Introduction to Life Cycle Analysis

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NATIONAL ENERGY TECHNOLOGY LABORATORY

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Attribution

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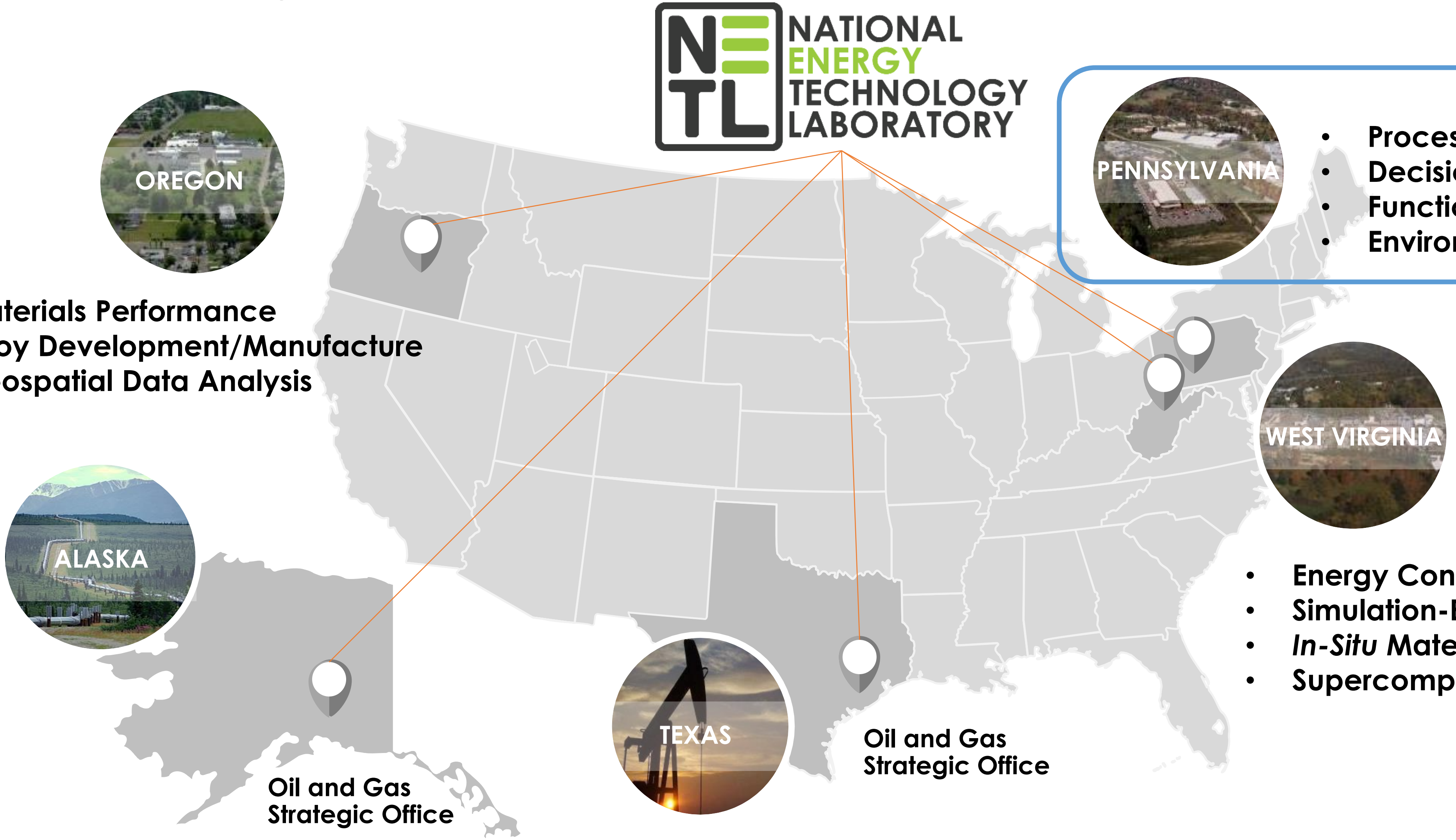
NETL sites

Multiple sites operating as 1 lab system



- **Materials Performance**
- **Alloy Development/Manufacture**
- **Geospatial Data Analysis**

- **Process Systems Engineering**
- **Decision Science**
- **Functional Materials**
- **Environmental Sciences**

- **Energy Conversion Devices**
- **Simulation-Based Engineering**
- ***In-Situ* Materials Characterization**
- **Supercomputer Infrastructure**

Life cycle analysis team

Team is located at Pittsburgh NETL location

NATIONAL ENERGY TECHNOLOGY LABORATORY

Tim Skone – 20 years
Federal Team Lead
BS Chem Engr | P.E. Env. Engr

PennState

Greg Cooney – 10 years
Contractor Team Lead
MS Env Engr | BS Chem Engr

PennState

James Littlefield – 17 years
Natural gas, system & process design
BS Chemical Engineering

Washington University in St. Louis

Matt Jamieson – 9 years
Power systems, CO_2-EOR
BS Mechanical Engineering

UMD Duluth

Michele Mutchek – 6 years
Loan program office, CO2U
MS Civil/Env/Sust Engr | BS Env Sci

ASU

Michelle Krynock – 4 years
Natural gas, fuel cells, coal
BS Civil/Env Engr & Public Policy

Carnegie Mellon University

Derrick Carlson – 7 years
I/O LCA, Energy efficiency
PhD/MS Civ/Env Engr | BS Chem

Carnegie Mellon University

Greg Zaimes – 4 years
Energy analysis; fuels
PhD Civ/Env Eng; BS Physics

Pitt

Selina Roman-White – 1 year
Energy/environment
BS Chem. Engr.

PennState

Joseph Chou – 1 year
Energy/environment
MS Civil & Env Engr

Carnegie Mellon University

Srijana Rai– 1 year
Energy/environment
MS Civil & Env Engr

Carnegie Mellon University

Joe Marriott – 12 years
Senior Advisor
PhD Env Engr & Public Policy

Carnegie Mellon University

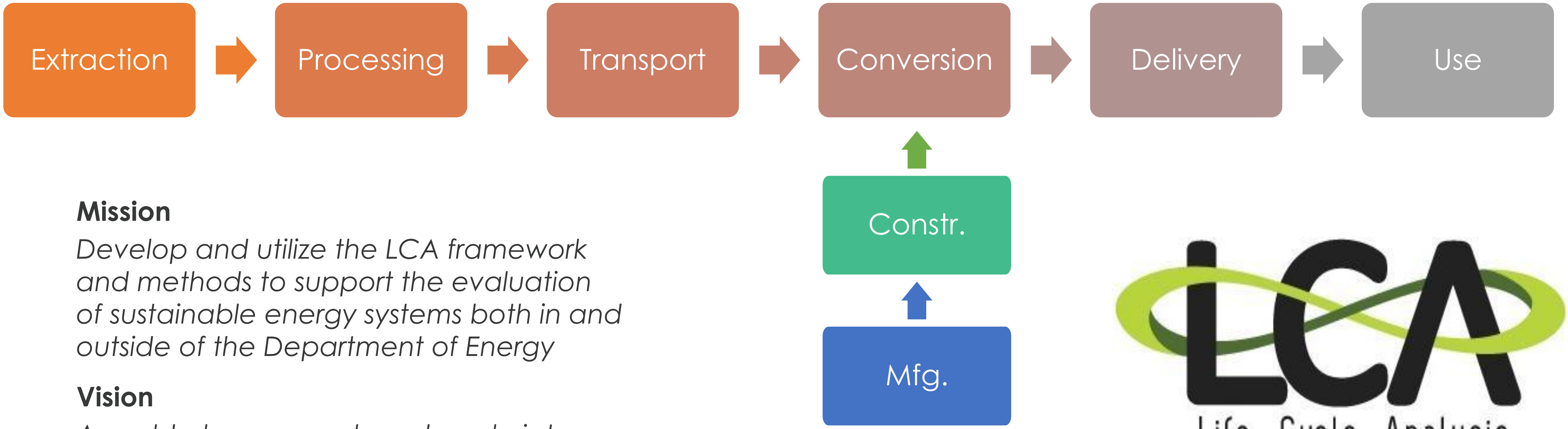
Life cycle analysis (LCA)

