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Discussion Document

SIAM
Society of Indian Automobile Manufacturers
(An ISO 9001- 2008 Certified Organisation)

booz&co.

Alternative Powertrains and Challenges for Next Decade

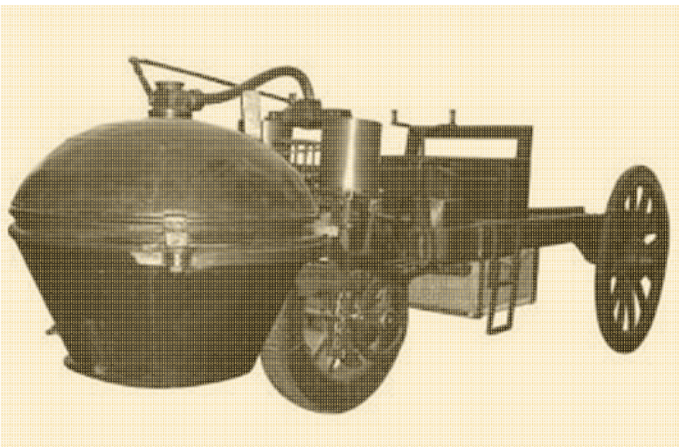
SIAM Annual General Meeting

Alternative Powertrains: Global Developments and Challenges

Insights from the Indian Hybrid / Electric Mobility Study

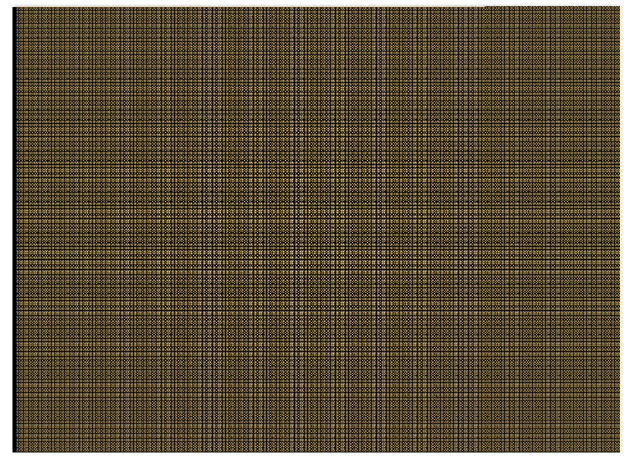
When the automobile was introduced in late 1800's, it was not readily apparent which engine technology would prevail

Steam vs. Electric vs. Internal Combustion



Steam Car
(Nicolas Joseph Cugnot 1769)

Electric Car
(Robert Anderson, 1839)



Gasoline-Powered Car
(Carl Benz, 1886)

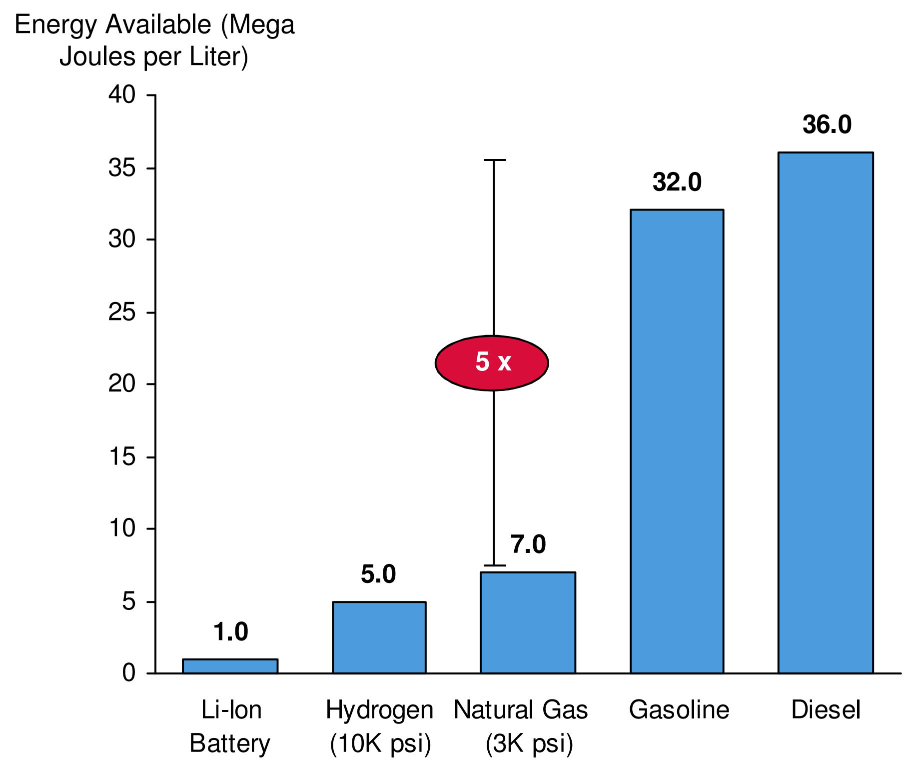
At the end of 19th century, electrics outsold all other types of cars

ICE prevailed over other technologies dues to its virtues speed, power, and range – courtesy of petroleum's high energy density

Competitive Advantages By Powertrain

Criteria	Electric	Steam	ICE
Clean, free of smoke/odor	✓	X	X
Quiet	✓	✓	X
Reliable, durable	✓	X	✓
Simple, easy to maintain	✓	X	X
Easy to drive and control	✓	X	✓
Free of vibration	✓	✓	X
Instant starting	✓	X	✓
Speed	X	✓	✓
Acceleration	✓	✓	✓
Power	X	✓	✓
Range, distance	X	X	✓
Infrastructure	X	X	✓

