Alternative Diesel Fuels

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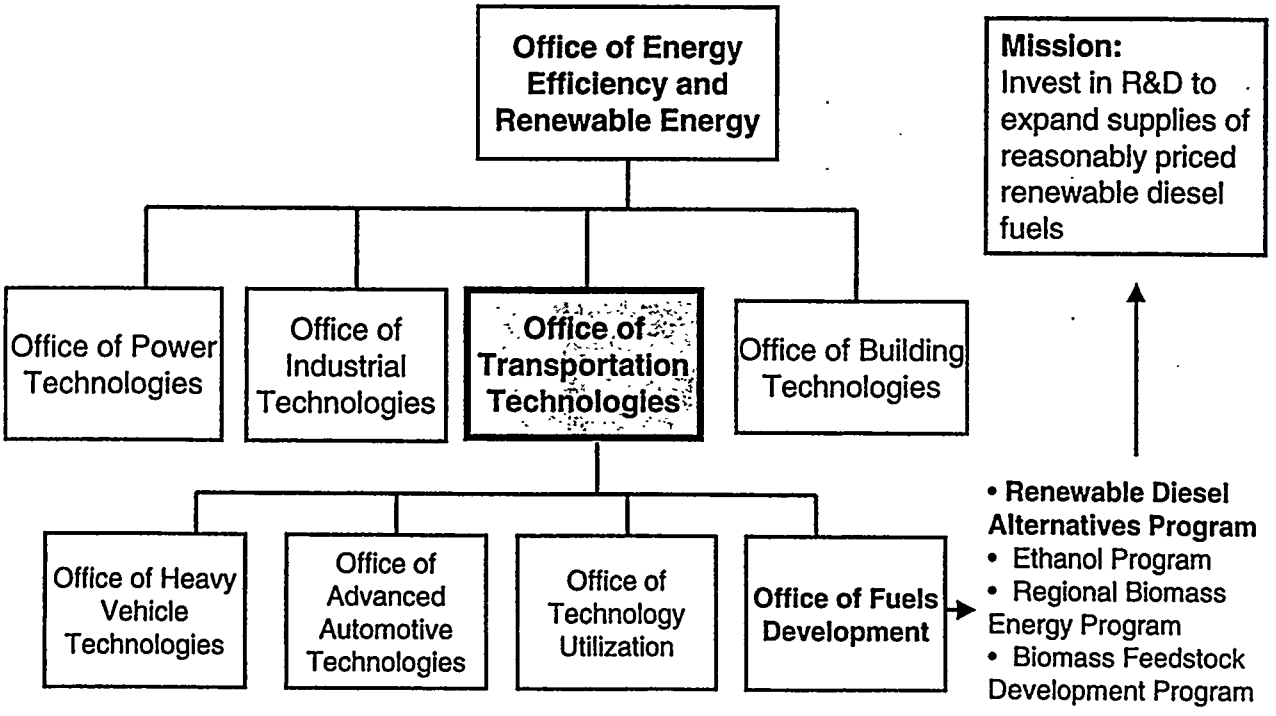
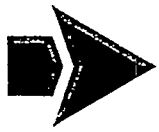
DOE Office and Program Structure



Alt. Diesel Fuels Feedstocks

- Coal
- Natural gas
- Electricity
- Biomass



- Natural gas/biogas
- Electricity
- Hydrogen
- Ethanol/methanol
- Fischer-Tropsch
- Biodiesel
- DMM, DEE, DME, ...

- All of the above could allow a transition to renewable fuels

Transition Approach

- Track the development of ADF engine and vehicles
- Identify fuels, current feedstocks, supply issues
  - Identify where renewable fuels can augment traditional fuel supplies
  - Identify where renewable fuels can play significant long-term roles
- Target R&D priorities for ADF

ADF Success Factors

- Able to compete in a non-crisis environment
- Sizable supply base
- Public benefits
- Appropriate engine/vehicle technology
- Public acceptance
- Good fit with application

- Unable to predict which fuel(s) may dominate future markets at this time

ADF Categories

- Liquid fuels that do not require engine or vehicle modifications

- Liquid fuels requiring modified or unique engines and vehicles
- Gaseous fuels
- Electricity
- Hydrogen fuels

ADF for Existing CI Engines

- Intuitively attractive
  - no new engine or vehicle purchases
  - no new infrastructure requirements
  - large immediate market potential - near term benefits
  - consumer flexibility
  - transitions from blends to pure in the future
  - useful in crises situations - put in existing vehicles
  - driven by perceived benefits
  - "stretches out petroleum supplies"
  - consumer may be unaware of changes

