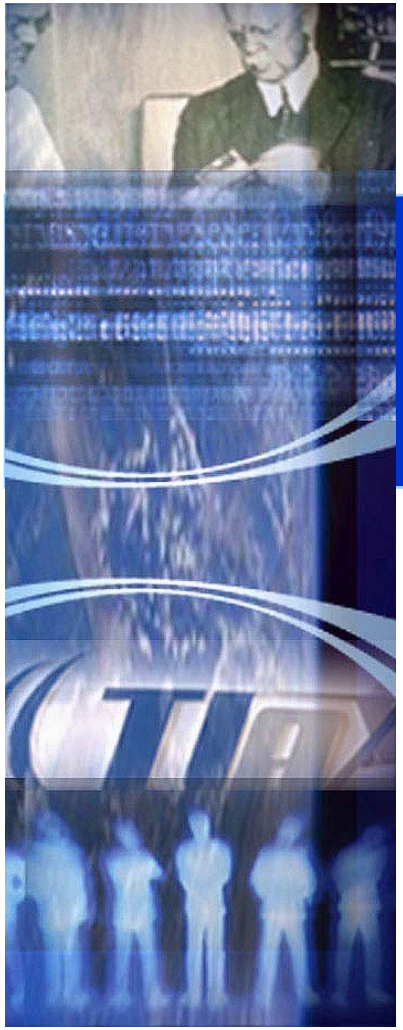


Powered by Innovation since 1886

Full Fuel Cycle Greenhouse Gas Considerations

Southern California Clean Vehicle Expo

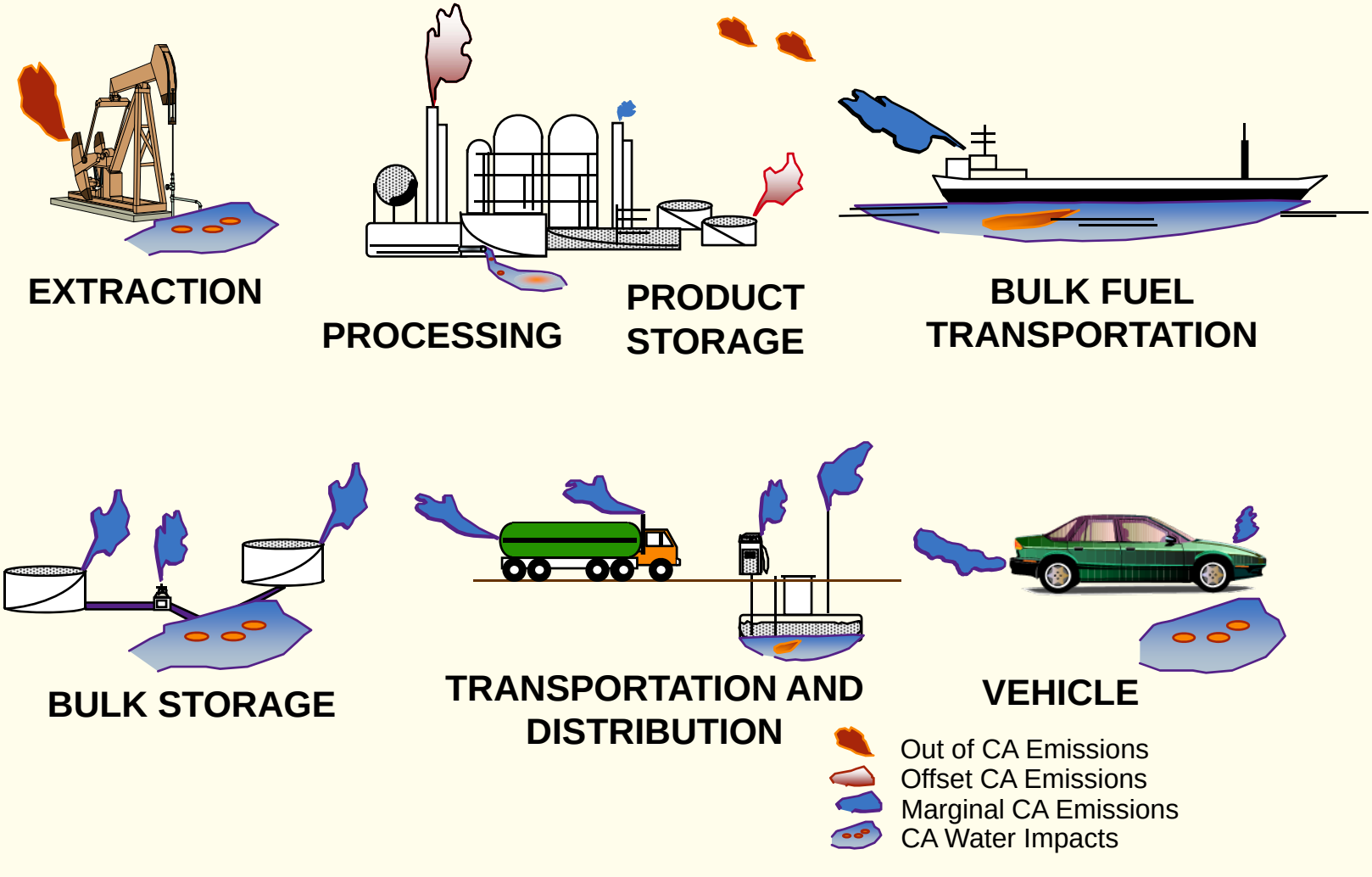
October 14, 2008

Jennifer Pont, TIAX LLC
20813 Stevens Creek Blvd., Suite 250
Cupertino, California 95014-2107
pont.jennifer@tiaxllc.com
(408) 517-1573

