Carbon Footprint Analysis at a Manufacturing Facility

AIChE Project Background Setup for CWRU Senior Capstone Internship

During Xellia Pharmaceuticals Spring 2020 Semester

AIChE Cleveland Section February 24, 2021 Meeting

Project Concept and Development:

Joseph Yurko, P.E.
Project Lead Xellia Pharmaceuticals USA, LLC (Retired)
AIChE Cleveland Section Newsletter Editor & Webmaster
Emeritus Member of AIChE and Fellow

Presentation Overview:

I. Dr. Bakshi's Sustainability Engineering Textbook Topics
  A. Goal Definition and Scope
  B. Inventory Analysis
  C. Mathematical Framework
  D. Footprint Assessment

II. CWRU Student Capstone Project at Xellia

Goal Definition and Scope

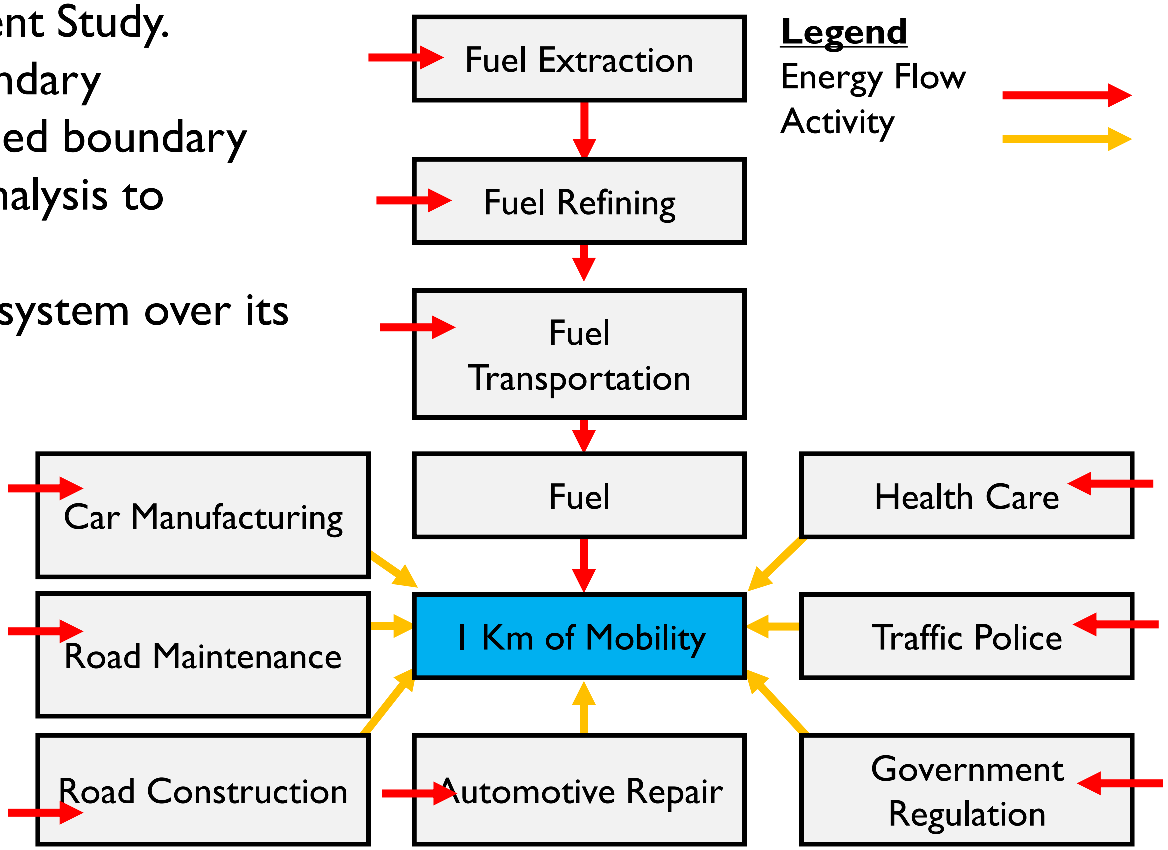
I. Nature of Life Cycle Networks
   A. Choose an environmentally friendlier transportation fuel that reduces reliance on fossil energy and CO2 emissions
   B. Ethanol from corn fermentation is a good replacement for gasoline
   C. Use ethanol as a fuel to reduce fossil fuel energy use and greenhouse gas emissions

II. Steps in Assessing Life Cycle Networks
   A. Goal Definition and Scope: For the Sustainability Assessment Study. Selecting the Functional Unit and defining the System Boundary
   B. Inventory Analysis: Finding data for processes in the specified boundary
   C. Impact Assessment: Utilizes the results of the Inventory Analysis to determine the impact of the selected system
   D. Interpretation: Evaluate the pros and cons of the selected system over its life cycle. Used to identify opportunities for improvement.

III. Goal Definition and Scope
   A. For a sustainability assessment choose between options
   B. Identify opportunities for improving a product or step
   C. Functional Unit is used for a basis of comparison

IV. Life Cycle Boundary
   A. Process Network: most important process steps
   B. Input – Output Network: grouping of similar processes
   C. Hybrid Network: Detailed network from A & B above

Contributions to the Life Cycle Energy used for a Car to obtain 1 Km of Mobility



Legend
Energy Flow
Activity

Fuel Extraction
Fuel Refining
Fuel Transportation
Fuel
Car Manufacturing
Road Maintenance
Road Construction
1 Km of Mobility
Automotive Repair
Health Care
Traffic Police
Government Regulation

Goal Definition and Scope

Calculation Example:
The goal in comparing ethanol with gasoline to choose between them from the perspective of mobility and what mixture of the two fuels that would provide the least CO2 and the best milage:

GIVEN:

A. The fuel E10 is 10% ethanol and 90% gasoline
B. The fuel E85 contains 85% ethanol and 15% gasoline
C. E85 covers 20% less distance per volume of fuel than E10 due to a lower fuel value as well as the difference between the two engines using them
D. Determine the functional unit for comparing the life cycles of these two fuels
E. How much ethanol and gasoline will each vehicle use for the selected functional unit given the fuel economy of the E10 vehicle is 15 km/L

SOLUTION:

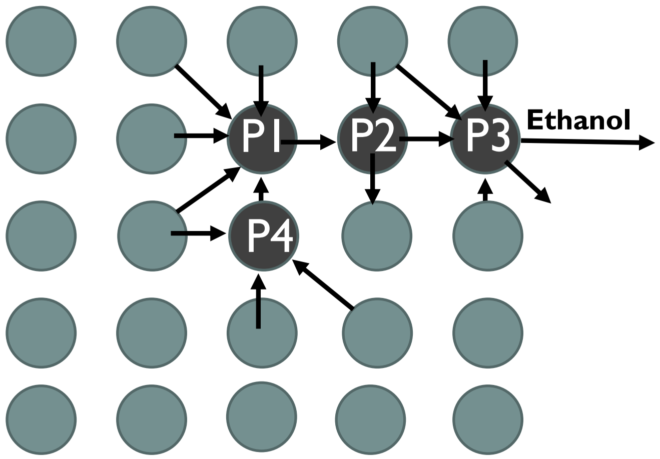
A. The function of the E10 and E85 fuels is to provide mobility
B. The Functional Unit may be the same distance traveled with either fuel, i.e. 100 km
C. Determine the amounts of ethanol and gasoline needed for the selected Functional Unit: ñ = 0.8 x 15 km/L = 12 km/L
D. To drive 100 km with E10 requires: **V(E10) = 100 km / 15 km/L = 6.67 L**
E. Since 10% of this is ethanol and 90% is gasoline, we get the volumes: V(E10, gas) = 6 L, and V(E10, EtOH) = 0.67 L
F. Similarly to drive 100 km with E85 we get: **V(E85) = 100 km / 12 km/L = 8.33 L**
G. Therefore: V(E85, gas) = 1.25 L and V(E85, EtOH) = 7.08 L

Life Cycle Boundary

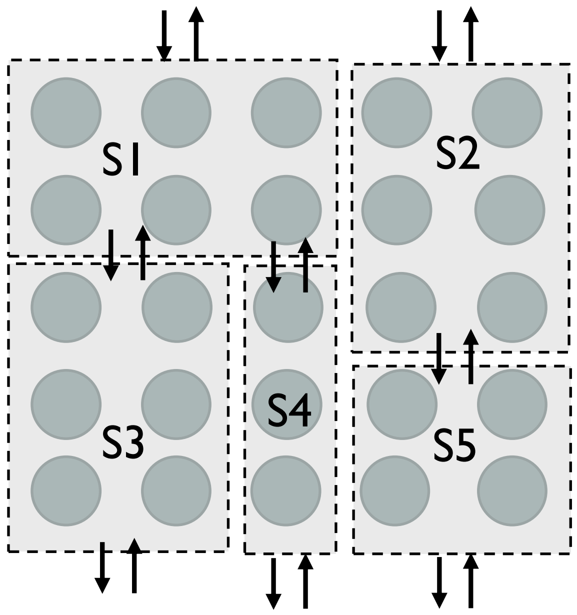
A. **Process Network Model**: Dark Circles Most Important Process steps (P1 – P4) for a Corn to Ethanol Process