Drivers for ADFs in Diesel Mkt

- Improve on diesel fuel characteristics
  - Improve lubricity or cold flow properties
  - Increase Cetane number
  - Reduce aromatics and sulfur
  - Reduce regulated emissions (NOx & PM) ←
  - Reduce smell or air toxics
  - Improve fuel efficiency or performance
  - Reduce cost
- Global warming, Fuel diversity & Energy security not monetarized

ADF Fuel Requirements

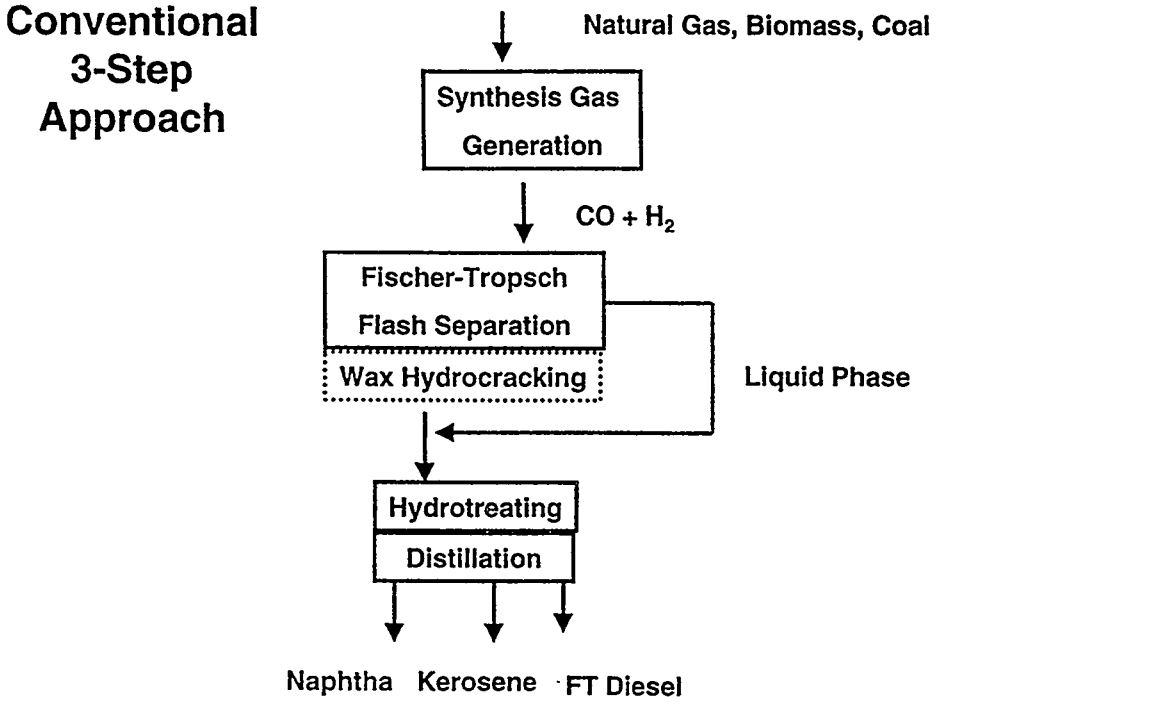
- Improved Emissions
- No phase separation in presence of
  - water, metal catalysts, etc.
- Good stability
- No undesirable fuel-fuel interactions
  - or material compatibility problems
- Long-term field performance record
- Reasonable cost for performance
- Properties within ranges set by ASTM D 975
  - either blended or pure

