Agenda

Motivation for improved efficiency & alternatives
Reducing Oil Consumption: Improving Efficiency
Alternative Fueled Powertrains
Biofuels
Natural Gas/CNG/LNG
LPG/Propane/Autogas
Electricity
Hydrogen
Transportation Dominates Oil Consumption

~42% of oil consumed in the U.S is imported

Gas & Diesel advantages:
- High Energy Density
- Energy Carrier and Storage
- Plentiful
- Pervasive distribution
- Relatively safe
- Acceptable Cost

Issues:
- Energy Security
- Stable supply
- Source Countries
- Trade Deficit
- Cost of energy
- Emissions
Economic Backdrop for Oil Alternatives

Incumbent gasoline/diesel powered vehicles advantages:
- Energy density of fuel
- Network/Eco-system for production, refining, distribution, consumption

Alternatives are beneficial for a variety of reasons
- Emissions, trade deficit, energy security, geopolitical issues
- But all of them have issues (some big, some small)

OPEC/Saudi Arabia is the “swing producer” since 1970’s
- Texas (and the Texas Railroad Commission) previously set prices
- OPEC wants prices high enough to support revenue requirements
  - but not so high to encourage alternatives
  - $80-$100/bbl appears to be their target range

Enviable position when one is the low-cost producer who can shift the supply curve, and the marginal price is set by far more expensive competitors

Whipsaw from volatility is detrimental to GDP growth
Substantial Risks to Global Oil Supplies

Major Oil Reserves in Middle-East

Unrest increases “the risk premium”
- Incentives to incite instability
- Increases oil prices & profits

Middle-East instability:
- Oppression, torture, inequality, lack of opportunity
- Awareness with internet, facebook, Twitter, cell phone cameras, SatTV
- Significant portion of population young and unhappy
- Countries often lacking history of strong positive institutions beneficial to population’s quality of life & opportunity
- 21st century in Middle-East: Similar to the 20th century for Europe?
- Massive conflicts finally so destructive that the region finally resolved to stop centuries of conflicts
Oil and the Trade Deficit

- The U.S. is losing its ability to generate export revenue from Advanced Technology.

- Advanced Technology thought to be the offset for importing goods such as oil.

- Normally, currencies would adjust to re-establish equilibrium.
- Dollar not declining from “flight to safety” into U.S. Treasuries at this time.
The U.S. Transportation Situation

No Single Silver Bullet

- U.S. land mass is huge: mass transit can help in some urban areas. But...

- Autos are a consumer durable: provide utility, enjoyment, fashion, convenience...
  - An emotional/aspirational consumer good

Problems:
- Emissions: the challenge now is CO₂
- Oil Imports: Energy Security, Trade Deficit
- Congestion...

How to achieve “Sustainable Mobility”
Vehicle Manufacturers Dream of “Sustainable Mobility”

Desire to “take the car out of the environmental equation”

H2FCV: long range, fast refill, zero tailpipe emissions
Improving Efficiencies of Gasoline/Diesel Conventional Vehicles
Improving Efficiencies

Major methods to improve Fuel Economy (hence emissions)

- Lower weight of vehicle
- Improve Aerodynamics
- Improve Powertrain Efficiency
- Lower Tire Rolling Resistance
- Reduce Other Parasitic Losses (e.g. Cabin HVAC)
Wasted Energy!!

= Wasted Energy ~

= 20.23/26.97

= 75%

(but some waste heat is useful for cabin heating)

Only about 14%–26% of the energy from the fuel you put in your tank gets used to move your car down the road, depending on the drive cycle. The rest of the energy is lost to engine and driveline inefficiencies or used to power accessories. Therefore, the potential to improve fuel efficiency with advanced technologies is enormous.

### Engine Losses
In gasoline-powered vehicles, most of the fuel's energy is lost in the engine, primarily as heat. Smaller amounts of energy are lost through engine friction, pumping air into and out of the engine, and combustion inefficiency.

### Parasitic Losses
Power steering, the water pump, and other accessories use energy generated by the engine. Fuel economy improvements up to 1% may be achievable with more efficient alternator systems and power steering pumps.

### Idle Losses
A vehicle spends significant time idling in city driving (stop and go traffic). Using energy to run the engine and power the water pump, power steering, and other accessories. Highway driving, however, includes little to no idling.

### Power to Wheels
Braking Losses
Any time you use your brakes in a conventional vehicle, energy initially used to overcome inertia and propel the vehicle is lost as heat through friction at the brakes.

