The Vehicle of the Future: Choices, Challenges and Opportunities

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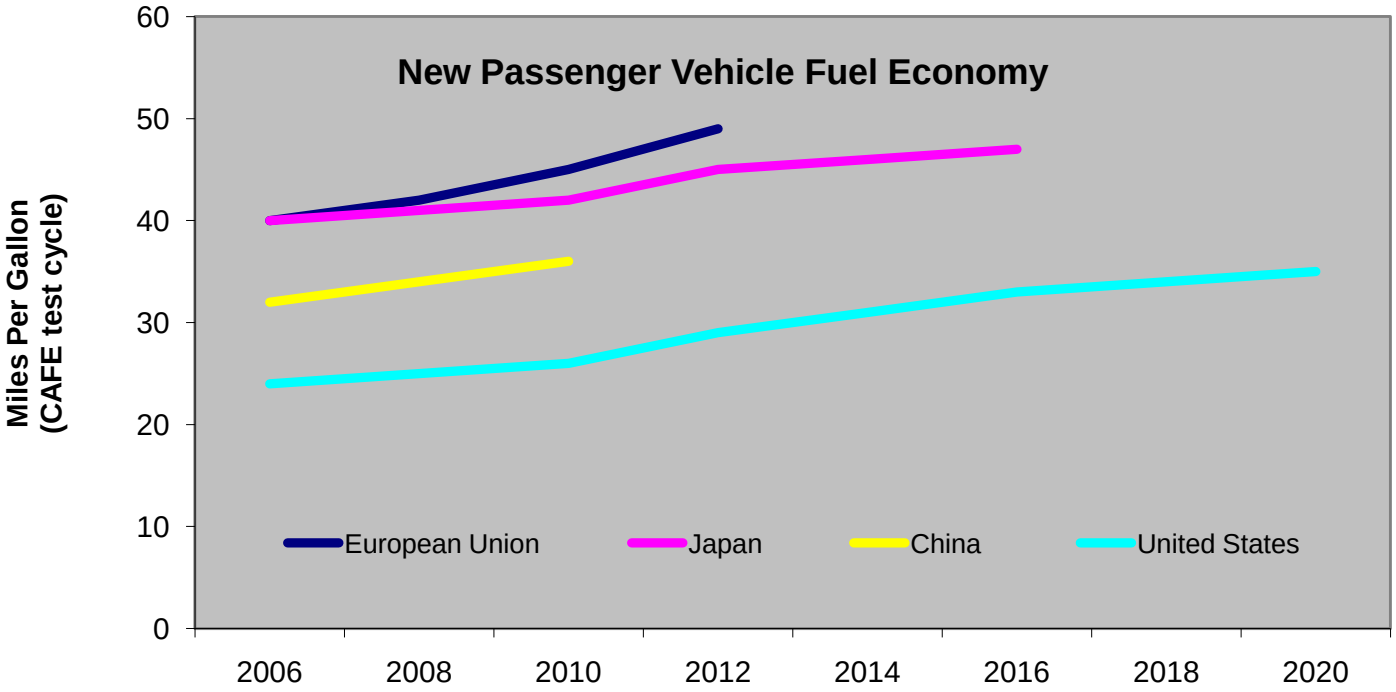
Current Vehicle Landscape

- The number of cars and light trucks worldwide are projected to increase from 800 million in 2009 to as much as three billion in 2040; China and India could contribute up to one billion of this vehicle increase
- Key US vehicle statistics over last 20 years:
  - On-road fuel economy has remained constant at about 22 mpg
  - Annual miles driven has increased from 9,000 to 12,000 miles
  - Average vehicle weight has increased 30%
  - Tailpipe CO_2 emissions are approaching 25% of all CO_2 emissions
  - Oil imports represent >50% of liquid fuel usage
- In the absence of fiscal incentives, consumers will opt for larger, heavier, higher horsepower vehicles

Continuation of existing vehicle trends will put a strain on the price and availability of oil that will negatively impact world economies, national security, and the environment

Sources: MIT Report, On the Road in 2035, General Motors

Worldwide Fuel Economy Trends



Incentives to reduce miles driven must accompany fuel economy improvements to make a substantial impact on oil usage and emissions

Note: Future mpg projections based on currently planned fuel economy standards

Sources: International Council on Clean Transportation, California Berkeley Transport Center

How Can We Change the Situation?