A definition

A comprehensive form of analysis that evaluates the environmental, economic, and social attributes of a product or system from the extraction of raw materials from the ground (cradle) to the final use and disposal of the product or system (grave).

Energy life cycle analysis

Cradle-to-grave environmental footprint of energy systems



Mission

Develop and utilize the LCA framework and methods to support the evaluation of sustainable energy systems both in and outside of the Department of Energy

Vision

A world-class research and analysis team that integrates results which inform and recommend sustainable energy strategy and technology development

Life Cycle Analysis

• energy sustainability •

LCA is well suited for energy analysis

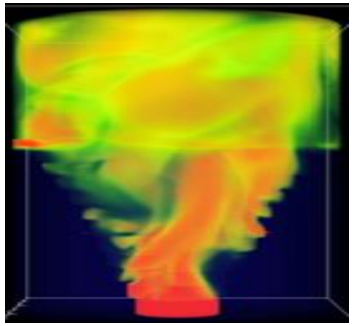
Widely accepted approach for evaluating energy systems

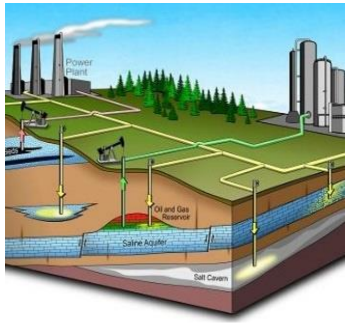
- **Draws a more <u>complete picture</u> than one focused solely on stack or tailpipe emissions**

- **Allows <u>direct comparison</u> of dramatically different options based on function or service**

- **Includes methods for evaluating a wide variety of emissions and impacts on a <u>common basis</u>**

- **Brings <u>clarity to results</u> through systematic definition of goals and boundaries**

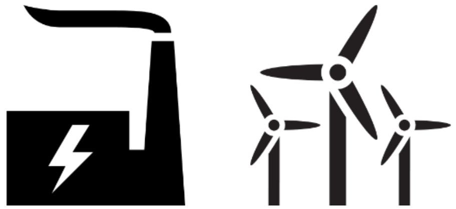




What do we want to compare and why?

Developing the goal and scope of a life cycle analysis

- **Compare the life cycle environmental impacts of…**

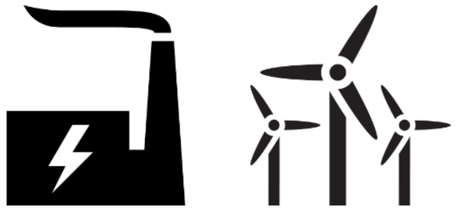


- **Paper vs plastic bags**
- **Electric vs gasoline vehicles**
- **Fossil fuel electricity generation vs wind**

What do we want to compare and why?

Developing the goal and scope of a life cycle analysis

- **Compare the life cycle environmental impacts of…**



- **Paper vs plastic bags**
- **Electric vs gasoline vehicles**
- **Fossil fuel electricity generation vs wind**

- **Determine the basis of comparison – the functional unit**

- **Paper vs plastic:**
  consumer use & disposal of 1 bag
- **Electric vs gasoline:**
  1 passenger-mile
- **Power plants:**
  1 MWh (more on this later)

Building the life cycle

Summary of lifetime power plant performance

92 million tons bituminous coal →

Coal-fired Power Plant
550 MW
39.3% Efficiency
85% Capacity Factor
60 yr Lifetime

→ 246 TWh Electricity

- 217 M tons CO_2
- 540 tons CH_4

Building the life cycle

And the power plants associated coal mine

Building the life cycle

Interconnected system of power plant and mine

Galatia Mine
Springfield 5/Illinois 6
Bituminous Coal
7 million tons annual production
60 yr life

22% of lifetime production & emissions

- 38,900 tons CO_2
- 9,500 tons CH_4

Coal-fired Power Plant
550 MW
39.3% Efficiency
85% Capacity Factor
60 yr Lifetime

246 TWh Electricity

- 217.3 M tons CO_2
- 10,100 tons CH_4

Compare original system to a different power plant

Summary of lifetime power plant performance

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126 million tons
Sub-bituminous coal

Coal-fired Power Plant
600 MW
37% Efficiency
85% Capacity Factor
60 yr Lifetime

268 TWh
Electricity

- 251 M tons CO_2
- 148 tons CH_4

Compare original system to a different power plant

And the power plants associated coal mine

Electricity
Fuel

Montana Rosebud
Powder River Basin
Subbituminous Coal
12 million tons annual production
60 yr life

720 M tons

- 240,100 tons CO_2
- 7,500 tons CH_4

Compare original system to a different power plant

Interconnected system of power plant and mine

Montana Rosebud
Powder River Basin
Subbituminous Coal
12 million tons annual production
60 yr life

17% of lifetime production & emissions

- 42,000 tons CO_2
- 1,300 tons CH_4

Coal-fired Power Plant
600 MW
37% Efficiency
85% Capacity Factor
60 yr Lifetime

268 TWh Electricity

- 251.1 M tons CO_2
- 1,560 tons CH_4

Systems are not directly comparable

Galatia Mine
Springfield 5/Illinois 6
Bituminous Coal
7 million tons annual production
60 yr life

22% of lifetime production & emissions

- 38,900 tons CO_2
- 9,500 tons CH_4

Coal-fired Power Plant
550 MW
39.3% Efficiency
85% Capacity Factor
60 yr Lifetime

246 TWh Electricity

- 217.3 M tons CO_2
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Montana Rosebud
Powder River Basin
Subbituminous Coal
12 million tons annual production
60 yr life

17% of lifetime production & emissions

- 42,000 tons CO_2
- 1,300 tons CH_4

Coal-fired Power Plant
600 MW
37% Efficiency
85% Capacity Factor
60 yr Lifetime

268 TWh Electricity

- 251.1 M tons CO_2
- 1,560 tons CH_4

Choose a basis for comparison & rescale

Galatia Mine
Springfield 5/Illinois 6
Bituminous Coal
7 million tons annual production
60 yr life

0.37 tons coal

Coal-fired Power Plant
550 MW
39.3% Efficiency
85% Capacity Factor
60 yr Lifetime

1 MWh Electricity

- 1,786 lbs CO_2
- 4.66 lbs CH_4

Montana Rosebud
Powder River Basin
Subbituminous Coal
12 million tons annual production
60 yr life

