# Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems -- Greenhouse Gases and Criteria Pollutants

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# What is a Well-to-Wheels Analysis?

**Systems approach**

**Assessment of energy consumption and emissions**

***Well-to-Tank***

***Tank-to-Wheels***

# Contributors

**GM sponsored the study and conducted the modeling of vehicle fuel consumption and greenhouse gases**

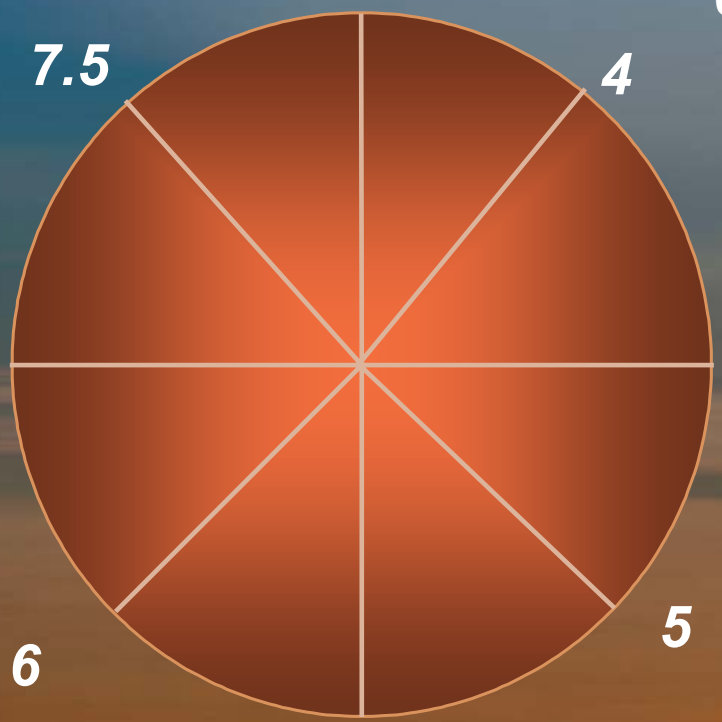
**Our partners in the well-to-wheels effort were:**

- Argonne National Laboratory (Well to Wheels)
- Air Improvement Resource (Vehicle Emissions)
- Eastern Research Group (Stationary Source Emissions)
- Advanced Development Corporation (Vehicle Fuel Economy Modeling Support)

# Key Study Features

- **Predicts energy consumption and emissions of VOC, CO, NOx, PM10, SOx, and greenhouse gases**
- **2010 Model Year full-size pickup truck operating in 2016 (year it reaches lifetime mileage midpoint)**
- **Equal performance maintained for all propulsion systems:**
  - Advanced internal combustion engines
  - Fuel cells with onboard hydrogen or fuel processing
  - Conventional drive and hybrid architectures
- **Not included**
  - Cold start penalties
  - Costs
  - Packaging

# Full-Size Truck Performance Targets




# Vehicle Propulsion Systems Analyzed

| | IC | IC Engine | Fuel Cell | Fuel Cell Hybrid |
|---|---|---|---|---|
| Gasoline | X | X | X | X |
| Diesel | X | X | | |
| F-T Diesel | X* | X* | | |
| CNG | X | X | | |
| Methanol | | | X* | X* |
| Ethanol | E85 | E85 | E100* | E100* |
| Hydrogen | X | X | X | X |

***Included in study but not in this presentation**

# Tank-to-Wheels Emissions Estimates

**2010 MY vehicle emissions targets (conventional & hybrid):**

| 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 |

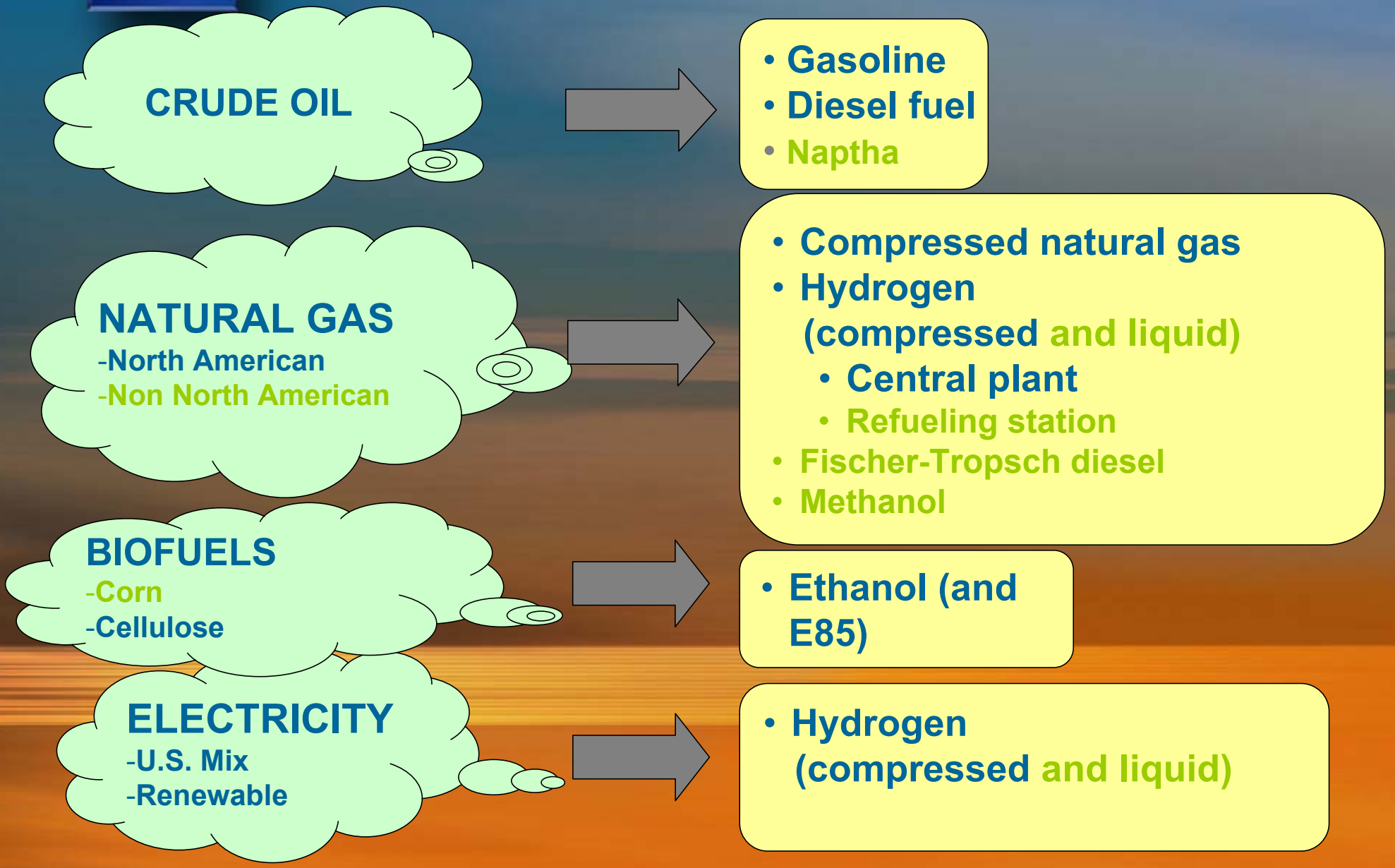
**** Based on targets for fuel consumption penalty of aftertreatment system – Bin 5 diesel has not been demonstrated***