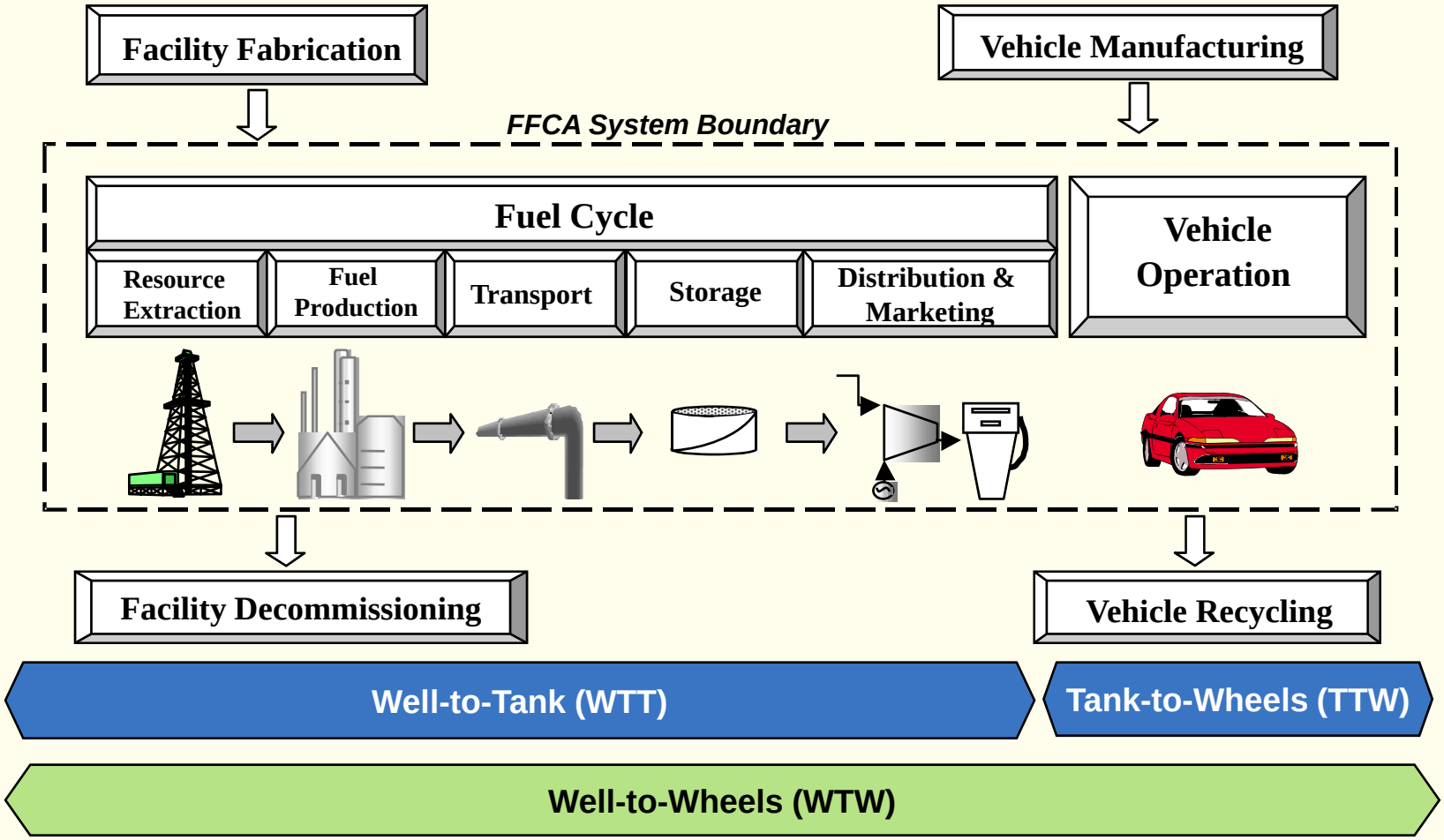
- What is Well-to-Wheel Analysis?
- Why Use WTW Analysis?
- How are WTW Emissions Quantified?
- WTW Results

- **What is Well-to-Wheel (WTW) Analysis?**
- **Why Use WTW Analysis?**
- **How are WTW Emissions Quantified?**
- **WTW Results**

