

Designing a Low-Carbon Fuel Standard for the Northeast

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Northeast LCFS Workshop

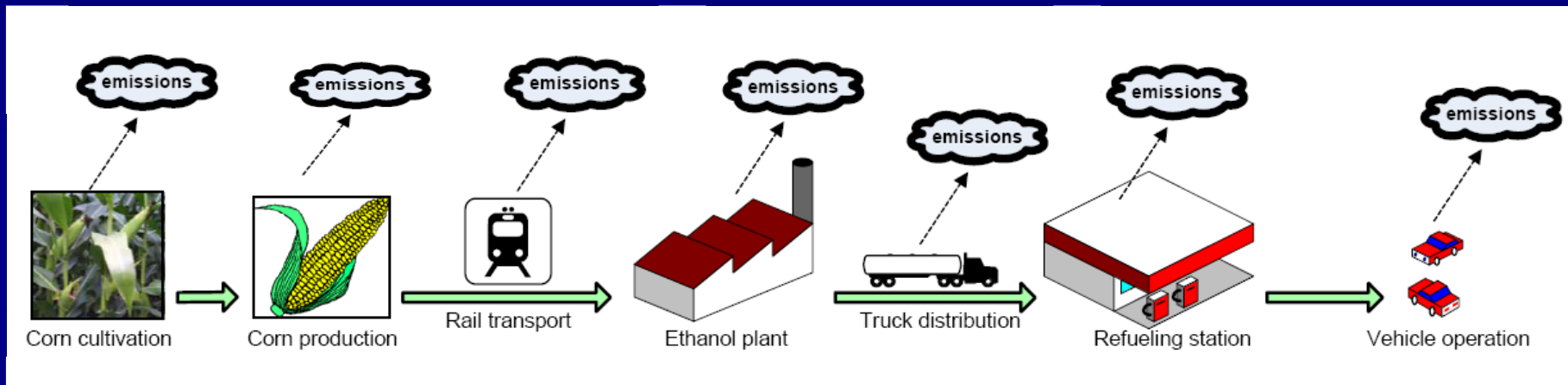
Yale University

October 14, 2008



What's “carbon intensity” again?

- A measure of the total CO₂-equivalent emissions produced throughout a fuel's lifecycle



(Source: Guihua Wang and Mark Delucchi, 2005. "Pathway Diagrams". Appendix X to the Report "A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials."
<http://www.its.ucdavis.edu/publications/2003/UCD-ITS-RR-03-17X.pdf>)

- Measured in grams of CO₂-equivalent GHG emissions per energy-unit of fuel

gCO₂e/MJ

Why “CO₂-equivalent”?

- ...to account for all relevant GHG emissions:
 - » CO₂ (GWP = 1)
 - » CH₄ (GWP = 25)
 - » N₂O (GWP = 298)

Why megajoules instead of gallons?

- To enable “apples-to-apples” comparisons of different fuels based on the utility each fuel provides
- Different fuels may have different energy densities (megajoules per gallon)
- For example:
 - Gasoline contains 120 MJ per gallon
 - Ethanol contains 80 MJ per gallon
 - Therefore it takes $120/80 = 1.5$ gallons of ethanol to achieve the same utility as one gallon of gasoline.
- 1 MJ = 948 Btu