B. **Input – Output Network Model**: Similar Process Steps lumped together into Sectors (S1 – S5) for a Corn to Ethanol Process

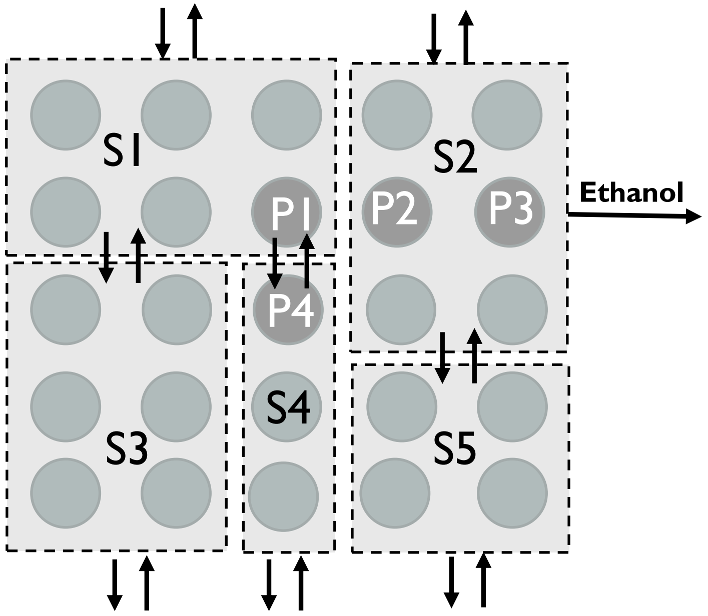
C. **Hybrid Network Model**: Combine A & B above with details from both A & B networks



A. **Process Network**



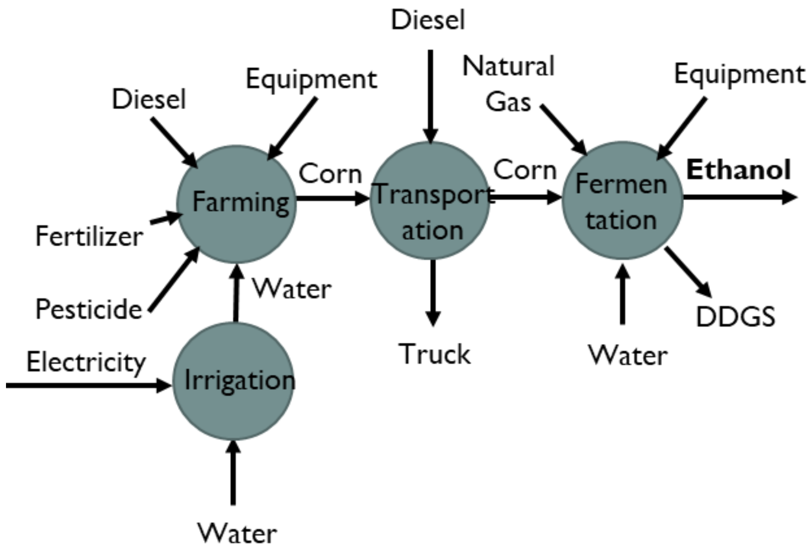
B. **Input – Output Network**



C. **Hybrid Network**

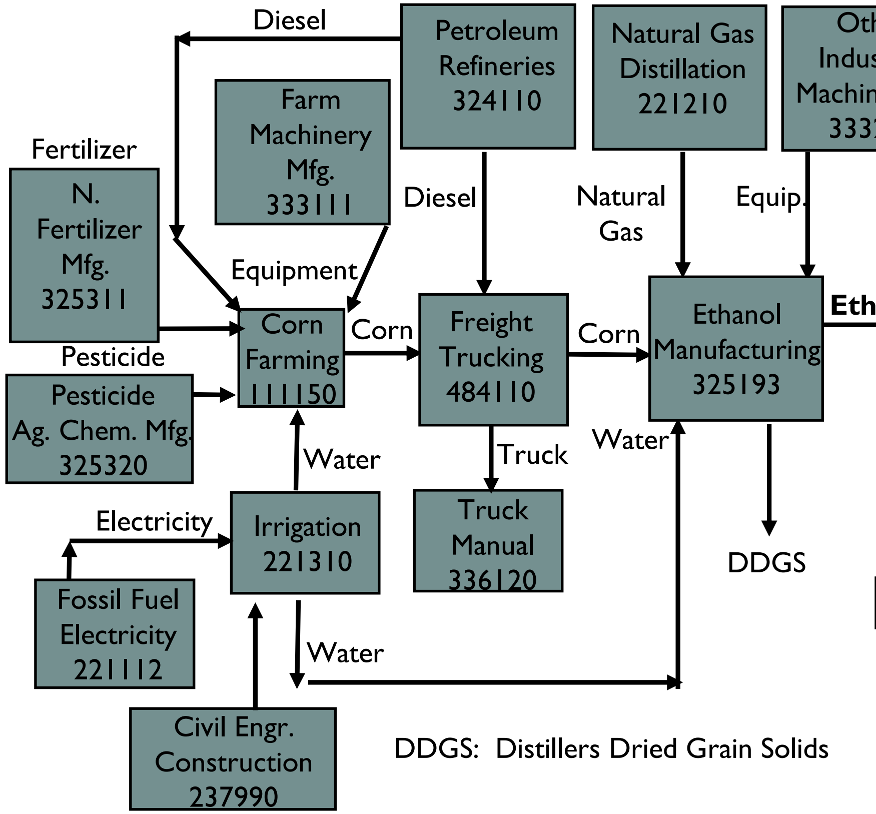
Goal Definition and Scope

D. Selected Processes in Corn to Ethanol Life Cycle Network Model
E. Selected Economic Sectors in the Input – Output Corn to Ethanol Life Cycle Network Model
F. Hybrid Network model combining the Process Network and the Input – Output Network Models
G. Note that the Economic Sectors are tagged with the North American Industrial Classification System (NAICS)
https://www.naics.com/search



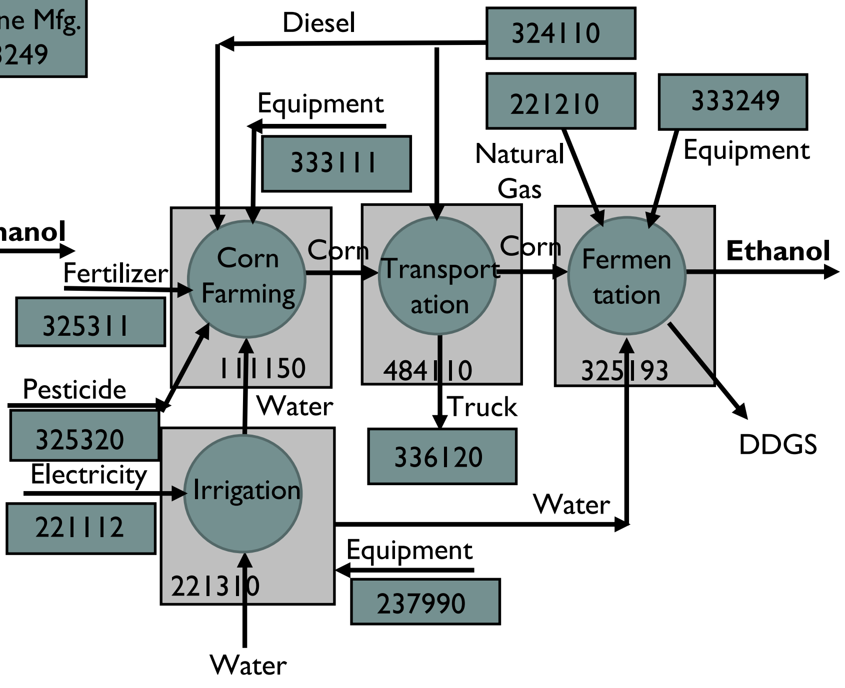
DDGS: Distillers Dried Grain Solids

D. Process Network Selected Processes



DDGS: Distillers Dried Grain Solids

E. Input – Output Network with Selected Economic Sectors



DDGS: Distillers Dried Grain Solids

F. Hybrid Network Combining Selected Processes & Economic Sectors

Inventory Analysis

I. **Sources of Data**
   A. Calculations with Life Cycle Network models require data about the selected activities and their flows: Life Cycle Inventory (LCI)
   B. Over the past years the LCIs for a large variety of systems have been compiled and have become available as free and commercial databases
      i. National Renewable Energy Laboratory. US Life cycle inventory database www.lcacommons.gov/nrel/search , accessed November 3, 2014
      ii. Argonne National Laboratory. The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model http://greet.es.anl.gov , accessed January 31, 2012
      iii. Swiss Center for Life Cycle Inventories. Ecoinvent life cycle inventory database www.ecoinvent.ch , accessed January 18, 2013
      iv. Environmental Protection Agency. National emissions inventory, Toxics release inventory www.epa.gov/ttn/chief/trends , www.epa.gov/triexplorer , accessed August 22, 2015
      v. Food and Agriculture Organization. FAOSTAT http://faostat3.fao.org , accessed July 8, 2017

