# Introduction of the GREET 2.7 Model

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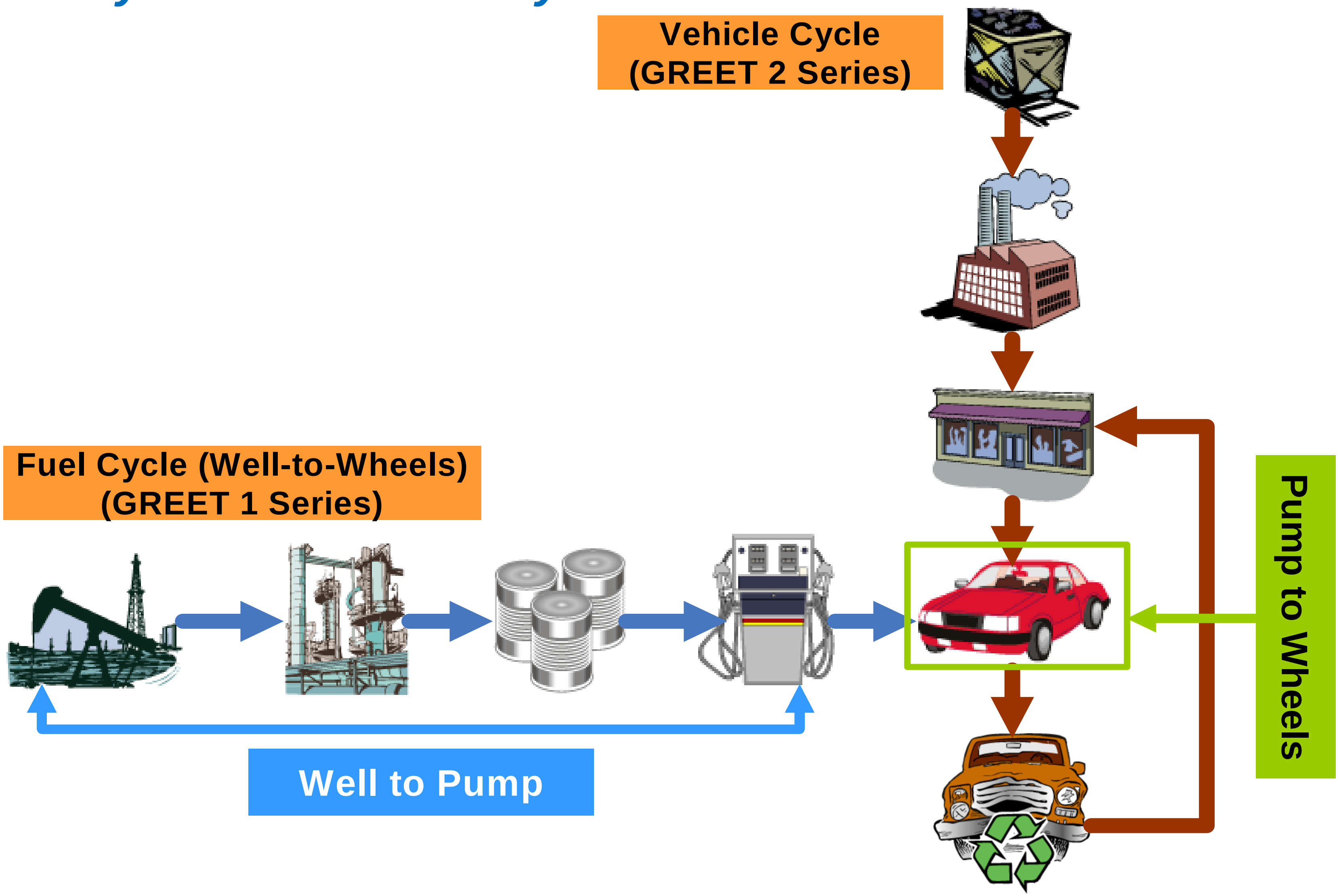
## *Argonne Has Been Working on Vehicle-Cycle Analyses for More Than a Decade*

- In 1995, Stodolsky et al. investigated the life-cycle energy savings from aluminum-intensive vehicles
- In 1997, Wang et al. examined the vehicle-cycle impacts of HEVs
- In 1998, Gaines et al. analyzed the life-cycle impacts of heavy duty vehicles
- Also in 1998, Argonne in a joint effort performed a total-energy cycle assessment of electric and conventional vehicles
- Argonne resumed its efforts with the release of a report, in 2006, documenting the development and applications of the GREET 2.7 vehicle-cycle model

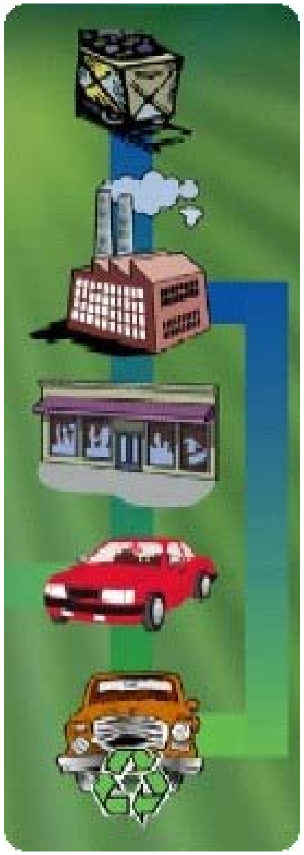
## *The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Vehicle-Cycle Model*

- Includes emissions of greenhouse gases
  - $CO_2$, $CH_4$, and $N_2O$
- Estimates emissions of six criteria pollutants
  - VOC, CO, $NO_x$, $SO_x$, $PM_{10}$, and $PM_{2.5}$
- Separates energy use into
  - All energy sources (fossil and non-fossil)
  - Fossil fuels (petroleum, natural gas, and coal combined)
  - Petroleum
  - Coal
  - Natural gas
- The GREET model and its documents are available at Argonne's website at ***http://www.transportation.anl.gov/software/GREET/***
- The most recent GREET Vehicle-Cycle version (GREET 2.7) was released in June 2007

