Well-to-Wheels Analysis with the GREET Model

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2005 DOE Hydrogen Program Review

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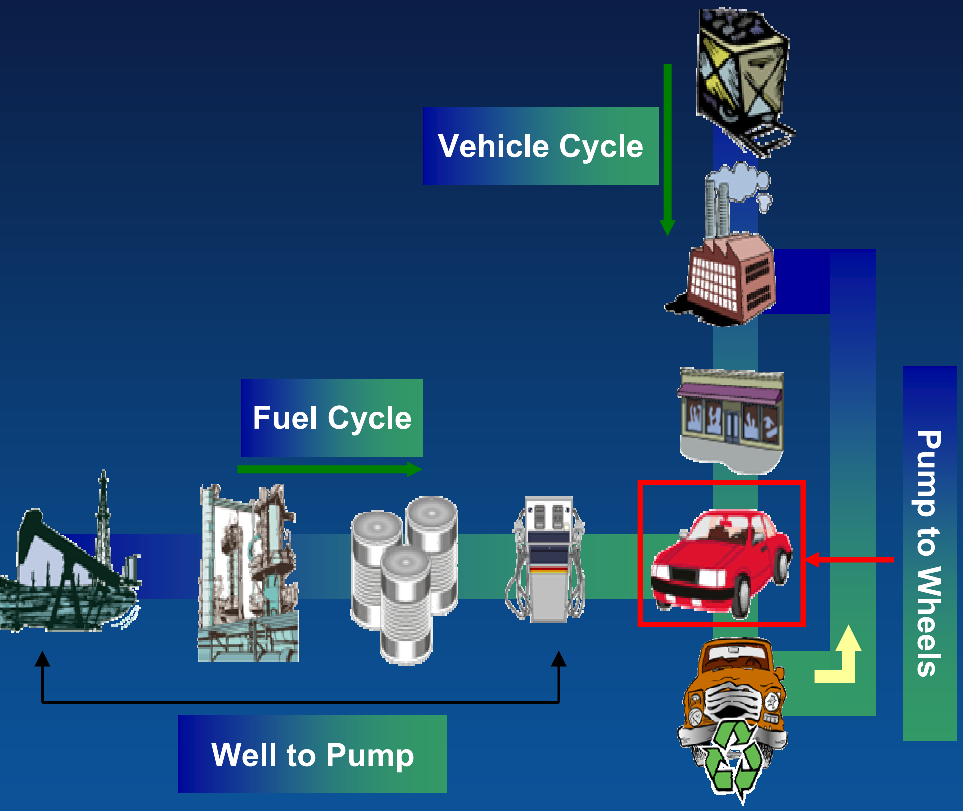
With DOE Support, Argonne Developed the GREET Model for Well-to-Wheels Analysis



Key GREET Features:

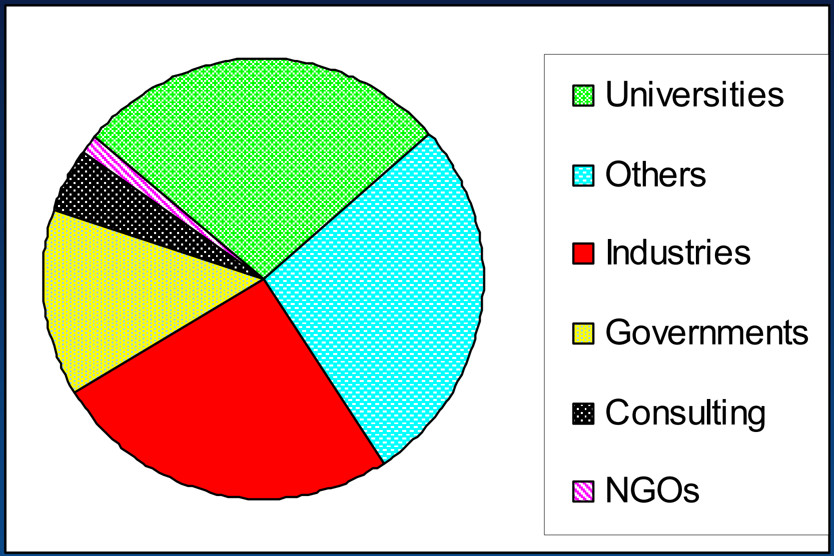
- **Emissions of greenhouse gases**
  - ✓ CO_2, CH_4, and N_2O
- **Emissions of five criteria pollutants**
  - ✓ Total and urban separately
  - ✓ VOC, CO, NO_x, SO_x, and PM_{10}
- **Energy use**
  - ✓ All energy sources
  - ✓ Fossil fuels (petroleum, NG, coal)
  - ✓ Petroleum

- **GREET and its documents are available at http://www.transportation.anl.gov /software/GREET/index.html**
- **Argonne has had major collaborative efforts with General Motors and EPA**

Objectives of GREET Development

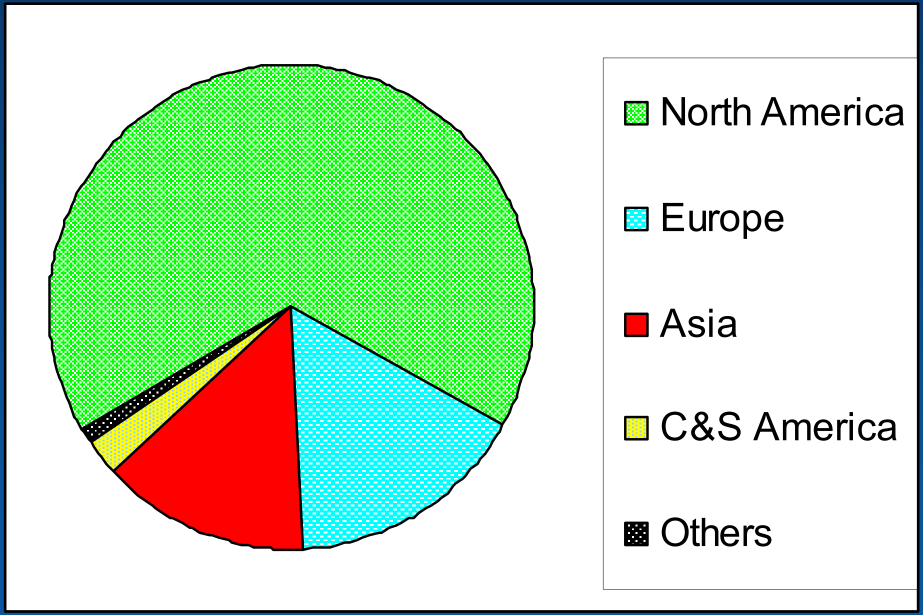
- The model can be used to evaluate energy and emission effects of vehicle/fuel systems on a consistent basis
- The model needs to be transparent in methodologies, data, and key assumptions
- The model needs to be user-friendly so that users can readily use it
- The model needs to be widely available so that governments and industries can use it