II. **Calculations**
   A. With LCI data for multiple processes we can calculate various quantities for the entire life cycle network formed by connecting the process modules
   B. The data in each process module are usually normalized to a unit output of the primary product
   C. It should be easy to determine the scaling factors for each module in order to connect them to obtain results for the selected functional unit

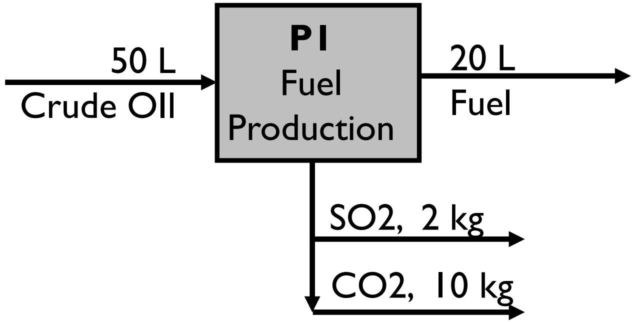
III. **Uncertainty**: Parametric (inherent variability in measured data), Scenario (modeler value judgement), Model (simplified)

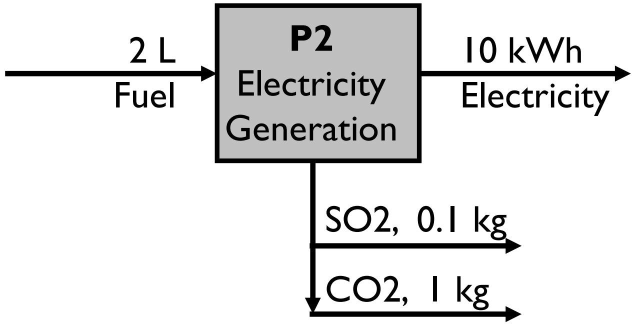
Inventory Analysis

Calculation Example (converting crude oil into electrical power):

GIVEN:

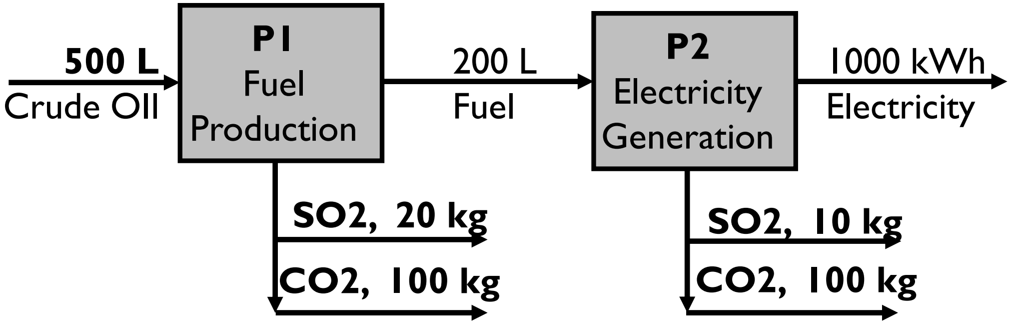
A. Module P1 for fuel production has an input of 50 L of crude oil to produce 20 L of fuel
B. It emits 2 kg SO_2 and 10 kg CO_2
C. Module P2 for electricity generation produces 10 kWh of electricity from 2 L fuel
D. It emits 0.1 kg SO_2 and 1 kg CO_2
E. For a network constructed by connecting these modules, determine the life cycle consumption of crude oil and the emissions of SO_2 and CO_2 generating 1,000 kWh elec.





SOLUTION:

A. To generate 1,000 kWh of electricity, P2 needs to be scaled by 1000/10 = 100
B. This scaled up module will need 200 L of fuel
C. To supply this fuel P1 needs to be scaled by 200/20 = 10
D. The resulting Life Cycle Network is shown in the following diagram
E. In this diagram the total consumption of crude oil is **500 L**
F. The emissions of **SO_2 = 30 kg** and **CO_2 = 200 kg**



Inventory Analysis

Calculation Example (environmental impact generating electrical power):

GIVEN:

A. Use the Input – Output Data in the **Table 1** to the right
B. Determine the Life Cycle emissions and resource use in the generation of 500 kWh of electricity in the USA
C. The producer price of electricity is 5 cents/kWh

SOLUTION:

A. The producer price of electricity is 500 kWh x $0.05 = $25
B. This is the final demand of electricity
C. Multiplying the coefficients for the electricity sector in **Table 1** to the right by this price gives the Life Cycle Flows of:
    i. CO2 to air = $25 x 6.27E00 = 156.75 kg
    ii. Cropland = $25 x 6;.24E-03 = 0.156 m^2 yr
    iii. Benzene to air = $25 x 1.62E-05 = 4.05x10^-4 kg
    iv. Glyphosate to water = $25 x 1.02E-08 = 2.55x10^-7
    v. Groundwater = $25 x 6.35E-03 = 0.16 m^3

Table 1: Typical Life Cycle Inventory data from Input-Output Models

Reference: Y. Yang, W.W. Ingwersen, T.R. Hawkins, M. Srocka, and D.E. Meyer USEEIO: a new and transparent United States environmentally extended input-output model. *Journal of Cleaner Production*, 158:308-318, 2017

FLOW (NAICS)>	Wheat, Corn, etc. (1111b0)	**Electricity (221100)**	Gasoline etc. (324110)	Couriers (492000)	Management Consulting (541610)	Vehicle Repair (811100)
CO2 to air (kg / $)	1.28E+00	**6.27E+00**	5.03E-01	1.82E-.01	9.97E-02	1.53E-01
Cropland (m^2Yr / $)	1.19E+01	**6.24E-03**	6.38E-03	6.63E-03	5.77E-03	5.35E-03
Benzene to Air (kg / $)	2.20E-05	**1.62E-05**	6.14E-05	8.65E-06	1.75E-06	2.09E-06
Glyphosate To water (kg / $)	2.95E-05	**1.02E-08**	1.17E-08	9.86E-09	1.04E-08	8.05E-09
Groundwater (m^3 / $)	3.71E-01	**6.35E-03**	2.82E-03	1.03E-03	7.12E-04	9.98E-04

Mathematical Framework

A. Process Network Analysis
   i. **Mathematical Framework**
      a. Previous calculation examples are basic models and easily scaled
      b. For more complicated models a more rigorous approach is needed
      c. **Life Cycle modules** contain two types of flows: economic and environmental
         i. **Economic Flows** generated by human activity are used in other economic activities
            Such flows are valuable to society and are not discarded directly into the environment
            This would be the Fuel and Electrical power flows (the Final Demand) from our example
         ii. **Environmental Flows** are inputs from nature and emissions into it
            These would be the Crude Oil flow from the environment and the SO2 and CO2 flow into it
   ii. **Allocation Methods**
      a. **Partitioning**: requires splitting a process with multiple products into multiple processes each with a single product
      b. **Displacement**: required data about a conventional process that produces each byproduct
      c. **No Allocation**: in the absence of allocation, all allocation weights are taken as equal to 1

B. **Input-Output Analysis**: overcome shortcoming of process network analysis, has larger analysis boundary with less accuracy
   i. Mathematical Framework: consists of a collection of nodes of various sectors with monetary flows between sectors
   ii. Environmentally Extended Input-Output Models: for assessing environmental impacts from monetary flows in sectors

C. **Hybrid Models**: combines the features of the Process Network and the Input-Output Network

Mathematical Framework

Theory (Matrix Notation):

