ARGONNE NATIONAL LABORATORY

TRANSPORTATION

TECHNOLOGY R&D CENTER

Well-to-Wheels Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions -- Hybrid Electric and Fuel-Cell Vehicles --

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WTP Criteria Pollutant Issues Are Addressed Through an On-Going Project with GM

- Data for relevant facilities were extracted from EPA's 1999 National Emissions Inventory database
- Total emissions for a given facility were divided by its throughput to develop emissions factors
- Distribution curves were fitted to current EPA emission data
- The curves were further adjusted to account for improvements by future technologies and emission controls

This Study Includes Many Fuel Pathways

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CRUDE OIL

- Gasoline
- Diesel fuel
- LPG

NATURAL GAS
- North American
- Non North American

- Compressed natural gas
- Hydrogen (gaseous and liquid)
  - ✓ Central plant
  - ✓ Refueling station
- Fischer-Tropsch diesel
- Methanol
- LPG

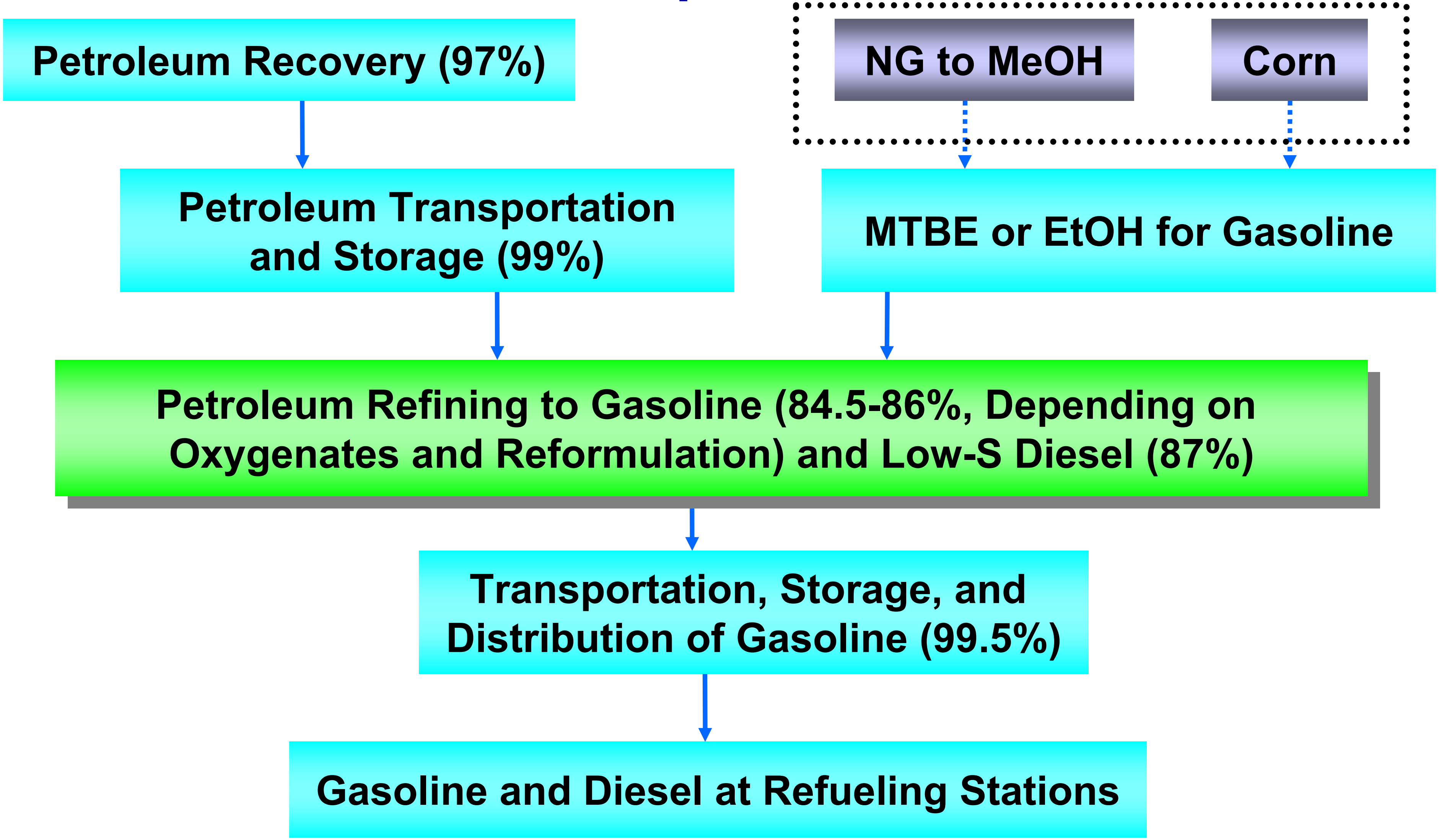
BIOETHANOL
- Corn
- Cellulose

- Ethanol
  Pure ethanol and E85

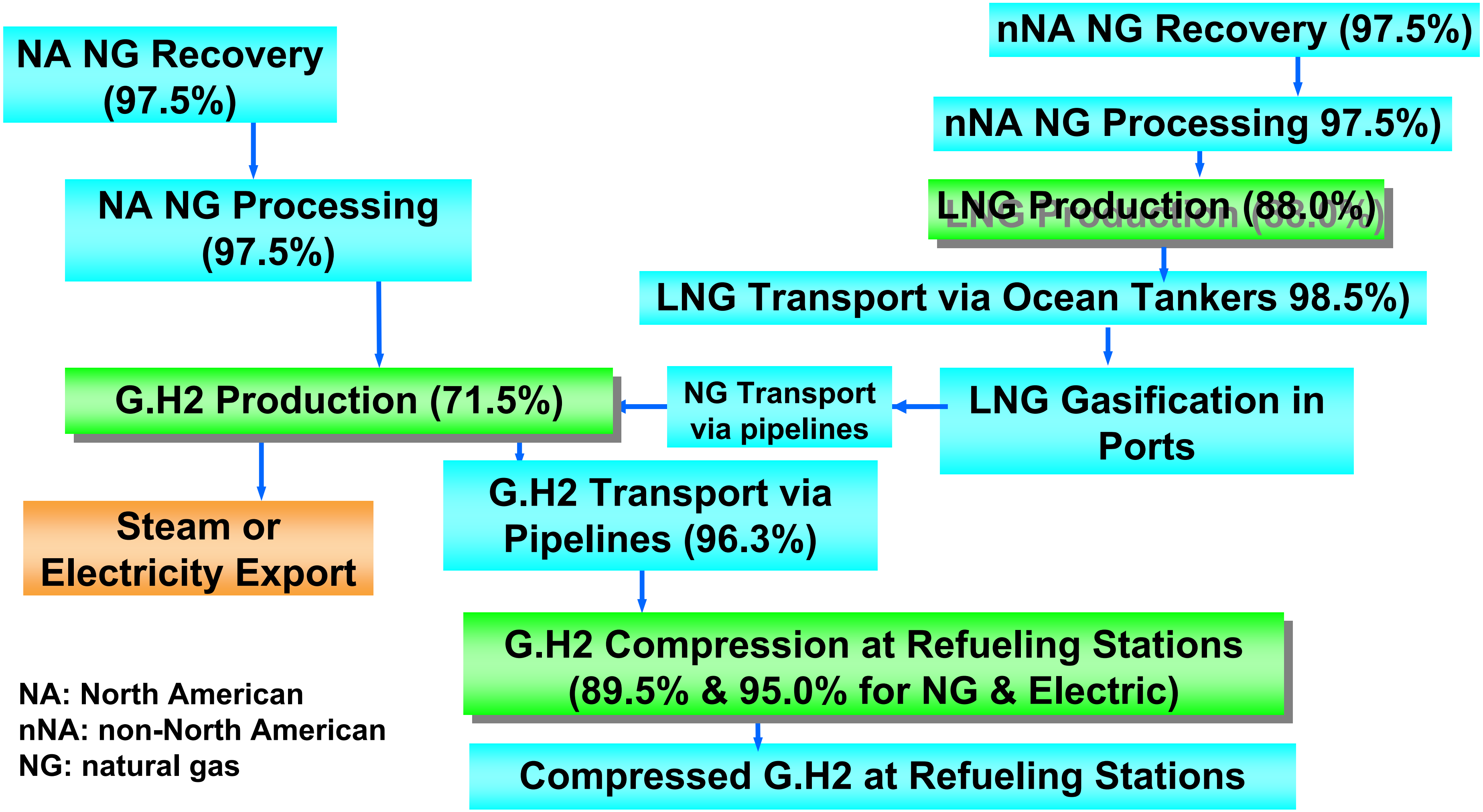
ELECTRICITY
- U.S. Mix
- Renewable

- Hydrogen
  Gaseous and liquid

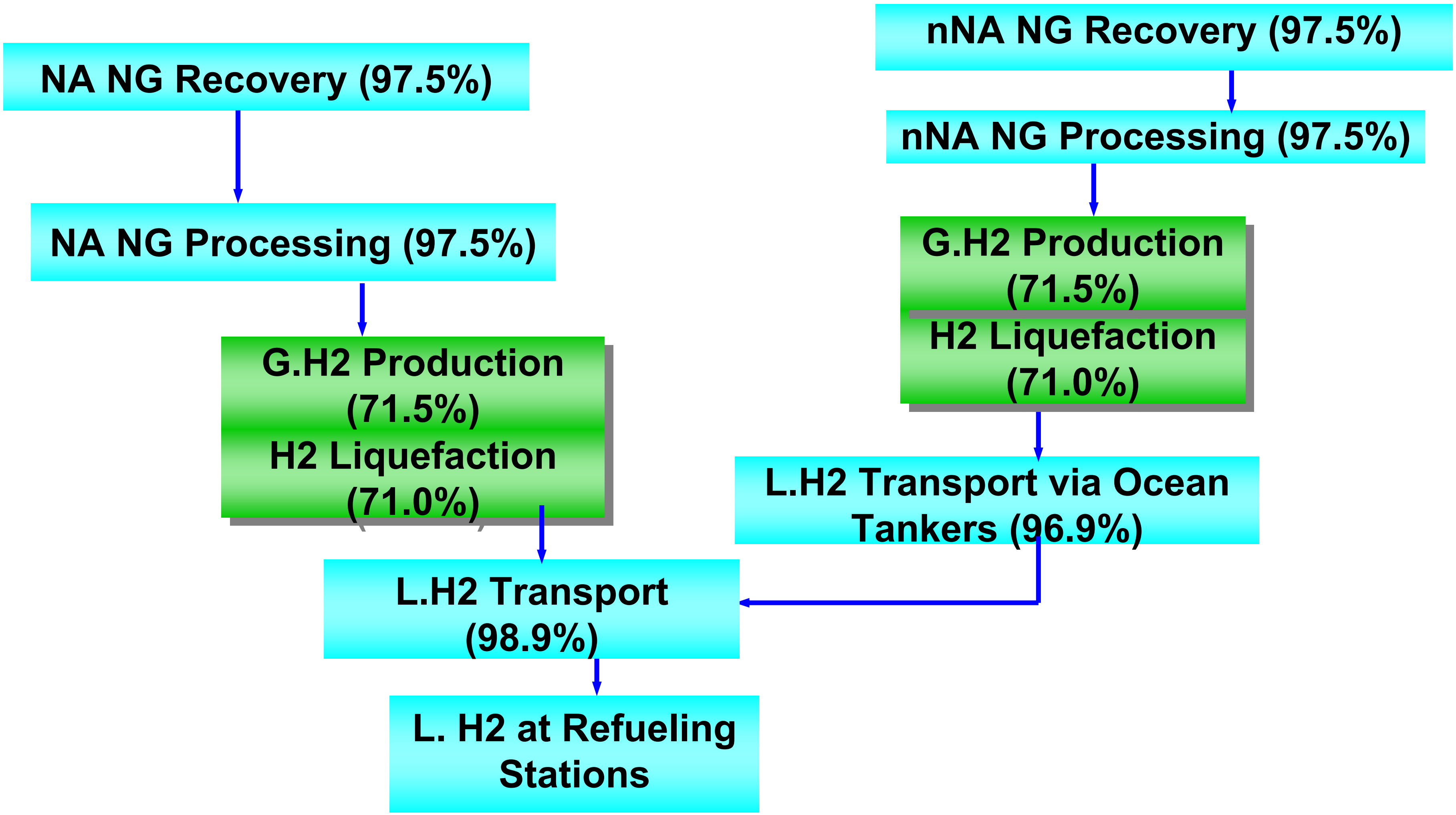
Petroleum Refining Is the Key Energy Conversion Step for Gasoline and Diesel



