Methanol as an alternative transportation fuel in the US

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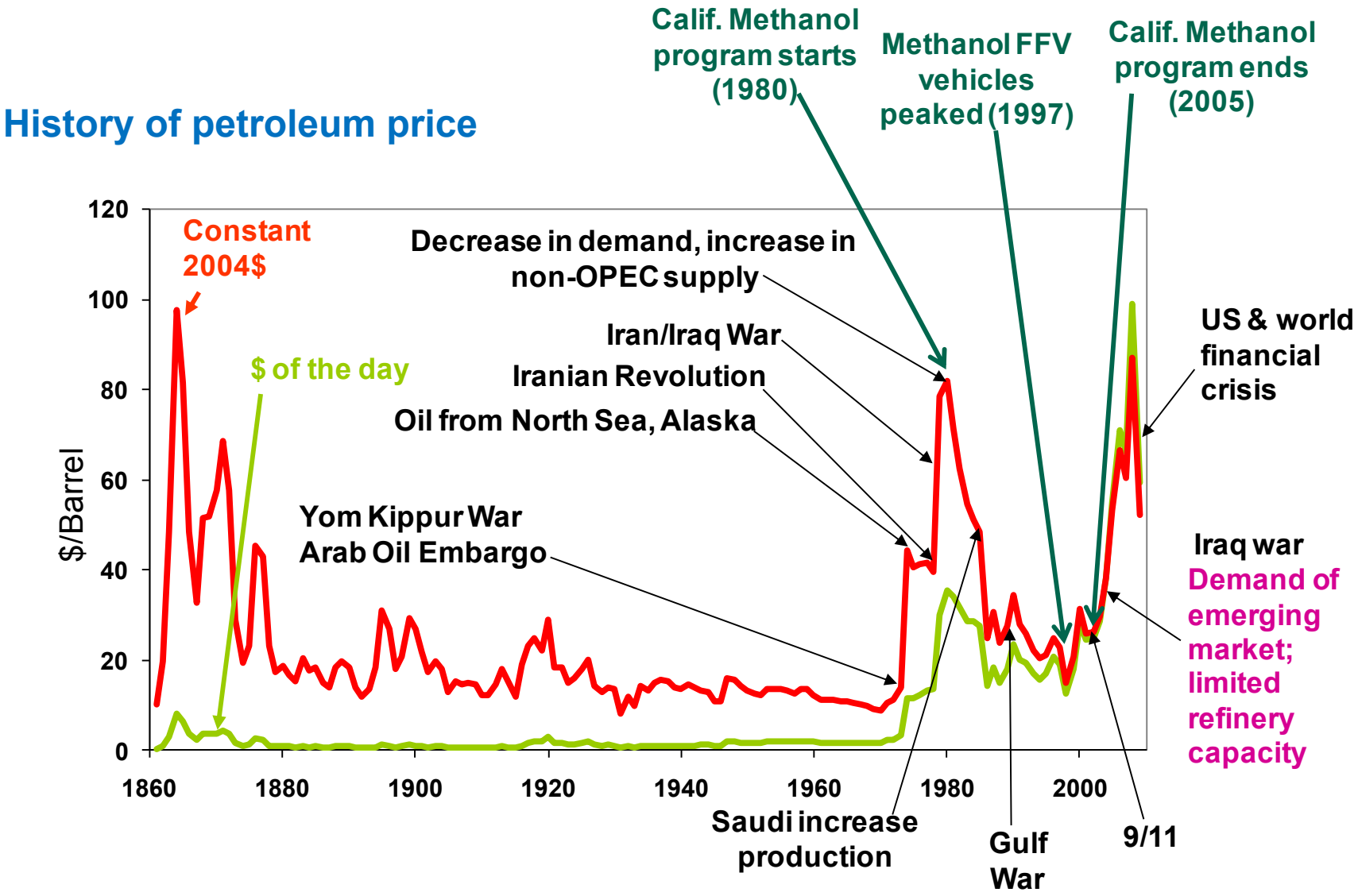
US experience with Methanol

- Large scale pilot tests mostly in California during the 80's and 90's demonstrated that methanol is a viable fuel
- Both dedicated and Flex Fuel vehicles were marketed, in light duty and heavy duty (buses)
  - At peak
    - 21,000 M85 flexible fuel vehicles
    - 12 million gallons consumed (1993)
- Refueling stations provided limited distribution of methanol
  - Finding methanol station is a major consumer inconvenience