Less energy is used to move a lighter vehicle. So less energy is wasted from braking a lighter vehicle. Weight can be reduced by using lightweight materials and lighter-weight technologies.

Hybrids, plug-in hybrids, and electric vehicles use regenerative braking to recover some braking energy that would otherwise be lost.

Wind Resistance (Aerodynamic Drag)
A vehicle expends energy to move air out of the way as it goes down the road—less energy at lower speeds and more as speed increases.

This resistance is directly related to the vehicle's shape and frontal area. Smoother vehicle shapes have already reduced drag significantly, but further reductions of 20%–30% are possible.

### DriveTrain Losses
Energy is lost in the transmission and other parts of the driveline. Technologies such as automated manual transmissions (AMTs), double-clutch, lock-up transmissions and continuously variable transmissions (CVTs) can reduce these losses.

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**Source:** www.fueleconomy.gov

**Primary Data Sources:**


Improving Internal Combustion Engines

- **Gasoline**
  - SIDI
  - V.V.T.
  - Variable Displacement
  - HCCI
  - Turbo/Super-charging
  - Scuderì Split-Cycle

- **Diesel:**
  - Common-Rail Clean Diesels

- Even greater potential improvements when combined w/hybridization

- Perpetual concerns over cost & durability
Diesels

Europe: Clean Diesels have >50% Marketshare
- Many Years of incentives and R&D
- Lower Diesel fuel taxes compared to Gasoline taxes
- Higher quality Diesel fuel (lower sulfur, higher Cetane)
- Lower yearly registration taxes
- Less stringent emissions requirements

US:
- History of dirty burning diesels, poor quality
- Lower quality U.S. Diesel fuel:
  - High sulfur fuels until 2006 (15ppm)
  - Cetane (40 min vs. 50 in Europe)
- Diesel & Gasoline emissions requirements the same
- Higher Diesel fuel tax than Gasoline to have large trucks pay for road damage
- No incentives
- $2k to $4k increase in purchase price, 10-15% higher Diesel fuel price for 10-30% better fuel economy (but also higher maintenance costs)

Expect an increasing number of Clean Diesel vehicles in US over time
Hybridization of Gasoline/Diesel Engines

- Internal Combustion Engine + Electric Motors + Electronics + Batteries

Hybrid Electric Vehicles (HEVs)
- Toyota Prius, Ford CMAX/Fusion, Honda Insight/Civic, Chevy Tahoe
  - Also, “mild-hybrids”: Start-Stop/eAssist

- Brake energy recapture, start/stop idle reduction, electronic continuously variable transmission (eCVT) which allows more efficient engine operation

- Proved the viability of electrified vehicles: Electronics + Big Batteries + Motors
Alternative Fuels
Which Propulsion System has the most flexibility of Energy Resources?
Which Energy Carriers are likely to be low cost, secure, & wide spread?
Critical Factors for Alternative Fueled Vehicles

**Costs**
- Fixed Costs: R&D, Manufacturing Tooling
- Variable Manufacturing Production Costs
- Operating & Maintenance (O&M): Fuel, repairs

**Refueling infrastructure**
- Availability of refueling locations
- Ease, speed, cost of refueling
- “Chicken & Egg” situation:
  - Drivers will only buy a vehicle if they can conveniently find fuelling stations
  - But Firms will build fueling stations only when a sufficient volume of vehicles

**Regulatory Factors**
- Emissions, Fuel Economy, Safety, recycling

**Can a “Compelling Vehicle” be designed which uses the fuel?**
- Range, fuel storage, performance, drivability, long term durability
BioFuels

Predominately Ethanol, Biodiesel, and drop-in JetA/JP8 substitute

Issues typically debated are scale, cost, distribution, land reuse
Modern computer controlled engine controls/sensors have enabled engine designers to support FlexFuel & meet cost/environmental/efficiency/durability goals

**Ethanol**: E10 through E85 in US (E100 in Brazil for example)
- Ethanol first used 100+ years ago in Henry Ford’s first engine
- Ethanol fuel may be the same, but can be made from many feedstocks

Input feedstock
- Corn, sugar, cellulosic (switchgrass, etc)
- Efficiency of production & costs vary (sometimes greatly)
- Fuel efficiency can be up to 26% less than E0 Gasoline in un-optimized engine
  - But 105-113 Octane rating can allow turbo/supercharging to overcome energy density disadvantage (Saab BioPower, SAE paper 2007-01-3994)
- All US FlexFuel vehicles appear to be Ethanol Tolerant, not Ethanol Optimized
- Considerable politics involved…but replacing Lead/MTBE with Ethanol for E10 in gasoline sound science. Increasing Octane essential to support higher compression ratio for higher engine efficiency