Analytical Methods: Overview

Carbon intensity
for each fuel type

Total energy
consumption for
each fuel type

**Average Fuel
Carbon Intensity
(AFCI)**

```
graph LR; A[Carbon intensity for each fuel type] --> C[Average Fuel Carbon Intensity (AFCI)]; B[Total energy consumption for each fuel type] --> C;
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The diagram illustrates the calculation of Average Fuel Carbon Intensity (AFCI). It features three main components: two input boxes on the left and one output box on the right. The top-left box, labeled 'Carbon intensity for each fuel type', has a white arrow pointing right and then down to the top of the output box. The bottom-left box, labeled 'Total energy consumption for each fuel type', has a white arrow pointing right and then up to the bottom of the output box. The output box, labeled 'Average Fuel Carbon Intensity (AFCI)', is highlighted in yellow with a white border and contains the text in bold black font.

Analytical Methods: Overview

Lifecycle Fuel Analysis

- Production pathway
- Land use effects (direct & indirect)
- Transport modes
- Storage, delivery

LCA Model
(GREET)

Carbon intensity for each fuel type

Scenarios

- Transportation fleet mix
- Annual VMT per vehicle
 - Fuel economy

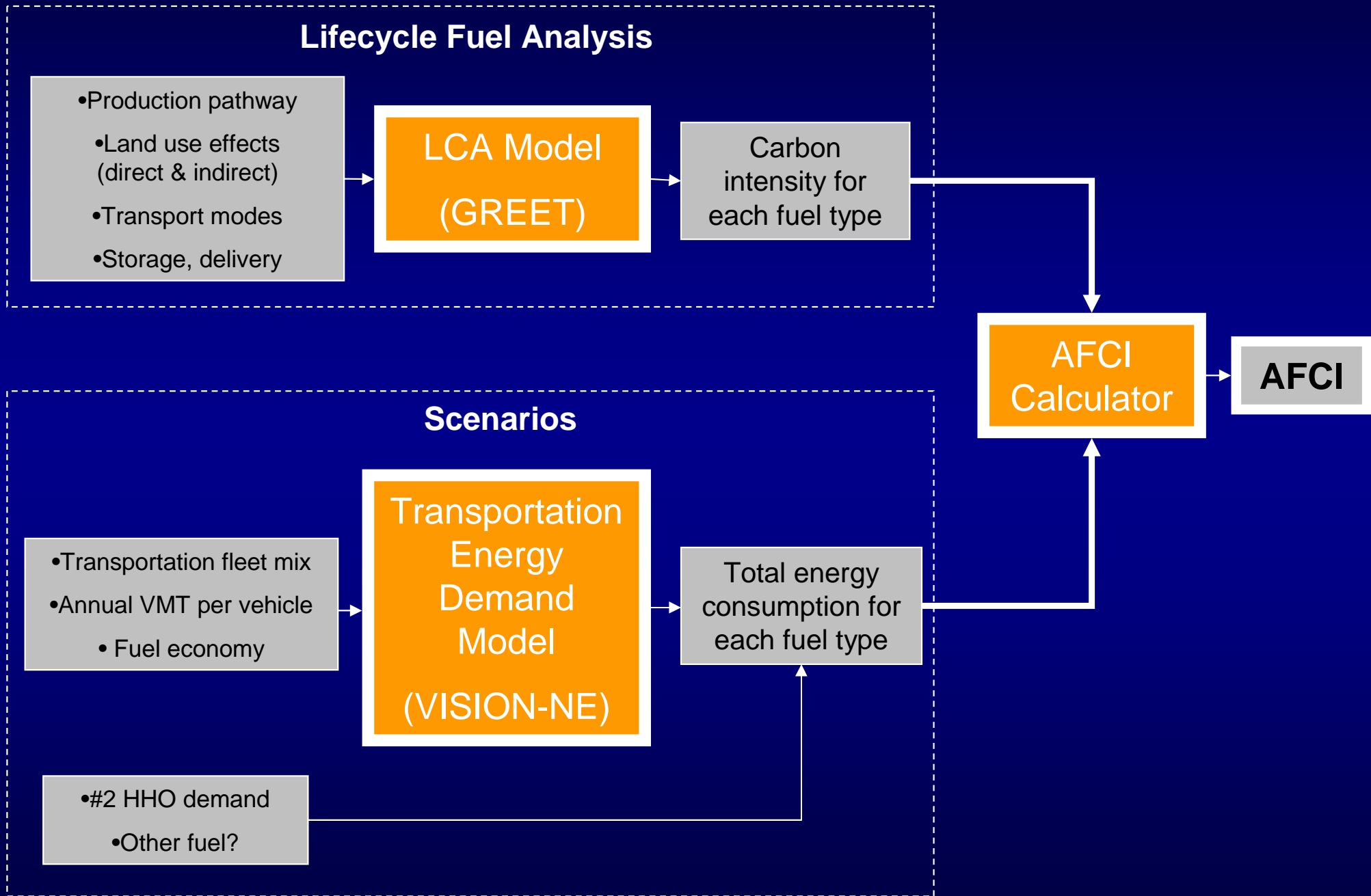
Transportation Energy Demand Model
(VISION-NE)

Total energy consumption for each fuel type

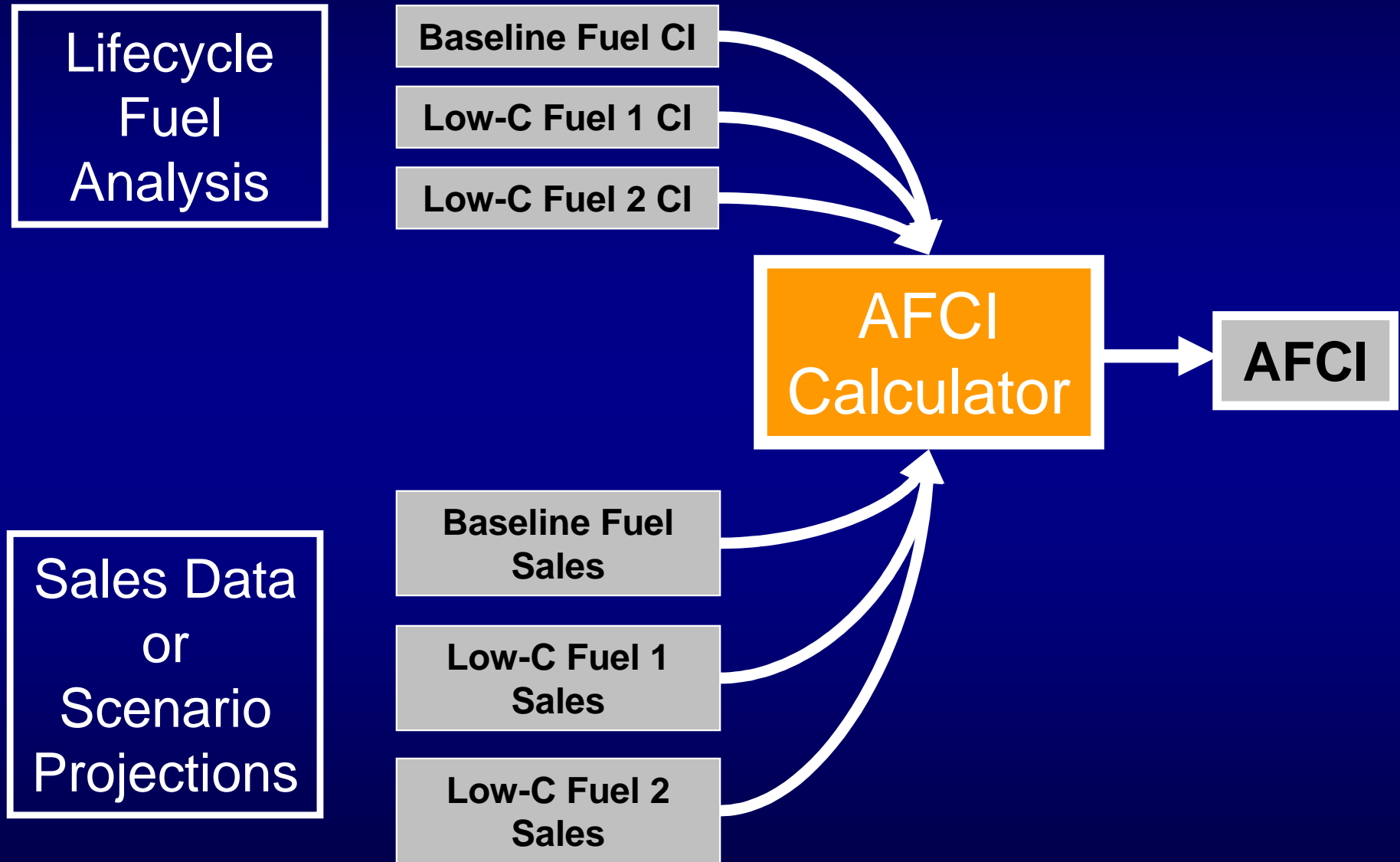
- #2 HHO demand
- Other fuel?

AFCI Calculator

AFCI



AFCI Calculator



AFCI Calculator

- AFCI is a *weighted average* of the CI values of every fuel in the mix.

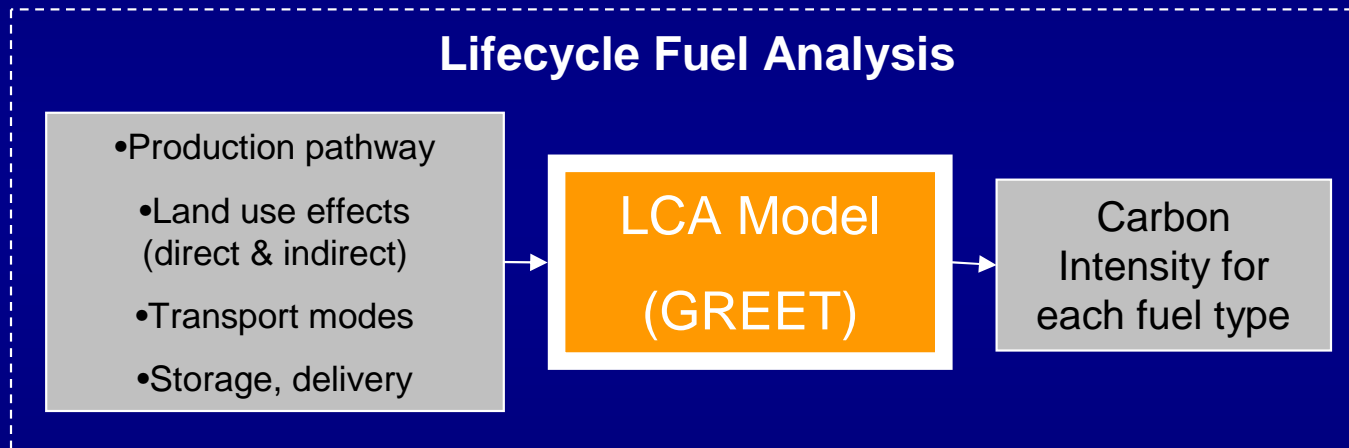
- Example:

- 100 MJ of gasoline at 95 g/MJ

- 20 MJ of low-C substitute at 50 g/MJ:

- AFCI =
$$\frac{(100 * 95) + (20 * 50)}{100 + 20} = 88 \text{ g/MJ}$$

Analytical Methods: Overview



GREET Lifecycle Model

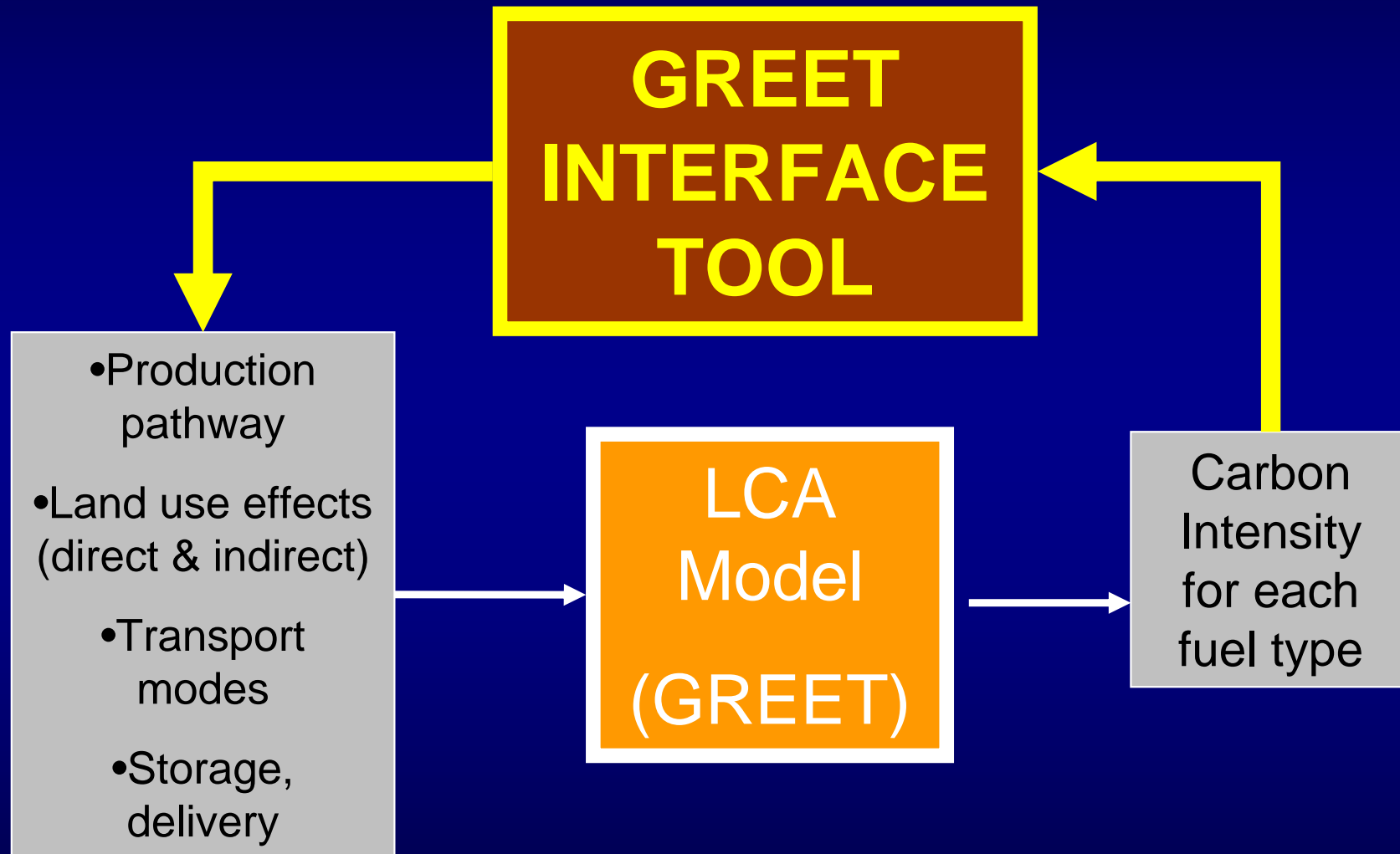
- Greenhouse Gases, Regulated Emissions and Energy Use in Transportation*
