# Sustainable Technology Choices for Alternative Fuels

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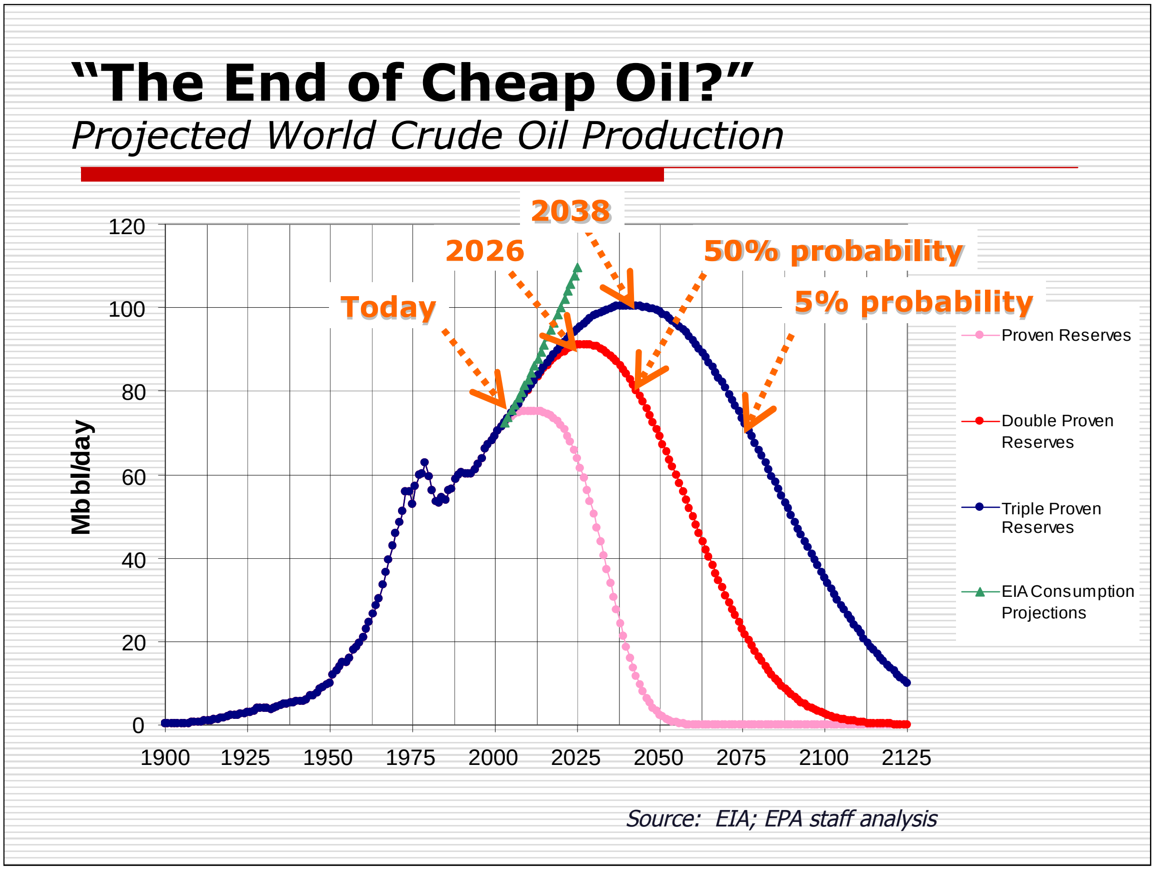
(Intro deleted)

Promoting the sustainable use of alcohol fuels presents us with a real opportunity for improving transportation emissions—especially global $CO_2$ emissions. Of course, that has long been the focus of our engine technology research at EPA, and I’d like to talk to you about progress we’ve made in this regard with our dedicated alcohol fuel engine program.




**One of the greatest challenges we will face in the coming decades is the depletion of our world petroleum resources.**

And, here I use a peak oil model to illustrate a point:

First, if we look at where we are today, with our projected consumption patterns and our proven reserves, the evidence suggests that we are nearing the peak in world oil production.

►If we look at a scenario with 2X today's proven reserves, corresponding to an "average" recovery probability, it tells us that world oil production will peak in about 20 years.

►In a much less likely scenario, with 3X today's reserves, we see that oil production will be near its peak in about 30 years.

The peak may come sooner, particularly if consumption continues to grow aggressively at it's present 2-3% annual rate, broadening the gap between demand and production and forcing significant changes in the global energy market.

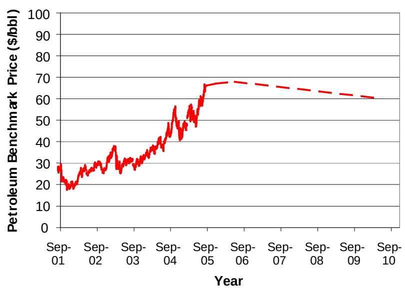
**The question is, how should we respond to this now?**

# Striving for Alternatives

*Overcoming the anticipated shortfall in oil reserves*


*AP Photo: Stockbridge, GA, 8/31/05*

- Decline in oil reserves forces changes in transportation fuel use
  - Aggressive fuel conservation efforts needed--worldwide
  - Significant petroleum alternatives will be needed to fulfill demand




*Source: EIA, Goldman-Sachs*

- Economic pressures will determine the long-term outcome
  - Policy needed to promote sustainable choices

**Faced with the imminent shortages in the world petroleum supply, what can we do?**

First, in the US and especially in the more energy-intensive economies around the world (e.g., China), we need to look specifically at transportation fuel use, and ways to ***conserve***.