Energy Density Of Petroleum Vs. Other Fuels

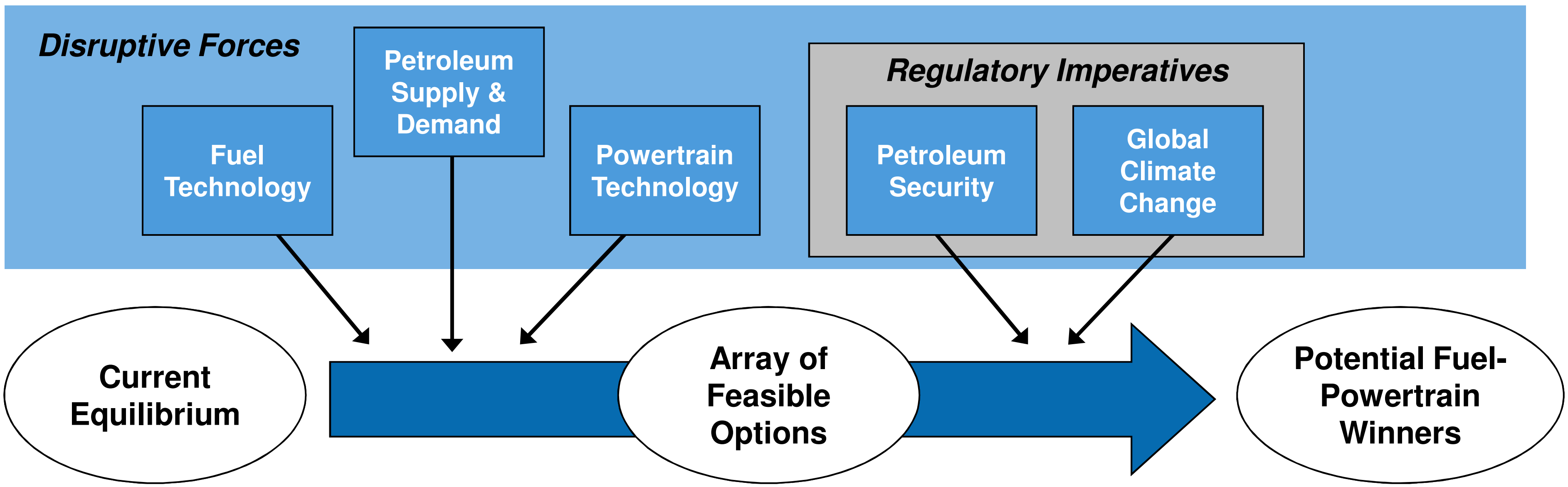


Is the future going to be different?

Note: ICE = Internal Combustion Engine
Source: ANL, DOE, Sion, NRC, Booz & Company analysis

There are at least five drivers that may shift the balance in favor of alternative fuels and powertrains

Disruptive Forces And Regulatory Imperatives



- Petroleum-fueled ICEs
- Gasoline for US passenger transport
- Diesel for commercial
- Roughly equal split of gasoline and diesel for European passenger cars

- Alternatives dependent upon emerging fuel and powertrain technologies
- Comparisons based on well-to-wheel economics and GHG production

- Otherwise equivalent economics swayed by political action
- Range of states possible dependent on environmental and political forces

Among different technology trends, the reinvention of automotive propulsion has been a key focus globally

Different Technology Trends

Mass Reduction via Light-Weight Materials

Telematics and Infotainment

Sustainable Mobility: the Reinvention of Automotive Propulsion

Enhanced Safety & Comfort

"Glocalization": Global Products Adapted to Local Requirements

1 Gasoline/ Diesel ICE

Mercedes E-Class

2 Biofuel ICE

Chevy Tahoe E-85

2 CNG ICE

Honda Civic GX

3 Conventional Hybrid

Toyota Prius

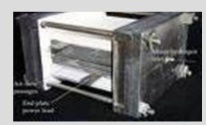
3 Plug-in Hybrid

Chevrolet Volt

3 Electric Vehicle

i-MiEV

4 Hydrogen Fuel Cell Vehicles



Honda FCX Clarity

xEVs - Covered in detail

Significant fuel efficiency gains are expected through innovations in ICE technologies by 2020

Technology Roadmap – Automotive Powertrains

Key Technology Milestones

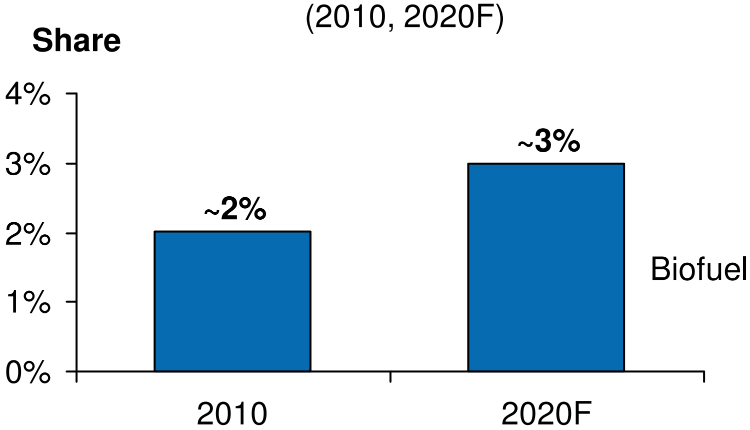
2010 | 2015 | 2020

ICE	Key Technology Milestones	Expected Fuel Efficiency Improvements by 2020
ICE	**Downsizing Optimization** ▪ Increases performance with smaller but higher performance engines ▪ Allows engines in the 0.8-1.4 L class to perform equivalent to much larger engines, while allowing for significantly improved fuel economy	10 – 15%
	Direct injection and Dual Clutch Technology ▪ With direct injection, high pressure fuel is injected inside the combustion chamber leading to more efficient fuel utilization ▪ The dual clutch allows seamless shifting between gears due to staggered arrangement of gears increasing efficiency	12 – 20%
	Rolling Resistance Optimization ▪ Airflow management and optimization impacts fuel efficiency without the need any major aerodynamic modifications	0.5 – 5%
	Weight Reduction ▪ Decreases strain on the engine by replacing and re-engineering heavier parts with light weight materials ▪ Every 10% of weight reduced from the average new car or light truck can cut fuel consumption by 5-10%	5 – 10%