- Excel spreadsheet model
- Calculates CO₂-equivalent GHG and criteria emission factors (g/mmBtu) for numerous fuel pathways
- Developed and maintained by Argonne National Laboratory (US DOE)
- Basis for CARB and USEPA lifecycle carbon intensity determination
- GREET is both a calculation methodology *and* a large set of input data
 - Methodology is valid for any region
 - Many default inputs are national averages; user can substitute state- or region-specific data

*http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

GREET Interface Tool

- GREET is very complicated to use, but:
 - an LCFS program requires modification of only a (relatively) small number of inputs...
 - ...and only one key output for each fuel pathway.
- Life Cycle Associates, LLC has developed a GREET interface tool to “poke” the key input parameters into GREET and “peek” at the results.
- This tool can be used as-is to assist states and other stakeholders in assessing CI values for selected fuel pathways.
- Could be developed further for use as a “compliance calculator” for regulatory purposes.

Lifecycle Fuel Analysis



CI Values for Selected NE Fuel Pathways (Draft Results):

Pathway	Carbon Intensity (gCO ₂ e/MJ)
Denatured Corn Ethanol	72.5 *
Soy Biodiesel	35 *
Forest Residue EtOH: (Fermentation)	1.8
Forest Residue EtOH: (Gasification)	15
Conventional Gasoline	92.7
Reformulated gasoline blendstock (RBOB)	96.7
Oilsand RBOB	107
Ultra-Low-Sulfur Diesel (ULSD)	93
Oilsand ULSD	104

* Does not include effects of land-use change

CI Values for Selected NE Fuel Pathways (Draft Results):

Pathway	Carbon Intensity (gCO ₂ e/MJ)
Compressed Natural Gas	73.4 *
Liquefied Natural Gas	78 *
Liquefied Petroleum Gas (LPG)	86.9
Natural gas for heating	71.4 *
ULSD for heating	91.2
Forest-Residue Pellets	24.2 *
Electricity for EVs (100% NG)	180.4 *
Electricity for EVs (100% Coal)	344 *
Electricity for EVs (100% Renewables)	0

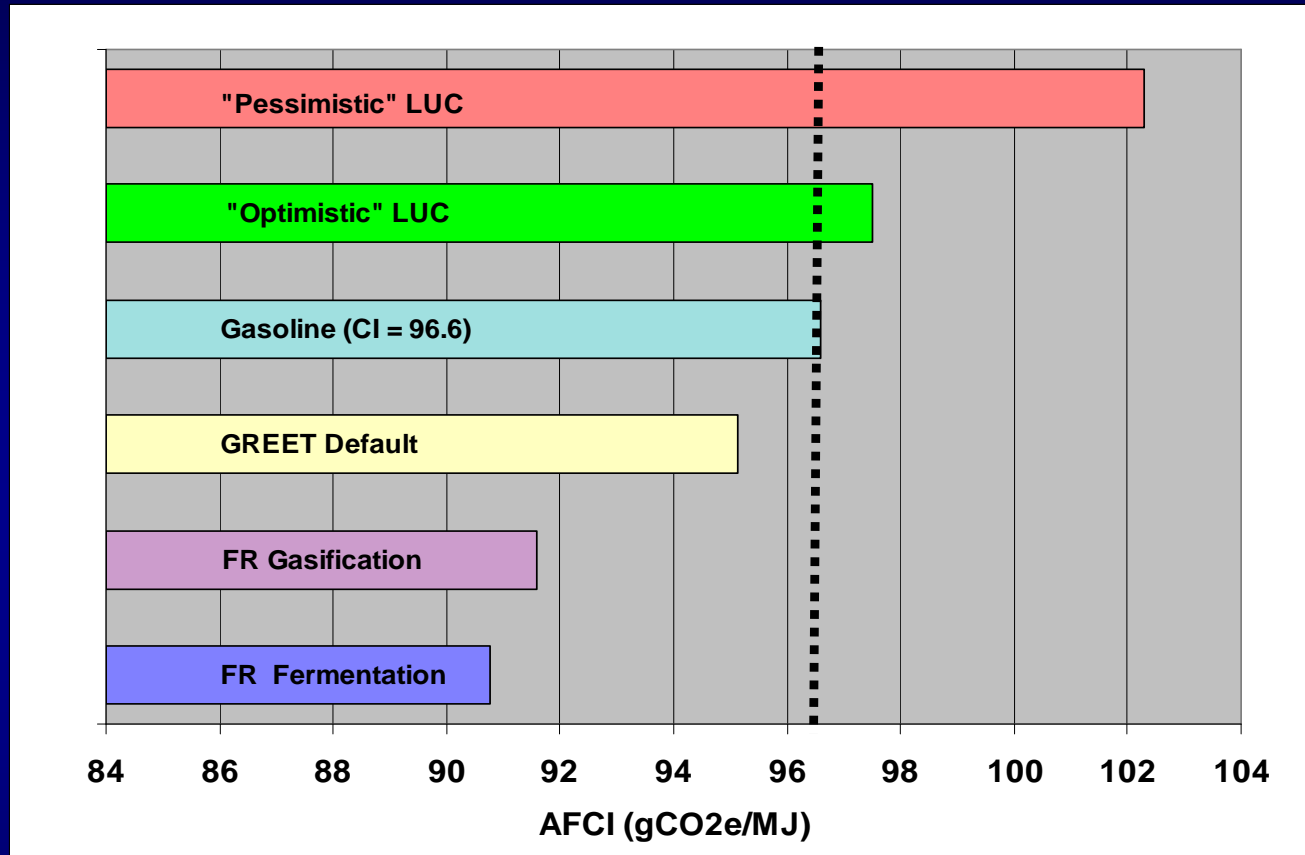