**In-use vehicle emissions modeled using**

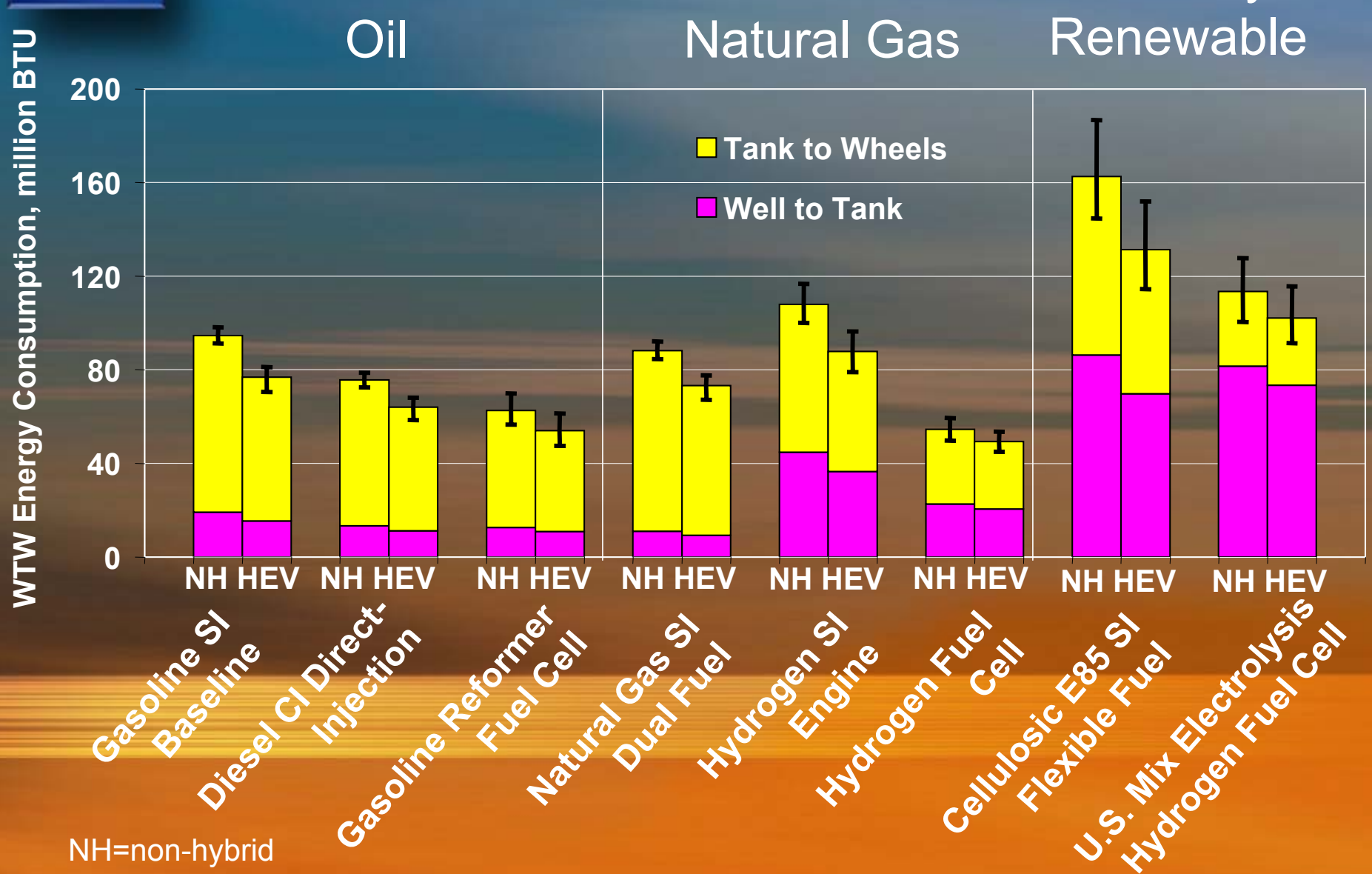
- **EPA's MOBILE6.2**
- **ARB's EMFAC2002 ver. 3**

