Designing a Low-Carbon Fuel Standard for the Northeast

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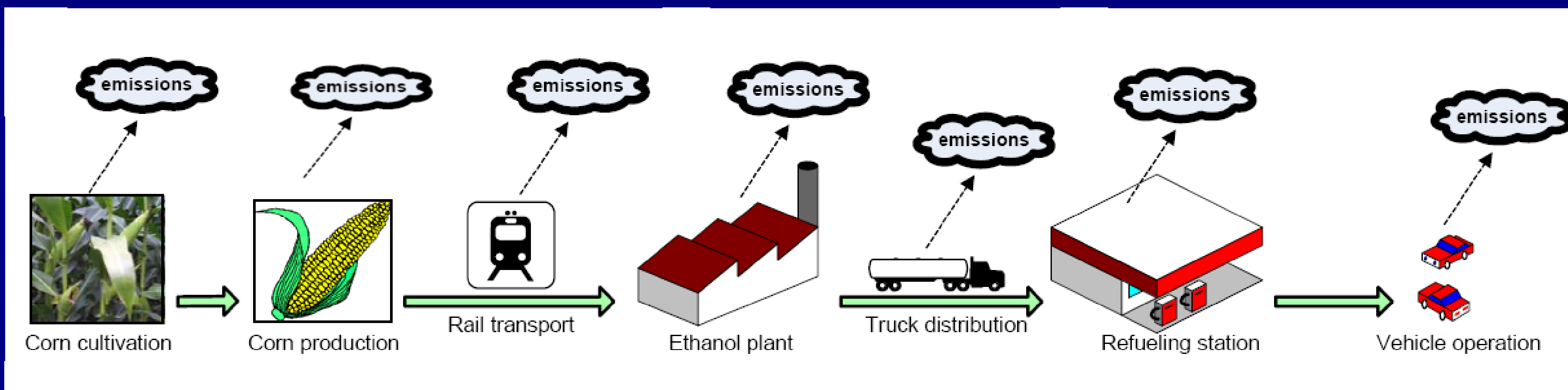
What's "carbon intensity" again?

- A measure of the total CO_2-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

gCO_2e/MJ

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Why "CO_2-equivalent"?

- …to account for all relevant GHG emissions:
  - »CO_2 (GWP = 1)
  - »CH_4 (GWP = 25)
  - »N_20 (GWP = 298)

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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

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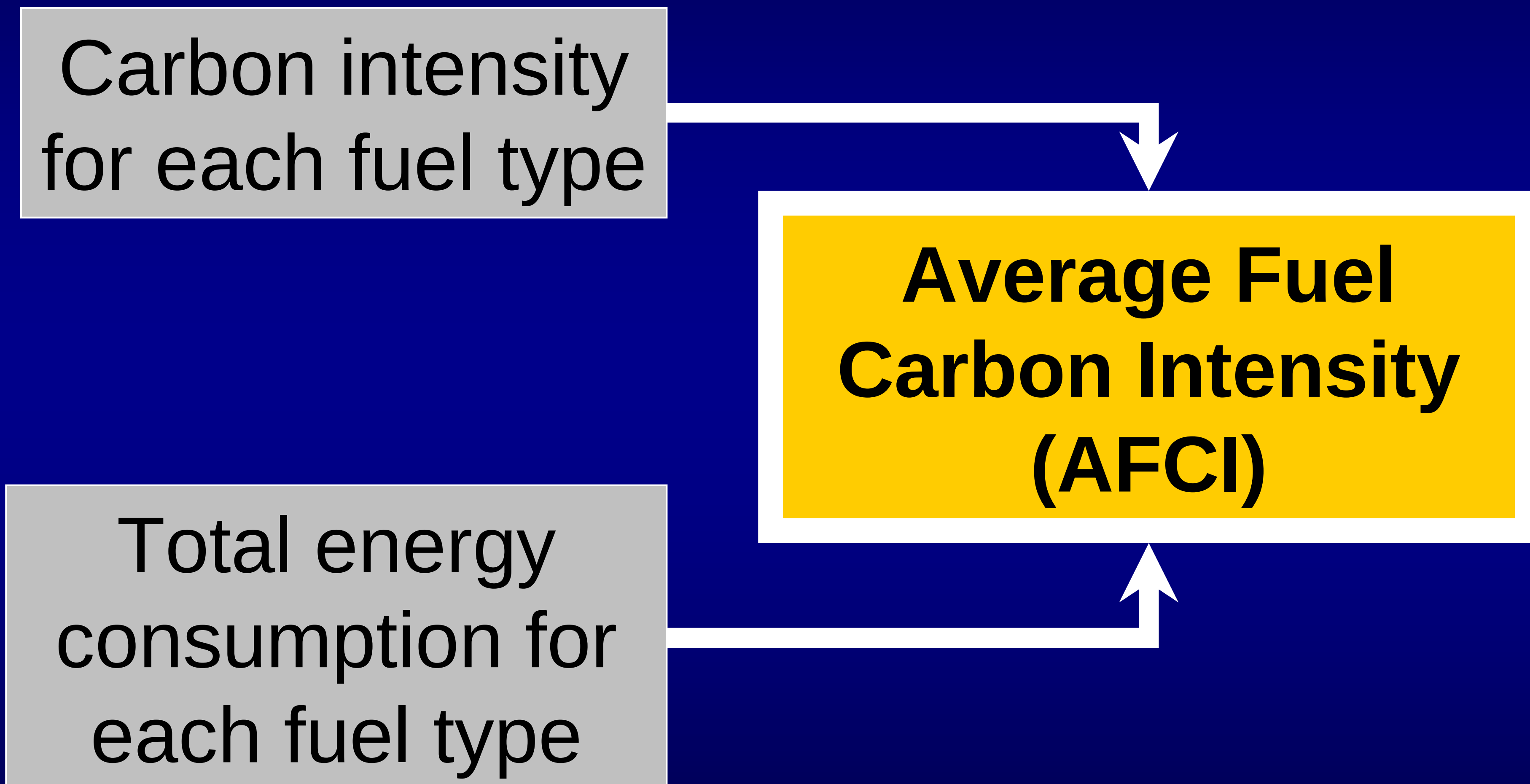
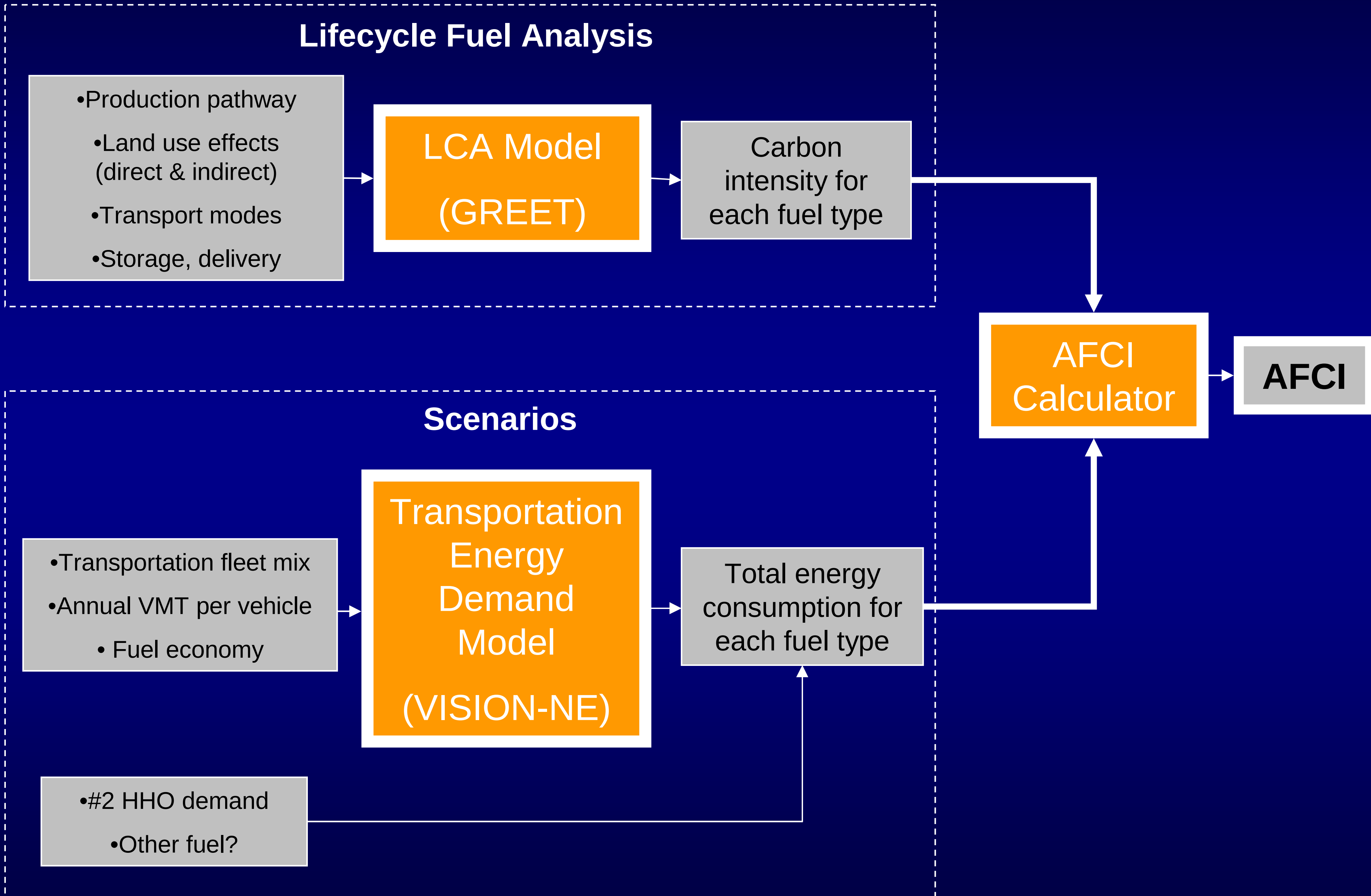
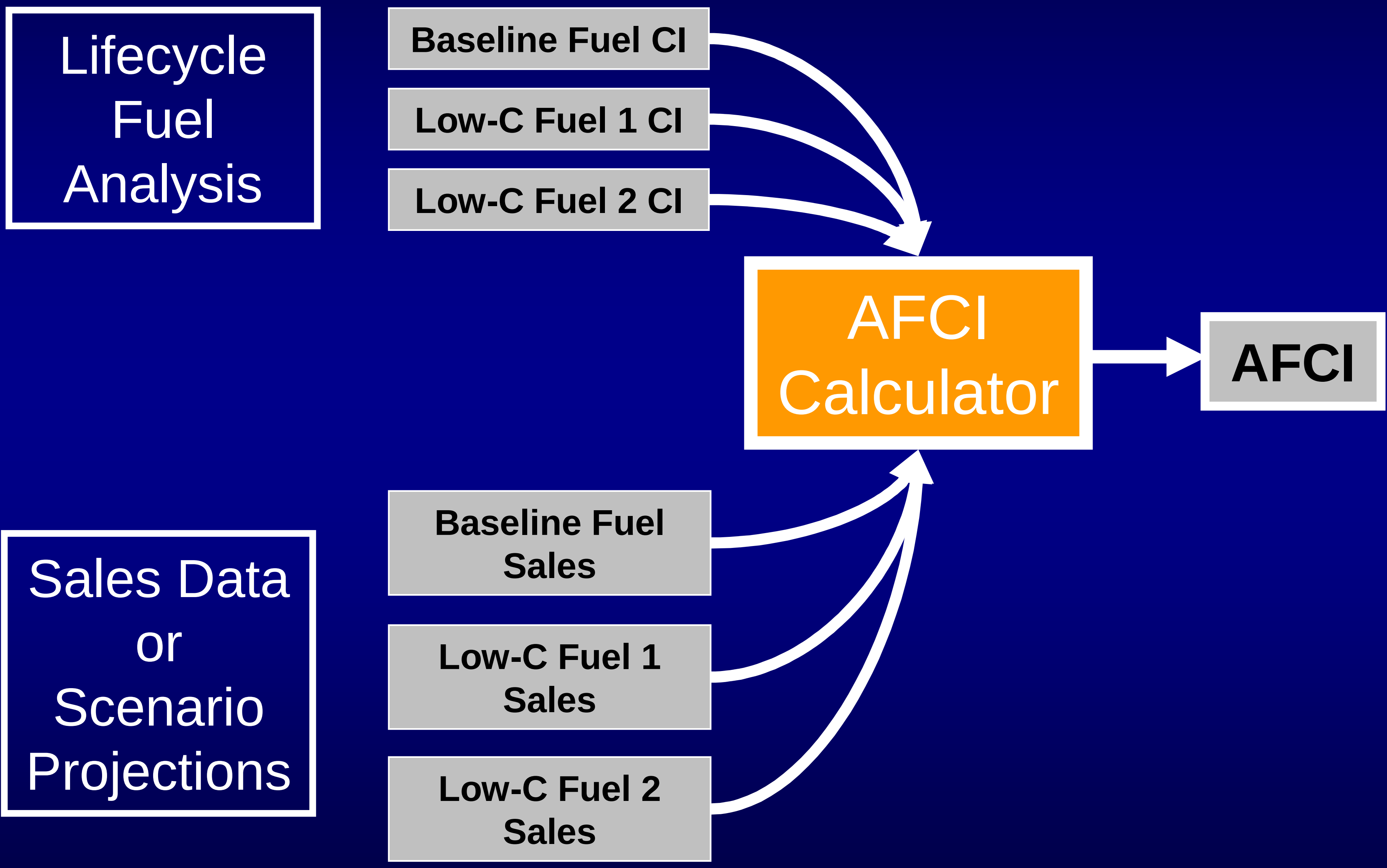
Analytical Methods: Overview