At Present, There Are More Than 1,900 GREET Registered Users Worldwide

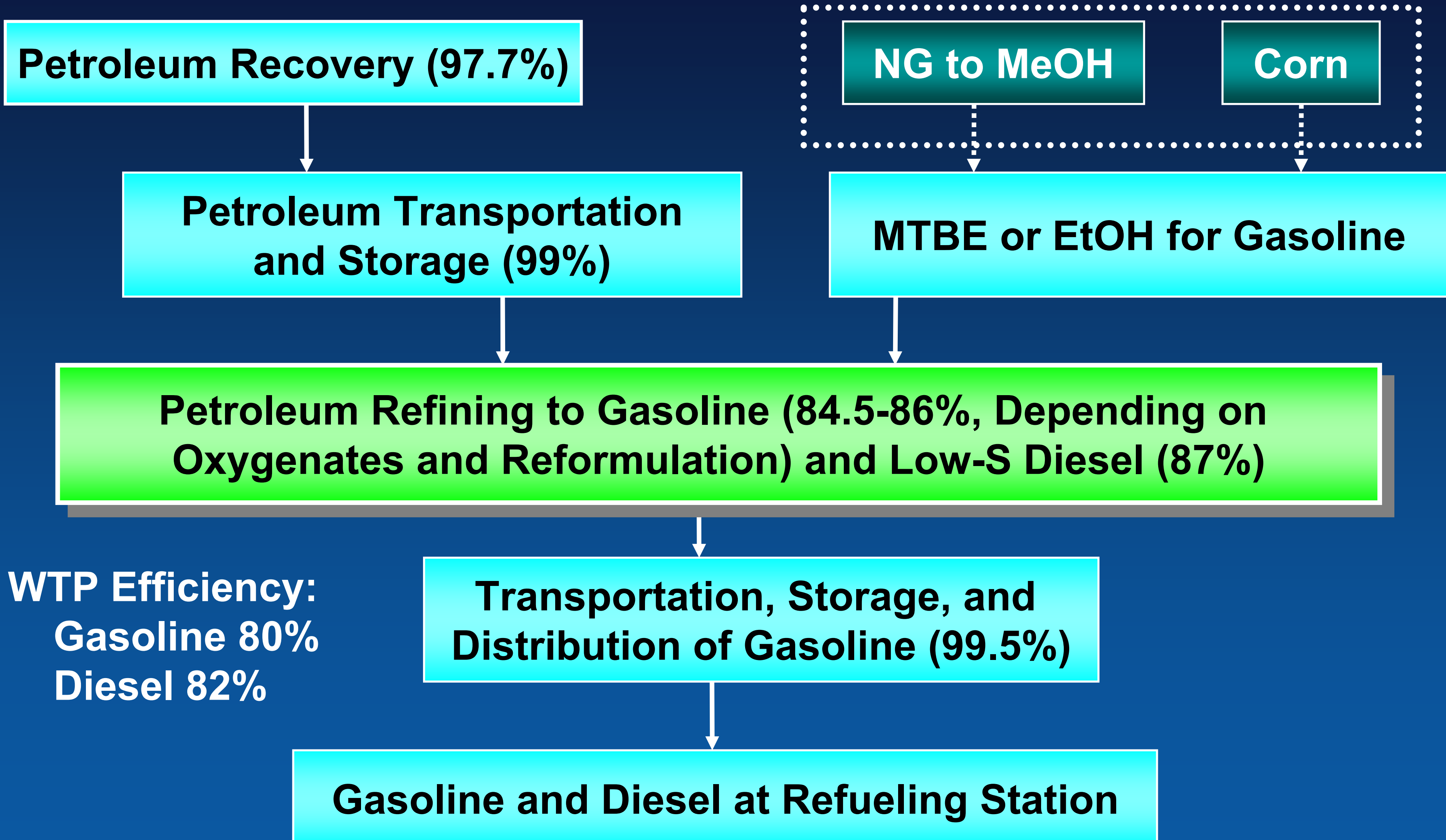


GREET users are primarily in universities, industries, and governments

They are primarily in North America, Europe, and Asia

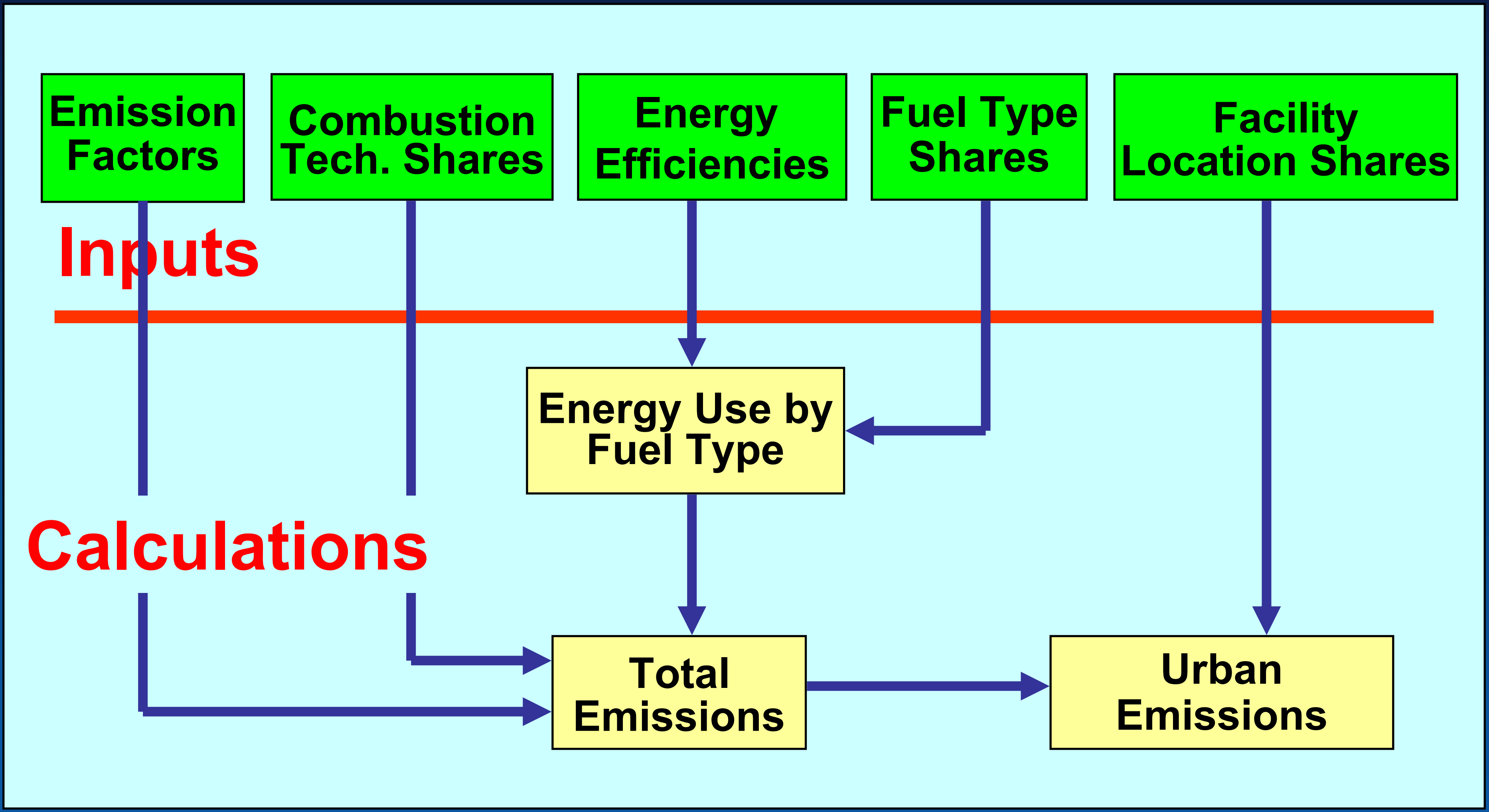


Well-to-Pump Activities for GREET Simulations: Examples of Petroleum Gasoline and Diesel

