# Introduction to the new GREET platform

Vadim Sokolov

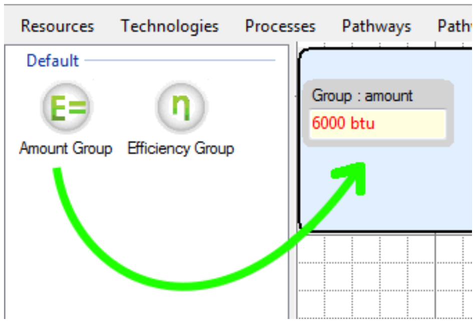
Energy Systems Division
Argonne National Laboratory
September 21, 2012

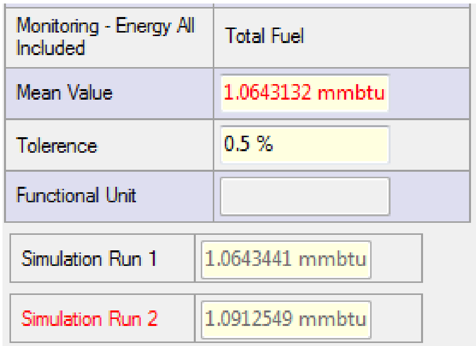
# Outline

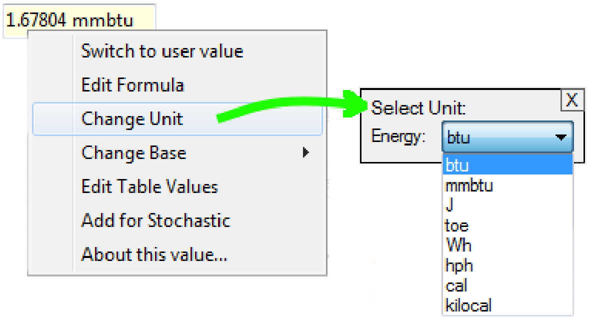
- Overview (Present, Future)
- Model
- User Community

# Why the new platform?

- Easy to use
  - Graphical data editors
  - Search by object name
  - Navigation through links
- Not bound by capabilities of Excel
  - Automated integrity checks
  - Automated unit conversions
  - Automated dimensions normalization
  - Automated quality control
  - Result exporting feature
  - Reporting capabilities



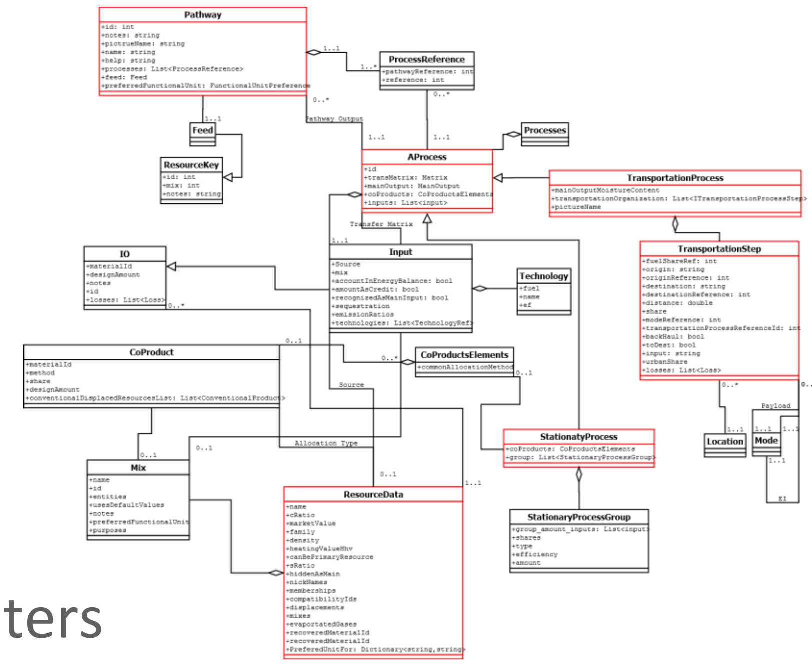



# What is the new GREET?

**Two Major Separate Components:**

1. Database (an XML file)
   - Model data
   - Images
   - User preferences
   - Unit system conversion parameters




2. Software
   - Uses database as an input
   - Graphical User Interface
   - Implements the underlying model logic
   - Implements the relations between database objects

# Where we are

- Database:
  - Replicates the data in GREET_1_2011
  - Some updates from GREET_1_2012 has been ported
  - All of the 2012 modifications are being ported
  - In the future the new GREET database is to become default
- Software
  - Allows  same operations as Excel version
  - In the future more features to be added
- Documentation
  - Quick start guide
  - User guide
  - Model description