Analytical Methods: Overview



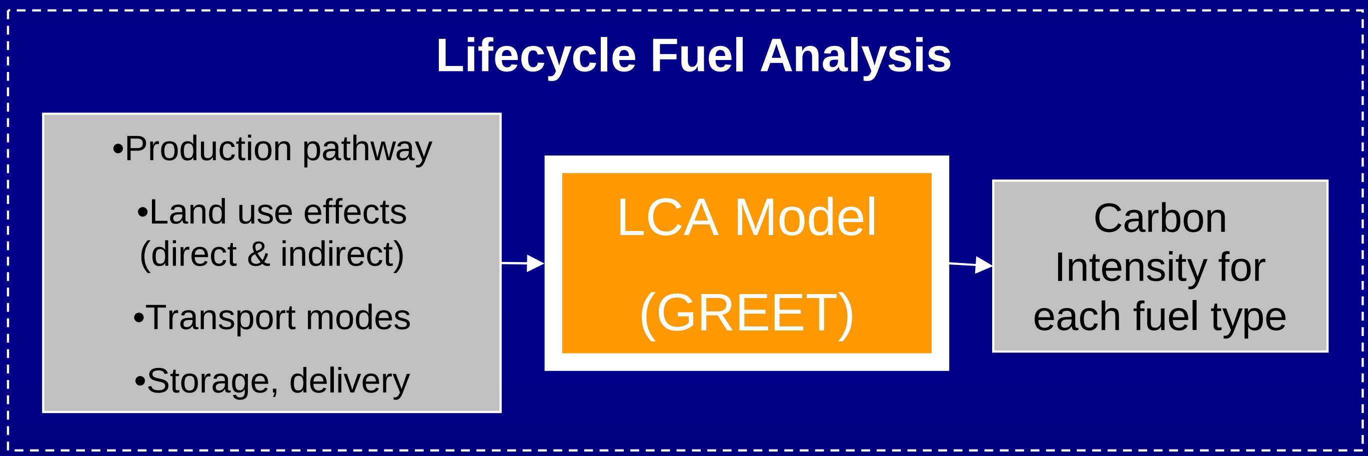
AFCI Calculator



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

Analytical Methods: Overview



GREET Lifecycle Model

- **G**reenhouse Gases, **R**egulated **E**missions and **E**nergy Use in **T**ransportation*
- Excel spreadsheet model
- Calculates CO_2-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**

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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.