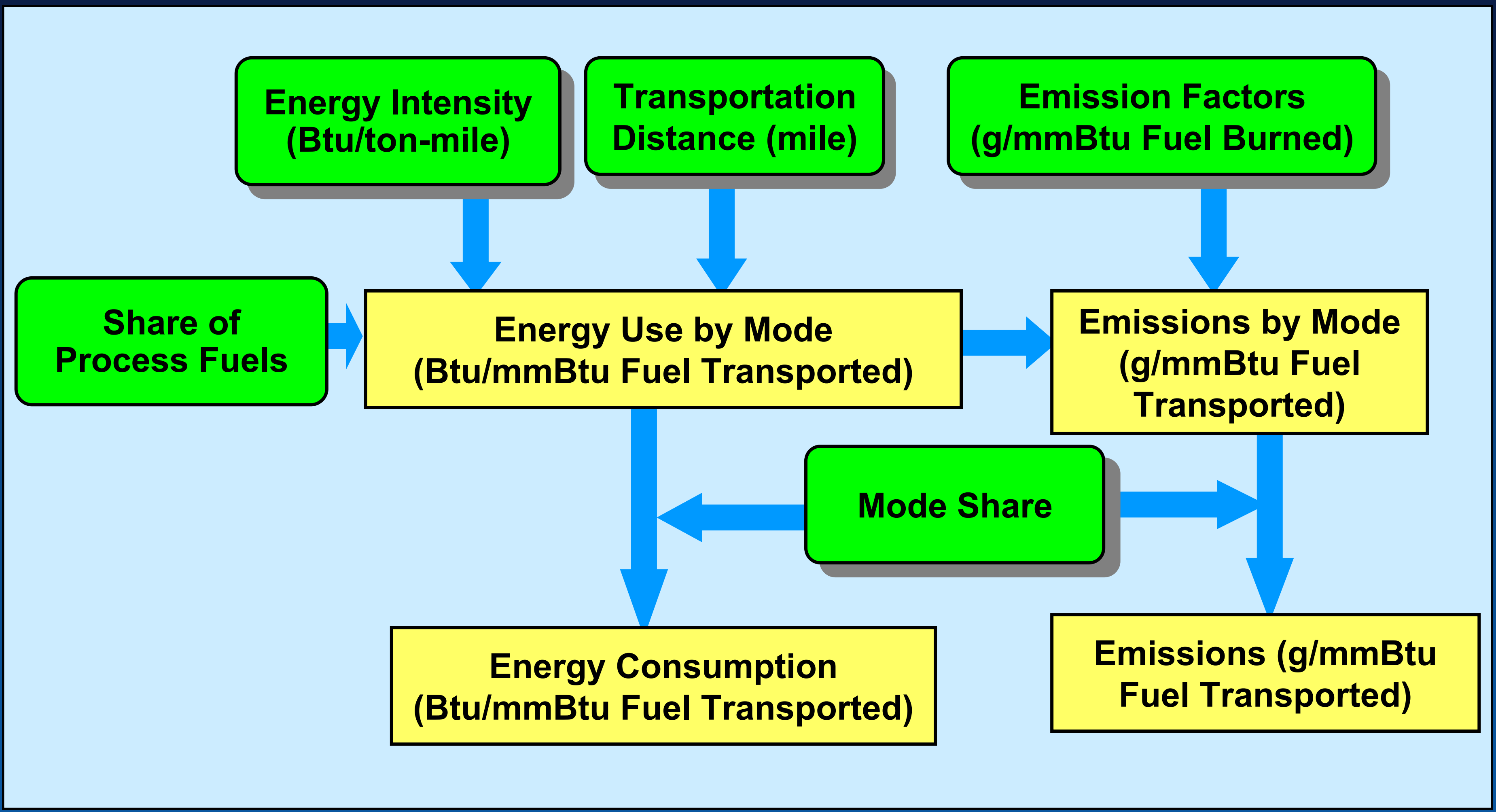


WTP Efficiency:
- Gasoline 80%
- Diesel 82%

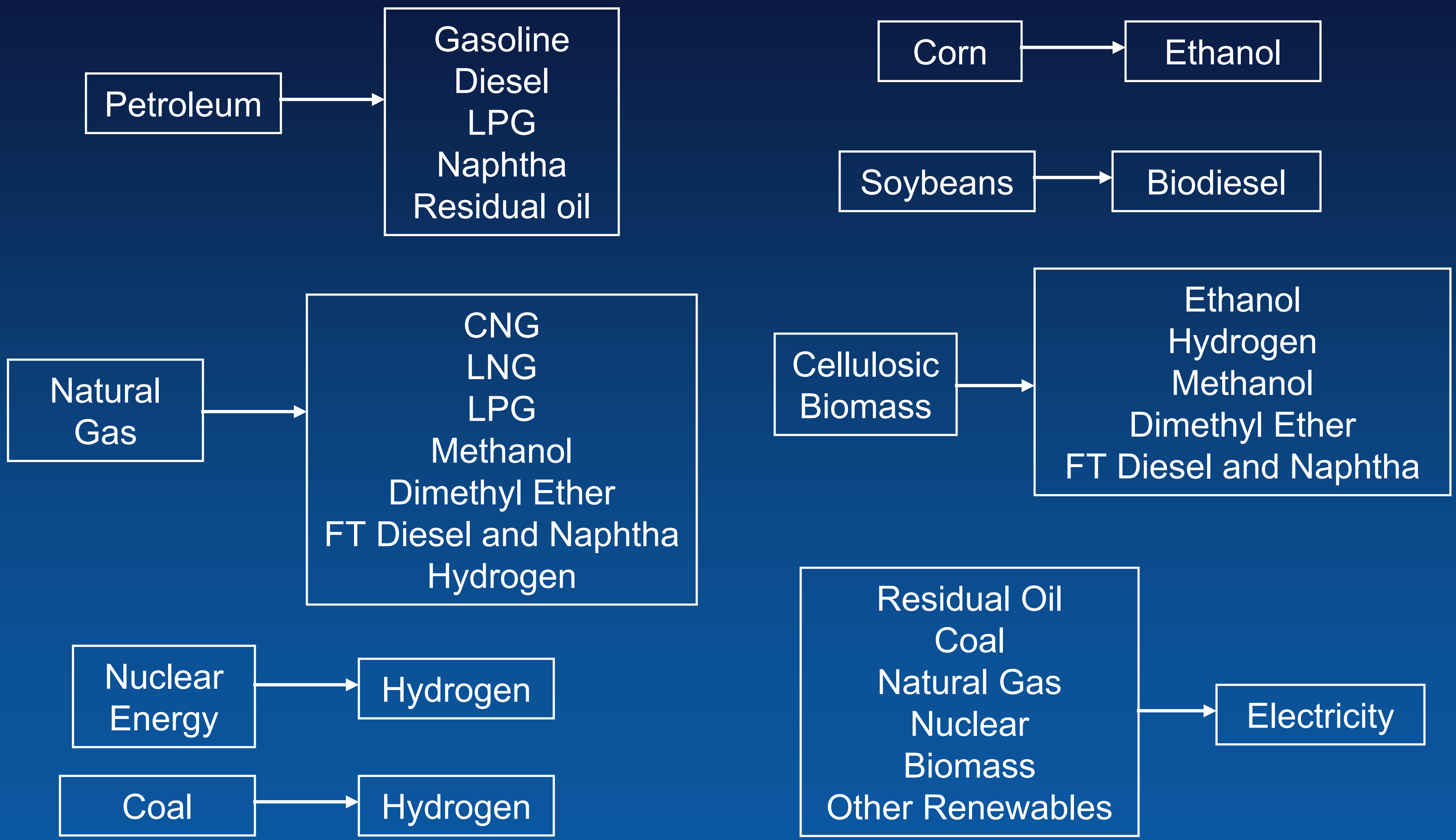
Calculation Logic for a Given Well-to-Pump Production Activity in GREET