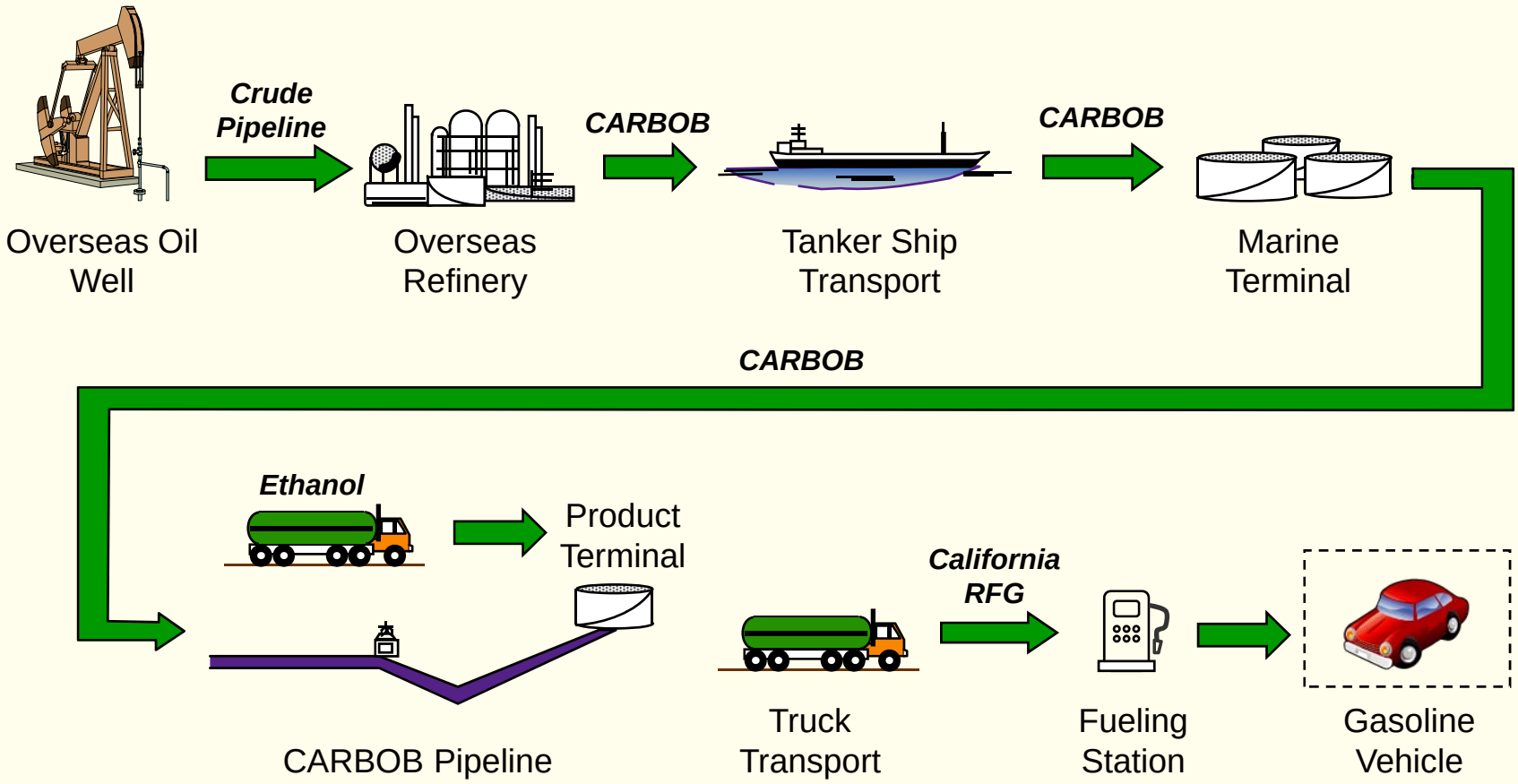
Processes Included in the Fuel Cycle



Processes Included in Fuel Cycle

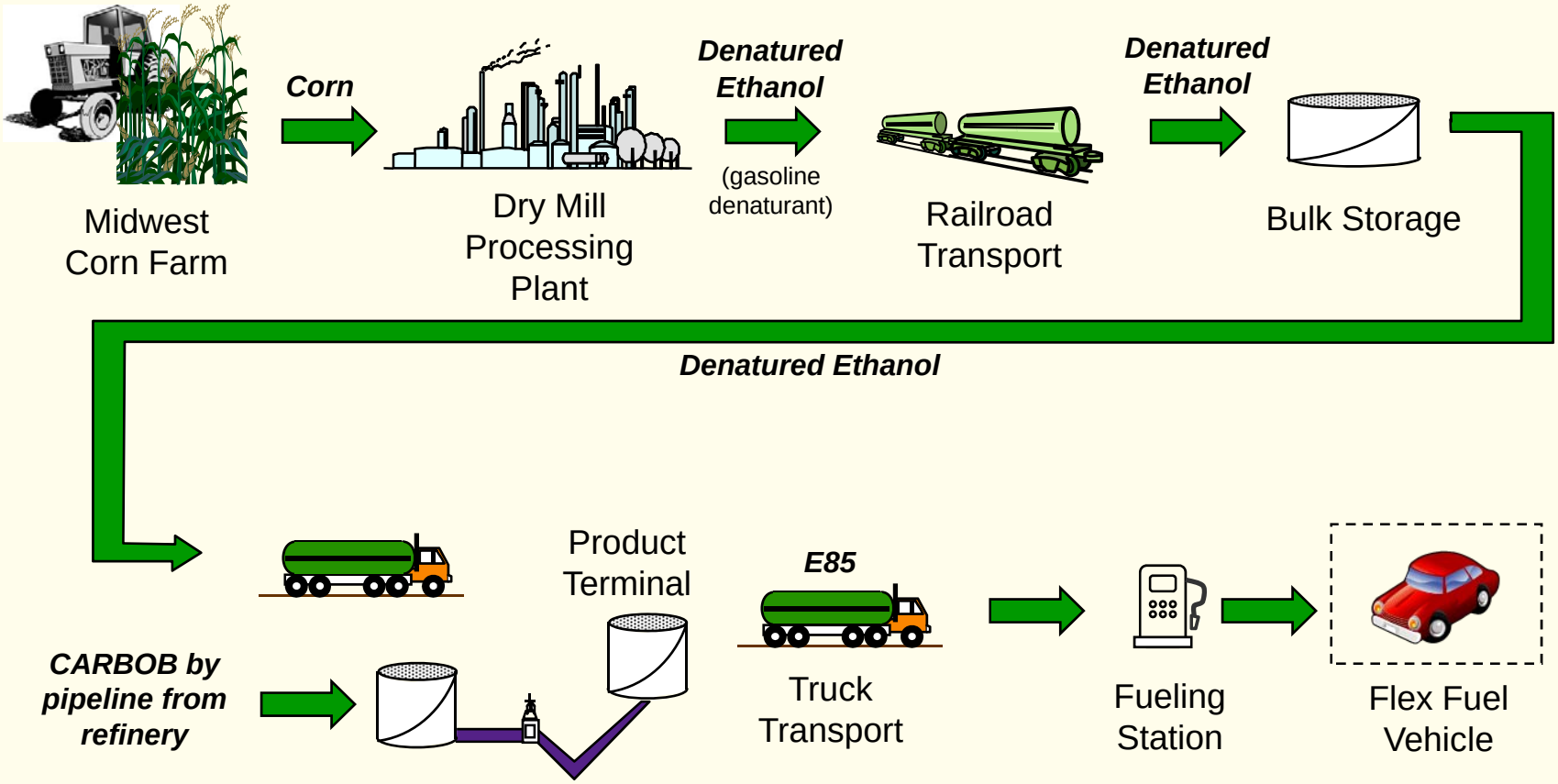


Example Pathway: Imported CARBOB from Middle East to California RFG



This schematic illustrates the sources of direct emissions and energy consumption, but the analysis also includes indirect emissions that are "upstream" of these sources.

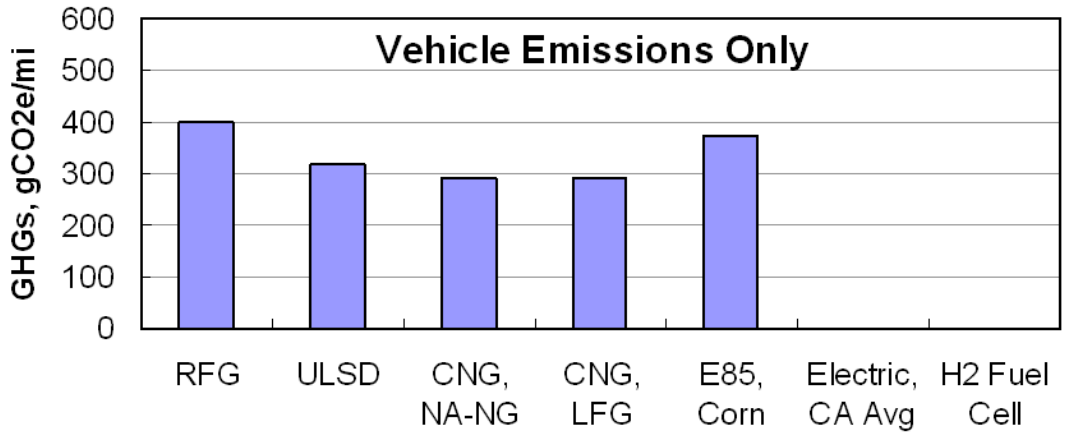
Example Pathway: Midwest Corn Ethanol Pathway to E85

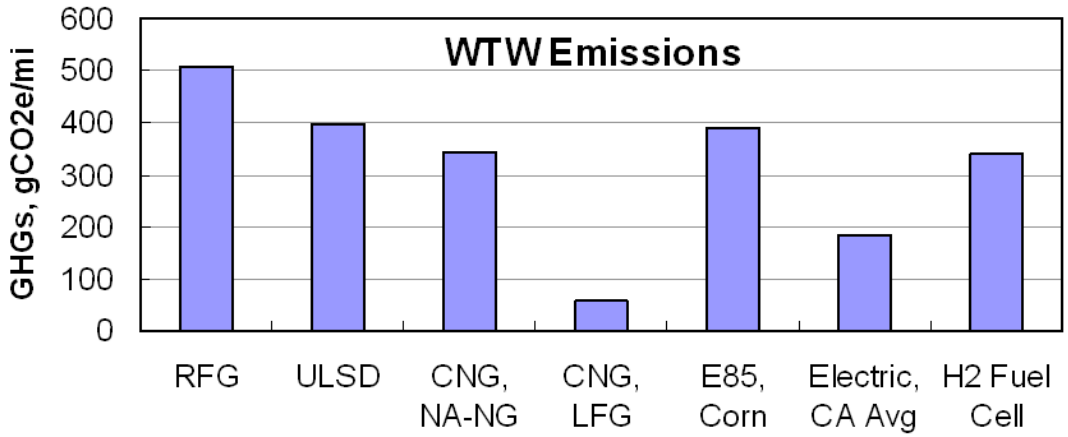


This schematic illustrates the sources of direct emissions and energy consumption, but the analysis also includes indirect emissions that are "upstream" of these sources.

