Ethanol, DME and Renewable Diesel for large scale displacement of fossil diesel in HD applications

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Intro and Question

Large content of biofuel needed to have impact

HD Vehicles Fleet with Biofuel

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Any fuel makes more sense? Drop-in Diesel? Ethanol? DME?

Conversion to BioFuels

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Large Scale Biomass Feedstock (e.g. One Billion Ton Initiative)

Agricultural Residues, Forestry Residues, Energy Crops

Fuel Properties

	Gasoline	Ethanol	Diesel or Renewable Diesel	ED95	DME	CNG/LNG
Formula	$C_nH_{1.87n}$	CH_3CH_2OH	$C_nH_{1.87n}$	CH_3CH_2OH	CH_3OCH_3	$CH_{3.8}$
LHV [MJ/L]	**33.0**	**21.1**	**35.7**	**20.5**	**19.3**	**10.2 / 22.5**
Combustion CO_2 [gCO_2/MJ_{fuel}]	**70.0**	**70.9**	**74.2**	**77.3**	**66.3**	**56.1**
Pump Octane #	84-93	110	-	-	-	120+
Cetane #	-	-	40-55	~10	55-60	-
Boiling Point [°C]	*35-200*	*78*	180-370	-	-25.1	-161.5
Flash Point [°C]	-40	13	64	12	-41.1	-184
Flammability Limits (%)	1.4 to7.6	3.3 to 19.0	0.6 to 5.6	-	3.4-17	5-15

Table 1 - Fuel Properties

Sources : (AFDC, 2104), (Heywood, 1988), (The University of California, 2015), Barbosa 2015, Wang 2017, *(Szybist, 2014), Arcoumanis 2008, other (web),* **calculated**

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Ethanol – Spark-Ignited approach

- Dedicated HD SI engine
- Ethanol Fuel System
- TWC – easier to reach ultra-low NOx
- Efficiency Potential
  - Faster flame than NG
  - Some level of charge cooling, especially if went DI
  - May not have to use as large a knock margin to accommodate wide fuel composition of NG
  - Likely could do close to or a little better than a CNG engine – say within 5 to 10% of diesel engine.

HD SI Engine: CWI ISX12G

Ethanol: Scania ED95 Compression Ignition Solution

- 4th generation ED95 engine
- ED95: 95% hydrous ethanol + additive package
  - Cetane enhancer
  - Denaturant
  - Lubricity additive
  - Corrosion Inhibitor
- Increased compression ratio (28:1)
- Larger capacity injector nozzles and fuel pump
- Fuel system materials resistant to ethanol
- Different Lubricating oil
- Reported efficiency very close to diesel

SCANIA PRESS info

13 October 2015

New Euro 6 bioethanol engine from Scania

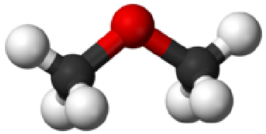
- **Scania is introducing a 9-litre inline 5 engine with 280 horsepower that runs on ED95 (bioethanol with ignition improver)**
- **Runs on the diesel principle with compression ignition**
- **Delivers 1,250 Nm, characterised by good driveability, efficient after-treatment and high efficiency (corresponding to diesel levels)**

Ethanol RCCI Concept

- RCCI: Reaction-Controlled Compression Ignition
- Typically achieved with 2 fuels of different reactivity, such as gasoline and diesel
- Low reactivity fuel (gasoline) is typically port injected – controls overall AFR
- High reactivity fuel (diesel) is directly injected, often in 2 injections, with the first injection relatively early in the compression stroke – controls Ignition
- Achieves the low temperature combustion of HCCI, but much easier to control and heat-release rate is smoother than HCCI

- Reitz report peak gross indicated efficiency for diesel-E85 of 59% which compares to 48% for conventional diesel combustion. This is achieved at mid load.
- Reitz report that similar results are obtained when ignition additives are used with gasoline (and presumably ethanol) instead of a second fuel like diesel.
- Potential for 5-10% improvement?