Production and Compression Are Key Steps for $G.H_2$ Production



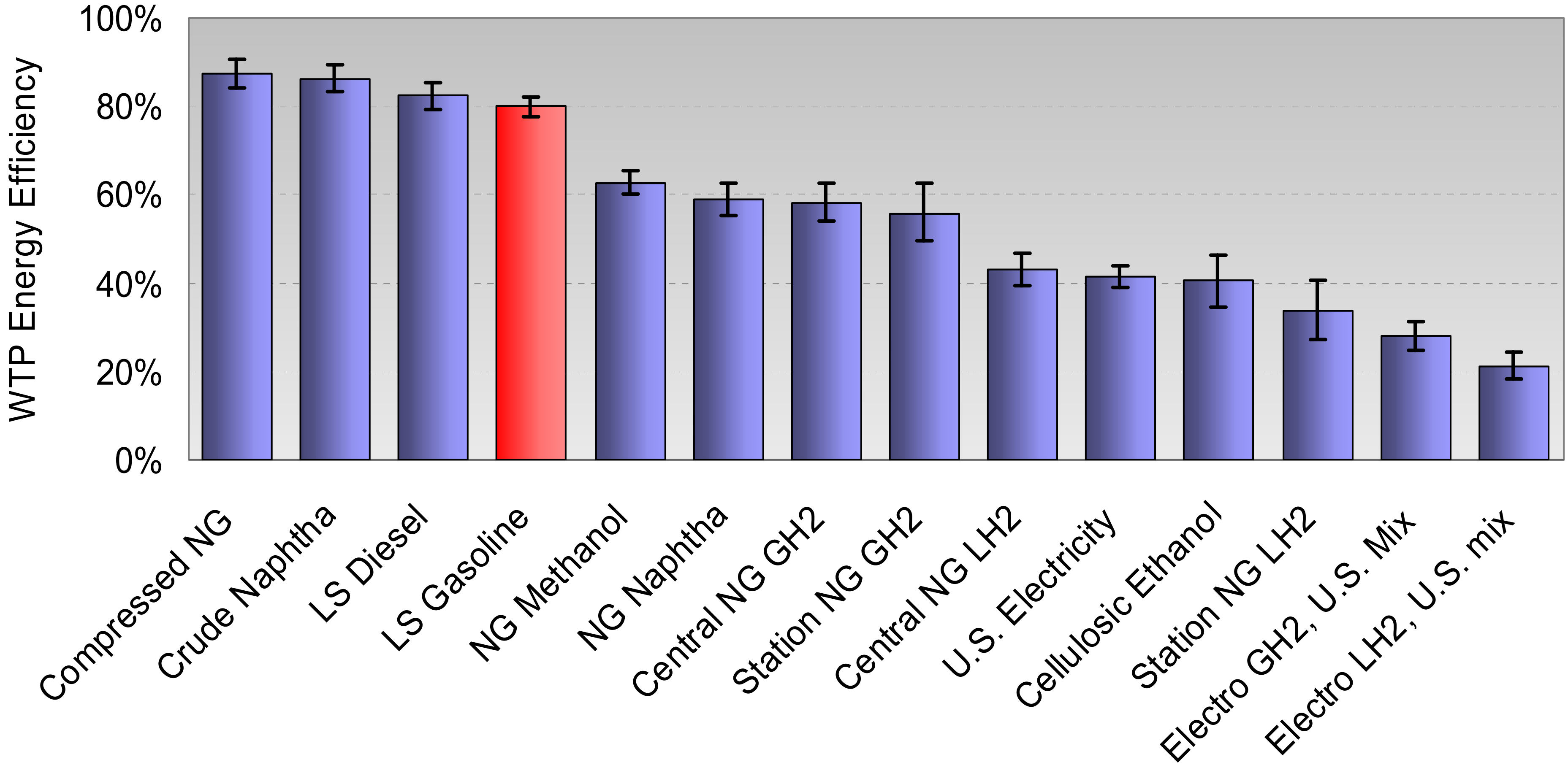
H_2 Liquefaction Has Higher Energy Losses Than H_2 Compression