- What is Well-to-Wheel (WTW) Analysis?
- **Why Use WTW Analysis?**
- How are WTW Emissions Quantified?
- WTW Results

If we only consider vehicle tailpipe emissions, transportation fuels are not compared on an equitable basis





- Importance of WTT portion varies among fuel types
- Utilizing renewable feedstocks can significantly reduce WTW emissions

California Policy on Transportation Fuels Utilizes WTW Estimates

- Low Carbon Fuel Standard
  - Governor's Executive Order S-1-07 and AB-32 Early Action Measure
  - Requires gasoline and diesel fuel suppliers to reduce **WTW carbon intensity** by 10% by 2020
  - ARB currently in rulemaking process
- Alternative and Renewable Fuel and Vehicle Technology Program (AB118)
  - Objective to develop and deploy innovative fuel and vehicle technologies
    - Reduce petroleum consumption
    - Improve air quality
    - Reduce **WTW GHG Emissions**
  - Funded at $120 million/yr for 7.5 years
  - Funding awarded as grants, revolving loans, loan guarantees and other appropriate measures to develop and deploy innovative fuel and vehicle technologies that reduce GHG emissions
  - Projects include production technologies, fueling infrastructure, vehicle demonstration and deployment, advanced efficiency technologies, alternative and renewable fuels, accelerated commercialization, workforce training

- What is Well-to-Wheel (WTW) Analysis?
- Why Use WTW Analysis?
- **How are WTW Emissions Quantified?**
- WTW Results

Five values are needed to estimate WTW GHG emissions:

1. **WTT** GHG Emission Factor, gCO2e/MJf
2. Fuel-Based CO2 Emission Factor (**Fuel CO2**), gCO2e/MJ
3. Vehicle Energy Consumption (**VEC**), MJ/mi
4. Vehicle **N2O** emissions, gCO2e/mi
5. Vehicle **CH4** emissions, gCO2e/mi

WTT GHG (g/mi) = **WTT GHG** (g/MJ) X **VEC** (MJ/mi)

TTW GHG (g/mi) = **Fuel CO2** (g/MJ) X **VEC** (MJ/mi) + **CH4** (g/mi) + **N2O** (g/mi)

WTW GHG (g/mi) = WTT GHG (g/mi) + TTW GHG (g/mi)

A number of FFCA models exist and each has its own attributes/drawbacks

- The most prominent FFCA (or LCA) models include:
  - GREET (Developed and supported by Argonne National Lab)
  - LEM (Developed by Mark DeLucchi of UC Davis)
  - GHG Genius (Canadian version of LEM)
  - BESS (University of Nebraska, EtOH only)
- There are a number of other models that may be used to support FFCA models by providing in-depth analysis for specific components
  - FASOM-GHG
  - FAPRI
  - GTAP
- Both EPA and CEC chose the GREET model as their preferred platform
  - Heavily used, reviewed, referenced by analysts, industry, academia
  - Input from EPA, USDA, DOE, and industry
  - Full fuel cycle analysis for a large number of alternative fuels
  - Difference between models generally results from different inputs, not methodology

Key Issues: Biofuels and Land Use Change

- Soils and plant biomass actively store carbon
- Land-use change (LUC) emissions result from modifying the existing vegetation on a piece of land for the purpose of biofuel production
- LUC CO2 emissions result from burning and microbial decomposition of organic matter
- The resulting CO2 emissions need to be amortized and assigned to the biofuel produced
- Recent work (Joseph Fargione, et al & Timothy Searchinger et al) suggests that land-use changes may significantly impact GHG emissions for many biofuels
- Improving agricultural practices and increasing crop yields can counteract
- Because of the uncertainty associated with these indirect emissions, it is not clear how they should be combined with direct emissions from a policy perspective

Examples of Land-Use Change

Direct Land-Use Change

Conservation Reserve Program → Corn Production

Tropical Rainforest → Palm Oil Production

Brazilian Grassland → Sugarcane Production

Indirect Land-Use Change

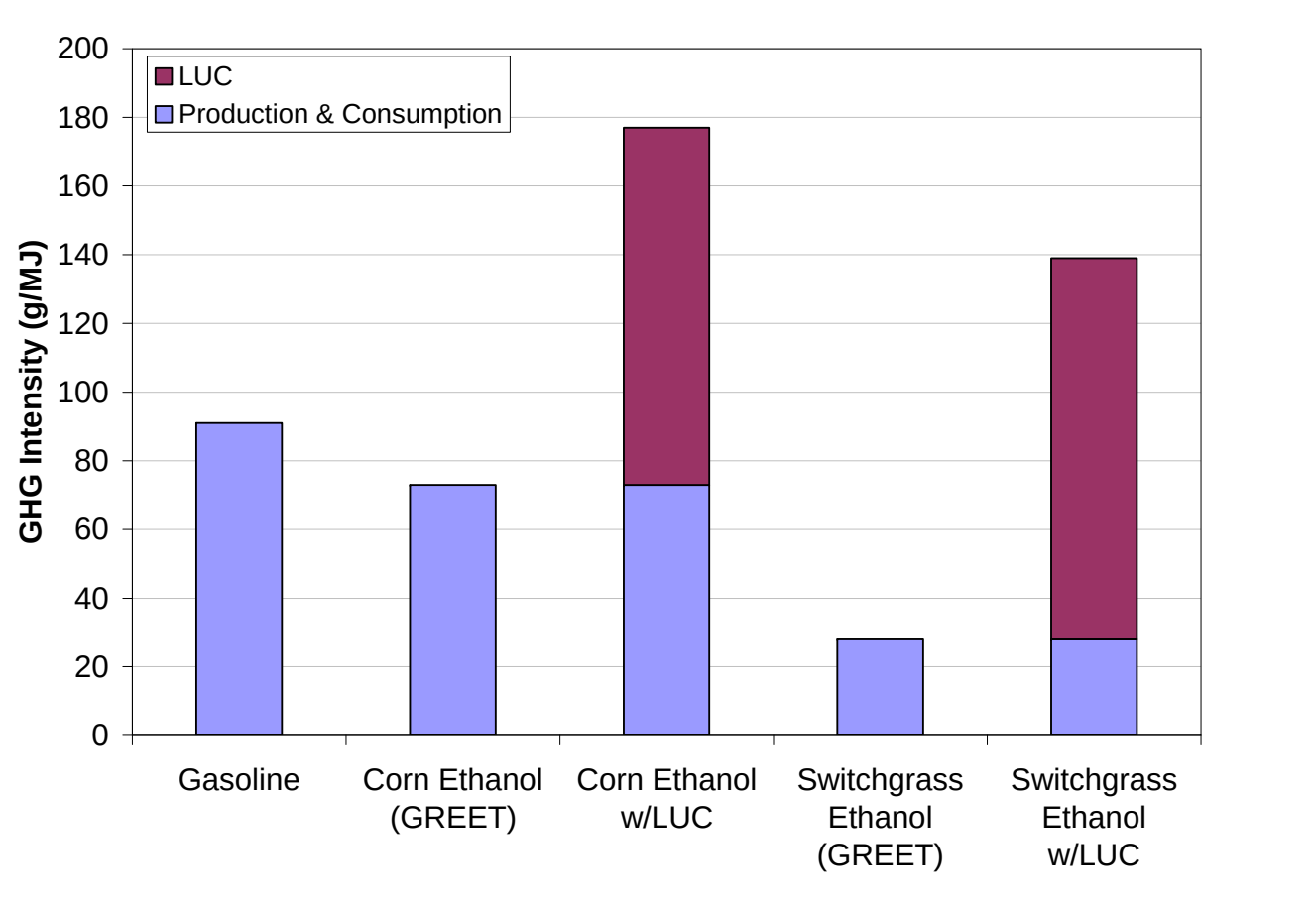
Corn for Food or Feed → Corn for Ethanol

→ Fluctuation in Corn Market

→ Conversion of Brazilian Grassland to Corn Production

A global general equilibrium model of the agriculture industry is necessary to accurately quantify indirect land-use effects

