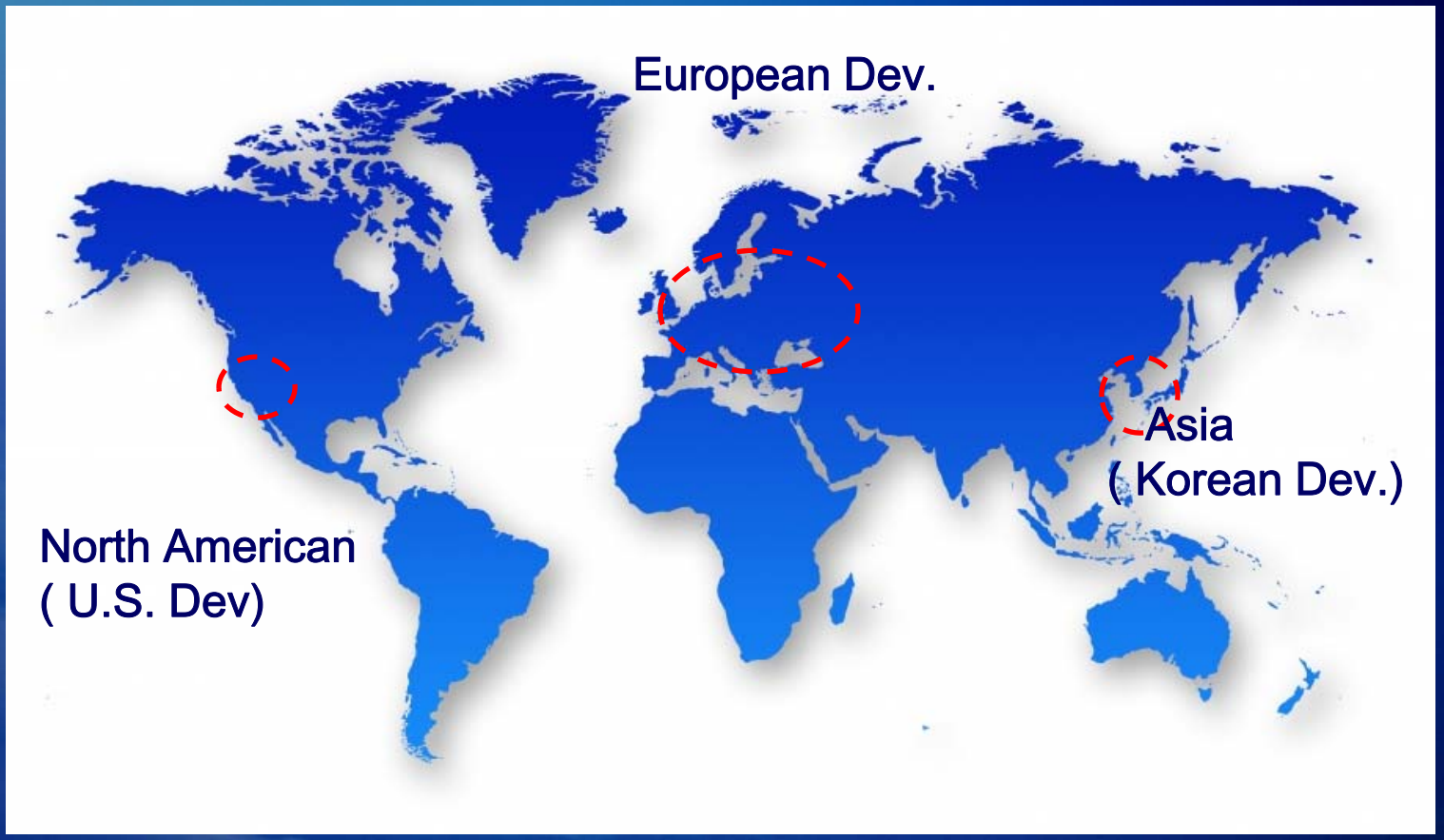


Cost Estimation



3. Hyundai's Global Approach

- Hyundai has a global approach to FCEV development: Working in Asia, Europe & North America
- Each region is being evaluated for viability of the technology and infrastructure



Korean Domestic Fleet Program (1st stage)