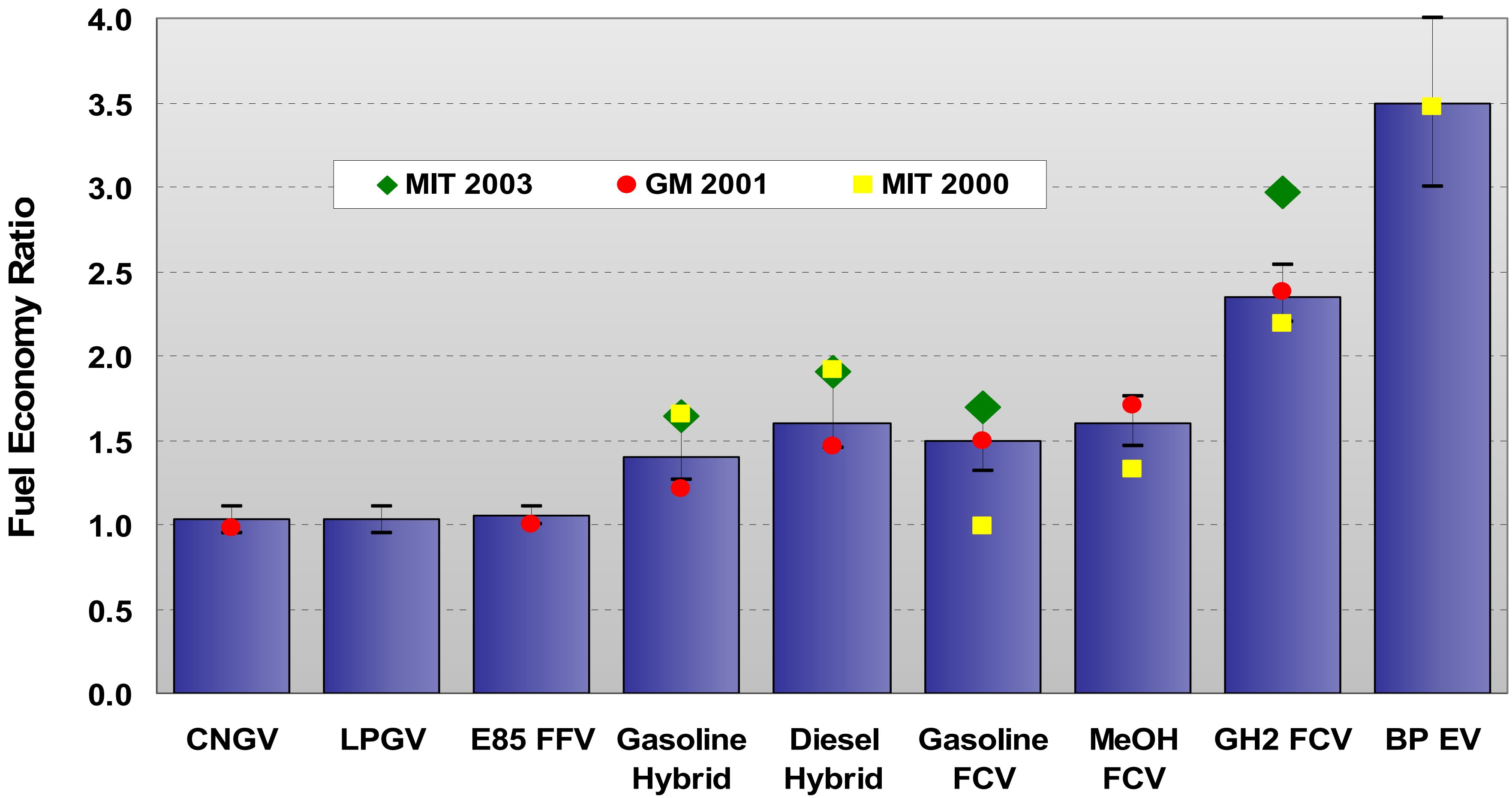
Resource and Infrastructure Options Result in Many Potential H2 Pathways

- H2 is produced from natural gas via steam methane reforming (SMR) now, and in the foreseeable future
- SMR plant emissions need to be taken into account
- Station SMR production
  - Could reduce or avoid expensive distribution infrastructure
  - But production emissions are close to urban areas
- Central SMR CO_2 emissions can be potentially sequestered
- Electrolysis' H2 energy and emissions depend on electricity sources
- Gasification for H_2 production
  - Coal: CO_2 and criteria pollutant emissions; possible CO_2 sequestration
  - Biomass: criteria pollutant emissions
- Nuclear electrolysis or thermal cracking H_2 - virtually no air emissions