Calculation Logic for a Given Well-to-Pump Transportation Activity in GREET



GREET Includes Transportation Fuels from Various Energy Feedstocks



Hydrogen Could Be Produced from NG at Station to Avoid Expensive Distribution

WTP Efficiency: 59%

NA NG Recovery (97.5%)

↓

NA NG Processing (97.5%)

↓

NG Transport via Pipelines

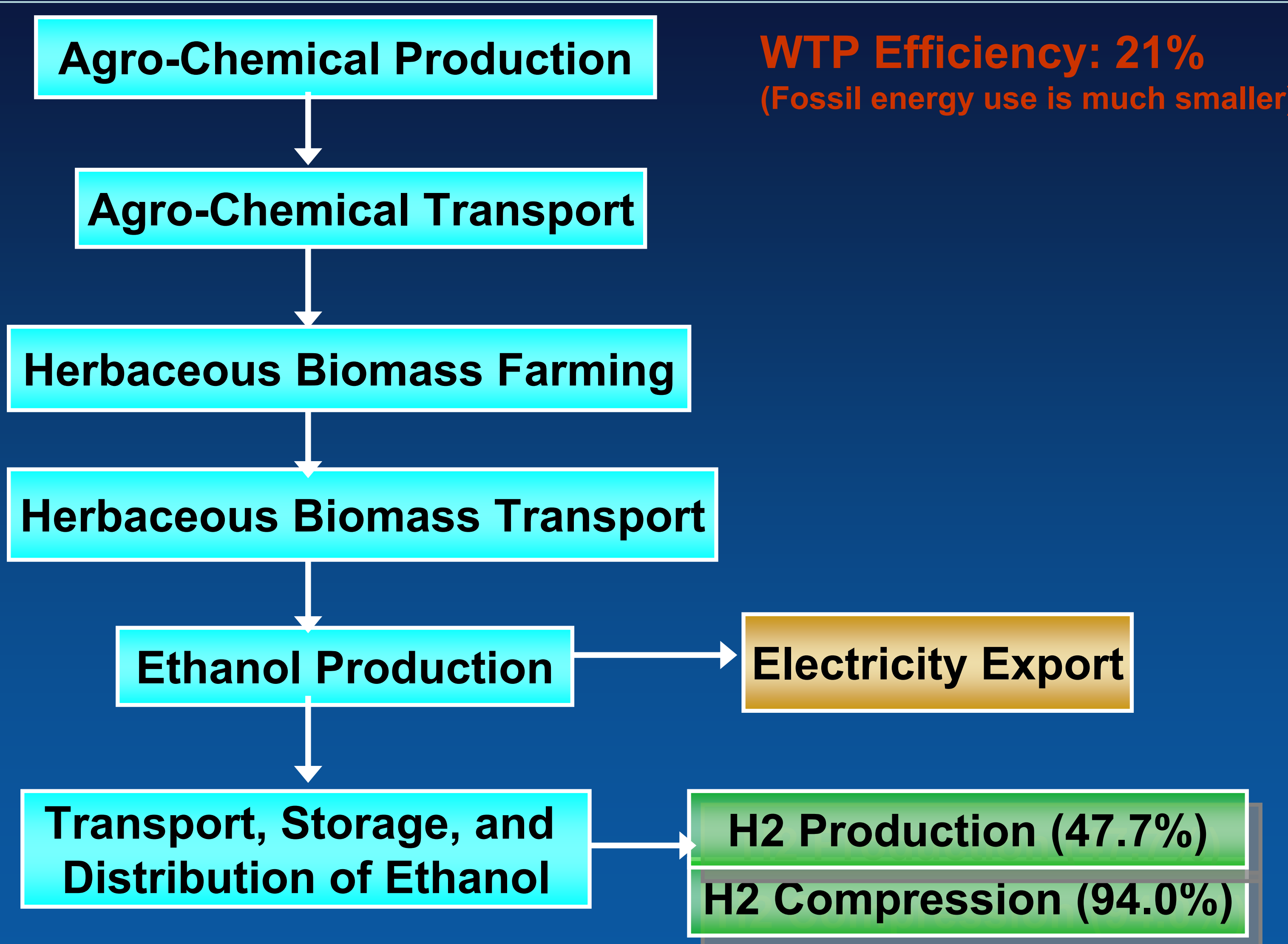
↓

G.H2 Production (70.5%)