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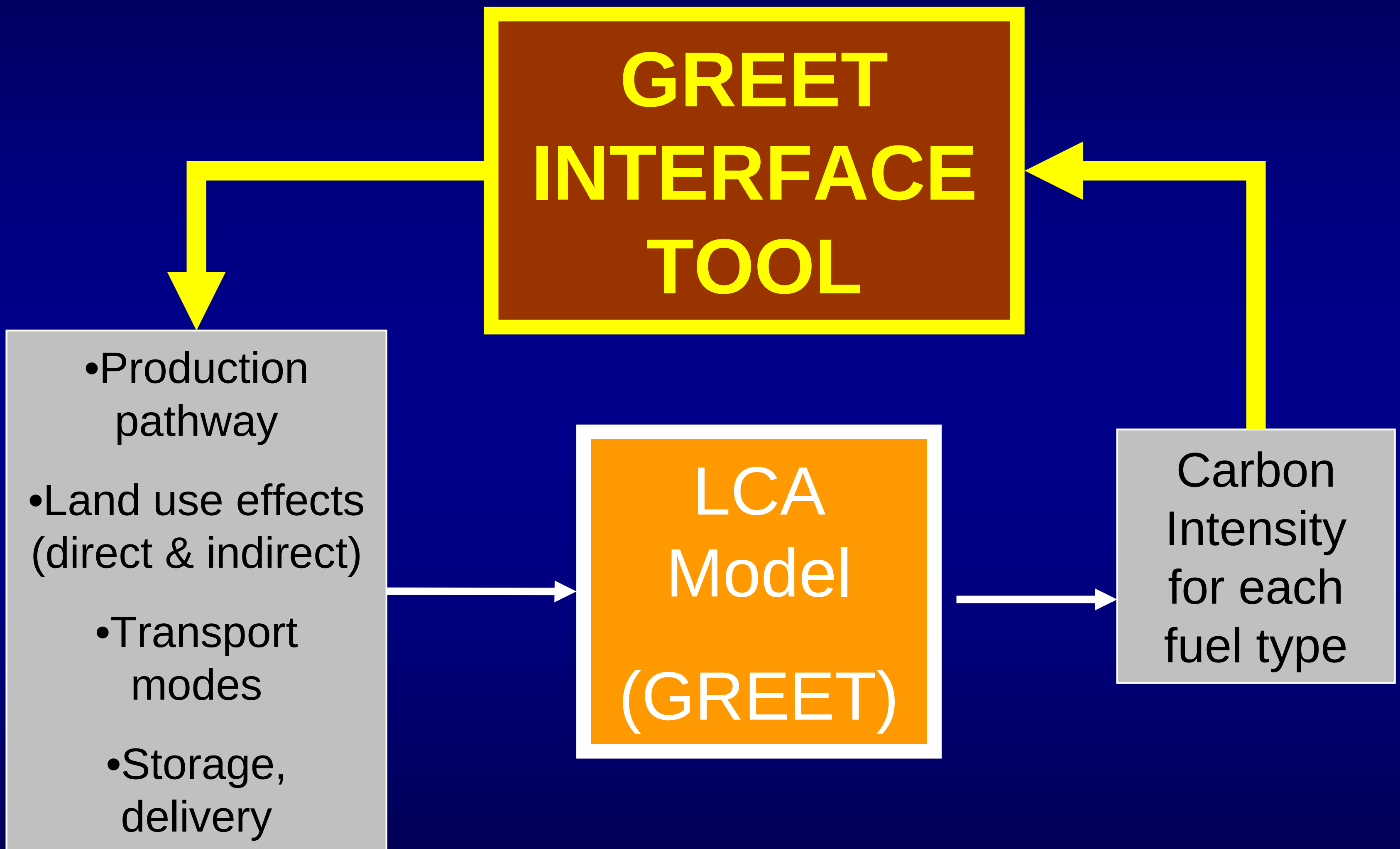
Lifecycle Fuel Analysis



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

Pathway	Carbon Intensity (gCO2e/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**

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

Pathway	Carbon Intensity (gCO2e/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.**

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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?

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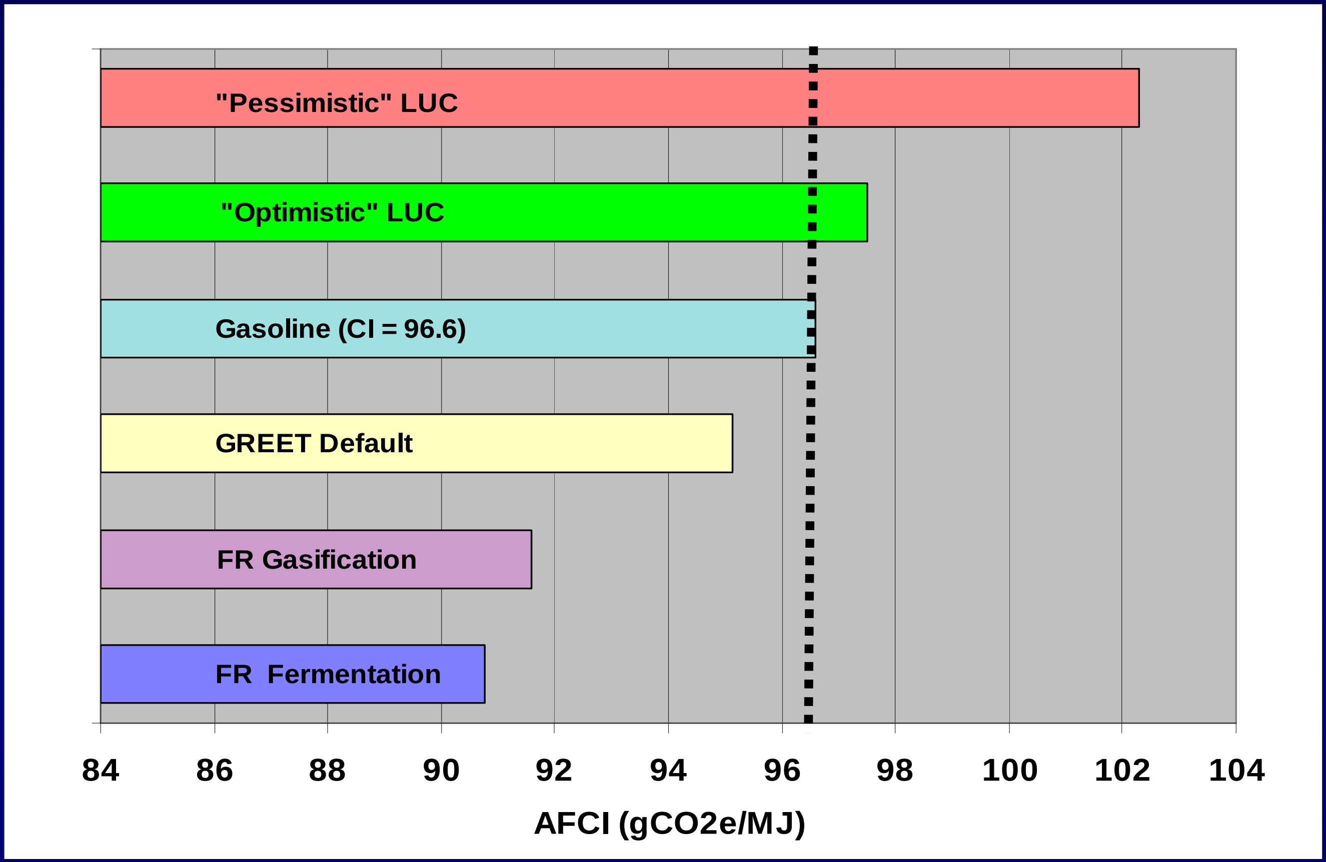
Effect of Ethanol CI on Gasoline AFCI: E10 Region-wide (Draft Results)



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 AFCI

"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.

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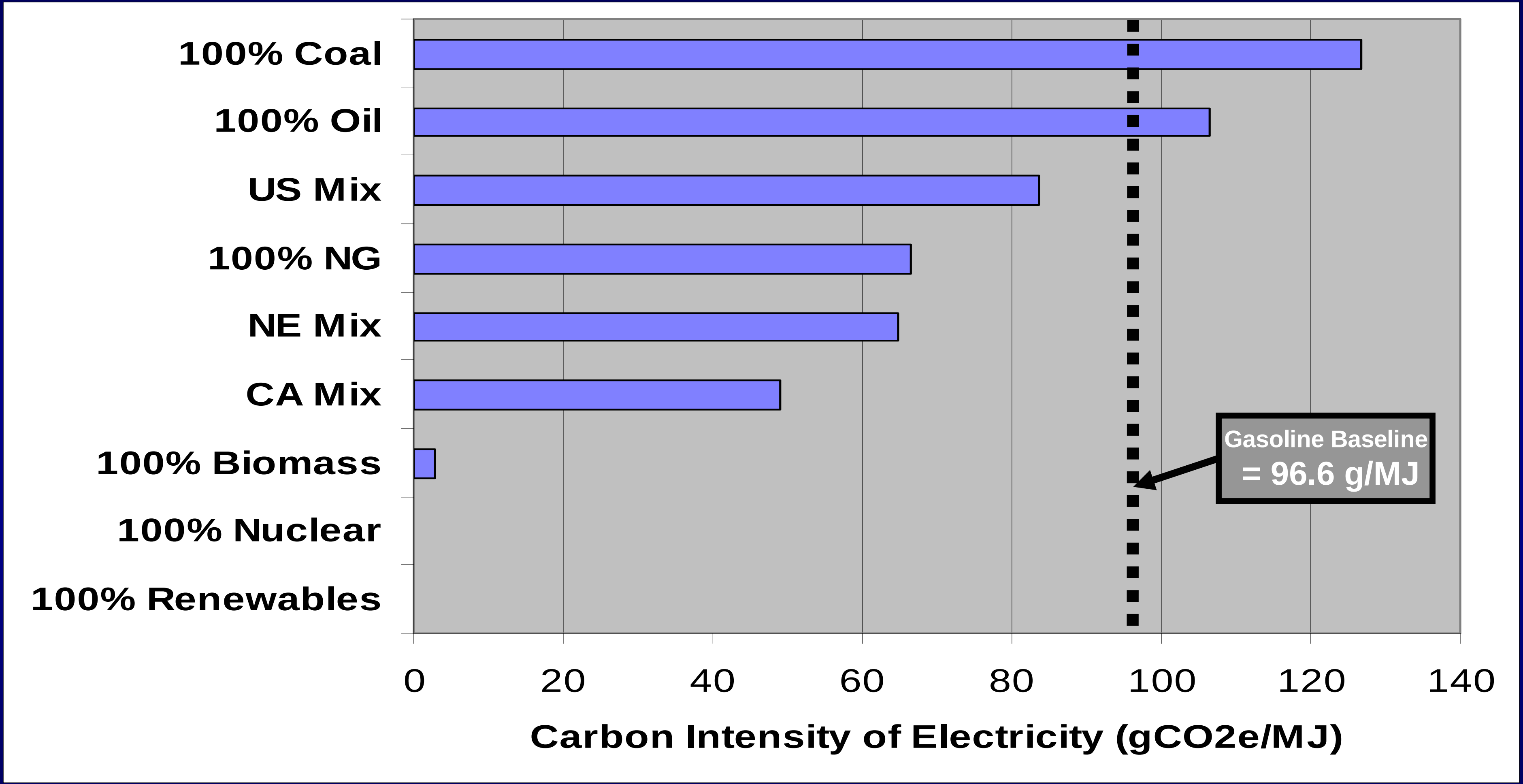
Effect of Grid Resource Mix on Electricity CI (Draft Results)

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



GREET-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

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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?

