Fuel-Cycle Energy and Emissions Analysis with the GREET Model

Michael Wang
Argonne National Laboratory
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Overview of GREET Model Development

Timeline
- Start – 1995
- Finish – continuous
- % complete – not applicable

Budget
- Total project funding
  - DOE share: ~$5 million from various EERE offices since 1995
- Funding received from VT Fuel Utilization
  - FY08: $500k
  - FY09: $400k

Barriers Addressed
- Develop a comprehensive tool to examine full energy and emission effects of vehicle/fuel systems
- Conduct thorough WTW analyses with the developed tool

Partners
- Other national labs
- The auto industry
- The energy industry
- Other government agencies
- Research institutions and universities
The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

- The GREET model and its documents are available at Argonne’s website at http://www.transportation.anl.gov/software/GREET/
- The most recent GREET version (GREET 1.8c) was released in March 2009
- GREET application reports are available at the GREET website
Objectives

• Develop the GREET model as a consistent, transparent LCA tool so that DOE and stakeholders can evaluate energy and GHG emission effects of advanced vehicle technologies and new transportation fuels

• Conduct thorough well-to-wheels (WTW) analyses of vehicle/fuel systems of interest to DOE and the nation

• Engage in discussions and exchanges with the auto industry, the energy industry, and government agencies to provide objective WTW results for technology R&D and policy development

• Interact with research institutions and universities to advance WTW analytic methodologies
GREET Development Milestones

• The first GREET version was released in 1996
• The most recent GREET version – GREET1.8c – was released in March 2009
• Major WTW studies were completed in the past 13 years:
  ✓ Alternative-fuel vehicles in 1990s
  ✓ NG-based fuel production pathways in late 1990s
  ✓ Hydrogen pathways in early 2000s
  ✓ Biofuels since the middle of 1990s
  ✓ XTLs since 2005
GREET Users and Their Distribution

Cumulative Number of GREET Users

- University
- Industry
- Other
- Government
- Consulting
- NGO

North America
Europe
Asia
Other
Approach

• Develop the GREET model as a user-friendly LCA model to serve researchers and policy makers for LCA needs
• Obtain and develop reliable input data for the GREET model
• Well-to-pump data sources
  ✓ Open literature
  ✓ Engineering analysis (such as ASPEN simulations for mass and energy balance)
  ✓ Stakeholder inputs (e.g., collaboration with the energy industry)
• Pump-to-wheels data sources
  ✓ Fuel economy
    ➢ Open literature
    ➢ Vehicle simulations with models such as Argonne’s PSAT model
  ✓ Vehicle operation emissions
    ➢ Open literature
    ➢ Emission testing results
    ➢ EPA MOBILE model
    ➢ CARB EMFAC model
GREET Includes More Than 100 Fuel Production Pathways from Various Energy Feedstocks

- **Petroleum:**
  - Conventional Oil Sands
  - Gasoline
  - Diesel
  - LPG
  - Naphtha
  - Residual oil

- **Natural Gas:**
  - NA
  - Non-NA
  - CNG
  - LNG
  - LPG
  - Methanol
  - Dimethyl Ether
  - FT Diesel and Naphtha
  - Hydrogen

- **Corn**
  - Ethanol
  - Butanol

- **Soybeans**
  - Biodiesel

- **Sugar Cane Cellulosic Biomass:**
  - Switchgrass
  - Fast growing trees
  - Crop residues
  - Forest residues
  - Ethanol
  - Hydrogen
  - Methanol
  - Dimethyl Ether
  - FT Diesel

- **Residual Oil:**
  - Coal
  - Natural Gas
  - Nuclear
  - Biomass
  - Other Renewables

- **Coal**
  - Hydrogen
  - FT Diesel
  - Methanol
  - Dimethyl Ether

- **Nuclear Energy**
  - Hydrogen

- **Electricity**
  - Coke Oven Gas
  - Hydrogen
GREET Includes More Than 75 Vehicle/Fuel Systems

**Conventional Spark-Ignition Vehicles**
- Conventional gasoline, federal reformulated gasoline, California reformulated gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol

**Spark-Ignition Hybrid Electric Vehicles: Grid-Independent and Connected**
- Conventional gasoline, federal reformulated gasoline, California reformulated gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol

**Compression-Ignition Direct-Injection Hybrid Electric Vehicles: Grid-Independent and Connected**
- Conventional diesel, low sulfur diesel, dimethyl ether, Fischer-Tropsch diesel, E-diesel, and biodiesel

**Battery-Powered Electric Vehicles**
- U.S. generation mix
- California generation mix
- Northeast U.S. generation mix
- User-selected generation mix

**Fuel Cell Vehicles**
- Gaseous hydrogen, liquid hydrogen, methanol, federal reformulated gasoline, California reformulated gasoline, low sulfur diesel, ethanol, compressed natural gas, liquefied natural gas, liquefied petroleum gas, and naphtha

**Compression-Ignition Direct-Injection Vehicles**
- Conventional diesel, low sulfur diesel, dimethyl ether, Fischer-Tropsch diesel, E-diesel, and biodiesel

**Spark-Ignition Direct-Injection Vehicles**
- Conventional gasoline, federal reformulated gasoline, and California reformulated gasoline
- Methanol and ethanol
The Pathway of Oil Sands to Gasoline and Diesel Requires a Large Amount of Steam and $\text{H}_2$

- Oil sands
  - Mining
  - In-situ (SAGD)
  - Steam
  - Hydrogen
  - Synthetic crude oil
  - Bitumen
  - Diluent
  - SCO or bitumen transportation
  - Petroleum refining to gasoline and diesel

- Gasoline and diesel at refueling station
- Gasoline and diesel transportation

- Natural gas
- Coal
- Pet coke
- Nuclear
GREET Well-to-Wheels GHG Results for Gasoline from Convention Crude and Oil Sands

WTW GHG Emissions: g/mmBtu

- Conventional Crude
- Oil sands-mining: GREET
- Oil sands-mining: GHGenius
- Oil sands-in-situ: GREET
- Oil sands-in-situ: GHGenius
Four FT Diesel Production Options Were Evaluated

- Natural gas to liquids (GTL)
- Coal to liquids (CTL)
- Biomass to liquids (BTL)
- Co-firing of coal and biomass to liquids (C/BTL)
  - 85/15 C/B co-feeding
  - 38/62 C/B co-feeding: GHG breakeven with petroleum diesel
Trade-Offs Between Petroleum Reductions and GHG Reductions by XTLs
Future Work

• Update GREET with new testing data for XTLs in U.S. diesel cars

• Expand GREET to include new fuel production pathways such as
  ✓ Landfill gas to CNG and LNG
  ✓ New biofuel pathways
  ✓ Other non-petroleum pathways

• Develop GREET with a new programming platform for easier expansion and use

• Conduct WTW analyses to serve DOE and others
Summary

• With EERE support, GREET has become a standard tool for LCAs of vehicle/fuel systems
  ✓ Examine energy and GHG reduction potentials of advanced vehicle technologies and new transportation fuels
  ✓ Identify opportunities and challenges of achieving energy and GHG emission reductions by vehicle technologies and fuel production pathways

• Expansion and maintenance of GREET to serve transportation LCA needs will continue