Impact of Ethanol Blends in SI Engines

"increasing the impact of ethanol"

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"INNOVATION"

- My approach to innovation (with a few colleagues):

unfunded

  - Research a topic that looks interesting
  - Determine what the problems are
  - Think of solutions, both conventional and unconventional
  - Evaluate the merits of the solution, mostly by modeling, compare with present day approach
  - PATENT the technology (mostly, through MIT)
    - Main question: What distinguishes good engineering from patentable ideas?
  - Look for funding/industrial interest
  - Success: If idea is seriously considered by industry

Ethanol (& Methanol)

- Alcohols (ethanol & methanol) have excellent combustion properties
- Ethanol is expensive and supply is limited

- IT WOULD BE A SHAME TO WASTE ETHANOL AS A FUEL
  - **Use it for improving the performance of other fuels**

Ethanol R&D Needs

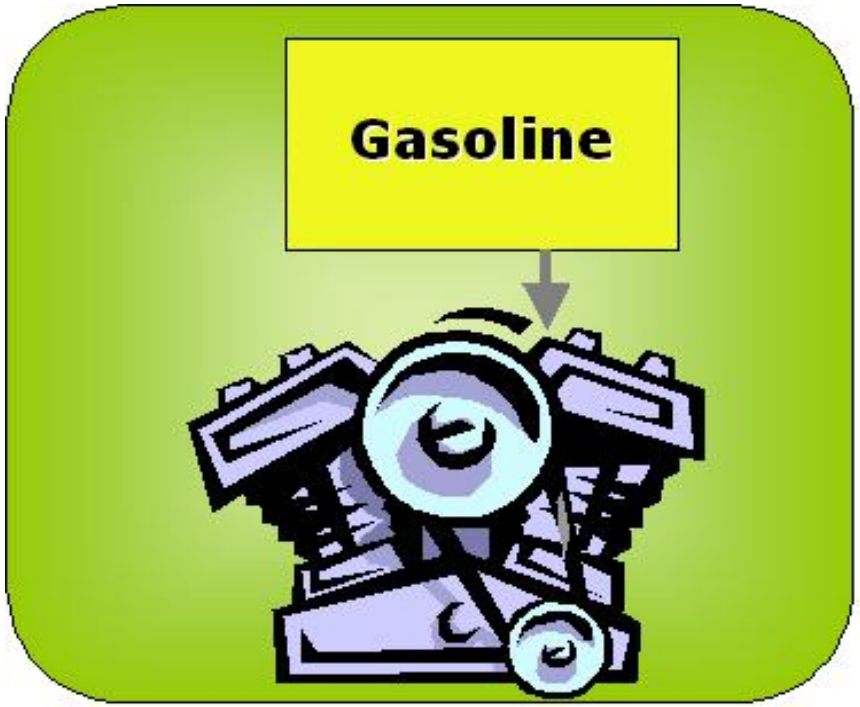
"increasing the impact of ethanol"

- Improved efficiency:
  - Investigation of combustion properties for boosting, downsizing, increasing compression ratio, MBT timing, DI vs PFI, stratification, EGR, downspeeding
  - Knock, misfire
- Means to address unavailability of alcohol
  - Heavy EGR, spark retard, with minimized impact on engine efficiency
- Means of using non-combusting properties of alcohol properties for improved efficiency
  - Exhaust energy recovery

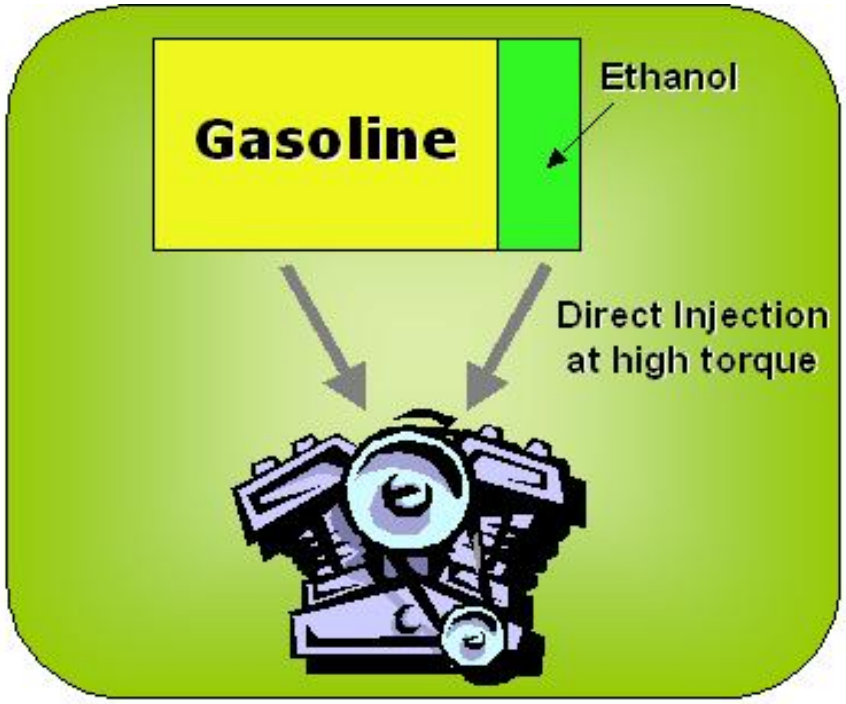
MIT Alcohol Research
Concepts for using ethanol/methanol

- Near term
  - Dedicated fuel vehicles
    - With degraded operation if no alcohol fuel available
  - Two-tank systems
    - Gasoline/alcohol and Natural gas/alcohol
  - Hydrous ethanol
  - Onboard fuel separation
- Longer term
  - Exhaust energy recovery using alcohol coolants
- Modeling and experiments