US experience with Methanol

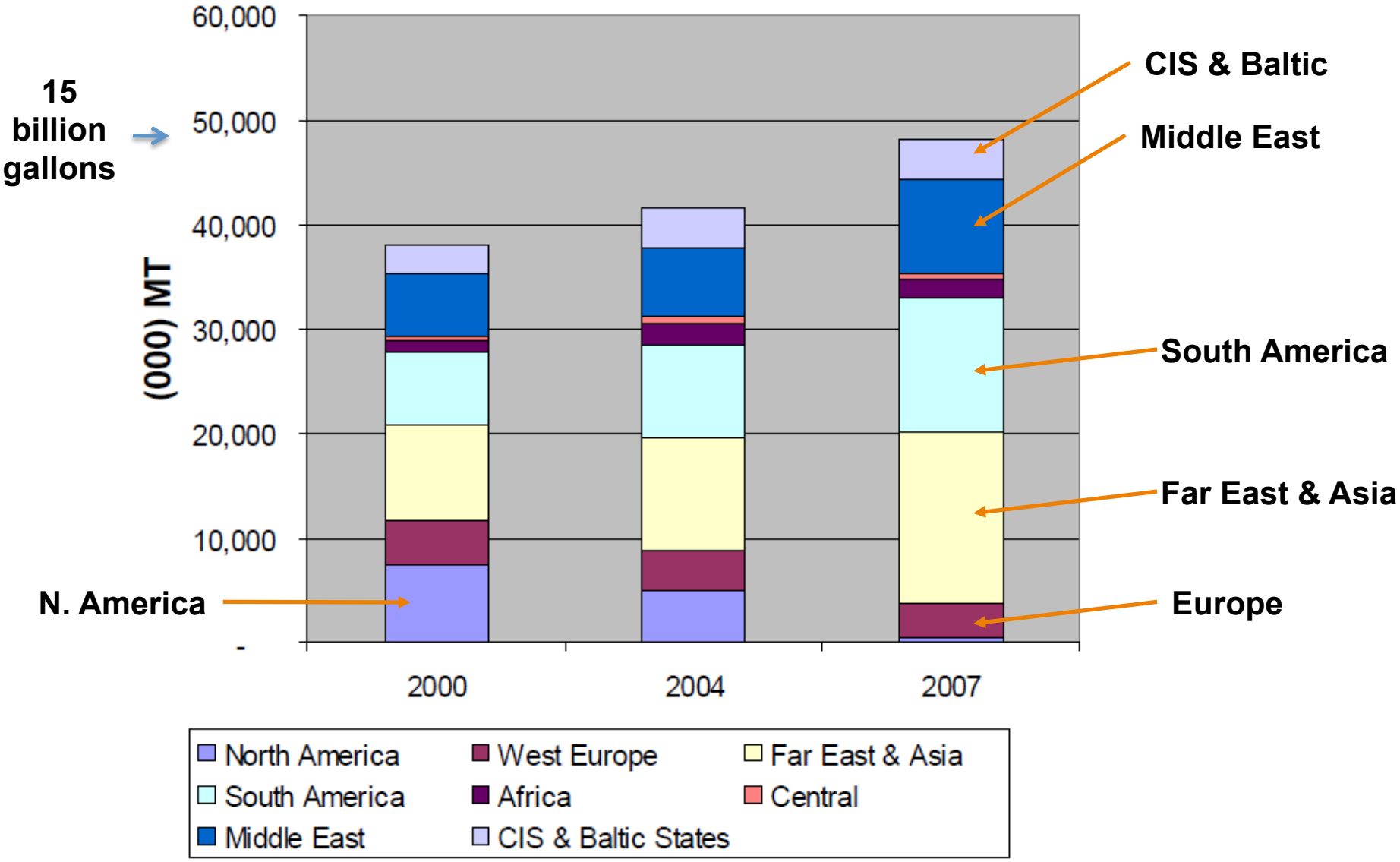
- Methanol succumbed to decreasing oil prices and lack of advocacy, replaced by MTBE (now banned) and ethanol