0.46 tons coal

Coal-fired Power Plant
600 MW
37% Efficiency
85% Capacity Factor
60 yr Lifetime

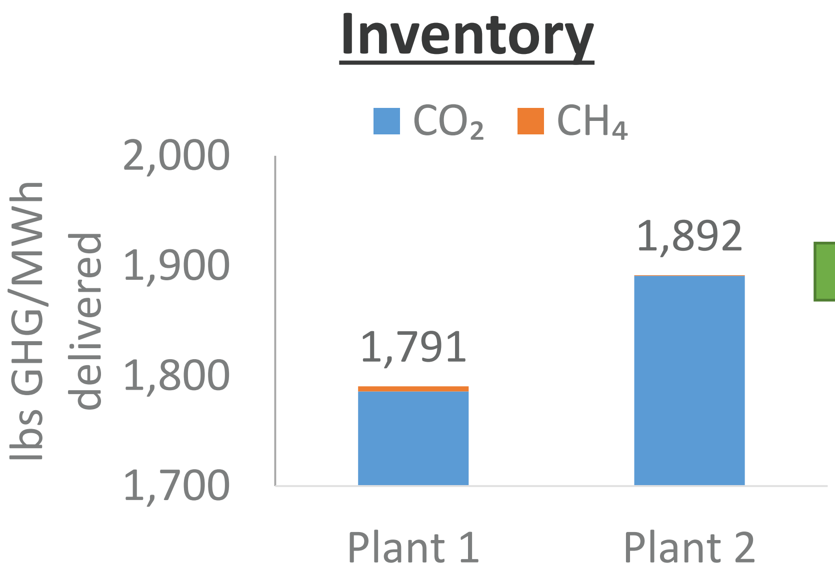
1 MWh Electricity

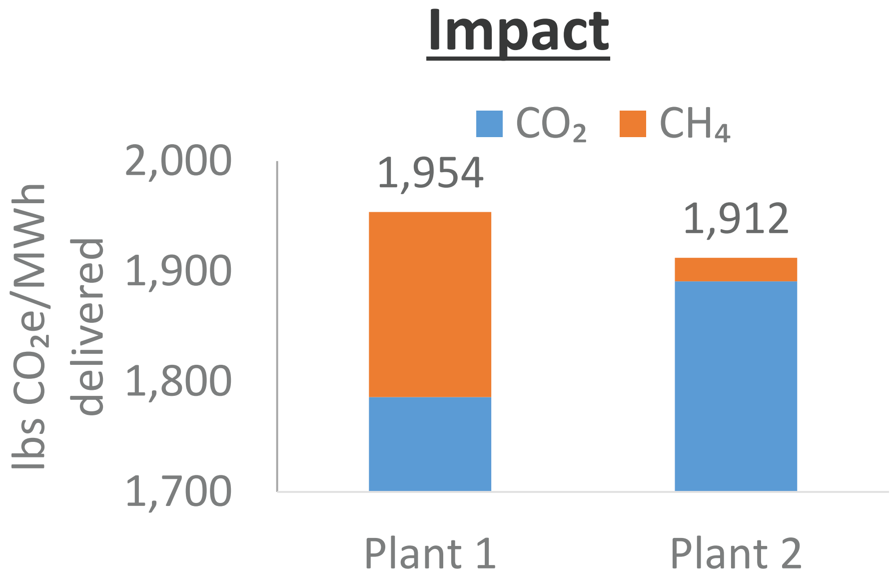
- 1,891 lbs CO_2
- 0.59 lbs CH_4

Comparing multiple emissions in the inventory

Characterization factors

- CO_2 and CH_4 are both GHGs
- Both can be compared on the basis of their global warming potentials (GWP)
  - Measured in carbon dioxide equivalents (CO_2e)
- Relative to CO_2 (GWP=1)
  - CO_2 = 1 CO_2e
  - CH_4 = 36 to 87 CO_2e





Comparable basis, comparable emissions

Galatia Mine
Springfield 5/Illinois 6
Bituminous Coal
7 million tons annual production
60 yr life

→ 0.37 tons coal →

Coal-fired Power Plant
550 MW
39.3% Efficiency
85% Capacity Factor
60 yr Lifetime

→ 1,954 lbs CO_2e/MWh →

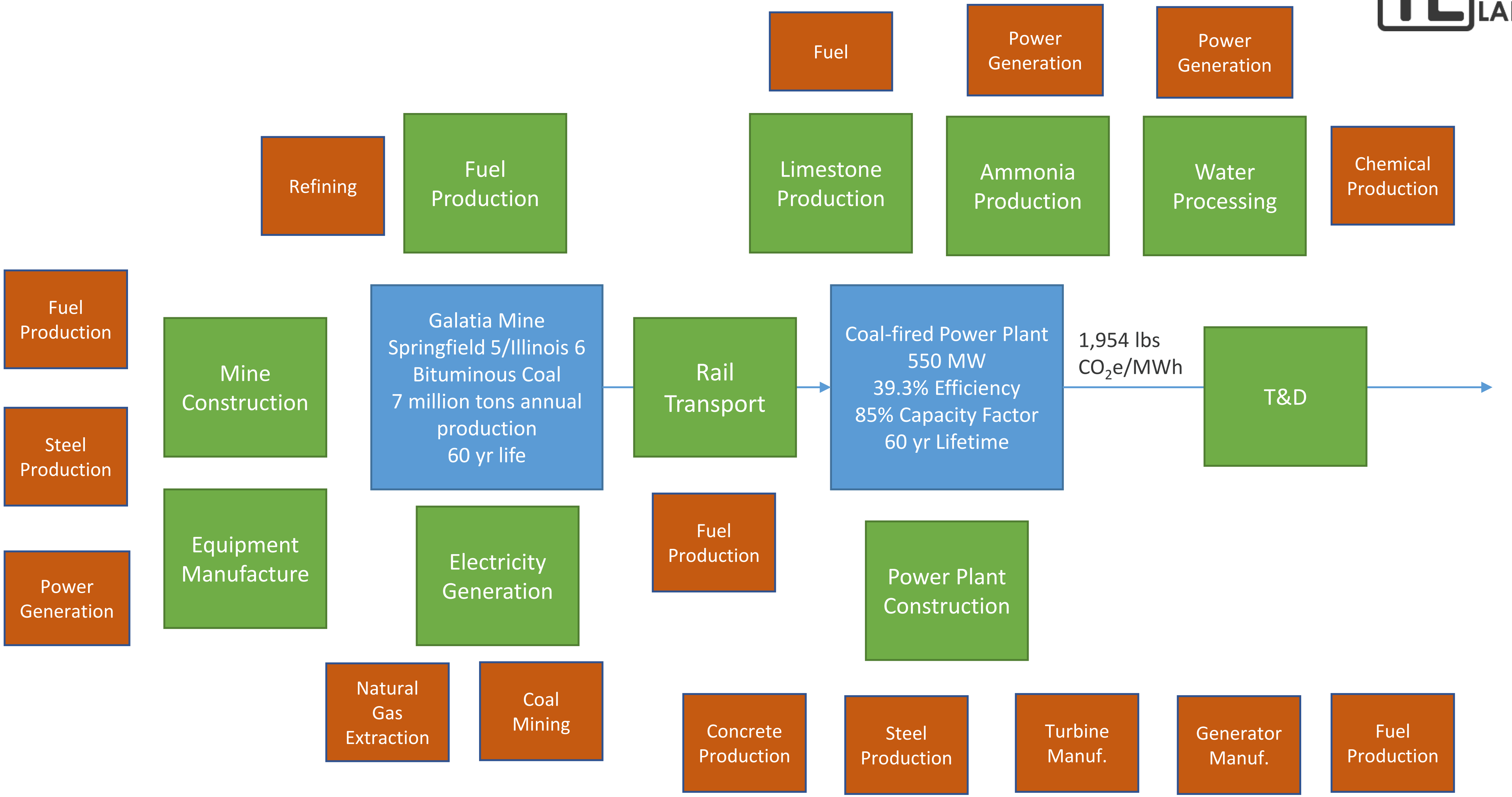
Montana Rosebud
Powder River Basin
Subbituminous Coal
12 million tons annual production
60 yr life