WTP Energy Use Significantly Affects Ranking of Total WTW Energy and GHGs



Vehicle Fuel Economy Is One of the Most Important Factors for WTW Results



Fuel economy ratios are relative to improved future gasoline ICE technology

ANL Vehicle/Fuel Technologies for WTW Energy and GHG Emission Results

- **Crude oil-based technologies**

RFG ICE	LPG ICE
LS Diesel ICE	RFG ICE hybrid
Gasoline FCV	LS diesel ICE hybrid

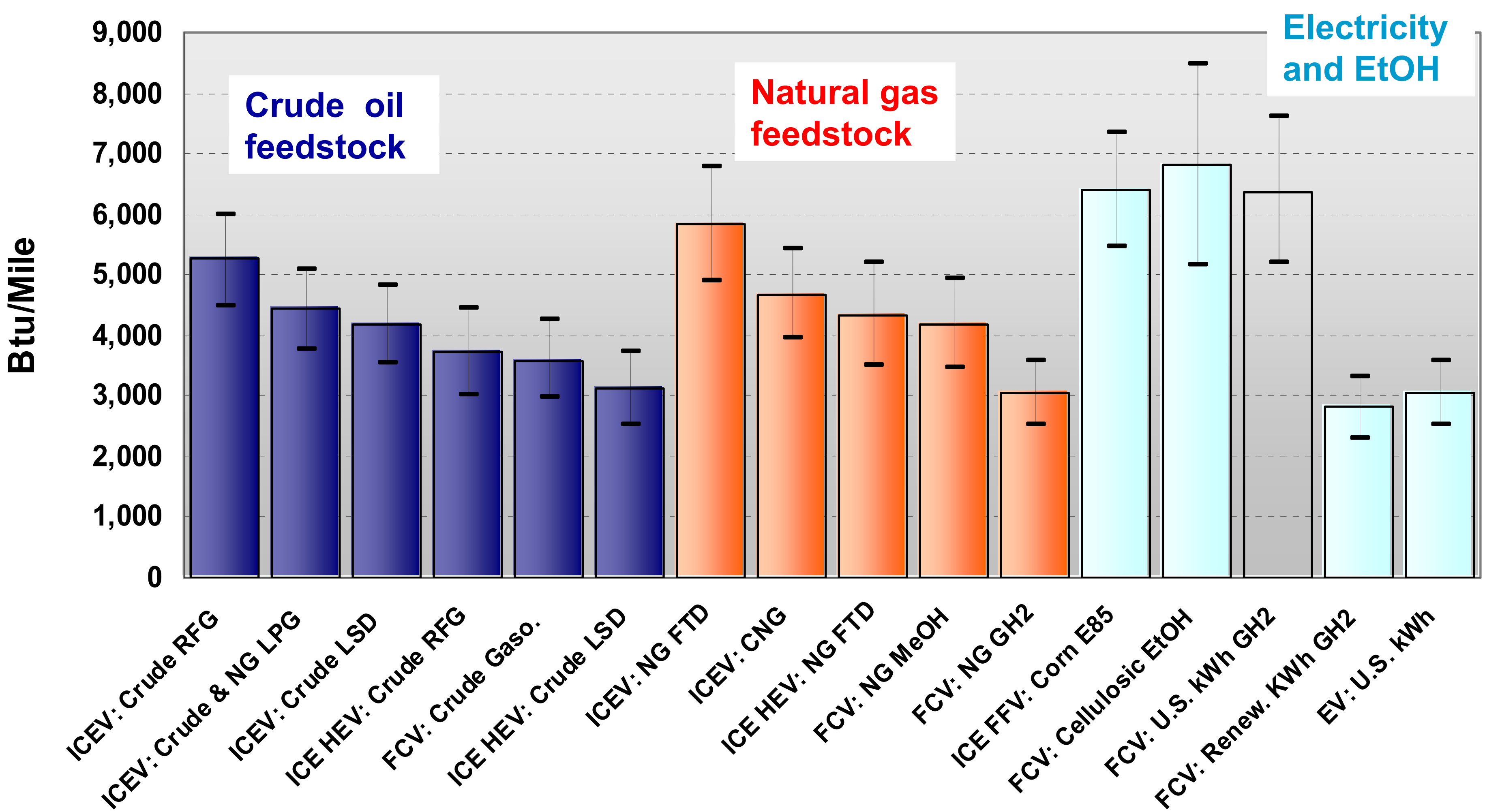