- Vehicle and Propulsion Technology Solutions
  - More efficient, lighter weight, more aerodynamic vehicles
  - New energy sources (e.g., batteries, fuel cells, hybrid technologies)
- Alternative Fuels Solutions
  - Oil from tar sands
  - Biofuels (e.g., ethanol, biodiesel)
- Fiscal and Regulatory Solutions
  - Fuel economy standards
  - Feebates–rebates on fuel-efficient vehicles, and add-on fees for fuel inefficient vehicles
  - Fuel and carbon taxes
  - Scrappage incentives (e.g., cash for clunkers)
  - Pay-as-you-drive insurance premiums–those vehicles driving below average mileages would pay lower insurance premiums

Source: MIT Report, On the Road in 2035

Propulsion System Pathways

Mechanical/Chemical ⟷ Electrochemical

ICE-Based

TSI

Improvements

- Turbo-charging
- Direct injection
- Cylinder deactivation

TCID

Improvements

- Turbo-charging
- Direct injection
- Improved exhaust gas recirculation

Battery-Based

HEV

Improvements

- Parallel hybrid with two drive-trains
- Series hybrid with gas engine recharging an electric drive train
- Regenerative braking helps recharge battery

PHEV

Improvements

- Same as HEV, but can recharge vehicle from the grid
- Runs off battery and switches to engine power when battery reaches pre-determined charge state

BEV

- Battery only energy source
- Practical driving range limited to 100 to 200 miles at best
- Rapid recharge and smart charging modes
- Rapid battery replacement techniques

Fuel Cell-Based

FCV

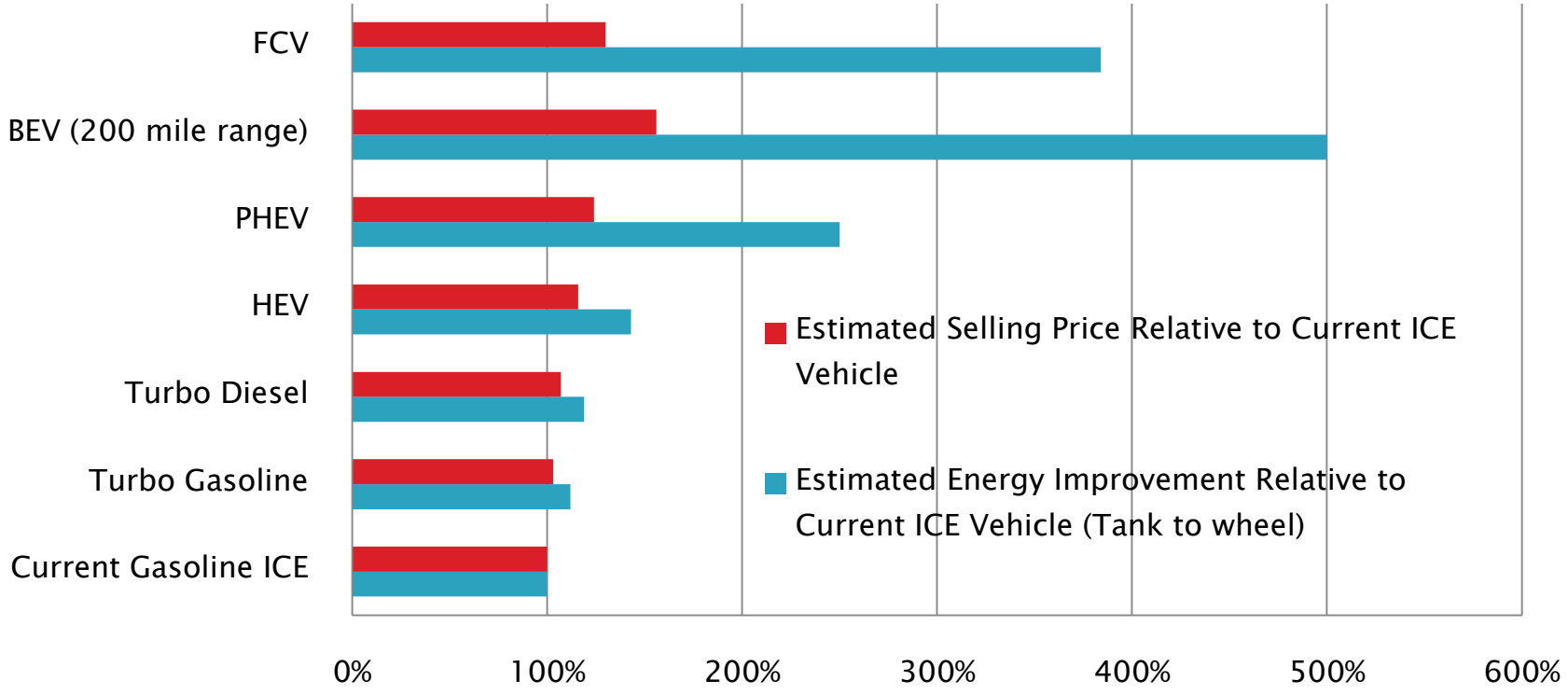
Improvements

- Hybrid configuration where proton-exchange membrane fuel cell and batteries power motor
- On-board gaseous compressed hydrogen storage is most likely source of hydrogen
- Fuel cell and regenerative braking help recharge battery