Conventional Engine Replaced by Alcohol Boosted Turbo Engine



Conventional engine



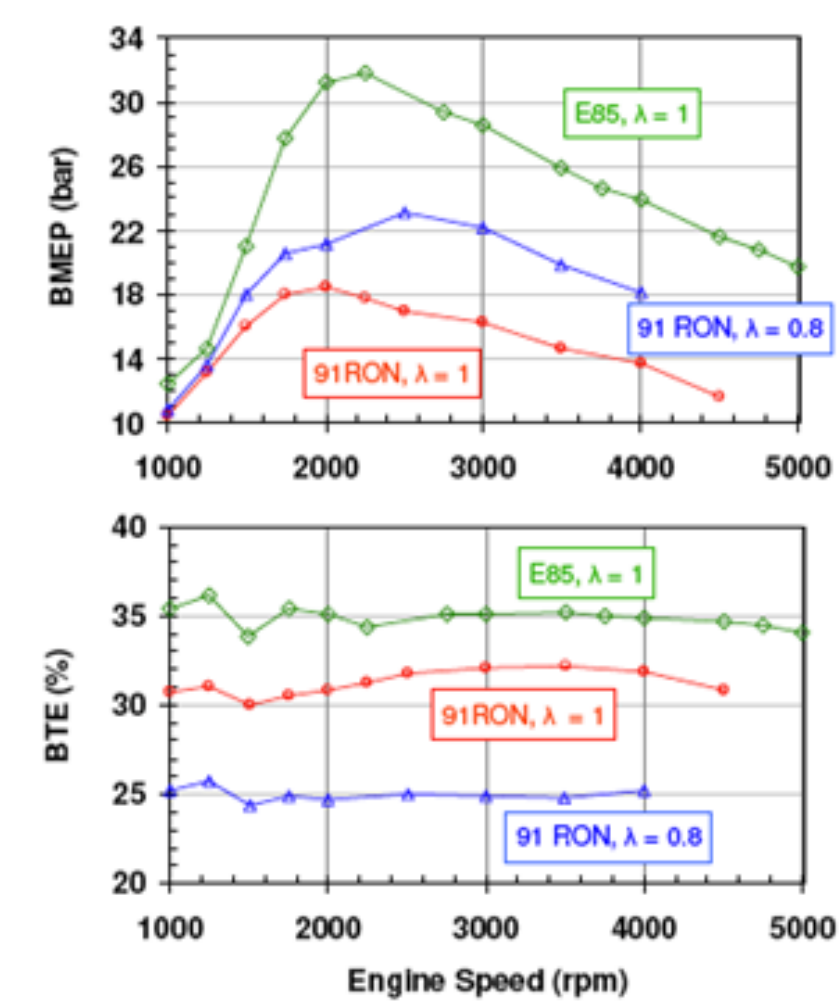
Ethanol turbo boost engine

“Ethanol Boosting”

- Use of a small amount of optimally injected ethanol from secondary tank
  - Goal: < 1-2% of gasoline use
- Removes knock limit (unwanted detonation), allowing high compression ratio and highly turbocharged operation
- Enables diesel-like high efficiency in gasoline engine