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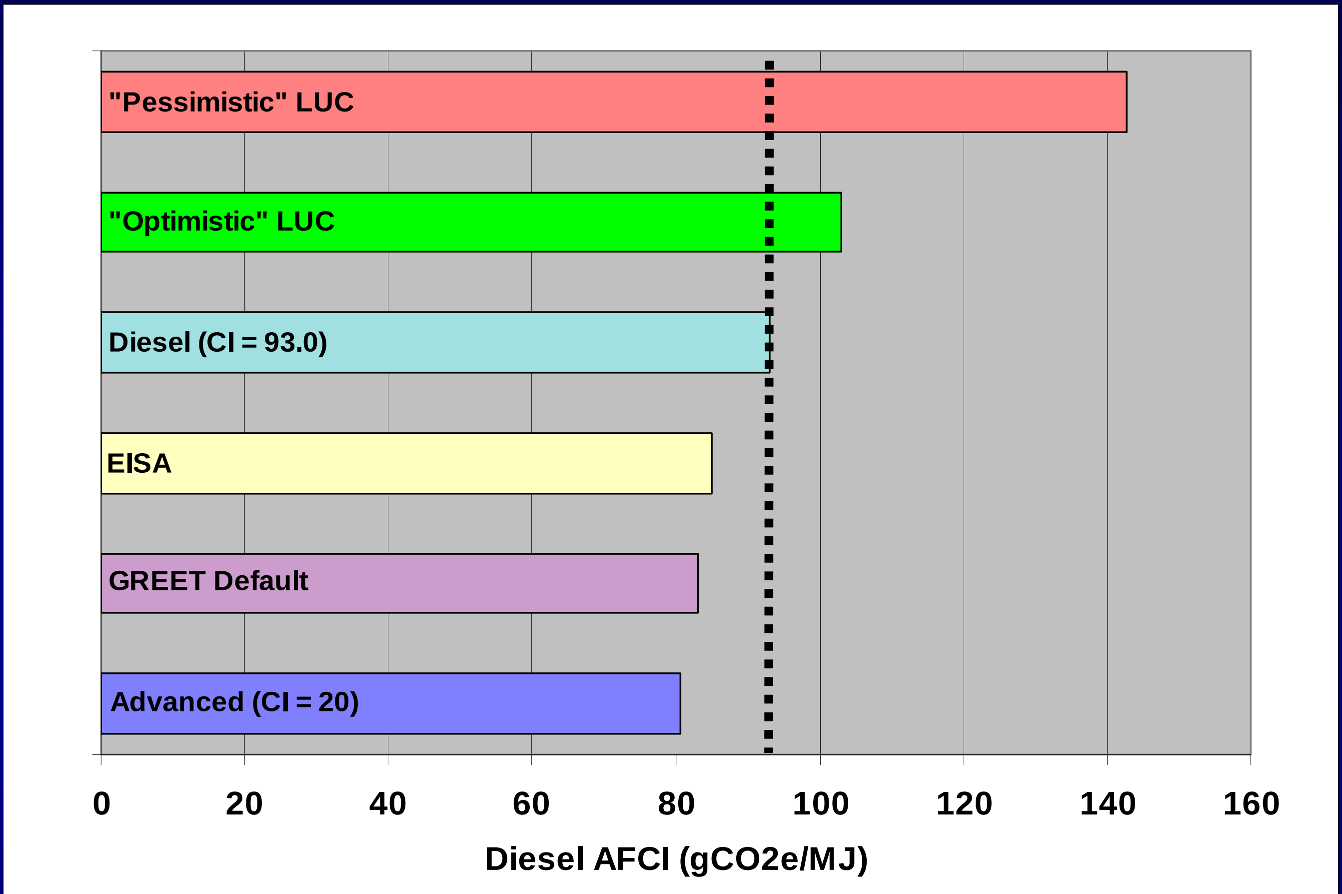
Effect of Biodiesel CI on Diesel AFCI: B20 in all Highway Fuel (Draft Results)



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 AFCI. Total biodiesel demand is 820 mgal. Non-highway fuels not counted toward baseline AFCI. “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.

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Example Compliance Scenarios:

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

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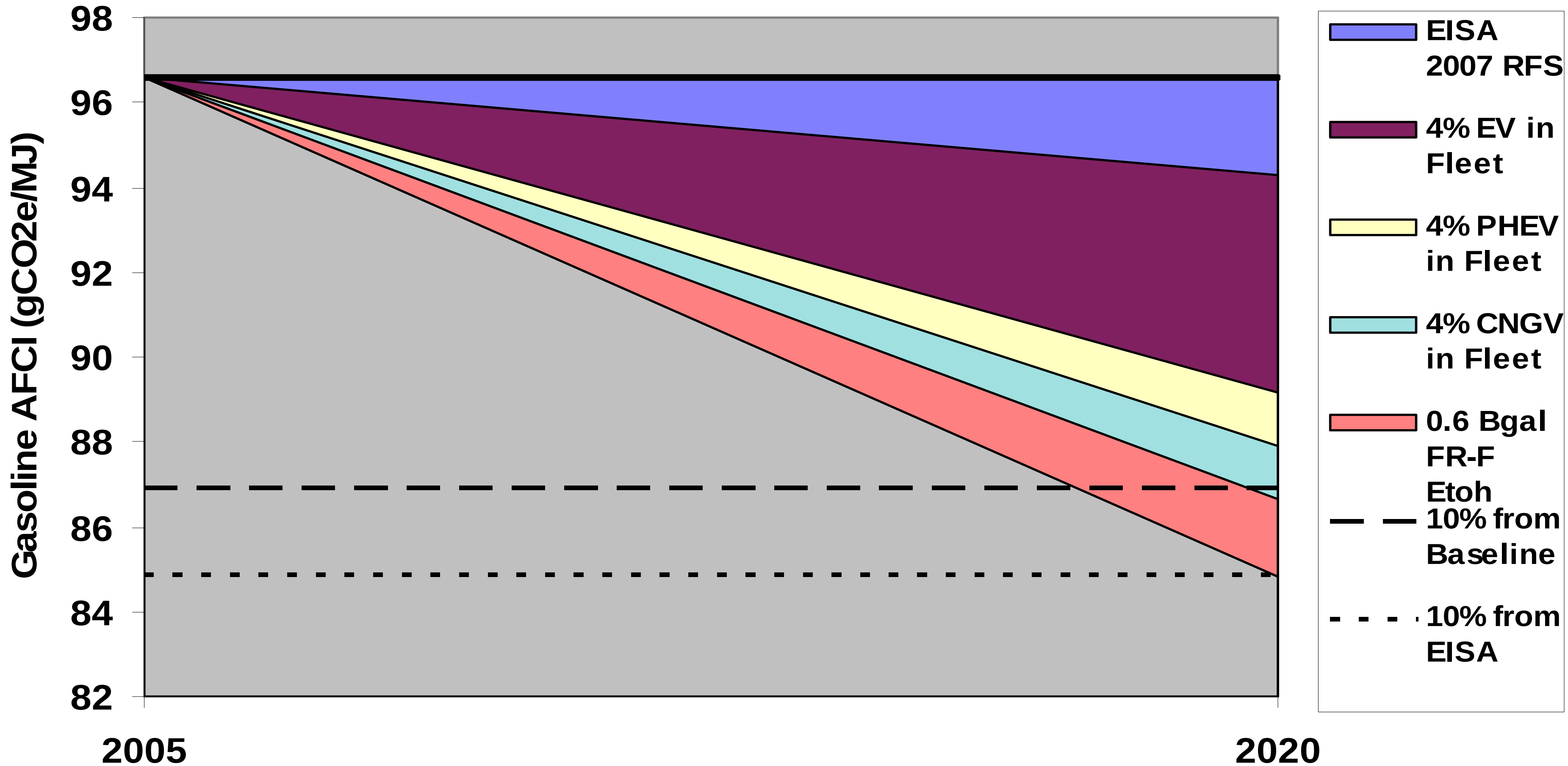
Example Compliance Scenario (Draft Results): 100% Renewables for EV and PHEV