**to simulate in-use emissions of 2010 model year vehicles in 2016**

# Fuel Pathways

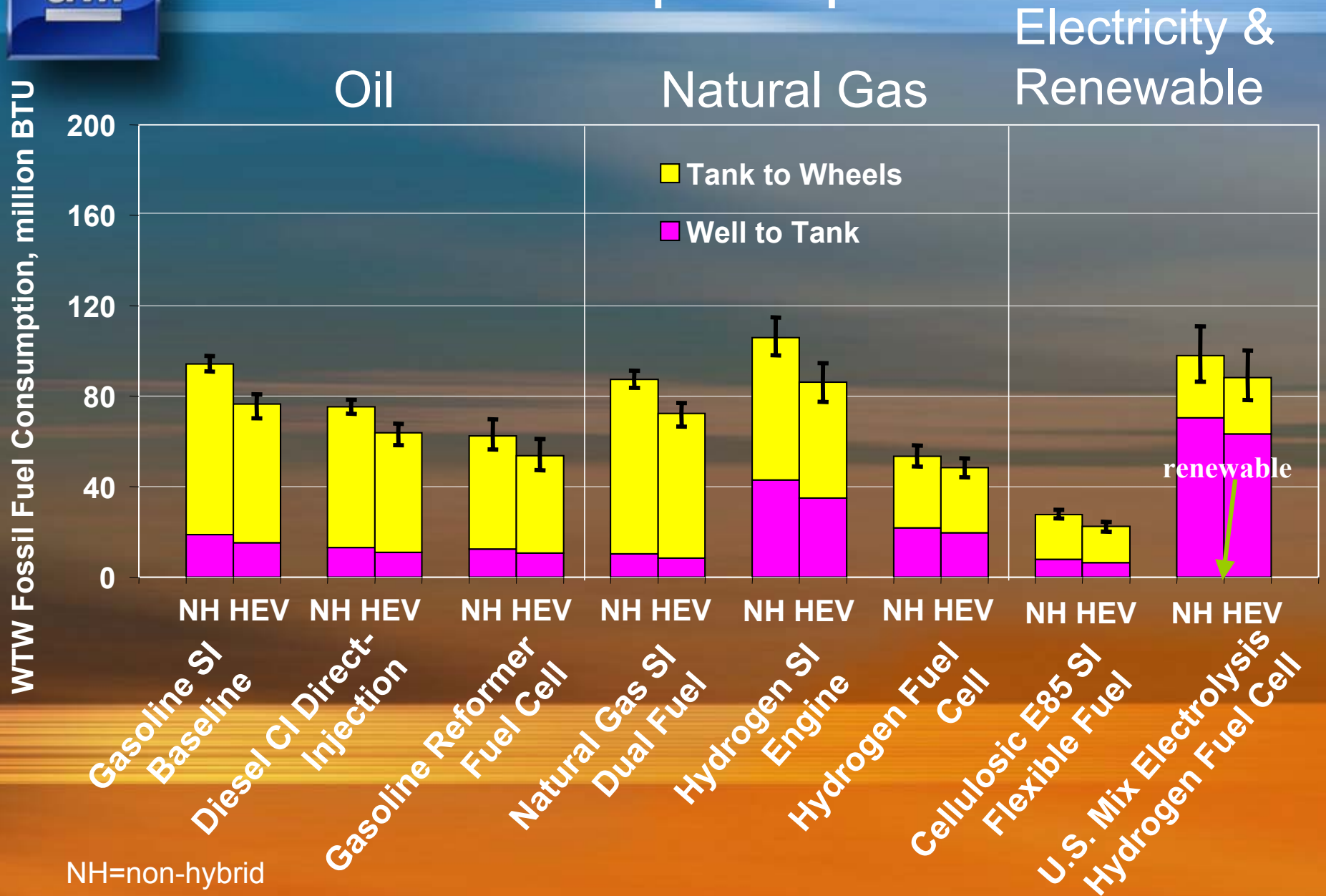


# Well-to-Wheels Annual Energy Consumption per Vehicle




NH=non-hybrid
HEV=hybrid electric vehicle

# Well-to-Wheels Annual Fossil Fuel Consumption per Vehicle

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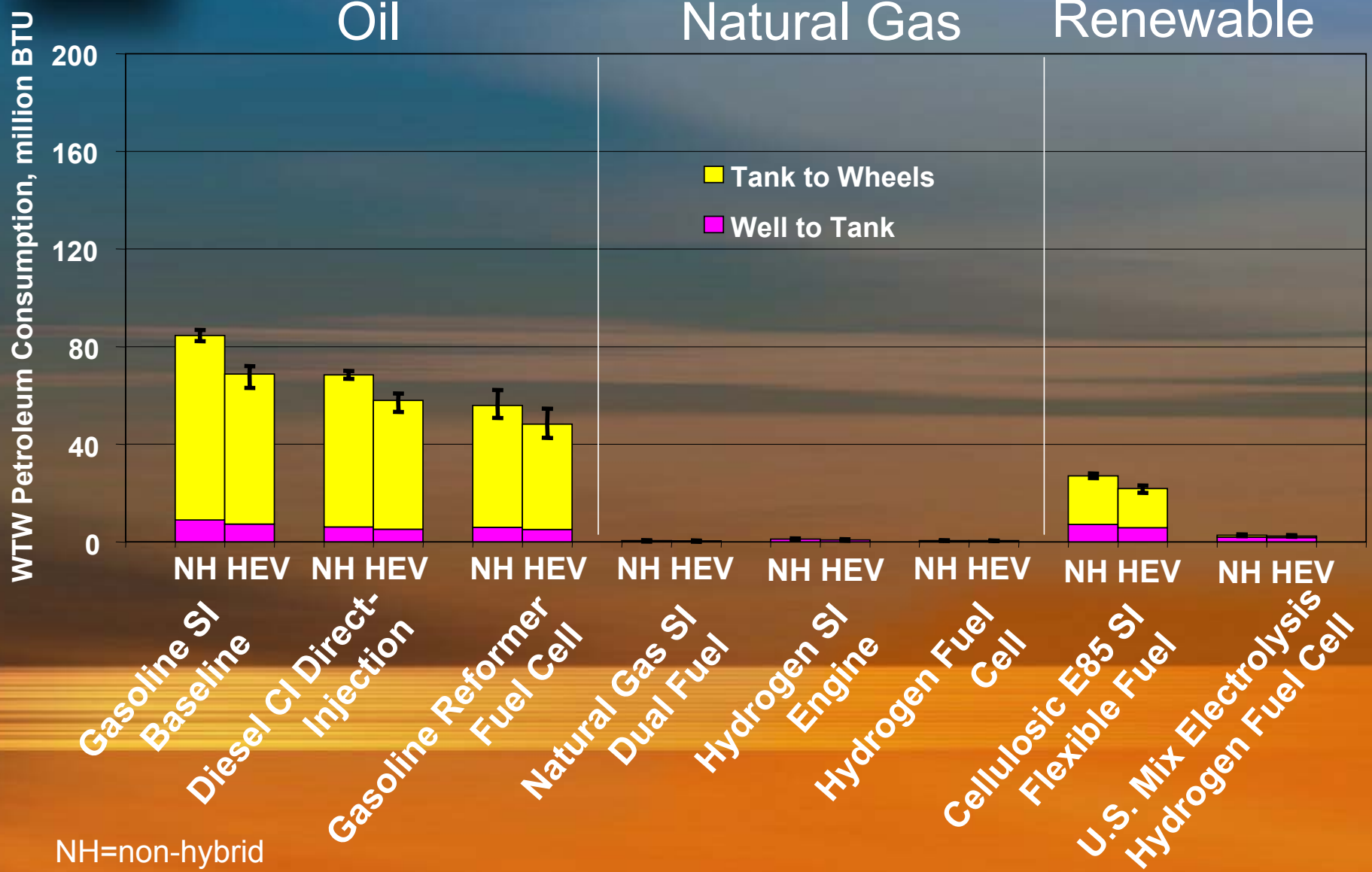
# Well-to-Wheels Annual Petroleum Consumption