- **Natural gas-based technologies**

FT diesel ICE	CNG ICE
FT diesel ICE hybrid	MeOH FCV
G.H2 FCV	

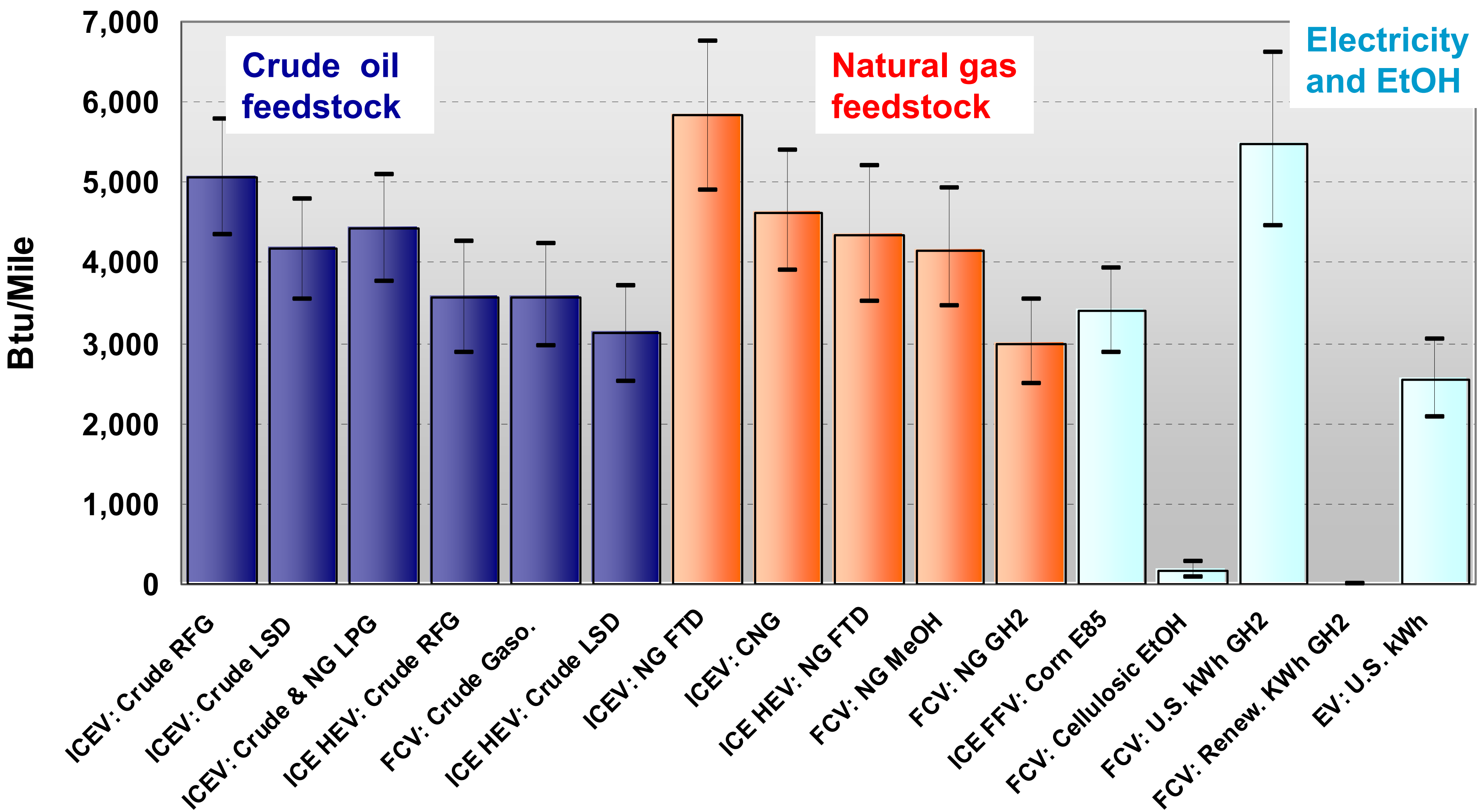
- **Bioethanol and electricity**

Corn E85 ICE FFV	Cellulosic EtOH FCV
U.S. average electri.-to-G.H2 FCV	Renewable electricity-to-G.H2 FCV
U.S. average electricity battery-powered EV	

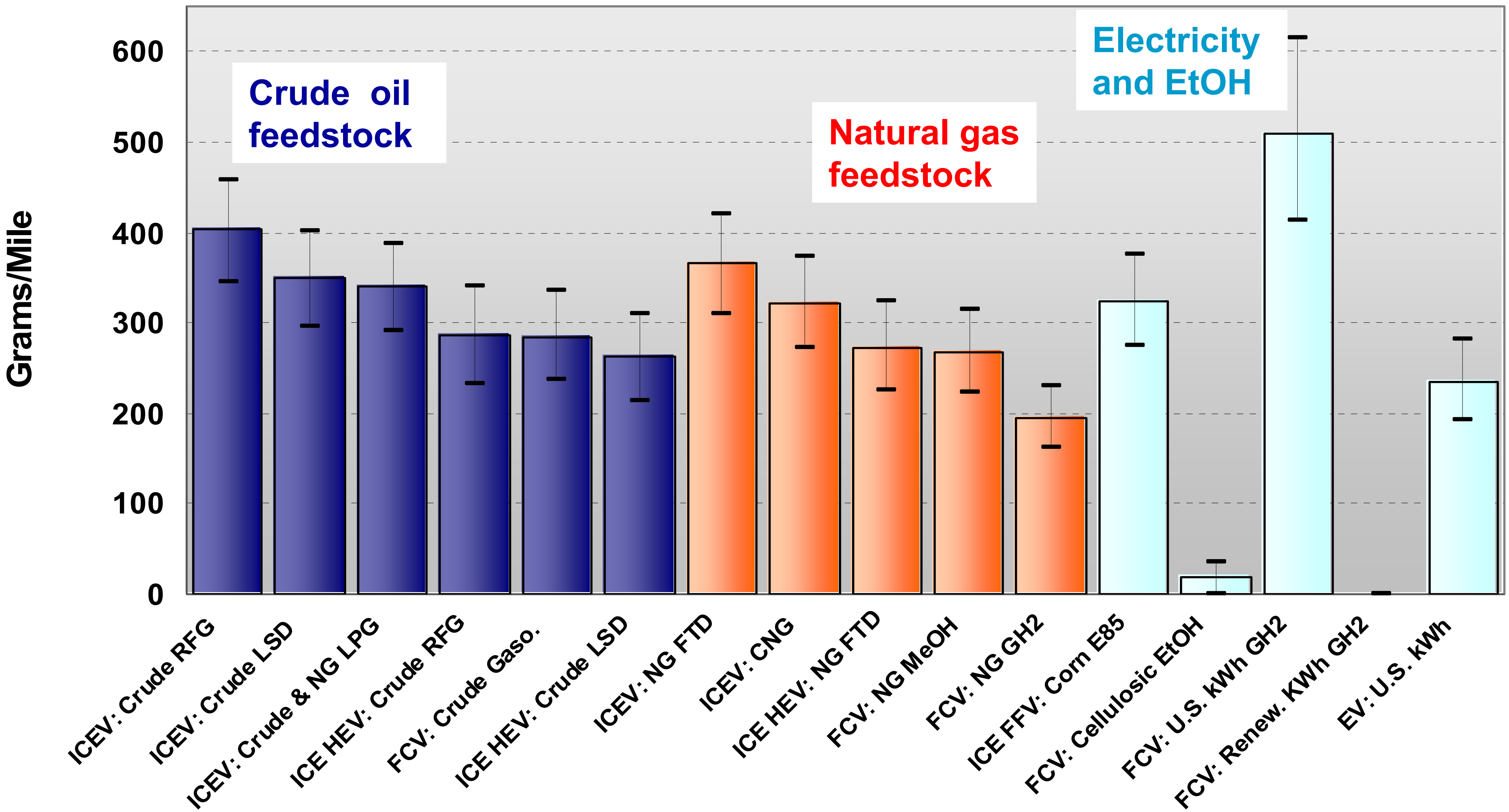
WTW Total Energy Use of Selected Vehicle/Fuel Systems