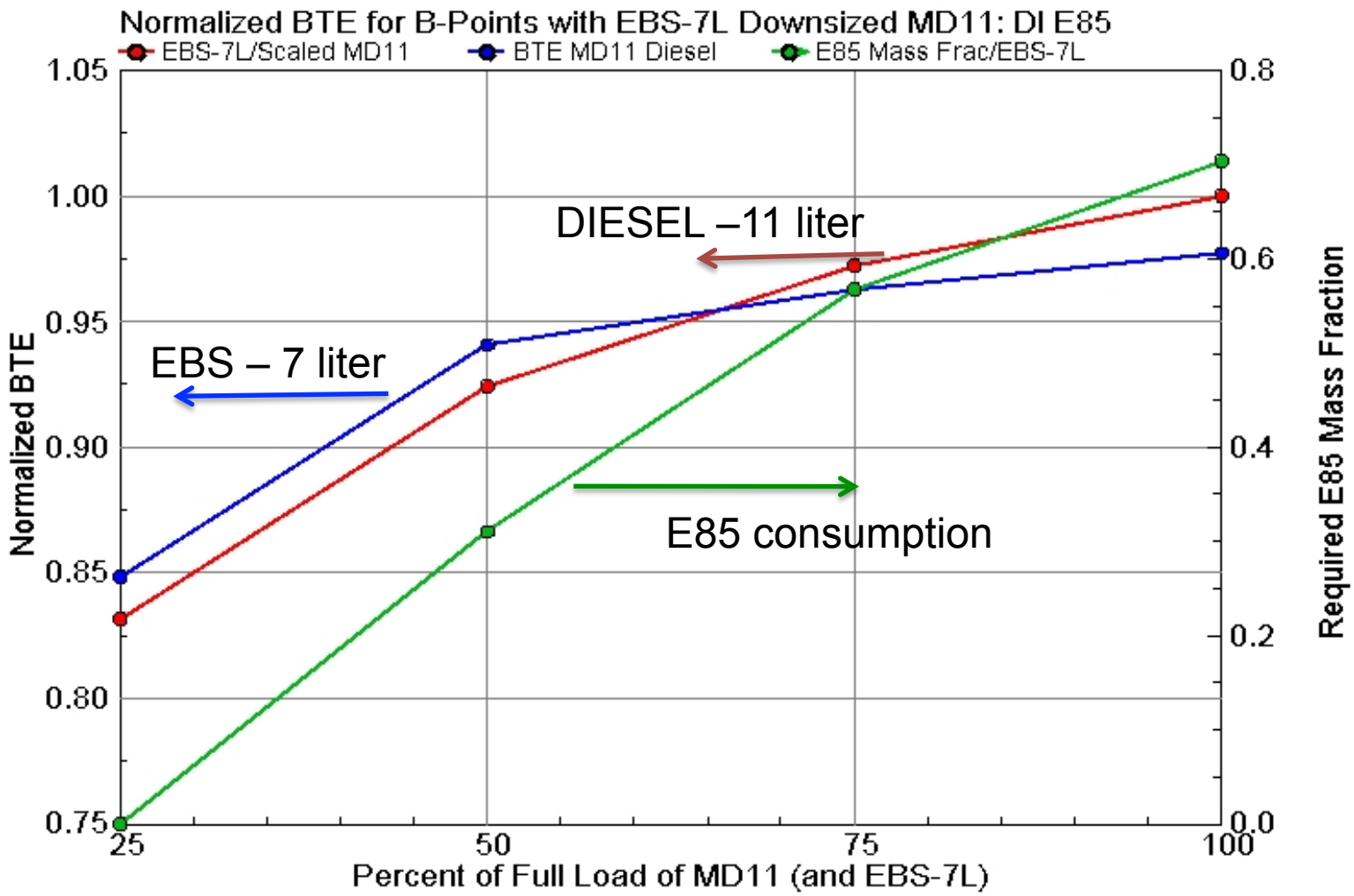
Ford/AVL/EBS

Multicylinder engine; CR 9.5
ethanol boost (E85) and GTDI (gasoline)



SIMULATIONS

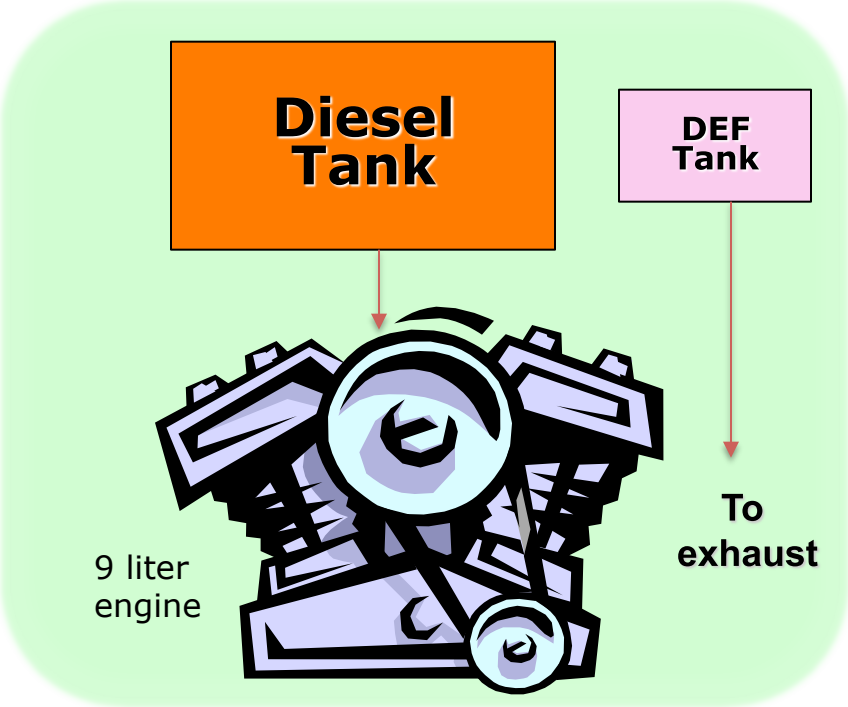
Volvo HD truck; 1550 rpm



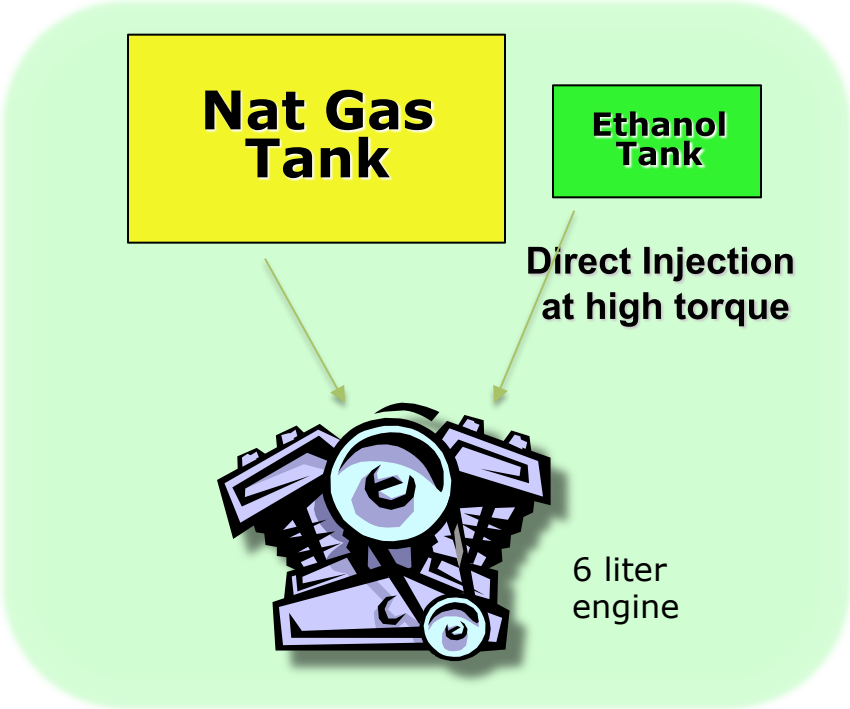
2008-01-2447

Schematic of Ethanol Boosted Natural Gas Engine

Enables replacement of a standard diesel engine…



… with a much smaller, more efficient NG engine with same or greater torque/power