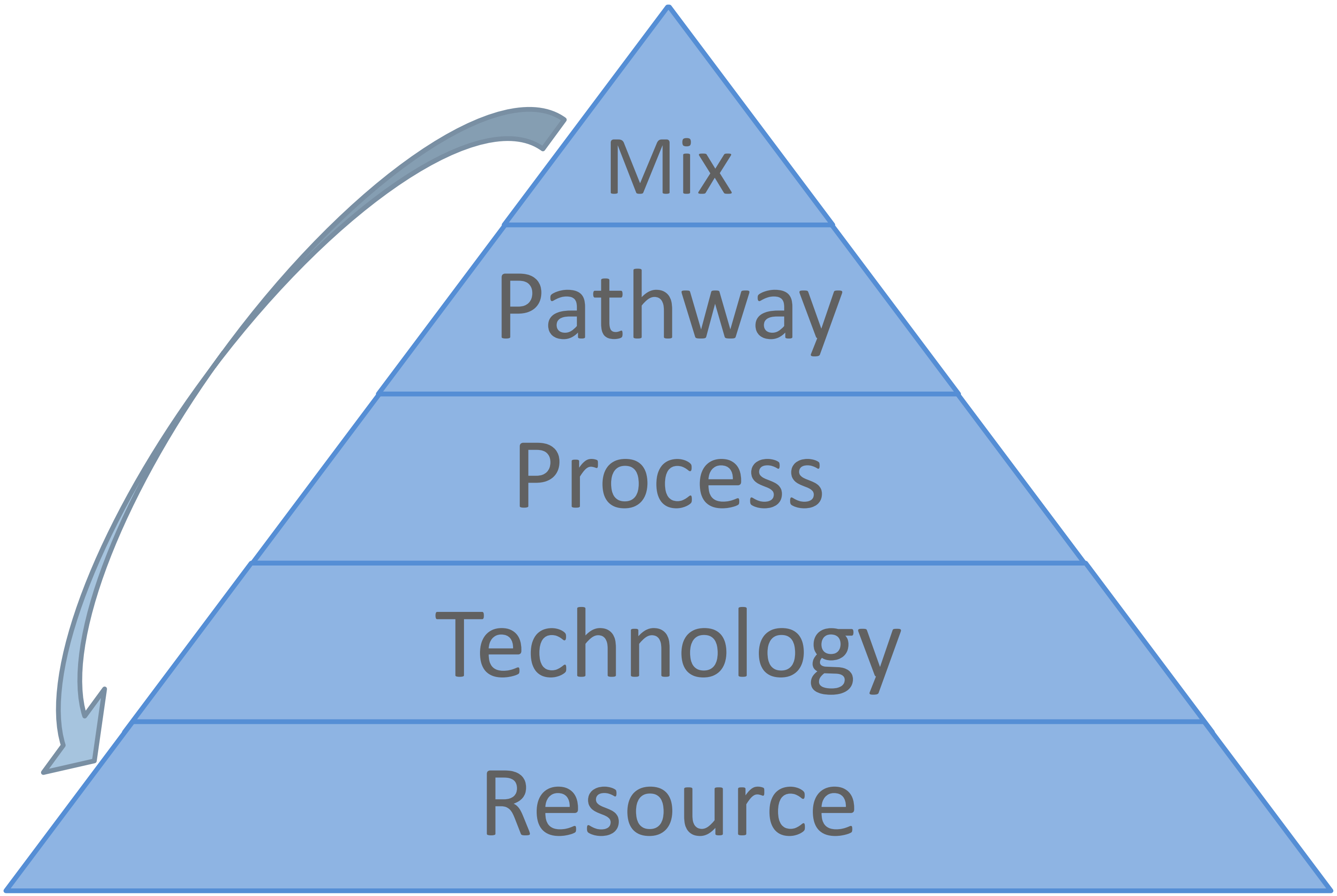
# Documentation

- Getting started guide:
  - Key concepts
  - Step-by-step pathway creation process
- User guide:
  - Download and Installation
  - Updating
  - All of the GUI features
- Model guide: mathematical model used in GREET is described
  - Sulfur and carbon balance
  - Upstream calculations
  - Stationary process
  - Stationary process efficiency
  - Transportation process
  - Pump To Wheel

# Updates to Data and Software

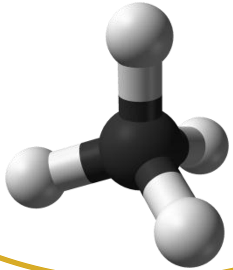
- Data and Software updates are pushed separately
  - Data includes all of the input parameters (processes, pathways, technologies, etc.) and some user preferences
  - Software includes graphical interface and mathematical model
- Software updates do not affect data and vice versa
- Updates are pushed automatically and require user's consent
- User's changes are always stored in a separate database on the user's machine
- Default data is always backed up on before a data update and can be reverted to if needed

# Modeling Approach



# Resources

Fuels (liquid, solid, gas)

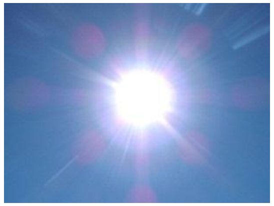


- Coal
- Natural Gas
- Diesel

...

Electricity

Renewable Resources



- Wind
- Solar
- Geothermal

...

Other Materials

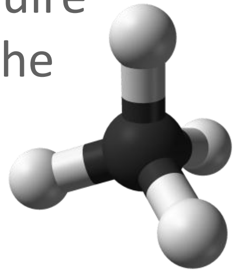

- Uranium Ore
- Fertilizers

...

# Primary Resources

- A primary resource is a one which is given by nature.
- Processing is not required
- Primary Resource = no upstream (e.g. from well)
- All Fossil resources
- Renewable resources
- Corn, soy beans and biomass are not primary resources. They require farming (solar energy is used as a "proxy" for energy content of the product)