* Values not adjusted for end-use efficiency.

Meeting a Low-Carbon Fuel Standard: Gasoline Baseline

Potential compliance options might include:

- Low-carbon ethanol
 - Production: cellulosic fermentation, gasification, conventional, other?
 - Feedstocks: Forest products and residues, corn, sugar, switchgrass, MSW, other?
- Natural gas
 - Pipeline, imported LNG, landfill gas, other?
- Electricity in battery-electric or plug-in hybrid vehicles?
- Light-duty diesel?
- Hydrogen?
- Other?

Effect of Ethanol CI on Gasoline AFCl: E10 Region-wide (Draft Results)



CI values for ethanol under each scenario:

Pessimistic LUC: 190

Optimistic LUC: 110

Gasoline-equivalent 97

GREET Default 73

FR → Gasification 15

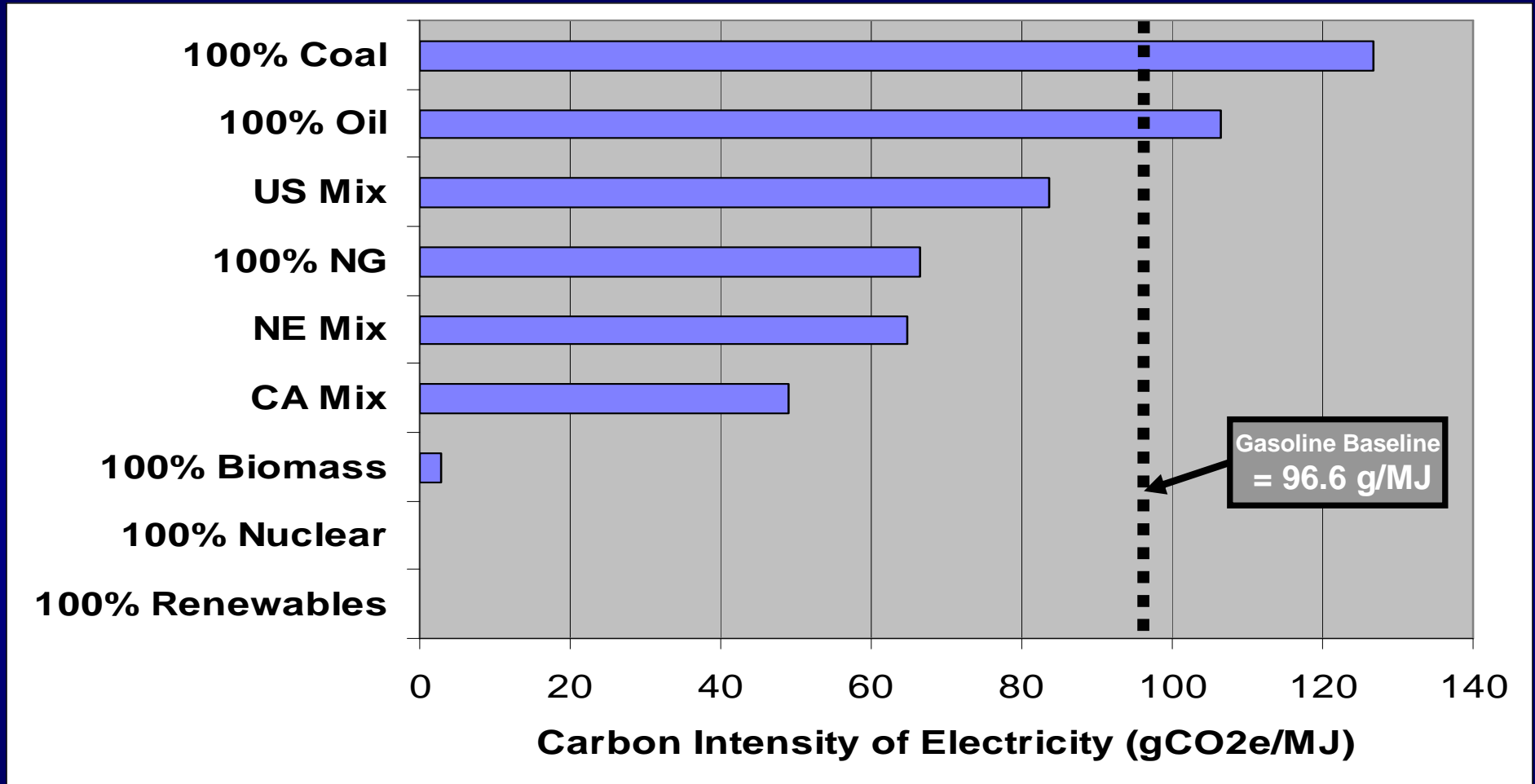
FR → Fermentation 1.8

Assumes 10% ethanol by volume in all gasoline, and no other fuels contribute to gasoline AFCl

"Optimistic" and "Pessimistic" estimates of land-use change based on "Draft Calculation of Land Use Change for Bio-fuels production utilized GTAP model (Global Trade Analysis Project)" presented 6-30-08 to ARB by University of California - Berkeley (<http://www.arb.ca.gov/fuels/lcfs/lcfs.htm>). The study considered four scenarios. We reference the 'best' and 'worst' of the four cases, which do not necessarily represent upper and lower bounds.

Effect of Grid Resource Mix on Electricity CI (Draft Results)

EV energy consumption = 313 Wh/mi; Baseline vehicle fuel economy = 41.37mpg



REET-default grid profiles:

- US Mix: 2.7% oil, 18.9% NG, 50.7% coal, 18.7% nuclear, 1.3% biomass, 7.7% other (hydro & renewables)
- NE Mix: 6.6% oil, 20.9% NG, 32.2% coal, 31.0% nuclear, 3.6% biomass, 5.7% other
- CA Mix: 0.7% oil, 41.5% NG, 14.6% coal, 18.9% nuclear, 1.7% biomass, 22.6% other

Meeting a Low-Carbon Fuel Standard: Diesel Baseline

Potential compliance options might include:

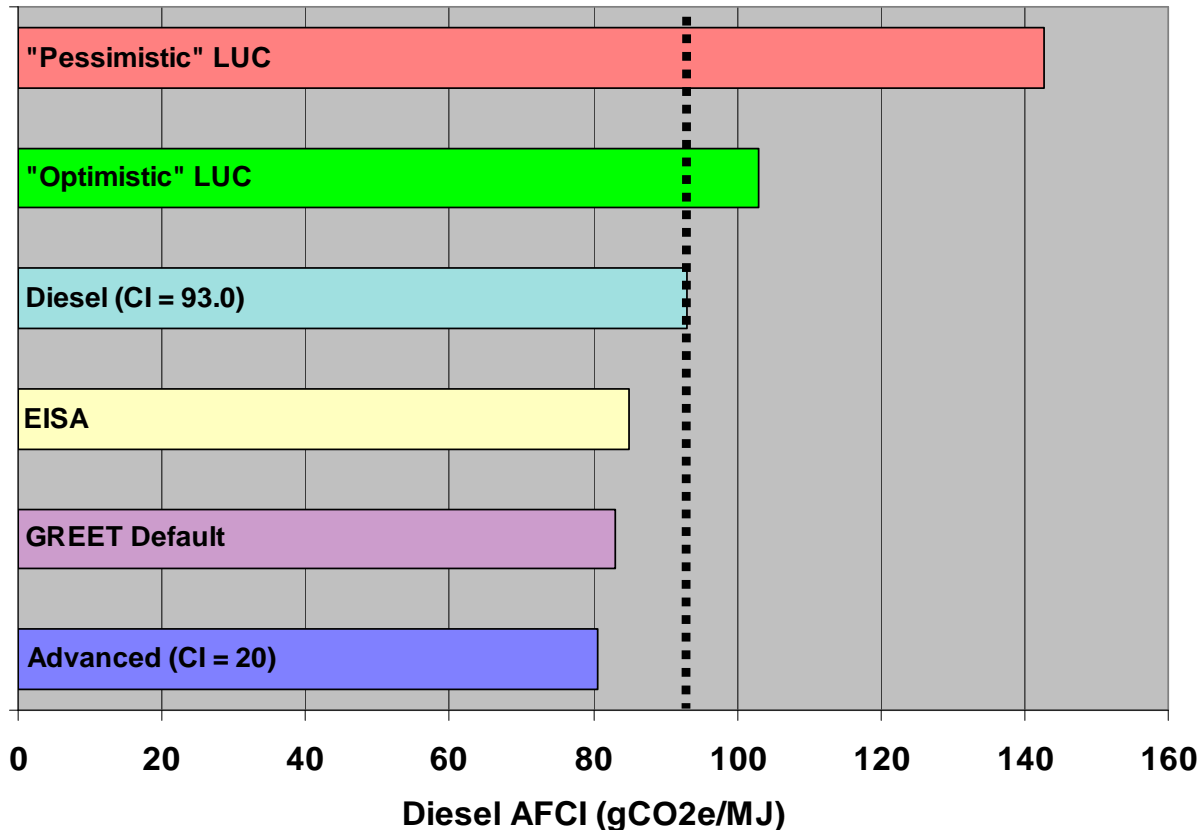
- Vehicle fuels:

- Low-carbon biodiesel
- Renewable diesel