Stoichiometric, no EGR

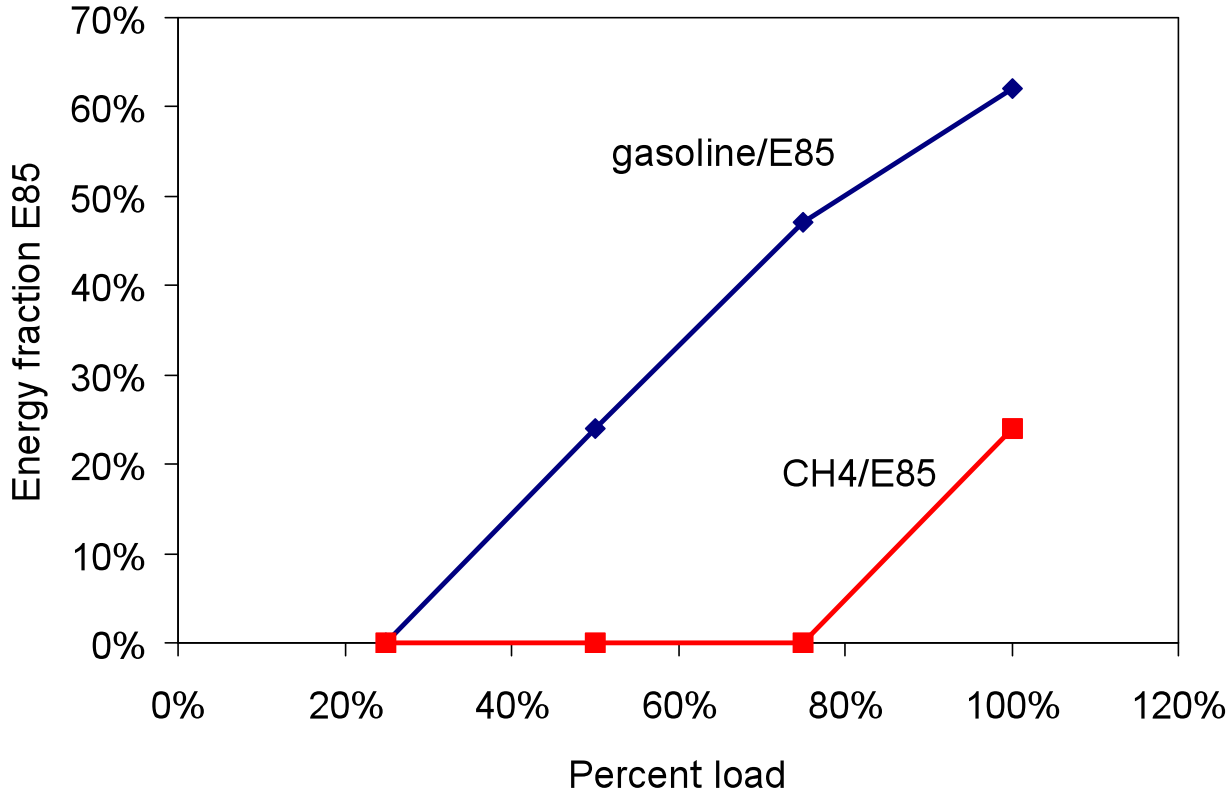
3-way catalyst (low emissions)

