The Great Race Revisited
A Future Powertrain Technology Outlook

Tom De Vleesschauwer
Associate Director, Automotive Consulting

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The Act of Racing Forces One to Focus Only on That Which Is Essential to Win

- History of the Great Race
- Competition regulations evolve as our objectives change
- Competitor line-up
- And the winner is….

At One Time, Electric, Steam-powered and Gasoline-fueled Cars All Had Significant Market Shares

- U.S. production shares in 1900:
  - Gasoline 33%
  - Battery Electric Vehicles 33% (BEV)
  - Steam 33% (external combustion)

- Registrations in major cities: (New York, Chicago & Boston)
  - Gasoline: 400
  - BEV: 800
  - Steam: 1,170
  - Total: 2,370

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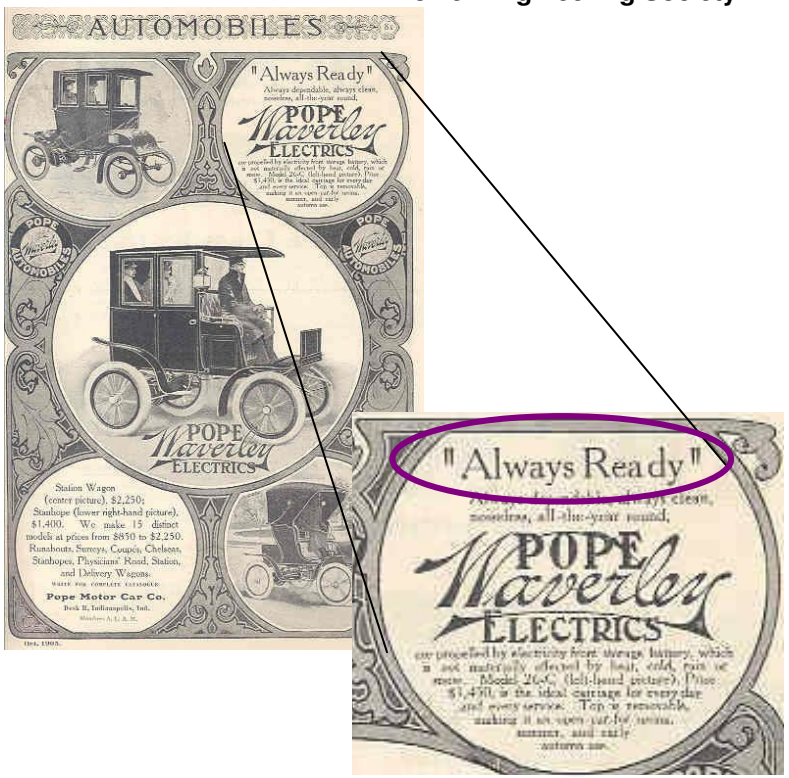
Performance and Public Opinion Favored Electric

- 1899: the world land speed record was pushed to 100 km/hr by the BEV ***La Jamais Contente***

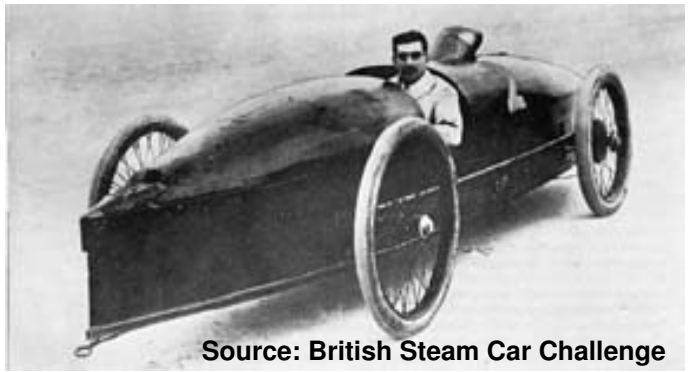
- 1900: A poll at the National Automobile Show in NYC indicated that the public preferred electric vehicles overall, but this choice was followed closely by steam

- 1903: First-ever speeding ticket issued. Driver was operating a BEV.