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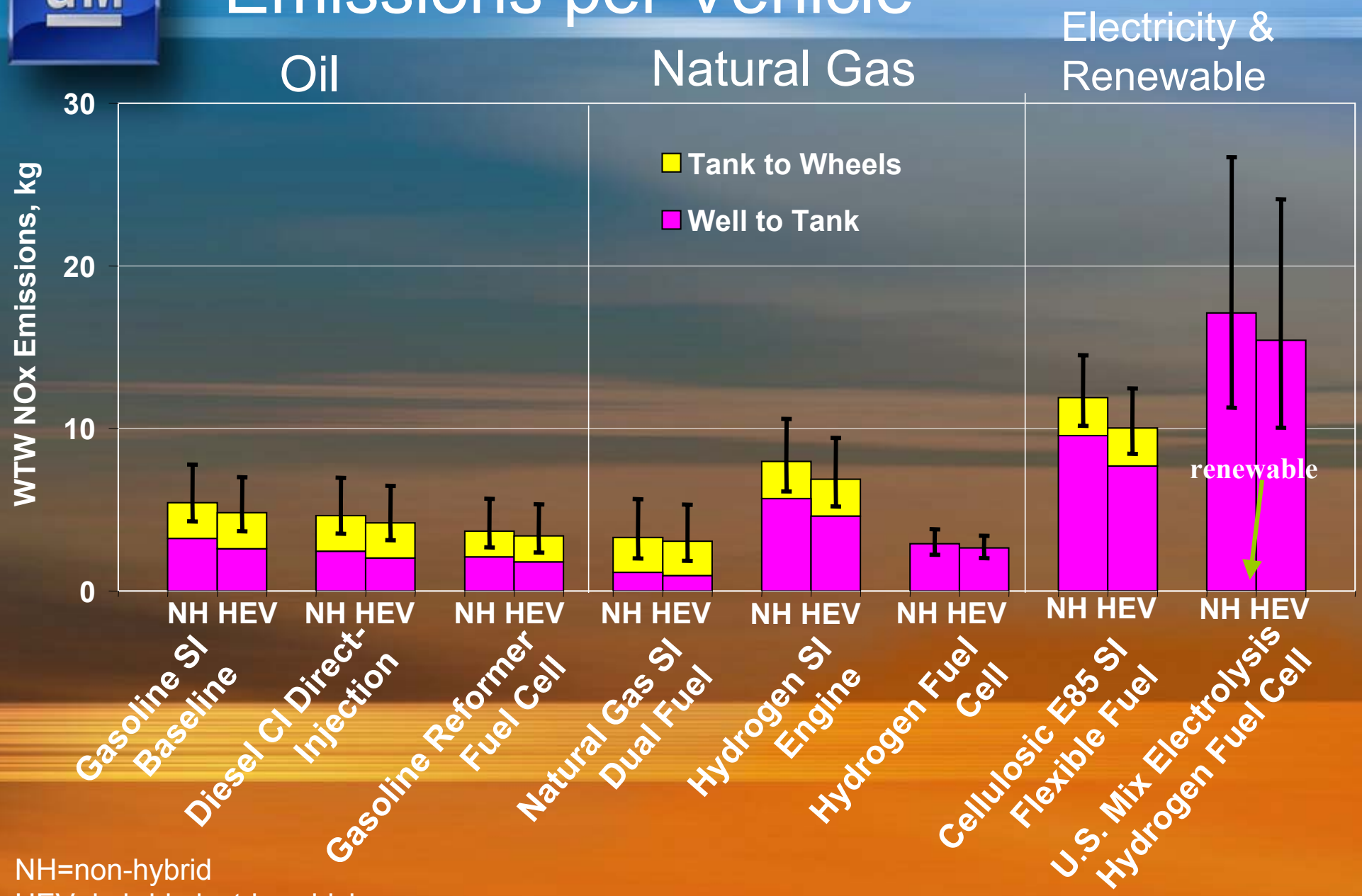
# Estimation of Well-to-Tank Criteria Pollutants

- Data for relevant facilities extracted from EPA's 1999 National Emissions Inventory
- Total emissions divided by throughput to develop emissions factors
- Distribution curve fit through existing data
- Distribution adjusted to account for improved future technology and new source controls