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

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

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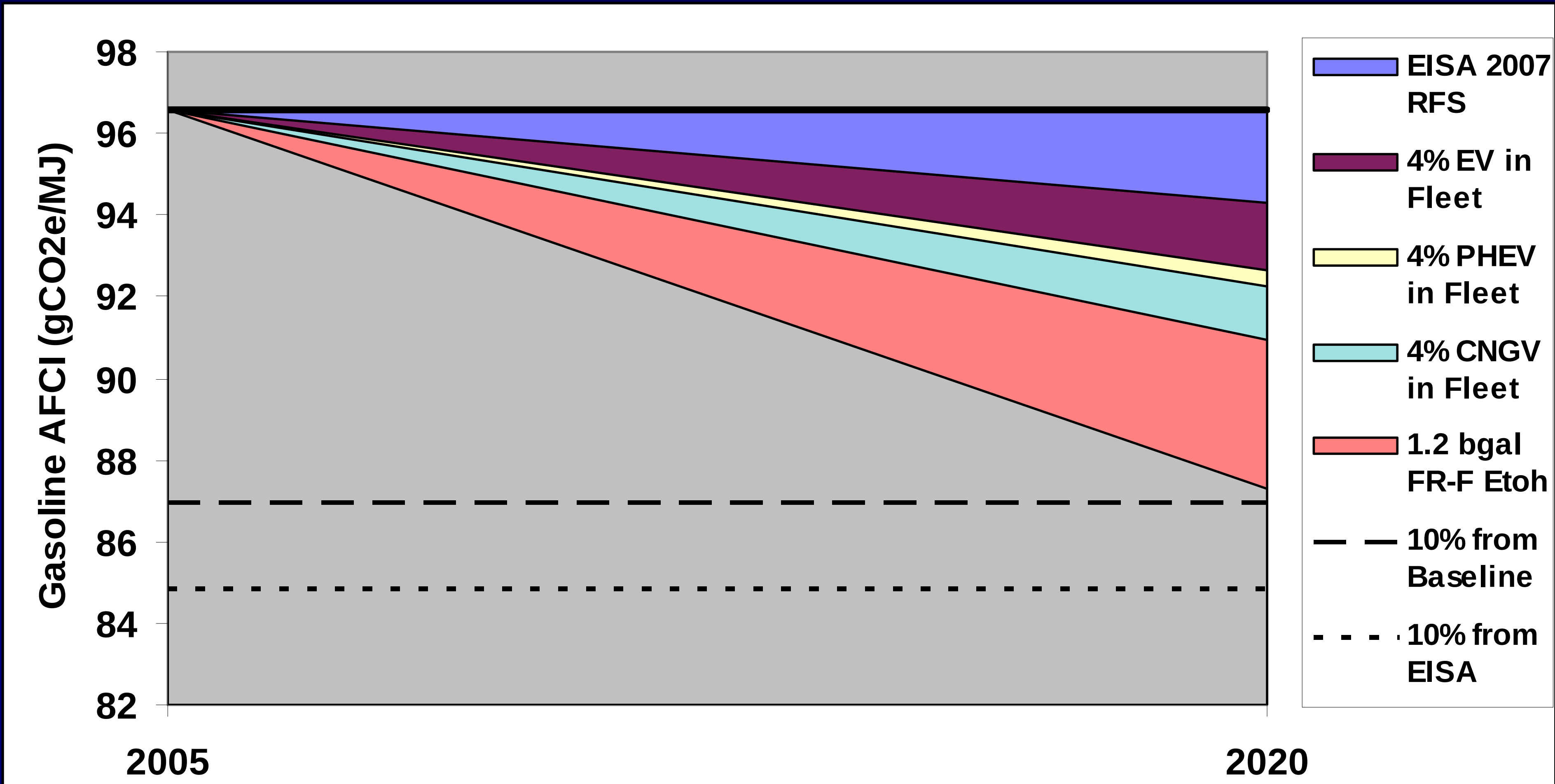
Example Compliance Scenario (Draft Results): 100% NG Electricity Generation for EV and PHEV



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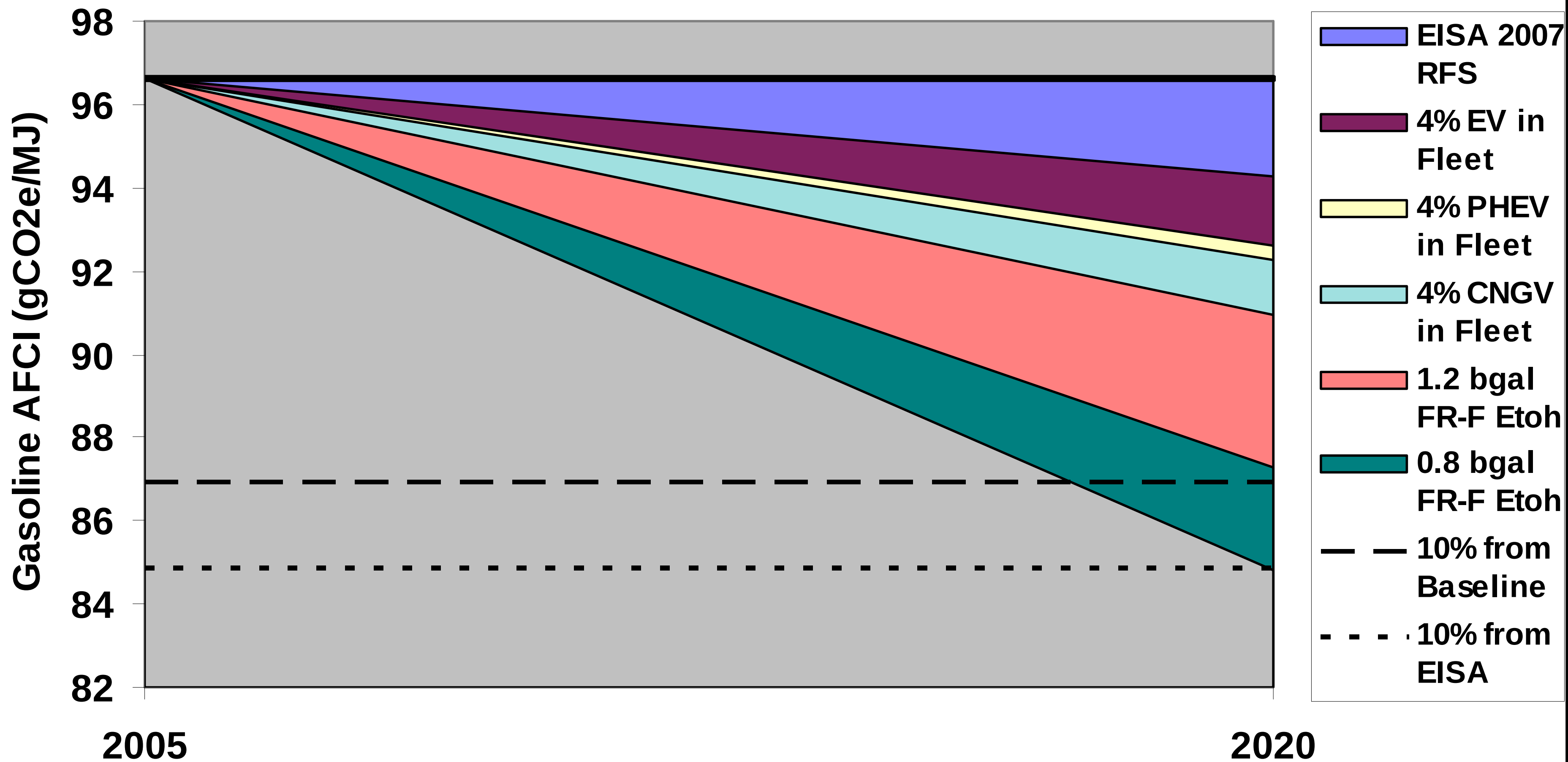