- Natural gas vehicles
- Electricity in battery-electric or plug-in hybrid vehicles
- Hydrogen
- E-diesel
- Other?

- Heating fuels:

- Wood/biomass
- Natural gas
- Other?

Effect of Biodiesel CI on Diesel AFCl: B20 in all Highway Fuel (Draft Results)



CI values for biodiesel under each scenario:

Pessimistic LUC: 390

Optimistic LUC: 150

Diesel-equivalent 93

EISA 47

GREET Default 35

"Advanced" 20

Assumes 20% biodiesel in all highway diesel fuel, and no other fuels contribute to diesel AFCl. Total biodiesel demand is 820 mgal. Non-highway fuels not counted toward baseline AFCl. "Advanced" biodiesel CI chosen arbitrarily and shown for illustration.

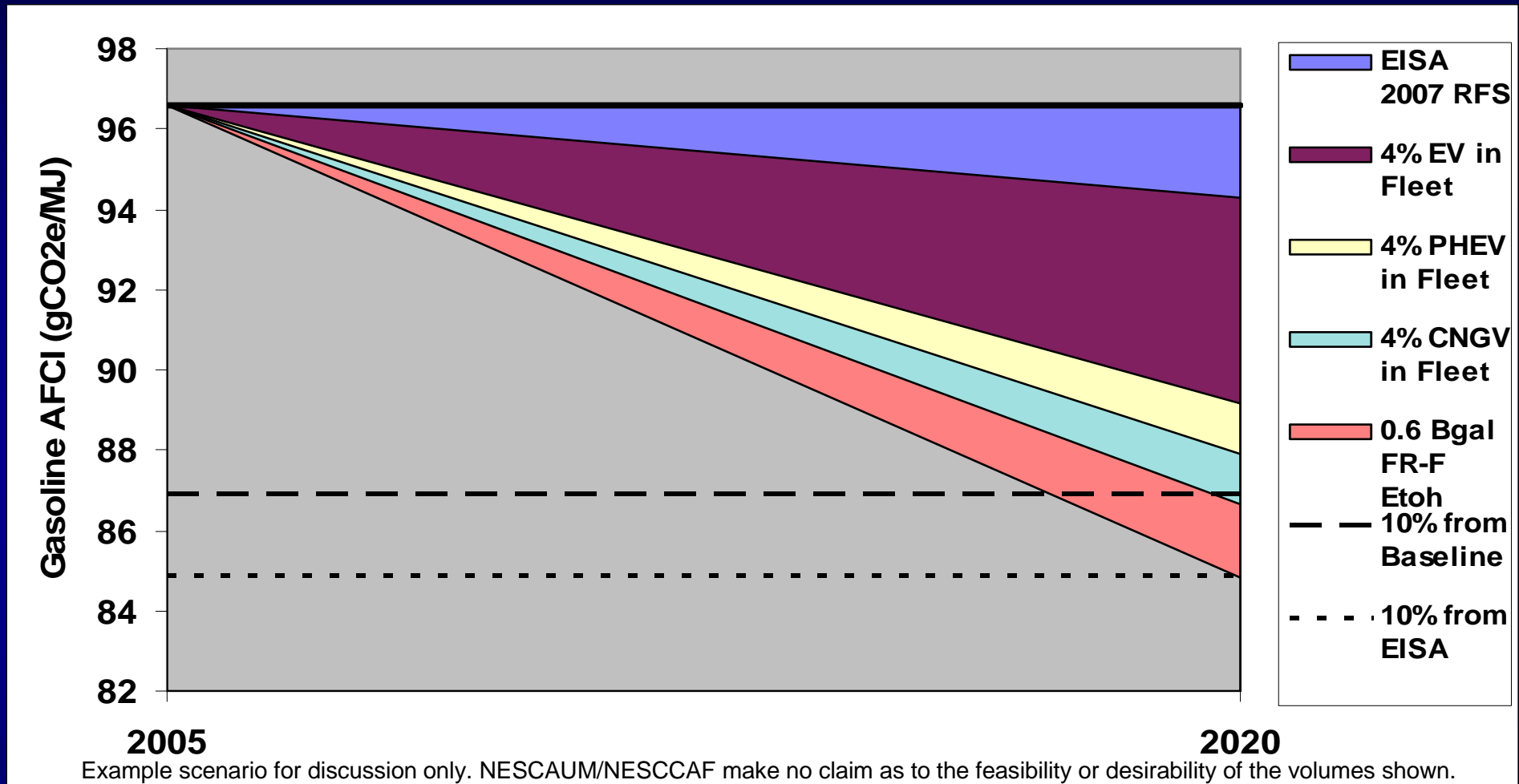
"Optimistic" and "Pessimistic" estimates of land-use change based on "Draft Calculation of Land Use Change for Bio-fuels production utilized GTAP model (Global Trade Analysis Project)" presented 6-30-08 to ARB by University of California - Berkeley (<http://www.arb.ca.gov/fuels/lcfs/lcfs.htm>). The study considered four scenarios for corn ethanol production. We reference the 'best' and 'worst' of the four cases, and we assume that the LUC impacts for biodiesel are four times greater than for ethanol, reflecting an average energy yield per acre for soybeans of roughly one fourth that for corn. Examples are shown for illustrative purposes only.

Values do not necessarily represent upper and lower bounds.

Example Compliance Scenarios:

- The following scenarios are *examples only*.
- Provided to illustrate the AFCl impacts of various sets of assumptions
- NESCAUM / NESCCAF is not advocating for any one or group of fuels or fuel pathways.

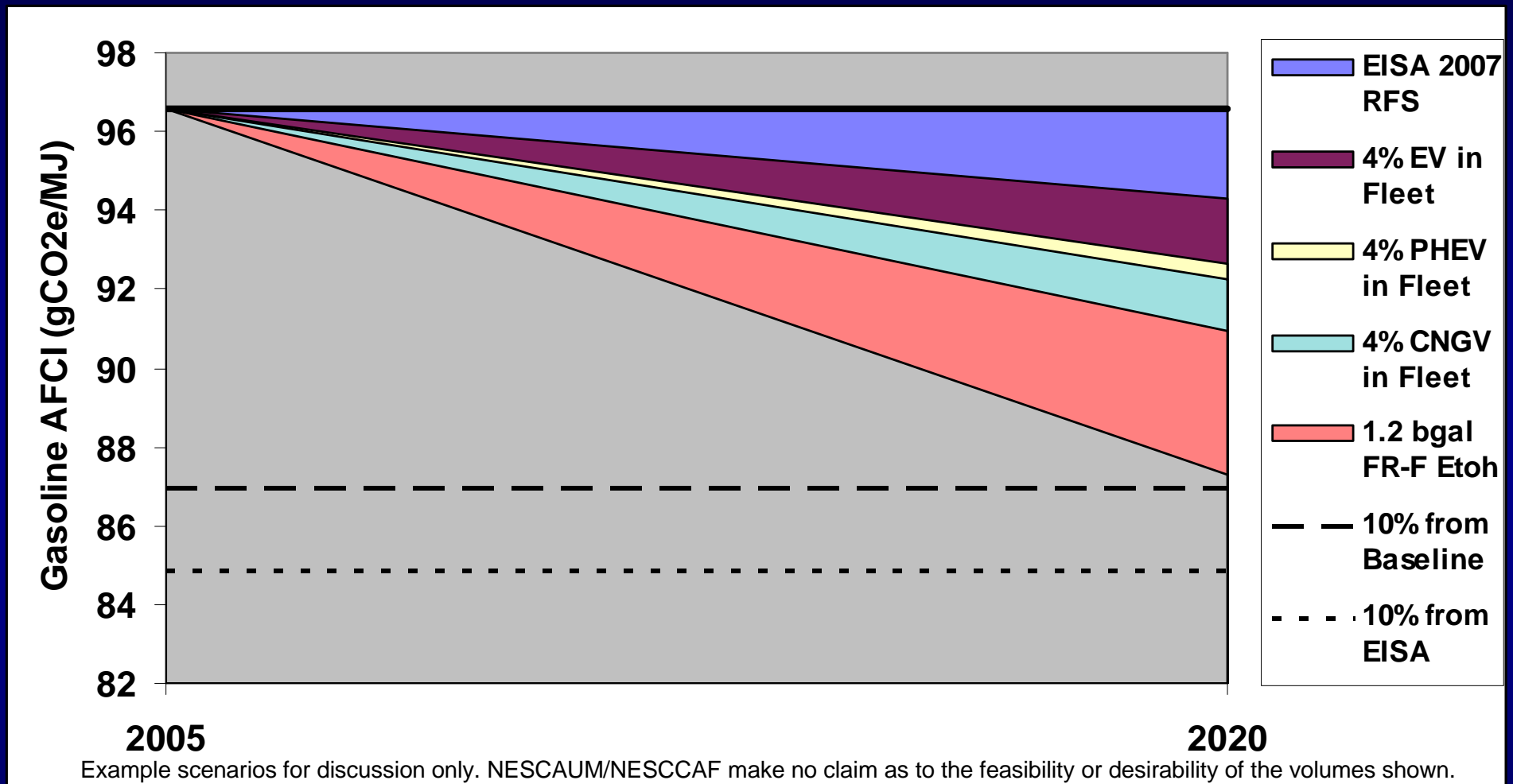
Example Compliance Scenario (Draft Results): 100% Renewables for EV and PHEV



Assumptions:

- BEV and PHEV electric energy consumption = 313 Wh/mi
- Baseline vehicle fuel economy = 41.37 mpg.
- 4% fleet penetration in 2020; new vehicle sales increase linearly from 1.2% in 2011 to 12% in 2020.