# Well-to-Wheels Annual NOx Emissions per Vehicle

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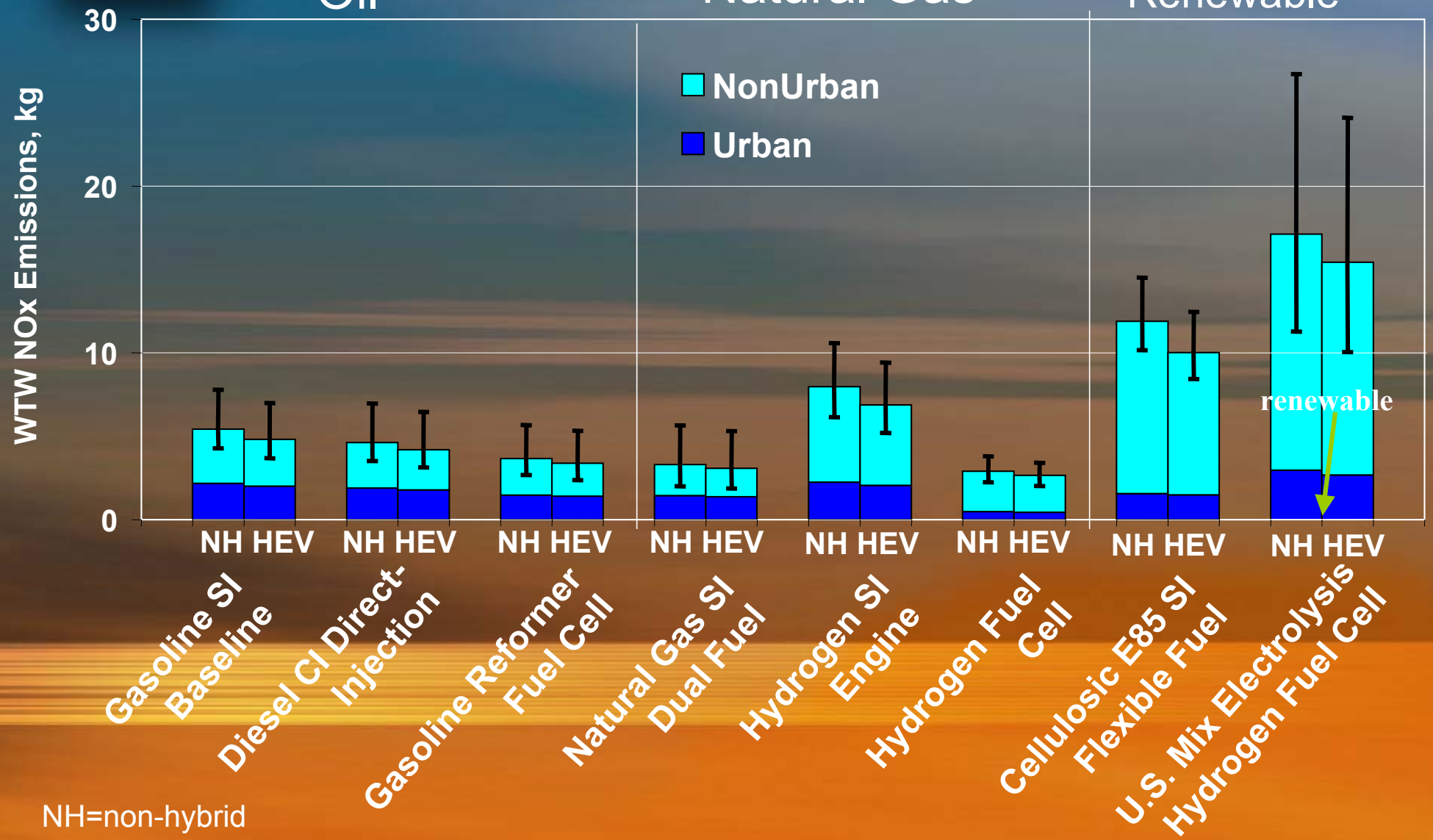


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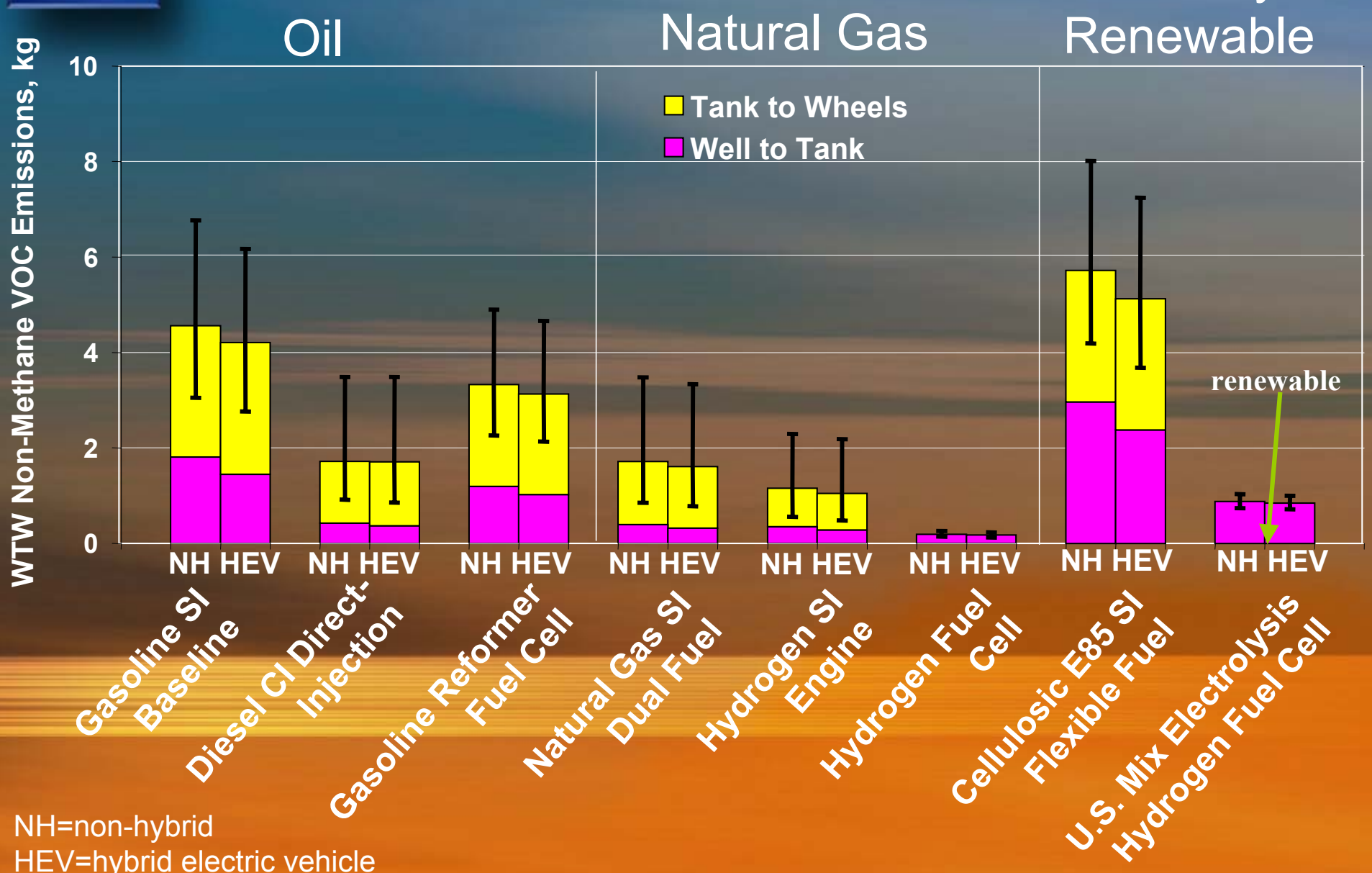
# Well-to-Wheels Annual VOC Emissions per Vehicle

