Assessment of Future ICE and Fuel-Cell Powered Vehicles and Their Potential Impacts

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One Way to State "The Energy Problem"

"The fundamental problem is that China is following the path of the United States, and probably the world cannot afford a second United States."

Zhang Jia'nyu, Beijing Office of Environmental Defense; New York Times, The Week in Review, March 14, 2004.

Future Vehicle, Powertrain, Fuels, Assessments

Focus on energy, greenhouse gas and air pollutant emissions, and costs:

1. Well to tank
2. Tank to wheels
3. Cradle to grave

All three stages are significant in a total system accounting.

Three MIT Analyses of Future Automotive Technologies

1. "On the Road in 2020: A life-cycle analysis of new automobile technologies," M.A. Weiss, J.B. Heywood, E.M. Drake, A. Schafer, and F. AuYeung, MIT Energy Lab. Report, MIT EL 00-003, October 2000. http://lfee.mit.edu/publications/PDF/el00-003.pdf.

2. "Comparative Assessment of Fuel Cell Cars," M.A. Weiss, J.B. Heywood, A. Schafer, and V.K. Natarajan, MIT Lab. For Energy and Env. Report, MIT LFEE 2003-001 RP, http://lfee.mit.edu/publications/PDF/LFEE_2003-001_RP.pdf.

3. "Coordinated Policy Measures for Reducing the Fuel Consumption of the U.S. Light-Duty Vehicle Fleet," A.P. Bandivadekar, and J.B. Hewood, MIT LFEE 2004-001 RP, http://lfee.mit.edu/publications/PDF/LFEE_2004-001_RP.pdf.

Many Recent Automotive Technology and Fuels Studies

Comparisons between studies need to review:

1. Objectives and timescales
2. Vehicle concepts studied
3. Input technology performance assumptions
4. Baseline used for comparisons
5. Set of attributes examined

Note that vehicle technology assessments focus on the individual vehicle, and do not assess in-use fleet impacts.