**Biodiesel** (B20): Manufacturers who have tested for up to 20% biodiesel
## Alternative Fuels

### Alternative Fuels Data Center – Fuel Properties Comparison

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel (No. 2)</th>
<th>Biodiesel</th>
<th>Propane [LPG]</th>
<th>Compressed Natural Gas (CNG)</th>
<th>Liquefied Natural Gas (LNG)</th>
<th>Ethanol</th>
<th>Methanol</th>
<th>Hydrogen</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical Structure</strong></td>
<td>C\textsubscript{6} to C\textsubscript{12}</td>
<td>C\textsubscript{6} to C\textsubscript{25}</td>
<td>Methyl esters of C\textsubscript{16} to C\textsubscript{18} fatty acids</td>
<td>C\textsubscript{3}H\textsubscript{8} (majority) and C\textsubscript{2}H\textsubscript{6} (minority)</td>
<td>CH\textsubscript{4} (80-95%), C\textsubscript{2}H\textsubscript{6} (1-13%)</td>
<td>CH\textsubscript{4}H\textsubscript{2}</td>
<td>CH\textsubscript{3}OH</td>
<td>CH\textsubscript{3}OH</td>
<td>H\textsubscript{2}</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Fuel Material (feedstocks)</strong></td>
<td>Crude Oil</td>
<td>Crude Oil</td>
<td>Fats and oils from sources such as soybeans, waste cooking oil, animal fats, and rapeseed</td>
<td>A by-product of petroleum refining or natural gas processing</td>
<td>Underground reserves</td>
<td>Underground reserves</td>
<td>Corn, grains, or agricultural waste (cellulosic)</td>
<td>Natural gas, coal, or, woody biomass</td>
<td>Natural gas, methanol, and electrolysis of water</td>
<td>Coal, nuclear, natural gas, hydroelectric and small percentages of wind and solar</td>
</tr>
<tr>
<td><strong>Gasoline Gallon Equivalent</strong></td>
<td>100%</td>
<td>1 gallon of diesel has 113% of the energy of one gallon of gasoline.</td>
<td>R100 has 103% of the energy in one gallon of gasoline or 93% of the energy of one gallon of diesel. B20 has 100% of the energy of one gallon of gasoline or 99% of the energy of one gallon of diesel.</td>
<td>1 gallon of propane has 79% of the energy of one gallon of gasoline.</td>
<td>5.68 pounds or 126.67 cu. ft. of CNG has 100% of the energy of one gallon of gasoline.</td>
<td>1 gallon of LNG has 49% of the energy of one gallon of gasoline.</td>
<td>1 gallon of R85 has 73% to 83% of the energy of one gallon of gasoline (variation due to ethanol content in E85). 1 gallon of E10 has 96.7% if the energy of one gallon of gasoline.</td>
<td>1 gallon of methanol has 49% of the energy of one gallon of gasoline.</td>
<td>1 kg or 3.73 lbs. of H\textsubscript{2} has 100% of the energy of one gallon of gasoline.</td>
<td>33,700 kWh has 100% of the energy of one gallon of gasoline.</td>
</tr>
</tbody>
</table>

### Energy Content (Lower heating value)

|                         | 116,090 Btu/gal (g) | 128,450 Btu/gal (g) | 119,550 Btu/gal for B100 (g) | 84,950 Btu/gal (g) | 20,288 Btu/lb (g) | 74,720 Btu/gal (g) | 76,330 Btu/gal for E100 (g) | 57,250 Btu/gal (g) | 51,585 Btu/lb (g) | 3,414 Btu/kWh |

*source: [http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf](http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf)*
Natural Gas: CNG/LNG

Natural gas sold in units of gallon equivalents (GGEs)
- Based on the energy content of a gallon of gasoline or diesel fuel
- $0.50/gallon equivalent Federal Tax Credit (http://www.afdc.energy.gov/laws/laws/US/tech/3254)
- 30% Federal Tax Credit on refueling infrastructure

Compressed Natural Gas
- For acceptable range, CNG stored pressures of 3,000 to 4,500 psi
- CNG-vehicle ~ same fuel economy as gasoline vehicle on a gasoline gallon equivalent basis.
- A GGE equals about 5.66 pounds of CNG.
- Massive U.S. Natgas pipeline infrastructure
- Fracking leading to huge domestic production & reserves and low prices
- Lower emissions than gasoline or diesel