Engine and Vehicle Technologies for DME



DME

- is a non-toxic chemical
- High oxygen content (35% by mass) and no C-C bonds so very clean burning, does not soot.
- Liquid under moderate pressures (5 bar) like propane.
- Like propane it is denser than air, so caution must be exercised
- ~60% of the volumetric energy density of diesel, it has a high compressibility for a liquid and has low lubricity, low viscosity so leaks easily between metal-metal seals
- Corrosive to certain elastomers

- No DPF needed
- Likely strategy is to use SCR for NOx treatment to achieve best efficiency
- May require special oxidation catalyst formulation to treat formaldehyde
- Similar efficiency as diesel achieved
- Requires a new fuel injection system (lubricity, energy density, storage, vapor avoidance within fuel lines)
- May require different lubricating oil

Upstream – Existing and Default Pathways in GREET2016

Feedstock Gathering

- There are detailed models for the farming, fertilizers, gathering and transport, and LUC of
  - Corn Stover
  - Switchgrass
  - Forest Residues

Feedstock Conversion

- There is a detail model for the conversion of Corn Stover and Switchgrass to Ethanol through fermentation
- There is a detail model for the conversion of Forest Residue to Ethanol through gasification
- There are simplified models for the conversion of Corn Stover, Switchgrass and Forest Residues to DME and FTD