# *Life-Cycle Analysis of Vehicle/Fuel Systems Covers Both Fuel-Cycle and Vehicle-Cycle*

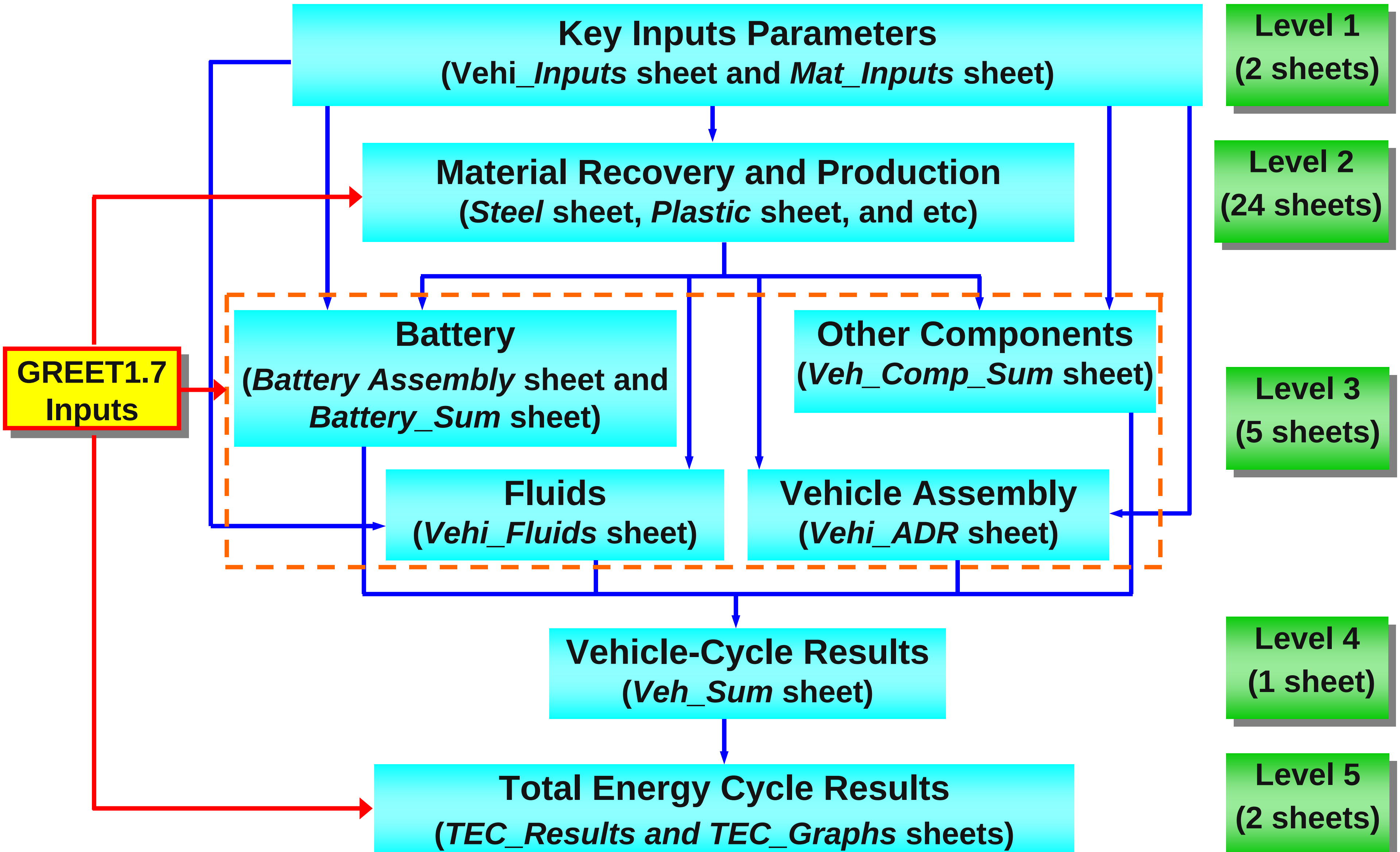


## *GREET 2 Simulates Vehicle-Cycle Energy Use and Emissions from Material Recovery to Vehicle Disposal*



- Raw material recovery
- Material processing and fabrication
- Vehicle component production
- Vehicle assembly
- Vehicle disposal and recycling

# Model Structure of GREET2.7 (34 Sheets + Overview)

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# *Brief Description of 35 Sheets in GREET 2.7*

- *Overview*: GREET copyright statement. It also presents a brief summary of each worksheet in GREET and is intended to provide brief introduction to the functions of each sheet
- *Vehi_Inputs*: Key vehicle and component input parameters that users can specify for GREET simulations
- *Mat_Inputs*: Key material input parameters that users can specify for GREET simulations
- *Steel*: Calculations of energy use/emissions for virgin, recycled and stainless steel
- *C.Iron*: Calculations of energy use/emissions for cast iron
- *W.Al*: Calculations of energy use/emissions for virgin and recycled wrought aluminum
- *C.Al*: Calculations of energy use/emissions for virgin and recycled cast aluminum
- *Lead*: Calculations of energy use/emissions for virgin and recycled lead
- *Nickel*: Calculations of energy use/emissions for virgin and recycled nickel/nickel hydroxide
- *KOH*: Calculations of energy use/emissions for potassium hydroxide
- *Cobalt*: Calculations of energy use/emissions for virgin and recycled cobalt oxide
- *Copper*: Calculations of energy use/emissions for copper
- *Zinc*: Calculations of energy use/emissions for zinc
- *Magnesium*: Calculations of energy use/emissions for magnesium

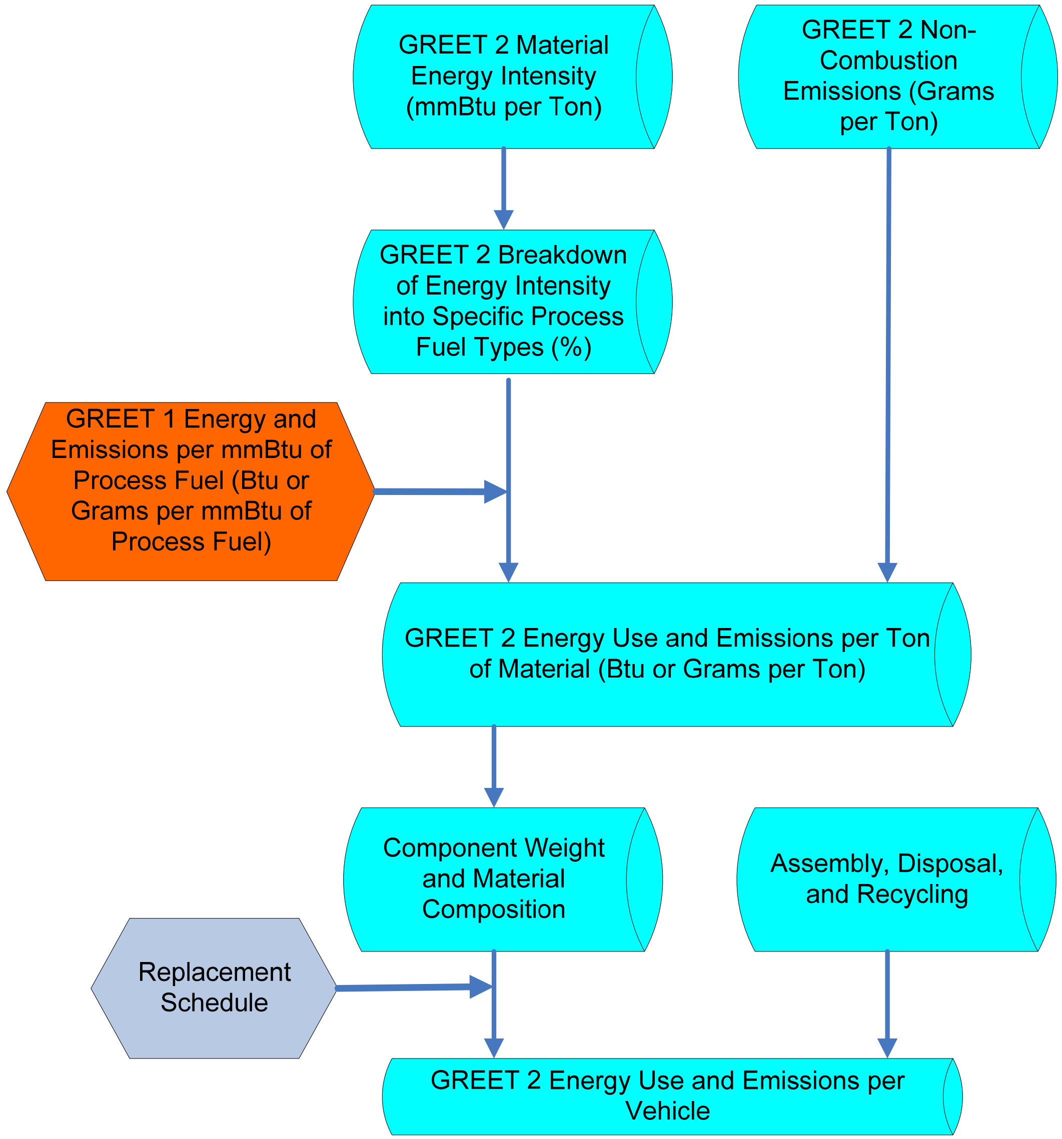
## *Brief Description of 35 Sheets in GREET 2.7 (cont'd)*