A. Economic Flows Fuel and Electricity have a final demand
B. Let f1 and f2 represent the final demand of these two flows in our Crude Oil to Electrical Power Example
C. The final demand for fuel is 0, and the final demand for electrical power is 1,000 kWh
D. Let s1 and s2 be our scaling factors for these two modules
E. We can write two equations based on the conservation of each economic flow:
    i. Eq. 1, $20s1 - 2s2 = f1$
    ii. Eq. 2, $10s1 = f2$
F. Eq. 1 is for fuel and represents fuel produced is 20s1, and fuel used is 2s2
G. Eq. 2 is for electricity and represents electricity produced is 10s2
H. In matrix notation as:

$$\begin{vmatrix} 20 & -2 \\ 0 & 10 \end{vmatrix} \begin{vmatrix} s1 \\ s2 \end{vmatrix} = \begin{vmatrix} f1 \\ f2 \end{vmatrix}$$

or, more generally, as **As = f** Where **A** is the **Technology Matrix**

I. For the Environmental flows we have similar balance equations:
    i. Eq. 3, $rCrude = -50s1$
    ii. Eq. 4, $rSO2 = 2s1 + 0.1s2$
    iii. Eq. 5, $rCO2 = 10s1 + s2$

or in matrix notation:

$$\begin{vmatrix} -50 & 0 \\ 2 & 0.1 \\ 10 & 1 \end{vmatrix} \begin{vmatrix} s1 \\ s2 \end{vmatrix} = \begin{vmatrix} rCrude \\ rSO2 \\ rCO2 \end{vmatrix}$$

with **Bs = r**

Where **B** is the **Intervention Matrix**

J. Where ri is the total Environmental Flow of the i th component. With negative signs are inputs and positive signs as outputs
K. Where r is the vector of **Resource Consumption and Emissions**. Where**: r = BA^(-1)f**

Mathematical Framework

Calculation Example (solving previous example with matrix notation):

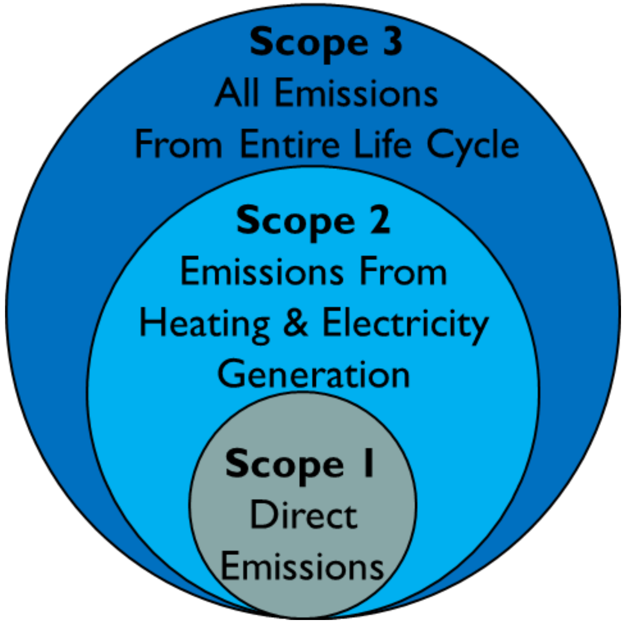
GIVEN:

A. Consider the fuel and electricity modules in our previous example
B. Calculate the Life Cycle Flows of crude oil, sulfur dioxide, and carbon dioxide in the production of 1,000 kWh of electricity

SOLUTION:

A. The Final Demand is specified as **f1 = 0** and **f2 = 1000 kWh**
B. Solving Eq. 1 and Eq. 2 simultaneously, we find the scaling factors **s1 = 10** and **s2 = 100**
C. Substituting the scaling factors in Eq. 3, Eq. 4, and Eq. 5 we get **rCrude = -500L**, **rSO2 = 30 kg**, and **rCO2 = 200 kg**
D. Using matrices, define $f = \begin{vmatrix} 0 \\ 1000 \end{vmatrix}$
E. The resource consumption and emissions can then be expressed as $r = \begin{vmatrix} -500 \\ 30 \\ 200 \end{vmatrix}$
F. Where the Crude Oil = 500 L, SO2 = 30 kg, and CO2 = 200 kg as found in the previous calculation example

Footprint Assessment



Scope 3
All Emissions
From Entire Life Cycle

Scope 2
Emissions From
Heating & Electricity
Generation

Scope 1
Direct
Emissions

A. Carbon Footprint
  i. Global Warming Potential (GWP) relative to CO2
    a. If we consider a 100 year time period
    b. Methane is 25 times more potent than CO2
    c. Nitrous Oxide is 298 times more potent than CO2
    d. Their potency changes with time each gas lasts in the atmosphere
    e. In 2016 in terms of CO2 equivalents the atmosphere contained 489 ppm CO2 eq, an increase of 40% since 1990 (or over 26 years)
  ii. Greenhouse Gas (GHG) Emissions
    a. Data about GHG emissions from various human activities are compiled in public and private databases
    b. The US Environmental Protection Agency compiles data about GHG flows in the USA and the world
    www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990*2016
    c. In 2016 total USA emissions were ~6.5 billion tons of CO2 eq. with sequestration at ~1 billion tons CO2
    d. An overshoot of ~5.5 billion tons of CO2 eq. in 2016 above nature's capacity to sequester CO2 in USA
    e. This CO2 will be sequestered by ecosystems in other parts of the globe or accumulate in the atmosphere
    f. The boundary of Carbon Footprint calculations is classified as Scope 1, 2, or 3
      i. Scope 1 is a narrow boundary for direct GHG emissions from selected processes
      ii. Scope 2 includes GHG emissions in generating electricity and those caused by heating the processes
      iii. Scope 3 is the full Life Cycle of GHG emissions

Footprint Assessment

B. Water Footprint

- i. Direct and Indirect dependence of products, processes and other systems on water
- ii. Important for water intensive activities in water stressed regions of the world
- iii. Water Footprint relies on the concept of Virtual Water (water used to make a product or service)
  - a. Virtual Water use in thermal power is mainly due to evaporative losses and leaks
  - b. Virtual Water use in a beverage is the water contained in it
  - c. Water withdrawn and returned to the environment in a form it can be used directly is not Virtual Water
- iv. The Water Footprint is the sum of direct and Indirect virtual water flows
  - a. Water Footprint of thermal electricity includes the water used in the steps of its Life Cycle such as mining and cleaning coal, producing solvents used for scrubbing the flue gas, manufacturing of equipment, etc.
  - b. For a geographic region or nation, its Water Footprint accounts for the virtual water in imports and exports along with the water use in the region

C. Sources of water and changes in quality based on following categories of water:

- i. **Blue Water**: Includes fresh water available at the surface in rivers, lakes, canals, and groundwater
- ii. **Green Water**: Precipitation that falls on land and does not runoff or recharge the aquifer
- iii. **Gray Water**: Focuses on the quality of water needed to dilute pollutants to acceptable levels

Gray Water quality is from a material balance calculation with information about the current and desired concentration of contaminants in the water. Where P = pollutant loading (mass/time),

Cmax = max contaminant loading (mass/volume), and

Cnat = natural concentration of this contaminant in the environment

Then the Gray Water Footprint for this flow may be calculated as: $W_{gray} = P / (C_{max} - C_{nat})$

Footprint Assessment

Calculation Example (determine the Global Warming Potential, GWP, from a Life Cycle Inventory of emissions with Table 2):

GIVEN:

A. Table 2 to the right

B. Life Cycle Inventory emissions

C. Determine the GWP using a 100 year time horizon

SOLUTION:

A. Using **Table 2**, the GWP of these emissions is
GWP = (20 x 1) + (0.001 x 4750) + (0.5 x 298)
GWP = 173.8 kg CO2 eq

B. Note that NO2 does not contribute to global warming and is excluded from this calculation

Table 2: Global Warming Potential relative to CO2

P. Forster, V. Ramaswamy, P. Artaxo, et al. Changes in atmospheric constituents and in radiative forcing. Ln S. Solomon, D. Qin, M. Manning, et al., editors, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 2007

Common Name	Chemical Formula	GWP for given time horizon 100 Year
Carbon Dioxide	CO2	1
Methane	CH4	25
Nitrous Oxide	N2O	298
CFC-11	CCl3F	4750
Carbon Tetrachloride	CCl4	1400
HCFC-22	CHClF2	1810
HFC-134a	CH2FCF3	1430
Sulfur Hexafluoride	SF6	22,800
Methyl Chloride	CH3Cl	13

CWRU Student Capstone Project

xellia
PHARMACEUTICALS

Kickoff Meeting with four ChE Senior Students
Non-Disclosure Agreement review and sign-off
Xellia Plant Tour
Scope of Work review and sign-off
Project Schedule and Deliverables review and sign-off

xellia
PHARMACEUTICALS

Carbon Footprint Analysis at Xellia

Sanjana Kamath, Nathan Ewell, Katie Francissen, Andy Swyers
CWRU Capstone Project