Land-use change may have a large impact on biofuel carbon intensity



***Data Source: Searchinger et al. *Use of U.S. Croplands for Biofuels*, Science, 2008.**

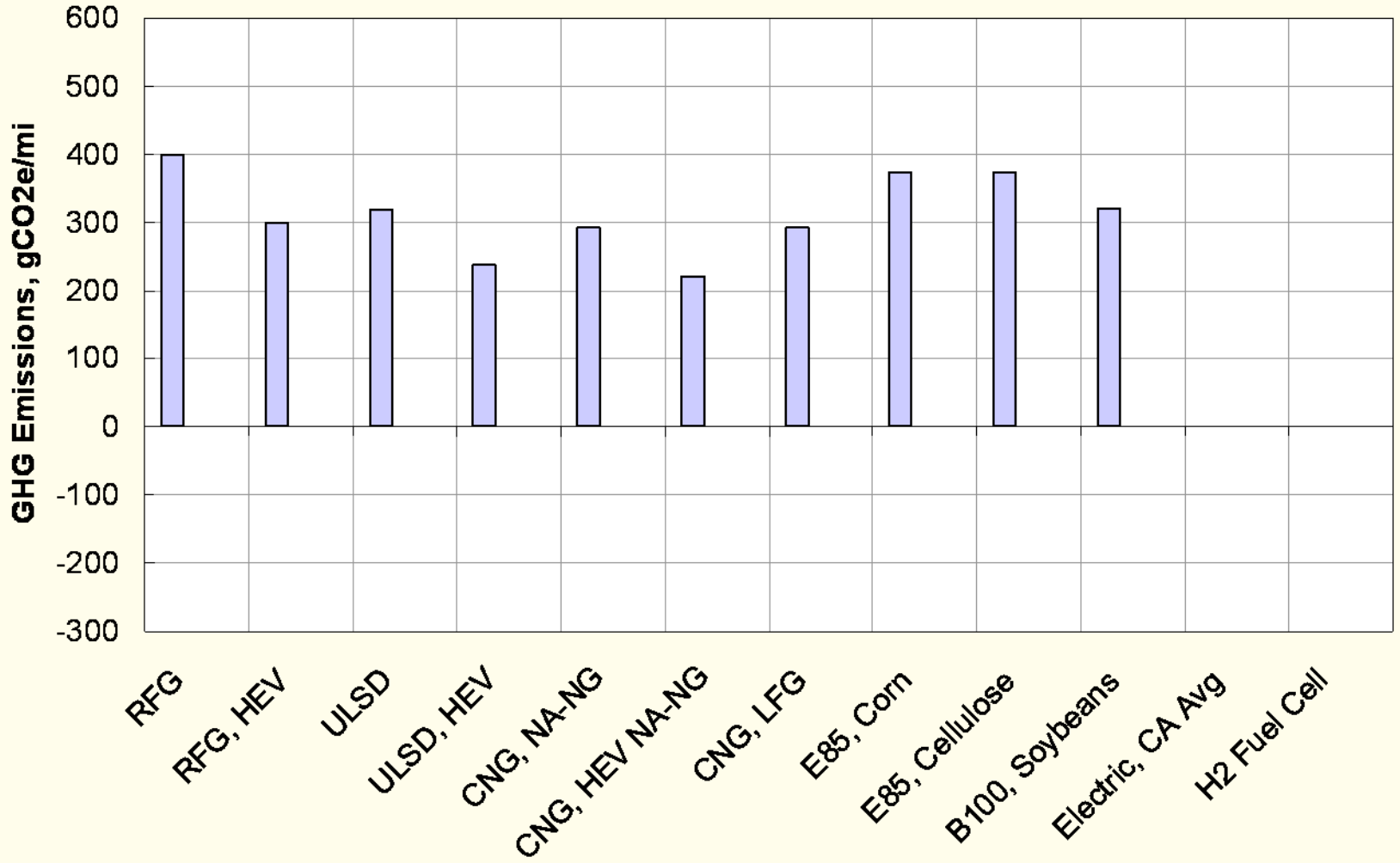
- What is Well-to-Wheel (WTW) Analysis?
- Why use WTW Analysis?
- How are WTW Emissions Quantified
- **WTW Results**

Show Results for Selected Cases:

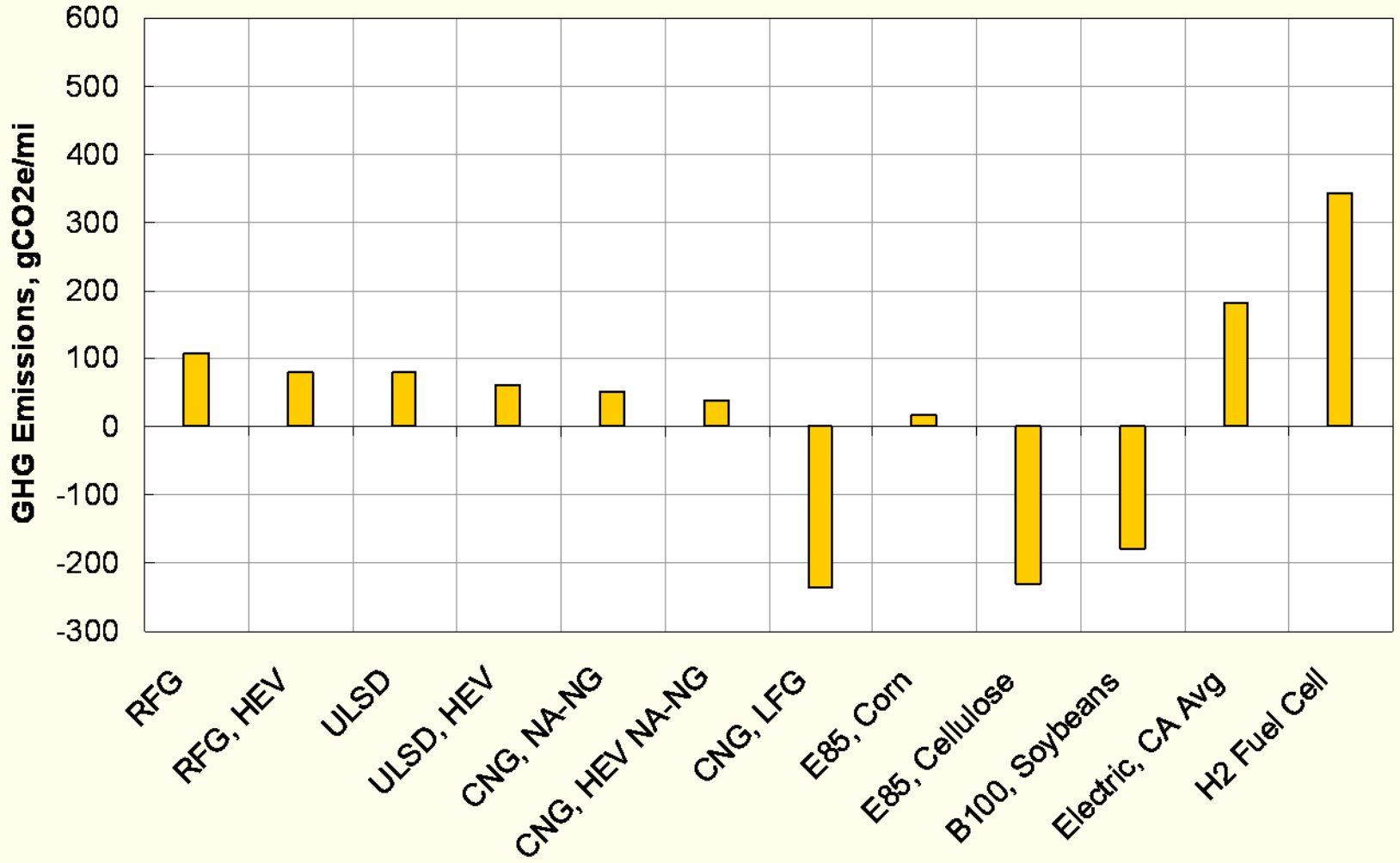
– All results shown based on CA-GREET1.7 v99