Coal



CH4

Solar

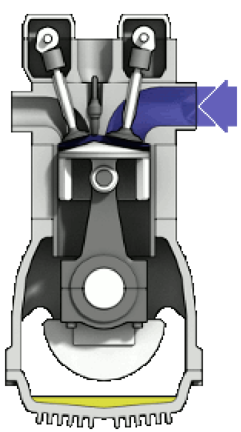
Wind

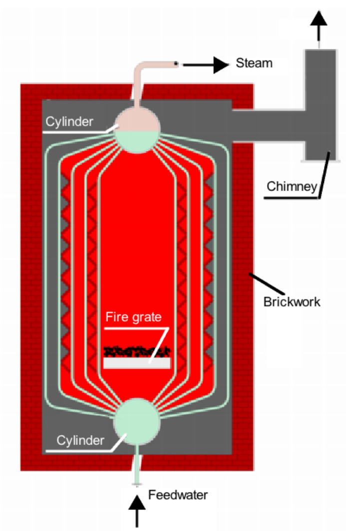
Uranium Ore

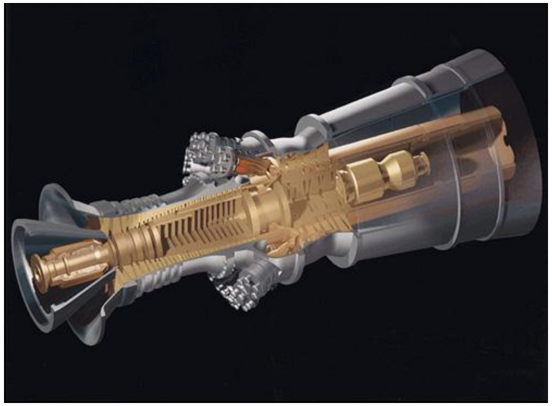
# Technologies

- Technologies include boilers, engines, turbines, etc.
- Technologies are used to trace emissions (as a result of combustion or chemical reaction)
- Each technology is associated with a fuel (resource)
- Each technology has a list of emission factors (VOC, CO, $NO_x$, $PM_{10}$, $PM_{2.5}$, $SO_x$, $CH_4$, $CO_2$, $N_2O$)
- Emission factors can be defined as a time series

1





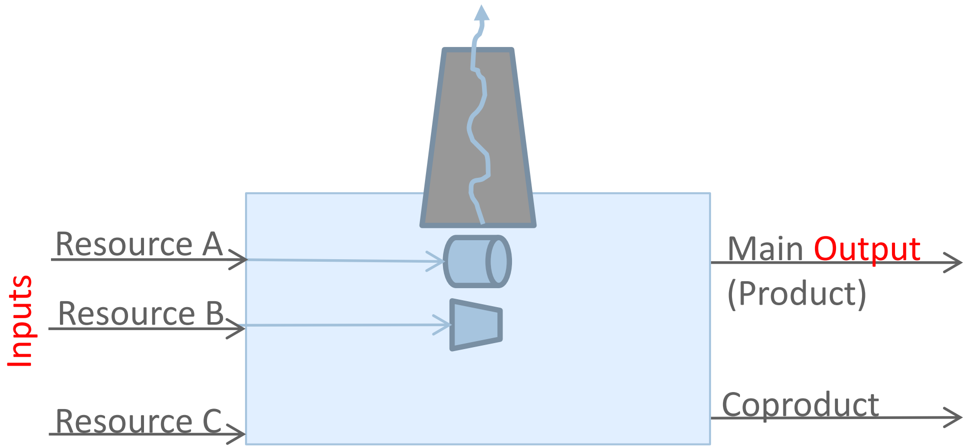
# Processes

- Process: Inputs (Resources) + Technologies → Outputs
- Names are analogous to what they represent
- Transportation and Stationary are represented differently
- Emissions are generated by process technologies and/or losses

Stationary

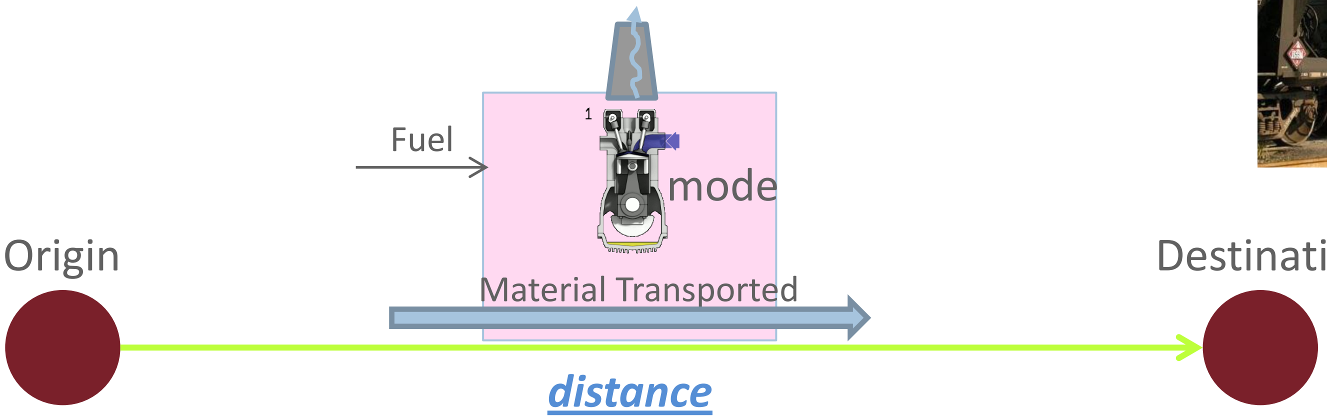

Transportation

# Stationary Process



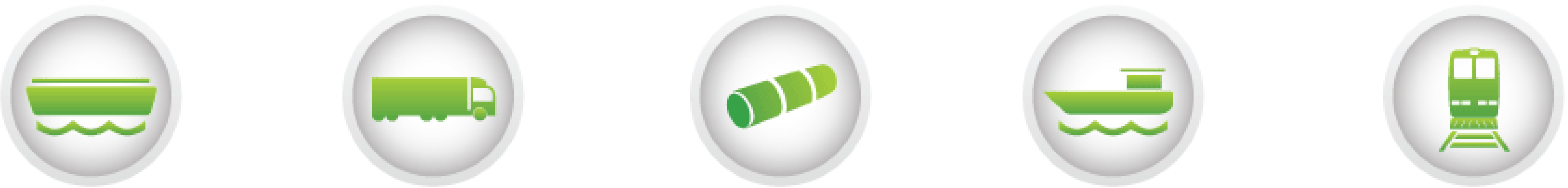

- A process input amount requirements can be specified in several ways
  - Requirement for each individual input
  - Efficiency plus energy shares for each of the inputs (legacy)
  - Combination
- Resources with no energy content are supported (Agricultural Inputs, Uranium Ore, etc.)
- A technology need to be specified for an energy input in order to account for emissions