SIMULATIONS

Volvo HD truck running on Natural gas

E85 requirements for knock avoidance

1500 rpm, Rc = 14, bmep = 35 bar, 155 bar peak pressure

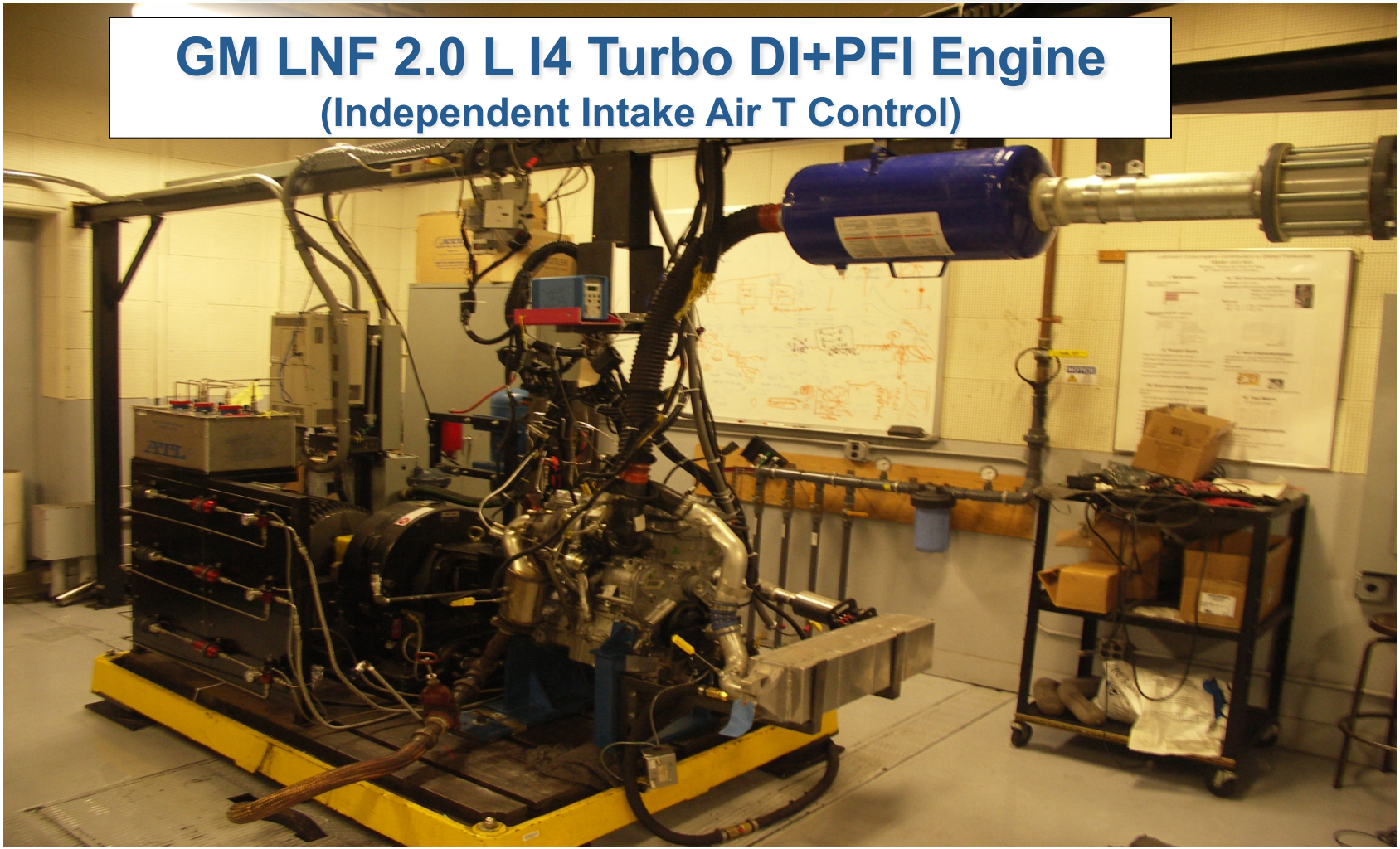


Calculations for methane; natural gas would be much lower “octane”

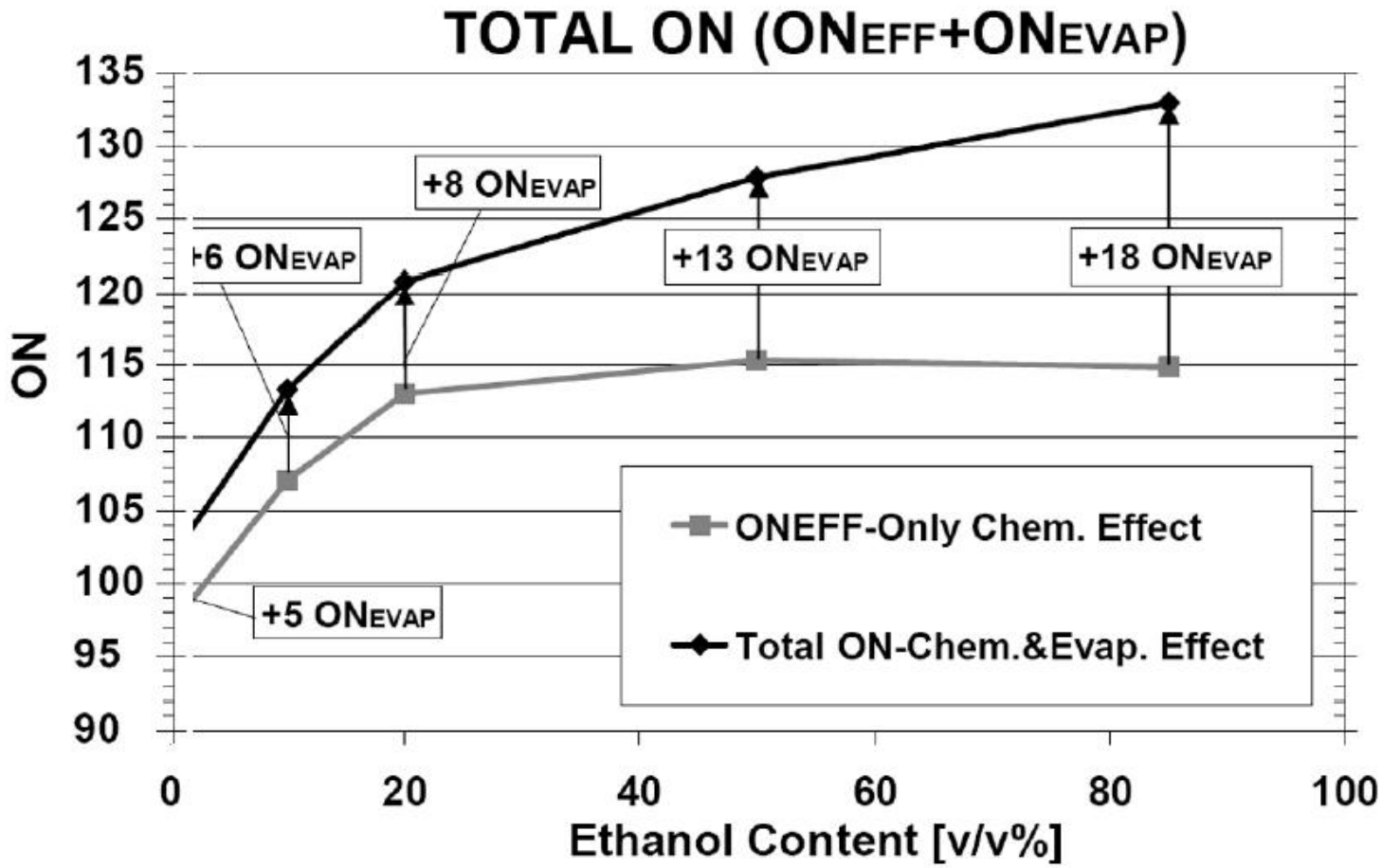
Fuel separation?