Fuel	Feedstock	Comments
RFG	Crude oil	Average mix of crude oils refined in CA
ULSD	Crude oil	Average mix of crude oils refined in CA
CNG-NA NG	North American Natural Gas	Assume pipeline transport distance of 1000 miles from field to compression
CNG-LFG	Landfill Gas	Credit assumes otherwise flared (not vented)
LNG-NA NG	North American Natural Gas	Assume pipeline transport distance of 1000 miles from field to compression
LNG-LFG	Landfill Gas	Credit assumes otherwise flared (not vented)
E85 Corn	Corn	Produced in Midwest using natural gas as process fuel, dry distillers grains and solubles
E85 Cellulose	Poplar	Assumes trees grown in CA, gasification
B100	Soybeans	Produced from midwest soybeans, esterification
Electricity	California Avg Mix	Generation resources CA avg mix in 2005
Hydrogen	Natural Gas	Central plant production, liquid hydrogen delivery

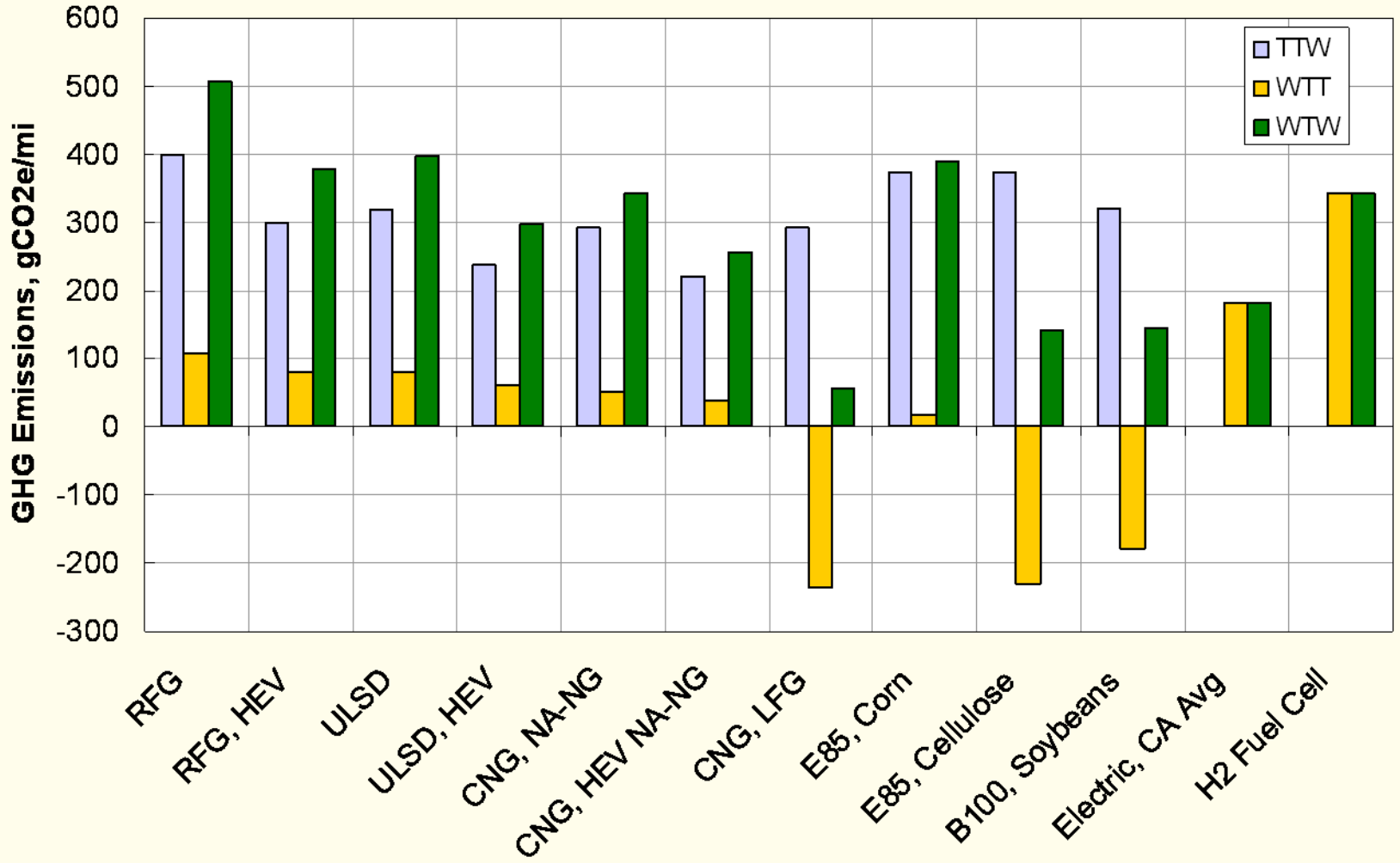
Passenger Car Results: TTW



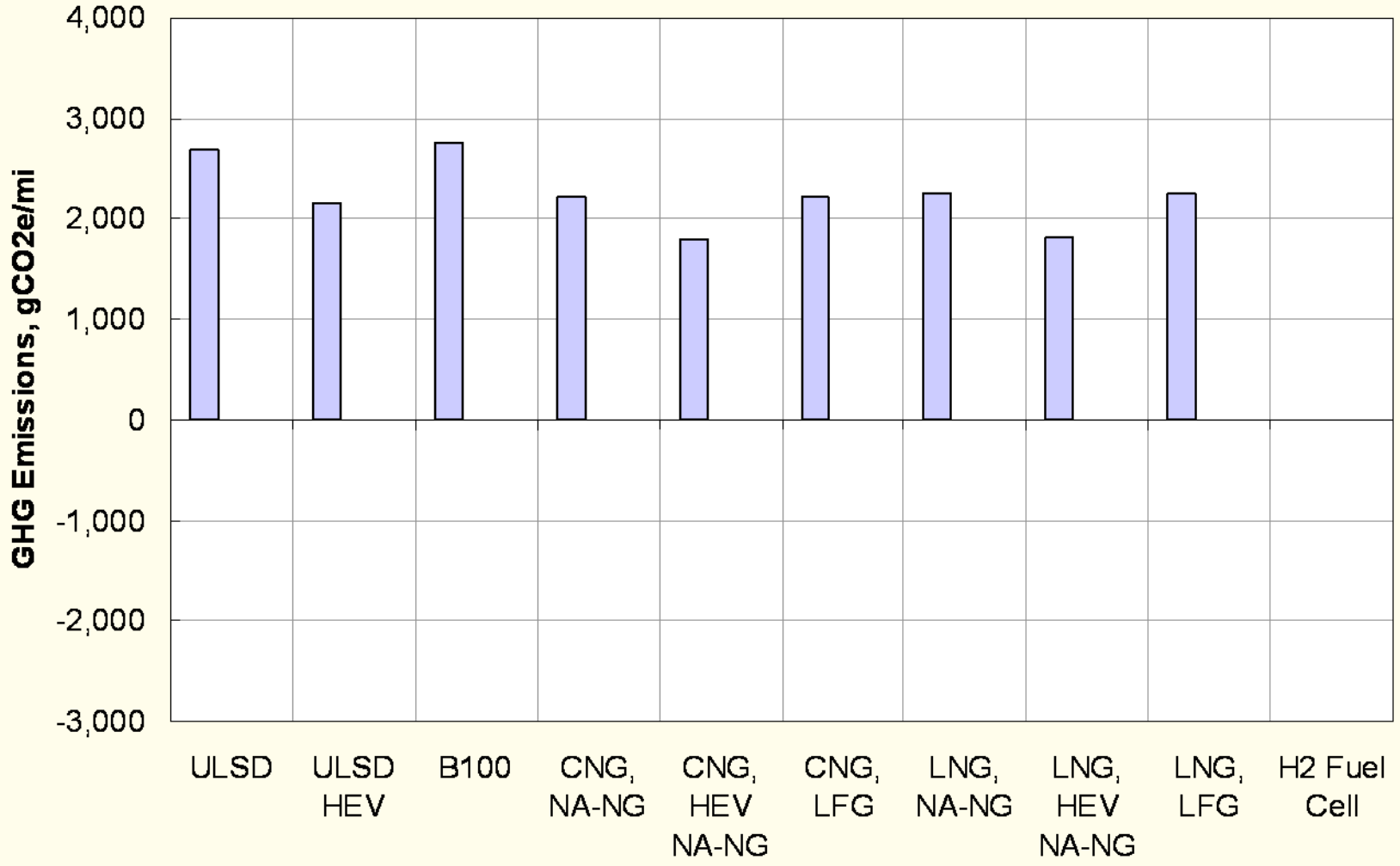
Passenger Car Results: WTT



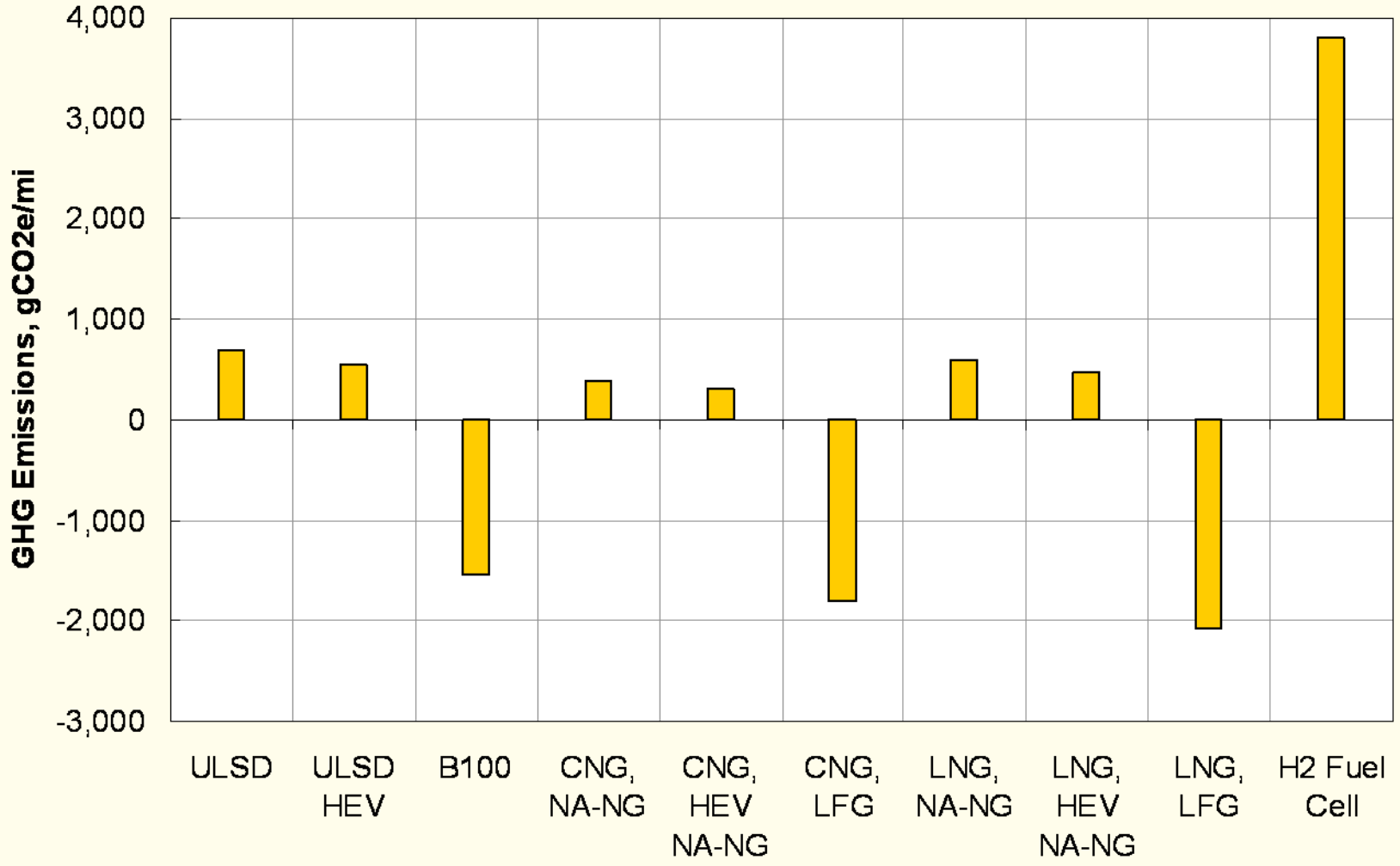
Passenger Car Results: WTW



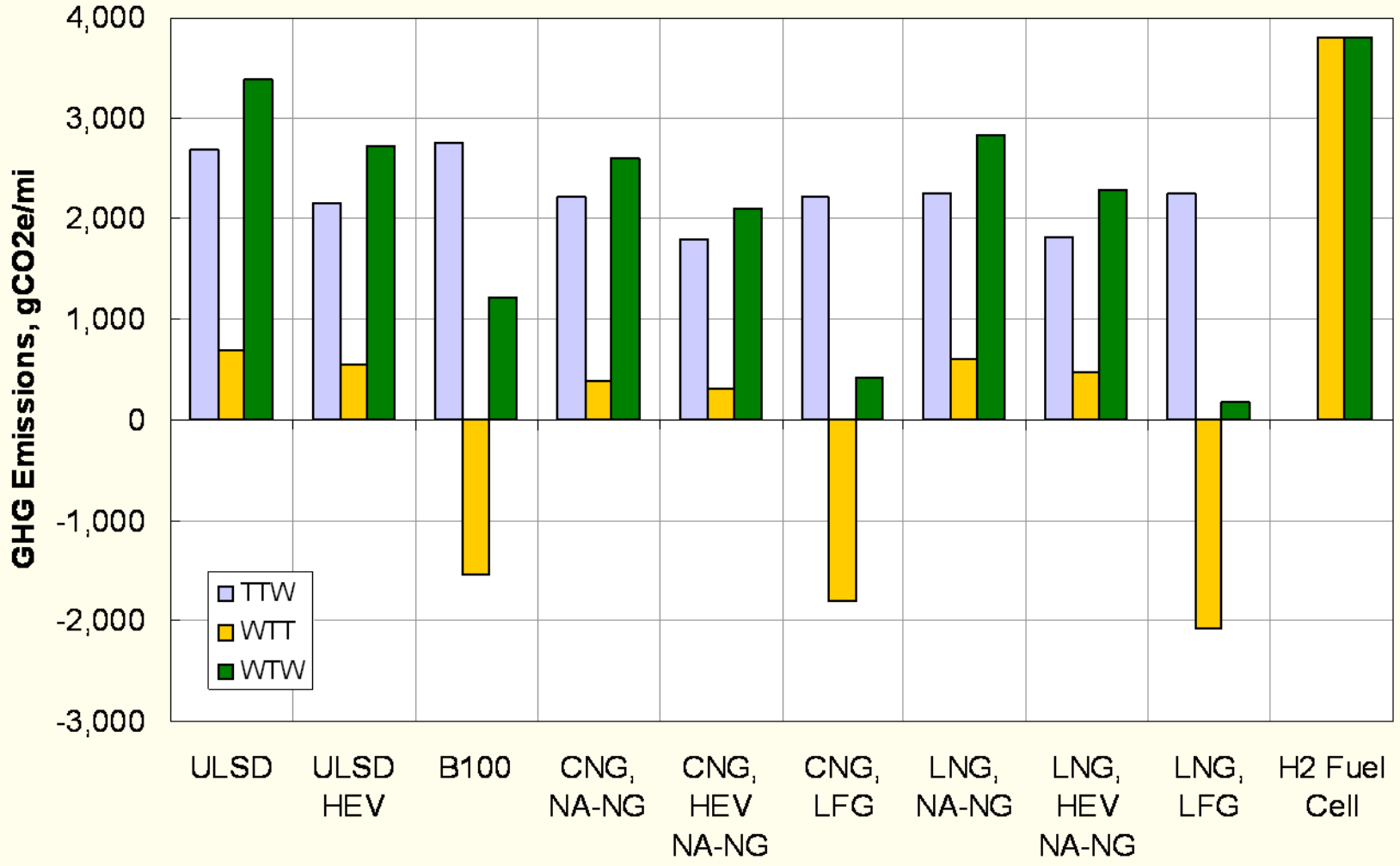
Urban Bus Results: TTW



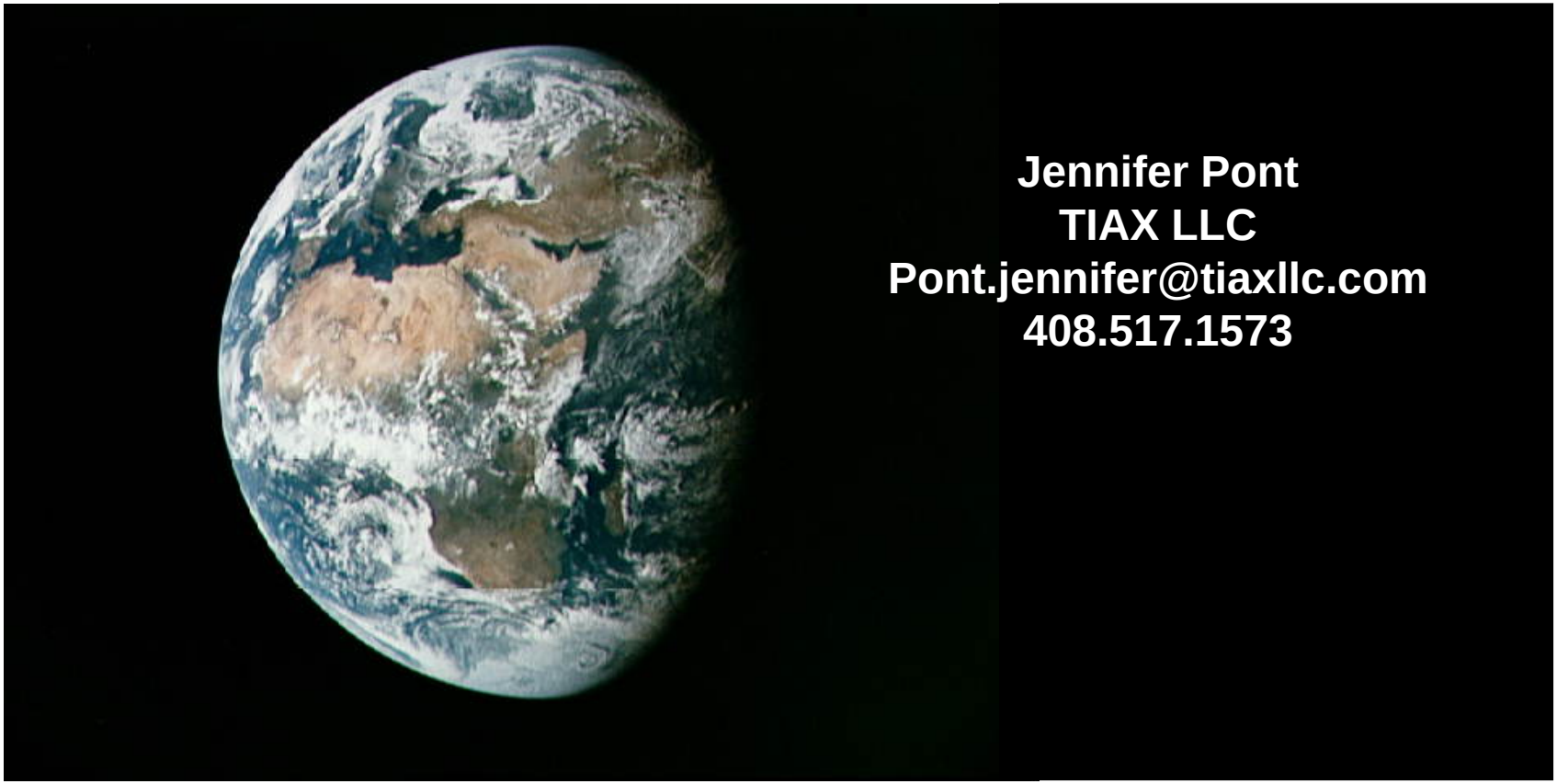
Urban Bus Results: WTT



Urban Bus Results: WTW



Thank you for your Attention



Jennifer Pont
TIAX LLC
Pont.jennifer@tiaxllc.com
408.517.1573

Some useful references – update this

- California Low Carbon Fuel Standard
  - http://www.arb.ca.gov/fuels/lcfs/lcfs.htm
- AB118 Alternative and Renewable Fuel and Vehicle Technology Program
  - http://www.energy.ca.gov/altfuels/index.html
- California State Alternative Fuels Plan and backup documentation
  - http://www.energy.ca.gov/2007publications/CEC-600-2007-011/CEC-600-2007-011-CMF.PDF
- Full Fuel Cycle Assessment: Well-To-Wheels Energy Inputs, Emissions, and Water Impacts
  - http://www.energy.ca.gov/2007publications/CEC-600-2007-004/CEC-600-2007-004-REV.PDF
- Full Fuel Cycle Assessment: Well to Tank Emissions and Energy Consumption
  - http://www.energy.ca.gov/2007publications/CEC-600-2007-002/CEC-600-2007-002-D.PDF
- Full Fuel Cycle Assessment: Tank To Wheels Emissions and Energy Consumption http://www.energy.ca.gov/2007publications/CEC-600-2007-003/CEC-600-2007-003-D.PDF