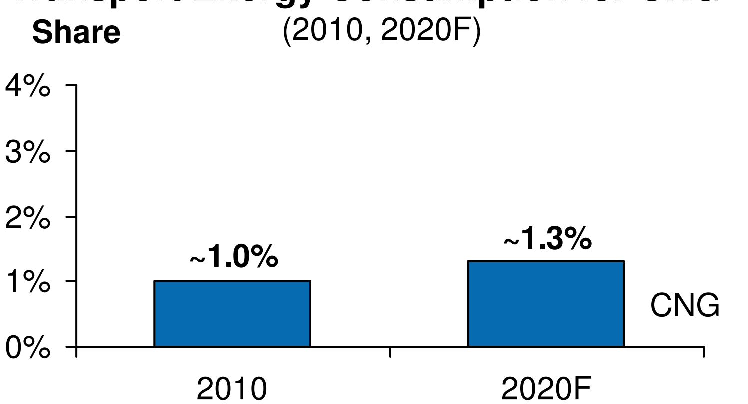
Source: Argonne National Laboratory, Automotive OEM press releases, Booz Allen Hamilton Technology Center, Booz & Company

Biofuel and CNG are gaining momentum due to favorable economics and small modifications required for ICE vehicles

Transport Energy Consumption for Biofuels[1]
(2010, 2020F)



Transport Energy Consumption for CNG[1,2]
(2010, 2020F)



Trends

- Second generation (not based on edible crops) biofuels are beginning to reach commercial stage
- Prices of cellulosic bio-fuel is expected to come down from ~0.9 $/l to ~0.5 $/l by 2020 making it cheaper than first generation biofuels
- Favorable economics of CNG based vehicles have driven their demand in Pakistan, Argentina, Brazil, Iran and India (~8.2M CNG vehicles in 2009)

Challenges

- Distribution of ethanol is difficult as it is more corrosive than gasoline
- Modification of vehicles is required to make them compatible with high blend of ethanol
- Bio-diesels can be unstable, have poor cold weather performance and have variable quality
- CNG vehicles can be more expensive than ICEs vehicles, have lower engine efficiency and range

1 Includes all modes of transportation
2 Includes negligible share of LPG as well
Source: IEA, World Energy Outlook 2010, Renewable Fuels Association; USDA Gain Report; FO Licht; World Watch; IEA, Mobility Report, Booz & Company analysis

xEVs are becoming popular as they provide higher fuel efficiency by using electric motor to supplement/ replace engine power

Comparison between Different Powertrain Technologies

	Internal Combustion Engine (ICE)	Hybrid Electric Vehicle (HEV)	Plug-In Hybrid Electric Vehicle (PHEV)	Extended Range Electric Vehicles (ER-EV)	Electric Vehicle (EV)
Car Model	 Honda Civic	 Toyota Prius	 Ford Escape	 Chevrolet Volt	 Tesla Roadster
Technology	**Petrol usage:** Powered entirely by petrol, diesel, CNG or biofuels, other than a battery for starting **Electricity usage:** None	**Petrol usage:** Engine powers car when additional power is required **Electricity usage:** Generated by regenerative braking, supplements engine power	**Petrol usage:** Petrol generator recharges battery when charge is low **Electricity usage:** Battery with mains runs the vehicle alone or to supplement	**Petrol usage:** Petrol generator recharges battery when charge is low **Electricity usage:** Battery with mains or generator charge runs the vehicle alone	**Petrol usage:** None **Electricity usage:** Runs entirely on electricity from mains charge
Fuel Efficiency savings	0%	5 - 40% [1]	5 - 50% [1]	35 – 60% [1]	100%
Electrification	Petrol / Diesel				Electricity

1) Depends on xEV battery size
Source: Official car websites, Booz & Company analysis

Unless several technical challenges are not solved, fuel cell powertrains will trail behind cost of ICE and EV technologies

Technology Roadmap – Fuel Cell Powertrains

Key Technology Milestones

2010 — 2015 — 2020 — 2025

Fuel Cell

Longevity Improvement

- Gravity dependence!
- Improved operating hour life close to 5000 hr ICE standard

H_2 Storage Cost Reduction

- Lower cost carbon fiber tanks
- Higher compression storage, thus greater range

Cold Start Improvement

- Membranes with higher tolerance of moisture extremes (wet or dry)
- Extended system lifetime

Fuel Cell Stack Cost Reductions (Pt Reduction, catalyst)

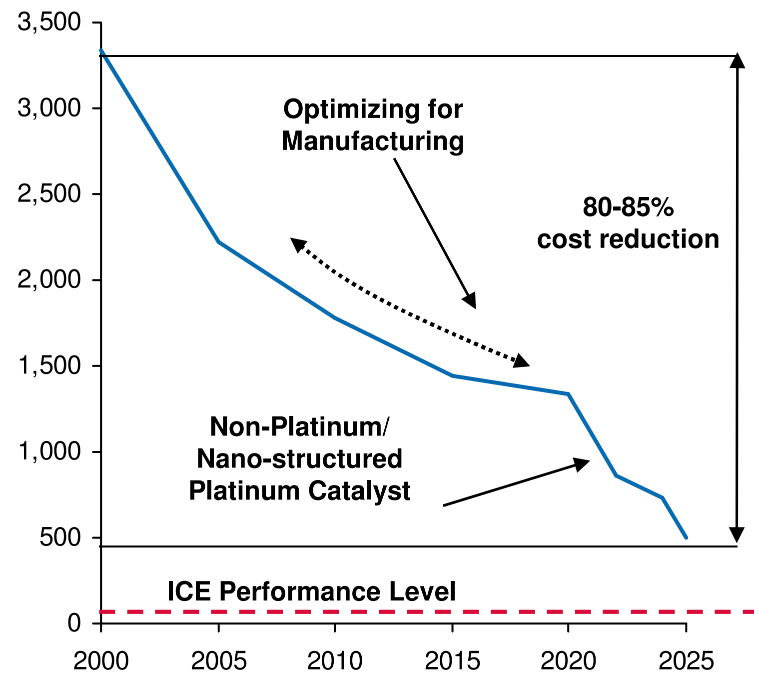
- Improved current density through material advances creates more power per fuel cell stack, thus reducing the total number of stacks and requisite platinum catalyst
- Nanoscale catalyst development and non-platinum catalysts
- Significantly reduced system cost