Pure ADF for Existing Engines

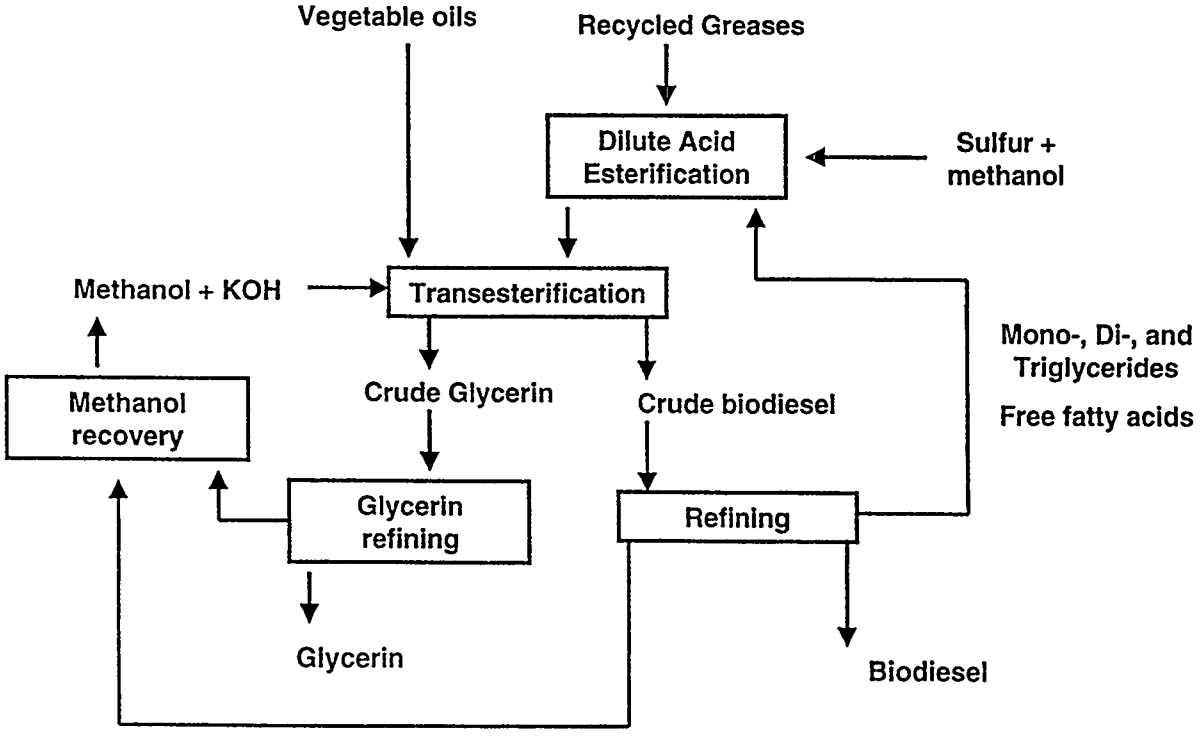
- Neat Fuels
  - Fischer - Tropsch Diesel
  - Biodiesel

- Others may exist but not evaluated yet

Fischer-Tropsch



Biodiesel



Pure Fuel Properties

	Diesel	Biodiesel	Fischer Tropsch
Fuel Standard	ASTM D975	ASTM PS 121	n/a
Fuel composition	C10-C21 HC	C12-C22 FAME	C_nH_{2n+2}
Lower Heating Value, Btu/lb	130,250	120,910	121,300
Kin. Viscosity, @ 40 °C	1.3-4.1	1.9-6.0	3.21-3.57
Specific Gravity kg/l @ 60 °F	0.85	0.88	0.783
Density, lb/gal @ 15°C	7.079	7.328	6.52
Water, ppm by wt	161	.05% max	
Carbon, wt %	87	77	85
Hydrogen, wt %	13	12	15
Oxygen, by dif. wt %	0	11	neg.
Sulfur, wt %	.05 max	0	<.001
Boiling Point			
°F	370-650	360-640	350-670
°C	188-343	182-338	177-354

Pure Fuel Properties

	Diesel	Biodiesel	Fischer Tropsch
Flash Point, °C	60-80	100-170	60-81
Cloud Point, °C	-15 to 5	-3 to 12	-23 to 8
Pour Point, °C	-35 to -15	-15 to 16	-20 to 11
Cetane Number	40-55	>48	>74
Autoignition Temperature			
°F	600		600
°C	316		316
Stoichiometric Air/Fuel Ratio, wt./wt.	15	13.8	15.2
Flammability Limits, Vol. % Rich	7.6		
Flammability Limits, Vol. % Lean	1.4		
RVP			
psi @ 100 °F	<0.2	n/a	n/a
kPa @ 37.8 °C	<1	n/a	n/a
BOCLE Scuff, grams	3,600	>7,000	1,700-2,300
HFRR, microns	685	314	

HD FTP Hot Start Emissions

		% Change from Diesel No. 2		
	PM	NOx	CO	HC
FT 1	-26.94	-9.12	-44.91	-46.06
FT 2	-31.90	-6.68	-47.48	-25.46
FT 3	-28.10	-9.13	-44.58	-41.26
FT 4	-13.33	-14.26	-38.89	-42.77
FT 5	-15.57	-6.50	-12.89	-8.74
FT 6	-37.00	-6.00	-27.00	-50.00
FT 7	-21.30	-27.94	-32.90	-59.09
FT 8	-22.74	-27.38	-34.20	-50.00
Average	-24.61	-13.38	-35.36	-40.42