CWRU Capstone Project Concept and Development by: Joseph Yurko, PE
AIChE Fellow

Meet the Team

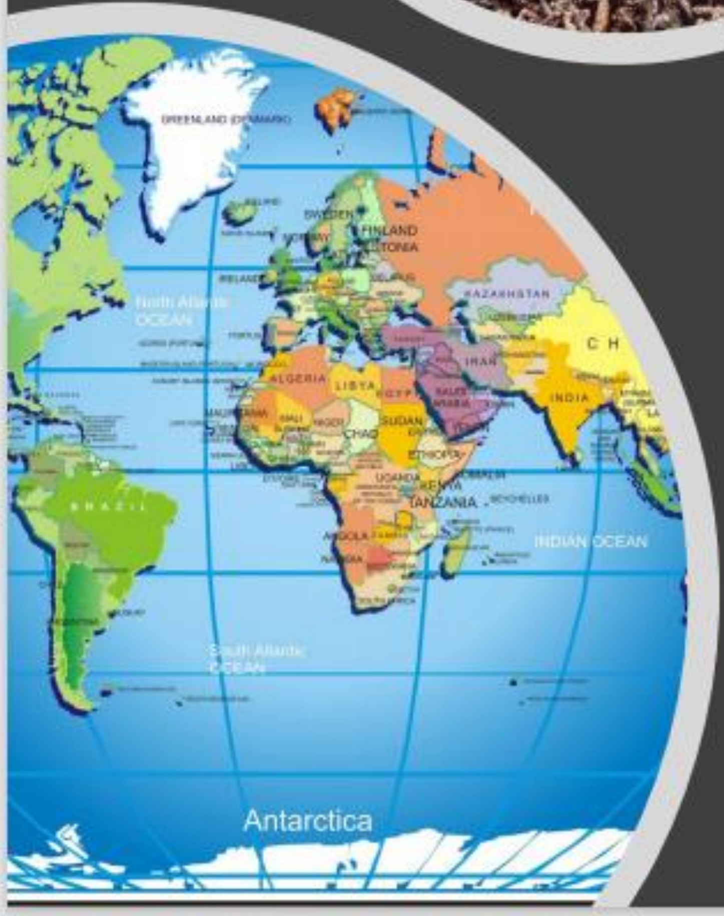
Nathan Ewell

Katie Francissen

Andy Swyers

Sanjana Kamath

CWRUcible, Inc.



The Crippling Effects of Climate Change

Economical Environmentalism

ESG is Environmental, Social Governance

Of 200 studies analyzed by Arabesque and University of Oxford…

90% conclude that good ESG standards lower the cost of capital

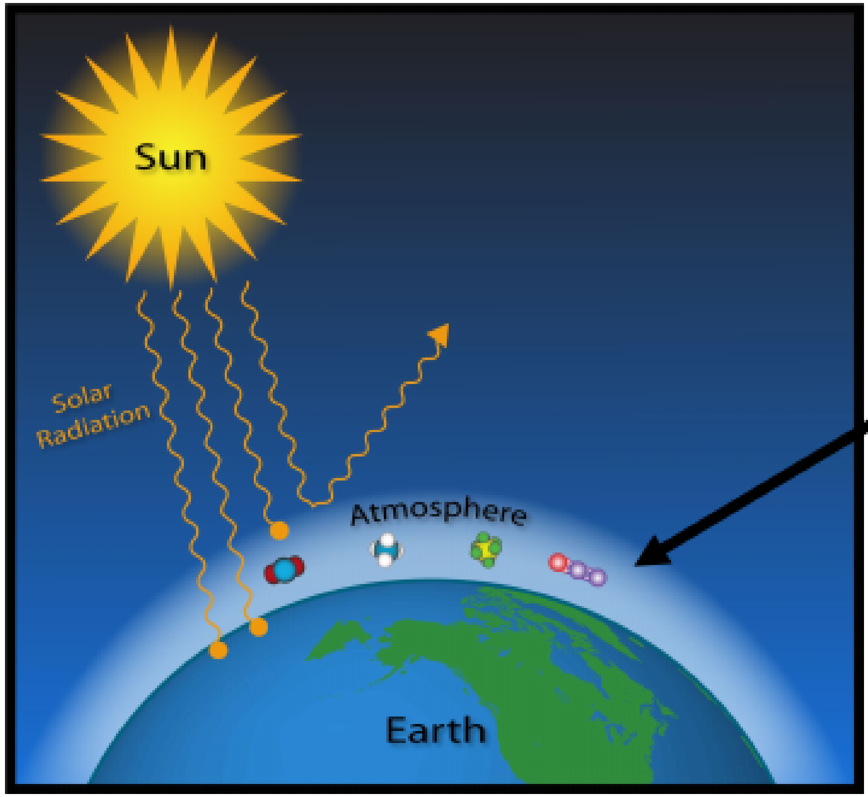
88% show that good ESG practices result in better operational performance

80% show that stock price performance is positively correlated with good sustainability practices

Project Objective and Scope

- **Carbon footprint analysis of building 22**
    - **Convert process loads into CO_2 equivalents**
    - **Assess overall environmental impact**
    - **Pinpoint areas of improvement**

Methods: Carbon Footprint Analysis



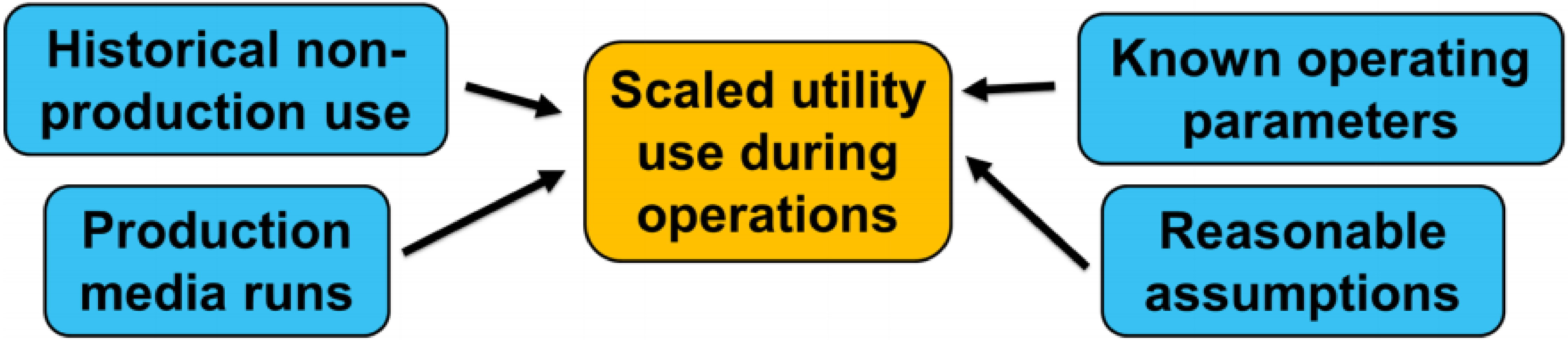
Chemicals in the atmosphere absorb solar radiation, warming the earth

Chemical	20 year GWP	100 year GWP	500 year GWP
Carbon Dioxide	1	1	1
Methane	72	25	7.6
Nitrous Oxide	289	298	153

Global warming potential (GWP) can be defined for chemicals relative to CO_2

Activity	CO_2 Factor (kg/unit)	CH_4 Factor (kg/unit)	N_2O Factor (kg/unit)	Unit
Natural Gas Combustion	1.922	0.036	0.004	m^3
Electricity Usage (midwest)	564	0.050	0.0086	MWh

Methods: Projecting Utility Usage



Historical non-production use

Production media runs

Scaled utility use during operations

Known operating parameters

Reasonable assumptions

Building 22 Carbon Footprint

- Overall carbon footprint = 31,000 mt CO_2 eq.*
- Broken down into two major categories

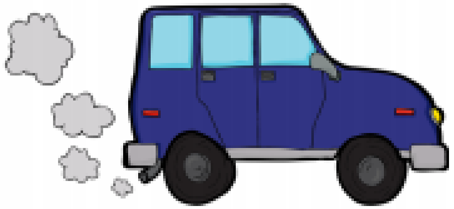
→ Natural gas: 17,000 mt CO_2 eq.