→ 0.46 tons coal →

Coal-fired Power Plant
600 MW
37% Efficiency
85% Capacity Factor
60 yr Lifetime

→ 1,912 lbs CO_2e/MWh →

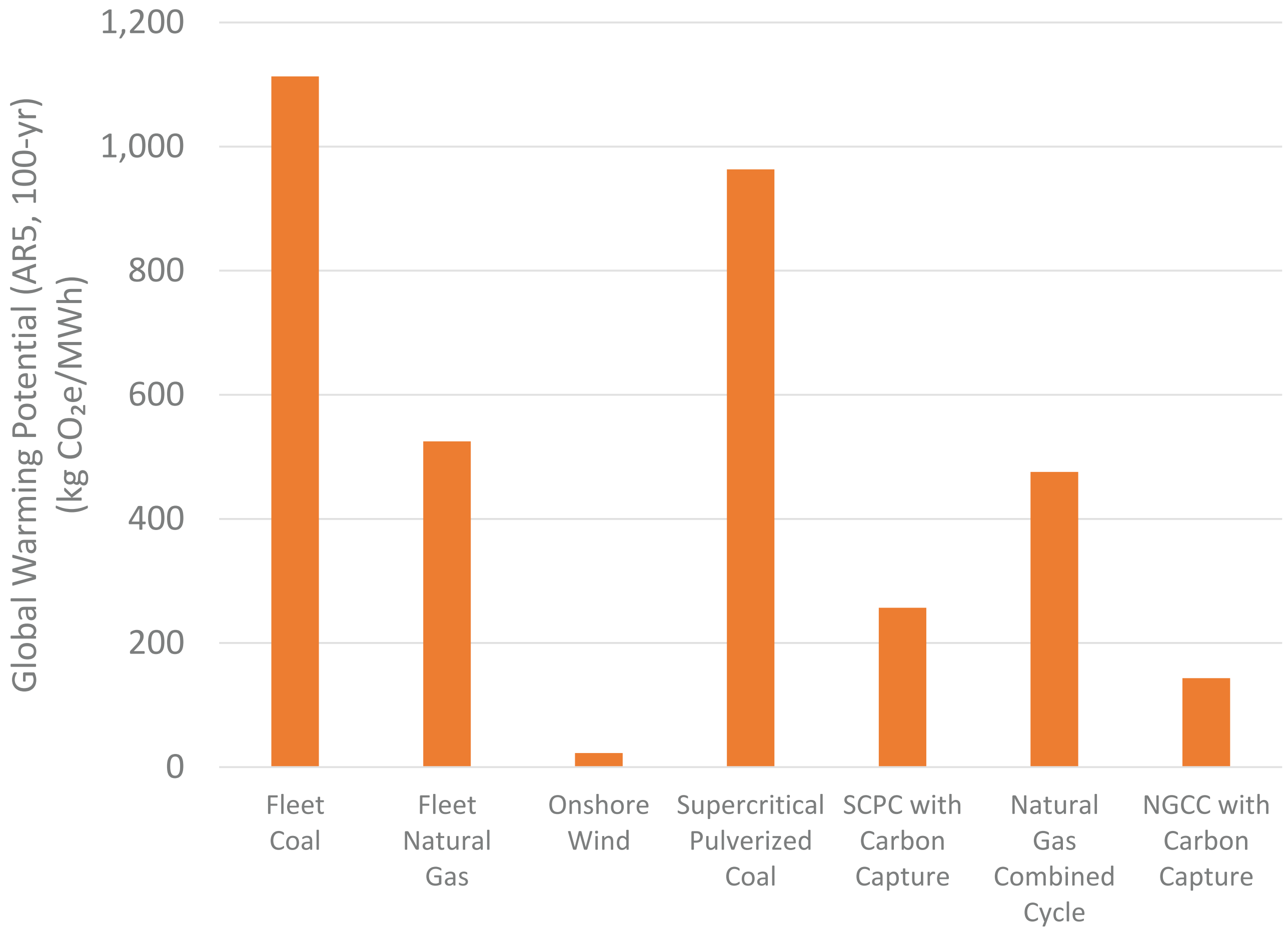
Now it gets a bit more complicated…



Putting it together

A comparison of some power plant options

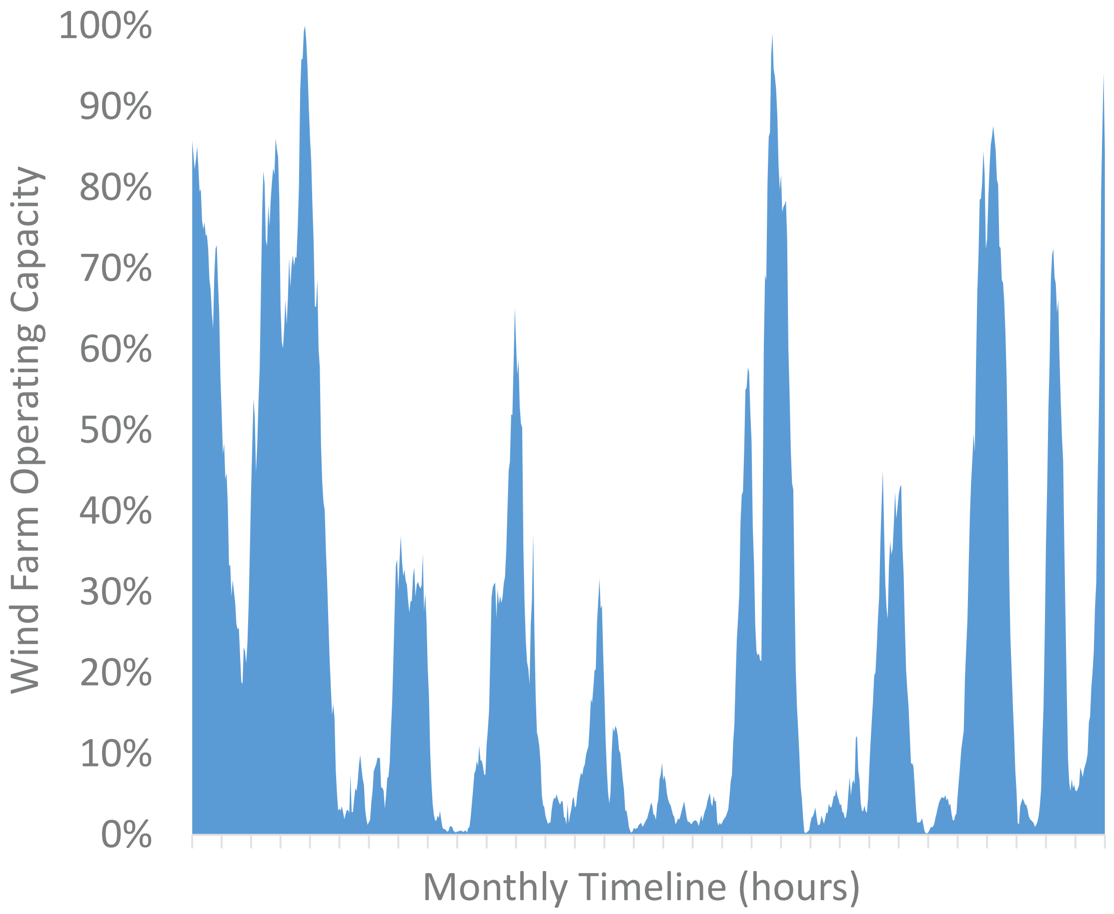
- **Repeat process for different technologies**
- **Graph compares the life-cycle greenhouse gas emissions**
- **New plants perform better than fleet at large**
- **Onshore wind is considerably lower…**