- TSI=Turbo spark ignition gasoline engine
- TCID=Turbo compression ignition diesel engine
- HEV=Hybrid gas-electric vehicle
- PHEV=Plug-in hybrid gas-electric vehicle
- BEV=Battery only electric vehicle
- FCV=Fuel cell vehicle

Sources: MIT Report, On the Road in 2035, Audi, Ford, General Motors

Fuel Economy and Pricing Comparison



For PHEV, BEV and FCV, tax credits and other subsidies will be required to permit advanced technologies to compete on initial selling price

ICE=Internal combustion engine
HEV=Hybrid gas-electric vehicle
PHEV=Plug-in hybrid gas-electric vehicle
BEV=Battery only electric vehicle
FCV=Fuel cell vehicle

Sources: MIT Report, On the Road in 2035

Other Pathways to Fuel/Emission Reduction

- **Vehicle Weight Reduction**
  - Lighter body materials and vehicle size reduction
  - 20% reduction in weight could result in a 12% reduction in fuel consumption for about $800 increase in vehicle purchase price
- **Increase Consumer Awareness of Fuel Usage**
  - Dashboard displays that prominently indicate real time fuel usage and remaining range before refill/recharge
  - Conversion to cents/mile instead of miles per gallon in comparing vehicle energy usage
- **Make Smaller Vehicles More Desirable**
  - More luxurious, roomier interiors
  - State-of-the-art electronics packages for music, video, internet
  - GPS-based services to avoid traffic jams or to identify nearest battery recharge station

Sources: MIT Report, On the Road in 2035, International Council on Clean Transportation

Alternative Liquid Fuel Options

- Tar sand reserves could contribute 10% of US petroleum supply by 2030
  - Well to tank greenhouse gas emissions are projected to increase by 5% at the 10% supply level
- Ethanol could displace about 10% of gasoline by 2025
  - Corn-based ethanol produces only modest improvements in greenhouse gas emissions at the 10% level, and could drive feedstock prices up to an unacceptable level
  - Biomass-based ethanol could provide substantial improvements in greenhouse gas emissions, but only with significant changes in land use implementation and policy and improvements in distribution channel
  - Ethanol currently requires subsidies to be price competitive with gasoline

Sources: MIT Report, On the Road in 2035

Entrepreneurial Opportunities

- Emissions-Related
  - Intelligent reuse or capture of tailpipe emissions to avoid greenhouse gas impacts
  - Creative ways to employ carbon caps to encourage reduced vehicle usage
  - Innovative vehicle or battery leasing plans

- Battery and Fuel Cell-Related
  - Improved battery performance in terms of energy density, power density, recharge rate, overall weight
  - Battery designs that use more readily available materials such as zinc or nickel, or that intelligently replace or recycle key materials
  - Innovative on-board hydrogen storage for fuel cell vehicles
  - Novel battery recharging or replacement concepts, and innovative carbon capture techniques for external refueling of hydrogen fuel cell vehicles

- Materials-Related
  - Recovering lithium from used lithium-ion batteries
  - Cost-effective replacement of rare earth metals in batteries and electric motors
  - More durable membrane technology for fuel cell vehicles
  - Reuse of salvaged vehicle batteries as solar or wind storage devices
  - More efficient electric motor, inverter, and power control electronic components

Summary

Vehicle ecosystem in Year 2025 will look something like this:

- Application-specific
  - All-electric urban vehicles
  - Hybrid electric and fuel cell vehicles for long range driving
  - Smaller, fuel efficient, high performance gasoline or diesel vehicles for image-conscious
- More fuel-efficient
  - ICE new fleet average of 40 mpg or more
  - Plug-in hybrid and fuel cell vehicles with new fleet average of 100 mpg or more
- More expensive
  - $2000 to $4000 more for comparable size and performance
- More costly liquid fuel
  - Gasoline and diesel fuel will exceed $5.00 per gallon worldwide
- Cleaner emissions
  - Slow reduction in fleet emissions as older vehicles are removed from the road and average miles driven decreases

How Will the Transition Evolve?

RevGen Group can provide important insights on key questions:

- How will car makers adapt their manufacturing philosophies to build these new vehicles and drive trains?
- What technologies should component suppliers pursue to add value for car makers?
- How will the vehicle mix differ in key geographic regions?
- Are well-to-wheel emissions significantly improved with the introduction of HEV and PHEV?
- What infrastructure plays are most likely to benefit from the vehicle of the future?

Go to RevGen Group Web Site

Email Mort Cohen for more insights and analyses on the vehicle of the future

The RevGen Group assists high technology clients to:

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- Manage due diligence

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- Smart grid
- Wireless communications
- PC software, Web 2.0, enterprise networking
- Semiconductor equipment and technology

We deliver:

- Advice, strategies, models and tools, alternatives
- Research, analysis, evaluation, validation
- Operational assistance