(If we see gas prices like last month's—this being an extreme example—that will definitely provide an incentive to conserve!)

And in order to meet transportation energy demands in a post-peak oil scenario, even with the best conservation efforts, there's no doubt that alternative fuels will have to play a critical role.

►As supply and demand in the run-up to the oil peak continues to push the price of oil higher in relation to other fuel commodities (Wall Street is already projecting 60+ dollar per barrel oil prices for the next several years), we will continue to see the alternatives growing much more cost-effective by comparison.

**We just need to ensure that the fuels that come out the "winners" in this economic battle are good <u>environmental</u> choices, and good <u>consumer</u> choices as well.**

# Technology/Policy Choices

*Where do we go from here?*

- Fuel conservation is imperative: long- and short-term
  - Market opportunity for more efficient technology choices
- Diesels and hybrids offer best short-range options
  - Most benefit within existing infrastructure
  - Will eventually incorporate next-generation fuel economy/emissions refinements
- Begin long-range transition to technologies that use alternative fuels effectively
  - Alternatives well-known (alcohols, GTL, CNG, H2, etc)
  - Capital investment high, <u>long lead time</u>
  - Distribution hurdles substantial
  - Lifecycle GHG considerations <u>MUST</u> be part of analysis

**So, given today's warning signals, what choices do we have? Where do we go from here?**

First and foremost, we need to conserve fuel—and a key element of any conservation strategy is **<u>improved</u> <u>engine technology</u>**.

(With petroleum commodity prices remaining high, there will certainly be a market opportunity for more efficient engine and vehicles—and eventually alternative fuel vehicles)

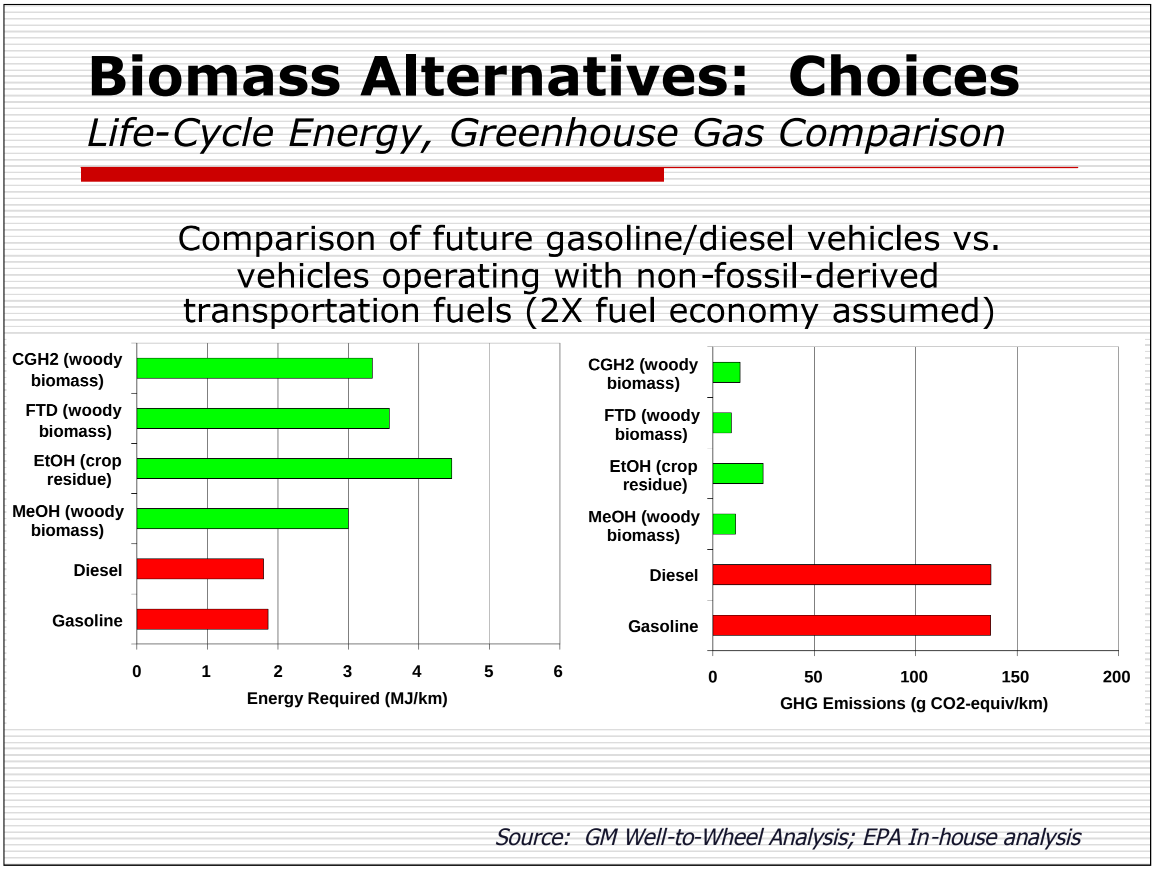
►**<u>But, in the short run</u>**, hybrids and diesels seem to offer the best hope, since they provide the greatest benefit within the existing petroleum infrastructure. And, we can expect them to eventually incorporate "next-generation" vehicle fuel economy improvements (Variable valvetrains, CVTs, lower-weight, aerodynamic chassis, etc).