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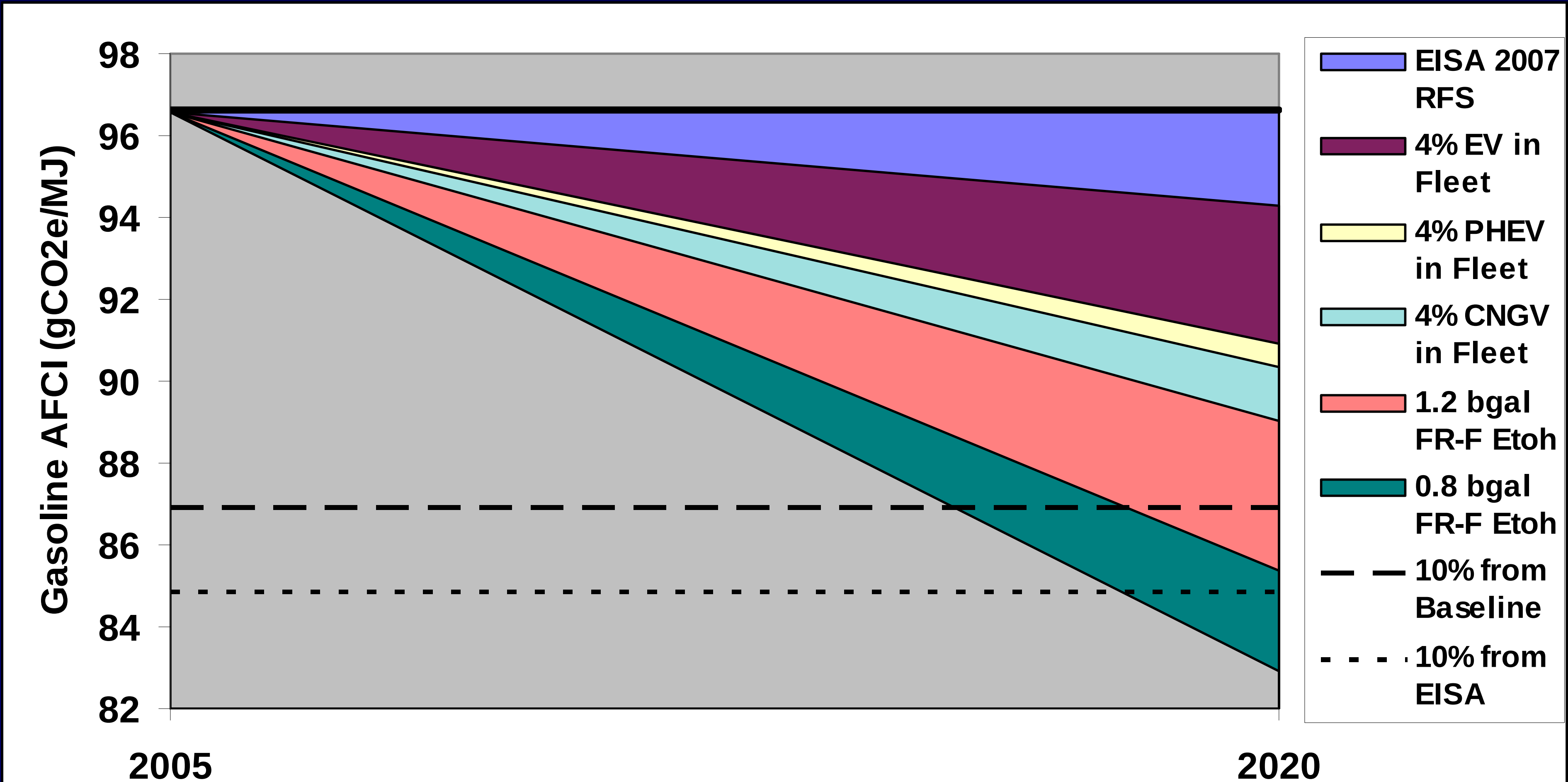

Example scenarios for discussion only. NESCAUM/NESCCAF make no claim as to the feasibility or desirability of the volumes shown.

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

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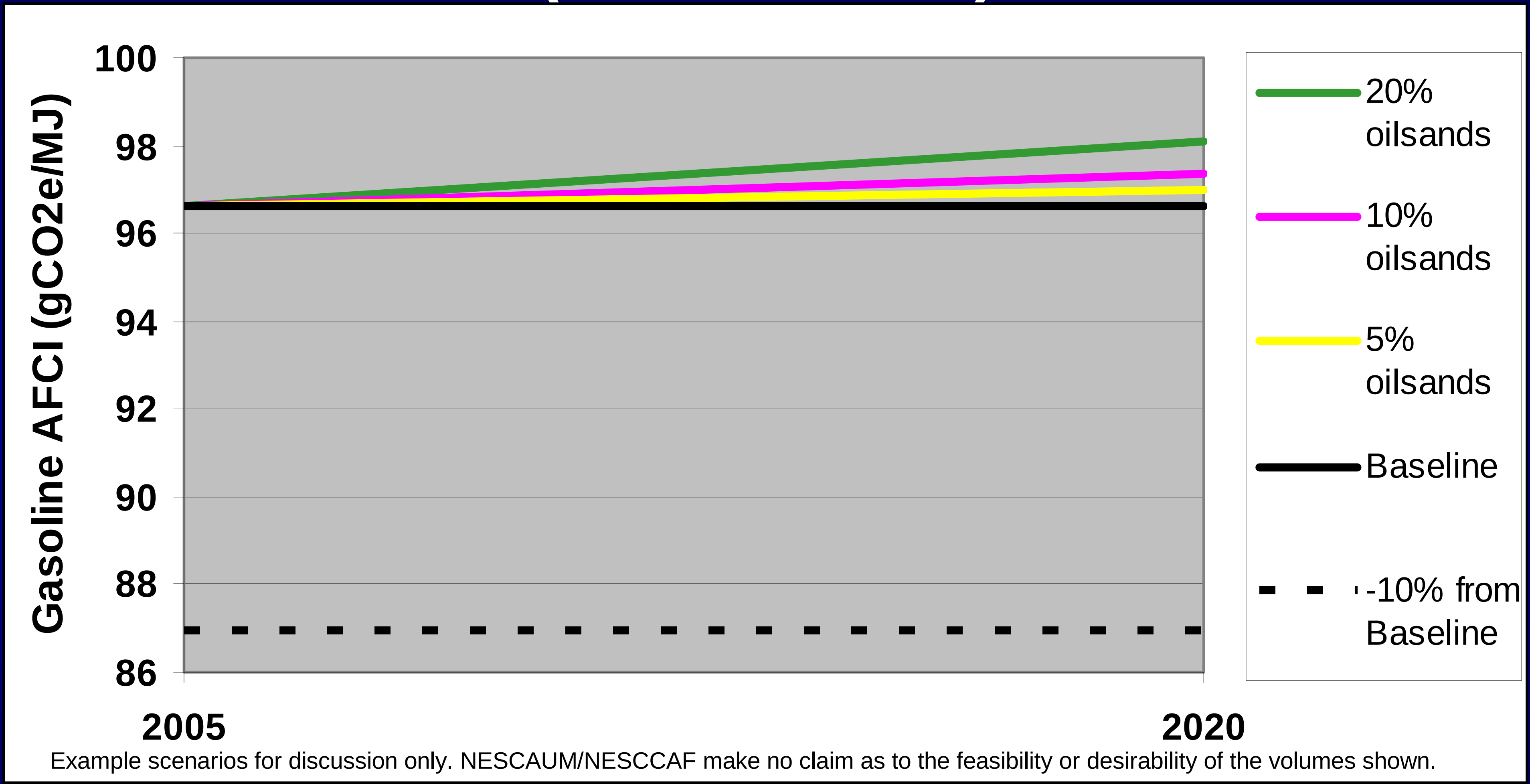
Effect of Oilsands on Gasoline AFCI (Draft Results)