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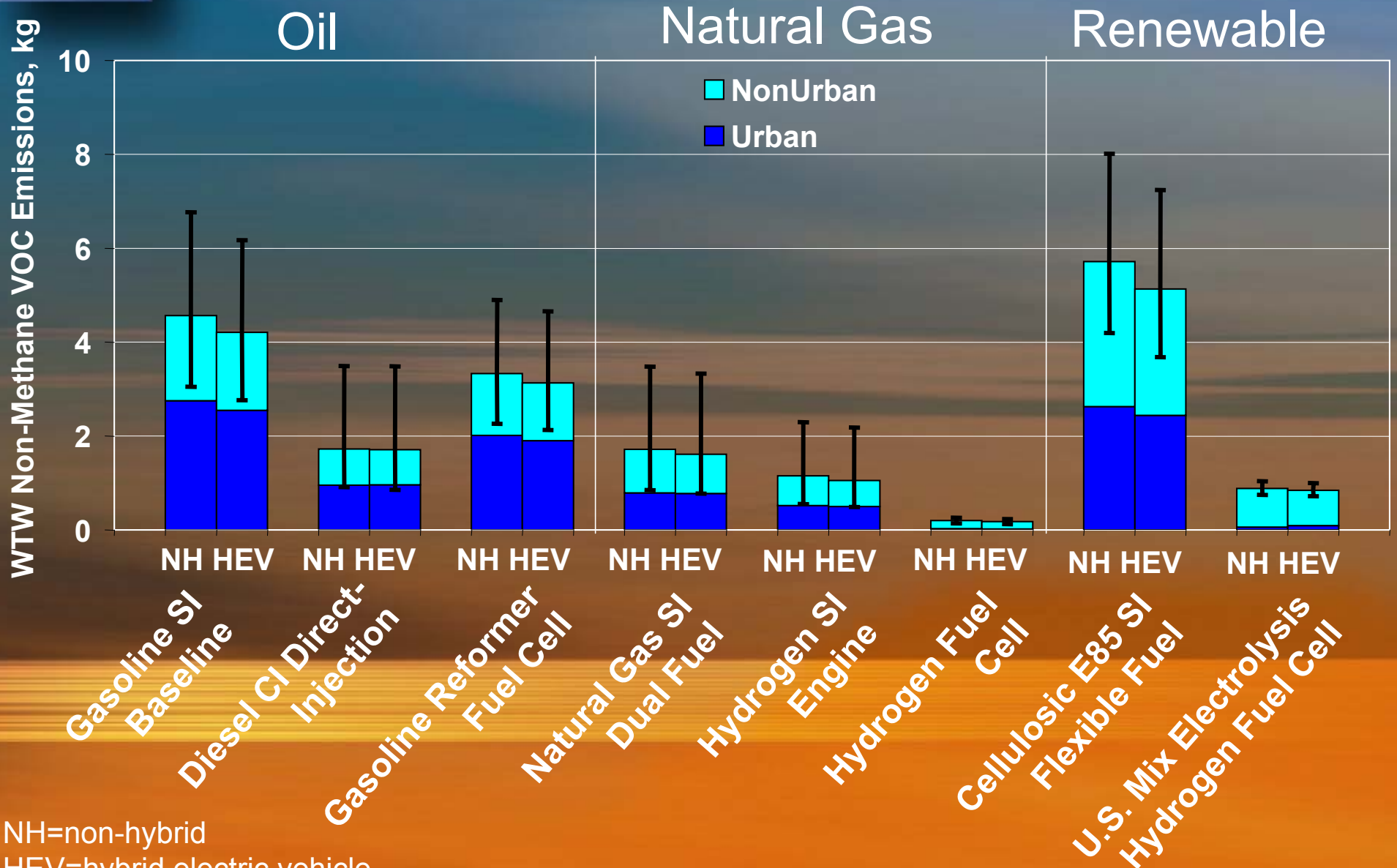