►**<u>In the long run</u>**, we need to find a transition to technologies that use alternative fuels effectively:

The alternatives are well-known, and alcohol fuels are chief among these.

But the transition process won't be easy: alt fuels (and alcohol fuels) face many market challenges, such as high (and rapidly growing) capital investment requirements, long lead times on infrastructure buildup, and comparatively high distribution costs.

But during this transition, we need to be mindful of the <u>environmental impact of these fuels</u>, in the choices we make in both the short-term and long-term, and ensure that these represent **<u>sound choices for global emissions</u>**.




**So, first, on that subject, let's look ahead and examine the life-cycle energy and global emissions of some candidate biomass-derived fuels. Let's also assume that these fuels are used in relatively efficient (2X fuel economy) future vehicles. In this scenario, there appear to be several competitive alternative fuel options: methanol, Fischer-Tropsch Diesel, and possibly hydrogen.**

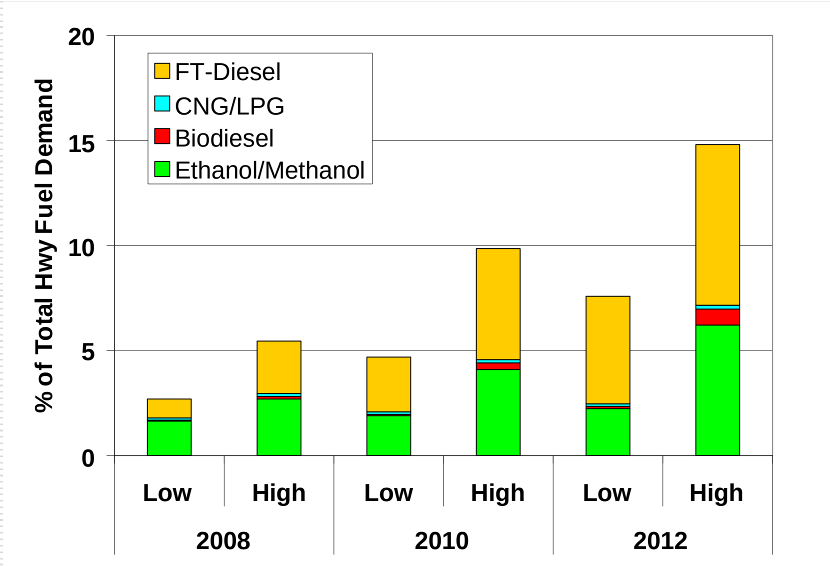
If we compare these to today's petroleum fuels, biomass alternatives require more energy to produce, and therefore tend to be relatively expensive. But, as our oil drilling taps into fewer and less-productive wells, and tertiary petroleum recovery methods become more widespread in an effort to meet demand, this gap will close. On the renewable side, as biomass conversion technology improves, we can expect the gap to narrow even further.

Moreover, in the anticipated "carbon-constrained world" scenario, we will see CO2 increasing in value either as a tradable commodity or a tax credit, and thus these biomass fuels will become increasingly attractive economically by virtue of their near-neutral Life Cycle "Well-to-Wheel" (or, perhaps more appropriately in this case, "Woods-to-Wheel") carbon emissions.

Which of these options eventually wins out (or, none of the above) may largely depend on technology improvements on the production side, and especially on the vehicle technology side.

## Near-Term Production Capacity

*Projected trends for the coming decade*




***Note:*** From non- coal/shale feedstocks; biomass sources not included

*Source: EPA In-house staff sensitivity projections.*

**Biomass fuels, though, still appear to be several years away. So, next, let's look at the potential transitional alt fuel market…and near-term production capacity.**

Projecting tomorrow's winners from today's trends, as this figure shows, is difficult, particularly since many of today's alternatives such as FTD and methanol are principally derived from fossil fuel sources, which may not be attractive in tomorrow's energy market.

But, if we track projected domestic infrastructure investments, we see that alcohol fuels (along with FT) in particular are poised to gain the most market share in the short-term.

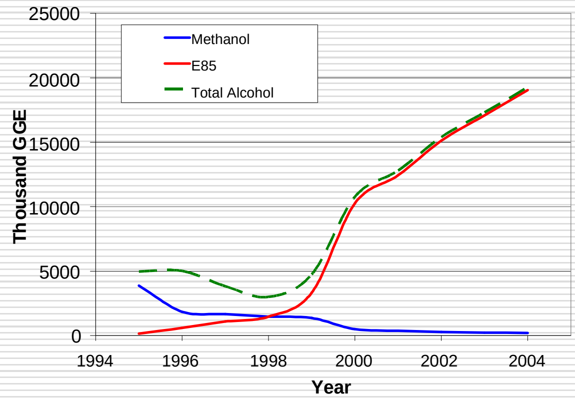
What is difficult to determine is whether this is sufficient to build momentum toward a future of highly-efficient dedicated fuel vehicles.