- Will the perceived operator inconvenience prevent implementation of 2-tank solution?
  - Can be addressed by on-board fuel separation
- In the case of low ethanol blends, separate the alcohol components from gasoline/ethanol blends

MIT Experimental Setup



MIT Research – effective octane



Kasseris. E and J. Heywood, *Charge Cooling Effects on Knock Limits in SI DI Engines Using Gasoline/Ethanol Blends: Part 2-Effective Octane Numbers*, *SAE Int. J. Fuels Lubr*. **5**, Issue 2 (May 2012); also SAE 2012-01-1284

Summary

Gasoline/ethanol 2-tank or dedicated ethanol

- For light duty, with infrequent operation at high torque, can increase efficiency by 10-15% relative to GDTI with low ethanol consumption
  - Exception: prolonged towing
- For heavy duty, large decrease in size and cost (both initial and operating) possible
  - Much simpler aftertreatment, less complex injection systems
  - Comparable efficiency to diesel
  - Requires frequent refilling of secondary tank
- Challenges: Minimize utilization of ethanol, optimize engine efficiency, minimize impact of no ethanol

Hydrous ethanol for knock avoidance Modeling results

	Antiknock heat of vaporization kJ/kg	Antiknock mass fraction	Antiknock Mass flow rate ratio	Antiknock Volume flow rate ratio	Antiknock refill interval
E85	745	0.78	1	1	1
h40EtOH	1480	0.5	0.72	0.62	1.60
h70EtOH	1900	0.44	0.68	0.55	1.82

- Hydrous ethanol can decrease the cost of antiknock agent, and reduce its use
- Model indicates that 40-60 H_2O/C_2H_5OH is sufficient
- This much water may result in problems with misfire

Alcohols for
Enhanced waste heat recovery

Cummins Waste Heat Recovery

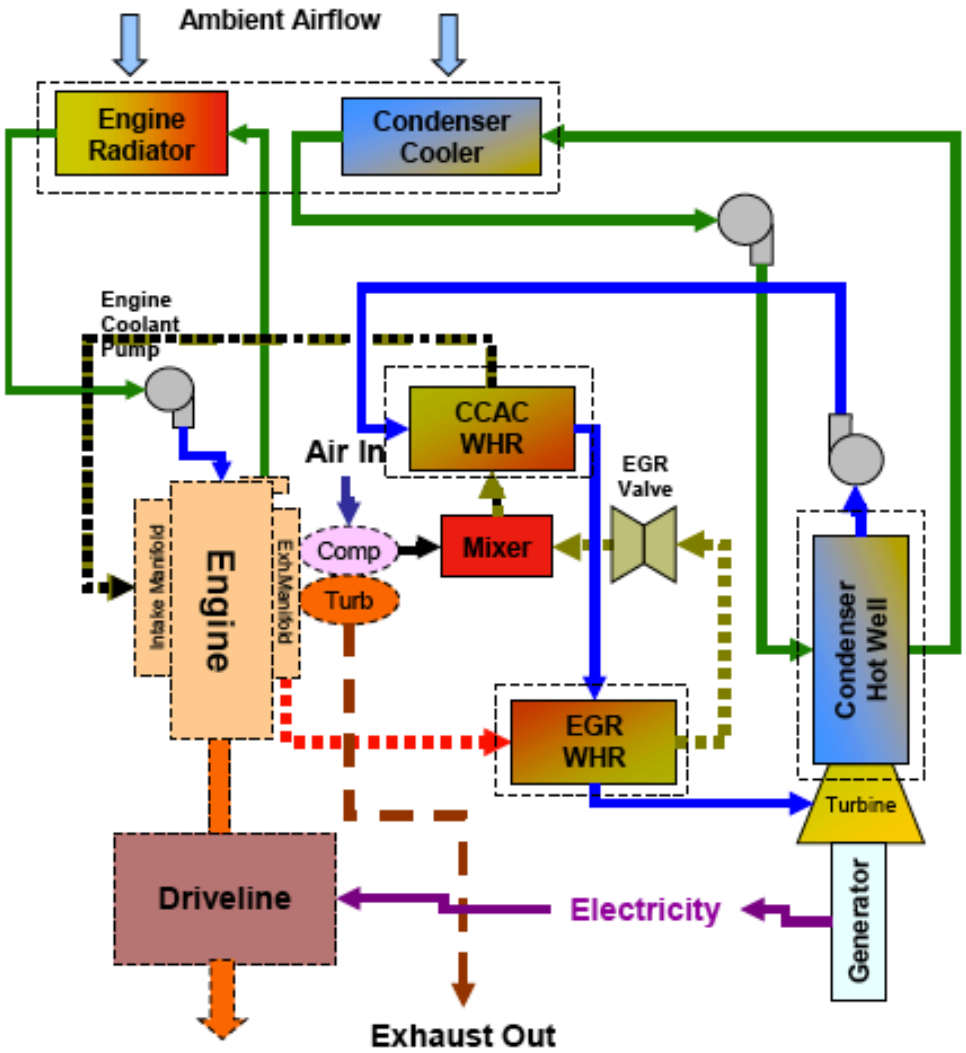
Initial Proposal - Presented at DEER, 2006

Organic Rankine Cycle

Capturing energy from EGR and combined EGR and CAC (CCAC)