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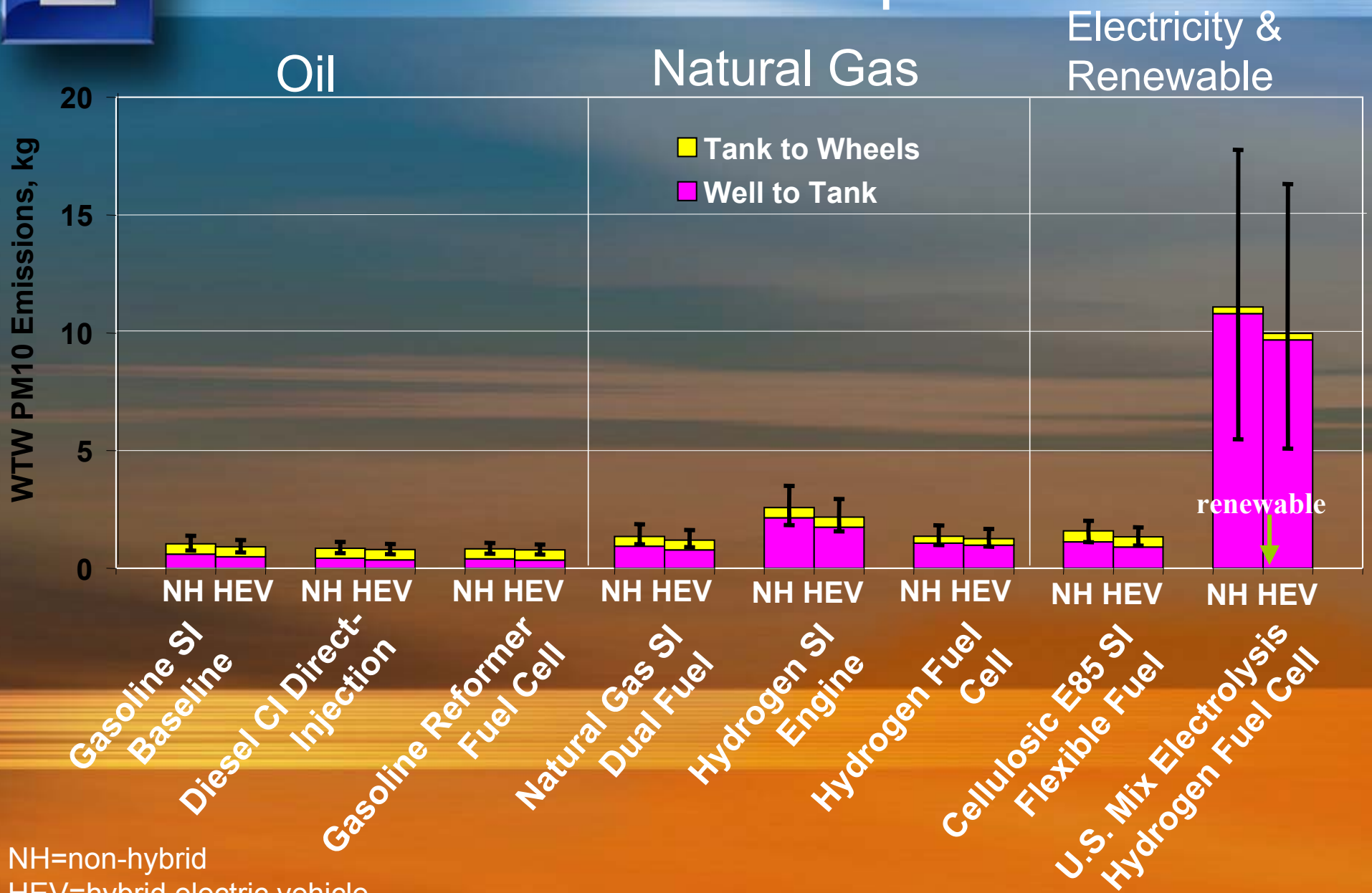
# Well-to-Wheels Annual Particulate Emissions per Vehicle

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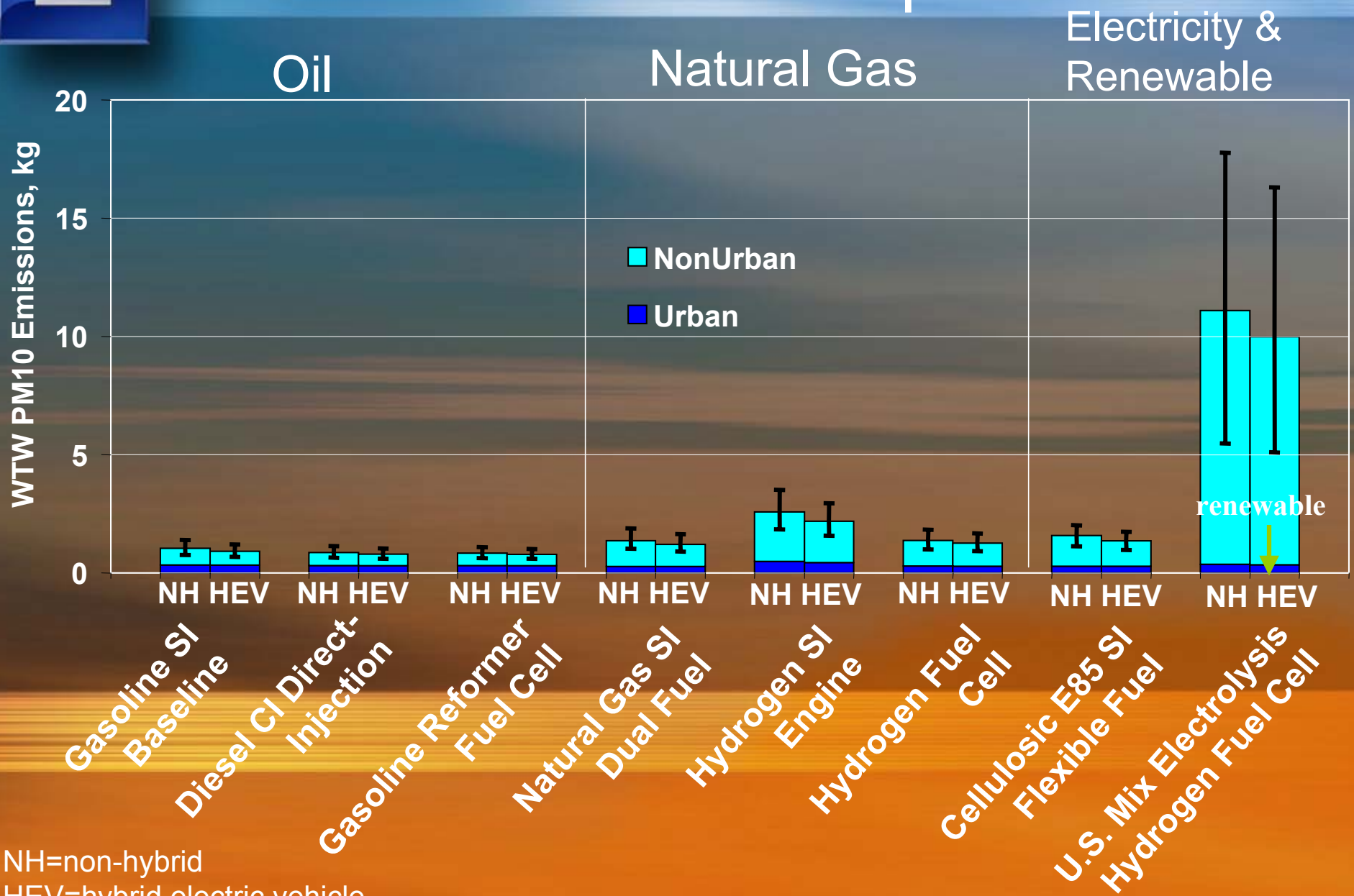