# Transportation Process

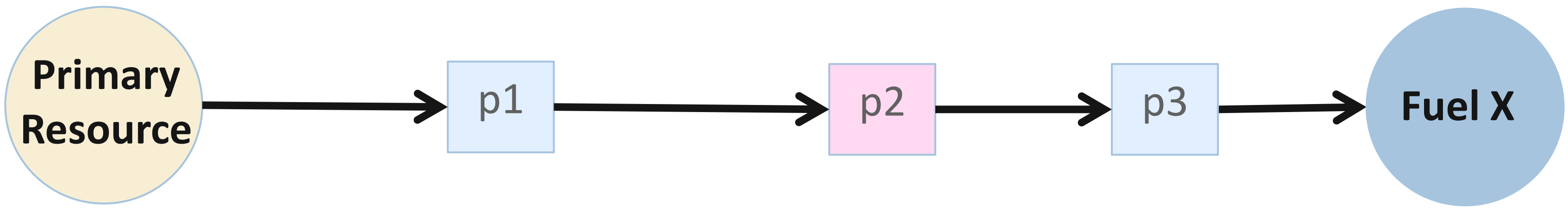

- Transportation process consists of transportation steps
- Transportation Step = mode + mode share + distance
- Several technologies can be specified for a transportation mode
- Five modes of transportation includes with support for user defined modes

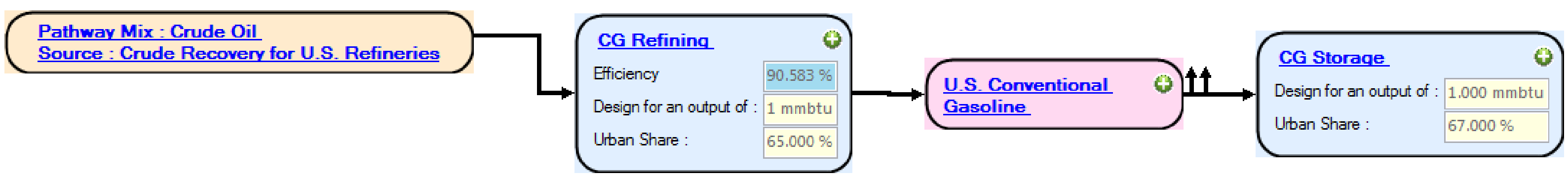
**Barge** **Truck** **Pipeline** **Ocean Tanker** **Rail**



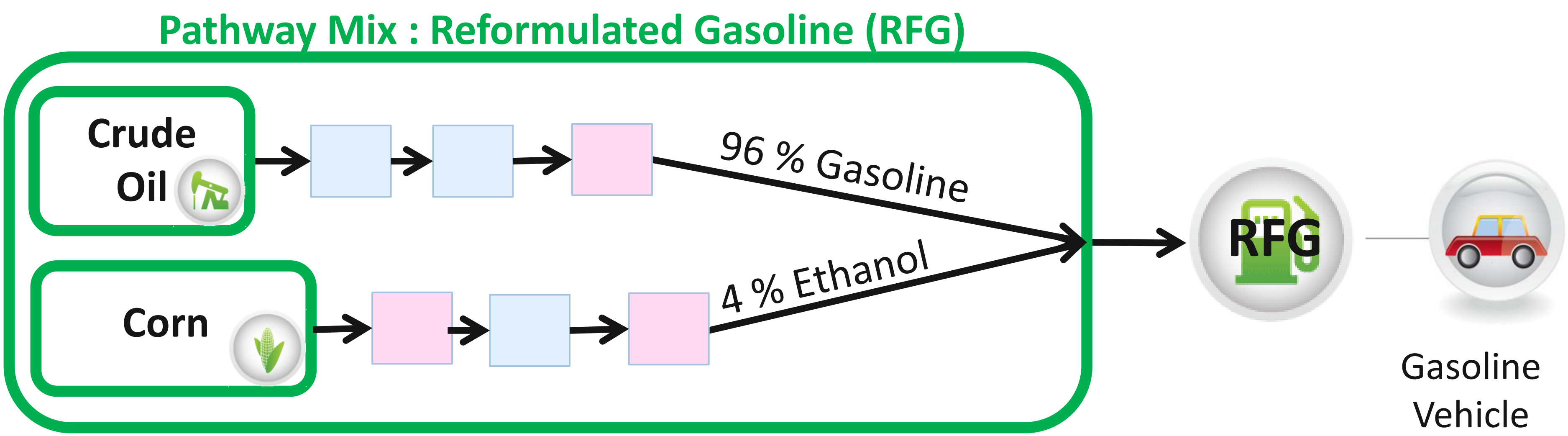
# Pathways: Series of steps for fuel production

- Pathway are series of Processes
- I/O of a Pathway is defined by it's first and last process



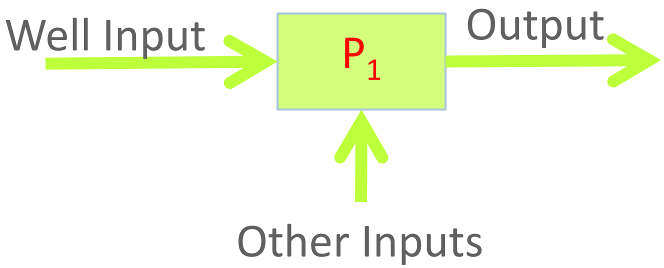



# Pathway Mix



Pathway Mix : Reformulated Gasoline (RFG)
Crude Oil
Corn
96 % Gasoline
4 % Ethanol
RFG
Gasoline Vehicle