Intermittency of wind power

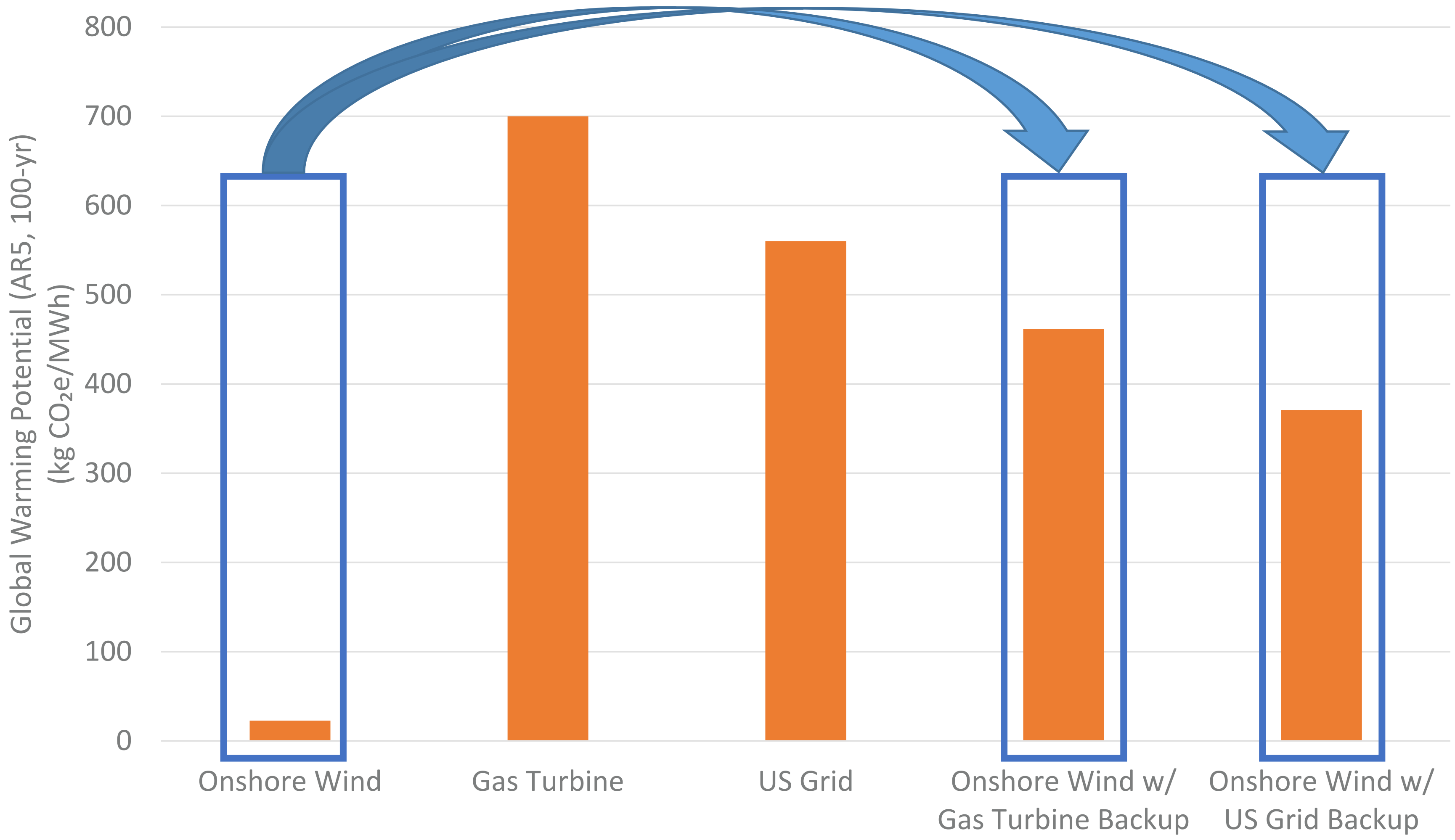
Refining the basis of comparison

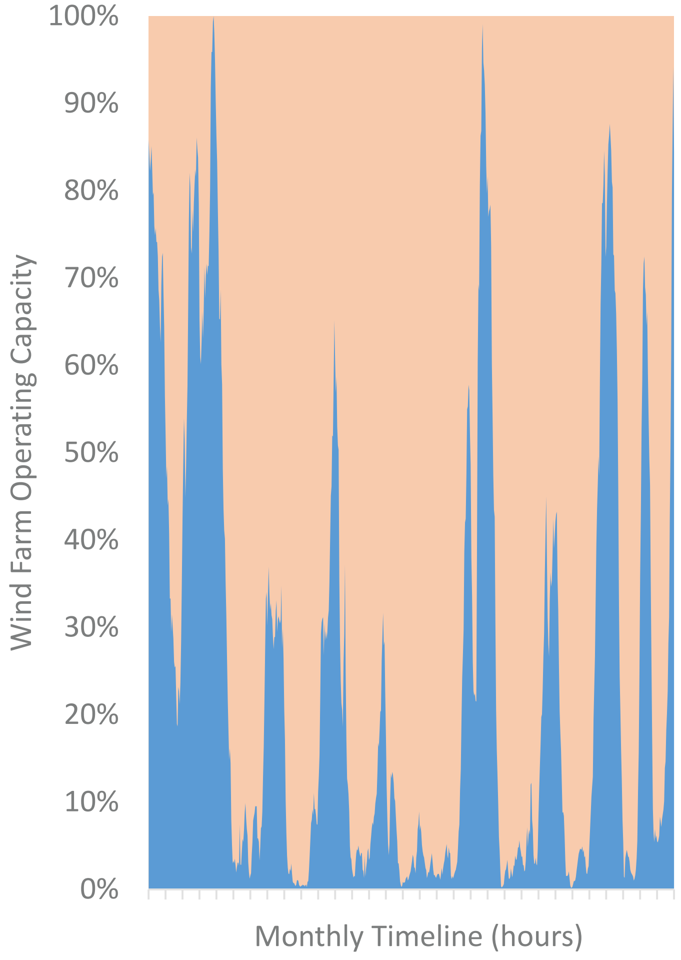
- **Wind farm cannot provide the same service as a coal or natural gas plant**
- **Options for meeting electricity demand**
  - Supplement with a gas turbine
  - Assume the grid at large will fill in the gaps
  - Overbuild wind capacity and time-shift with energy storage
- **All options require us to change our wind system**