La Jamais Contente courtesy of IEEE Power Engineering Society

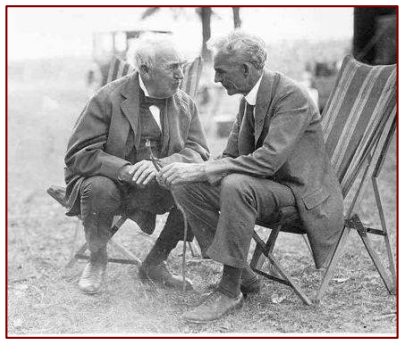


But Limitations of Batteries Quickly Outweighed the Performance Advantages



Source: British Steam Car Challenge

- 1906: Fred Marriott Achieves a World Land Speed Record of 127.659 mph in a Stanley Steamer
  - This remains today as the longest standing FIA-recognized LSR attributed to steam-powered cars
- Subsequent records were set by internal combustion-powered vehicles
- Visionaries had seen this coming all along. Is the future still that obvious?



Source: U.S. National Park Service

"Young man, that's the thing: You have it. Keep at it. Electric cars must keep near to power stations. The storage battery is too heavy. Steam cars don't do either for they have to keep a boiler and a fire. Your car is self contained – carries its own power plant – no fire, no boiler, no smoke and no steam. You have THE thing. Keep at it!"

Thomas A. Edison to Henry Ford, August, 1896

Competition Regulations

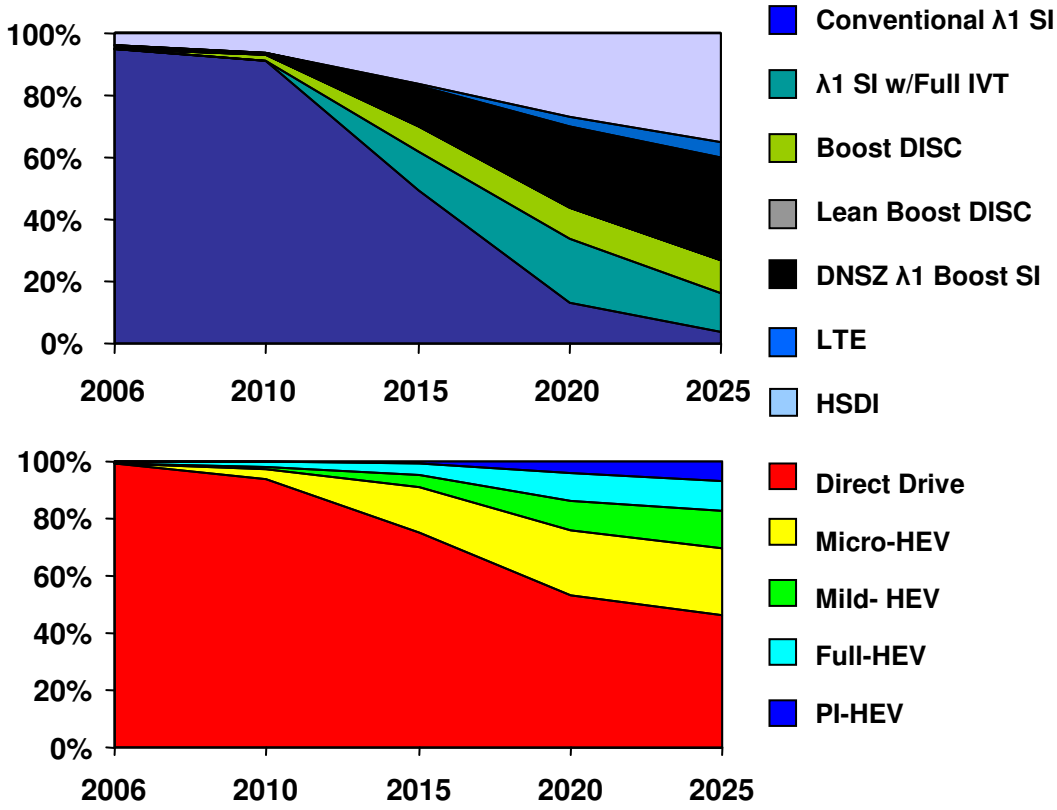
- The early race for powertrain supremacy was won by:
  - Autonomous range
  - Speed
  - Ease of operation