Methanol use worldwide: China

- Methanol production/consumption
  - China is the largest methanol producer (from coal)
  - China consumes the largest amount of methanol in transportation (2010 est. 1.5 to 2 billion gallons)
- Vehicles
  - Light-Duty vehicles are being introduced into regular fleets (private) as well as commercial fleets
  - No dedicated vehicles yet, but several methanol-capable models are in production
- Infrastructure
  - Distribution is becoming widespread, both with high and low methanol blends
- Lower fuel cost obtained by using methanol blends, driving customer interest

World methanol production

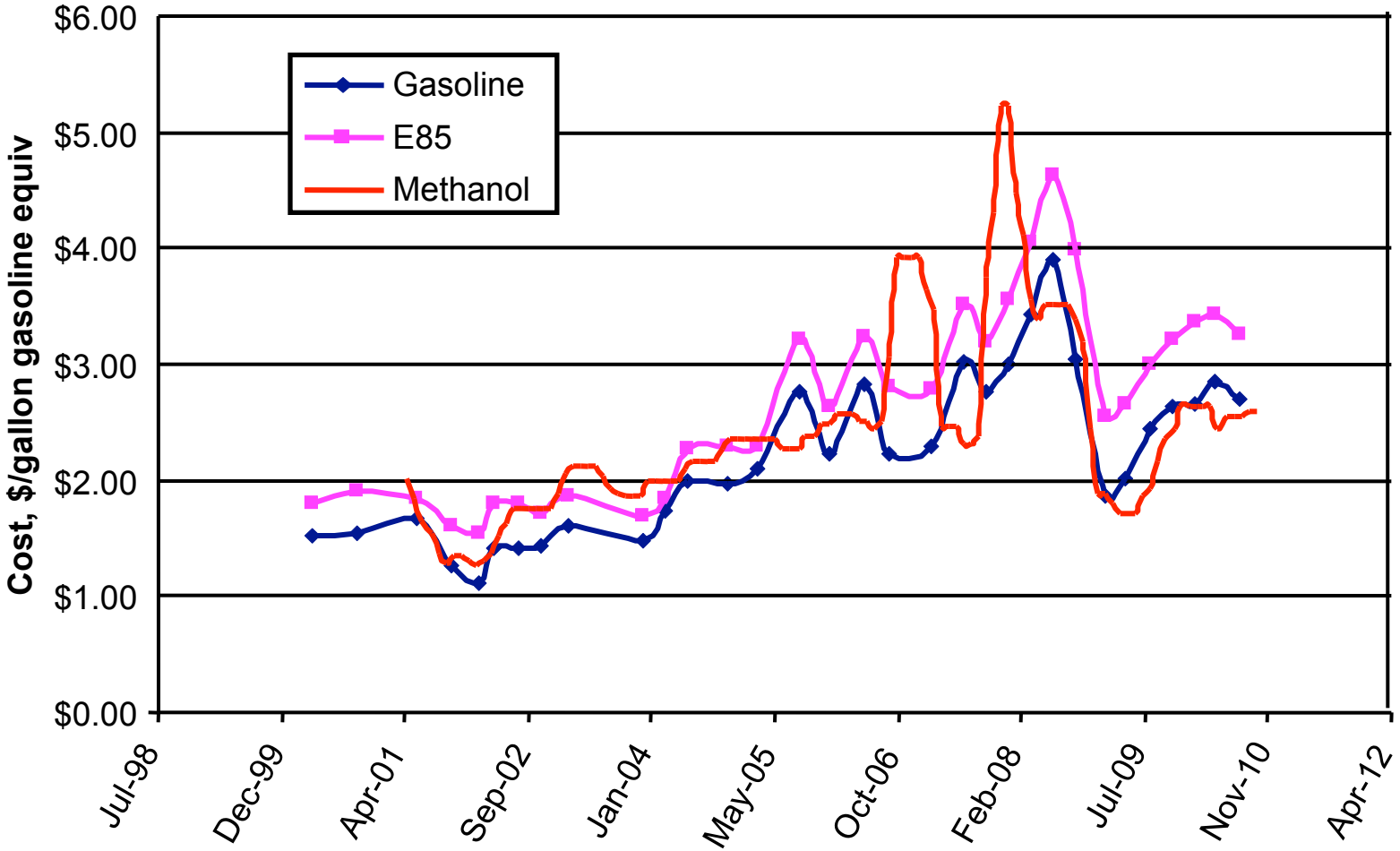


(1 MT corresponds to 338 gallons)