1. Period: 2006. 8 ~ 2010. 12 (4 years)

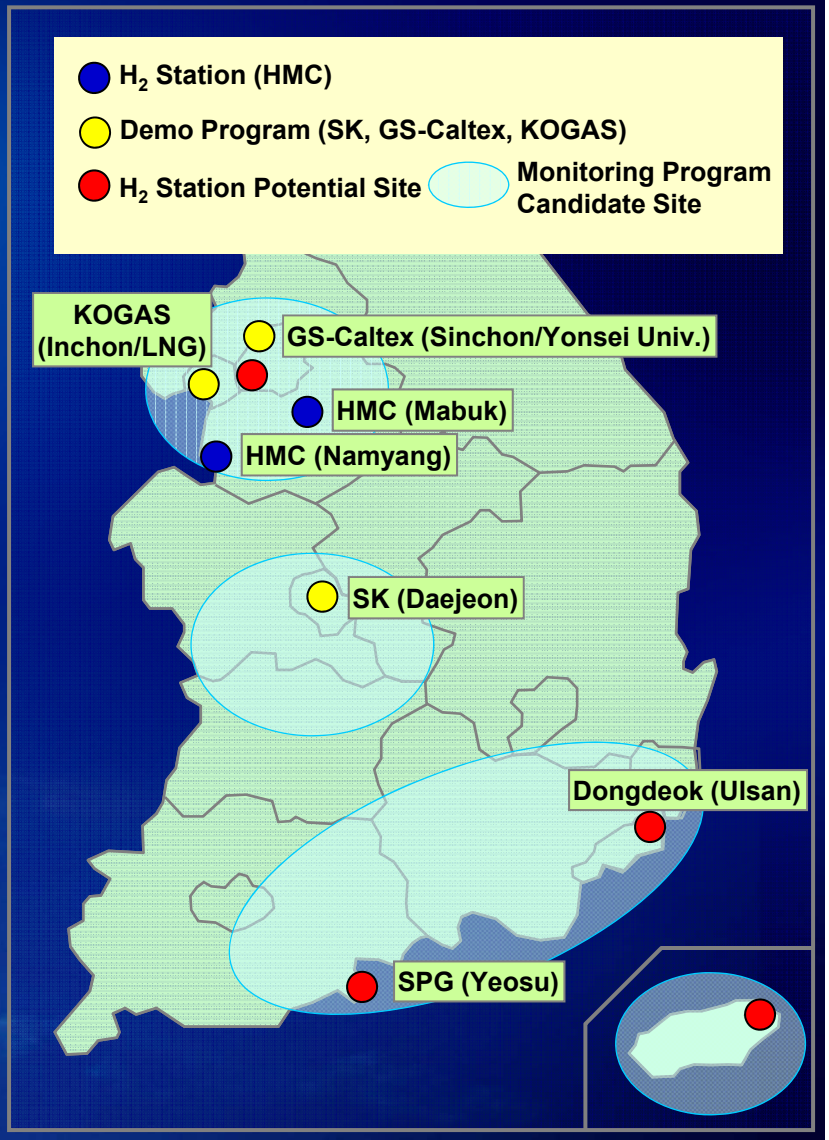
2. Vehicles: 30 SUVs, 4 Buses

Year	SUV	Bus	Station
1st	4	1	2
2nd	8	1	2
3rd	18	2	1

3. Budget: $ 46.6 million (Government 50%)

4. Hydrogen Stations: 11 in operation as of Feb. '11

- Had 4 stations in '07 (SK, GS-Caltex, KOGAS, HMC Mabuk)
- Planned 5 more stations by '10 (Seoul, HMC Namyang, Jeju Island, Ulsan, Yeosu)