H_2 Fueling Infrastructure

- Build out of hydrogen fueling stations and distribution networks (or decentral production)
- Build out of major hydrogen manufacturing plants (renewable based or hydrocarbon)

Expected Cost Reduction Range

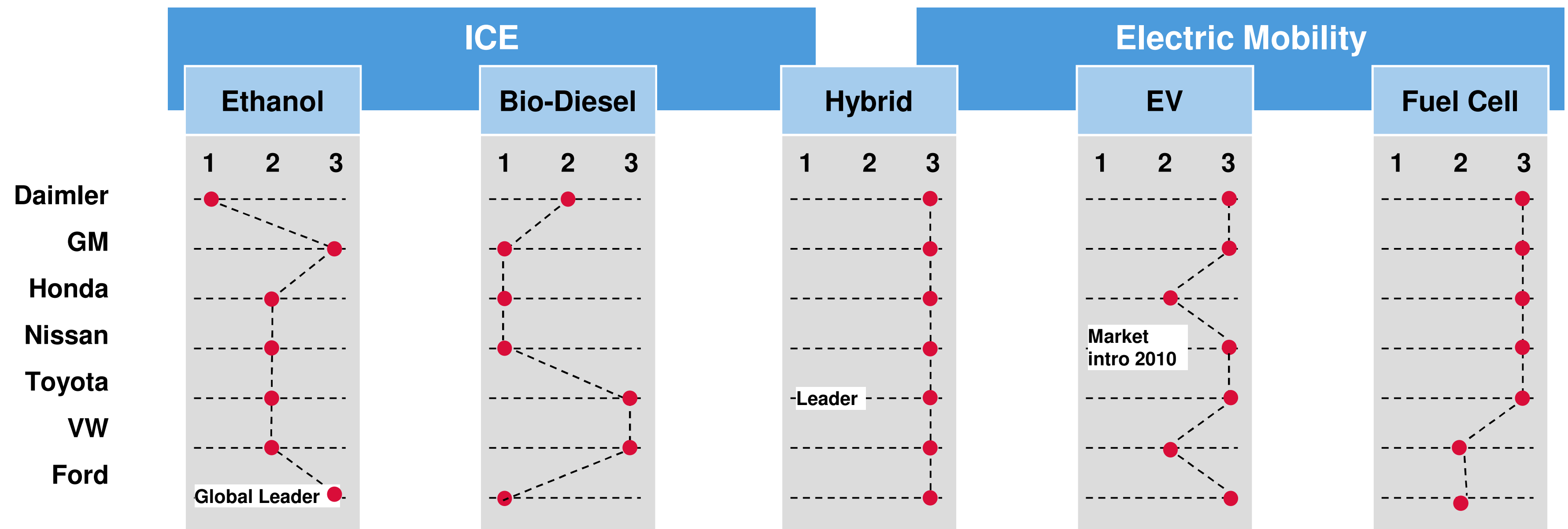
(in €/kWh ~100 kW powertrain)



Source: US Department of Energy, Booz Allen Hamilton Technology Center, Booz & Company

While OEMs are currently researching different powertrain technologies, they are getting more active on electric mobility

OEM Development Activities on Various Powertrains



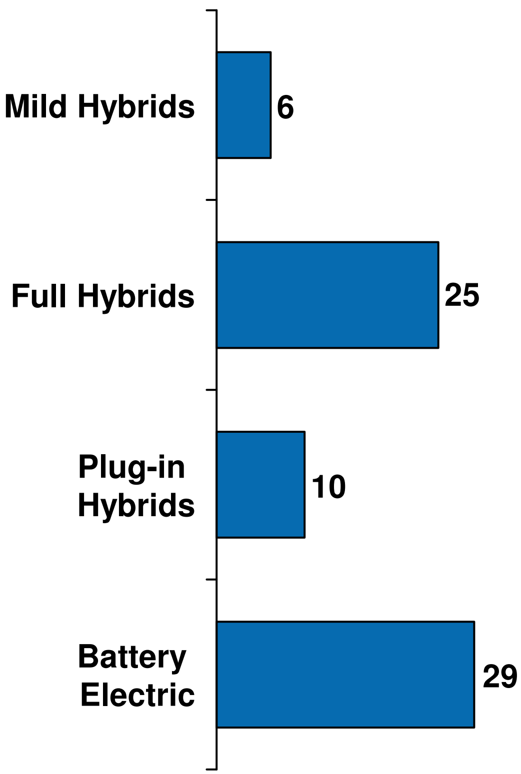
Ethanol	Bio-Diesel	Hybrid	EV	Fuel Cell
Regional application – must have if global presence	Regional focus	Success of Toyota induced focus on hybrid by other OEMs	Had difficulties in the 90s; OEMs are again showing interest	Promising technology; will take time to be commercial

1 = Not active/little information
2 = Somewhat active
3 = Very active/strong focus

1 FCV = Fuel Cell Vehicle
Source: OEM Interviews, literature search, Booz & Company analysis

Among electric mobility solutions, OEMs are focusing on development of full hybrids and full battery electric vehicles

Number of Electric Models Launched
By Technology, 2009-2013



Main Models

- BMW ActiveHybrid 5 Series
- Chery A5 Mild Hybrid
- Mercury Milan Hybrid

- Toyota Prius III
- Ford Fusion Hybrid
- Mercedes E400 Hybrid

- Toyota Prius Plug-in Hybrid
- Chevrolet Volt
- Mercedes S500 Plug-in-Hybrid

- Nissan Leaf
- Renault Fluence Z.E
- Ford Focus BEV.