Working fluid is proposed as R245fa
Honeywell Genetron

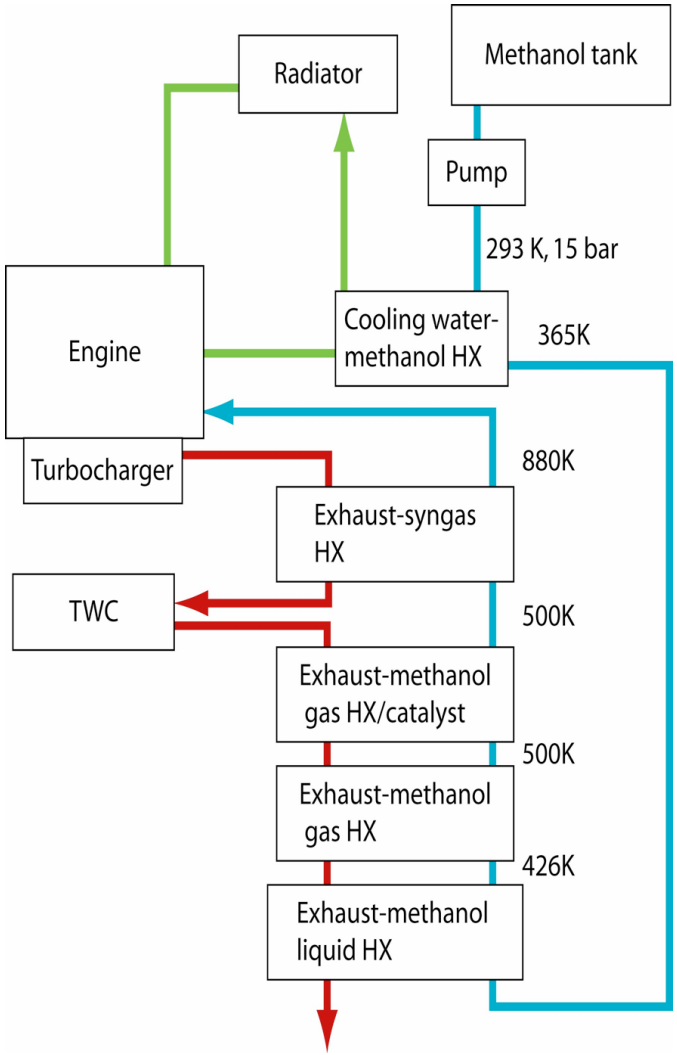
Proposed a 10% BTE Benefit



Ethanol or Methanol Rankine Cycle

Reforming + superheating

- Alcohol:
  - preheated by engine coolant
  - heated by exhaust to reforming temperatures
  - Reformed
    - Very endothermic for methanol
    - Slightly endothermic for ethanol
  - superheated



Alcohol Exhaust-Energy Recovery

- Potential to recover substantial fraction of exhaust energy
  - Increased efficiency by ~15-20% with ethanol, 20-25% with methanol
- Potential for further increased overall efficiency by using hydrogen to modify combustion
  - Ultra lean operation (decreases potential energy recovery, but increases engine efficiency)
- Some work on ethanol reforming by AVL/Monsanto, but not using Rankine cycle

Summary

Efficiency improvement potential of ethanol

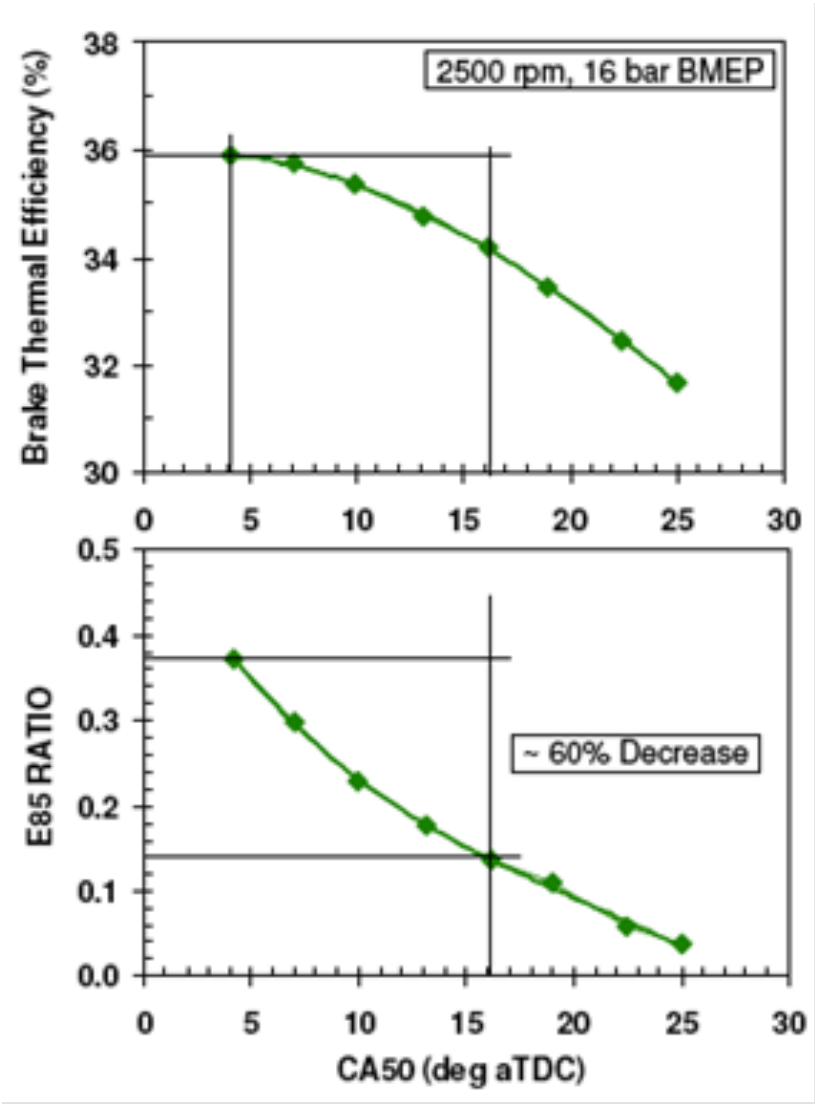
- There is potential for substantial engine efficiency improvements by using properties of ethanol
  - In the near term, SI efficiencies comparable to diesels are feasible (Today!)
  - In the long term, alcohol + energy recovery could be more efficient than fuel cells, at a fraction of their costs
- Experiments and modeling needed for optimizing efficiency
- Brazil is an ideal place for fleet testing of some of these concepts because of its unique infrastructure
  - Some of the approaches are expensive (boosting, DI) for light duty, but with relatively short pay-back times
  - VERY attractive for HD (reduced initial cost, reduced cost of ownership