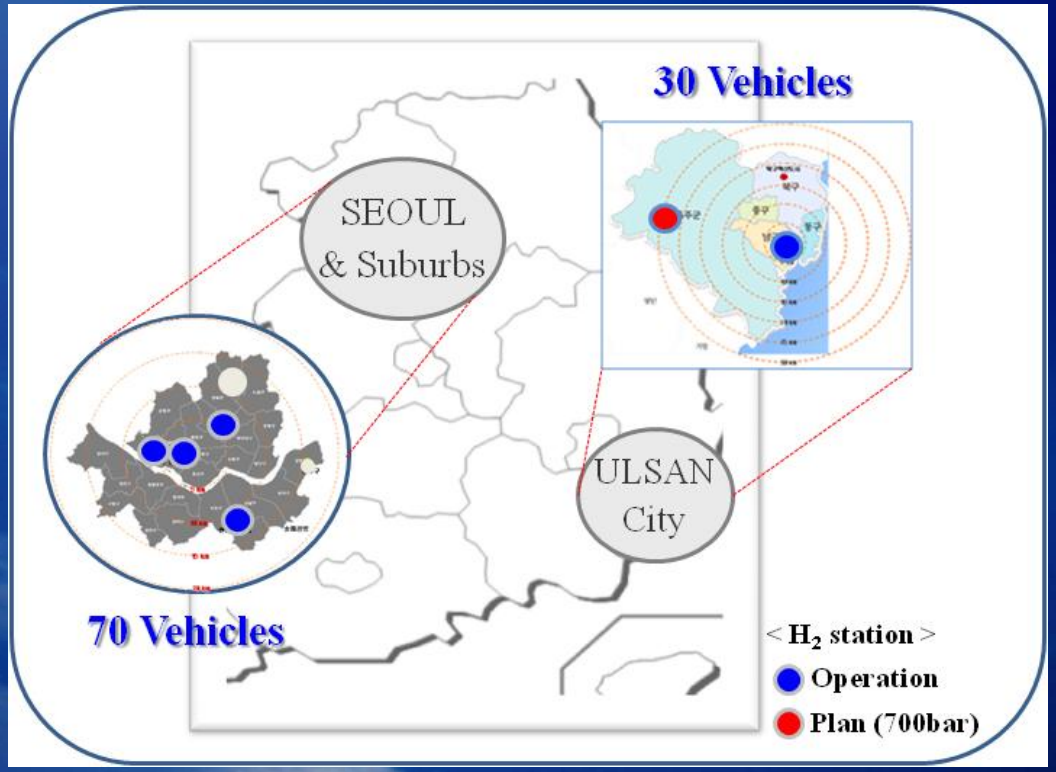


4. Results

- Total: 1,297,799km (806,587miles)
- Avg. fuel economy: 19.2km/l (45.2 mpg)

Domestic Fleet Program (2nd Stage)

- Launched in Dec. 2010 as Phase 2
  - 100 vehicles to general customers in capital area and Ulsan (center of auto & oil industry)
  - 13 stations are ready by 2011
  - Total mileage: 1,137,789 km (706,989 miles)



H_2 Stations in Korea

- 13 stations in operation (Jan., 2012)

#	City	Installer	Year	Type	Pressure	Project
1	Yongin	HMC	2005	Truck-in	350/700bar	-
2	Seoul	GS-Caltex	2006	Naphtha reforming	350 bar	H_2 station development
3	Incheon	KOGAS	2007	NG reforming	350 bar	↑
4	Daejeon	SK Energy	2007	LPG reforming	350 bar	H_2 station development
5	Seoul	KIST	2008	Mobile	350 bar	FCEV Fleet
6	Hwaseong	HMC	2008	Truck-in	350/700bar	-
7	Ulsan	Dongdeok Gas	2009	↑	350 bar	FCEV Fleet
8	Yeosu	SPG Chemical	2009	↑	350 bar	FCEV Fleet
9	Seoul	HMC	2009	Mobile	350 bar	2nd FCEV Fleet
10	Seoul	HMC	2010	Truck-in	350 bar	FCEV Fleet
11	Seoul	City of Seoul	2011	Landfill gas reforming	350 bar	-
12	Jeju	HMC	2011	Electrolysis	350 bar	FCEV Fleet
13	Ulsan	Dongdeok Gas	2011	Truck-in	700bar	2nd FCEV Fleet

Hyundai's Hydrogen Station

1. Yongin
- Capacity: 26 vehicles/day
- Refueling pressure: 350/700 bar

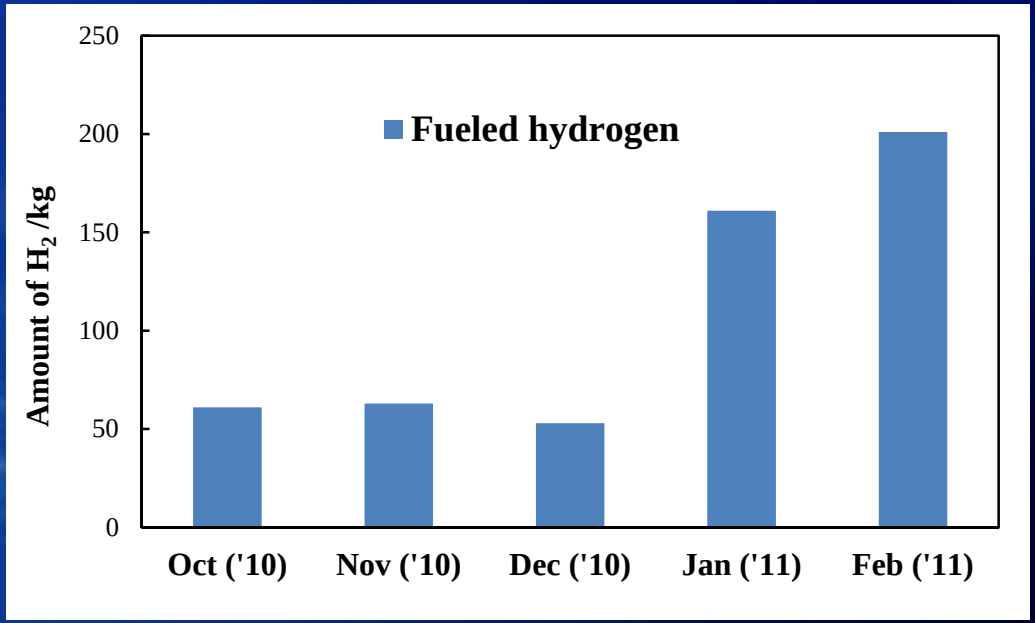
2. Hwaseong
- Capacity: 43 vehicles/day
- Refueling pressure: 350/700 bar