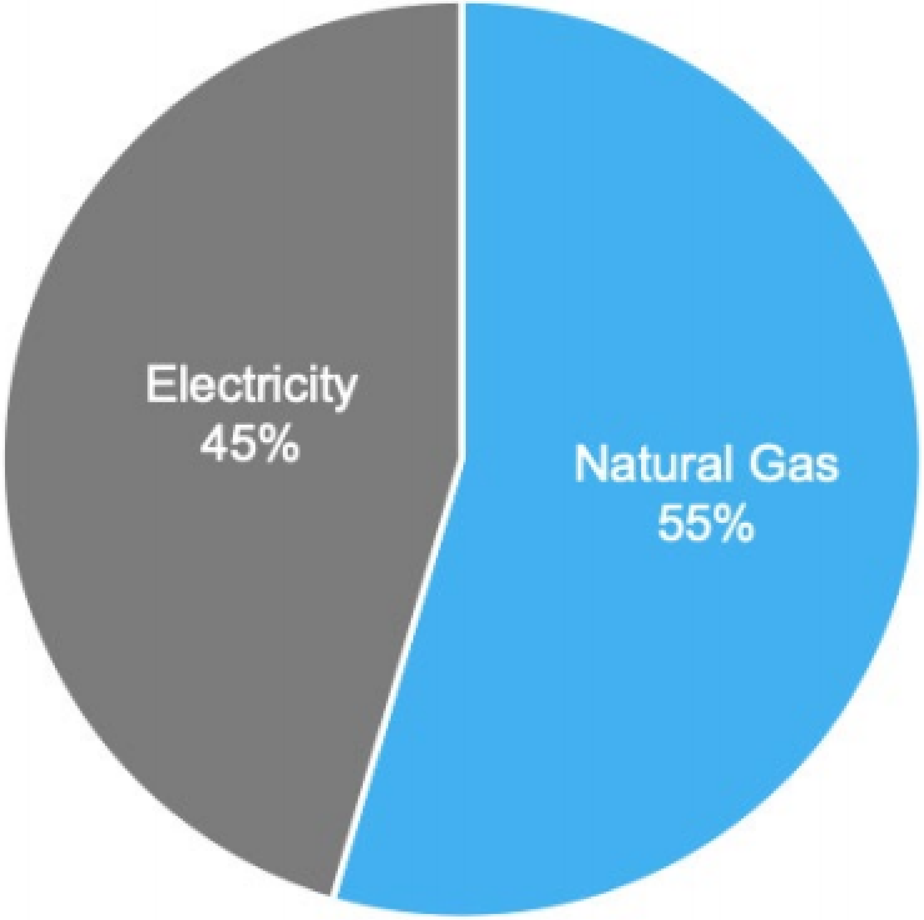
→ Electricity: 14,000 mt CO_2 eq.

*20 year global warming potential

Average American Car has a carbon footprint of 4.6 mt CO_2 per year (Source: EPA)

← ***for reference***

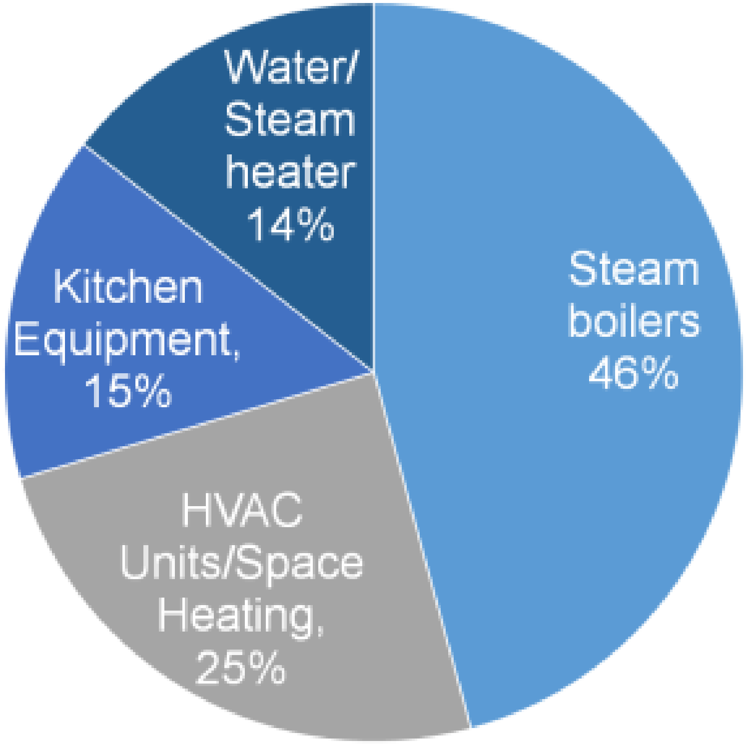




Annual Usage Breakdown: Natural Gas

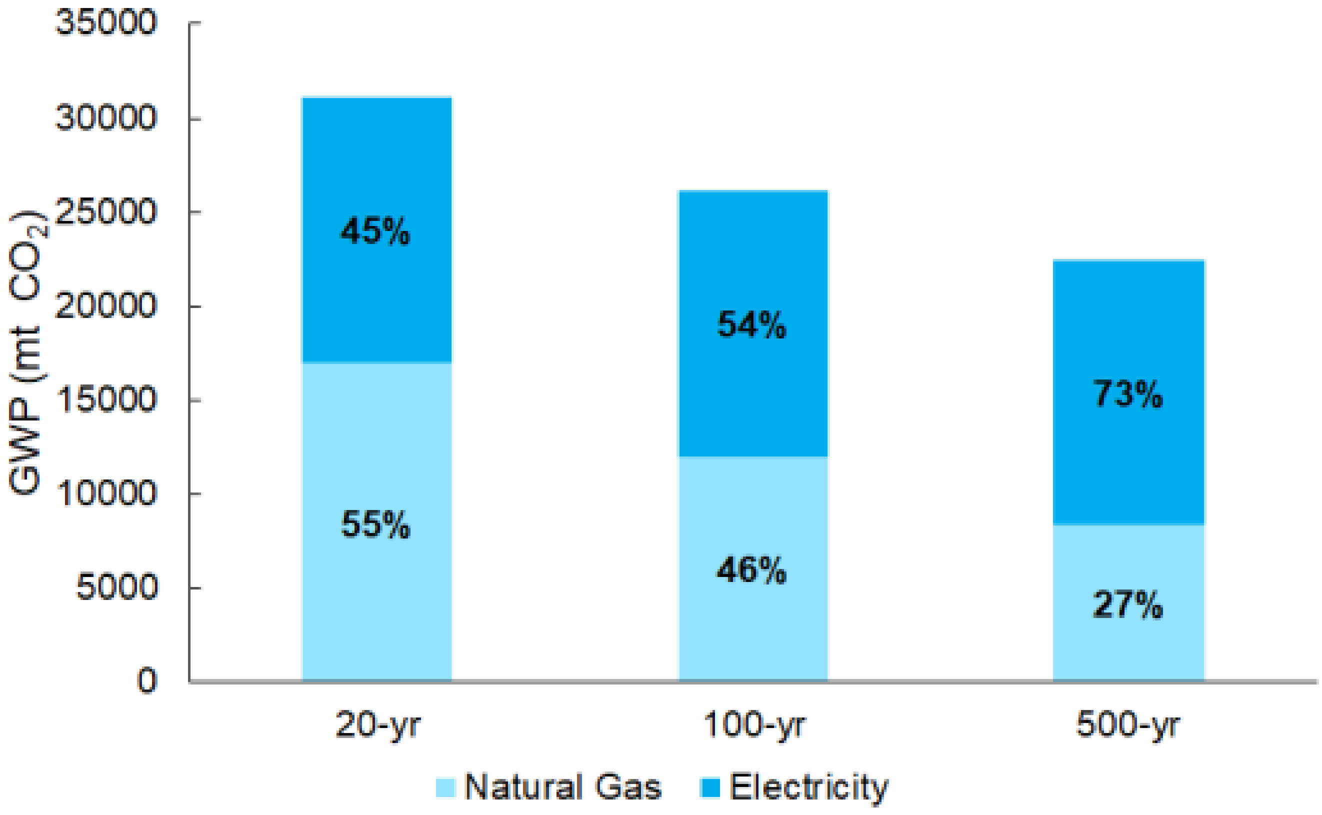
- Almost half of NG consumption from boilers
- Other major contributors*
    - Water/steam heaters
    - Kitchen equipment
    - HVAC units/space heating