Production

- US produced ~ 20% of world methanol in 2000, present production down to ~ 2% of world methanol
  - Unfavorable economics in the US, with cheap "stranded" natural gas elsewhere
  - US production in 2010 ~ 1 million tons (300 million gallons)
- In the US, estimated present day price of methanol is comparable (at the pump, on same energy-basis) to gasoline

Fuel comparison; retail (gasoline-equivalent)



Ethanol: Includes subsidy of ~ $0.45 /gallon for ethanol

Methanol: wholesale+distribution+taxes

Methanol production

- Methanol can be produced from natural gas, coal or biomass
  - Established method
    - ➢ Convert feed stock to synthesis gas
    - ➢ Catalytic conversion of synthesis gas to liquid fuel
      - Process favors methanol output

Methanol production from fossil fuels

- Either coal or natural gas could provide enough methanol to satisfy a substantial fraction of the US liquid fuel in the near term

Time-to-exhausting of US reserves if entirely committed to methanol
(10% displacement of liquid transportation fuels)

	Reserve/Production methanol ratio (years)
NG to methanol	121
including shale gas	429
Coal to methanol	> 1000

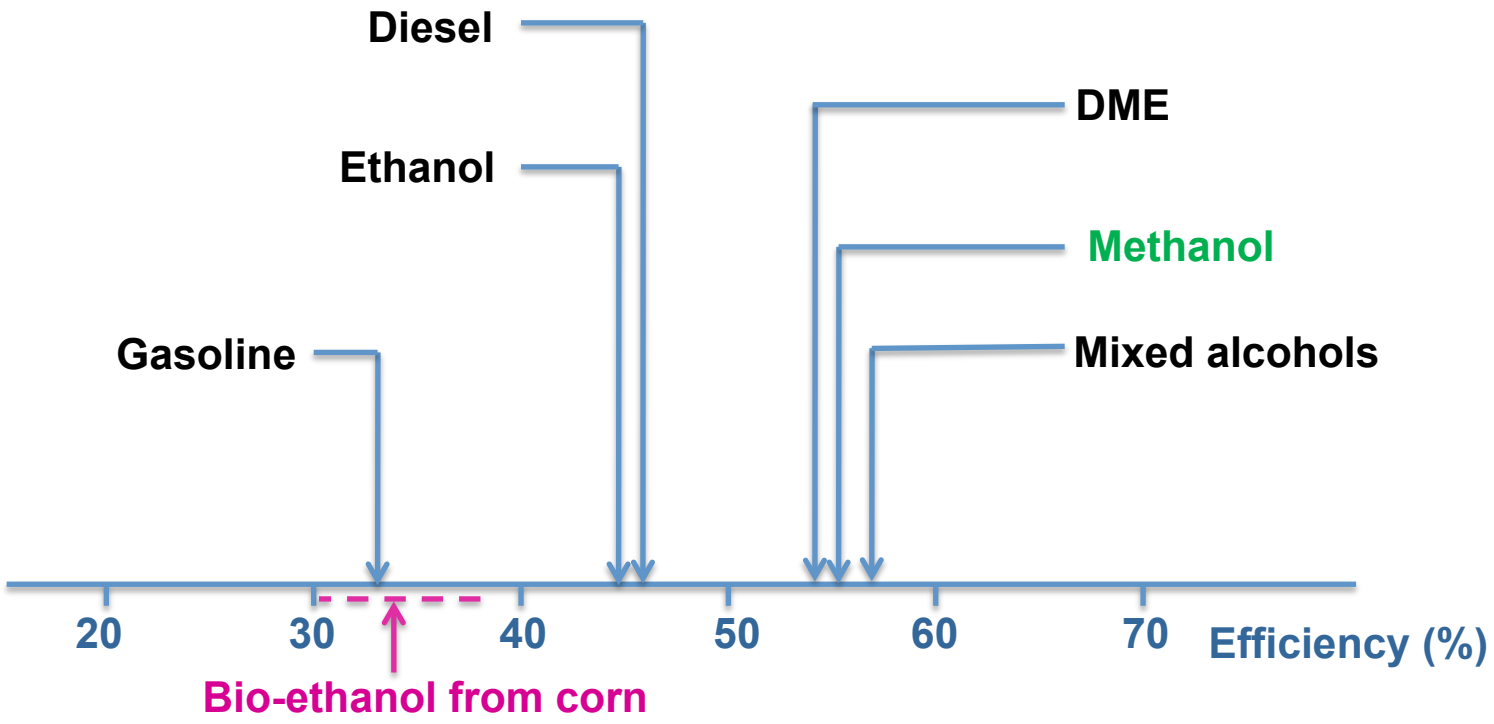
Methanol in transportation

Sustainable transportation: biomass-to-methanol

- Alcohols can be manufactured through thermochemical processes (conversion of biomass to synthesis gas) followed by catalytic reactors:
  - Catalytic conversion favors methanol, rather than ethanol, production
  - It is an established alternative to biological production of cellulosic ethanol

biomass-to-tank utilization efficiency

Thermochemical conversion



Efficiency values take into consideration of feed stock, transportation, conversion, and distribution; each consideration is fuel specific

Source: A.K. Stark, "Multi-Criteria Lifecycle Evaluation of Transportation Fuels Derived from Biomass Gasification"