Liquefied Natural Gas (LNG)
- LNG produced by purifying natural gas & super-cooling it to a -260°F liquid
- Must be kept at cold temperatures, stored in double-walled, vacuum-insulated tanks
- LNG for medium and heavy-duty trucks needing a longer range
- Liquid is more dense than gas (CNG), more energy can be stored in a tank
- A GGE equals about 1.5 gallons of LNG
- Use it or lose it

Source: http://www.afdc.energy.gov/fuels/natural_gas Basics.html
Natural Gas Vehicle Storage

CNG Vehicles

BiFuel Vehicles
- Run On CNG, then
- Gasoline backup
e-Gas

Wind Energy
Renewable energy generated by land and off-shore wind parks.

Power Network
Renewable energy for immediate use.

H₂ Extraction
Electrolysis separates water into dioxygen and hydrogen.

Generation of e-gas
Methanation joins hydrogen and carbon dioxide into water and e-gas.

e-gas Station
A vast growing number of e-gas stations supplies e-gas driven cars.

e-gas Supply
Renewable energy available at any time for any purpose.
LPG/Propane/Autogas

Third most popular vehicle fuel behind Diesel, Gasoline
- Largest Markets: Turkey, South Korea, Poland, Italy, Australia

More energy dense than CNG (range, tank size)

Do not have to super cool like LNG

Refueling stations far less costly than CNG (~$100k vs. $1M for CNG)

But NatGas has extensive pipeline infrastructure

More attractive for fleets with larger vehicles
- Home delivery possible, but costs may be equal or higher than gasoline
- Fleets can buy wholesale at higher volumes ($1.14/gallon, 2013 Flint Mass Transit)
- Lower maintenance costs & emissions than Diesel engines, higher purchase price
- $0.50/gallon equivalent Federal Tax Credit (http://www.afdc.energy.gov/laws/laws/US/tech/3254)
Plug-In Electric Vehicles (PEVs)
Modern PEVs: Plug-In Electric Vehicles

- **Non-Range-Extended: BEV (Battery Electric Vehicles)**

- **Range-Extended vehicles: eREVs and PHEVs**
  - eREV: Extended Range Electric Vehicle
  - PHEV: Plug-in Hybrid Electric Vehicle
  - Electric + gas combination to solve traditional BEV “Range Anxiety” problem & improve ICE Fuel Economy
As the number of PEVs sold radically increases, there is the potential for “Clustering” of PEVs on home-end transformers
- Upstream in distribution and transmission system averaging effects eliminate PEV clustering specific concerns
- Trusted neighbors influence adoption patterns (Prius, PV,) tending to experience “clustering”
- The Solution is simple: dispatch a repair truck & Lineman replace & upgrade old transformer with a new larger one
  - A management issue, no technological breakthroughs required

-Who should pay for transformer upgrade?
  - Century+ old model is that costs of distribution are spread across entire customer base: too hard and not fruitful to partition
  - Transformer upgrades in past from new home loads from pools, room additions, appliances, HVAC never separately allocated
  - Divert a portion of new PEV electricity sales to pay for upgrades
- Grid has been successively upgraded multiple times over the last century for Home Appliances, HVAC, Computers/Electronics
The “Big Vision”

Energy Efficiency
- Homes/Businesses (lighting, HVAC/Insulation)
- Transportation

De-Carbonize the Grid
- Zero (or much lower) Emissions Generation

Electrify Transportation (where possible)

Use Hydrocarbons for
- Recyclable Plastics, Fertilizer, Planes, Ships
An eREV in real use in Austin, Texas

3,864 miles over 4 months on 1 tank of gas
- Further than the distance from New York City to Los Angeles
- 8.1 gallons of gasoline + 1188 kWh of electricity ($131 at Austin Energy rates)
  - ~3 miles/kWh energy consumption, Electricity = $0.11/kWh (U.S. Average ≈ Austin Texas costs)
  - 35 to 42 miles/gallon when running on gasoline
- Typically fill up gas tank every 2 months or when taking an out-of-town trip
Powering a Vehicle with the Sun, Today

Summary for time-period shown in graph
- Energy Used: 52.2 kWh (approx. $5.22 used)
- Energy Generated: 87.0 kWh (approx. $3.70 saved)
- Net: 15.2 kWh bought (approx. $1.52 spent)

Summary over last 30 days
- Energy Used: 1.90 MWh (approx. $189.92 used)
- Energy Generated: 883 kWh (approx. $88.28 saved)
- Net: 1.02 MWh bought (approx. $101.63 spent)