**In other words, WHAT IS THE CRITICAL MASS? Is a 5-10% share of all transportation fuel use really enough to tip the balance and force a change?**

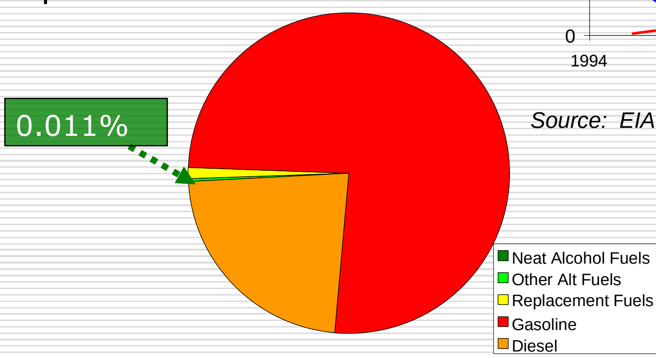
# Alcohol Fuel Supply

*Growing, but not fast enough*

- E85 production rising fast
- Still, represents a small portion of total transportation fuel picture




*Source: EIA*




**One crucial deciding factor may be whether the alcohol fuel market can accelerate its growth sufficiently to make a difference in the next decade.**

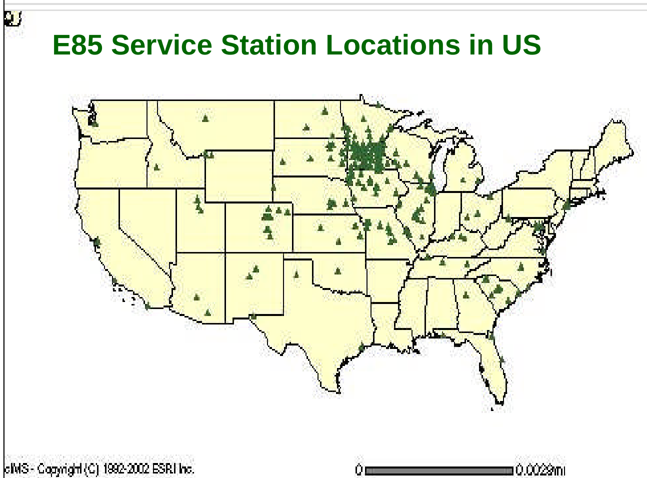
Today, when you speak of alternative alcohol fuels, you talk almost strictly of E85.

The growth of E85 production has certainly been impressive—almost doubling in the span of a few years—but it's use is not very widespread.

►And, it hardly has been able to make a dent in the overall transportation energy picture, and so it simply doesn't present a terribly compelling business case to the OEMs for dedicated fuel vehicles.

# Alcohol Fuel Availability

*Regional supply and distribution*




- Centered tightly in Midwest
- Not generally available in more heavily populated areas on West Coast, East Coast

*Source: US DOE AFDC*

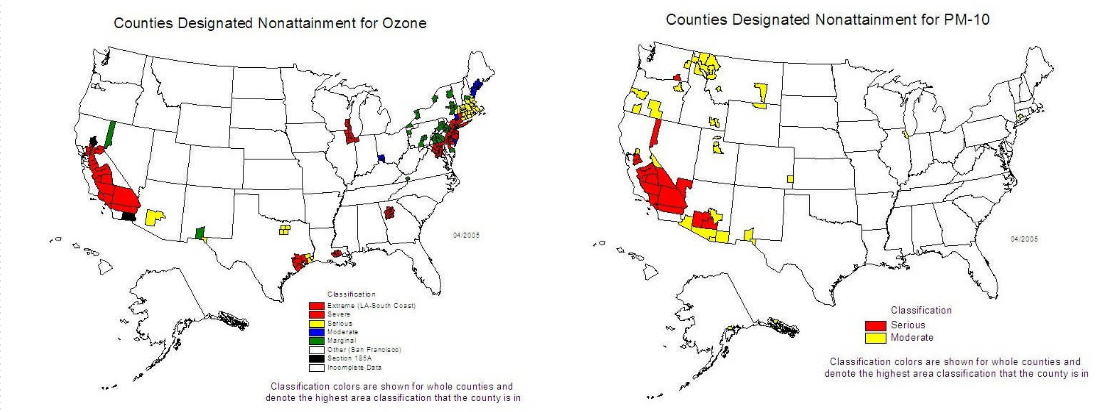
**Further compounding these difficulties is the somewhat limited availability of E85**.

High distribution costs, mainly, restricts it's use to a concentrated region in the Midwest. (If you're in Minnesota, you probably don't have much of a problem finding an E85 station, but the rest of us have to hunt around a bit to find them).

For future growth, obviously, this regional limitation must be overcome—either through improved distribution means or, better yet, through utilization of more diverse feedstocks.

## Potential Air Quality Impact

*Regional Benefits of Alcohol Fuels*




*Source: EPA*

- Alcohol fuels could be a cost-effective means of improving air quality in EPA-designated non-attainment areas

**For environmental reasons, especially, these regional distribution challenges must be solved.**

In areas of the country that would benefit most environmentally from neat alcohol fuel use, E85 is not widely available—and often not at all.

In areas of the West and East coast that are EPA designated non-attainment zones for ozone and particulate matter, E85 availability is scarce. More optimistically, I suppose, the options for alt fuels in these areas may be considered to be wide open, since none of the alternatives has yet been able to secure a strong foothold.

A strategy to promote vehicles using alcohol fuels (ethanol OR methanol) could be a cost-effective means of improving these air quality issues.