Market Issues for FT

- Fischer-Tropsch
  - No domestic supplies, limited international supply
  - Price uncertainty, but premium value assured
  - No available field test info
  - Need ASTM standard or other
  - Material compatibility as a pure fuel
  - Cold weather issues
  - Higher value as a blend stock initially
  - Dedicated engines for FT with NOx/PM aftertreatment may provide higher emission benefits

Biodiesel HD FTP Emissions

		% Change from Diesel No. 2			
B100	PM	NOx	CO	HC	Test
Soy	-66.00	11.46	-46.99	-43.90	FTP Avg
Rape	-14.15	-2.52	-35.37	-63.33	FTP Avg
Rape	-24.53	3.43	-38.78	-70.00	FTP Avg
Grease	-78.09	2.81	-52.31	-100.00	FTP Hot
Grease	-74.31	4.46	-41.56	-45.27	FTP Hot
Tallow	-73.56	0.94	-44.14	-39.19	FTP Hot
Tallow	-74.69	1.92	-46.74	-31.08	FTP Hot
Lard	-73.94	1.29	-52.07	-25.00	FTP Hot
Canola	-70.92	10.41	-41.89	-32.09	FTP Hot
Soy	-69.40	13.69	-34.32	-23.98	FTP Hot
Soy	-28.30	13.13	-45.33	-95.65	FTP Avg
Soy	-49.02	11.33	-38.26	-83.33	FTP Avg
Soy	-36.72	4.26	-38.05	-74.19	FTP Avg
Grease	-42.50	4.36	-48.87	-61.20	FTP Hot
Avg	**-55.44**	**5.78**	**-43.19**	**-56.30**	

Market Issues for Biodiesel

- Biodiesel
  - Cost high but declining ($1.30/gal 1/2000)
  - Material compatibility as pure fuels
  - NOx emissions need reducing
    - as fuel cost declines and market expands, "optimized" biodiesel engines may be developed
    - additive testing underway
  - Long term field experience
  - Cold weather issues
  - Dedicated engines for BD with a NOx/PM aftertreatment may provide higher emission benefits

ADF for Blends with Diesel

- **Fuel Blends**
  - Fischer-Tropsch Diesel
  - Biodiesel
  - Methylal
  - Diethyl ethers
  - Ethanol
- **Blend Benefits**
  - reduce material compatibility concerns
  - Reduce impact of "poor" fuel properties
  - Reduce impact of cost
  - Meet diesel emission goals
  - Meet diesel fuel quality goals
    - Cetane
    - Lubricity
    - Lower S and aromatics

ADF Blend Issues

- "Optimal" blend levels not well established
  - depend on objectives & tradeoffs
- Data on blended fuel properties scarce
  - Emissions data
  - Properties of blended fuels
- Fuel supply issues vague
- EPA 211(b) Health Effects and "Sub Sim" regs may add substantial costs

FT Blends - Emission Data

		% Change from Diesel No. 2			
% FT	PM	NOx	CO	HC	Test
20	-27	-6	-20	-42	13 M avg
50	-9.84	-5.48	-5.89	-10.76	FTP Hot
30	0.36	-12.48	-17.23	-40.91	FTP Hot
50	-4.33	-18.87	-24.28	-50.00	FTP Hot
80	-13.00	-24.82	-31.59	-59.09	FTP Hot

Biodiesel Blends - Emissions

		% Change from Diesel No. 2			
% BD	PM	NOx	CO	HC	Test
5 Soy	-4.40	0.65	-8.03	0.00	FTP Hot
10 Soy	-10.30	2.06	0.00	-10.34	FTP Avg
20 Soy	-14.91	3.16	-3.64	-18.97	FTP Avg
20 Soy	-24.60	3.04	-17.79	-11.69	FTP Hot
20 Soy	-3.77	4.16	-14.67	-17.39	FTP Avg
20 Soy	-13.73	3.56	-7.38	0.00	FTP Avg
20 Soy	-14.84	1.91	-21.46	-32.26	FTP Avg
20 Soy	-9.09	-0.85	-9.29	25.00	FTP Hot
20 Soy	-9.39	2.48	-15.88	-7.87	FTP Avg
20 Soy	-13.67	1.14	-7.11	-12.80	FTP Avg
20 Soy	-17.12	-3.99	-18.77	-20.83	FTP Avg
20 Soy	-16.52	0.51	-5.12	14.53	FTP Hot
20 Soy	-32.00	0.00	-20.00	-31.00	13 mode avg
20 Grease	-59.17	1.68	-34.16	-4.35	FTP Hot
20 Grease	-13.50	2.29	0.72	-5.74	FTP Hot
20 Tallow	-10.86	-2.03	-2.54	-30.06	FTP Hot
35 Soy	-26.00	0.97	-17.72	-9.76	FTP Avg
50 Grease	-31.67	-0.09	-38.95	-29.77	FTP Hot
50 Rape	-13.21	-2.75	-29.93	-43.33	FTP Avg
50 Rape	-17.92	-1.60	-34.01	-46.67	FTP Avg
65 Soy	-45.00	4.60	-28.71	-26.83	FTP Avg
B20 Average	-18.08	1.22	-12.65	-10.96	