Source: www.local.aaca.org

Current Forecasts Suggest a Diversity of Evolutionary Powertrains For the Future

- Current forecasts are based on the assumptions that we need to address tomorrow only the challenges we face today
  - "Toxic" emissions of HC, CO, NO_x and Soot
  - Global demand for localized resources
  - Climate change attributed to the greenhouse effect of CO_2 and other gases attributed to the activities mankind

Forecasts of Future Powertrain Technologies



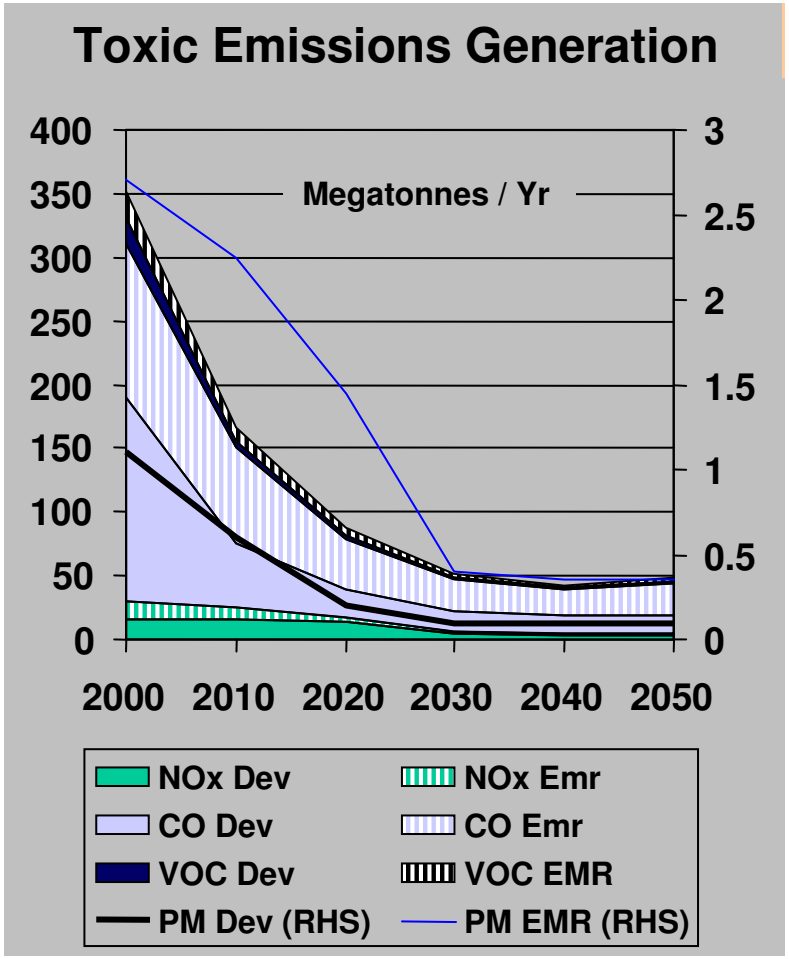
Source: Global Insight and TIAX, LLC: Future Powertrain Technologies, 2010 to 2025

Competition Regulations Under Revision

What problem(s) do we need to solve?

- Toxic emissions?
- CO_2?
- Global warming?
- Limited energy resources?
- Localized energy reserves?