*Estimates for non-boiler components were based on capacity values



Long Term Impacts

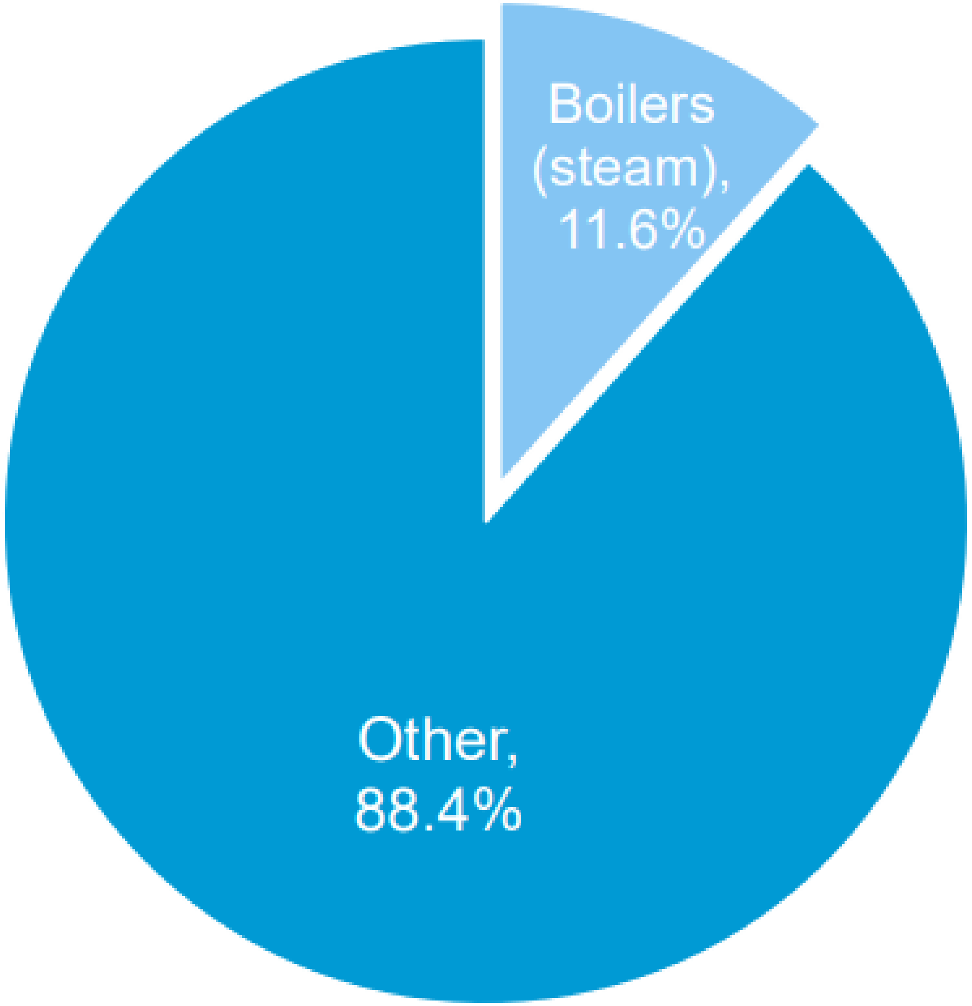
- Small decrease in carbon footprint as gases decay
- Electricity use has more persisting impact



Water Footprint

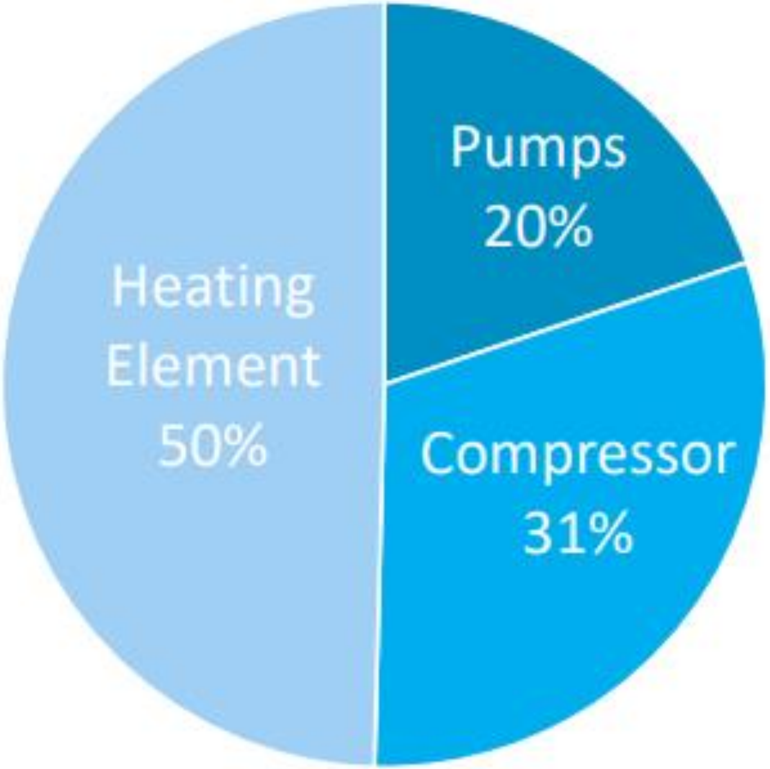
- Water usage was broken down in terms of:
  - Contribution due to boilers and other equipment
  - Batches produced per week

	Batches/week		
	1	1.5	2
Water footprint (gal/batch)	780,000	520,000	390,000



Annual Electricity Usage Breakdown: Lyophilizer

- Analyzed electricity consumption of different components of lyo process
- **440 mt CO2 eq.** emitted per year
- Heating element is primary contributor



Recommendations: High Efficiency Boiler*

Environmental Benefits

- 13.7% reduction in natural gas usage due to boilers

→ 6% reduction in carbon footprint due to natural gas

→ 3% reduction in overall carbon footprint

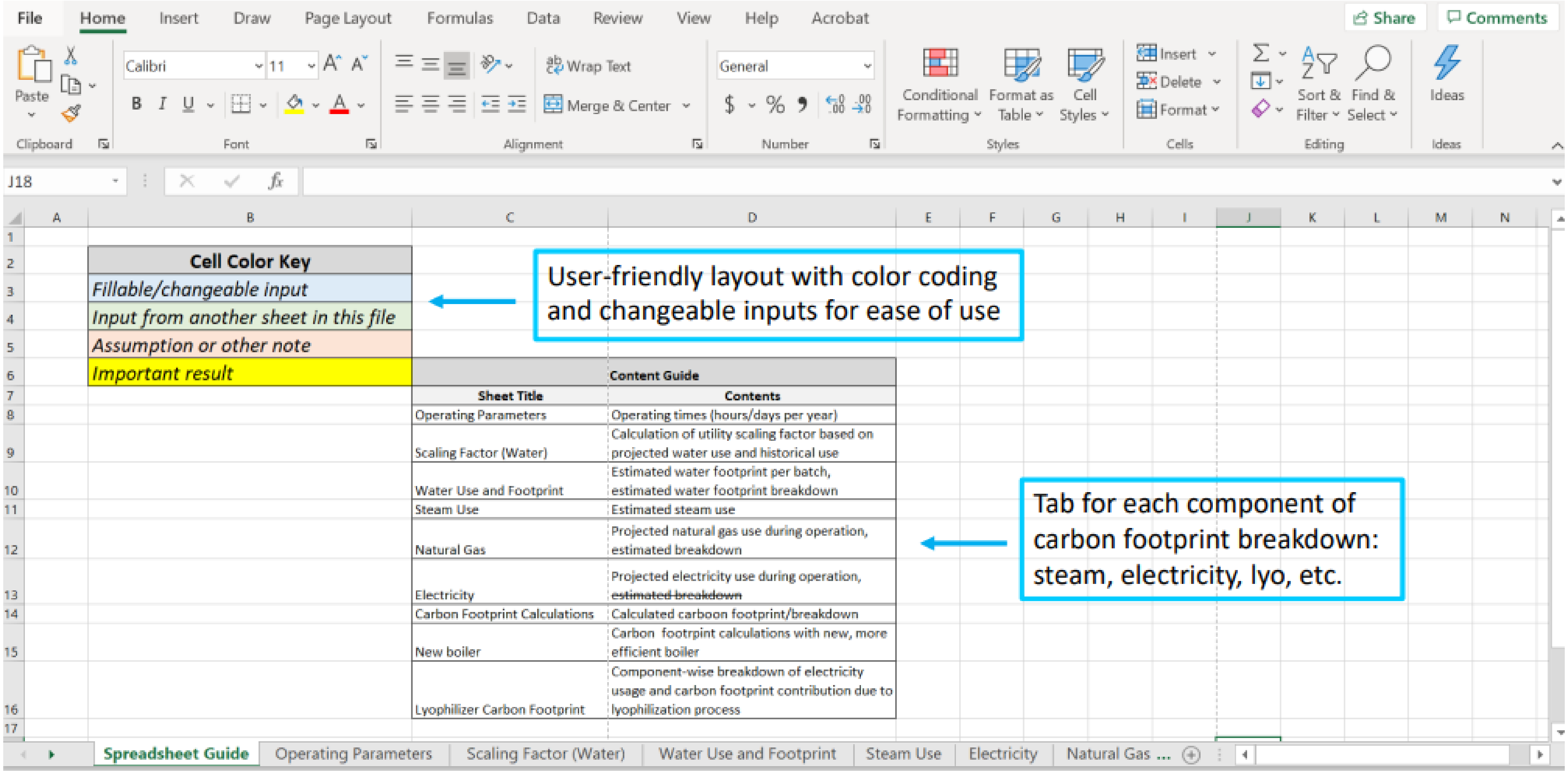
Economic Benefits

- Reduced natural gas usage

→ Annual savings of $13,000

*Calculations based on boiler with 95% efficiency
Current boiler has efficiency of 82%