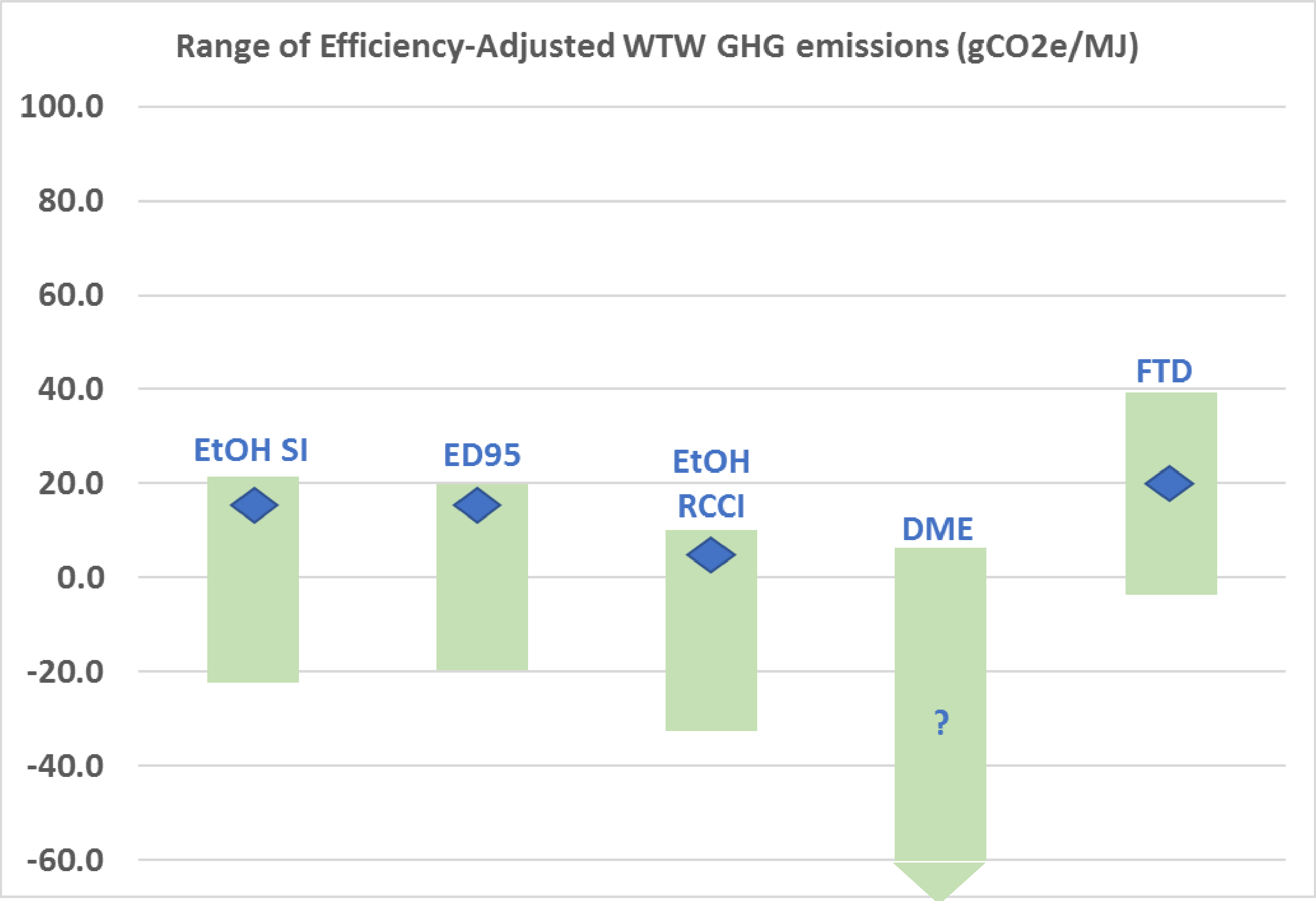
WTT Results

GREET 2016	Ethanol	DME	FTD
Conversion Process Efficiency[1]	45.0%	54.8%	47.8%
Fuel Yield	93.5%	55.3%	89.1%
GHG [gCO_2/MJ_{fuel}]	-57.4	-220	-77.8

[1] Conversion of biomass to fuel and electricity – electricity displaces electricity mix

Other References	Ethanol	DME	FTD
Conversion Process Efficiency[1]	47% (Wang 2012)		52% (Xie 2011)
GHG [gCO_2/MJ_{fuel}]	-65 (Wang 2012) -97 to -67 (EPA RFS)	*-60 (Lee 2016)*	-50 (Xie 2011) -76 to -35 (EPA RFS)

WTW Ranges



Diamond indicates higher confidence results

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Conclusions

- **Ethanol**
  - Could possibly lead to lower WTW GHG than FTD, with largest reduction from RCCI strategy
  - Ethanol SI should lead to ultra low NOx emissions more easily/robustly and still provide very good GHG reductions
  - Ethanol could lead to some vehicle cost reductions
  - WTW GHG Reduction may not be sufficient enough to warrant several significant challenges with ethanol
    - Infrastructure changes and investment needed, may require a fraction of Fischer-Tropsch Gasoline, reduced range, safety aspects
  - But can't rule it out as there may be other reasons why it might be attractive (uniformity of supply? cost? maximum yield, etc…)

Conclusions

- **DME**
  - Looks very good from a GHG perspective, owing to both lower carbon content per unit energy and low upstream emissions;
  - GHG benefits are more dependent on co-electricity generation; may not look as good in future when grid is more de-carbonized;
  - Confidence in results is limited by available information, need more studies of DME made from biomass sources.
  - Vehicles should not be more expensive in long term; infrastructure investment non negligible, but easier than NG

Outline

- Biomass and biofuels considered
- Vehicle efficiency potential and impact
- Biofuels production
- Conclusions

Biofuels considered

3 Liquid Biofuels	3 Common Biomass Sources
Ethanol	Fermentation of Corn Stover
Dimethyl Ether	Gasification of Switchgrass
Renewable Diesel	Gasification of Forest Residues

Fuel Production Considerations

- Question: out of a large amount of biomass (agricultural waste, forestry residues, energy crops), which of the fuels considered could be produced with lowest energy and carbon intensity?
- Examined the available pathways to make ethanol, DME and Renewable Diesel (as Fischer-Tropsch Diesel or FTD) from biomass
  - Reviewed recent literature (mostly focused on US)
  - Used GREET2016
- Context
  - Large scale : so did not look into smaller feedstocks
  - Large CO_2 reduction potential: no significant fossil fuel input
  - Common feedstock for all 3 fuels so as to compare