Toxic Emissions Seem to Be Controllable…



Source: World Business Council For Sustainable Development

Decline based on:

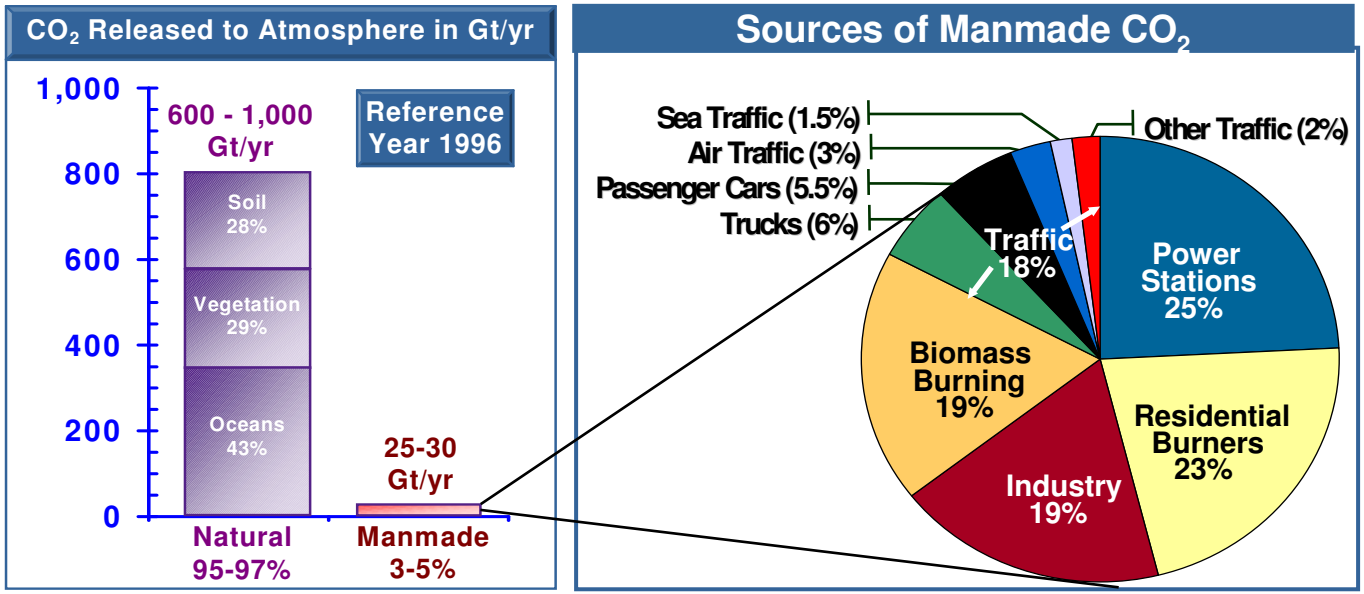
- Implementation of advanced emission standards with little lag between first introduction date and global adoption
- Proper maintenance of in-use fleet
- Life-of-vehicle solutions

But Control Is Frustrated by Sheer Volumes of Vehicles and Uncertain Maintenance Programs

Source:www.nd.edu

Is CO_2 THE Real Problem?

- A strong correlation exists between the average temperature of the earth, mankind's activities and the atmospheric concentration of CO_2
- If we reduce man made CO_2, will we make a positive impact on the earth's temperature?



Source: Lenz & Cozzarina, *Emissions and Air Quality*, SAE, 1999

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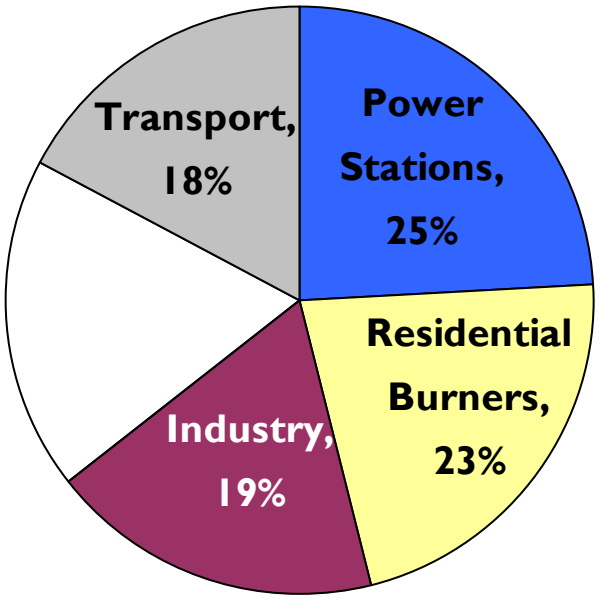
Most of Our CO_2 Generation Comes From Combustion Sources