Oilsand Gasoline CI = 105 gCO2e/MJ

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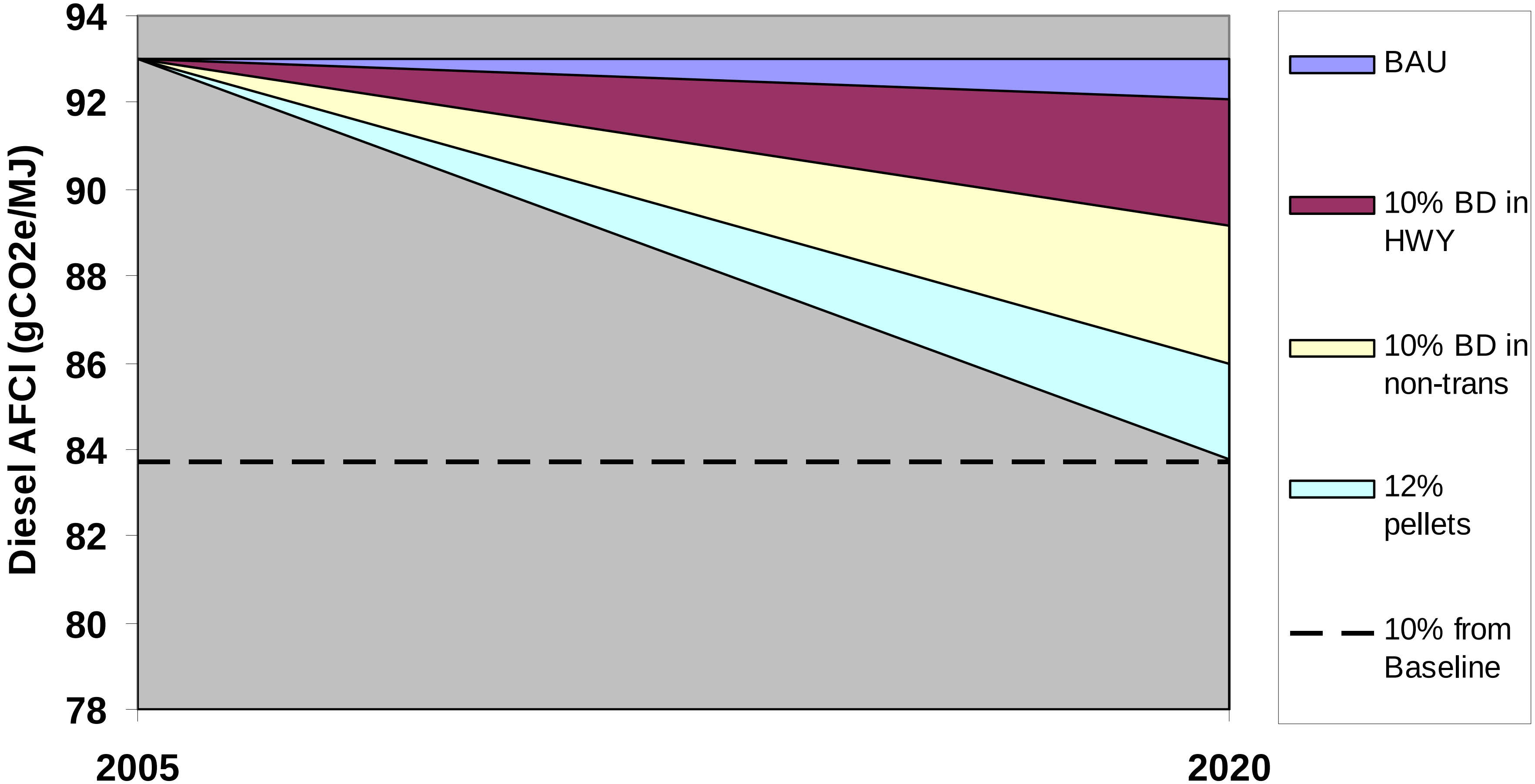
Example Compliance Scenario (Draft Results): Diesel AFCI

Advanced Biodiesel (CI = 20) and FR 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 supply.**

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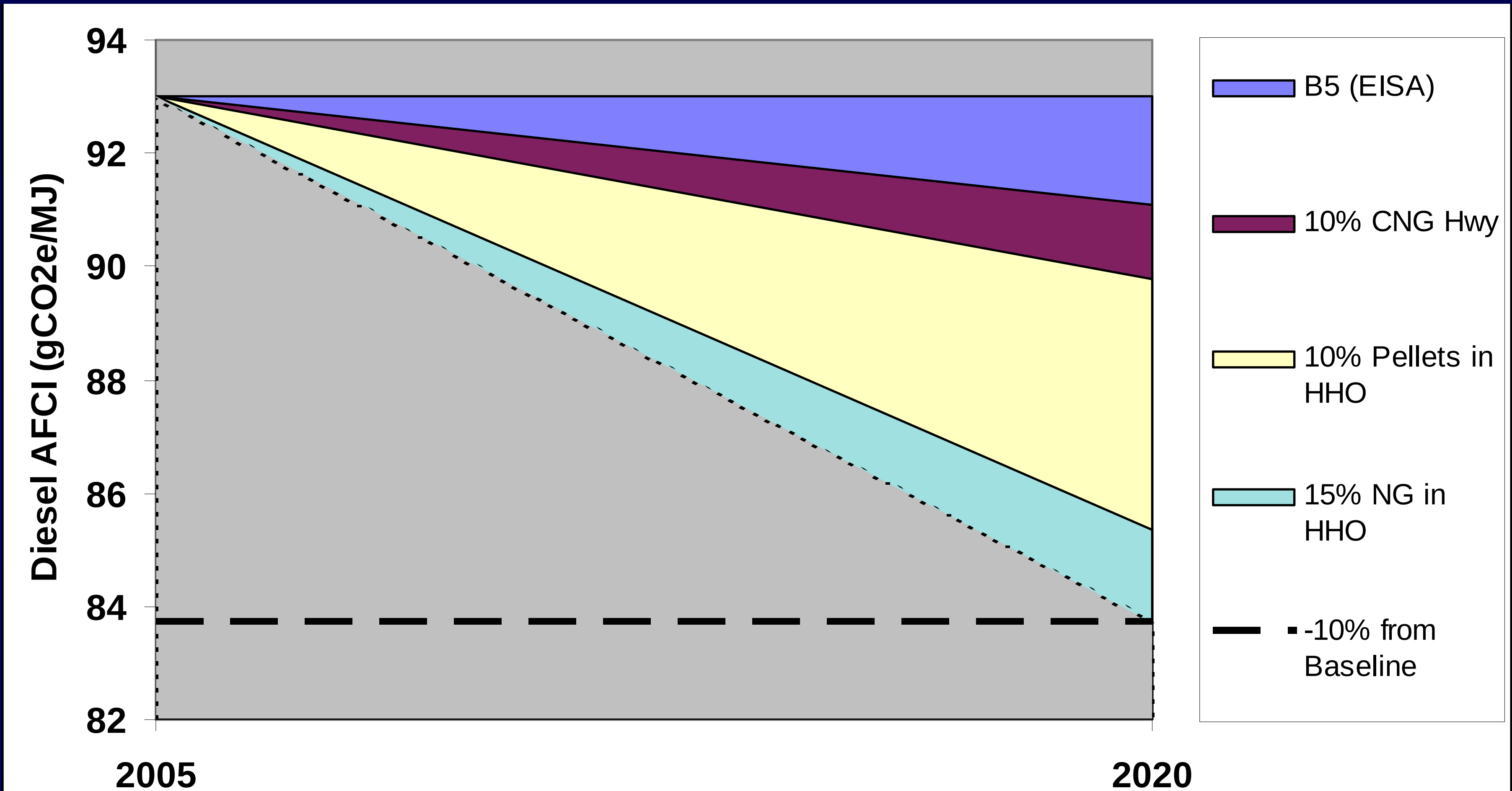
Example Compliance Scenario: Diesel AFCI (Draft Results) Baseline = Highway Diesel Only



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

- **Heating fuels not counted towards baseline but allowed to generate credits.**
- **5% BD Iin 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 supply.**

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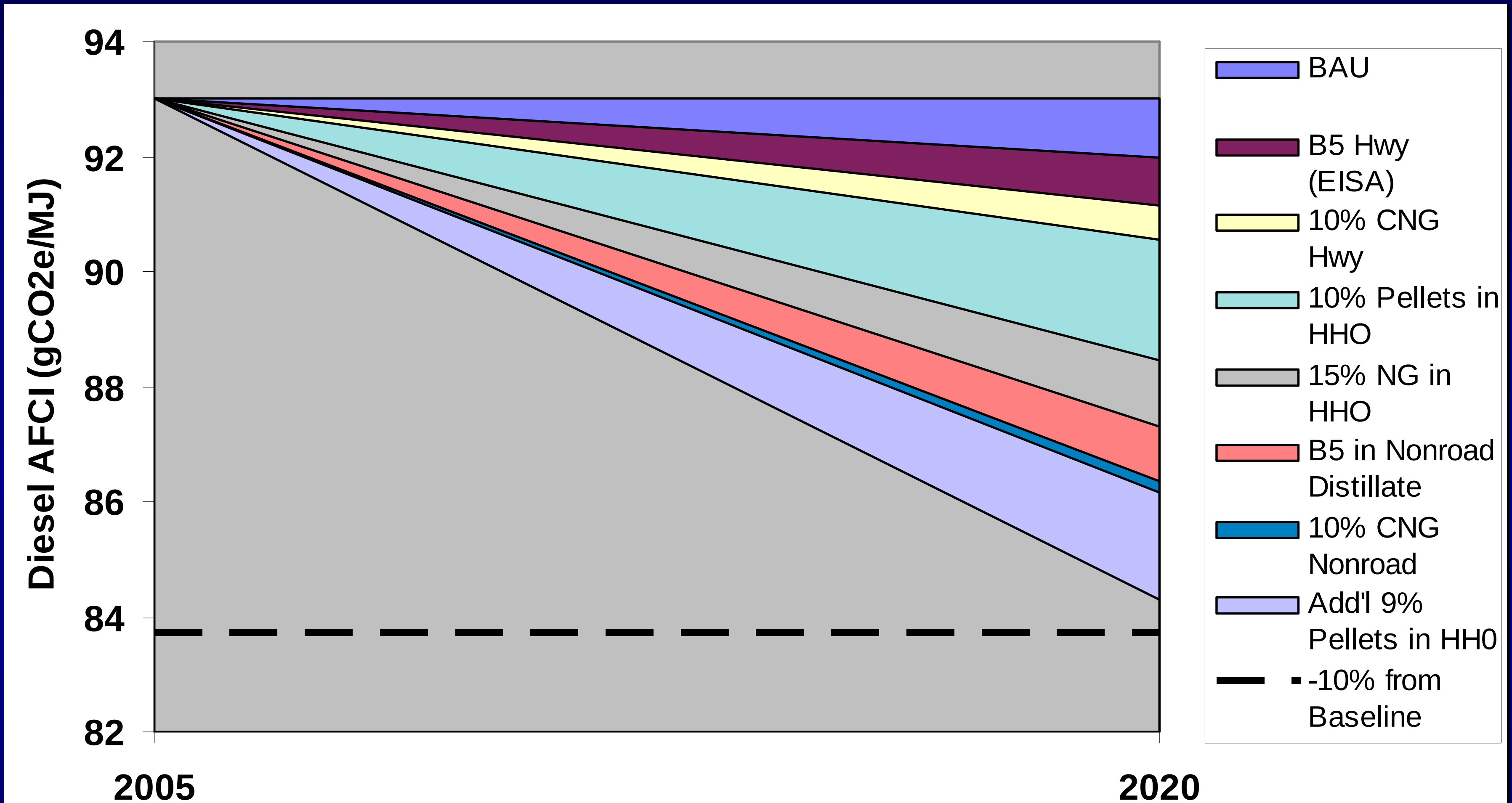
Example Compliance Scenario: Diesel AFCI