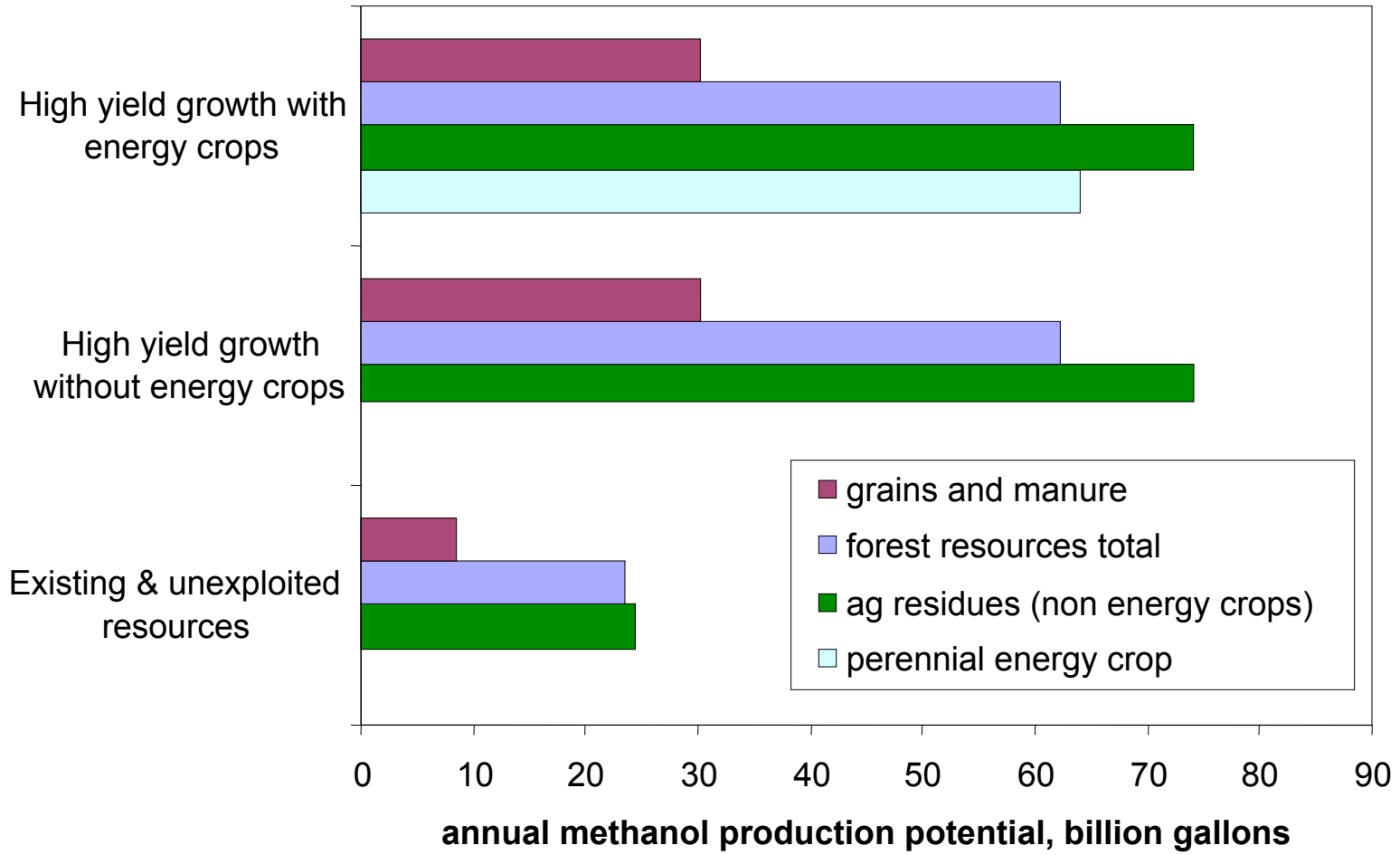
Methanol in transportation

Sustainable transportation: biomass-to-methanol

- There is an abundance and variety of biomass sources in the US:
  - Agricultural residues, forest resources, energy crops, and municipal waste
  - A substantial fraction of liquid fuel consumption in the US could be met with bio-fuels from biomass
    - With decrease in consumption, all liquid fuel consumption may be met
- Cost of methanol from biomass expected to be comparable to cost from natural gas
  - Cost of biomass feedstock is comparable to natural gas (including harvesting, transportation and handling of biomass)

Biomass-to-methanol production potential

(Ref: 2009 US consumes 138 billion gallons of gasoline; corresponds to 280 billion gallons of methanol)



Source: Perlack, R.D.; Wright, L.L.; Turhollow, *et al., Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply. A joint U.S. Department of Energy and U.S. Department of Agriculture report.* DOE/GO-102995-2135 & ORNL/TM-2005/66. April 2005