# Alcohol Fuel Utilization

*Moving forward from today's fuel scenario*

- First, alternative fuels need to meet criteria for sustainability
  - Energy-efficient and cost-effective
  - Readily-available, renewable feedstocks
  - Low local and global life-cycle emissions
- Short-term goals: use of fuel blends, improved engine technology
  - Extend existing limitations in alcohol fuel supply
  - Significantly improve engine efficiency with blends containing as little as 20-30% alcohol
- Longer-term goal: widespread use of dedicated-fuel vehicles

**So, with this view of today's alcohol fuel market, what can we do for the future?**

►There is no strong front-runner—yet—in the alternative fuel market, with the possible exception of some small regional markets. But, clearly, any candidate must meet certain criteria for ultimate market sustainability:

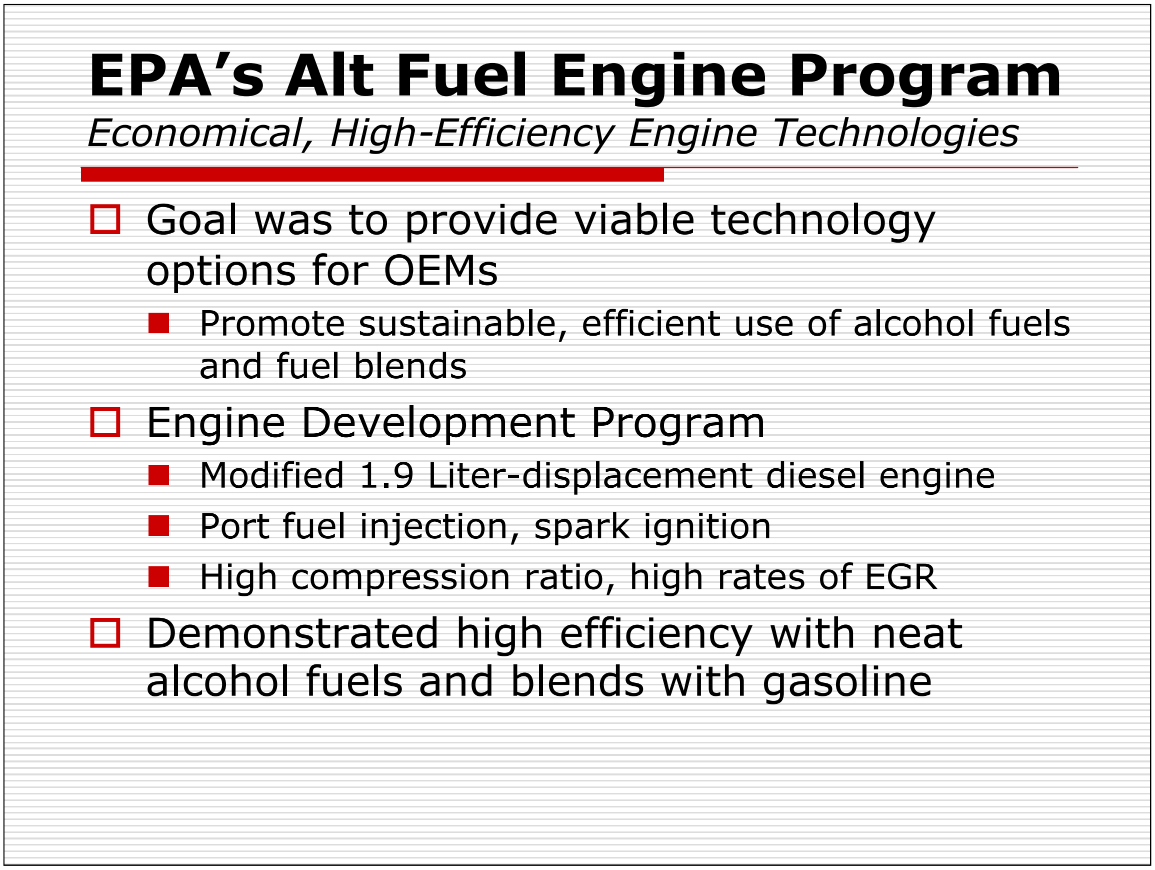
Most importantly, the fuel—and the vehicle it's used in—must be relatively cheap for consumers and reasonably energy efficient.

Long-term sustainability also means that the fuel needs to be made from readily-available and renewable resources.

It also must meet federal and local vehicle emissions standards and give low GHG emissions—or, environmentally, it's a non-starter.

►What can we do in the short term? One proposal is to deal with limited alcohol fuel supplies by promoting broader use of fuel blends. If you can get much of the benefit of neat fuels with fuels containing as little as 20-30% alcohol, then you can effectively extend existing fuel supply limits considerably.

►In the longer-term, when capital investment yields greater production capacity for alcohol fuels, its most efficient use will be in dedicated fuel vehicles.




**Such a strategy partly underlies the dedicated fuel engine development program at EPA.**

►The main goal of the program was to provide an efficient and cost-effective option for dedicated fuel vehicles, operating with either neat alcohol fuels or blends with gasoline.