Two Important Paths Forward

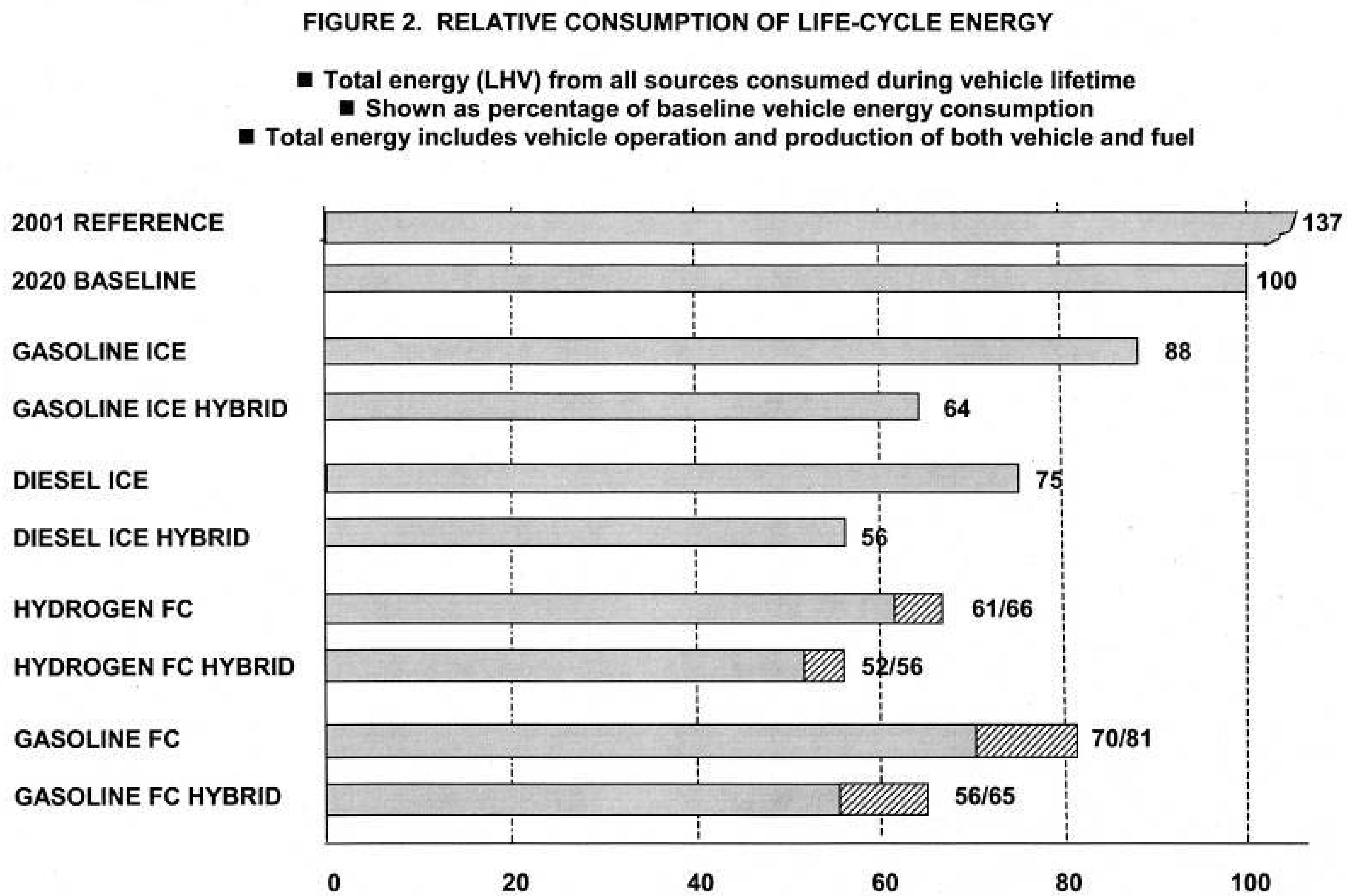
1. Evolutionary Improvements
   - Engine improvements
     Gasoline ICE, diesel ICE, ICE hybrid
   - Transmission improvements
   - Vehicle improvements
     Weight, drag, accessories

2. Radical changes
   - Large-scale biofuels
   - Major vehicle weight (and size) reduction
   - Fuel cell propulsion systems and hydrogen

Technology Options in MIT Studies

1. Evolving mainstream technologies
   - Vehicle: better conventional materials (e.g. high strength steel), lower drag
   - Engine: higher power/volume, improved efficiency, lighter weight
   - Transmission: more gears, automatic/manual, continuously variable
   - Fuels: cleaner gasoline and diesel
2. Advanced technologies
   - Vehicle: lightweight materials (e.g. aluminum, magnesium), lowest drag
   - Powertrain
     Hybrids (engine plus energy storage)
     Fuel cells (hydrogen fueled; liquid fueled with reformer)
   - Fuels: gasoline, diesel, natural gas, hydrogen

Relative Consumption of Life-Cycle Energy and CO2



Technology Summary

1. Mainstream engines, transmissions, vehicles can be steadily improved over time to give a 35% fuel consumption reduction in new vehicles in about 20 years, at an extra cost per vehicle of $500-1000.

2. Hybrids can improve on this by 20-30 percent, at an additional cost of a few thousand dollars.

3. Prospects for the diesel in the U.S., attractive from a fuel consumption and CO_2 perspective, are uncertain due to the extremely stringent U.S. NO_x and particulate standards, low U.S. fuel costs, and higher initial cost.

Technology Options: Summary (cont.)

4. Fuel cell systems would result in more efficient vehicles than ICE-based technology. BUT the energy lost and CO_2 emissions released in producing hydrogen (from natural gas) are significant and result in no overall benefit.

5. If we need very low CO_2 emission transportation system in the longer term (~ 50 years), then fuel cells and hydrogen (from "non" CO_2 releasing sources) appear to be one of the promising options.