# Process Results

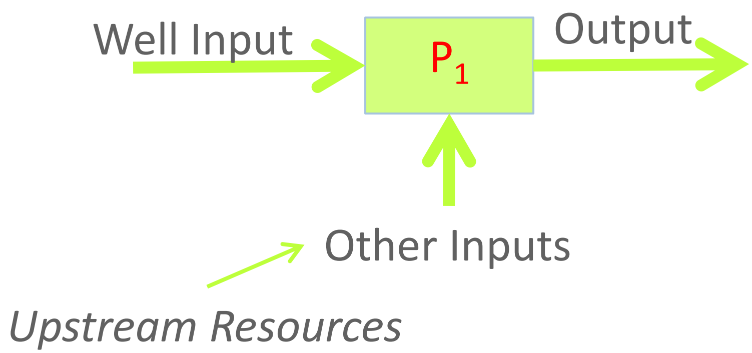



| | |
|---|---|
| On Site | |
| Resources | 1.104 mmbtu |
| Crude Oil | 1.000 mmbtu |
| Residual Oil | 41381.861 btu |
| Natural Gas | 27875.866 btu |
| Gaseous Hydrogen | 21771.556 btu |
| Liquefied Petroleum | 8470.355 btu |
| Electricity | 4426.457 btu |
| Coal | 29.108 btu |

For $P_1$:

- On-Site Resources = Well Input + Other Inputs (without upstream)

# Process Results

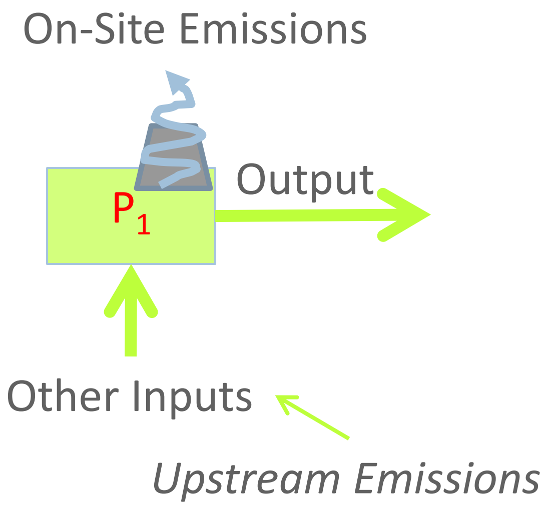



| | |
|---|---|
| Life Cycle | |
| Resources | 1.169 mmbtu |
| Crude Oil | 1.057 mmbtu |
| Natural Gas | 91112.427 btu |
| Coal | 12998.849 btu |
| Bituminous Oil | 4912.265 btu |
| Nuclear Energy | 1950.149 btu |
| Hydroelectric Power | 623.422 btu |
| Wind Power | 221.130 btu |
| Forest Residue | 107.437 btu |
| GeoThermal Power | 40.688 btu |
| Renewable (Solar, Hy | 36.265 btu |
| Solar | 3.538 btu |
| Uranium Ore | 19.489 mg |

For $P_1$:

- Life Cycle Resources = Well Input + Other Inputs (with upstream)

# Process Results

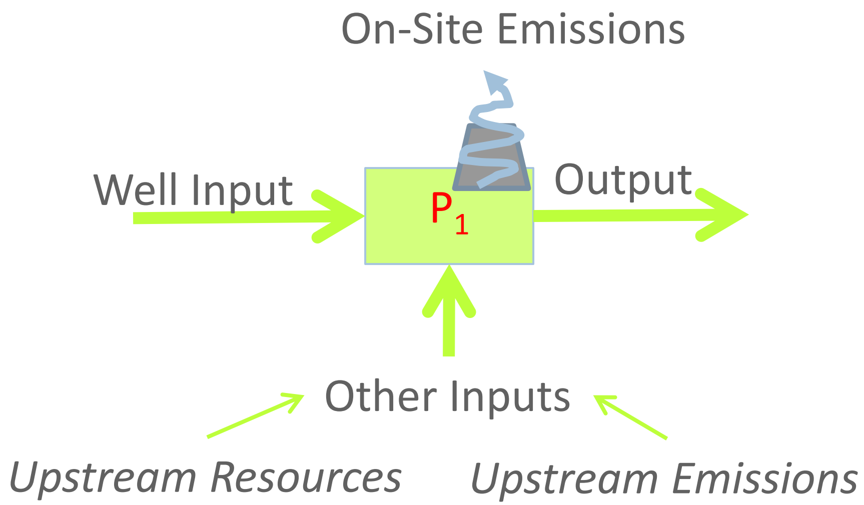



| | |
|---|---|
| **Emissions** | |
| Life Cycle | ... |
| Emissions | ... |
| VOC | 7.600 g |
| CO | 10.943 g |
| NOx | 34.957 g |
| PM10 | 6.010 g |
| PM2.5 | 3.191 g |
| SOx | 19.347 g |
| CH4 | 139.411 g |
| N2O | 182.653 mg |
| CO2 | 14.422 kg |
| CO2C | 14.463 kg |
| Groups | ... |
| Criteria Pollutant | 82.048 g |
| Emission Gas | 29.107 kg |
| From Combustion | 29.107 kg |
| Non-Balanced Vehicl | 202.294 g |
| Upstream Emission | 14.644 kg |
| Greenhouse Gas | 18.003 kg |

For $P_1$:

- Life Cycle Emissions = On-Site Emissions + Upstream Emissions for Other Inputs

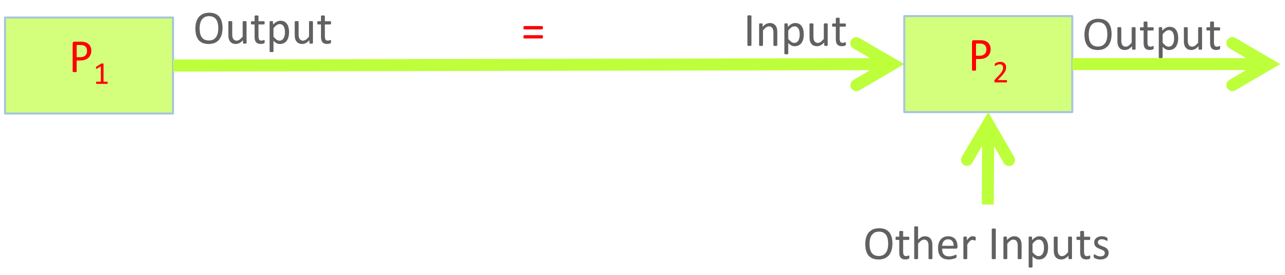
# Process Results




For $P_1$:

- On-Site Resources = Well Input + Other Inputs (without upstream)
- Life Cycle Resources = Well Input + Other Inputs (with upstream)
- Life Cycle Emissions = On-Site Emissions + Upstream Emissions for Other Inputs

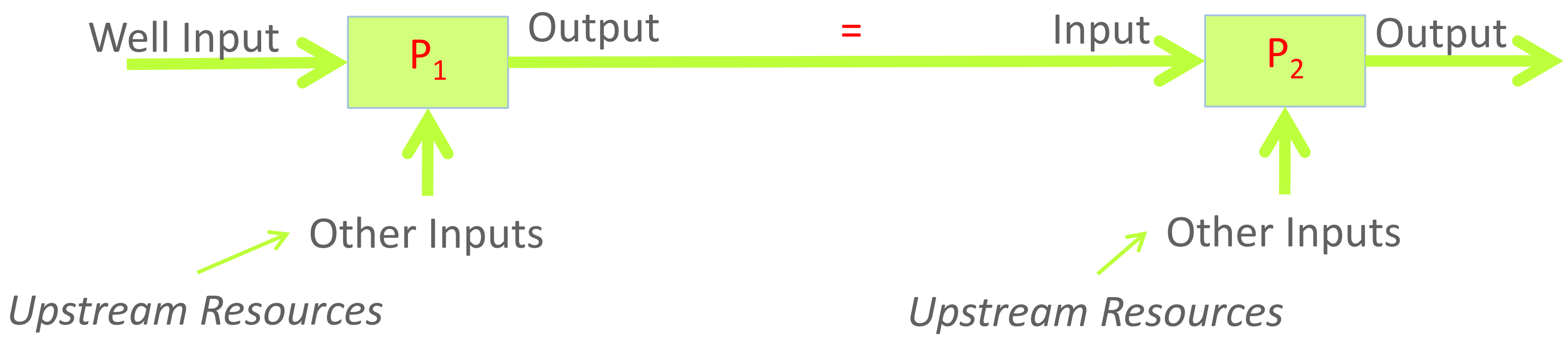
# Process Results




For $P_2$:

- On-Site Resources = Main Input ($P_1$ Output) + Other Inputs (without upstream)

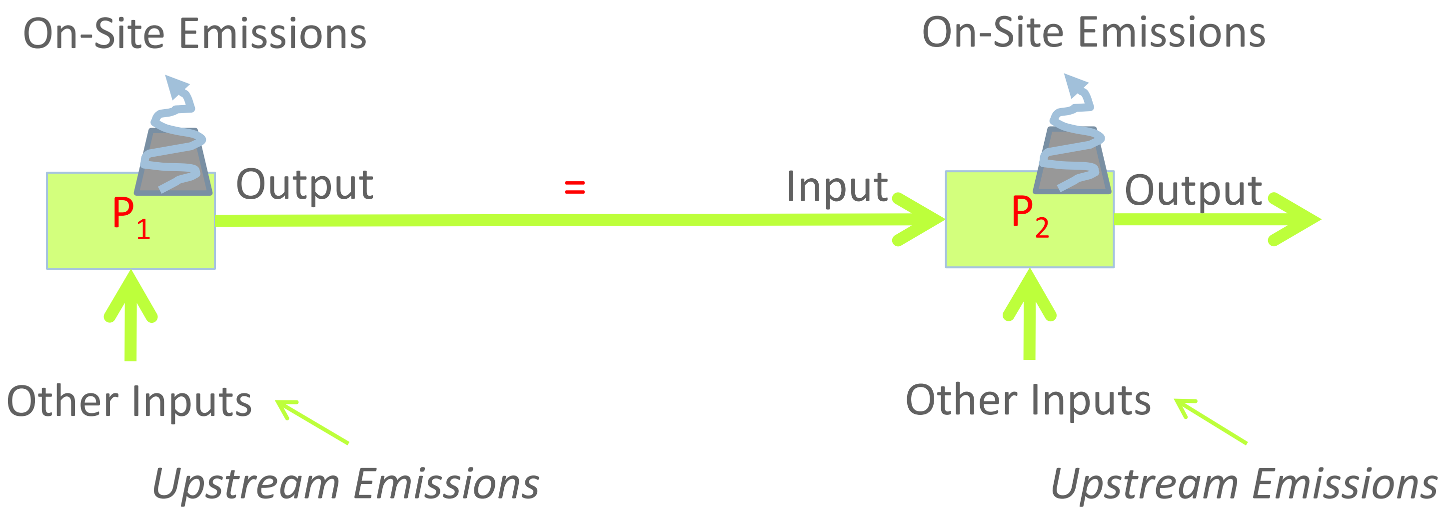
# Process Results




For $P_2$:

- Life Cycle Resources = Life Cycle Resources of $P_1$ + Other Inputs (with upstream)