- *S.Acid*: Calculations of energy use/emissions for sulfuric acid
- *Glass*: Calculations of energy use/emissions for glass and glass fiber
- *Plastic*: Calculations of energy use/emissions for polypropylene, polyester, high-density polyethylene, inert filler, carbon fiber, carbon and glass fiber-reinforced plastic
- *Rubber*: Calculations of energy use/emissions for styrene-butadiene rubber
- *Platinum*: Calculations of energy use/emissions for platinum
- *Vanadium*: Calculations of energy use/emissions for vanadium
- *Zirconium*: Calculations of energy use/emissions for zirconium
- *Titanium*: Calculations of energy use/emissions for titanium
- *Chromium*: Calculations of energy use/emissions for chromium
- *Rare Earth*: Calculations of energy use/emissions for rare earth metals
- *Manganese*: Calculations of energy use/emissions for manganese
- *FC Materials*: Calculations of energy use/emissions for PTFE (Teflon®) and Nafion® PFSA and dry polymer
- *Mat_Sum*: Summary of energy use/emissions results for vehicle materials production
- *Vehi_Fluids*: Calculations of energy use/emissions for fluid production, use, and disposal

## *Brief Description of 35 Sheets in GREET 2.7 (cont'd)*

- *Battery Assembly*: Calculations of energy use/emissions results for lead-acid, nickel metal hydride and lithium ion battery assembly
- *Vehi_ADR*: Calculations of energy use/emissions for paint production, vehicle painting, vehicle assembly, and vehicle disposal
- *Battery_Sum*: Summary of energy use/emissions results for batteries (per vehicle lifetime)
- *Vehi_Comp_Sum*: Summary of energy use/emissions results for vehicle components (per vehicle lifetime)
- *Vehi_Sum*: Vehicle-cycle energy use/emissions results for various vehicle technologies (per vehicle lifetime)
- *TEC_Results*: Well-to-Pump, vehicle operation, and vehicle-cycle energy use/emissions results for vehicle/fuel technology combinations (per mile)
- *TEC_Graphs*: Graphic presentation of energy use and emissions for various vehicle/fuel technology combinations

# Simulation Logic for GREET Vehicle-Cycle Analysis



## *GREET 2.7 Vehicle-Cycle Technology Options*

- Vehicle propulsion technologies
  - Internal combustion engine vehicle (ICEV)
  - Grid-independent hybrid electric vehicle (GI HEV)
  - Fuel cell vehicle (FCV) with hybrid configuration
  - Grid-connected (or plug-in) hybrid electric vehicle (GC HEV)
- Evaluate vehicle material compositions
  - Conventional
  - Lightweight (LW)
- Vehicle types
  - Light-duty vehicles: passenger car, SUV, light truck & minivan
  - Heavy-duty trucks: long haul, dump, platform, tanker & garbage

Options marked in red are currently being developed but not ready for the public version

## *GREET 2.7 Breaks Vehicles Down Into Four Categories*

1. Components
   - Includes powertrain (engine or fuel cell), transmission, chassis, traction motor, generator, electronic controller, fuel cell auxiliaries (H2 tank, piping, etc), and body
2. Batteries
   - Startup = Lead-acid
   - Motive = Ni-MH or Li-Ion
3. Fluids
   - Engine oil, power steering fluid, brake fluid, transmission fluid, powertrain coolant, windshield fluid, adhesives
4. Vehicle Assembly, Disposal, and Recycling

# *GREET 2 Vehicle-Cycle Component Breakdowns*

| | ICEV | HEV | FCV |
|---|---|---|---|
| **Components** | | | |
| Body system | X | X | X |
| Powertrain system | X | X | X |
| Transmission system | X | X | X |
| Chassis system | X | X | X |
| Traction motor | | X | X |
| Generator | | X | |
| Electronic controller | | X | X |
| Fuel cell auxiliary system | | | X |
| **Batteries** | X | X | X |
| **Fluids (w/o fuel)** | X | X | X |
| **Total Vehicle Weight** | X | X | X |

# Total Vehicle and Component Weights are Key Assumptions to be Provided by the User (Vehi_Inputs)

- Total vehicle weight (lb)

| ICEV: Conventional Material | ICEV: Lightweight Material | HEV: Conventional Material | HEV: Lightweight Material | FCV: Conventional Material | FCV: Lightweight Material |
|---|---|---|---|---|---|
| 3,330 | 1,970 | 2,810 | 2,000 | 3,020 | 2,280 |

- Component weight distribution (battery and fluids examined separately)

| | ICEV: Conventional Material |
|---|---|
| Powertrain System | 26% |
| Transmission System | 6% |
| Chassis (w/o battery) | 24% |
| Traction Motor | 0% |
| Generator | 0% |
| Electronic Controller | 0% |
| Fuel Cell Auxiliary System | 0% |
| Body: including BIW, interior, exterior, and glass | 44% |

- Fuel cell weight is calculated by inputting stack power (kW)

| | |
|---|---|
| 70 | Conventional Material |
| 54 | Lightweight Material |

- Stack and auxiliary system weight (lb)

| | |
|---|---|
| 226 | Stack: Conventional Material |
| 546 | Auxiliary System: Conventional Material |
| 174 | Stack: Lightweight Material |
| 421 | Auxiliary System: Lightweight Material |

# *Material Compositions Can be Adjusted by the User for Each Component (Mat_Inputs)*

- Material composition by component

| | ICEV: Conventional Material |
|---|---|
| **Body** | |
| Steel | 68% |
| Wrought Aluminum | 1% |
| Copper/Brass | 2% |
| Magnesium | 0% |
| Glass | 7% |
| Carbon Fiber-Reinforced Plastic | 0% |
| Average Plastic | 18% |
| Rubber | 1% |
| Others | 4% |