37 kWh = 2 to 3x daily PEV electricity consumption
Hydrogen Fuel Cell Vehicles (H₂FCV)
Hydrogen Vehicle Rationale and Vision

- **Alternative to oil with:**
  - The attractive fast refueling speed of gas/diesel
  - The range of gas/diesel
  - The same business model for the distributors
  - Lower emissions
  - Domestic sources

- **Sources of Hydrogen:**
  - Original vision was associated with Nuclear energy
  - In the past when Nuclear energy was supposed to be “too cheap to meter”
  - Now mainly from methane/Natural Gas (used in industrial H2 production)
Fuel Cell Hydrogen Powered Vehicles

- **Substantial Progress in Fuel Cell Stack & Vehicle**
  - Size is now viable for vehicle application
  - Durability, cost are remaining Fuel Cell Stack challenges
  - Vehicle H2 Storage volume and cost

- **Greatest Challenges for H2 Fuel Cell Vehicles**
  - Entirely new Hydrogen refueling distribution system
  - Lower cost generation of hydrogen
    - High Temperature Nuclear Reactors
    - Hydrogen producing Algae (UC-Berkeley)
  - “Well to Wheels” efficiency & CO2 analysis

- **Fuel Cells attractive for large stationary or small portable applications (for now)***
  - some vehicle manufacturers are targeting H2FCV by 2015
Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and potentially useful heat as the only byproducts. Hydrogen-powered fuel cells are not only pollution-free, but also can have more than two times the efficiency of traditional combustion technologies.

Source: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fct_h2_fuelcell_factsheet.pdf
Fuel Cell Stack Cost

Projected Transportation Fuel Cell System Cost
-projected to high-volume (500,000 units per year)-

<table>
<thead>
<tr>
<th>Year</th>
<th>FC System Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>$275/kW</td>
</tr>
<tr>
<td>2006</td>
<td>$108/kW</td>
</tr>
<tr>
<td>2007</td>
<td>$94/kW</td>
</tr>
<tr>
<td>2008</td>
<td>$73/kW</td>
</tr>
<tr>
<td>2009</td>
<td>$61/kW</td>
</tr>
<tr>
<td>2010</td>
<td>$51/kW</td>
</tr>
<tr>
<td>2011</td>
<td>$49/kW</td>
</tr>
<tr>
<td>2012</td>
<td>$47/kW</td>
</tr>
<tr>
<td>2017</td>
<td>$30/kW</td>
</tr>
</tbody>
</table>

- Initial Estimate
- Balance of Plant ($/kW, includes assembly & testing)
- Stack ($/kW)

Current status: $47/kW vs target of $30/kW

What should **NOT** be an Impediment to Adoption

If in an accident, H\textsubscript{2} will disperse into the atmosphere
- Unlike gasoline/diesel which will leak onto ground and can ignite
Alternative Powertrain Adoption Outlook

Source: CARB 2007 ZEV Technology Review
Cost of Fuels

Average Retail Fuel Prices in the U.S.

Source: Clean Cities Alternative Fuel Price Reports
Notes: Fuel volumes are measured in gasoline-gallon equivalents (GGEs), representing a quantity of fuel with the same amount of energy contained in a gallon of gasoline.

This chart shows average monthly retail fuel prices in the United States from 2000 to 2013. The price of petroleum fuels (gasoline and diesel fuel) is the primary driver of overall fuel prices. As petroleum prices rise, so does demand for alternative fuels, thereby pushing their prices upward as well. However, natural gas prices have been buffered from this driver, because its primary market is utilities, and due to recent increases in domestic natural gas production.

source: http://www.afdc.energy.gov/fuels/prices.html
An Optimistic Projection to 2050

California (CARB) Scenario for LDVs: 87% PEVs and FCVs in 2050

Year

% of On-Road LDV Fleet

Advanced Gasoline Vehicles

Plug-in Hybrid Electric Vehicles

Conventional (Non-Plug-in) Hybrids

Battery Electric Vehicles

Hydrogen Fuel Cell Vehicles

2000 2010 2020 2030 2040 2050
Emissions & Efficiency Comparisons (Well-To-Wheels)
W2WAnalysis (WindPEV, Wind-FCEV, NatGas-FCEV)
Well to Wheels Analysis (NatGasICE vs PEV)

Result for 2010

- **Natural Gas**
  - Pipeline 7000 km, on site compression
  - Complete Chain: 31, Vehicle only: 40