- Combustion systems work by extracting energy from a high temperature source, doing some work and rejecting the remaining heat to a low temperature reservoir (the atmosphere)

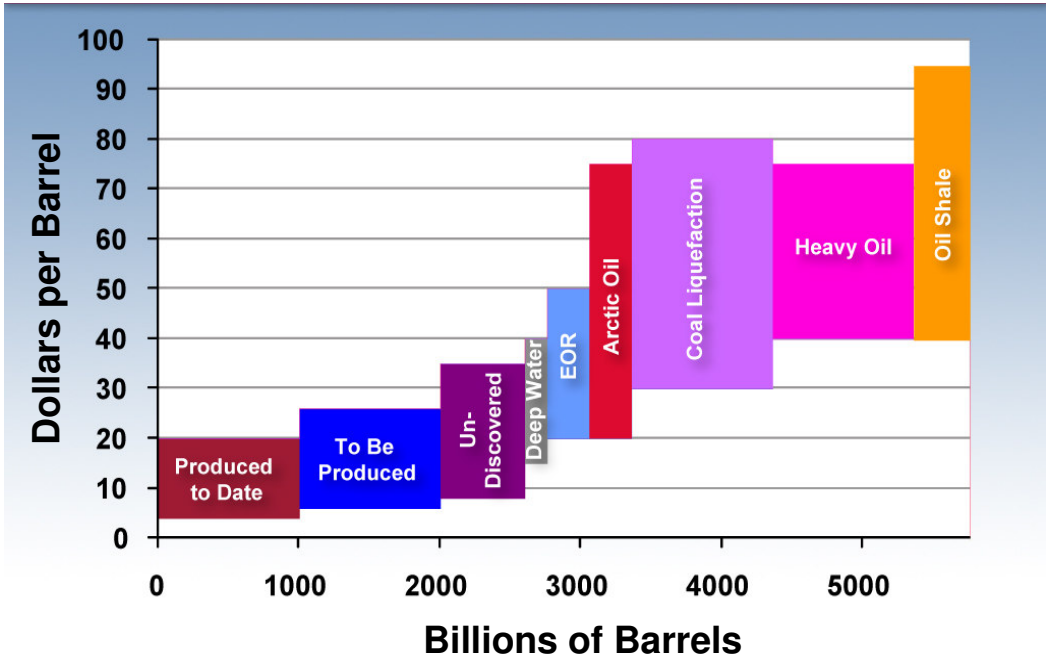


- This means that in addition to CO_2, we produce a lot of heat that is not used

- In fact, most of our systems are less than 50% efficient: we put more of the energy of combustion into warming the earth than in transport, lighting or heating homes, making things, etc.

How Limited Are Energy Reserves?