Intermittency of wind power

Filling in the gaps

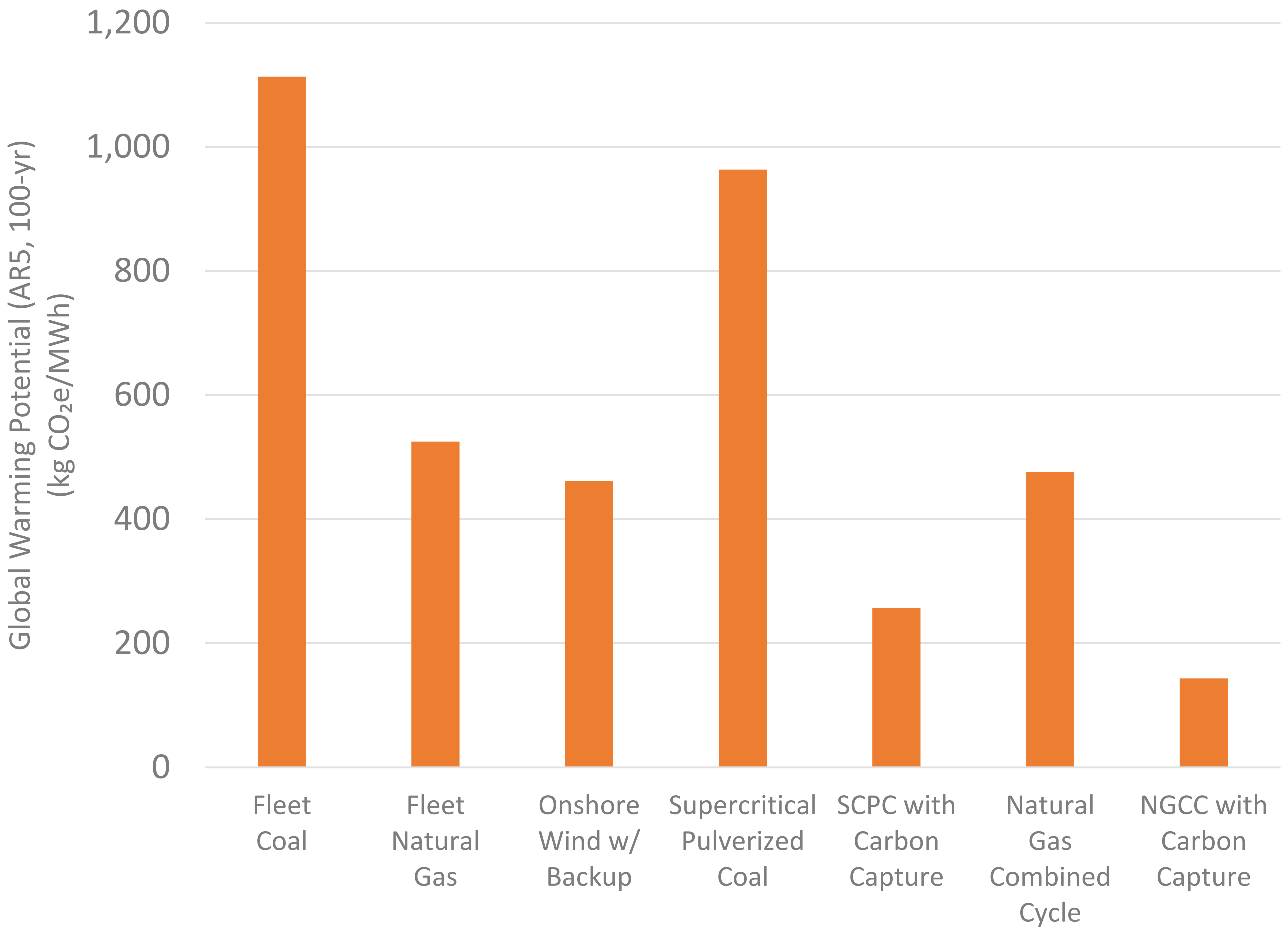




Another look at the comparison

Effects of changing the basis of comparison

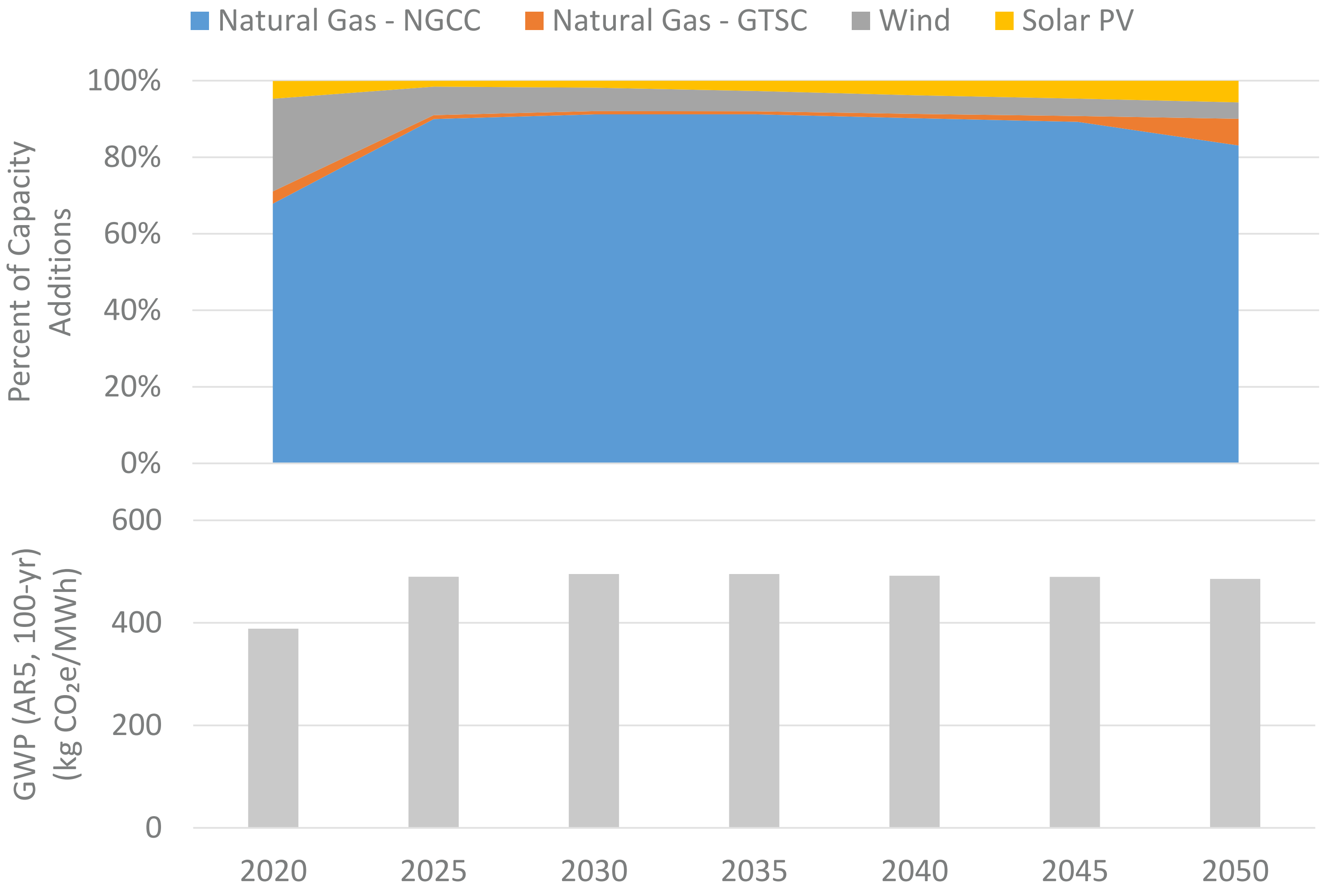
- **Comparison of systems capable of "baseload" power generation**
- **Wind is now on-par with natural gas plants**
- **Emphasizes importance of the question being asked**
    - Paper or plastic bag for carrying a bunch of knives?