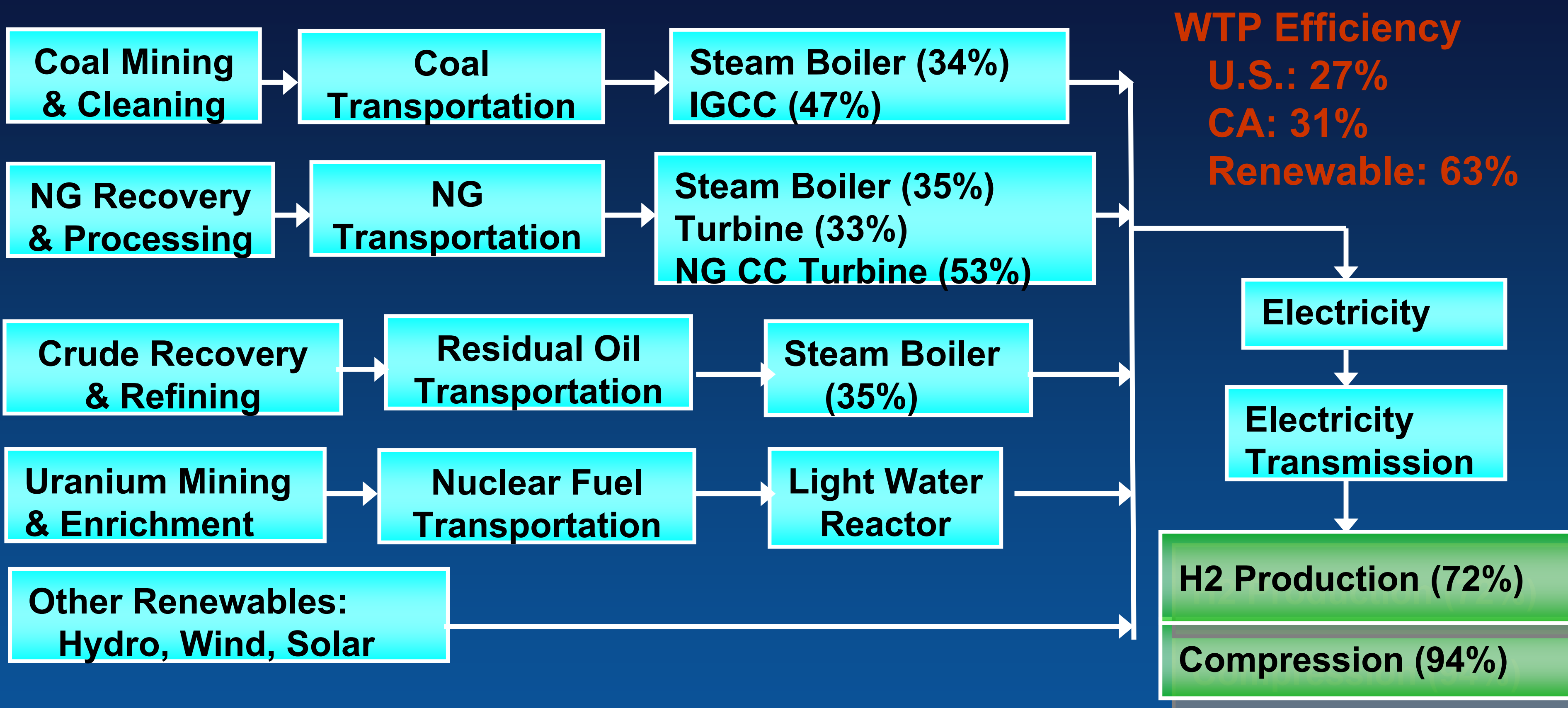
G.H2 Compression at Refueling Station (94.0% for Electric Compressor)

G.H2: gaseous H2
NA: North American
NG: natural gas

Renewable Hydrogen Could Be Produced from Cellulosic Ethanol at Station



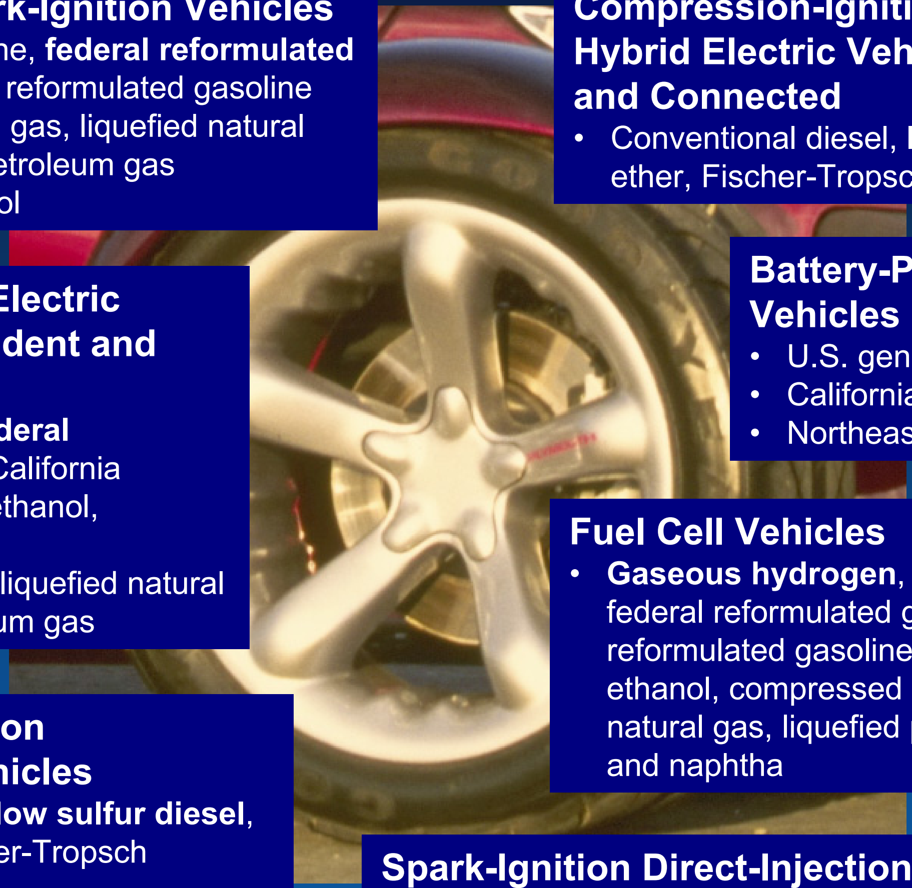
Electrolysis Hydrogen Could Serve As a Transition Option



Mix	Coal	NG	Nuclear	Oil	Others
US	50.2%	20.6%	17.7%	1.7%	9.9%
CA	19.1%	38.4%	16.2%	0.5%	25.7%

IGCC – Integrated gasification combined cycle
NGCC – Natural gas combined cycle

GREET Includes More Than 50 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
- Methanol and ethanol

Compression-Ignition Direct-Injection Hybrid Electric Vehicles: Grid-Independent and Connected

- Conventional diesel, **low sulfur diesel**, dimethyl ether, Fischer-Tropsch diesel, and biodiesel

Spark-Ignition Hybrid Electric Vehicles: Grid-Independent and Connected

- Conventional gasoline, **federal reformulated gasoline**, California reformulated gasoline, methanol, and ethanol
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas

Battery-Powered Electric Vehicles

- U.S. generation mix
- California generation mix
- Northeast U.S. 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, and biodiesel