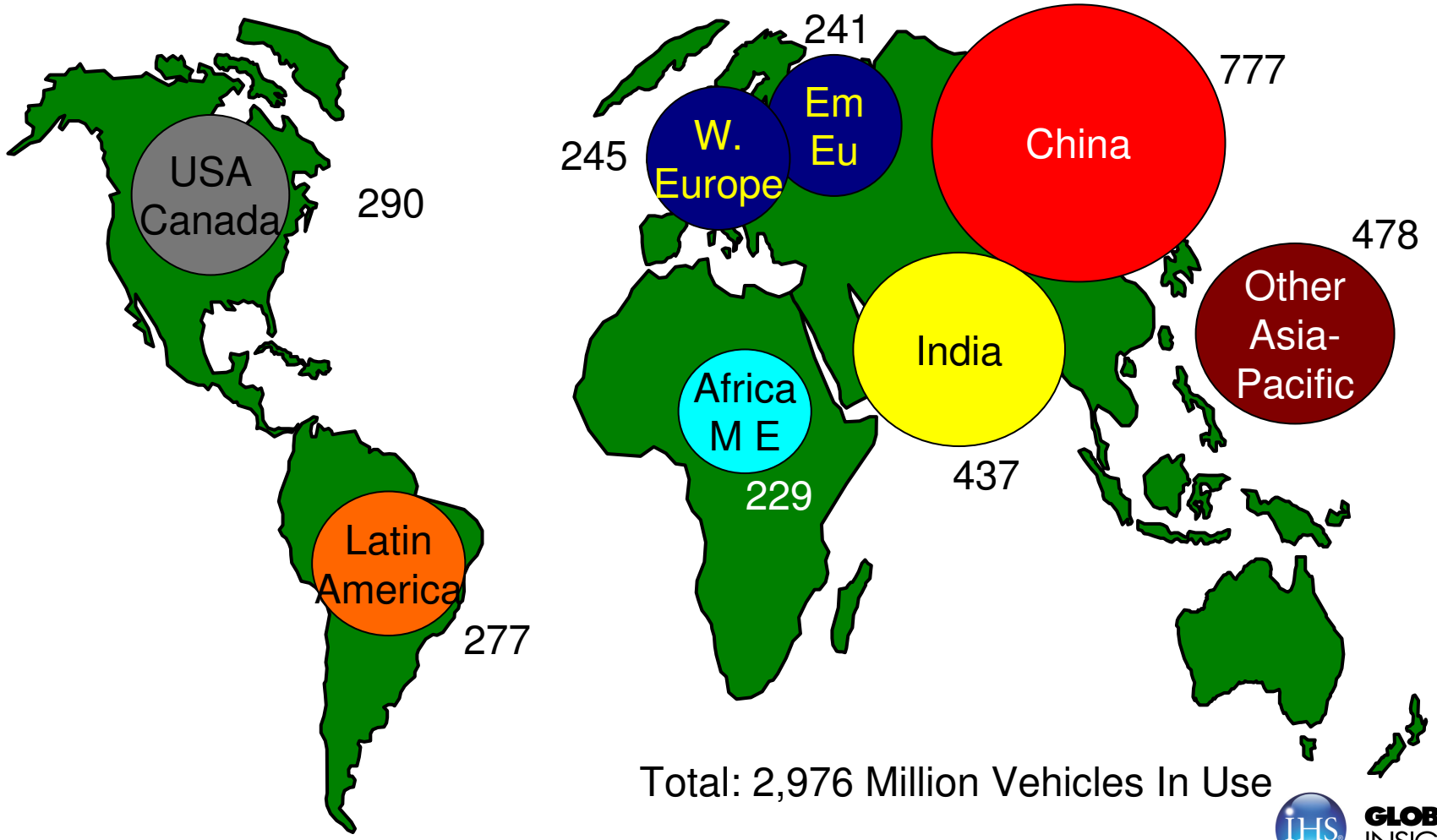
- Peak Oil is a theory that suggests the price we are willing to pay is an independent variable
- In fact, the more we are willing to pay, the more energy reserves we can access
- Fossil energy is limited and should be conserved, but it's not an emergency
- We have time to act reasonably



Source: *IEA, EIA, Company Websites, O&G Journal, World Oil, Rand Corporation, ECG*