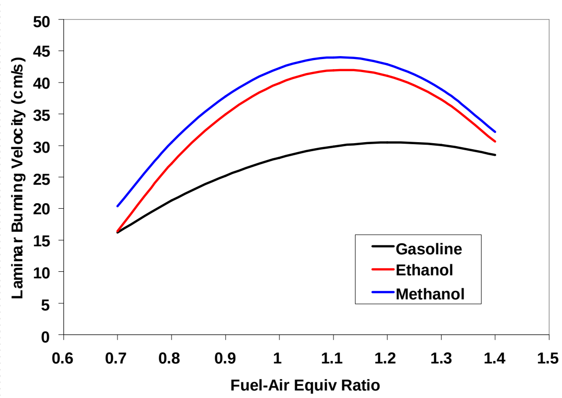
►The focus was on a 1.9L VW Jetta diesel engine, but with the costly DI diesel fuel system replaced with a low-cost PFI system, and with spark plugs used instead of diesel glow plugs.

The high diesel-like compression ratio of 19.5:1 was retained for high efficiency, while the Exhaust Gas Recirculation (EGR) system was modified for higher rates of flow.

►With such an engine, we were able to demonstrate high fuel efficiency with both neat fuels and fuel blends...**and I'd like to share with you some of the highlights.**

# Combustion Properties

*Neat Methanol and Ethanol—Efficiency Advantages*




| | Octane Number | Heat of Vaporization |
|---|---|---|
| | (RON) | (kJ/kg) |
| Methanol | 105-110 | 1103 |
| Ethanol | 105-110 | 840 |
| Gasoline | 91-99 | 350 |

Burning Velocity = rate of fuel heat release in a spark engine

Faster burn velocity enables more dilution, less throttling

Octane = knock resistance

Enables high compression ratio

Heat of Vaporization = charge cooling

Reduces compression work

**To start with, we took advantage as much as possible of some of the favorable combustion properties of alcohol fuels that give them inherent efficiency advantages over petroleum fuels.**

First, one of the principal sources of engine efficiency losses is due to intake air throttling.

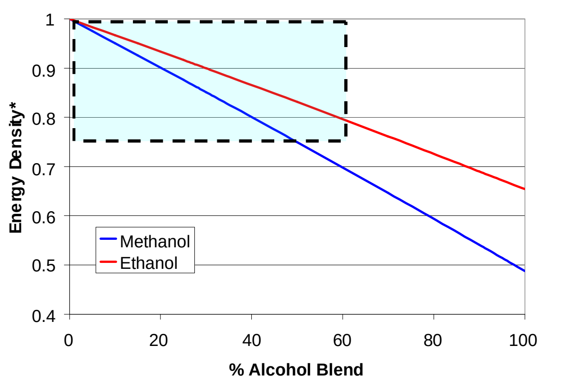
The flame velocity of methanol and ethanol, for one, is somewhat higher than it is for gasoline. What this means is that methanol and ethanol can operate leaner, at higher air-fuel ratios, or with more EGR than gasoline, thereby reducing the need for intake throttling to control engine load.

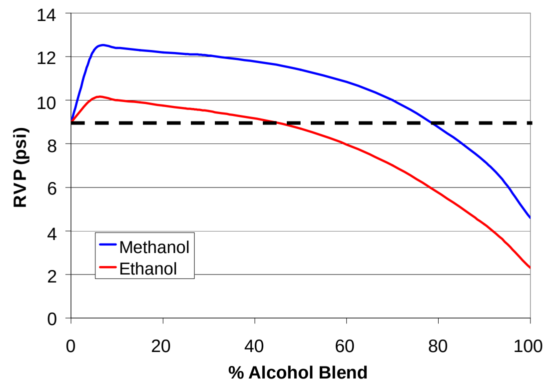
►High compression ratios give higher engine efficiency. Methanol and ethanol are high octane fuels, that will tolerate higher compression ratios without knock.

In addition, they absorb a lot of energy upon evaporation, and thereby cool the cylinder charge and reduce the amount of work needed during the engine's compression stroke (resulting in a more efficiency cycle), while at the same time reducing the tendency for autoignition (knock).

# Properties of Alcohol Fuel Blends

*Blends with Gasoline*




Energy density = energy per gallon of fuel, relative to gasoline

Engine improvements can compensate for as much as 25-30% loss in energy density (see box above)

RVP = vapor pressure; measure of fuel volatility

Major factor in evaporative emissions and cold starting

**When we mix alcohol fuels with gasoline, the properties change—sometimes in proportion, sometimes not.**

First, it's well known that alcohol fuels are less energy-dense than gasoline—that is to say, you can't go as far on a gallon of fuel.

(A gallon of neat methanol has about one half the energy of a gallon of gasoline, ethanol about two-thirds.)

When you mix these fuels with gasoline, you get a more energy-dense fuel, and the difference can be partly or completely offset through improvements in engine efficiency.

(The shaded area approximately indicates the range of gasoline blends for which engine efficiency can compensate for the energy density difference)

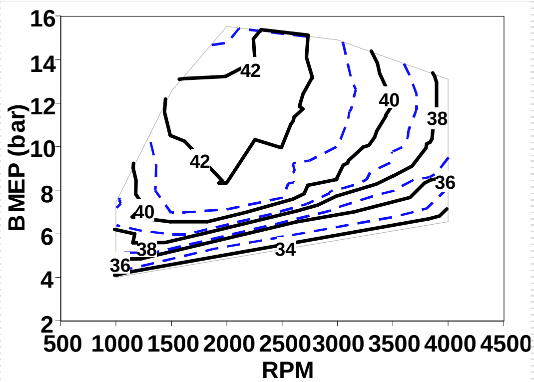
►Another fuel property of concern is the fuel vapor pressure, for evaporative emissions and cold starting.