- Vehicle composition aggregated by material

| | ICEV: Conventional Material |
|---|---|
| Steel | 62% |
| Stainless Steel | 0% |
| Cast Iron | 11% |
| Wrought Aluminum | 2% |
| Cast Aluminum | 5% |
| Copper/Brass | 2% |
| Magnesium | 0.02% |
| Glass | 3% |
| Average Plastic | 11% |
| Rubber | 2% |
| Platinum | 0.001% |
| Others | 2% |

# *Both Ni-MH and Li-Ion Can Be Simulated as Motive Batteries (Vehi_Inputs)*

- Total battery weight (lb) inputted for lead-acid (startup/accessories)

| | ICEV: Conventional Material | ICEV: Lightweight Material | HEV: Conventional Material | HEV: Lightweight Material | FCV: Conventional Material | FCV: Lightweight Material |
|---|---|---|---|---|---|---|
| Lead-Acid | 36 | 23 | 22 | 14 | 22 | 14 |
| Ni-MH | | | 84 | 51 | 110 | 70 |
| Li-Ion | | | 34 | 21 | 44 | 28 |

- Motive battery weight for HEV & FCV is calculated by inputting power (kW)

| | Ni-MH | Li-Ion |
|---|---|---|
| HEV: Conventional Material | 23 | 23 |
| HEV: Lightweight Material | 14 | 14 |
| FCV: Conventional Material | 30 | 30 |
| FCV: Lightweight Material | 19 | 19 |

- Battery replacement (per vehicle lifetime)

| | Lead-Acid | Ni-MH | Li-Ion |
|---|---|---|---|
| ICEV | 2 | | |
| HEV | 2 | 1 | 1 |
| FCV | 2 | 1 | 1 |

# *Like Other Components User Can Adjust the Material Composition of Each Battery (Mat_Inputs)*

| Lead-Acid | |
|---|---|
| Plastic: Polypropylene | 6% |
| Lead | 69% |
| Sulfuric Acid | 8% |
| Fiberglass | 2% |
| Water | 14% |
| Others | 1% |

| Ni-MH | |
|---|---|
| Iron | 12% |
| Steel | 24% |
| Aluminum | 1% |
| Copper | 4% |
| Magnesium | 1% |
| Cobalt | 2% |
| Nickel | 28% |
| Rare Earth Metals | 6% |
| Average Plastic | 23% |
| Rubber | 0.1% |

| Li-Ion | |
|---|---|
| Lithium Oxide (LiO2) | 5% |
| Nickel | 3% |
| Cobalt | 3% |
| Manganese | 3% |
| Graphite/Carbon | 11% |
| Binder | 2% |
| Copper | 25% |
| Wrought Aluminum | 19% |
| Cast Aluminum | 11% |
| Electrolyte | 9% |
| Plastic: Polypropylene | 8% |
| Plastic: Polyethylene | 3% |
| Steel | 0.2% |
| Thermal Insulation | 1% |
| Electronic Parts | 0.1% |

## *Other Key Input Parameters for Material Use (Mat_Inputs)*

- Share of primary (virgin) vs. secondary (recycled)
  - Steel, wrought aluminum, cast aluminum, lead, nickel
  - Very important especially when considering aluminum since the difference in production energy intensity is significant

| | Virgin Material | Recycled Material |
|---|---|---|
| Steel | 30% | 70% |
| Wrought Aluminum | 89% | 11% |
| Cast Aluminum | 41% | 59% |
| Lead | 27% | 73% |
| Nickel | 56% | 44% |

# *Fuel Is Not Examined in the Vehicle-Cycle, While All Other Fluids Are (Vehi_Inputs)*

- Total Fluid Weight (lb)

| | Engine Oil | Power Steering Fluid | Brake Fluid | Transmission Fluid | Powertrain Coolant | Windshield Fluid | Adhesives |
|---|---|---|---|---|---|---|---|
| ICEV | 9 | 0 | 2 | 24 | 23 | 6 | 30 |
| HEV | 9 | 0 | 2 | 2 | 23 | 6 | 30 |
| FCV | 0 | 0 | 2 | 2 | 16 | 6 | 30 |

- Fluid Replacement (per vehicle lifetime)

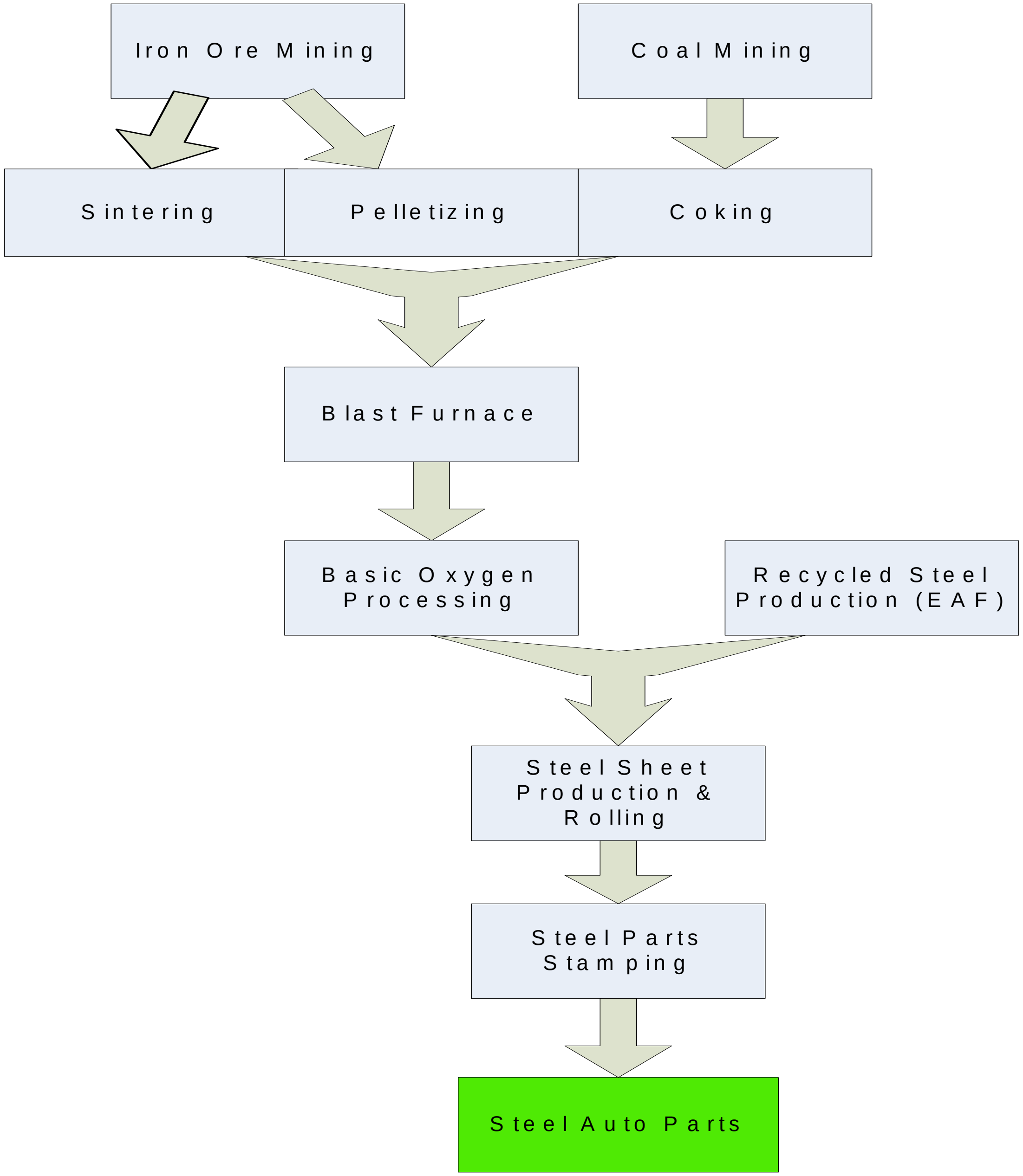
| Engine Oil | Power Steering Fluid | Brake Fluid | Transmission Fluid | Powertrain Coolant | Windshield Fluid | Adhesives |
|---|---|---|---|---|---|---|
| 40 | 0 | 3 | 1 | 3 | 20 | 0 |