6. However, market demand for improving mainstream vehicle fuel consumption is currently low.

Necessary Steps for New Technology Impact

1. Technology must become market competitive in overall vehicle performance, convenience, and cost

2. Then technology must penetrate across new vehicle production to significant (more than 35%) level

3. Then need substantial in-use fleet penetration; more than 35% mileage driven

Time Scales for Significant U.S. Fleet Impact

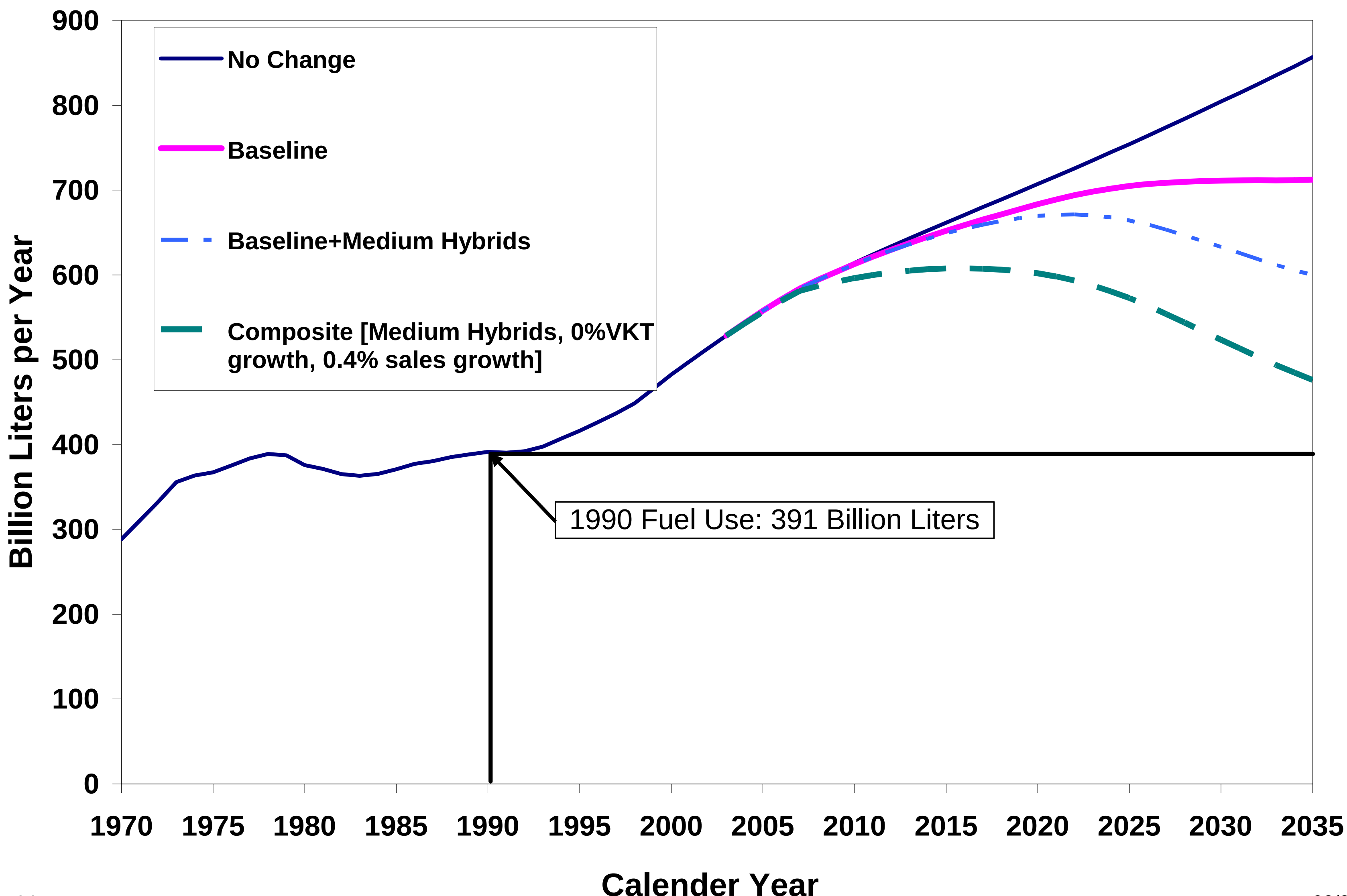
Implementation Stage	Gasoline DI Spark-Ignition Boosted Downsized Engine	High Speed DI Diesel with Particulate Trap, NO_x Catalyst	Gasoline SI Engine/ Battery-Motor Hybrid	Fuel Cell Hybrid Vehicle On board Hydrogen Storage
Market competitive vehicle	~ 5 years	~ 5 years	~ 5 years	~ 15 years
Penetration across new vehicle production	~ 10 years	~ 15 years	~ 20 years	~ 25 years
Major fleet penetration	~ 10 years	10 - 15 years	10 – 15 years	~ 20 years
Total time required	~ 20 years	~ 30 years	~ 35 years	~ 55 years