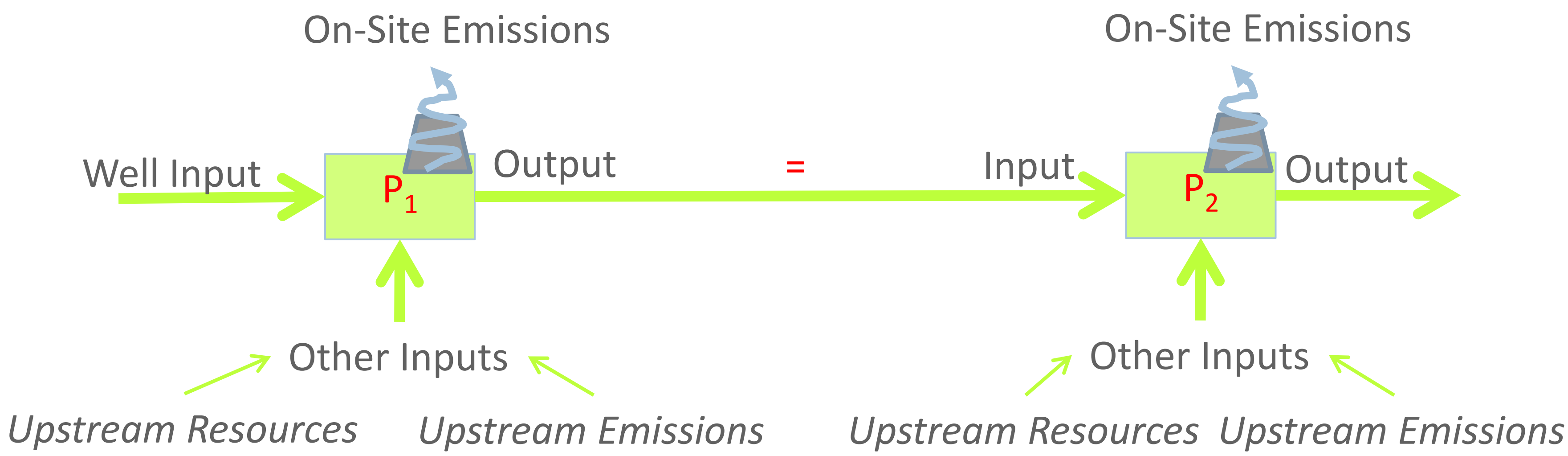
# Process Results




For $P_2$:

- Life Cycle Emissions = Life Cycle Emissions of $P_1$ + On-Site Emissions +
  + Upstream Emissions for Other Inputs

# Process Results




For $P_1$:

- On-Site Resources = Well Input + Other Inputs (without upstream)
- Life Cycle Resources = Well Input + Other Inputs (with upstream)
- Life Cycle Emissions = On-Site Emissions + Upstream Emissions for Other Inputs

For $P_2$:

- On-Site Resources = Main Input ($P_1$ Output) + Other Inputs (without upstream)
- Life Cycle Resources = Life Cycle Resources of $P_1$+ Other Inputs (with upstream)
- Life Cycle Emissions = Life Cycle Emissions of $P_1$ + On-Site Emissions +
  + Upstream Emissions for Other Inputs

# Result Groups

## Emissions

- Greenhouse Gas
- Criteria Pollutant
- From Combustion
- Other (Non-Combustion) Emissions
- Upstream Emissions

| | |
|---|---|
| Emissions | ... |
| VOC | 6.434 g |
| CO | 10.626 g |
| NOx | 33.678 g |
| PM10 | 5.953 g |
| PM2.5 | 3.157 g |
| SOx | 19.123 g |
| CH4 | 138.852 g |
| N2O | 176.552 mg |
| CO2 | 14.162 kg |
| CO2C | 14.199 kg |
| Groups | ... |
| Criteria Pollutant | 78.972 g |
| Emission Gas | 28.579 kg |
| From Combustion | 28.579 kg |
| Non-Balanced Vehicle Emiss | 198.877 g |
| Upstream Emission | 14.380 kg |
| Greenhouse Gas | 17.723 kg |

## Energy

- By Primary Resource
  - Fossil Fuel
  - Coal
  - Natural Gas
  - Renewable
  - Petroleum
  - Biomass

| | |
|---|---|
| Resources | 1.169 mmbtu |
| Crude Oil | 1.057 mmbtu |
| Natural Gas | 91112.427 btu |
| Coal | 12998.849 btu |
| Bituminous Oil | 4912.265 btu |
| Nuclear Energy | 1950.149 btu |
| Hydroelectric Power | 623.422 btu |
| Wind Power | 221.130 btu |
| Forest Residue | 107.437 btu |
| GeoThermal Power | 40.688 btu |
| Renewable (Solar, Hydro, Wi | 36.265 btu |
| Solar | 3.538 btu |
| Uranium Ore | 19.489 mg |
| Herbaceous Biomass (Switcl | 0.000 btu |
| Farmed Trees | 0.000 btu |
| Groups | |
| Fossil Fuel | 1.166 mmbtu |
| Petroleum Fuel | 1.062 mmbtu |
| Natural Gas Fuel | 91112.427 btu |
| Coal Fuel | 12998.849 btu |
| Non Fossil Fuel | 2982.629 btu |
| Nuclear | 1950.149 btu |
| Renewable | 1032.480 btu |

# Pathway and Pathway Mix (Skip)

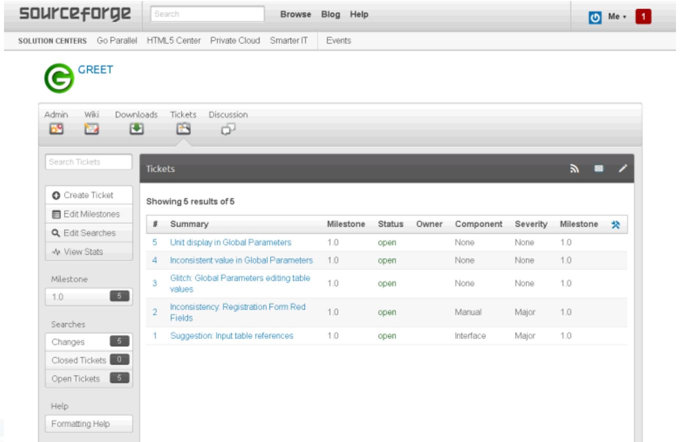
- Upstream values of a product produced by a pathway is defined by *Life Cycle* values of the last process
- Upstream of a product produces by a pathway mix is defined by weighted average values of the corresponding pathways
- Each product for which a pathway or pathway mix is defined has upstream