Number of Electric Models Launched
By Technology and Segment 2009-2013

Type of Vehicle	Mild Hybrids	Full Hybrids	Plug-in Hybrids	Battery Electric
A & B – "Mini & Small"		3		13
C – "Middle"	2	3	3	7
D – "Large"	1	5	2	1
E&F "Luxury & Sport"	2	6	3	4
SUV		6	1	1
MPV		1		2
LCV	1	1		
Total	**6**	**25**	**10**	**29**

Source: Just-Auto, Booz & Company

The road to the new automotive world order will be challenging and will require significant transitions from today's status quo

Key Challenges

Capabilities

- How can OEMs build up the new structures and capabilities required to develop alternative powertrain vehicles?
- Who should the OEMs partner with in order to build and improve these capabilities?

Suppliers

- Where and how do OEMs find the suppliers for new technologies? How will these relationships be different from relationships with current suppliers?
- How can the supply chain be aligned to meet the needs of the new supplier landscape?
- How will infrastructure supply (e.g. electric charging stations) be built up?

Change Management

- What changes are in store for the current manufacturing structure and how can they be managed most effectively? Engineering? Sales & Marketing?

Solutions for the "mobility revolution" require a new "eco-system" of collaborative partnerships

3 Dimensions of the New Eco-system

Regulatory Innovation Frontier (Government)

- New policies (including subsidy policy) to support the commercialization of green transportation technologies

Technical Innovation Frontier (Auto Industry)

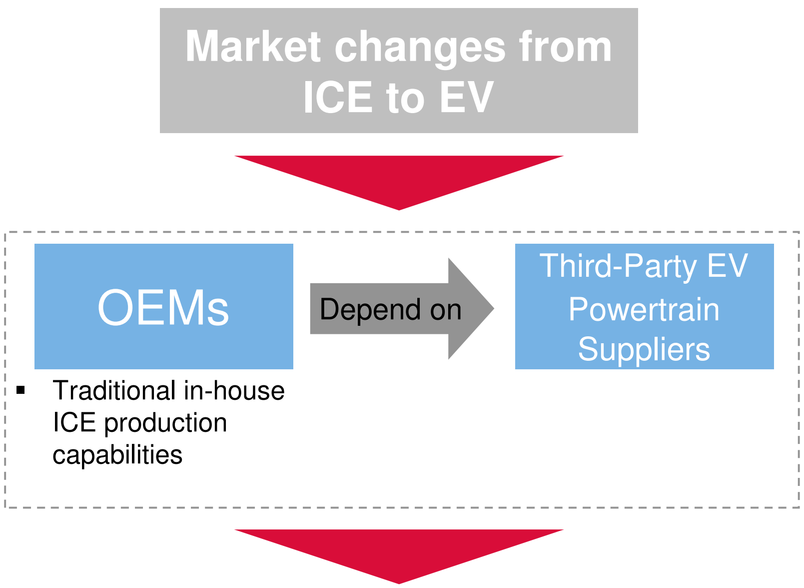
- Partnerships among key players to deliver deep, scalable solutions for future green transportation

Business Innovation Frontier (Cross Industry/Value Chain)

- Partnerships between other industries and auto makers/suppliers to develop new business model for future green cars

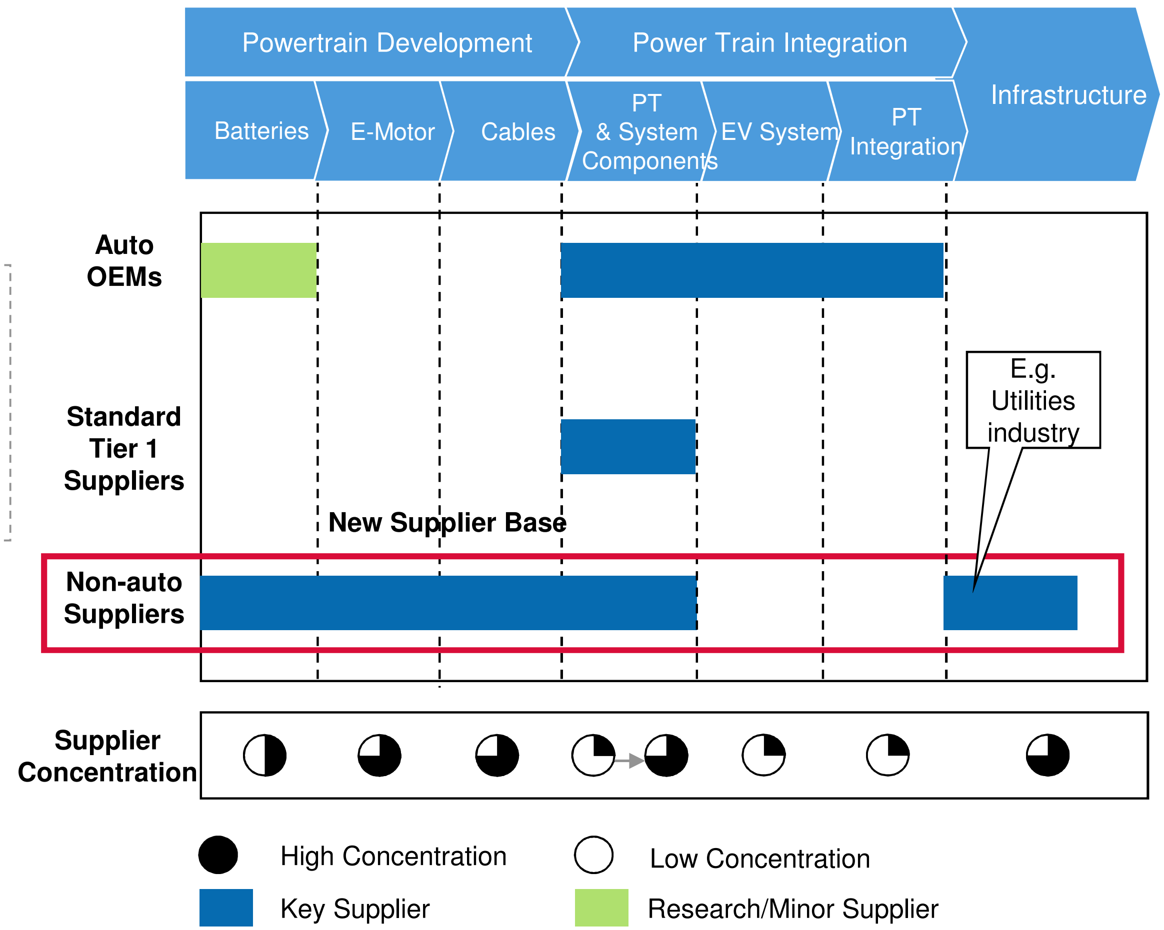
For EVs, there will be changes in OEM manufacturing footprint, and new suppliers will play a role in the powertrain value chain