Baseline Includes All Distillate (Highway, Nonroad and HHO)



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 inclusion of thermal at lower CI**
- **5% BD Iin 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 supply.**

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Thank you!

Questions or comments please contact

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Backup Slides

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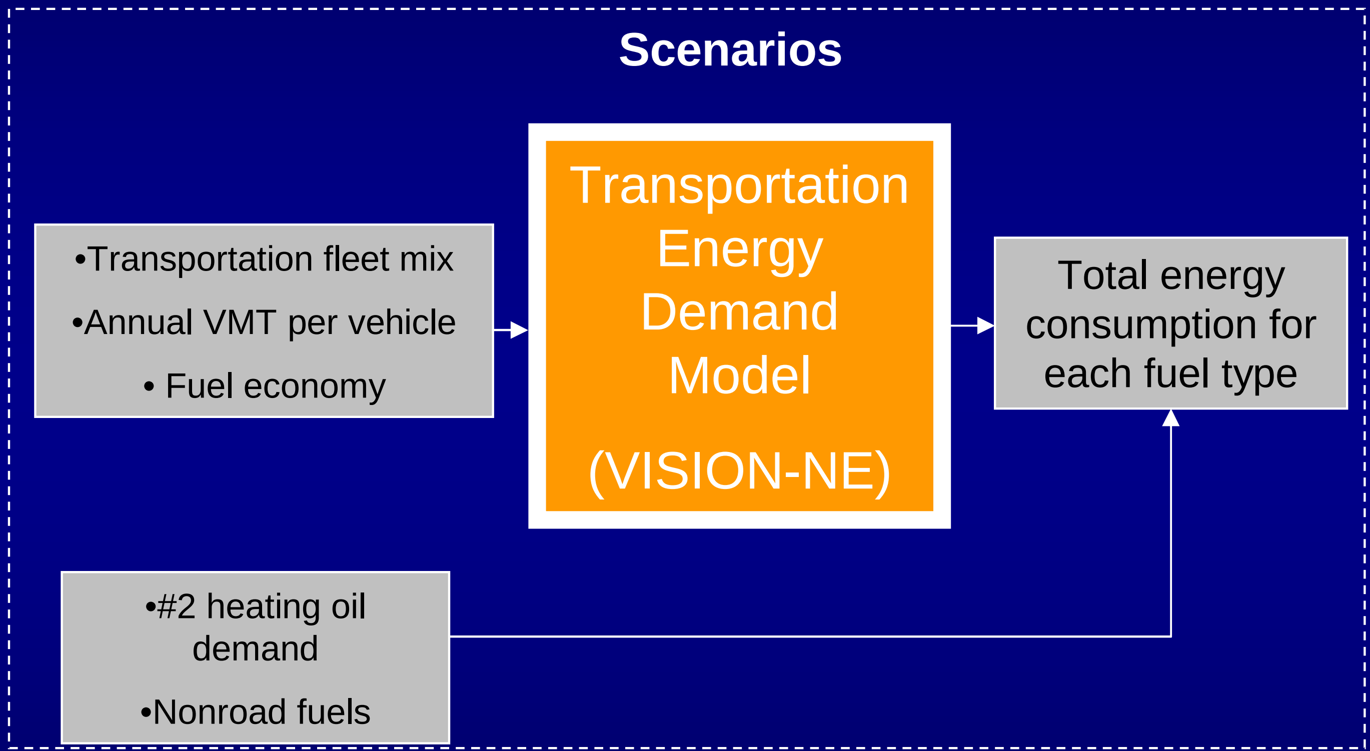
Analytical Methods: Overview



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/**

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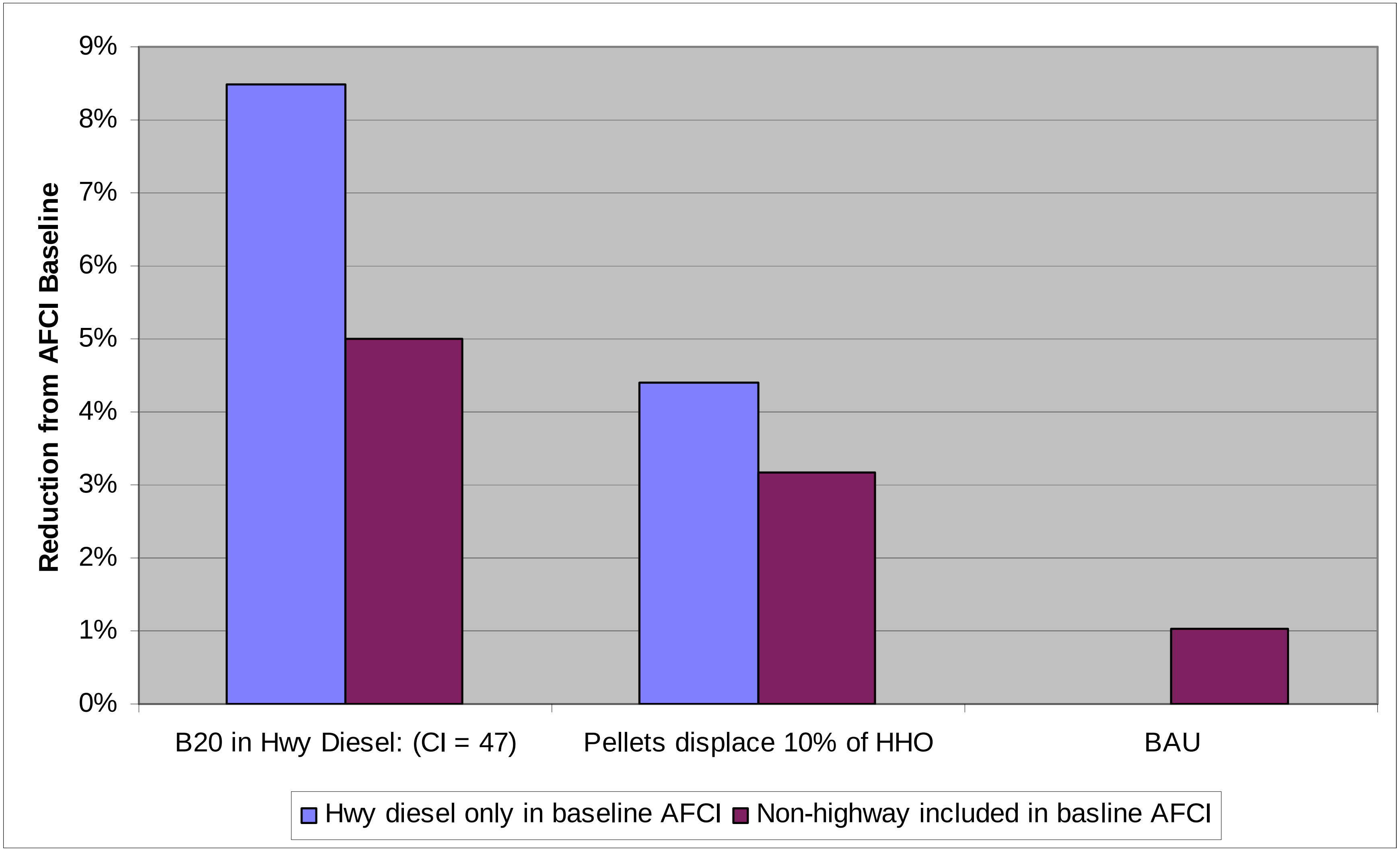
Including Non-Highway Fuels in Baseline (Draft Results)



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

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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 AFCI 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 AFCI?

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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

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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.
  - Thus the AFCI 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

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