- FR-F Etoh = Ethanol produced from forest residue via cellulosic fermentation.
- CI values (gCO₂e/MJ): Electricity for BEVs and PHEVs: 0; CNG: 73.4; FR-F EtOH = 1.8

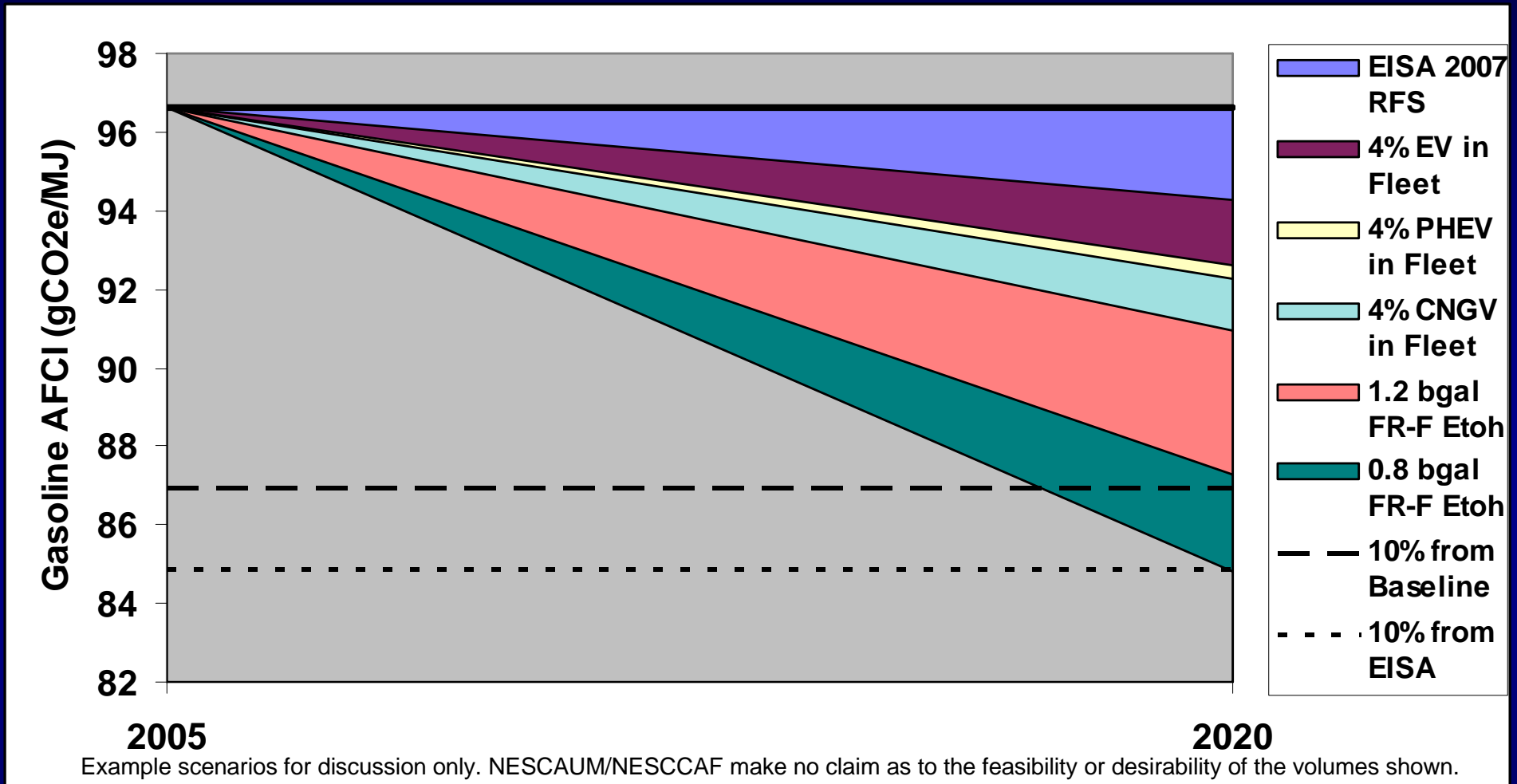
Example Compliance Scenario (Draft Results): 100% NG Electricity Generation for EV and PHEV



Assumptions:

- BEV and PHEV electric energy consumption = 313 Wh/mi
- Baseline vehicle fuel economy = 41.37 mpg.
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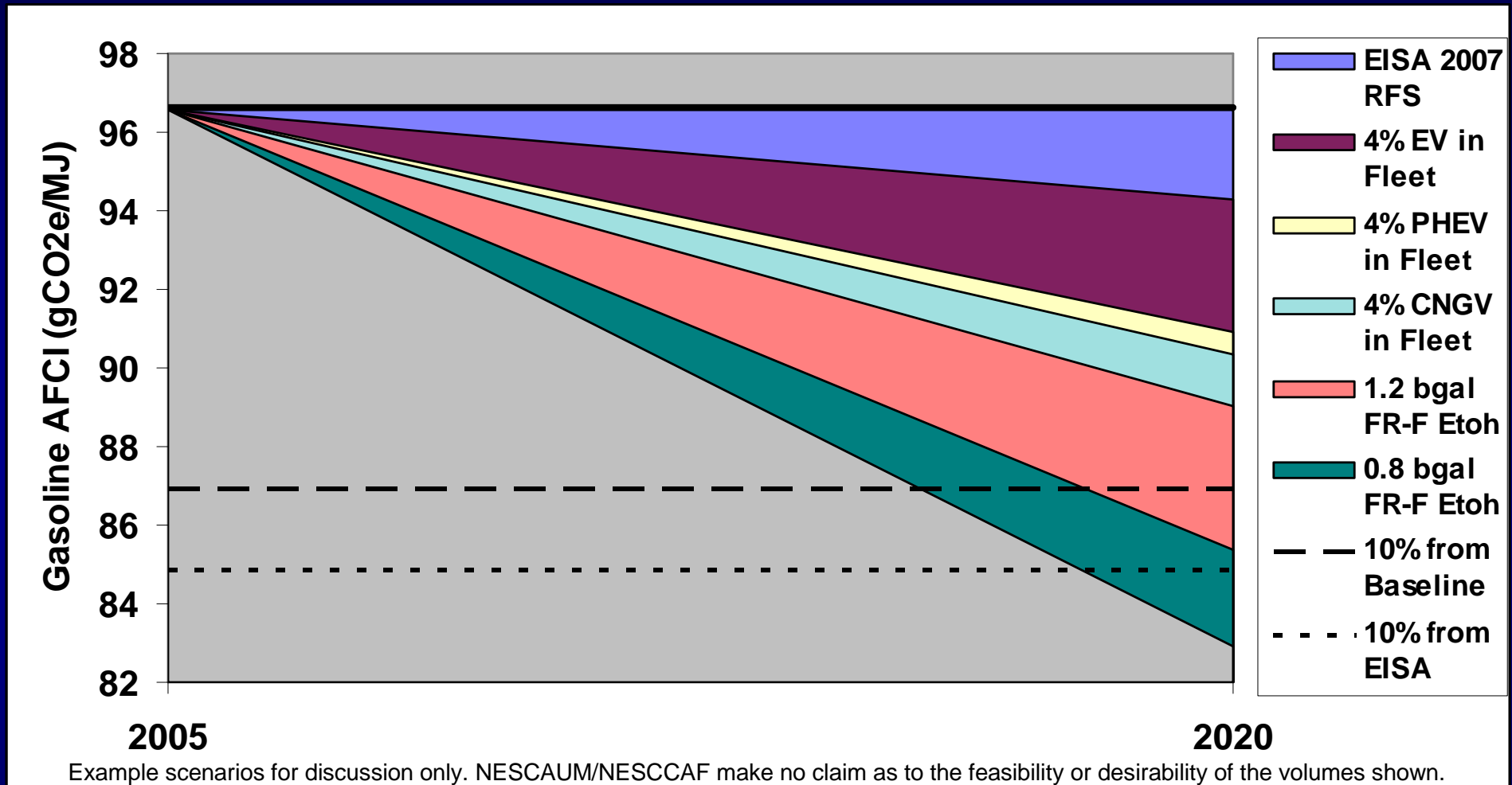
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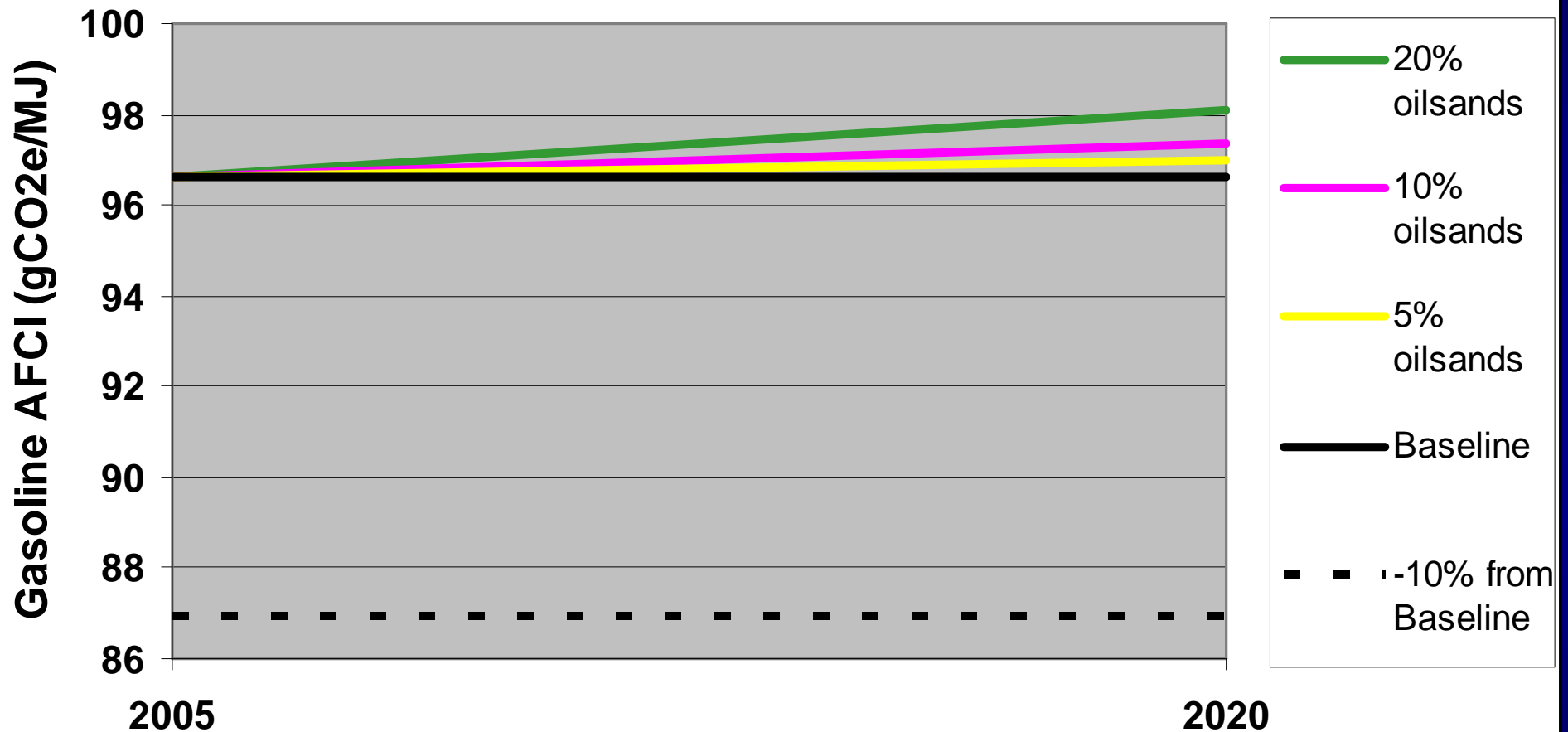
Example Compliance Scenario (Draft Results): 100% NG Electricity Generation for EV and PHEV



Assumptions:

- BEV energy consumption = 167 Wh/mi; PHEV electric energy consumption = 250 Wh/mi.
- Baseline vehicle fuel economy = 41.37 mpg.
- 4% fleet penetration in 2020; new vehicle sales increase linearly from 1.2% in 2011 to 12% in 2020.
- FR-F Etoh = Ethanol produced from forest residue via cellulosic fermentation.
- CI values (gCO₂e/MJ): Electricity for BEVs and PHEVs: 0; CNG: 73.4; FR-F EtOH = 1.8

Effect of Oilsands on Gasoline AFCI (Draft Results)

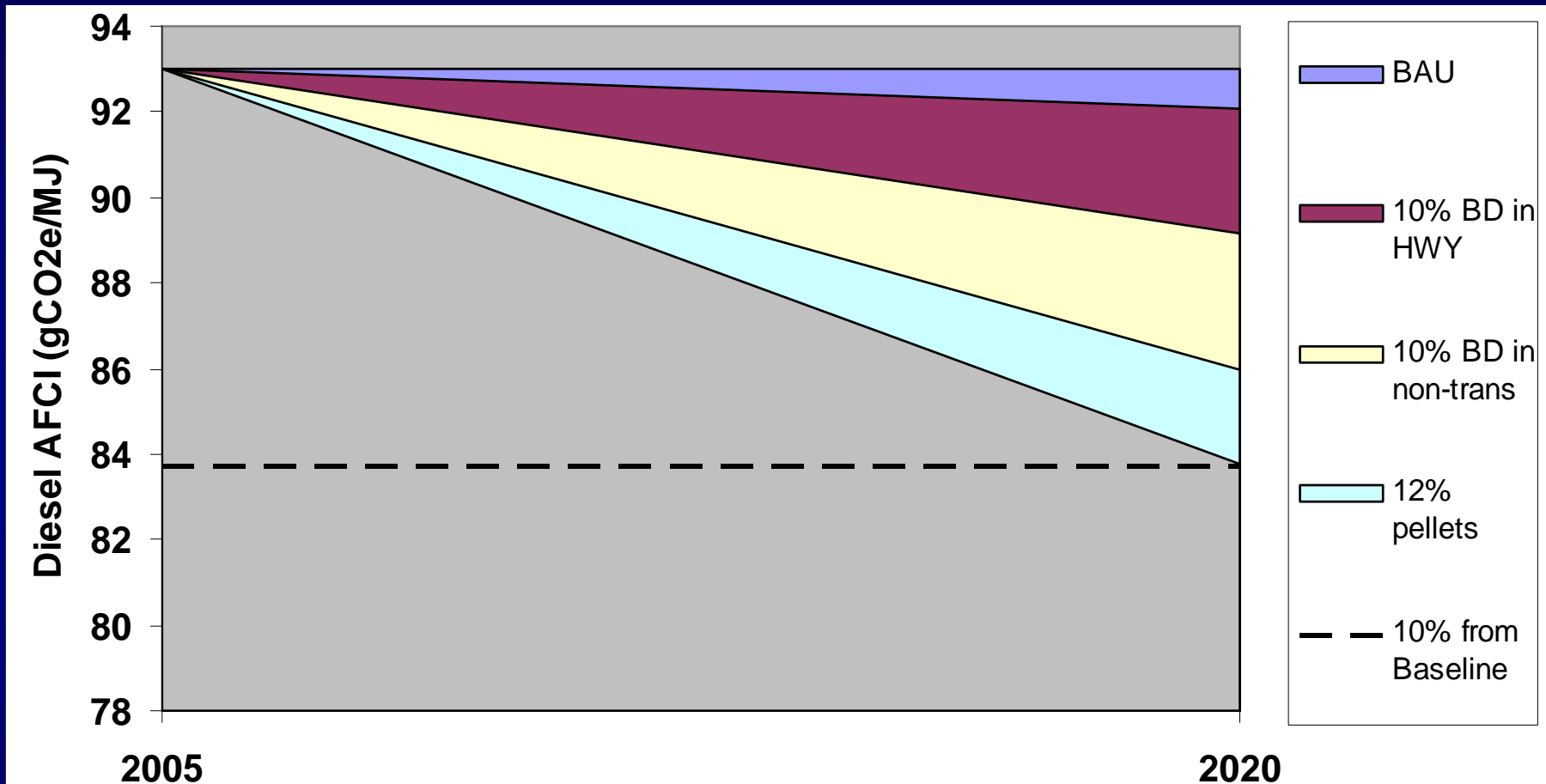


Example scenarios for discussion only. NESCAUM/NESCCAF make no claim as to the feasibility or desirability of the volumes shown.

Oilsand Gasoline CI = 105 gCO₂e/MJ

Example Compliance Scenario (Draft Results): Diesel AFCI

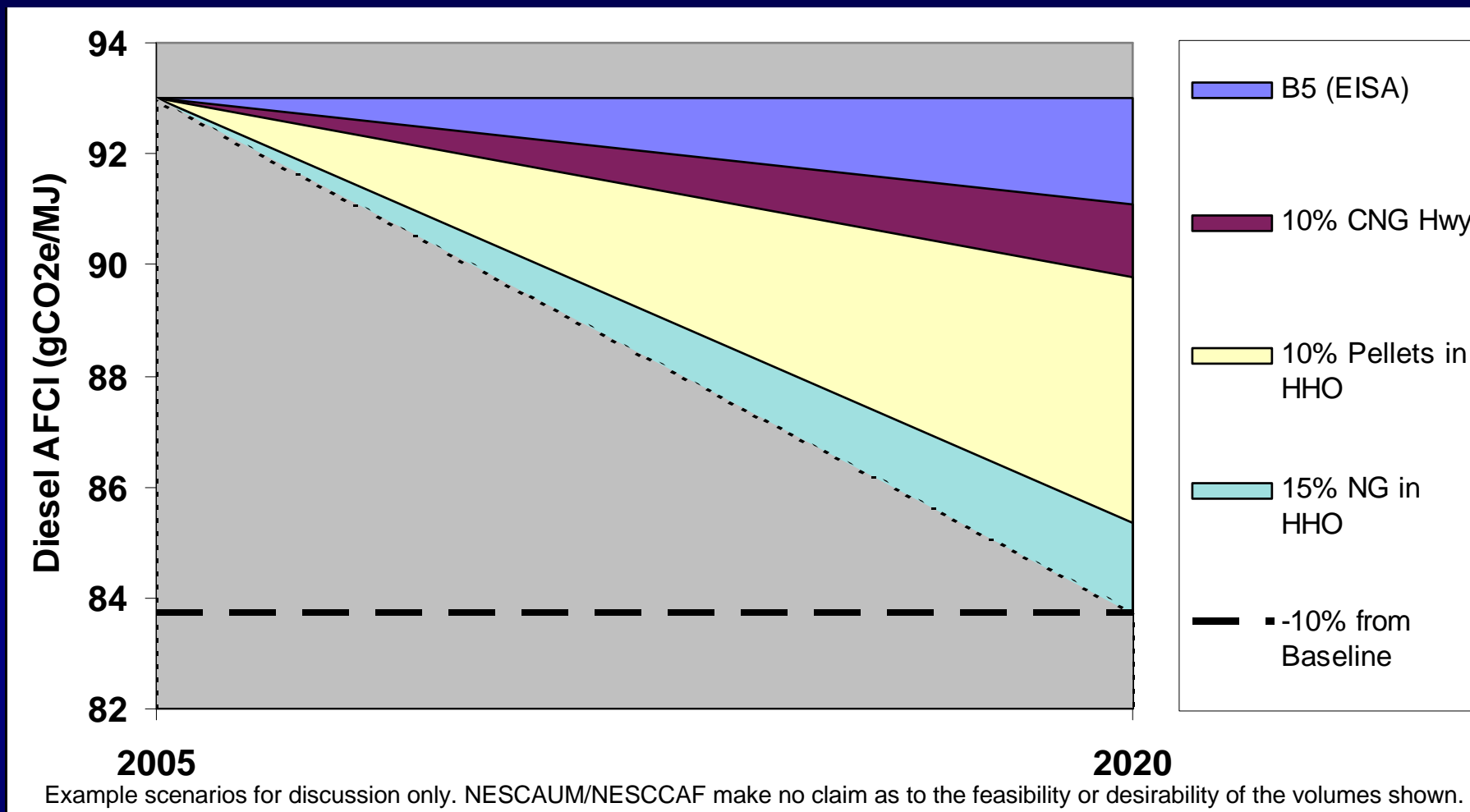
Advanced Biodiesel (CI = 20) and Wood Pellets for Home Heating



Example scenarios for discussion only. NESCAUM/NESCCAF make no claim as to the feasibility or desirability of the volumes shown.

- BAU decline in AFCI due to lower CI of #2 HHO compared to ULSD
- 10% BD in highway fuel = 408 Mgal in 2020; 10% BD in non-trans = 470 Mgal in 2020;