3. Seoul
- Capacity: 13 vehicles/day
- Refueling pressure: 350 bar

Hyundai's Hydrogen Station in Seoul

Built in Sep., 2010

Period		Vehicle type	# of fueling (Vehicle/month)	Avg. pressure (bar)	H_2 (H_2 kg/Vehicle)
2010	Sep	SUV	16	96	3.21
	Oct		21	117	2.92
	Nov		25	134	2.52
	Dec		15	97	3.53
2011	Jan	SUV	34	127	2.92
		Bus	4	97	15.5
	Feb	SUV	59	136	2.77
		Bus	3	96	12.4
SUV avg.			28	118	2.89
Bus avg.			4	97	14.2

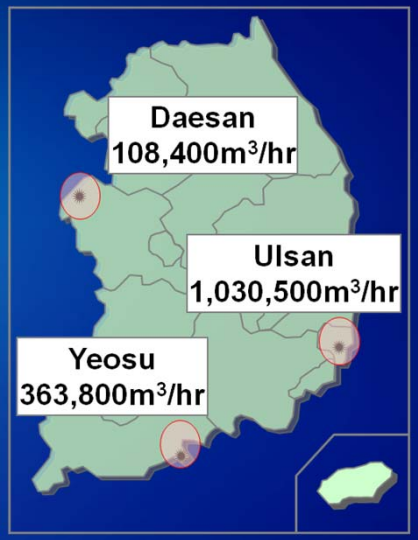


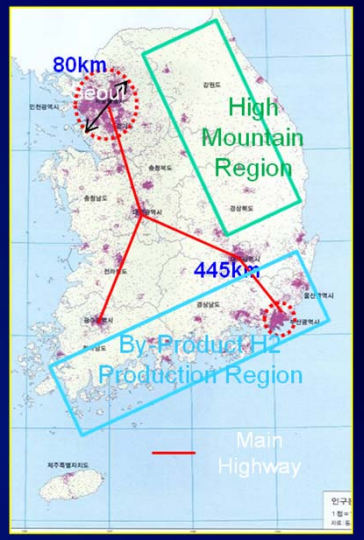
H_2 Production and Infrastructure

- Most H_2 from chemical process
- Annual capacity: 1.171 million ton
- By-product H_2: 100k ton

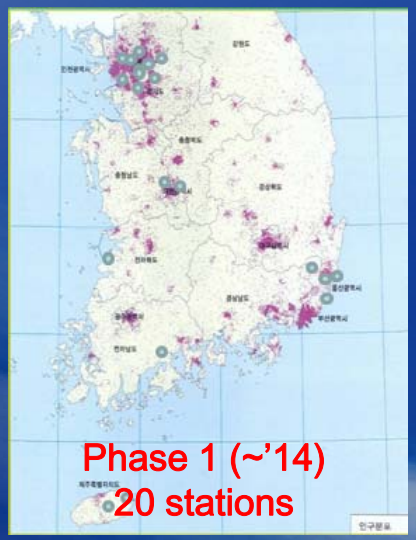
20% of By-product H_2 ☞ 100k FCEV/year

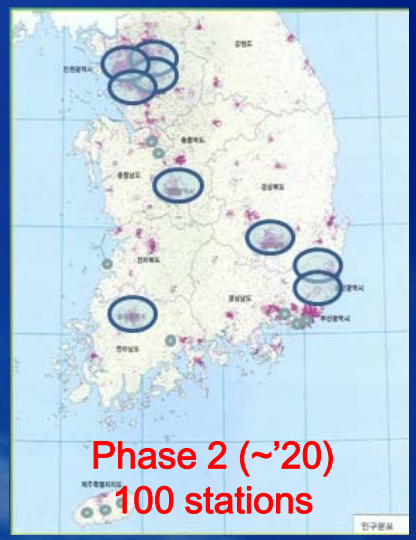
No additional investment for H_2 production for early market introduction