# *Vehicle Assembly, Disposal, and Recycling (Vehi_ADR)*

- Assembly
  - Vehicle
    - *Paint Production*
    - *Vehicle Painting*
    - *Assembly Plant*
  - Battery
    - *Assembly Plant for each type (Lead-Acid, Ni-MH, Li-Ion)*
- Disposal and Recycling
  - Takes into account the dismantling process required for disposal and recycling
  - Recycling is handled separately for each material

## *Key Input Parameters for Material Use*

- Both steel and aluminum are modeled step-by-step from ore mining to part stamping
- Other metals are examined in three stages
  - Mining
  - Primary (virgin) production
  - Secondary (recycled) production
- Non-metals only look at production



# *First Lets Look at the Key Assumptions for Steel Production (Mat_Inputs)*

- Tons of intermediate material needed per ton of final steel product

| | Ore Recovery | Ore Pelletizing & Sintering | Coke Production | Blast Furnace | Basic O2 Processing | Electric Arc Furnace | Sheet Production & Rolling | Stamping |
|---|---|---|---|---|---|---|---|---|
| Virgin Steel | 5.2 | 1.9 | 0.5 | 1.2 | 1.4 | 0.2 | 1.3 | 1.0 |
| Recycled Steel | | | | | 0.1 | 1.5 | 1.3 | 1.0 |
| Stainless Steel | | | | | | 1.6 | 1.3 | 1.0 |

- Energy use (million Btu) per ton of material product

| | |
|---|---|
| 0.05 | Taconite Mining |
| 1.4 | Ore Pelletizing & Sintering |
| 5.6 | Coke Production |
| 15.9 | Blast Furnace |
| 1.6 | Basic O2 Processing |
| 4.2 | Electric Arc Furnace (for virgin steel and recycled steel) |
| 4.8 | Electric Arc Furnace (for stainless steel) |
| 6.1 | Sheet Production & Rolling |
| 5.5 | Stamping |

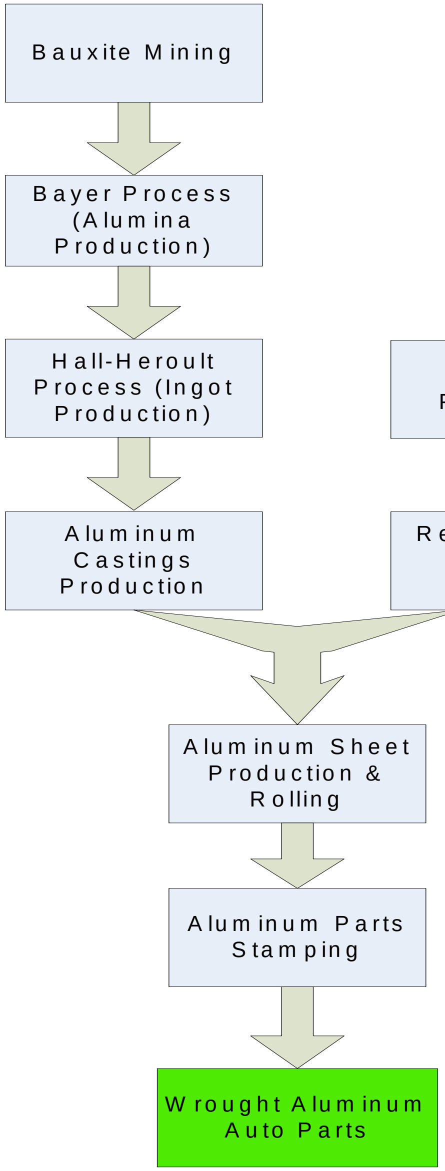
# *Key Assumptions and Results for Steel Production (Steel)*

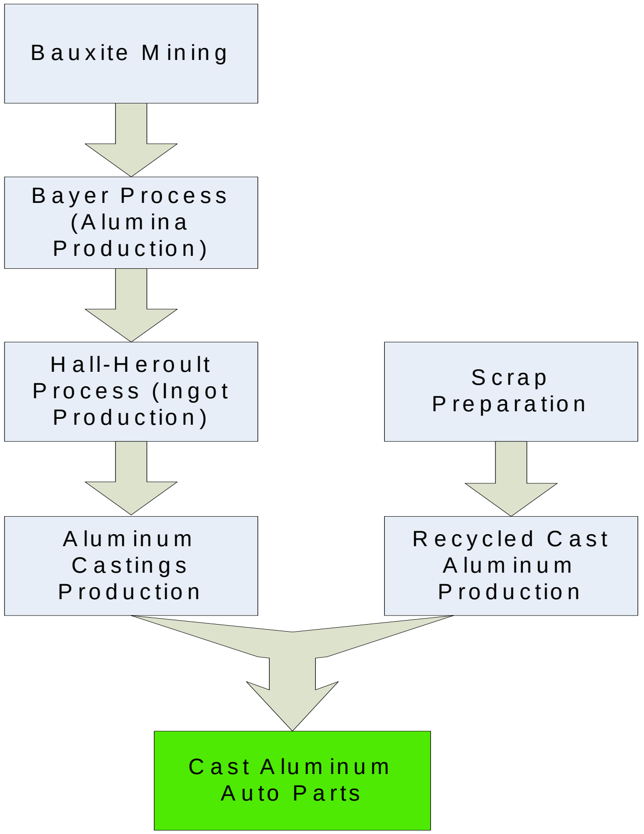
- Next the fuel share of the energy use just inputted
  - Lets look at ore pelletizing and sintering as an example (1.4 mmBtu/ton)
  - 83% of those Btu's are from natural gas and 17% from electricity
- Using formulas from GREET 1.7, the upstream energy use, combustion criteria pollutant emissions, and combustion GHG emissions are calculated
  - Non combustion emissions can be inputted by the user

- The result of these calculations are the following

| **Energy Use: mmBtu per lb of final steel product** | per lb |
|---|---|
| Total energy | 0.019 |
| Fossil fuels | 0.019 |
| Coal | 0.012 |
| Natural gas | 0.006 |
| Petroleum | 0.001 |
| **Total Emissions: grams per lb of final steel product** | per lb |
| VOC | 0.27 |
| CO | 54.44 |
| NOx | 1.82 |
| PM10 | 7.30 |
| PM2.5 | 2.10 |
| SOx | 1.04 |
| CH4 | 2.60 |
| N2O | 0.02 |
| CO2 | 2,389 |