U.S. Light-Duty Fleet Fuel Consumption Projections

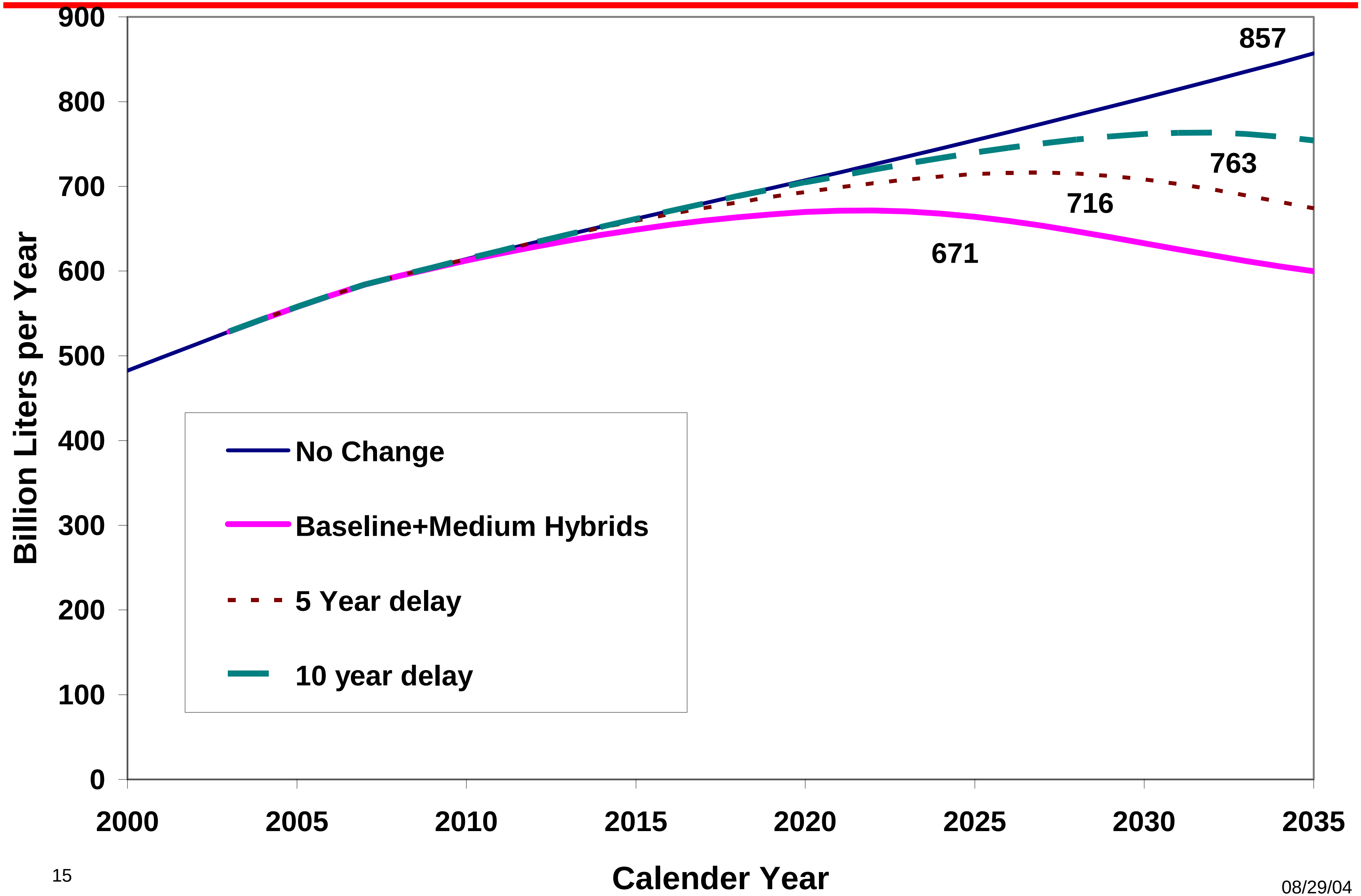
1. Car and light truck fleet model with sales, scrappage, vehicle miles (km) per year, fuel consumption per year, as function of age, included. Light truck and car fleet behaviors similar.