Methanol in transportation

Fuel characteristics

- Combustion properties
  - Very high octane
    - ➢ can be used in high compression, highly turbocharged engines
  - Dedicated methanol engines can have efficiency approaching that of today's diesel engines, but potentially less expensive
    - ➢ Lower cost-of-ownership to operator
- Exhaust emissions effectively controlled by a 3-way catalyst

Methanol in transportation

Fuel characteristics

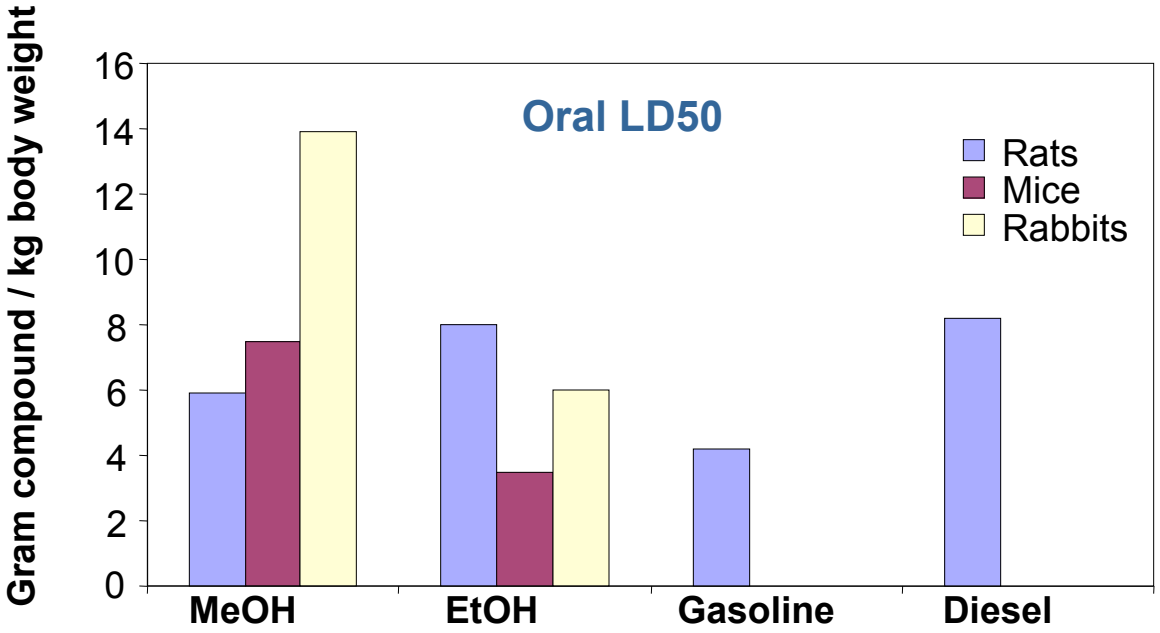
- Energy density lower (45%) than diesel or gasoline (requires larger tank or decreases range)
- Phase separation from hydrocarbon an issue at lower blending ratios, requiring co-solvents
- Evaporative emissions from lower blending ratios requires increased canister size
- Requires corrosion-resistant hardware
- More difficult cold start