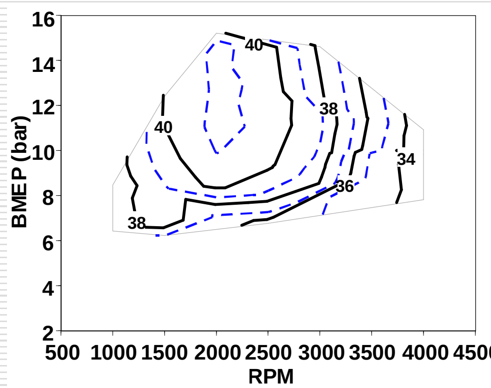
(Gasohol blends containing relatively little alcohol present a greater challenge for evaporative emissions in hot regions of the country. Our friends in CA are, I'm sure, very familiar with this issue.)

Neat alcohol fuels, on the other hand, have such low volatility that they make engine cold starting difficult. Nevertheless, this can be overcome with the addition of 10-15% gasoline.

# Engine Efficiency: Neat Alcohols

*Over 25% better than best gasoline engines*




- M100 Brake Efficiency
  - Over 42% peak; better than baseline diesel
  - Broad range over 40%
- E100 Brake Efficiency
  - Peak over 41%
  - Diesel-like efficiency

**<u>So, now, when we look at the engine test results, first with neat fuels, these show impressive brake efficiency numbers</u>**, exceeding that of the baseline diesel engine.

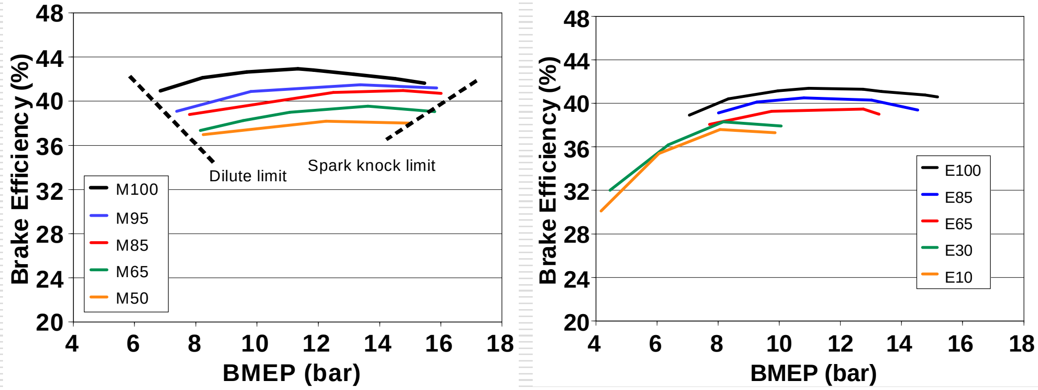
With neat methanol (M100), we obtained over 42% peak efficiency, and more than 40% efficiency over a broad range of loads and speeds. (For reference, the base diesel peaked at about 40-41% efficiency, in a relatively small corner of the map.)

►With ethanol (E100), the results were similar.

A typical FFV engine, designed to operate with gasoline, has peak efficiencies in the low- to mid-30% range. So, the efficiency benefit of these dedicated fuel engines is quite impressive.

## Engine Efficiency: Blends

*Preserving high efficiency with less alcohol*




- **Methanol Blends**
  - Increasing methanol content significantly raises efficiency
  - Good efficiency with M50
- **Ethanol blends**
  - "Near neat" blends give best efficiency
  - Peak efficiency with E30 exceeds best gasoline engines

**When blends with gasoline are used, the octane rating and charge cooling effects are reduced, decreasing the upper range of operating loads.**

The engine also becomes less tolerant of dilution with EGR, thus requiring more throttling at light loads.

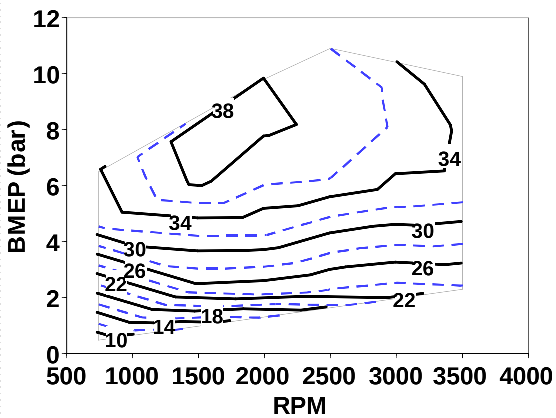
As a result, we see that the efficiency increases with higher amounts of alcohol in the fuel. Despite this, the efficiency with M50 is still in a range well above today's gasoline engines.

►With ethanol blends, again, the trends are similar. ("Near-neat" fuels give best efficiency)

Even with lower-level blends such as E30 (30% ethanol), the efficiency exceeds that of the best known gasoline engines.