2. Base scenario:
   - New vehicle sales grow 0.8% per year
   - Average per vehicle km/year increase 0.5% per year
   - 15-year median lifetime for all vehicles from 2000
   - Light truck sales fraction levels out at 60%
   - Same percentage new technology fuel consumption benefits for cars and light trucks

U.S. Light-Duty Fleet Fuel Use for Various Scenarios



Effect of Delay in Initiating Improvements



Integrated Policy Approach

Combine Fiscal and Regulatory Measures to:

- Exploit *synergies*
- Spread *impact* and *responsibility*
- Generate positive *commitment* among all stakeholders
- Increase *effectiveness*

A Promising Combination of Policies

- CAFE Standards
  - 36 MPG for cars and 28 MPG for light trucks by 2020
  - 41 MPG for cars and 32 MPG for light trucks by 2030
- Feebates
  - Fees for gas guzzlers, rebates for gas sippers
  - Fee/rebate rate of $25,000/GPM (-$1500, +$400)
- Gasoline Tax
  - 10 cents/gallon/year increase
  - Revenue neutrality through tax credits
- Increased renewable content of fuels
  - 5-10 % cellulosic ethanol content by 2025

Potential U.S. Fleet Impacts in 2035

- 24% reduction in new vehicle fuel consumption
- 18% reduction improvement in the overall light-duty fleet fuel consumption
- 30-50% reduction in oil use and CO_2 emissions relative to no change scenario
- 14% decrease in Vehicle Kilometers Traveled as compared to no change scenario