Life cycle analysis in projections

Projecting the global warming potential of capacity additions in RFC

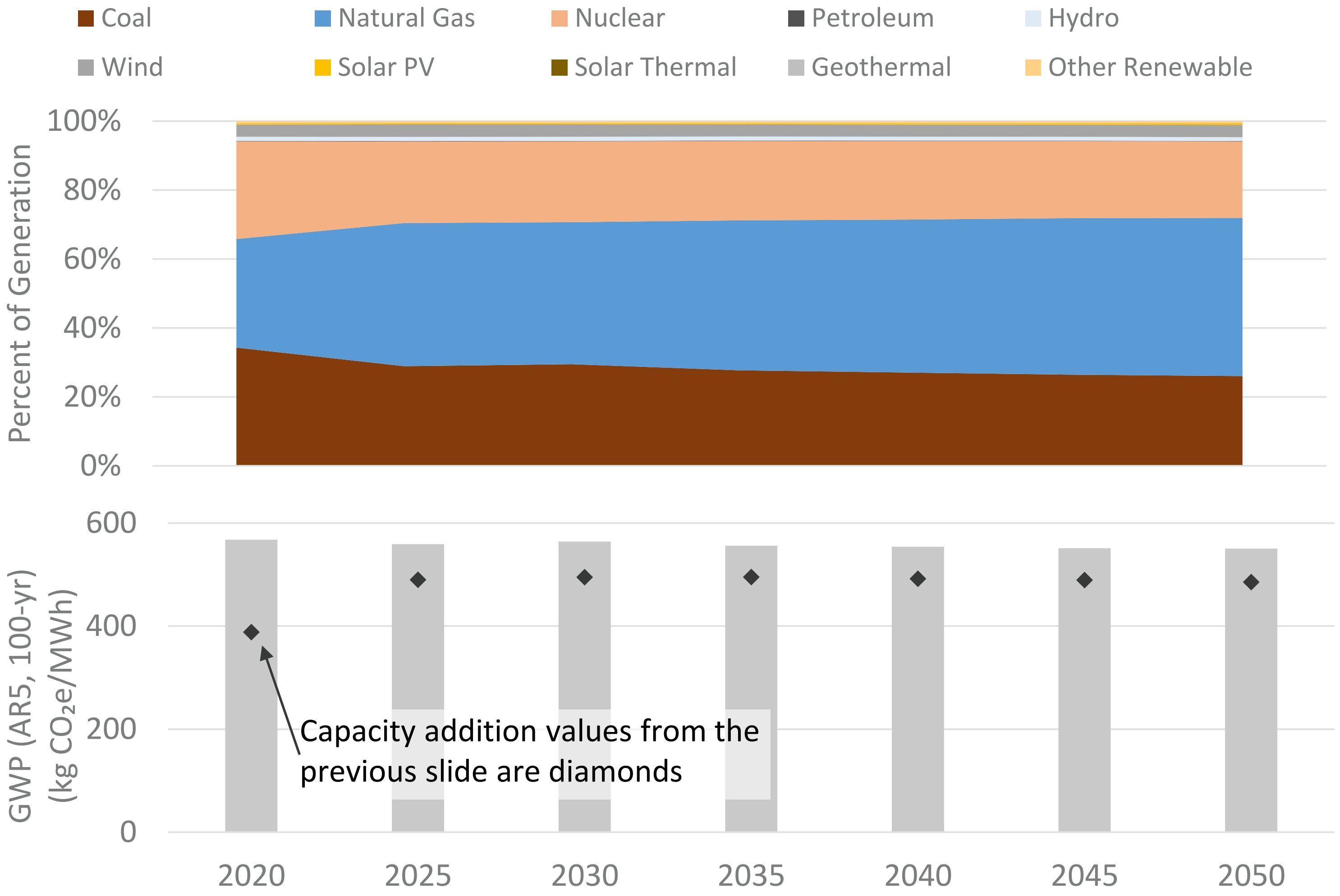
- **Capacity additions are from EIA Annual Energy Outlook**
- **Global warming potential calculated for the mix of capacity additions each year**



Life cycle analysis in projections

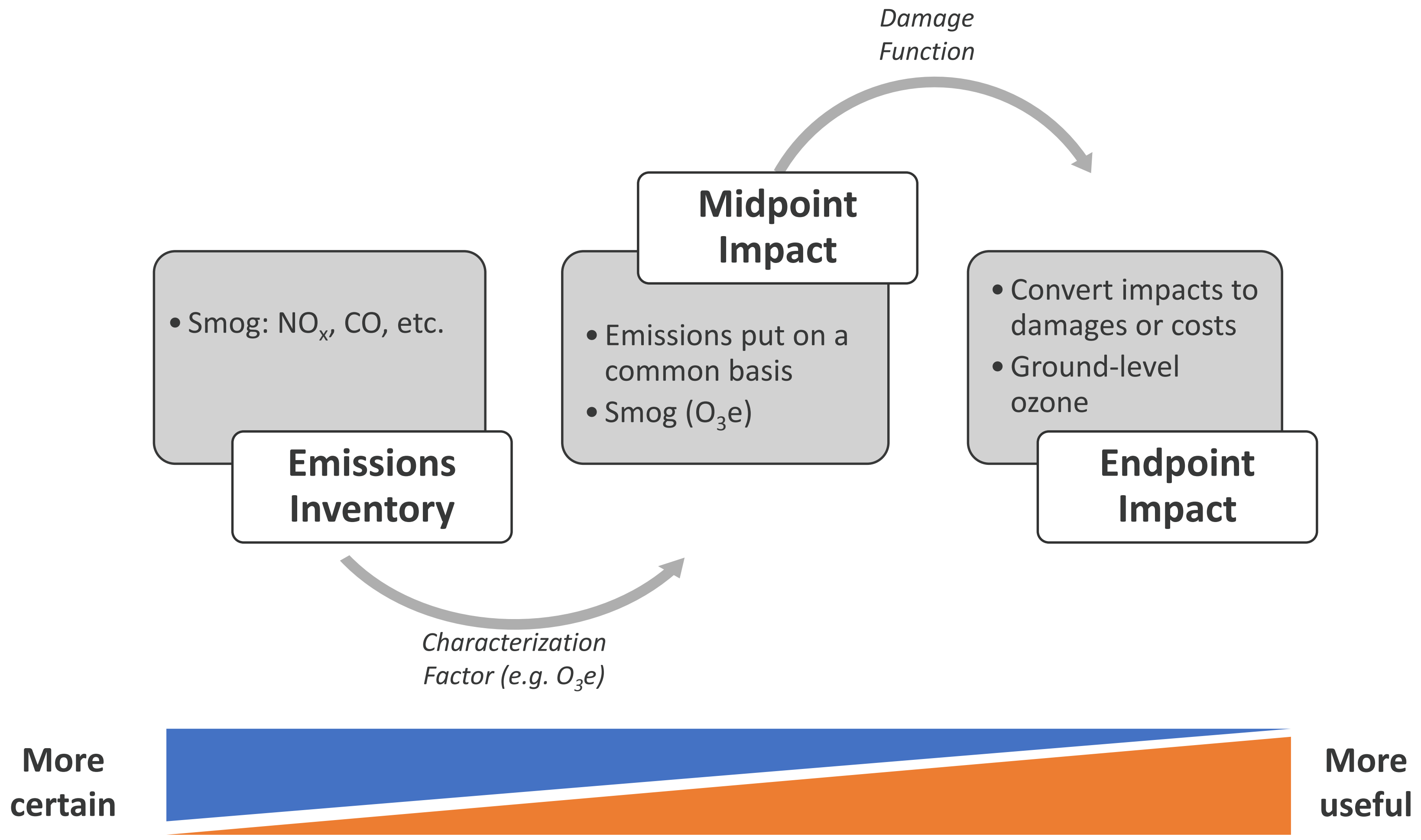
Projecting the global warming potential of generation in RFC