- 12% pellets = 43.6 quadrillion BTU; 3.2 million tons of pellets; enough for 530,000 homes; 55% of potential regional biomass supply. AFCI reduction based on FR Pellet CI of 24.2 gCO₂e/MJ. Actual pellet production is likely to use mill-residue or new-growth feedstocks, each resulting in lower pellet CI, and thus greater AFCI reductions than shown.

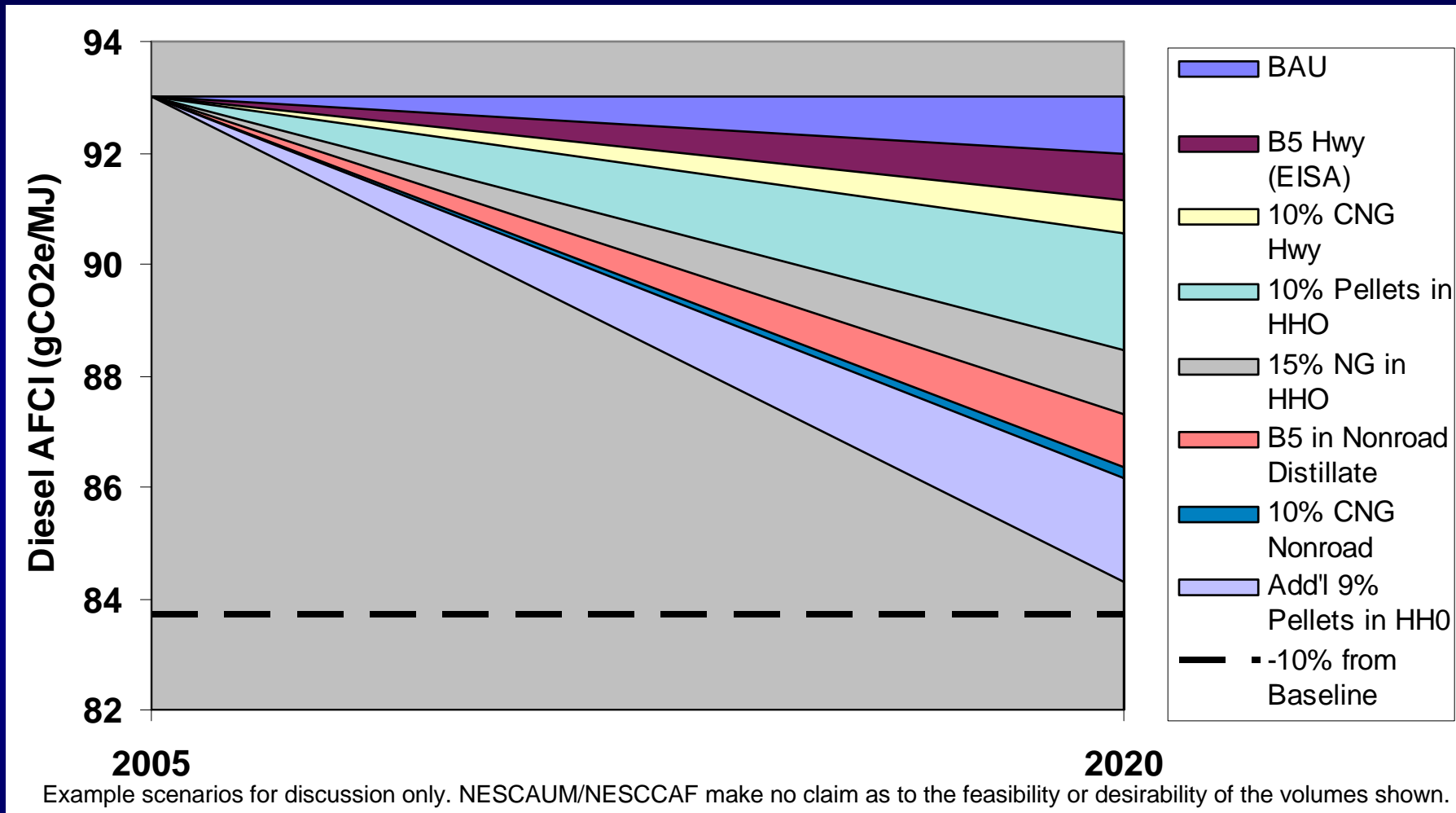
Example Compliance Scenario: Diesel AFCI (Draft Results) Baseline = Highway Diesel Only



- Heating fuels not counted towards baseline but allowed to generate credits.
- 5% BD lin highway fuel = 200 Mgal in 2020; Assume 50% CI reduction compared to ULSD.
- 10% CNG in highway diesel = 54.2 quadrillion btu, displacing 420 Mgal in 2020
- 10% pellets = 36.3 quadrillion BTU; 2.7 million tons of pellets; enough for 440,000 homes; 46% of total potential regional biomass supply. AFCI reduction based on FR Pellet CI of 24.2 gCO₂e/MJ. Actual pellet production is likely to use mill-residue or new-growth feedstocks, each resulting in lower pellet CI, and thus greater AFCI reductions than shown.

Example Compliance Scenario: Diesel AFCI

Baseline Includes All Distillate (Highway, Nonroad and HHO)



- BAU decline in AFCI due to inclusion of thermal at lower CI
- 5% BD in highway fuel = 200 Mgal in 2020; 5% BD in non-trans = 220 Mgal in 2020;
- 19% pellets = 78.6 quadrillion BTU; 5.7 million tons of pellets; enough for 960,000 homes; ~100% of potential regional biomass supply. AFCI reduction based on FR Pellet CI of 24.2 gCO₂e/MJ. Actual pellet production is likely to use mill-residue or new-growth feedstocks, each resulting in lower pellet CI, and thus greater AFCI reductions than shown.

Thank you!

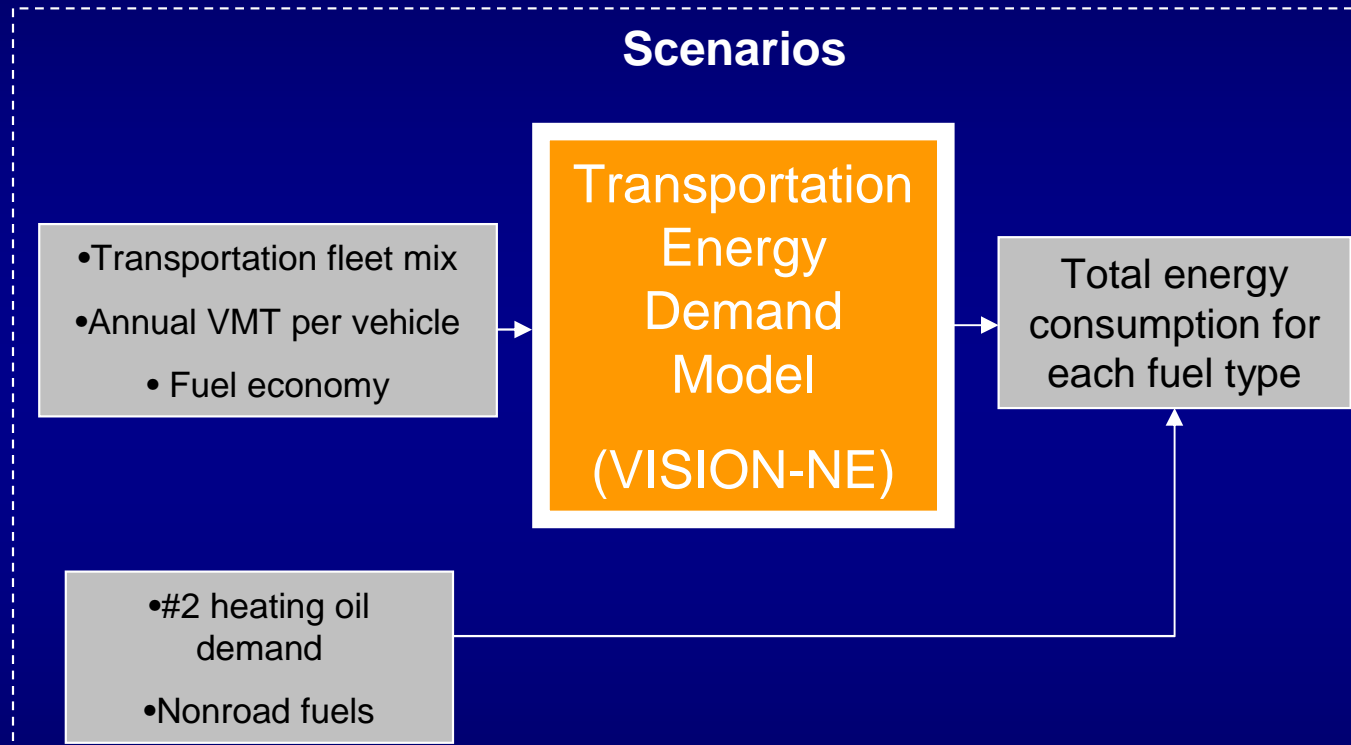
Questions or comments please contact

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Backup Slides

Analytical Methods: Overview

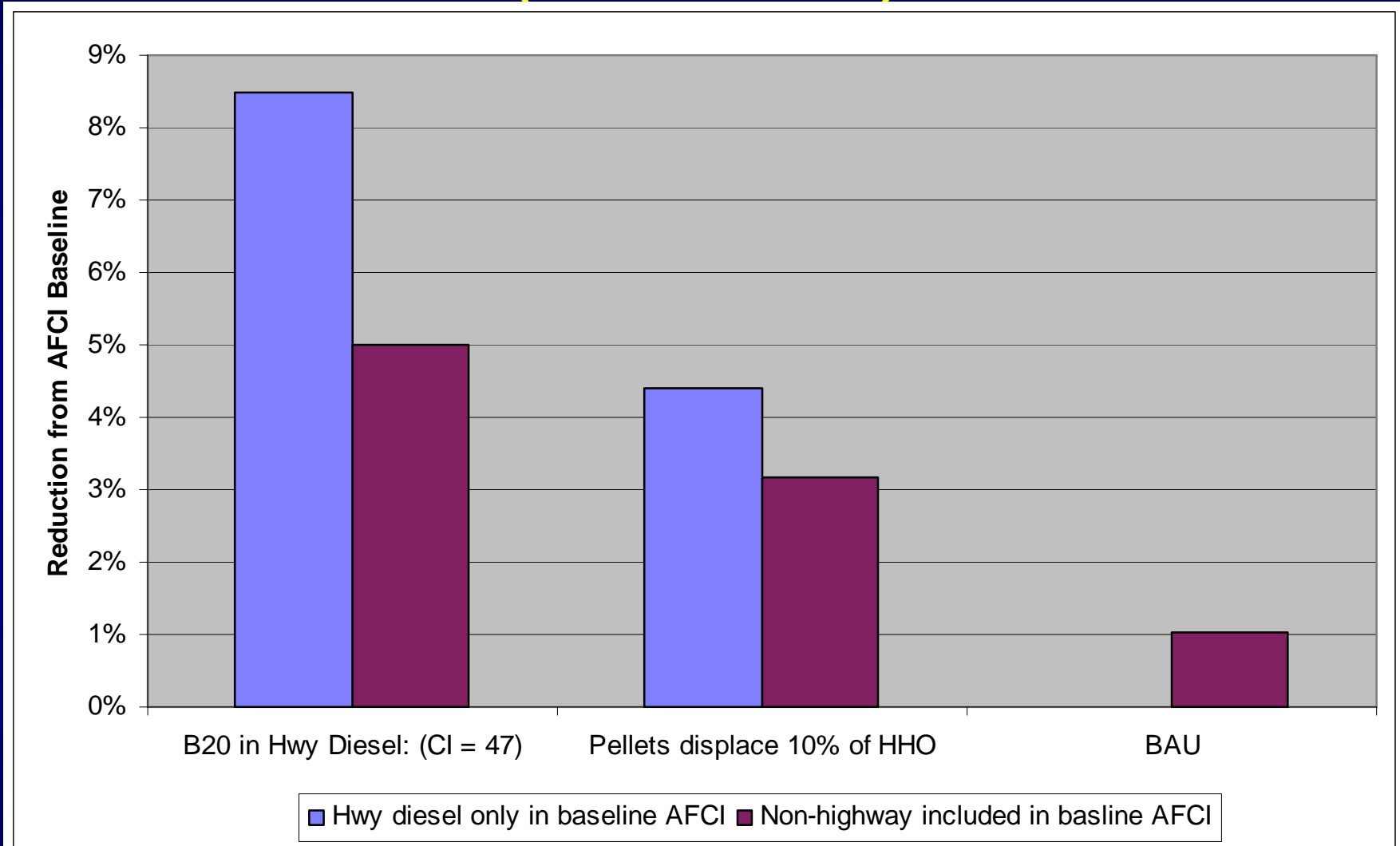


VISION-NE Energy Demand Model

- Based on VISION* transportation fleet turnover model developed and maintained by Argonne National Lab (US DOE)
 - National data, highway vehicles only