- **Compressed Natural Gas**
  - Complete Chain: 240, Vehicle only: 174

- **Otto Engine (conventional-PSt) - Bitul**
  - Complete Chain: 34, Vehicle only: 40
  - Complete Chain: 217, Vehicle only: 174

- **Natural Gas**
  - Pipeline 1000 km, on site compression
  - Complete Chain: 36, Vehicle only: 40
  - Complete Chain: 200, Vehicle only: 174

- **Electricity**
  - Complete Chain: 56, Vehicle only: 130

- **Electric Vehicle with Li-Ion Battery**
  - Complete Chain: 131, Vehicle only: 0

Reference vehicle: Compact car gasoline
- Fuel Consumption: miles per gallon gasoline equivalent
- Greenhouse Gas Emissions: g CO2 equivalent per mile

Source: http://www2.daimler.com/sustainability/optiresource/index.html
Well to Wheels Analysis (Oil vs NatGas PEV vs FCV)

Result for 2010

Fuel Consumption
miles per gallon gasoline equivalent

Greenhouse Gas Emissions
g CO2 equivalent per mile

Complete Chain Vehicle only
Oil 35 40
Gasoline 264 226

Natural Gas Oil drilling, ship, gasoline refining, land
Pipeline 1000 km, on site reforming + H2 compression

Compressed Hydrogen Otto Engine (conventional - PISI)

Fuel Cell

Electricity Electric Vehicle with Li-ion Battery
Pipeline 4000 km, electricity generation, grid

source: http://www2.daimler.com/sustainability/optiresource/index.html
Energy Implications

Lowest cost entrenched technologies exhibit strong inertia
- Energy carrier cost-advantage inertia from generation + refueling infrastructure + vehicle fleet
- .. Until supply disruptions occur (or externalities are finally included)
  - Externality: When participants in an economic transaction do not necessarily bear all of the costs or reap all of the benefits of the transaction…e.g. pollution
  - Can be considered a “market failure”, typically addressed by governmental action

Most of the energy sources for each sector are lowest cost (excluding externalities) and/or most secure when investments decisions are made
- The mix changes with:
  - Availability of supply
  - Forward looking expectation of price movements
  - Spot market price
  - Government policy

The Market is efficient over the mid/long term
- Rapid adoption occurs when an attractive new technology also becomes cost competitive
- Taxes/Credits/Fee-bates help set prices
  - Cannot compensate when technology breakthroughs still are not available
  - Can cause major economic impacts if extreme or imprudent
  - Useful for strong nudge (versus “Hail Mary Pass”)
  - Useful for helping market include externalities
Achieving Sustainable Mobility

- No one solution fits all customers’ requirements
- Some solutions solve some problems (but not all)
- Consumer behavior matters the most
- Technology based improvements viable, but even larger gains can be derived by consumer preference/behavior changes
  - Weight Reduction (or simply buying a smaller car)
  - Powertrain efficiency
  - Aerodynamics
  - Tire Rolling Resistance
  - Reducing other parasitic loads

- U.S. Policies & Options:
  - CAFÉ & Emissions regulations
  - Increased motor fuels tax to encourage efficiency
  - Create incentives for new technology & use market forces
Consumer Behavior

Vehicle selection (size, horsepower, features), maintenance
- (e.g. tire pressure), **Driving Habits**: speed, trip-grouping, carpooling

Technologies & Policy create new alternatives
- Exciting technologies under development

Customer willingness to accept increased costs or trade-offs for Clean Diesels, Hybrids, eREVs/PHEV, BEV, FCV, lower rolling resistance tires, lighter materials, underbody aerodynamics...
Alternative Powertrain Technologies

Actually, 100 years ago

Prius is now #1 Selling Car in CA, #14 in U.S.

Auto Industry Impacted most from “Addiction to Oil”?

Auto industry feels they are suffering from “Technology du Jour”

Broader understanding of costs of leading-edge R&D is beneficial
- Breakthroughs cannot be “scheduled”
- Progress is uneven & bursty, rarely a constant linear progression
- Learning the bounds of what works, and what does not work are both valuable

Technology du jour

- 25 years ago – Methanol
- 15 years ago – Electric vehicles
- 10 years ago – Hybrid/electric vehicles
- 6 years ago – Fuel cell vehicles
- 4 years ago – Ethanol
- Today – BEVs and PHEVs
- What’s next?

Extremely disruptive and wasteful

Source: John German, ICCT, Meeting Environmental and Fuel Efficiency Goals, 9/27/11
Questions??