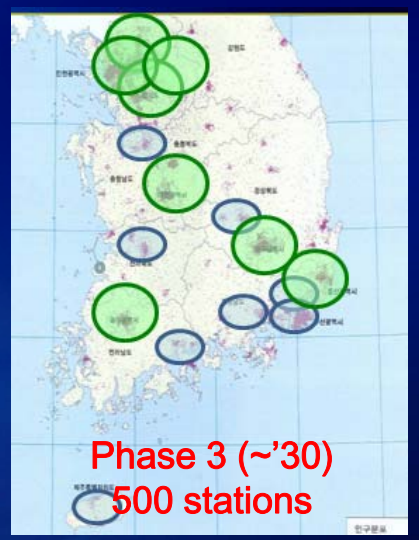




Projected Scenario







- Phase 1: Focusing on densely-populated area + H_2 production sites
- Phase 2: Spreading out to large cities
- Phase 3: Networking the large cities

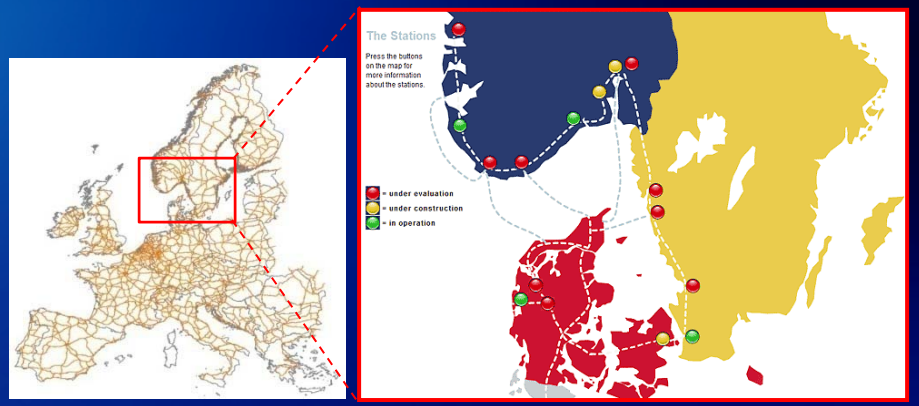
: 10 stations

: 50 stations

European Fuel Cell development

Distribution of FCEV in Europe

- FCV test & deployment project with Scandinavian countries (Jan., 31, 2011)
  - Norway, Sweden, Denmark and Iceland
  - FCVs developed by Hyundai's proprietary technology will be supplied



Construction of refueling stations (Scandinavian Hydrogen Highway Partnership)

- Partnership with CEP (Clean Energy Partnership) (Feb., 25, '11)

Present CEP members

Activities with EU Government

EU Government Supported Projects

1. H2MOVES

- Budget: Total 2.43M € (0.97M € by EU).
- Period: ’09. 11~ ’12. 12 (3 years)
- Participated in the events (Germany (HME), UK (Ecovelocity), Italy (EcoDolomites) and Denmark (COTY Jury events, Copenhagen))

2. H2CONNECT

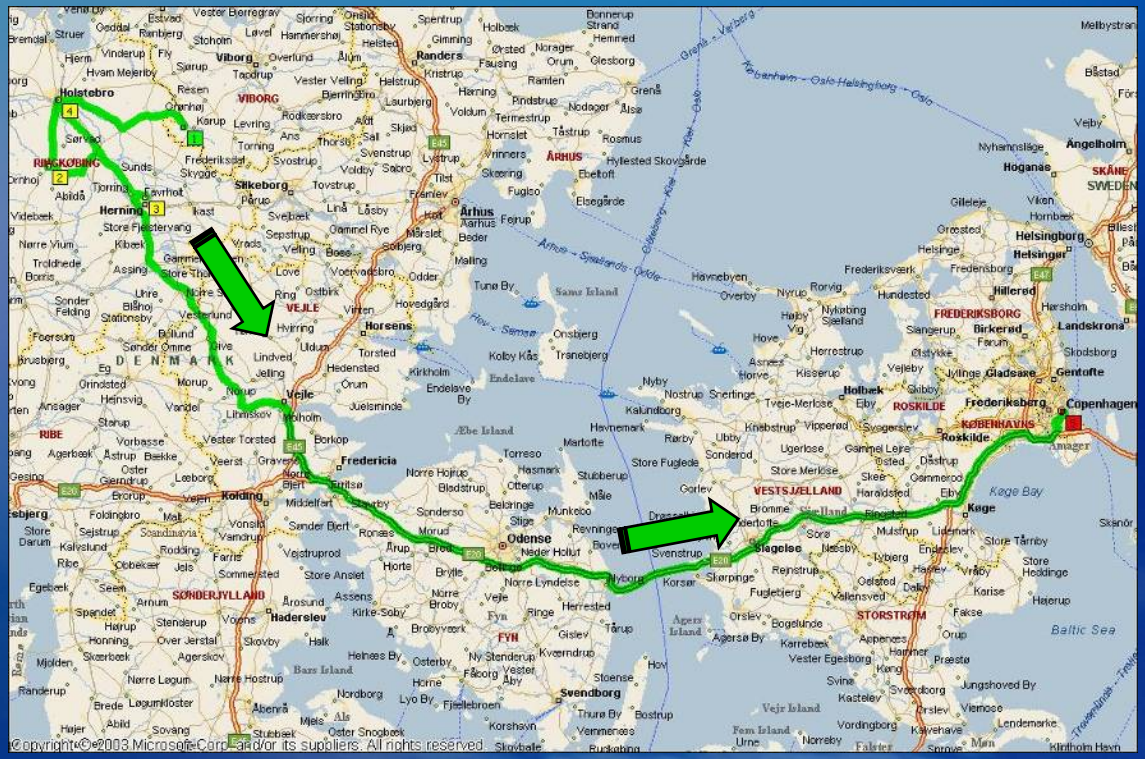
- Budget: Total 9.77M € (3.39M € by EU).
- Period: ’12. 9~ ’15. 8 (3 years)
- 25 Vehicles will be deployed in Germany (10 vehicles), Italy (10 vehicles) and Sweden (5 vehicles)