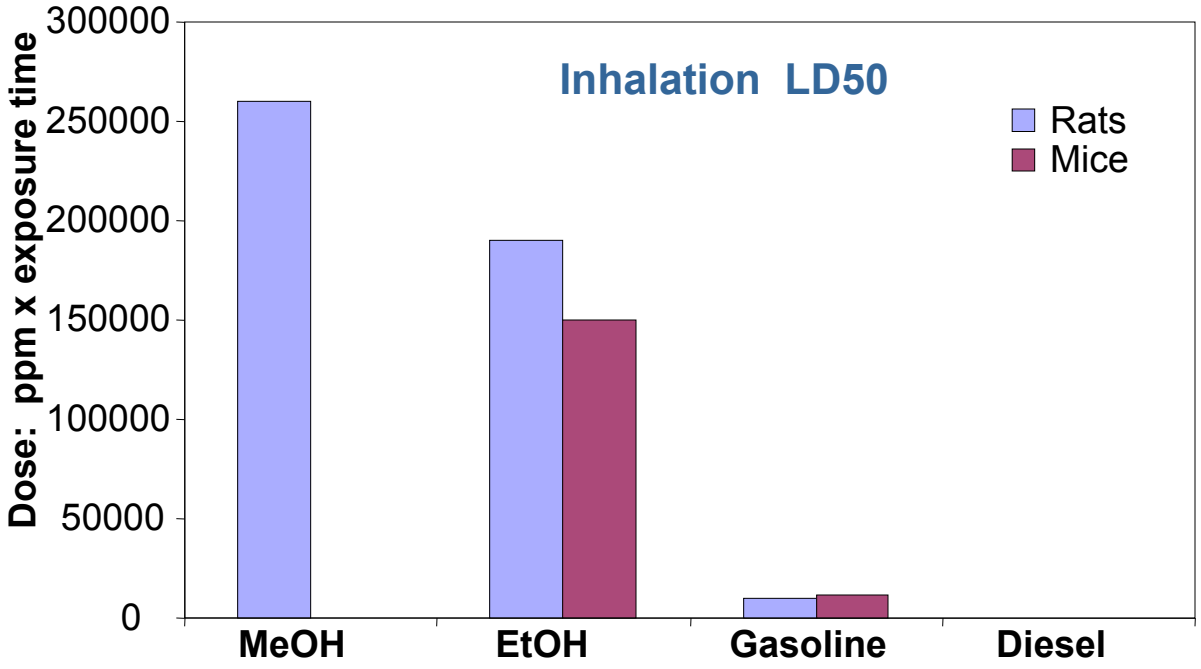
Technology for methanol in transportation has been proven; there is no technical hurdle for vehicle application and for distribution

Methanol in transportation

Health impact

- Prompt toxicity (median lethal dose) of methanol, ethanol, gasoline and diesel comparable
  - Exposure by ingestion, inhalation or contact
- Morbidity of methanol is more serious than ethanol
  - Affects central nervous system and can cause blindness
- In 2007, in the US, 11 deaths from over 2000 exposures
- Antidotes exist with early diagnosis and treatment
- In the US demonstration program in CA, with 20 years of experience and over 200 M miles driven on methanol, not a single harmful event
- There are existing commercial products with significant methanol content (e.g. wind shield wiper fluid)





Prompt toxicity

LD50: lethal dose for 50% kill

Methanol in transportation

Environmental impact

- Consequence of methanol spills
  - Half lives of methanol in soil, air and water longer than ethanol
  - Decays much faster than hydrocarbons
- Water soluble
  - Can migrate in the subsurface water, but decays within a few days (1-7 days)

Methanol in transportation

Safety

- Methanol safety characteristics:
  - Hard to ignite (much harder than gasoline and ethanol, comparable to diesel)
  - Lower radiant heat (lower flame temperatures)
  - Burns without smoke that obscure the objects for rescuers
  - Can be put out with water
  - However, methanol is nearly invisible in direct sunlight