Global Automotive Fleet Sizes Will Be More or Less Evenly Distributed by 2035

Millions Of On-Highway Vehicles In Use, 2035



Total: 2,976 Million Vehicles In Use

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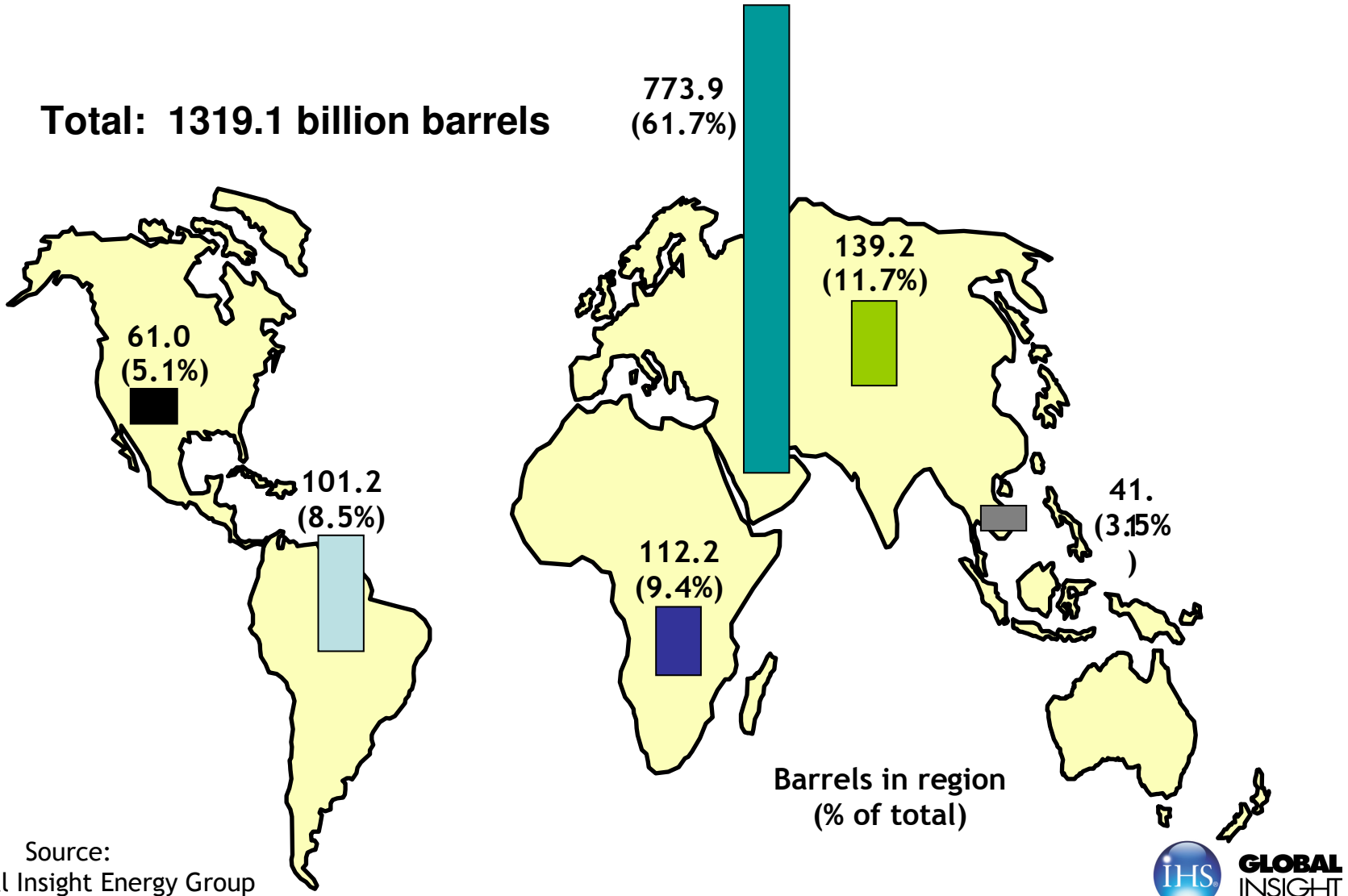
…But Known Global Oil Reserves Are Localized



Source:
IHS Global Insight Energy Group

Competition Regulations: Revised

- Whole-cycle efficiency (to reject less heat into the atmosphere)
- Readily monitored and maintained (to ensure low toxic emissions and ongoing high efficiency)
- Diversity of energy sources (to reduce tensions and imbalances caused by dislocations of energy demand and supply)
- Ease of use
- Adequate autonomous range
- Cost

Competition Line-up Presents a Confusing Array of Diverse Yet Possible Solutions

- Combustion Engines
  - Reciprocating (intermittent combustion)
  - Turbine
    - Direct drive
    - As an on-board generator
  - External combustion
- Fuel Cell
  - As commonly envisioned using hydrogen
- Battery Electric Solutions
  - Electric powertrains
  - Stand alone or in conjunction with above

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Combustion Engines – A Well-Known Benchmark