Dynamic Changes for OEMs and Suppliers



1. OEMs' assets previously bound in ICE manufacturing facilities will be diversified
2. New suppliers that do not have a role in the past will come into play

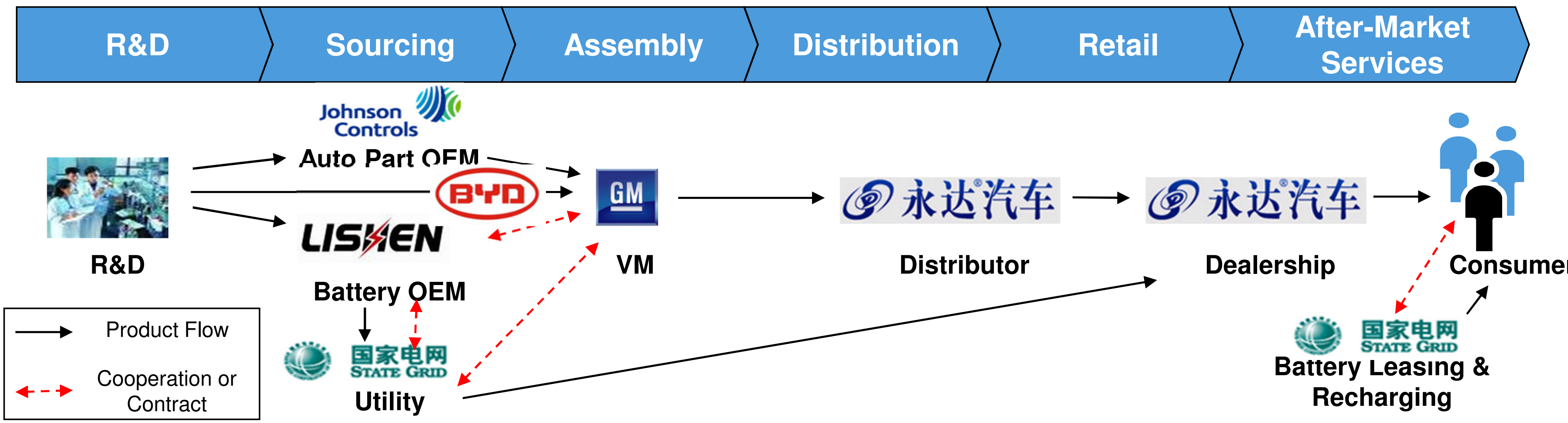
New Supplier Segmentation in the EV Powertrain Value Chain



Source: Interviews, Booz & Company analysis

In addition, the development of EV industry requires partnership across the value chain

Key Stakeholders of the EV Industry



Collaborative partnerships with emerging players will ultimately drive the green revolution

Source: Booz & Company analysis

Globally, economies have been pushing the xEV agenda by leveraging different policy levers

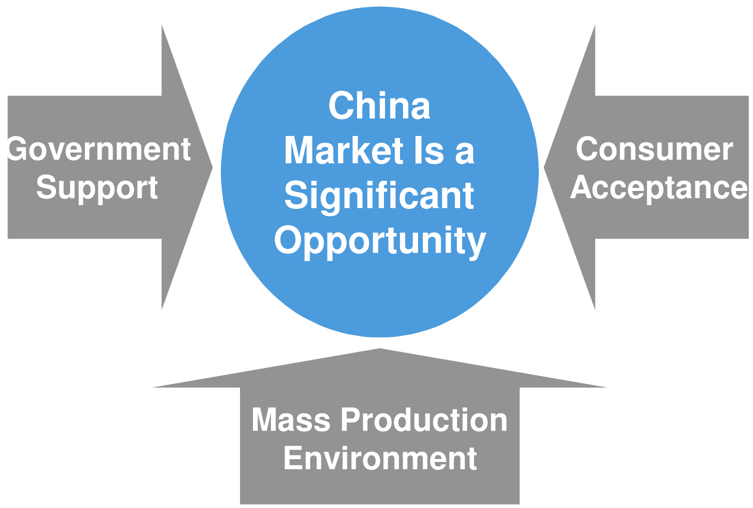
E-Mobility Models: Comparison of Select Countries