- Fuel of choice in several racing categories: IRL (1996-2006), CART (1979-2007), drag racing, Monster Truck racing

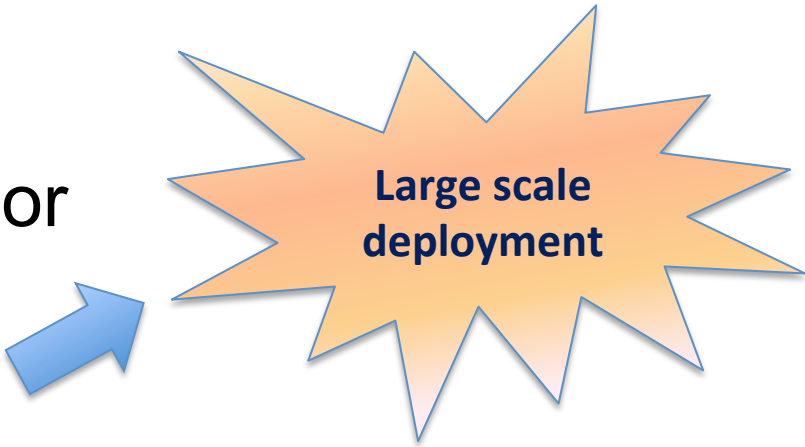
Methanol in transportation

Distribution

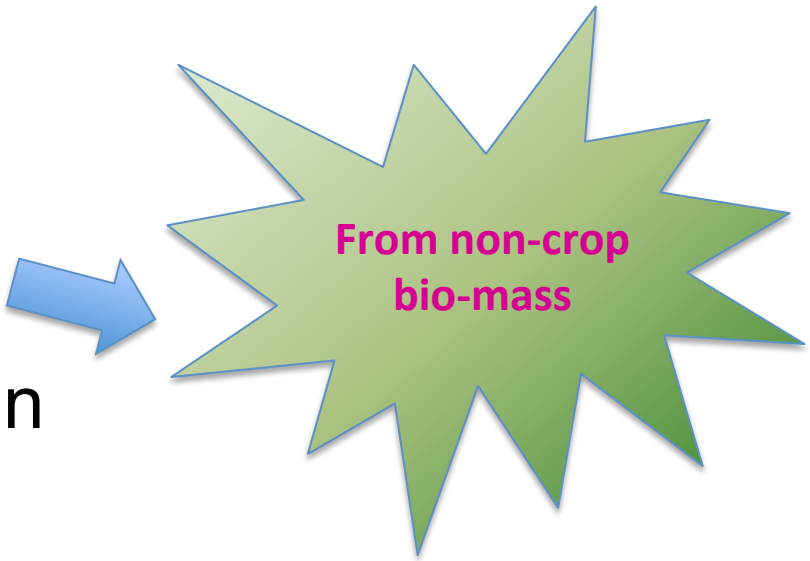
- Distribution of methanol has comparable challenges to ethanol
  - Can be transported by barge, railroad or truck tanker
  - In the US, limited methanol pipeline transmission for short distances
  - However, methanol pipeline transmission demonstrated in Canada over long distances
- Methanol dispenser, pump and storage tanks at service station require appropriate materials

Methanol:
the case for it

- Energy security
  - Must replace imported transportation fuel in a major way
    - Upwards of 50%; preferably 80-100%



- Sustainability
  - Low carbon intensity
  - Does not impact food chain



Methanol:
the case for it

- Methanol is a safe and viable fuel
  - No technical hurdle for vehicle use and distribution
- Not as good as ethanol as a transportation fuel (energy density and ease of handling)
- Advantage of methanol from renewable biomass:
  - Thermo-chemical production is energetically efficient and has been well developed
  - In comparison, large scale ethanol production from cellulosic materials is promising but not yet ready

Methanol:
the case for it

Bridging option

- Methanol from natural gas and coal as bridging option to renewable methanol
  - Large scale production, infra-structure and vehicle use can be developed
  - Such system is also amenable to the use of ethanol (or other renewable energy carriers), should large scale bio-production of cellulosic ethanol be realized in the future

Methanol:
the case

- Methanol is the only option for large scale deployment of alternative transportation liquid fuel in the US for the intermediate future

- To realize this methanol option, large capital investment and substantial political leadership are needed