- Efficiency
  - Peak of 35% for reciprocating
  - Potentially half that over a duty cycle
  - Turbines running at full load can do a bit better, but worse on a variable duty cycle
  - External combustion engines suffer efficiency losses due to energy transfer across a barrier
- Continuous combustion systems are more tolerant of a range of fuels
- Most engines done well should be transparent to the driver
- Turbines with wide speed/load range can be challenging and costly to integrate into a vehicle

Contender		Efficiency	Readily Monitored	Diversity of Energy Resources	Ease of Use	Range	Cost
Combustion Engines							
	Recip						
	Turbine direct						
	Turbo Gen						
	External						

Fuel Cells: The More We Know Them, the Less Ideal They Become

- Efficiency
  - Promise of 70%
  - Currently yield about 40%
  - Hydrogen production is a major energy issue
- Diversity of energy resources is favorable, as hydrogen can be made from electricity which in turn can be made from resources that are both abundant and well-dispersed
- Produce no known negative impacts that need constant monitoring
- Range should be no problem IF the promised efficiency can be achieved, offsetting the impact of the reduced energy density of the Hydrogen
- Cost is prohibitive due to the precious metals content of the stack and surrounding systems and hydrogen storage system

Contender	Efficiency	Readily Monitored	Diversity of Energy Resources	Ease of Use	Range	Cost
Fuel Cells					?	

Pure Battery Electric Solutions Are Greenest

- Efficiency
  - On-board efficiency of 70% or more
  - Overall efficiency of coal fired powerplants (~40%) needs to be addressed for worst case
  - Efficiency of hydro, solar and wind energy can be judged as moot: no atmospheric warming
- Produce no known negative impacts that need constant monitoring
- Electricity can be produced from any source
- Range issues are addressable with battery evolution and also societal change

Contender		Efficiency	Readily Monitored	Diversity of Energy Resources	Ease of Use	Range	Cost
Battery Electric							
	Stand-alone						
	Hybrid			As Engine			

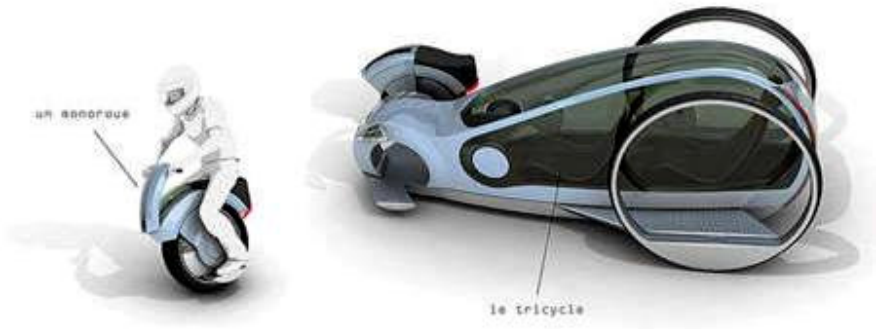
And The Winner Is…. Battery Electric Vehicles

- Major winning factors:
  - Can use a diversity of energy sources
  - Produce no known negative impacts that need constant monitoring
  - Affordable
- Electricity can be produced from any source
- Tank to wheel efficiency of BEV and Fuel Cells is roughly equal
  - Fuel cells fall short when compression and other “source to tank” potential processes associated with Hydrogen are taken in to account

Contender		Efficiency	Readily Monitored	Diversity of Energy Resources	Ease of Use	Range	Cost
Combustion Engines							
	Recip						
	Turbine direct						
	Turbo Gen						
	External						
Fuel Cells						?	
Battery Electric							
	Stand-alone						
	Hybrid			As Engine			

Conclusions

- We will move gradually to battery electric vehicles
- Electricity will come from a variety of sources, some of which have minimal to no negative environmental impact
- Powerplants will be upgraded as new technologies become available, making benefits realizable within a few years of invention
- But we will still produce much of our transport energy from combustion sources, still contributing to global warming. We must reduce the net energy consumption of moving people: improving the thermal efficiencies of our current transport means is not enough



Thank you

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tom.devleesschauwer@ihsglobalinsight.com
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