Summary

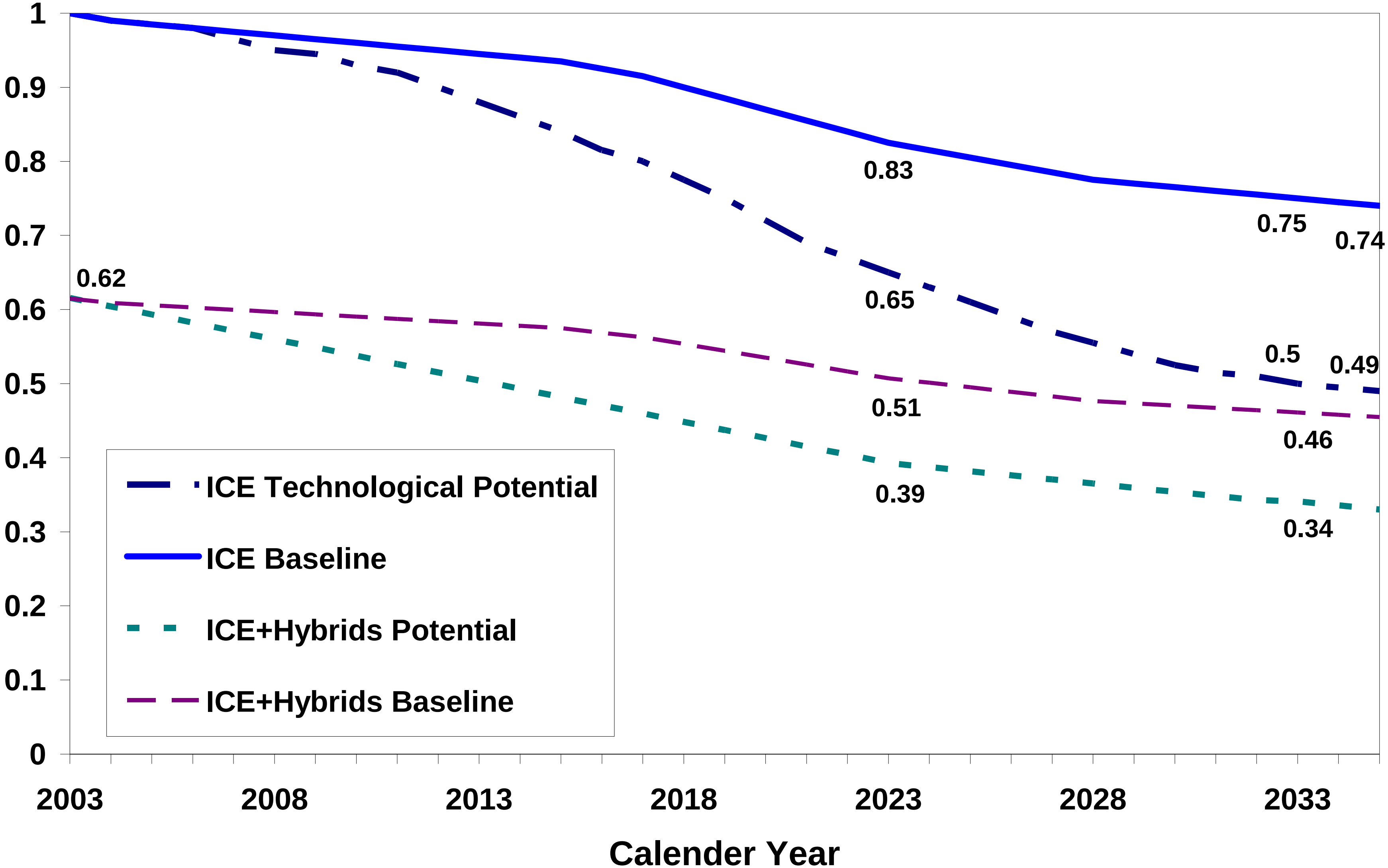
1. Delays in actions to reduce fuel consumption significantly worsen our petroleum dependence and greenhouse gas emissions problem.

2. A two path strategy is needed to reduce the magnitude of this problem, and explore radically different alternatives.

3. It will take coordinated fiscal and regulatory “pull” and “push” to reduce fleet petroleum consumption and GHG.

4. We need to generate broader public support for this to happen.

Relative Improvements in Fuel Consumption



Share of Life-Cycle Energy & GHG

Vehicle	Energy, % of Total			GHG, % of Total		
	Operation	Fuel Cycle	Vehicle Mfg.	Operation	Fuel Cycle	Vehicle Mfg.
2001 Reference	75	16	9	74	18	8
2020 Baseline	74	15	11	71	18	11
Gasoline ICE	73	15	12	72	18	10
Gasoline ICE Hybrid	69	14	17	67	17	16
Diesel ICE	75	10	15	74	12	14
Diesel ICE Hybrid	70	10	20	70	11	19
Hydrogen FC	45	34	21	0	81	19
Hydrogen FC Hybrid	44	35	21	0	79	21
Gasoline FC	67	14	19	66	16	18
Gasoline FC Hybrid	66	14	20	65	16	19

…maintaining the integrity of the biosphere (essential for the perpetuation of any civilization)… will be extraordinarily challenging but realistic assessments indicate that it can be done. Critical ingredients of an eventual success are straightforward: beginning the quest immediately, progressing from small steps to grander solutions, persevering not just for years but for generations--and always keeping in mind that our blunders may accelerate the demise of modern, high-energy civilizations while our successes may extend its life span for centuries, …

Vaclav Smil, *Energy at the Crossroads,* MIT Press, 2003, p. 318

New Vehicle Fuel Consumption