Lever	US	China	Japan	France
R&D	✓✓✓	✓✓✓	✓✓	✓✓
Supply Side	✓✓	✓✓✓	✓	✓
Demand-side Incentives	✓✓✓	✓	✓✓	✓✓✓
Infrastructure	✓✓	✓✓✓	✓✓	✓✓✓
HEV / PHEV / BEV Incentives	▪ Incentives for HEVs phased out ▪ Incentives for PHEVs and BEVs based on battery size	▪ Incentives in form of subsidy and exemption from road and annual tax ▪ Maximum for BEVs followed by PHEVs and HEVs	▪ Equal incentives for all xEV technologies	▪ Incentives for HEVs <50% compared to PHEVs / BEVs
Proposed Investment	>$5 B	> $20 B	>$1.7 B	>3.5 B

Note: Japan's investment is from 1998-2014
Source: Literature Research, Booz & Company analysis

Comparing with mature markets, China stands out as a significant opportunity and seems more ready to introduce EV

Key Forces in China



- Chinese government is driven by greater environmental pressure and energy consumption
- The government started stronger incentives to promote cleaner technologies in automobile industry
- China's automobile industry has lagged behind foreign OEMs in the ICE era
- Emergence of EV provides great opportunity for China to catch up

- China possesses ample resources to achieve low cost production
- Established battery manufacturers with large-scale capacity; supply lithium battery to cell phone/laptop industry

- Passenger ownership per capita in China suggest a very low penetration of vehicles
- Consumer habit in China is still in the forming process due to relatively short driving history
- Thus consumer acceptance to EV is comparatively high than mature markets (e.g. US with approx. 20-year driving history)
- Meanwhile, the switch cost is expected to be low

Readiness for EV

Mature Market

China

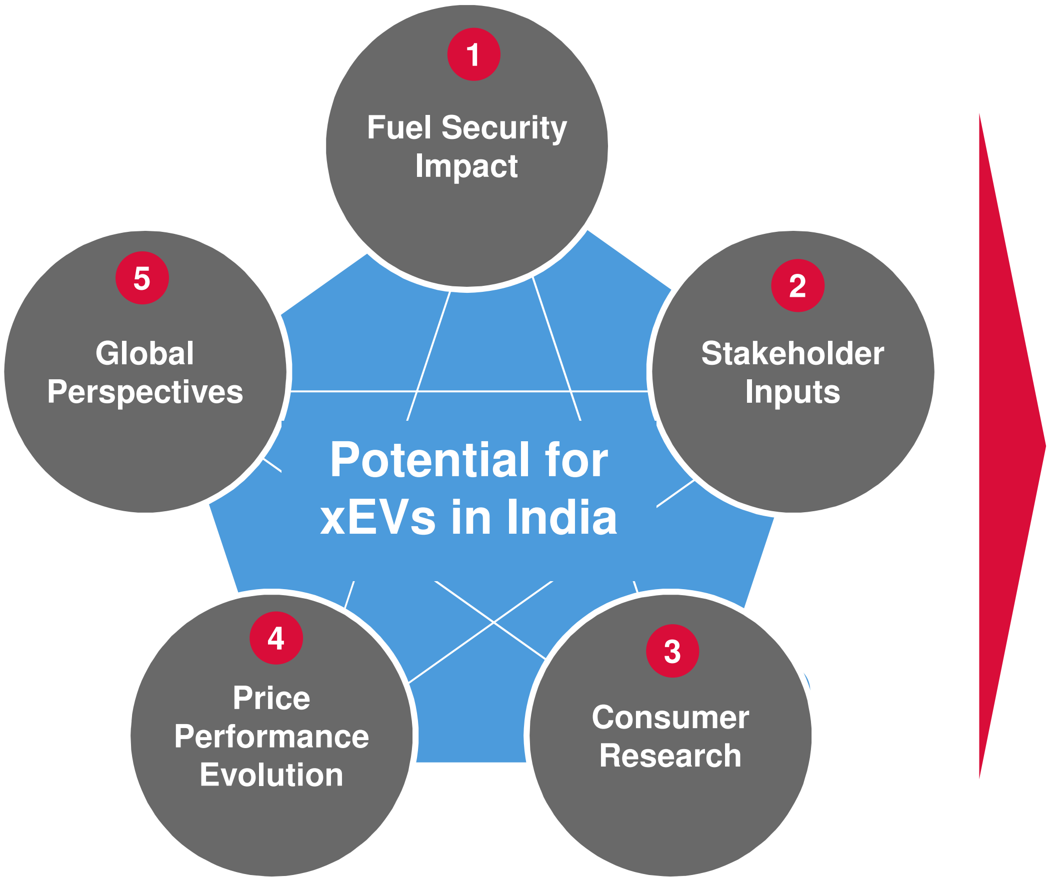
Source: Booz & Company analysis

Alternative Powertrains: Global Developments and Challenges

Insights from the Indian Hybrid / Electric Mobility Study

The total potential for xEVs in India could be 5 – 7 M units in new vehicle sales by 2020, based on extensive research and analysis

Inputs Used to Develop xEV Potential for India



Potential for xEVs – 2020

Vehicle / Technology Segment	Potential for xEVs (M Units)
BEV 2W	3.5 – 5
HEV Vehicles (4W, Bus, LCV)	1.3 – 1.5
Other BEV Vehicles (3W, 4W, Bus, LCV)	0.2 – 0.5
Total	**5 – 7**

Source: Booz & Company analysis

About 2 - 2.5 MT of liquid fuel savings are expected to accrue from 2W, 4W, LCVs, buses and 3W; with highest contribution from 2W