- **Capacity additions are in the context of an existing mix of generation**
- **Projected addition GWP is lower than the total and results in relatively small reductions**



Life cycle impact assessment (LCIA)

Maps inventory to impact - increases usefulness, broadens impacts to air/water

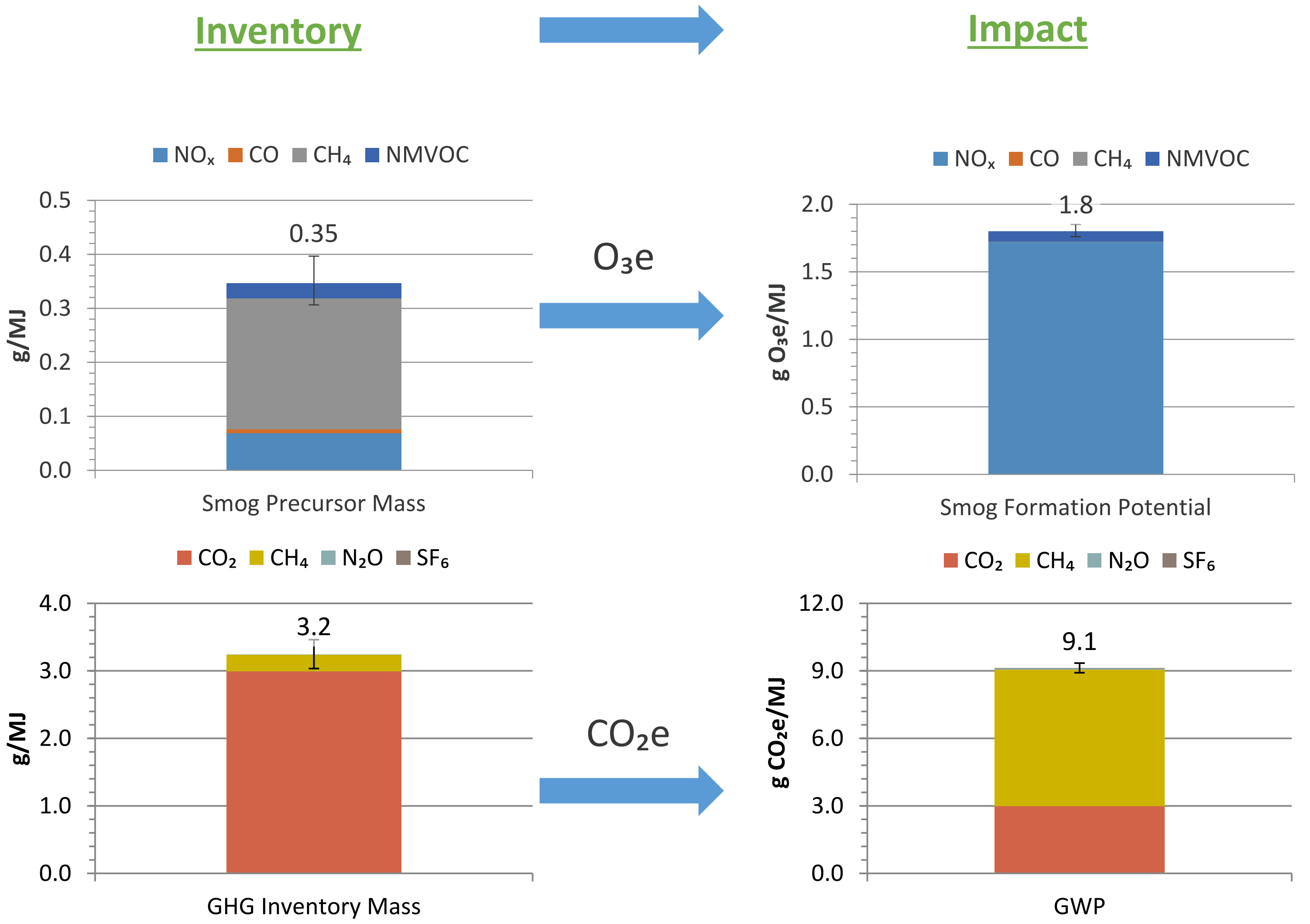


Impact Categories

- **Global Warming Potential (CO_2e)**
  - Increase in Earth's average temperature
- **Ozone Depletion Potential (CFC-11e)**
  - Thinning of ozone layer in the stratosphere
- **Acidification Potential (SO_2e)**
  - Increased concentration of H ions
- **Photochemical Smog Formation Potential(O_3e)**
  - Ground-level ozone (smog)
- **Particulate Matter Formation Potential ($PM_{2.5}e$)**
  - Health impacts caused by inhalation of PM
- **Resource Depletion**
  - Reduced future availability of a resource, due to use now
- **Eutrophication Potential (Ne)**
  - Increase in nutrients (primarily N and P) in an aquatic system

LCIA identifies key releases and processes

Focus emissions reductions efforts are the key species that yield impacts



Natural Gas Extraction from Marcellus Shale

The impacts associated with certain inventory items, such as CH_4 and NO_X, are critical to understanding the complete environmental footprint of natural gas extraction

Conclusions

- LCA is well suited for energy analysis – extensively used by public and private sector for evaluating energy options
- Inventory (mass emitted) shouldn't be used directly for decision making – strongly recommend converting inventory to impacts to make informed decisions between different technology choices
- Ensuring technical equivalence of service is critical when evaluating energy options – a MWh of fossil energy does not equal a MWh of renewable energy today

Contact information

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