- Excel spreadsheet model
- Enables demand projections for various fleet and fuel penetration scenarios
- VISION-NE includes non-transportation demand for northeast
 - Home heating oil
 - Nonroad gasoline and diesel
- Capable of modeling individual state or region
 - Registry data for NESCAUM region
 - Placeholder data (weighted by population) for other 42 states.
- Integrated with AFCI calculator
- Future versions could be linked to GREET Interface Tool

*http://www.transportation.anl.gov/modeling_simulation/VISION/

Including Non-Highway Fuels in Baseline (Draft Results)



Example scenarios for discussion only. NESCCAF/NESCAUM make no claim as to the feasibility or desirability of the volumes shown.

Fuel for thought:

- Mandatory inclusion or opt-in for non-highway fuel?
 - Nonroad diesel
 - Home-heating oil
- How to calculate credits for opt-in suppliers?
- Define baseline AFCl as single fuel or reflect actual mix?
- How to deal with current-generation biofuels (e.g. corn ethanol)?
- Allow light-duty diesel as compliance option toward gasoline AFCl?

Lifecycle CI Determination: Vehicle Efficiency Adjustments

- Carbon Intensity is defined per energy unit of fuel...
- ... but what if one MJ of a substitute fuel is more (or less) useful than a MJ of the baseline fuel?
- Need to adjust for the efficiency of use, e.g. the number of additional (or fewer) miles a vehicle will travel per energy unit of new fuel versus baseline.
- Depends both on baseline and substitute vehicle or fuel

Lifecycle CI Determination: The special case of Electricity (EVs and PHEVs)

- Significant efficiency adjustment
- Example:
 - A PHEV might consume 313 Wh/mi (when on battery power), equivalent to 107 mpg in terms of energy delivered at the plug.
 - New baseline vehicle in 2020 might get 42 mpg.
 - Then the AFCEI efficiency adjustment would be:

$$42/107 = 0.39$$

- Note this is only part of the story: Electricity CI depends on vehicle efficiency *AND* grid emissions