Potential xEV Vehicle Sales and Liquid Fuel Savings

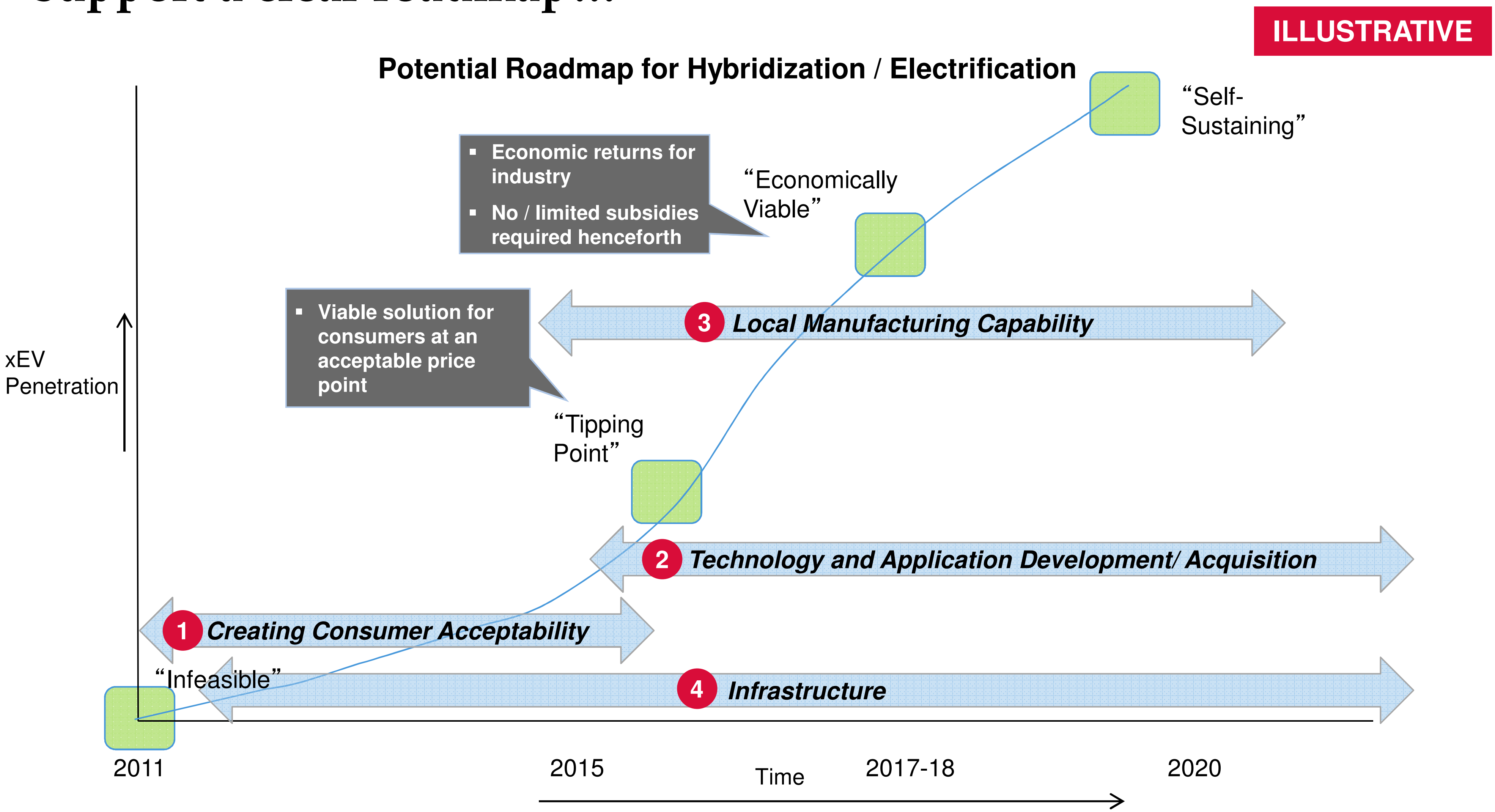
	2W	4W	Bus	LCV	3W
Vehicle Sales in 2020 ('000 Units)					
HEV / PHEV	-	1,275	2	120	-
BEV	4,800	170-320	0.3-0.7	30-50	20-30
Fuel Savings due to xEVs (Million Tonnes of Liquid Fuel)					
Fuel Savings	1.4	0.4 – 0.65	0.16 – 0.19	0.09 – 0.16	0.06 – 0.09

Total vehicles: 6 – 7 M

Total oil savings: 2.2 – 2.5 MT

Note: Liquid fuel = petrol / diesel
Source: Industry Interviews, SIAM, Booz & Company analysis

To realize this potential, the Government and the Industry need to support a clear roadmap…



Source: Booz & Company analysis

…which will require Government interventions

Key Policy Levers for Driving xEV Demand

Fuel Efficiency Regulations	▪ Mandate higher fuel efficiency norms with penalties for non-compliance → encourages OEMs to develop more fuel efficient vehicles	*Technology neutral*
Demand Side	▪ Mandate xEVs in government fleets, public transportation to create initial demand for OEMs ▪ Incentivize sales of xEVs through cash subsidies to consumers	▪ *Technology Dependent*
Supply Side	▪ Provide OEMs and suppliers benefits like accelerated depreciation and tax holidays to encourage local assembly and manufacturing of xEVs ▪ Phase out existing low import duties on components over ~5 years to encourage localization	
Research and Development	▪ Fund R&D programs along with OEMs / component suppliers to develop optimal solutions for India at low cost	
Infrastructure Support	▪ Roll out pilot programs to support hybrid/electric vehicles and test effectiveness ▪ Make modest investments to build public charging infrastructure to support electric vehicles (especially for buses)	

These suggested interventions will be examined by the NBEM and NCEM, which will outline the policy for xEVs in India