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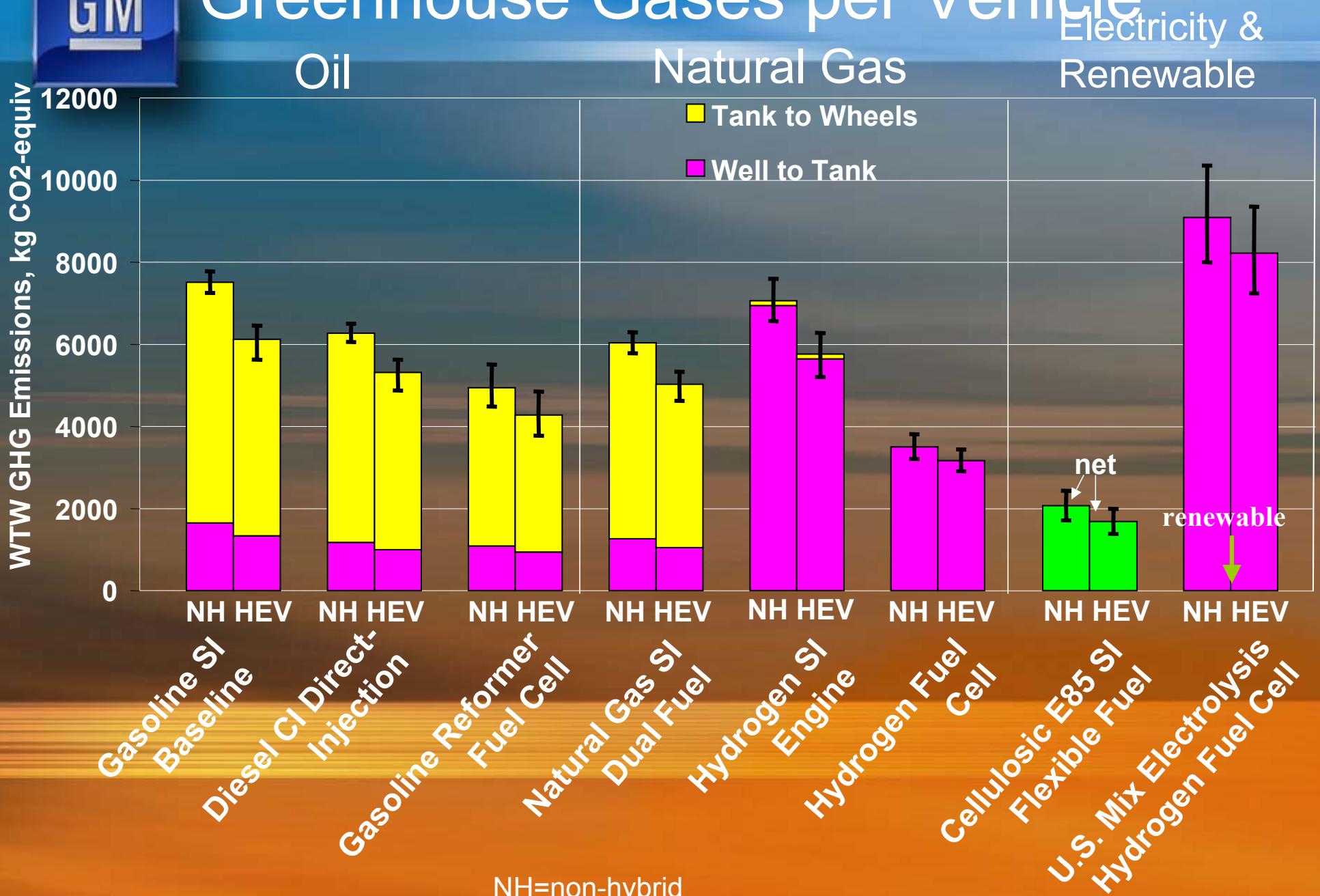
# Well-to-Wheels Annual Greenhouse Gases per Vehicle

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# Conclusions for Criteria Emissions

- Both well-to-tank and tank-to-wheels emissions have a significant impact on total well-to-wheels results for most pathways
- Compared to gasoline engines, total NOx emissions for hydrogen fuel cell pathways were tripled if the hydrogen is made from electrolysis with the U.S. mix, and halved if the hydrogen is made from natural gas
- Urban NOx emissions were lowest for fuel cells operating on hydrogen from natural gas or renewable sources
- Total and urban VOC emissions are highest for gasoline and E85, and lowest for fuel cell with hydrogen from natural gas
- Total PM10 emissions were highest when the U.S. electricity mix was used for generating hydrogen; oil-based pathways had the lowest total PM10
- Urban PM10 was low for all pathways

# Conclusions for Greenhouse Gas Emissions

**Well-to-Wheels greenhouse gases can be significantly reduced with the following (ordered by increasing impact):**

- Advanced gasoline and diesel engines and hybrids
- Fuel cells with hydrogen from natural gas
- Cellulosic ethanol in internal combustion engines
- Fuel cells with renewable electricity used to produce and compress hydrogen

# Acknowledgements

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