Fuel Property Data

	Diesel	Methylal	DEE	Ethan
Fuel Standard	ASTM D975	n/a	n/a	n/a
Fuel composition	C10-C21 HC	$CH_3OCH_2OCH_3$	$C_2H_5OC_2H_5$	C_2H_5O
Lower Heating Value, Btu/lb	130,250	73,067	86,521	76,00
Kin. Viscosity, @ 40 °C	1.3-4.1	0.33	0.23 (68°C)	
Specific Gravity kg/l @ 60 °F	0.85	0.86	0.714	0.79
Density, lb/gal @ 15°C	7.079	8.33	5.946	6.61
Water, ppm by wt	161	773		
Carbon, wt %	87	47.37	52	
Hydrogen, wt %	13	10.13	13	
Oxygen, by dif. wt %	0	42.5	35	
Sulfur, wt %	.05 max	0	0	
Boiling Point				
°F	370-650	107	94	172
°C	188-343	42	34	

Fuel Property Data

	Diesel	Methylal	DEE	Ethanc
Flash Point, °C	60-80	-28	-49	
Cloud Point, °C	-15 to 5	<-52	very low	
Pour Point, °C	-35 to -15	very low	very low	
Cetane Number	40-55	24	55-60 to 125	<5
Autoignition Temperature				
°F	600	459	320	793
°C	316	228-237	160	
Stoichiometric Air/Fuel Ratio, wt./wt.	15	7.1	11.1	9
Flammability Limits, Vol. % Rich	7.6	14.9	36	19
Flammability Limits, Vol. % Lean	1.4	3.3	1.9	4.3
RVP				
psi @ 100 °F	<0.2	12.2	9-16	2.3
kPa @ 37.8 °C	<1	84-86	110	
BOCLE Scuff, grams	3,600			
HFRR, microns	685	700	810	

DMM Blends - Emission Data

		% Change from Diesel No. 2			
% DMM	PM	NOx	CO	HC	Test Procedure
5	-5.08	-7.29	-9.22	40.82	9 mode avg SS
10	-13.56	-6.56	2.31	38.10	9 mode avg SS
15	-52	-4	-36	-24	13 mode avg. SS
20	-27.12	-4.94	19.40	32.65	9 mode avg SS
30	-25.42	-11.88	59.65	68.71	9 mode avg SS

DEE Blends - Emission Data

		% Change from Diesel No. 2			
% DEE	PM	NOx	CO	HC	
5	10.17	-5.59	-2.21	11.56	9 mode avg SS
10	-11.86	-1.32	1.63	29.93	9 mode avg SS
20	-16.95	-3.54	11.91	89.12	9 mode avg SS
30	-23.73	-8.56	26.03	118.37	9 mode avg SS
50	17.39	-40.12	47.61	128.86	Pt. SS, 1500 rpm
50	-30.91	-26.23	90.70	166.67	FTP Hot

"Oxydiesel"* Emission Data

Percentage change in Emissions

	10% Ethanol	15% Ethanol
CO	-20	-27
NOx	-4	-5
PM	-27	-41
HC	+71	+110

***Ethanol + emulsifier + Cetane improvers + diesel fuel**

Summary

- Current List a begining
- ADF may be viewed as "new" or "expanded" diesel capacity
- ADF provides flexibility when reformulating diesel fuel
  - lower aromatics & sulfur, higher Cetane & lubricity
- Blending can occur down stream or upstream

Summary

- Cities and States very interested in blends
  - air quality concerns
- Emission benefits equate to price premium
- FT and BD leading the way
- Customers appear to like blended fuels
  - no new vehicle or infrastructure expense
  - no new ES&H or training issues with FT or BD
  - "Seamless" transition for consumer
    - distributor has burden of learning curve

Conclusions

- Unresolved issues remain:
  - Monitor material compatibility
  - Monitor fuel oil interactions
  - Need more field experience
  - Need fuel standards
    - for pure fuels and/or for the blended products
  - Need standardizing testing for new products
    - streamlining and cost reduction issues
  - Need more sophisticated engine-fuel sensors and computer mapping