3. EU Parliament Officials Test Driving

- Available to test-drive by members of European Parliament, Commissioners, EU officials and other policy makers
- Period: ’11. 10 ~ ’12. 03 (6 months)

Field Test In Denmark May , 2011

Karub ➔ Ringkobing ➔ Herning ➔ Holstebro ➔ Copenhagen: 341 km for 3.7 hr



Michelin Challenge Bibendum (May 2011, Berlin)

<Exhibition Center>

<Mobile H2 Fueling Station (700 bar)>

<Ride & Drive>

<London Taxi INT>

<ZERT - Formula Zero (Max. 100 km/h)>

< CRF (Italy) >

ZERO Rally in Oslo, Norway (June , 2011)

Date	Zero Rally in Oslo
June 7, 2011	√ Driving Mileage: 144 km (89 miles) √ Test Driving for Vehicle Performance Evaluation 1) Slalom Tests – Twice 2) Racing Test – Once √ We successfully completed the whole rally with a Tucson iX vehicle.
June 8, 2011	√ Driving Mileage: 180 km (112 miles) √ Uphill Climbing (Grading) Test – Once (Gradability = 10 ~ 15%)

< Start>

< Racing Test>

< 1st Slalom Test>

< 2nd Slalom Test>

Other Activities in Europe (Sep.~Oct., 2011)

- **1st Eco-Velocity 2011 in London, UK**

  (Sep. , 2011)

- **EcoDolomites 2011 in Italy**

  (Sep. , 2011)

- **Klima Mobility 2011 in Italy**

  (Sep. , 2011)

- France FCEV Show in France

  (Oct. , 2011)

U.S. Fuel Cell development

US (DOE) Fleet Program History

1. Period: 2004. 12 ~ 2009. 12 (5years)
2. Budget: $105 million (Consortium, Government 50%)
3. Partners: Chevron Texaco (Hydrogen Filling Station)

   UTCFC (Fuel Cell Stack)

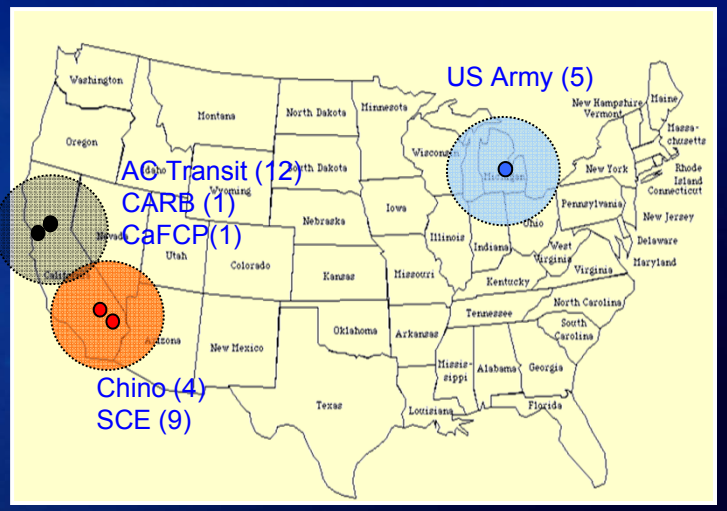
   AC Transit, SCE, US Army, CARB (Fleet Operators)
4. Vehicles: 32 Tucson/Sportage FCEVs
5. Accomplishments

   - Total: 835,212 km (522,000 miles)

   - Cold weather drivability proved for 3 years in Michigan

1st Vehicle for Demo Fleet Program
(2005. 12.16)