# Wrought and Cast Aluminum Production Flowcharts



# Now Lets Look at the Key Assumptions for Wrought and Cast Aluminum Production (Mat_Inputs)

- Tons of intermediate material needed per ton of final aluminum product

| | Bauxite Mining | Bauxite Refining | Alumina Reduction | Scrap Preparation | Reverb Melt and Ingot Cast | Al Melting and Casting | Sheet Production & Rolling | Stamping |
|---|---|---|---|---|---|---|---|---|
| Virgin Wrought Aluminum | 4.8 | 1.9 | 1.0 | | | 1.0 | 1.4 | 1.0 |
| Recycled Wrought Aluminum | | | | 1.1 | 1.0 | 1.0 | 1.4 | 1.0 |

| | Bauxite Mining | Bauxite Refining | Alumina Reduction | Al Melting and Casting | Al Casting | Al Recycling |
|---|---|---|---|---|---|---|
| Cast Aluminum | 4.8 | 1.9 | 1.0 | 1.0 | | |
| Recycled Cast Aluminum | | | | | 1.0 | 1.0 |

- Energy use (million Btu) per ton of material product

| | |
|---|---|
| 0.6 | Bauxite Mining |
| 9.5 | Bauxite Refining: Bayer Process |
| 65.8 | Alumina Reduction: Hall-Heroult Process |
| 4.1 | Al Melting and Casting |
| 8.3 | Sheet Production & Rolling |
| 5.5 | Stamping |
| 0.6 | Scrap Preparation (Recycled Al) |
| 9.5 | Reverb Melt and Ingot Cast (Recycled Al) |

## *Key Assumptions for Platinum Production (Mat_Inputs)*

- Platinum is simulated differently than the rest of the materials in GREET 2.7
  - Data collected shows that there are significant co-products and we came up with 3 ways of allocating the energy use

| 2 | 1 -- NA mine - weight based energy allocation |
|---|---|
| | 2 -- South African mine based |
| | 3 -- NA mine - market value based energy allocation |

- North American & South African weight-based case
  - Energy allocations: 1% PGMs, <1% gold, 40% copper & 59% nickel
  - PGMs account for <0.02% of total FCV vehicle-cycle energy use
- North American market value-based case
  - Energy allocations: 93% PGMs, 2% gold, 1% copper & 4% nickel
  - PGMs account for ~10% of total FCV vehicle-cycle energy use
- Our default assumption is South African weight-based case which fits with other data collected for other materials
  - Market-based is 2 orders of magnitude larger than any other material in GREET 2.7
- An economic analysis on how the price and demand of the co-products would be affected by growth in platinum mining could be done to help decipher the situation

# *Key Assumptions for Plastic Production (Mat_Inputs)*

- Average plastic, which is used to simulate all in the vehicle, is a mix of 3 major automotive plastics

| Polypropylene | Polyester | HDPE |
|---|---|---|
| 50% | 30% | 20% |

- Fiber-reinforced plastics are simulated separately from the “average plastic”

Material Composition (%)

| | Polyester | Glass Fiber | Inert Filler |
|---|---|---|---|
| Glass Fiber-Reinforced Plastic | 50% | 50% | 0% |
| | Polyester | Carbon Fiber | |
| Carbon Fiber-Reinforced Plastic | 70% | 30% | |

Tons of intermediate material needed per ton of final product

| | |
|---|---|
| Glass Fiber-Reinforced Plastic | 1.14 |
| Carbon Fiber-Reinforced Plastic | 1.14 |

- Energy use (million Btu) per ton of material product

| | |
|---|---|
| 28.4 | Polypropylene Production |
| 61.2 | Polyester Production |
| 33.0 | HDPE Production |
| 0.6 | Inert Filler Production |
| 160.2 | Carbon Fiber Production |
| 7.9 | Glass Fiber-Reinforced Plastic Fabrication |
| 7.9 | Carbon Fiber-Reinforced Plastic Fabrication |

# *Vehicle-Cycle Results*

- Each material characterized in GREET 2.7 has their energy use, criteria air pollutant emissions and GHG emissions summarized in a table in the Mat_Sum sheet
- The weights of each material used in a specific vehicle's lifetime are calculated through
  - Total weight, replacement frequency, and aggregated material composition of the components
  - Total weight, replacement frequency and material composition of each battery in the vehicle
  - Total weight of each fluid and replacement frequency
- The ADR results are added in to calculate the vehicle-cycle results

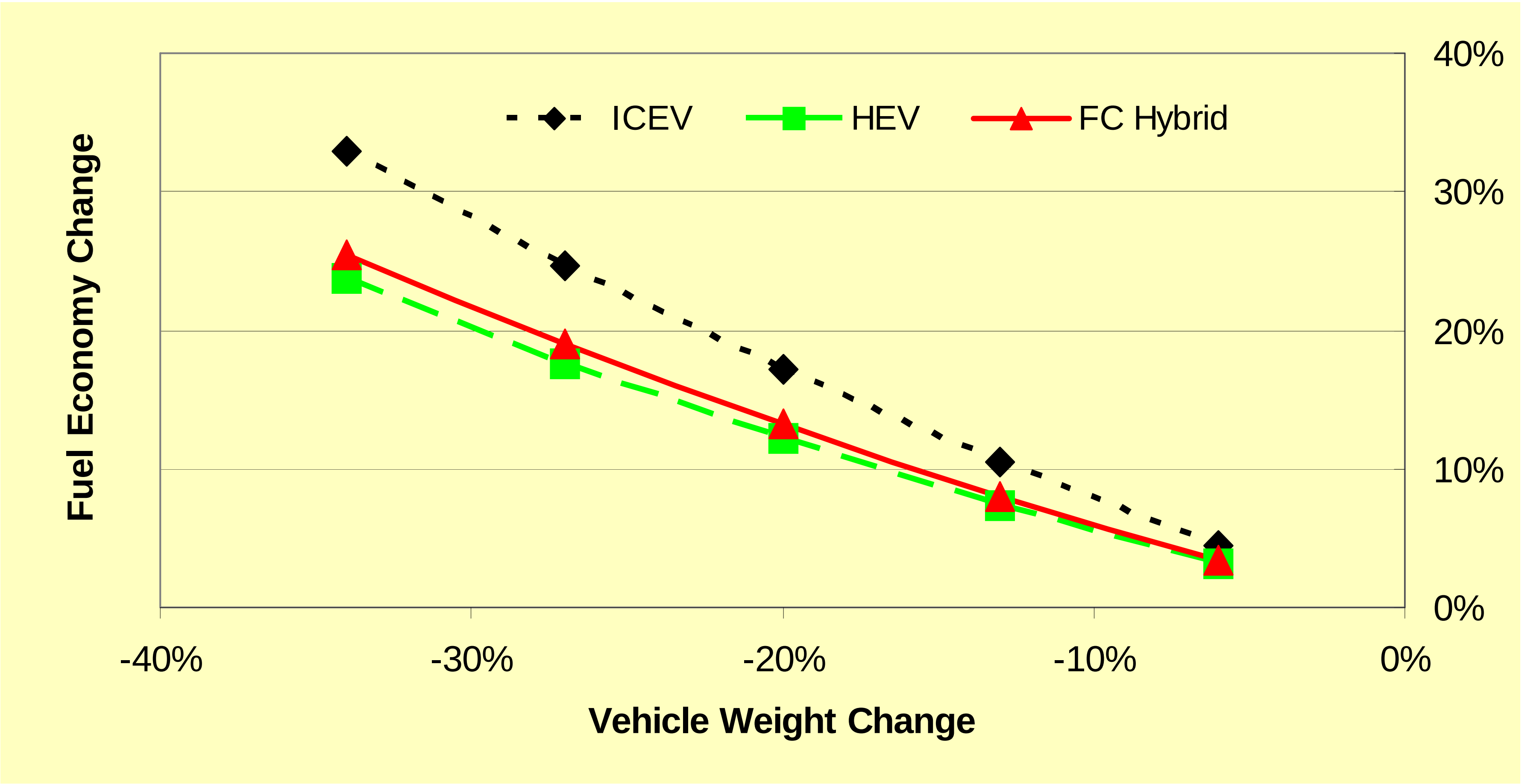
# *Sample Vehicle-Cycle Results for a Conventional Material HEV (Vehi_Sum)*