Spark-Ignition Direct-Injection Vehicles

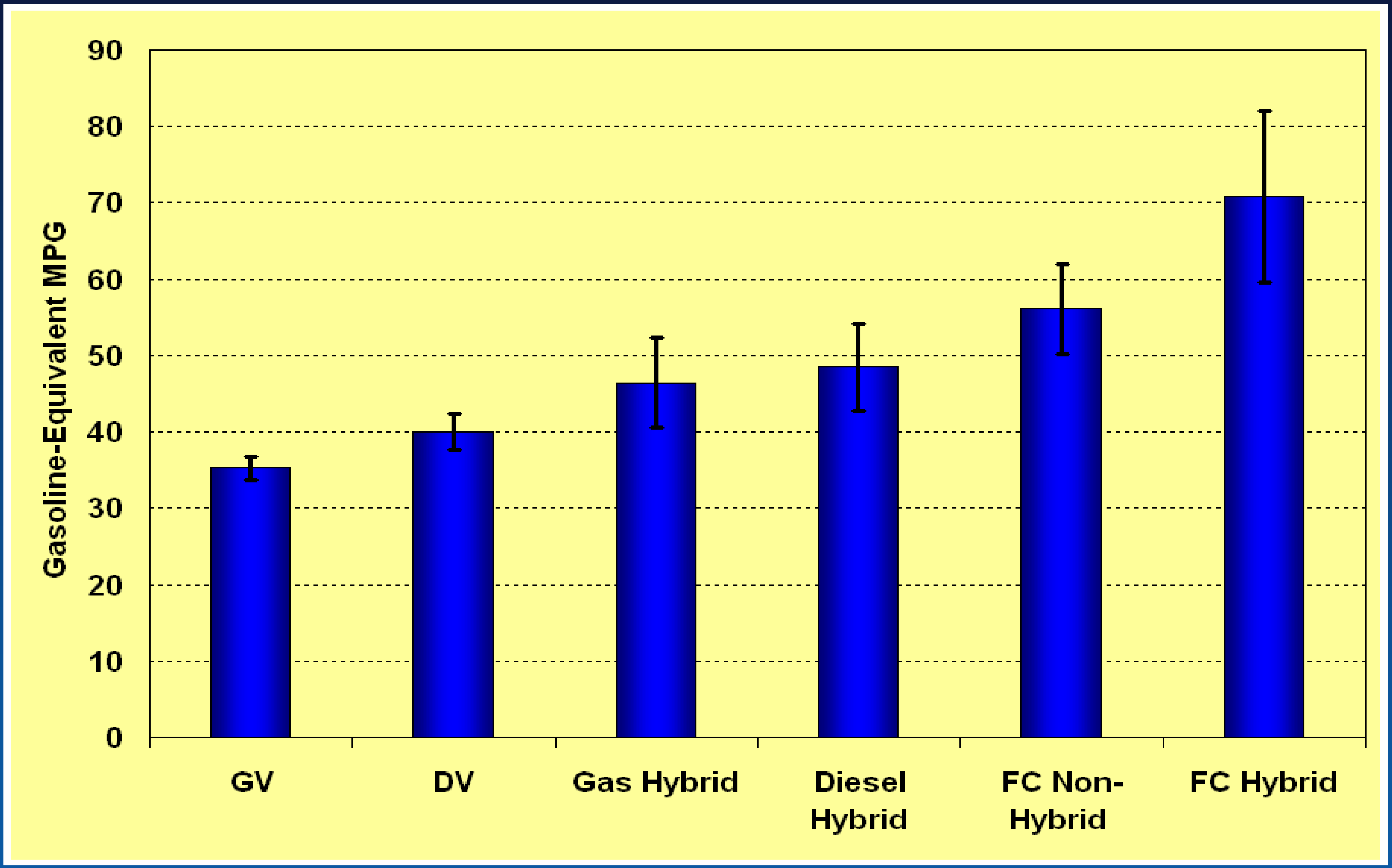
- Conventional gasoline, federal reformulated gasoline, and California reformulated gasoline
- Methanol and ethanol

The PSAT Model Was Used to Estimate Fuel Economy for a 2010 Model-Year Midsize Car

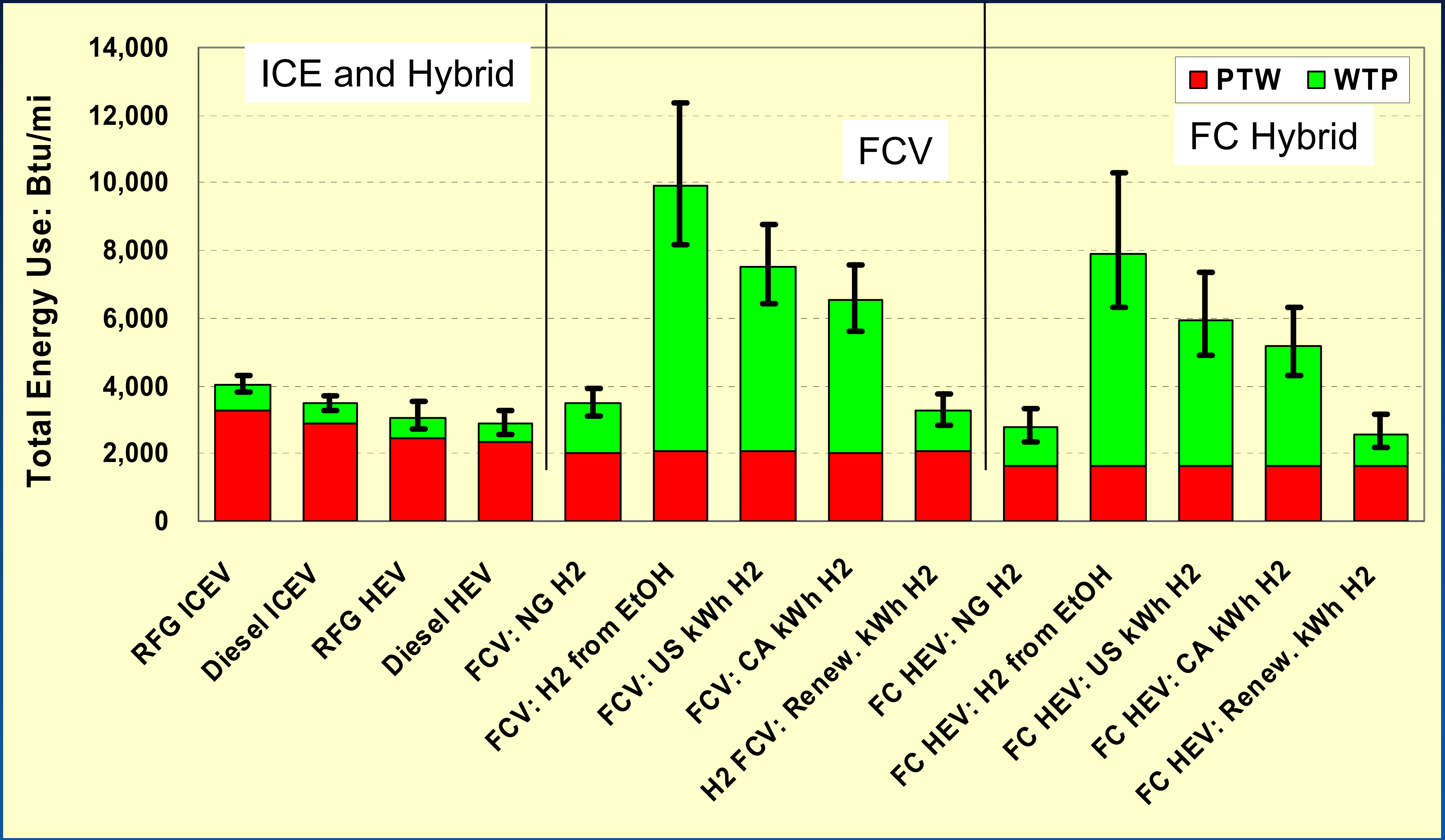
	Slow Technology	Fast Technology
Body-in-White Mass (kg)	988	889
Specific Power (kW/kg)		
Gasoline Engine	0.8–1.6	1.0–1.8
Diesel Engine	0.60–0.72	0.80–0.90
Fuel Cell System with Storage	0.280	0.322
Motor	1.0	1.3
Battery at 70% SOC	0.74	1.11
Peak Efficiency (%)		
Gasoline Engine	35	38
Diesel Engine	40.5	45
Fuel Cell System	55	60
Gearbox	96	97
Final Drive	97.5	97.5