WTW Fossil Energy Use of Selected Vehicle/Fuel Systems



WTW GHG Emissions of Selected Vehicle/Fuel Systems



GM/ANL Study Takes the Following Key Assumptions for PTW Emissions

2010 MY Vehicle Emissions Targets

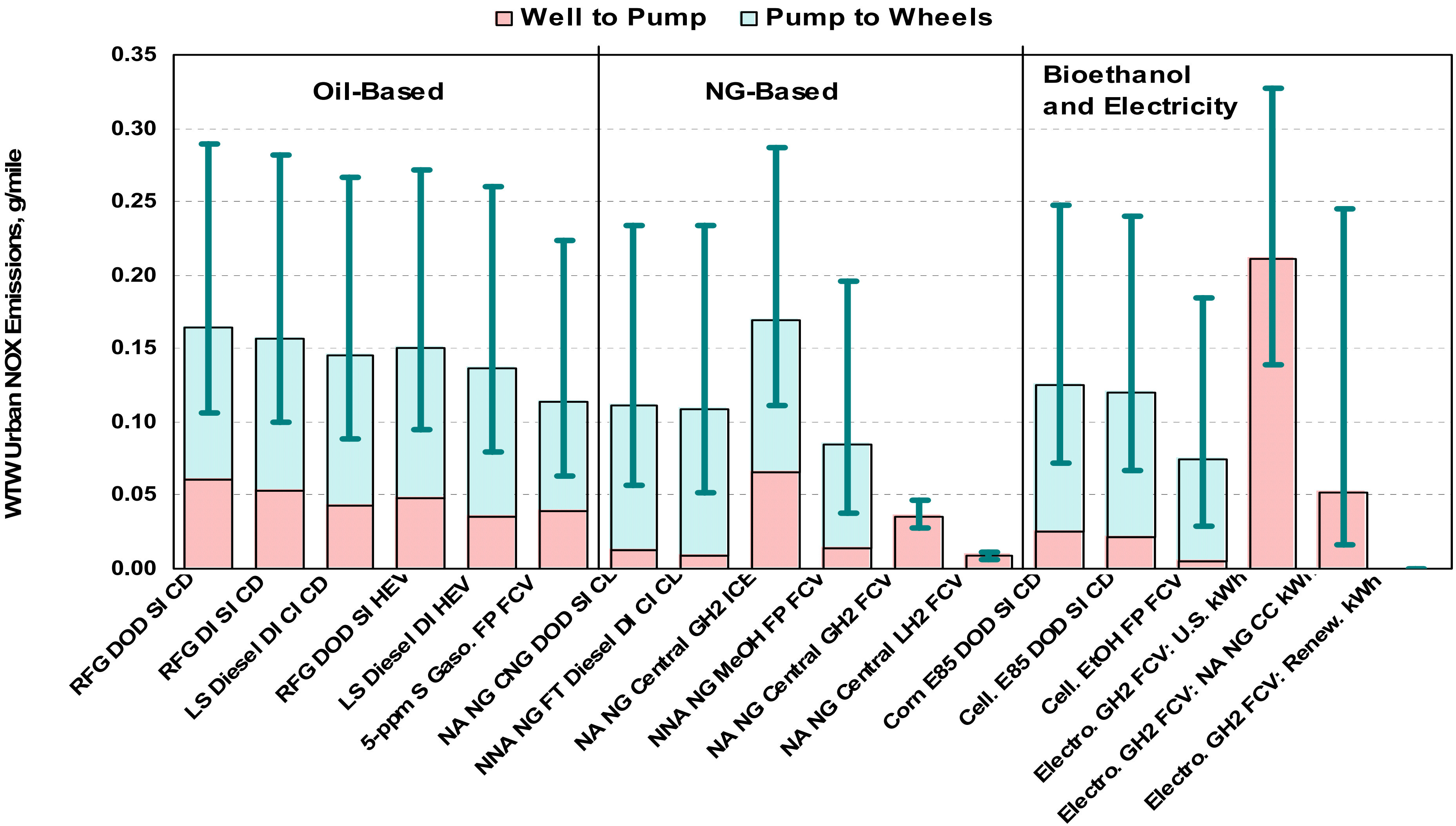
Propulsion System	Assumed Emission Performance
Gasoline ICE	Tier 2 Bin 5
Diesel and CNG ICE	Tier 2 Bin 5, but no evap VOC
Hydrogen ICE	Tier 2 Bin 2, no evap, Bin 5 NOx
Fuel processor fuel cell	Tier 2 Bin 2
Hydrogen fuel cell	Tier 2 Bin 1 (zero emissions)

- **Fuel consumption penalties of aftertreatment systems to meet standards were considered in the study**
- **Bin 5 diesel has not been demonstrated**
- **MY 2010 vehicle in-use emissions in 2016 were modeled using**
  - **EPA MOBILE 6.2**
  - **ARB EMFAC2002 version 3**