| | mmBtu or grams per vehicle lifetime | | | | |
|---|---|---|---|---|---|
| | **Components** | **ADR** | **Batteries** | **Fluids** | **Total** |
| Total energy | 61.4 | 12.7 | 16.9 | 10.7 | 101.7 |
| Fossil fuels | 58.6 | 11.5 | 15.1 | 10.6 | 95.8 |
| Coal | 21.5 | 6.3 | 9.6 | 0.5 | 37.9 |
| Natural gas | 27.5 | 4.7 | 4.0 | 2.0 | 38.3 |
| Petroleum | 9.6 | 0.4 | 1.4 | 8.2 | 19.6 |
| CO2 | 4,880,685 | 1,039,264 | 1,374,092 | 659,420 | 7,953,461 |
| CH4 | 8,526 | 1,624 | 1,976 | 1,073 | 13,198 |
| N2O | 57 | 15 | 19 | 5 | 95 |
| GHGs | 5,093,561 | 1,080,979 | 1,425,120 | 685,612 | 8,285,271 |
| VOC: Total | 1,327 | 2,230 | 136 | 29,211 | 32,904 |
| CO: Total | 34,014 | 767 | 1,089 | 226 | 36,096 |
| NOx: Total | 5,595 | 4,041 | 1,562 | 1,146 | 12,344 |
| PM10: Total | 8,261 | 2,261 | 1,873 | 431 | 12,826 |
| PM2.5: Total | 2,710 | 871 | 519 | 250 | 4,349 |
| SOx: Total | 17,580 | 5,673 | 12,100 | 1,349 | 36,702 |

## *Total Energy-Cycle Major Assumptions Requires Use of Both GREET 1.7 and 2.7*

- Lifetime VMT of vehicle: 160,000 miles (Vehi_Inputs)
- Fuel cycle assumptions are based on GREET 1.7 (here are some defaults)
  - ICEVs & HEVs fueled with RFG w/ ethanol
  - FCV fueled with gaseous $H_2$
    - *SMR of NA NG at refueling stations*
    - *Compressed at 6000 psi for 5000 psi onboard storage*
- Vehicle operation assumptions are based on GREET 1.7
  - Except fuel economy equations for lightweighting are built into GREET 2.7 (Vehi_Inputs)
- Fuel economy based on PSAT simulations
    - *LW vehicle assumptions from mass sensitivity analysis*

# *Improved Fuel Economy is Achieved by Lightweight Vehicles over Conventional Counterparts Though it Varies by Vehicle Type*