Values in RED are FreedomCAR 2010 Goals.

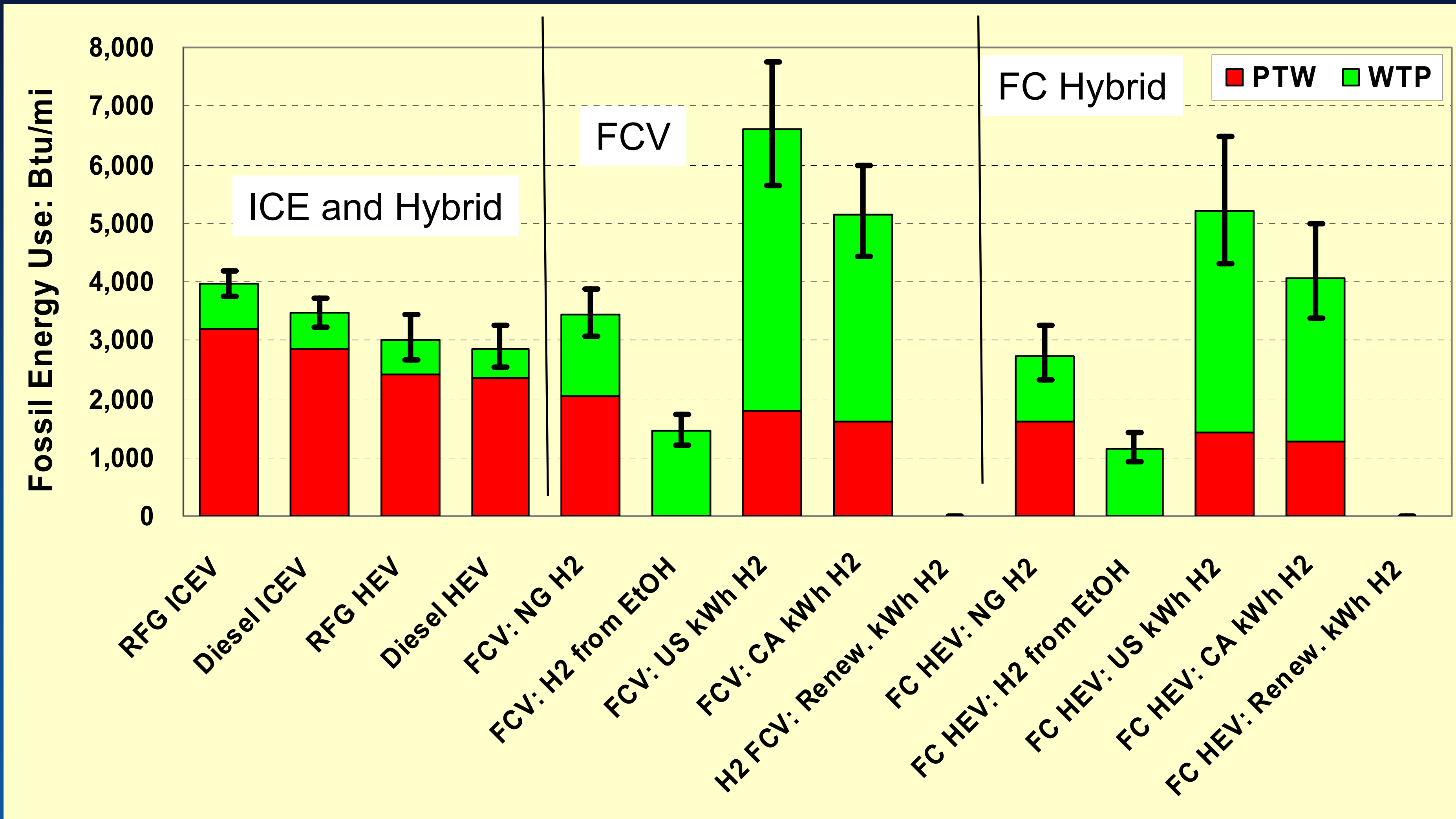
Fuel Economy Values of a 2010 Model-Year Midsize Car from PSAT Simulations



H2 FCVs with Ethanol or Conventional Electricity May Increase WTW Total Energy, But …