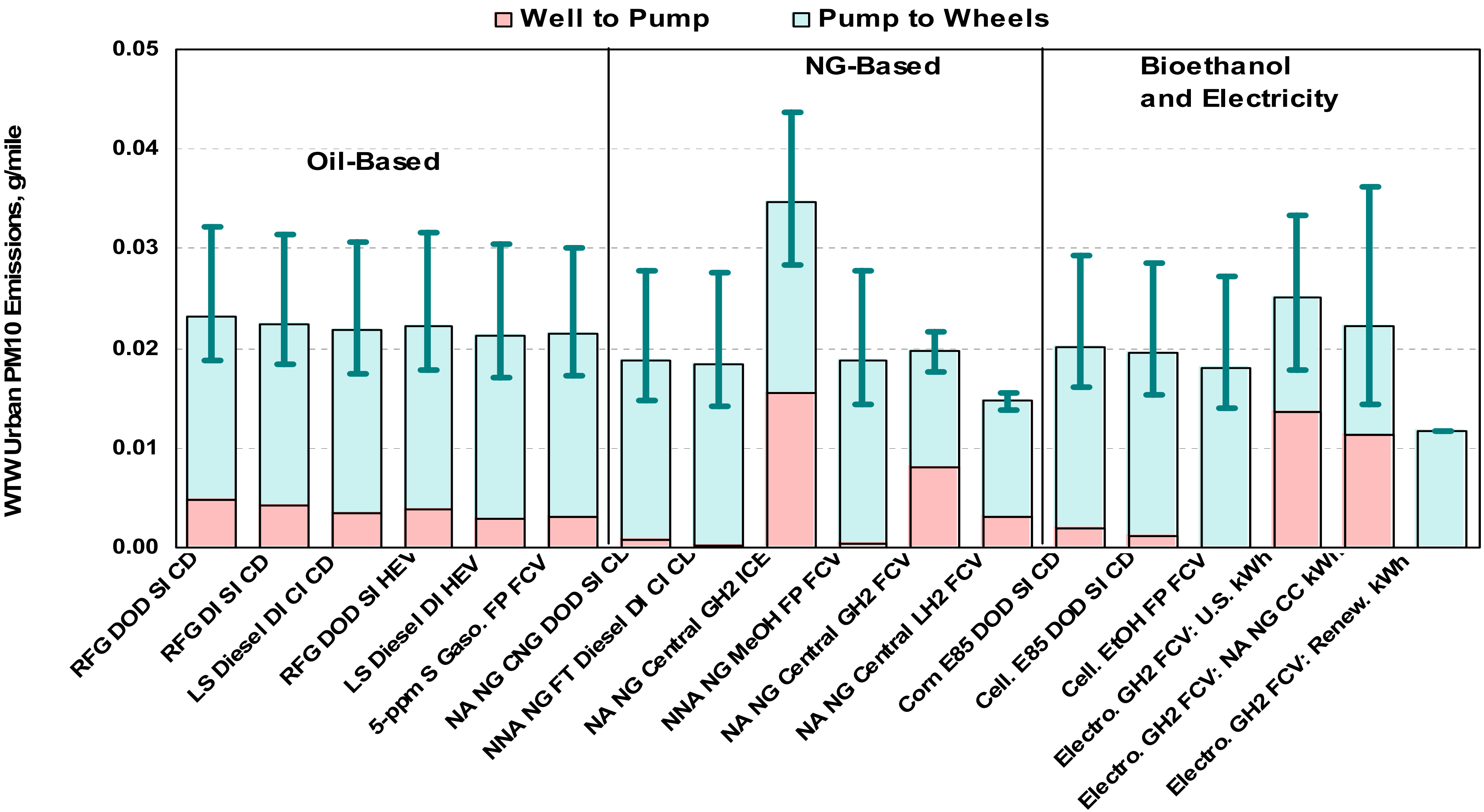
Vehicle/Fuel Technologies for WTW Criteria Pollutant Emission Results

- **Crude oil-based technologies**
  - RFG displacement on demand (DOD) SI conventional drive (CD)
  - RFG DI SI CD
  - LS Diesel DI CI CD
  - RFG DOD SI hybrid
  - LS diesel DI CI hybrid
  - Gasoline fuel-processor (FP) FCV
- **Natural gas-based technologies**
  - CNG DOD SI CD
  - FT diesel DI CI CD
  - G.H2 SI CD
  - MeOH FP FCV
  - G.H2 FCV
  - L.H2 FCV
- **Bioethanol and electricity**
  - Corn E85 DOD SI CD
  - Cellulosic E85 DOD SI CD
  - Cellulosic EtOH FP FCV
  - U.S. average electri.-to-G.H2 FCV
  - NG CC electri.-to-G.H2 FCV
  - Renewable electricity-to-G.H2 FCV

WTW Urban NO_x Emissions of Selected Vehicle/Fuel Systems



WTW Urban PM_{10} Emissions of Selected Vehicle/Fuel Systems



Conclusions

- WTW analysis becomes necessary when comparing vehicle technologies powered by different fuels
- Advanced vehicle/fuel technologies could significantly reduce energy use and GHG and criteria pollutant emissions
- Fuel pathways need to be carefully examined with respect to how advanced vehicle/fuel systems achieve intended energy and emission benefits

The GREET Model and Its Documents Are Available at: *http://greet.anl.gov*

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The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model

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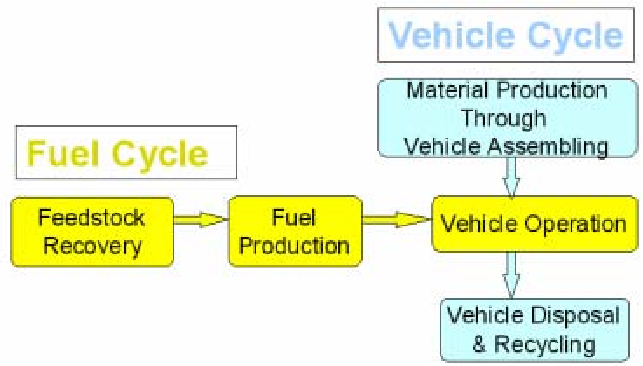
NEW VERSION AVAILABLE FEBRUARY 24, 2003



- How Does GREET Work?
- Uses of GREET
- Download of the GREET Model
- Publications and Presentations
- Posters

How Does GREET Work?

To fully evaluate energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from wells to wheels and the vehicle cycle through material recovery and vehicle disposal need to be considered. Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne has developed a fuel-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle basis.