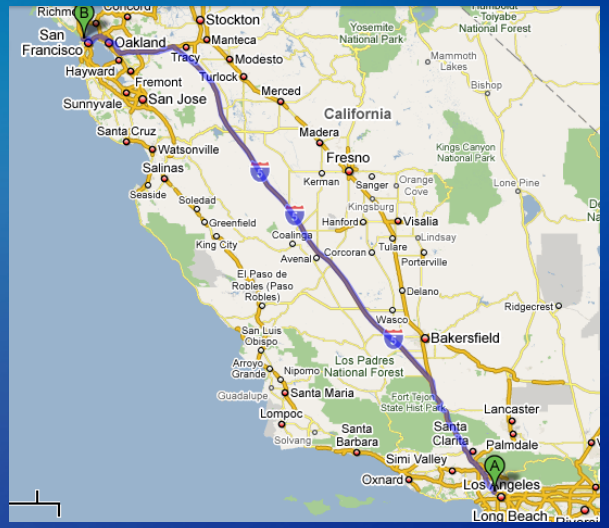
US Hydrogen Station Completion
(2005. 2.18)



Fuel Cell Vehicle Development

- Borrego FCEV: San Francisco → LA Driving Test (396 miles, 2008)

Departure Point



Traveling Route

Arrival Point

Item	Contents		Notes
Actual Mileage	634 km	396 miles	
H_2 Consumed	6.65 kg (84%)		• Actual H_2 Fueling Quantity: 7.76 kg (98%)
Total Capacity of H_2 Tank	7.92 kg (100%)		
H_2 Remained	1.27 kg (16%)		
Avg. Fuel Economy	25.7 km/L	(60.7 mpgge)	
Additional Available Distance	121 km	(75 miles)	• Based on Avg. Fuel Economy (@ 100% H_2 Consumption)
Driving Range	**758 km**	**(471 miles)**	

Hyundai Hope on Wheels – Tucson Drive 4 Hope

- FCEV team will drive from San Francisco to

New York between September 1st – 28th

- In addition to raising awareness for childhood cancer, the tour will demonstrate Hyundai's

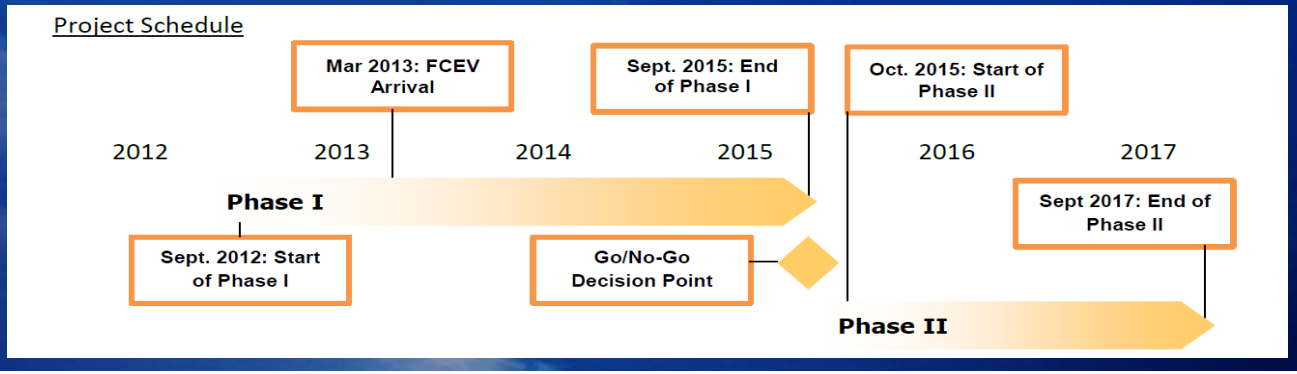
commitment to creating a cleaner future through environmental leadership

- The tour gives Hyundai the opportunity to highlight a potential future technology and the resulting environmental advantages