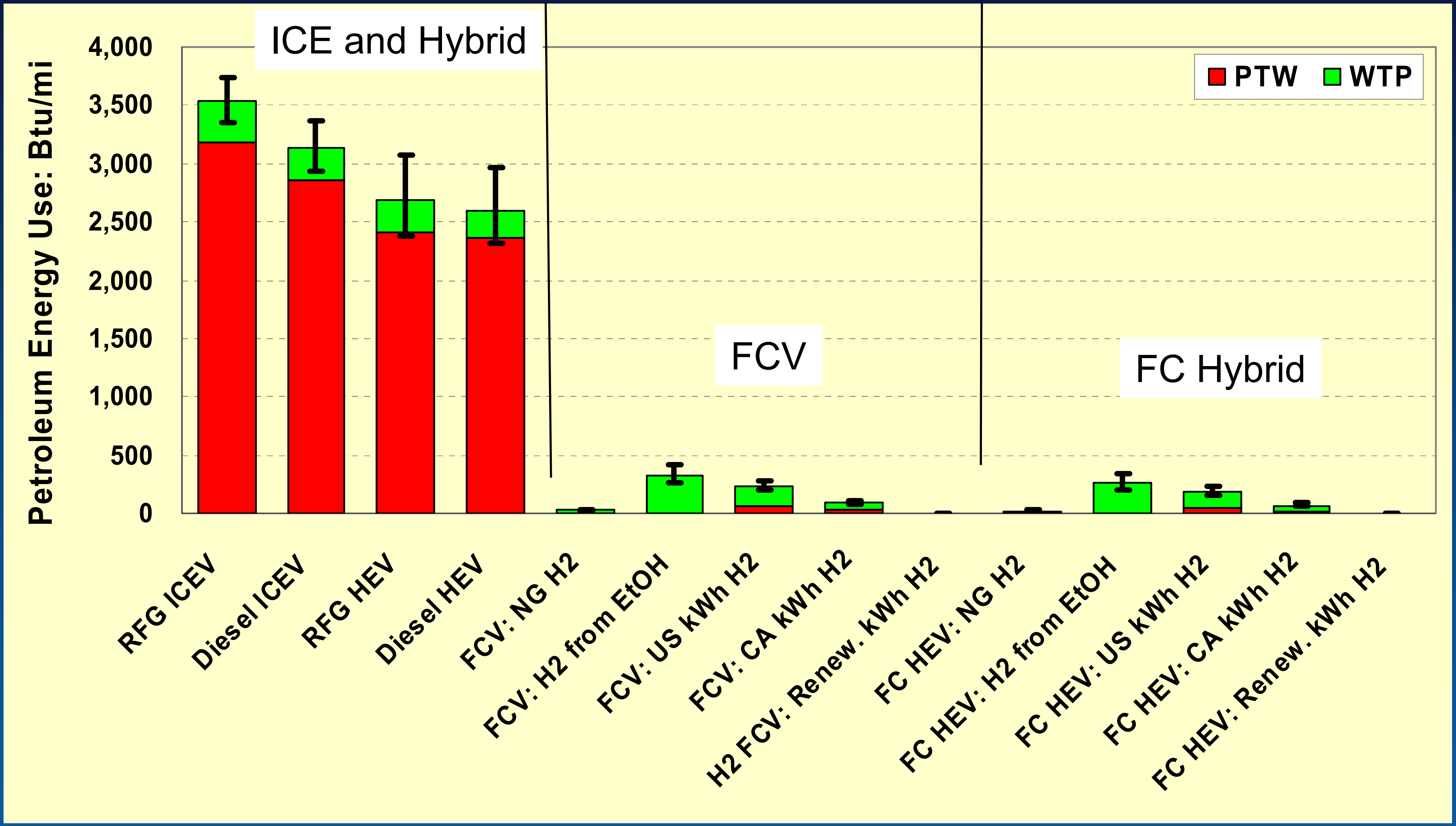


H2 FCVs with Cellulosic Ethanol Reduce WTW Fossil Energy Significantly

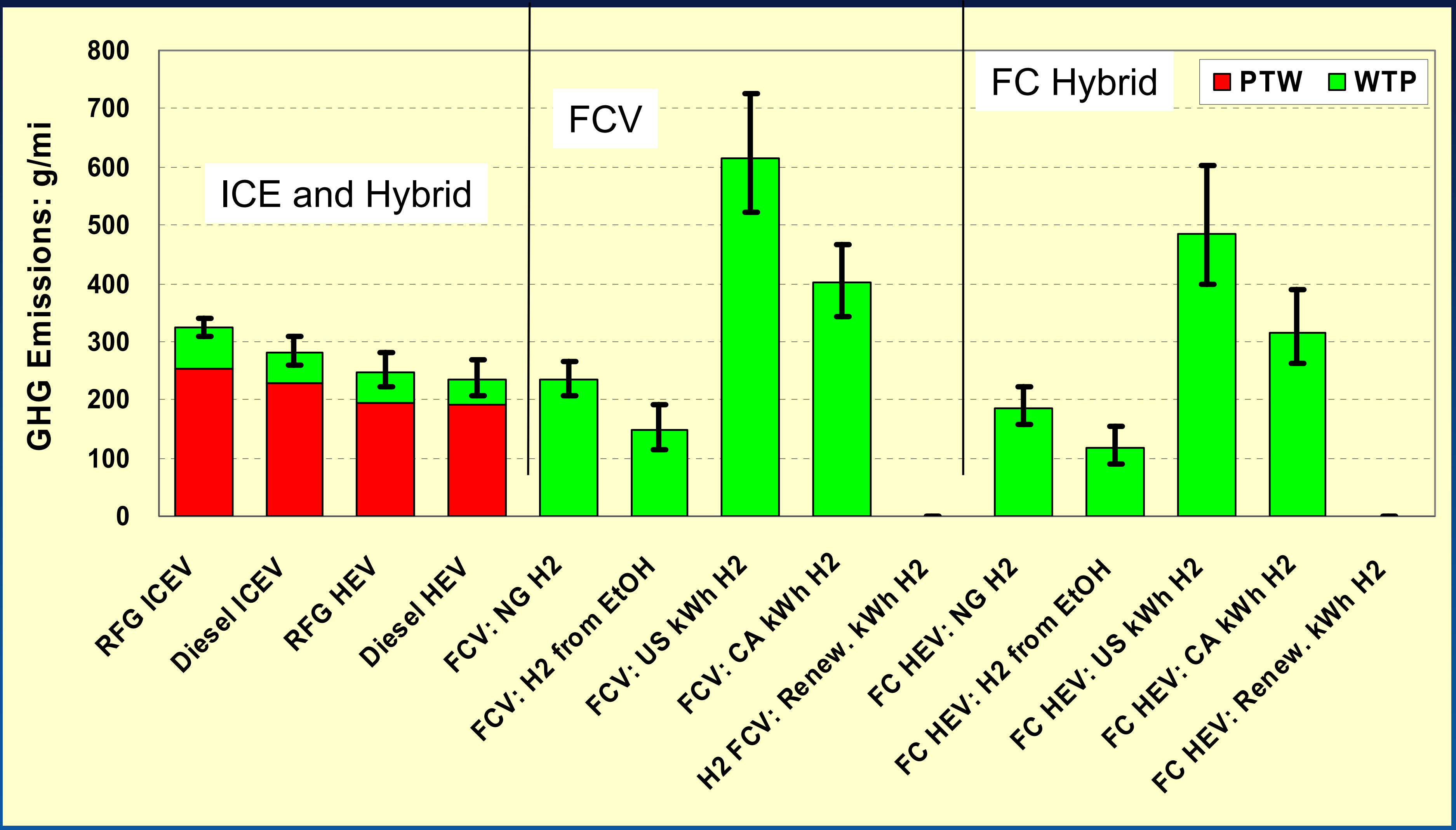


Electrolysis with average electricity may serve only as an early transition option, if at all.

Since H2 Is Produced from Non-Petroleum Sources, H2 FCVs Almost Eliminate Petroleum Use



Except for Average Electricity Options, H2 FCVs Achieve Large GHG Reductions



Concluding Remarks

- Efficiency improvements by H_2 fuel-cell vehicles help reduce oil use and GHG emissions
- Hydrogen production pathways can have significant effects on energy and emission results of H_2 FCVs
- In the long run, renewable H_2 for FCVs offers great energy and emission benefits