# Future Developments

- Port 2012 data updates (near future)
- Reporting tools
- More flexible process model?
- Demand driven development of new features
- Public release by the end of 2012

# User Community

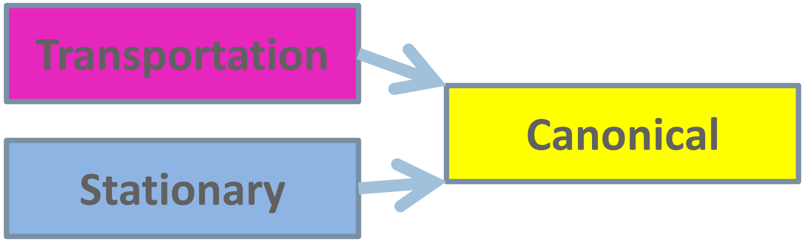
- Community driven support through user interaction via mailing list
  - A user may elect to subscribe/unsubscribe to the list
- The mailing list will be helpful as the first step in requesting for help
- Other users are able to reply to help requests
  - Archives are available to everyone and can be searched for previously asked questions
- Users interact with developers through issue tracker for bug reporting and features requests




greet.es.anl.gov/greet/support

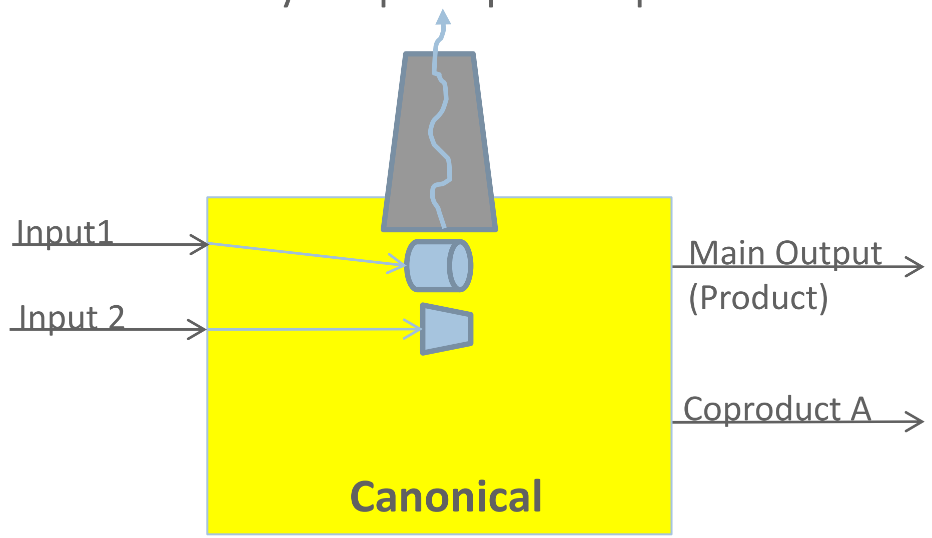
# Canonical Process

- Both transportation and Stationary Types of process are converted into a canonical from inside



# Canonical Process

- The Canonical Process has a very simple input-output form




- Energy Balance (emissions calculated similarly):

$$E = \frac{E(I) - E(Copr) - E(Credit)}{a(f_O)(1 - l_r(f_O))}$$

$$E(I) = \sum_{f \in I} E(f)$$

$$E(f) = a(f) E_{up}(f)$$

# Canonical Process

- Energy Balance:

$$E_b = \frac{E(I) - E(Copr) - E(Credit)}{a(f_O)(1 - l_r(f_O))}$$

- Emissions Balance

$$\frac{Em(I) - Em(Copr) - Em(Credit)}{a(f_O)(1 - l_r(f_O))} + l_r(f_O)Em_s(f_O)$$

- Balance = units of input per functional unit of output

# Conversion of Stationary Process Defined by Efficiency

- Defined by efficiency

$$\eta = \frac{a(f_O)}{\sum_{f_i \in G} a(f_i)}$$

$$a(G) = \frac{a(f_O)}{\eta} = \sum_{f_i \in G} a(f_i)$$

| | |
|---|---|
| $a(f_O)$ | Amount of Main Input |
| $a(f_i)$ | Amount of an Input resource |
| $G$ | Process inputs |

- The set of inputs within the group for which the amount is defined

$$\hat{a}(G) = a(G) - \sum_{f \in G_1} a(f)$$

- The rest of the input amounts are defined by shares

$$a(f) = s(f)\hat{a}(G), \ \ for \ f \in G - G_1$$

# Transportation Process

- Defined by a transportation steps
- Each step has a transportation mode, distance and share defined
- Each mode has 3 parameters defined
  - Energy Intensity $\left[\frac{J}{kg \times m}\right]$
    - Calculated for Ocean Tanker, Barge, Truck and an input for Pipeline and Rail
  - Process fuel (fuel used to propel an engine)
  - Emissions factors for each process fuel
- Amount of fuel required by a mode is calculated by

$$a(f) = ei(mode) \times distance \times sahre$$

# Canonical Process Calculations

- Two vectors are calculated:
  - Energy
  - Emissions
- Energy balance vector contains an energy amount associated with each of the basic resource
- Emissions balance vector contains the amount of each criteria pollutant

# Sulfur and Carbon Balance

- If the SOx emission factor is not specified as an input for a technology

$$ef(f, SOx) = \frac{\rho(f)}{hv(f)} \frac{sratio(f)}{sratio(SO_2)}$$

- An equivalent formula for calculating the $CO_2$ emission factor

$$ef(f, CO_2) = \frac{1}{crato(CO_2)} \left[ \frac{\rho(f) crato(f)}{hv(f)} - (ef(f, VOC) crato(VOC) + ef(CO) crato(CO) + ef(CH_4) crato(CH_4)) \right]$$