# Engine Efficiency:  E30 Blend

*A more economical option*




- E30 (30% ethanol)
  - High efficiency over a broad range
  - Demonstrates efficiency benefits of dedicated fuel vehicles, even with as little as 30% alcohol
  - Efficiency gain exceeds loss in fuel energy density
  - Potentially more economical option

**If we focus on the E30 efficiency map in detail**, we see that the brake thermal efficiency remains high over a significant range of the engine loads and speeds.

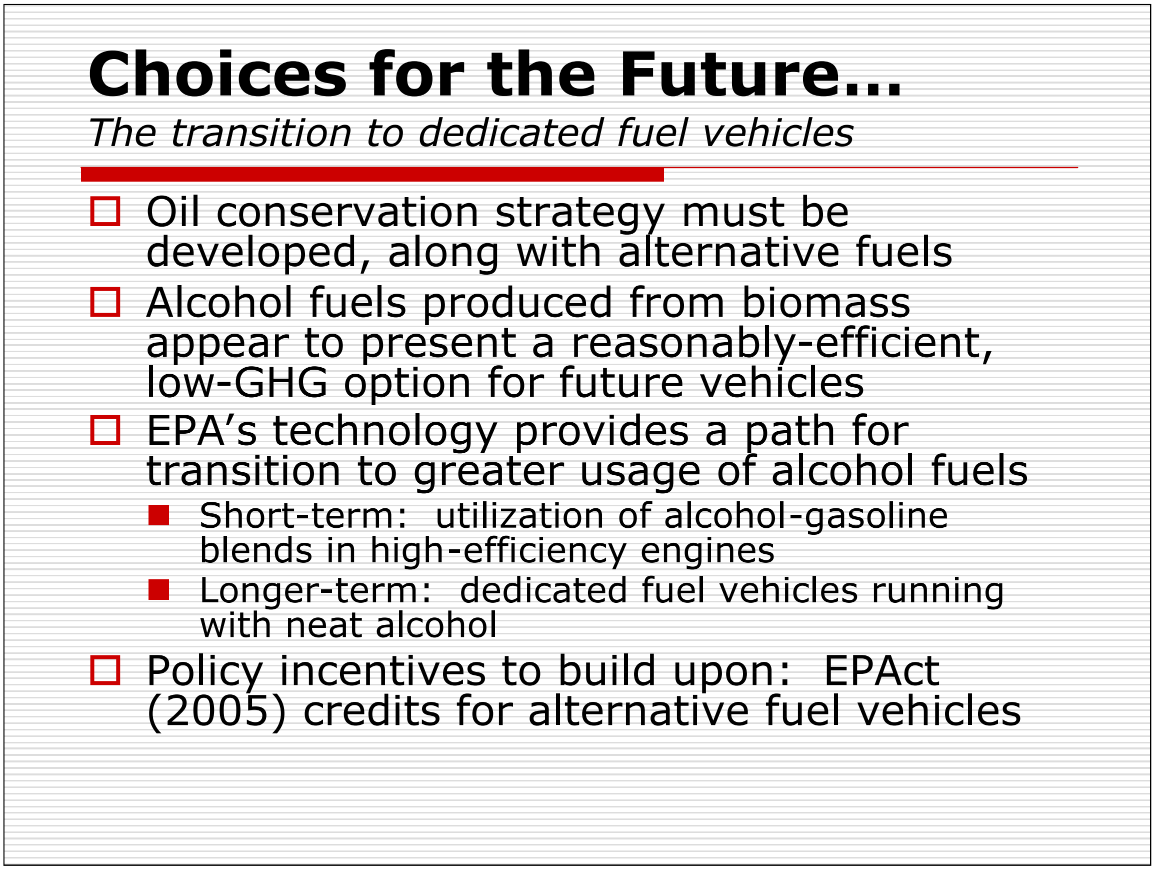
It demonstrates the benefits of a dedicated fuel vehicle, even with fuels containing as little as 30% alcohol.

What’s more, the efficiency gain more than makes up for the loss in fuel energy density, meaning that the range on a tank of fuel is not reduced.

Such a fuel/engine combination could be an economical option, while helping extend a limited fuel supply.

That concludes the brief summary of the dedicated fuel engine work we completed about two years ago at EPA.  We look forward to continuing this engine development work, but presently, our commitments to other programs and the current lack of interest from the OEMs have caused us to temporarily suspend this research.

With the world energy situation as it is today, however, we feel that it’s vital that we resume this work—**soon**!  And we’re pursuing that opportunity with our industrial partners.




**Finally, in conclusion, as we move forward toward a future with fewer petroleum resources, we realize two important strategic elements: we need to promote conservation of transportation fuels—as aggressively as possible, and we need to develop our alternative fuel options.**

►Among alt fuels, alcohol fuels produced from biomass appear to present a reasonably-efficient, low-GHG alternative for future vehicles

►EPA's technology provides a path for transition to greater usage of alcohol fuels

Short-term: utilization of alcohol-gasoline blends in high-efficiency engines

Longer-term: dedicated fuel vehicles running with neat alcohol

►Policy incentives to build upon: EPAct (2005) credits for alternative fuel vehicles are significant. **And we are challenging many of our colleagues in industry to work with us and take advantage of the present opportunities. I can only be optimistic about the chances for success, and there can be no doubt that there's a lot riding on the outcome of these programs!**

**THANK YOU VERY MUCH FOR YOUR TIME AND ATTENTION!**

## THANK YOU!!!

For more information:

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