Additional

Simulations

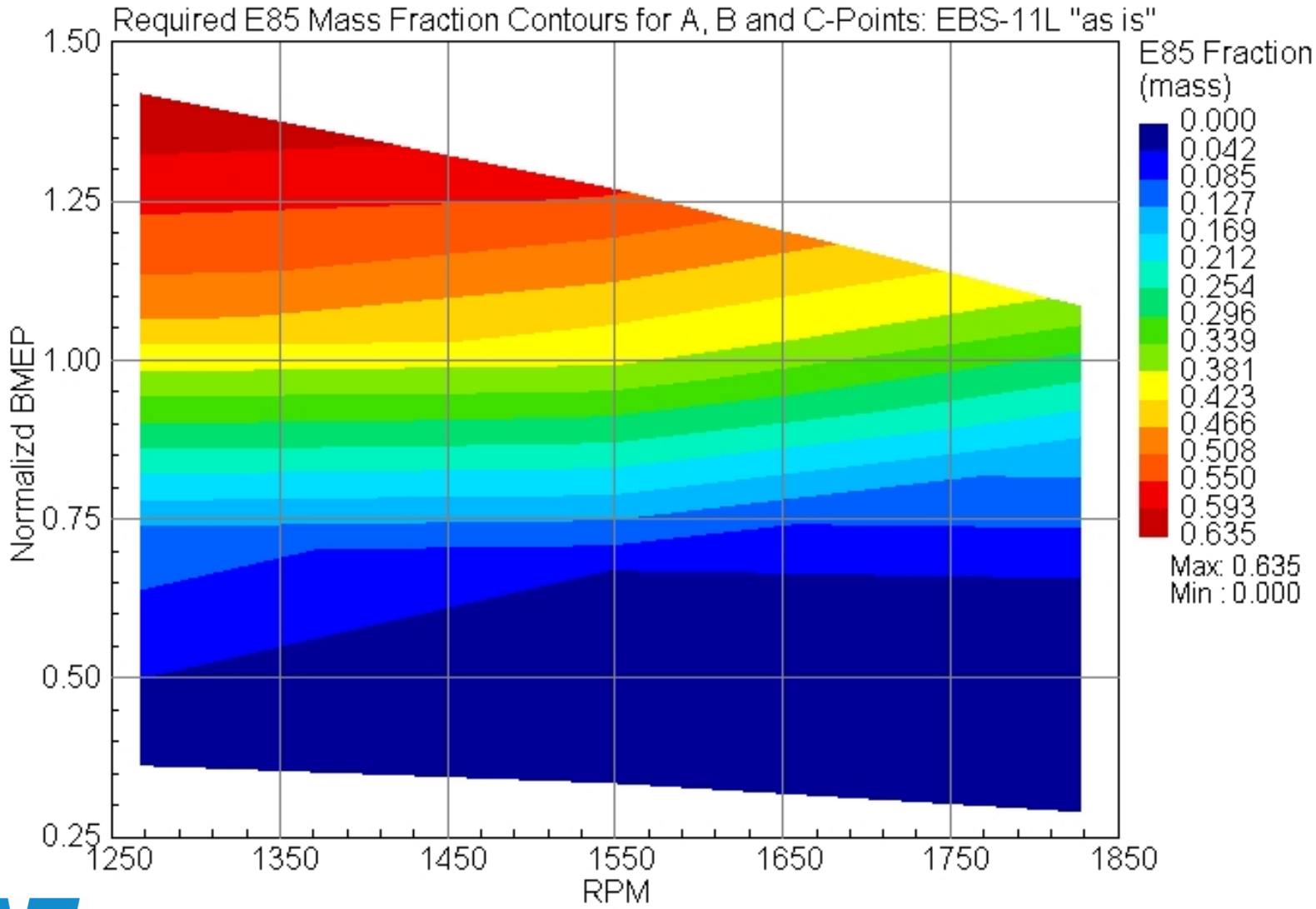
- Engine model: GT-Power
  - Single cylinder, CR = 14
  - 25 deg CA 10-90 combustion duration, near MBT timing
  - Compressor efficiency = 0.80; turbine efficiency = 0.72
  - Intercooler efficiency = 95%
- Knock model: CHEMKIN (Chemical kinetics)
  - Curran PRF Mechanism with 92 octane gasoline
  - Follow the temperature and chemistry of the unburned air-fuel mixture
  - Knock occurs when the unburned fuel self-ignites

Ford/AVL/EBS
Use Of Spark Retard To Reduce Ethanol Consumption For High Load Conditions



SIMULATIONS

Ethanol consumption (by mass, HD Volvo truck)



MIT/Cummins research on Alcohol blends

- Combustion properties of alcohol blends
  - Gasoline/ethanol, gasoline/methanol
  - Impact of hydrous alcohols
  - Effective octane
  - Evaporative vs chemical octane
- MIT investigating low pressure, Cummins will investigate at high pressure operation

Supported by US Department of Energy and Cummins