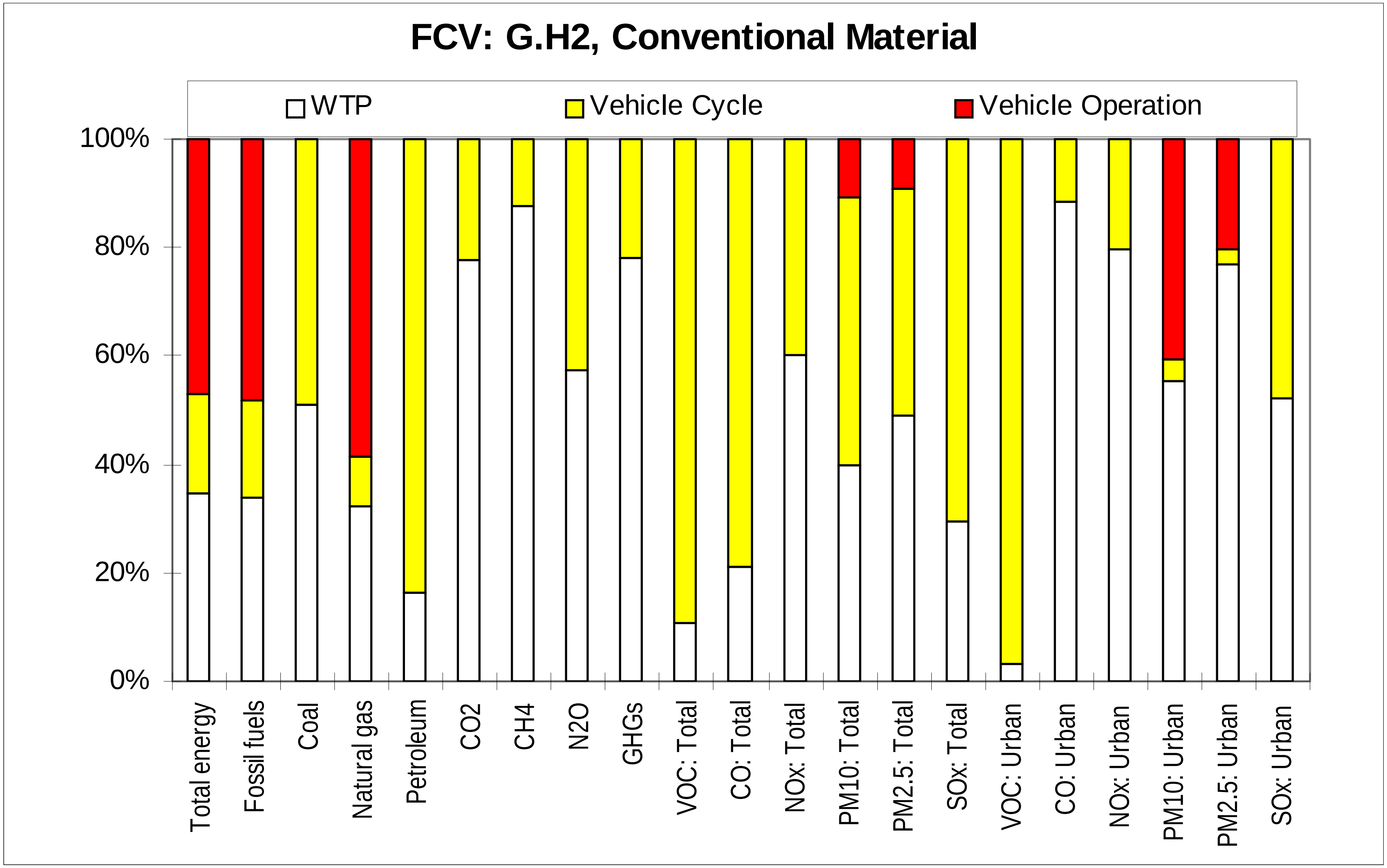



From PSAT simulations

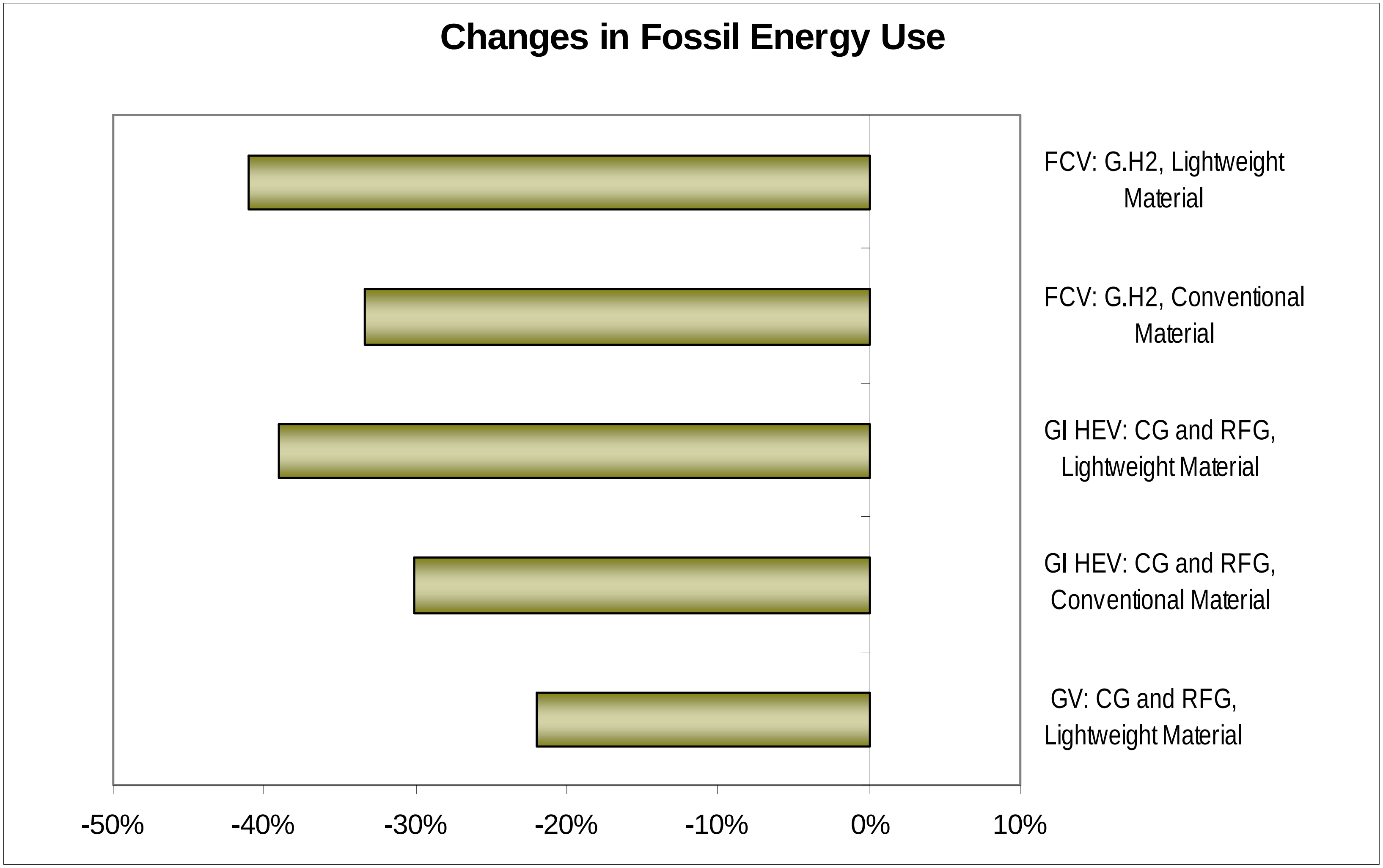
# *Sample Total Energy-Cycle Results for a Conventional Material FCV (TEC_Results)*

| Item | Btu/mile or grams/mile | | | | Percentage of each stage | | |
|---|---|---|---|---|---|---|---|
| | WTP | Vehicle Cycle | Vehicle Operation | Total | WTP | Vehicle Cycle | Vehicle Operation |
| Total energy | 1,473 | 792 | 1,996 | 4,261 | 35% | 19% | 47% |
| Fossil fuels | 1,416 | 745 | 1,996 | 4,156 | 34% | 18% | 48% |
| Coal | 283 | 274 | 0 | 557 | 51% | 49% | 0% |
| Natural gas | 1,101 | 310 | 1,996 | 3,406 | 32% | 9% | 59% |
| Petroleum | 32 | 161 | 0 | 192 | 16% | 84% | 0% |
| CO2 | 219 | 63 | 0 | 282 | 78% | 22% | 0% |
| CH4 | 0.720 | 0.103 | 0.000 | 0.823 | 87% | 13% | 0% |
| N2O | 0.001 | 0.001 | 0.000 | 0.002 | 57% | 43% | 0% |
| GHGs | 236 | 66 | 0 | 302 | 78% | 22% | 0% |
| VOC: Total | 0.024 | 0.205 | 0.000 | 0.230 | 11% | 89% | 0% |
| CO: Total | 0.058 | 0.218 | 0.000 | 0.276 | 21% | 79% | 0% |
| NOx: Total | 0.144 | 0.095 | 0.000 | 0.239 | 60% | 40% | 0% |
| PM10: Total | 0.076 | 0.093 | 0.021 | 0.190 | 40% | 49% | 11% |
| PM2.5: Total | 0.039 | 0.033 | 0.007 | 0.079 | 49% | 42% | 9% |
| SOx: Total | 0.122 | 0.290 | 0.000 | 0.412 | 30% | 70% | 0% |

# *Sample Total Energy-Cycle Graphs for a Conventional Material FCV (TEC_Graphs)*



# *Sample Total Energy-Cycle Graphs Showing Changes in Fossil Energy Use as Compared to the Baseline Gasoline ICEV (TEC_Graphs)*



# *GREET 1.7 plus GREET 2.7 = Comprehensive Life-Cycle Analysis*

- Vehicle cycle does not tell whole story
  - Still it is a nontrivial part of the life-cycle
- Goals
  - Add vehicle types
    - *SUVs should be included shortly*
  - Update material production energy use
    - *As data becomes available*
  - Refine vehicle assembly data and how its modeled
  - Include advanced battery recycling