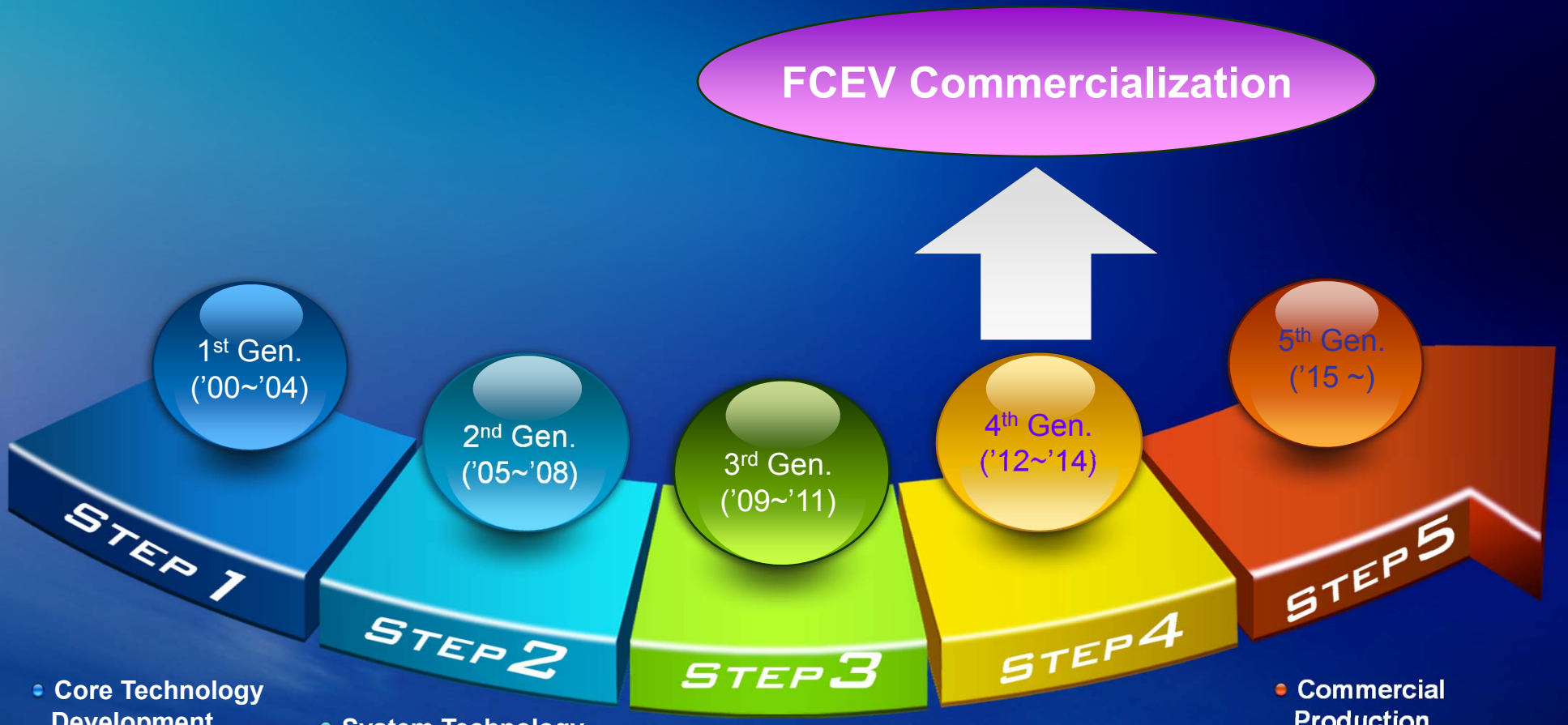
Future: Data collection and Fleet Validation

1. **DOE Opportunity:** 2012. ~ 2017 (5 years)
2. **Hyundai Motor Group**
   - Hyundai internal Designed fuel Stack Systems
   - Tucson Vehicle Architecture
3. **Vehicles: 10 FCEV SUVs (Tucson) in 2 phases**
   - Phase 1: 7 vehicles
   - Phase 2: 5 vehicles (2 carry over from Phase 1)
4. **Plan**
   - Operated in L.A. California Area
   - Hyundai ; Ca FCP, SCAQMD driving applications

FCEV proposed location



4. Roadmap of FCEV Commercialization



- Core Technology Development
- Outsourced Stack - 1st FCV
- Several FCEVs/year

- System Technology Development & Fleet Operation
- Stack Bipolar Plate - Graphite
- Tens of FCEVs/year

- Semi-Automatic Production
- Stack Bipolar Plate - Metal
- Hundreds of FCEVs/year

- Pre-commercial Production (Pilot-scale)
- 1,000 FCEVs/year

- Commercial Production - Initial Market
- Full Automation
- 10,000 FCEVs/year

FCEV Commercialization in the U.S.

Pre Commercial and Commercial US Implementation

- Fuel Cell Vehicles (Hyundai / OEMs)
  - Infrastructure deployment studies (Market identification)
  - Continued System validation In North America (Environmental conditions)
  - Customer acceptance (Validation of Production intent designs)
  - Validation of Production Intent Components and Suppliers (Pre-commercial Volumes)
- Infrastructure
  - Training and preparation of dealer supply network for FCEVs
  - Refueling Infrastructure: Currently the single biggest inhibiter for FCEV deployment

- Next Steps (Recommended)
  - Increased emphasis from Government entities to support Infrastructure (Tax Incentives, Mandates, Legislation)
  - Industry support for infrastructure , collaboration with CaFCP and other other similar organizations in the US.

Thank you!