Recommendations: Continual Updating of Spreadsheet



Cell Color Key
Fillable/changeable input
Input from another sheet in this file
Assumption or other note
Important result

User-friendly layout with color coding and changeable inputs for ease of use

Content Guide	
Sheet Title	**Contents**
Operating Parameters	Operating times (hours/days per year)
Scaling Factor (Water)	Calculation of utility scaling factor based on projected water use and historical use
Water Use and Footprint	Estimated water footprint per batch, estimated water footprint breakdown
Steam Use	Estimated steam use
Natural Gas	Projected natural gas use during operation, estimated breakdown
Electricity	Projected electricity use during operation, ~~estimated breakdown~~
Carbon Footprint Calculations	Calculated carboon footprint/breakdown
New boiler	Carbon footrpint calculations with new, more efficient boiler
Lyophilizer Carbon Footprint	Component-wise breakdown of electricity usage and carbon footprint contribution due to lyophilization process

Tab for each component of carbon footprint breakdown: steam, electricity, lyo, etc.

Spreadsheet Guide | Operating Parameters | Scaling Factor (Water) | Water Use and Footprint | Steam Use | Electricity | Natural Gas ...

Other Recommendations

Recommendation	Outcome
Manipulate control of compressor	• Reduced use of backup compressor • Reduced electricity waste
Renewable sources of electricity	• Reduce long-term carbon footprint
Breakdown of electricity use	• Identify areas of improvement

Conclusions

Estimated footprint of 31,000 mt/year CO2 eq.

Simple actions can reduce environmental impact and result in cost savings

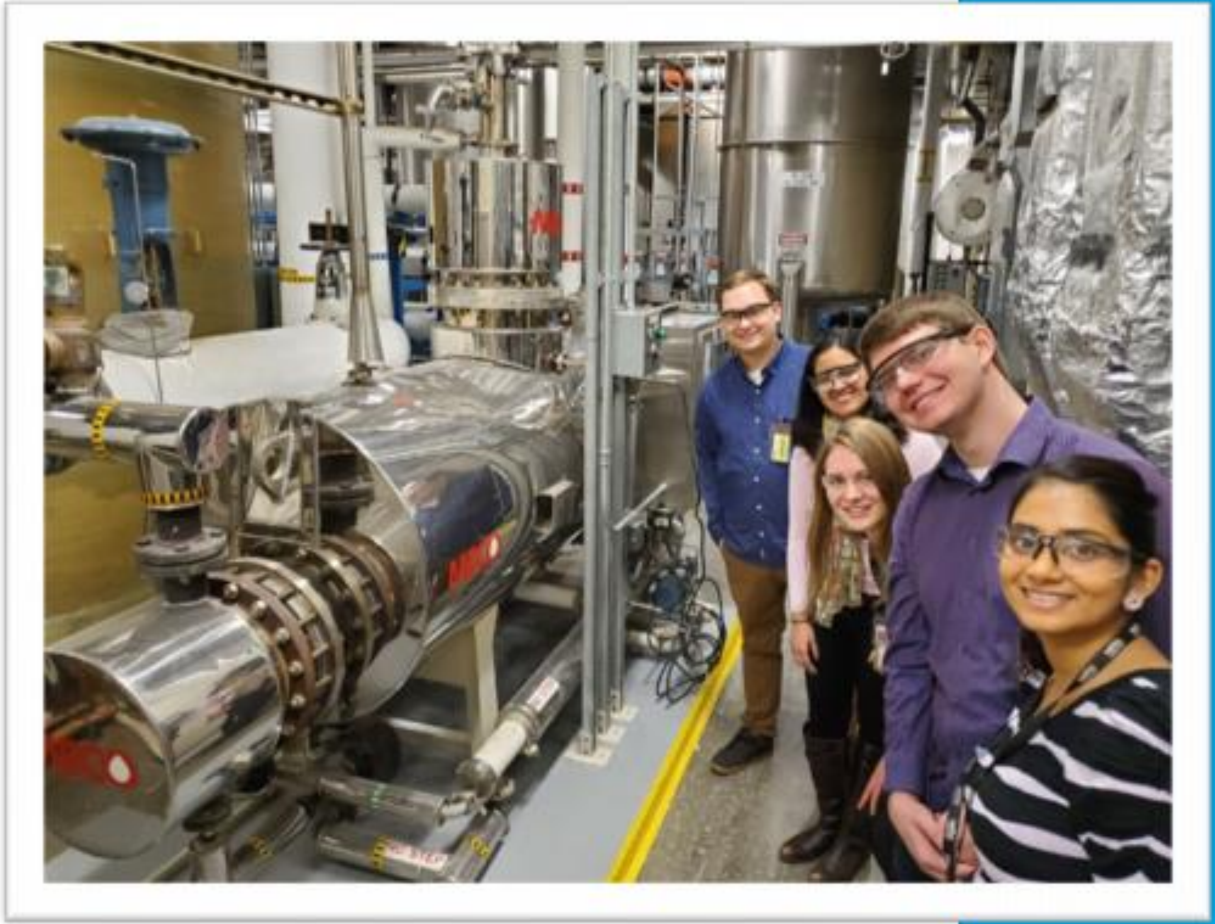
Improve upon projections using additional data

Apply methods to other processes on site

Acknowledgments

- The Xellia team: Kruttika Patel, Frank Medina, and Jeffrey Bores
- CWRU advisors: Prof. Uziel Landau and Prof. Daniel Lacks
- Others: Joe Yurko

AIChE Consultant



Environmental Footprint Assessment: Xellia Pharmaceuticals

Nathan Ewell, Katie Francissen, Sanjana Kamath, and Andrew Swyers
Department of Chemical and Biomolecular Engineering, Case Western Reserve University, Cleveland, OH 44106

BACKGROUND

Xellia Pharmaceuticals

- Danish pharmaceutical company
- Soon to begin production at Bedford, OH site soon
- Want to quantify environmental impact

Carbon Footprint

- Measure of global warming potential normalized to CO_2 emissions
- Important for promoting culture of sustainability

PROJECT OBJECTIVES

Predict the carbon footprint of Building 22 during full production

Identify key contributors to the carbon footprint as possible areas for improvement in the future

METHODS

Determining Carbon Footprint

Activity	CO_2 Factor (kg/unit)	CH_4 Factor (kg/unit)	N_2O Factor (kg/unit)	Unit
Natural Gas Combustion	1.922	0.036	0.004	m^3
Electricity Usage	564	0.050	0.0085	MWh

Activities during operation produce greenhouse gases

Greenhouse gasses have different global warming potentials compared to CO_2

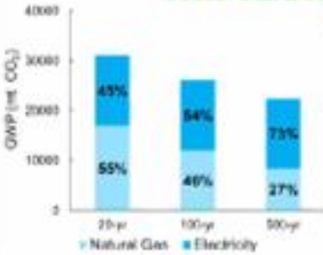
Species	20-yr GWP	100-yr GWP	500-yr GWP
CO_2	1	1	1
CH_4	72	25	7.6
N_2O	289	298	153

Projecting Utility Use During Production

Historical non-production use
Production media runs
Scaled utility use during operations
Known operating parameters
Reasonable assumptions

RESULTS

Total Carbon Footprint



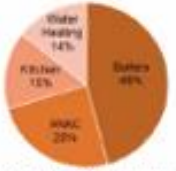
- 20-year carbon footprint of **31,000 mt/yr CO_2 eq.**
- Impact lessens with time as some greenhouse gases decay
- Emissions due to electricity have longer lasting impact

Average American Car has a carbon footprint of 4.6 mt CO_2 per year (Source: EPA)

for reference

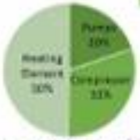
Natural Gas

- Footprint of **17,000 mt/yr CO_2 eq.**
- Primary contributor: steam boilers
- Other significant contributors noted



Natural Gas Usage

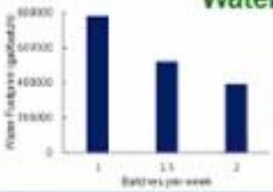
Lyophilization Process

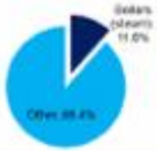


Lyophilizer Electricity Usage

- Important process step for freeze drying product
- **440 mt CO_2 eq.** emitted per year

Water Footprint





- Concentrating production reduces footprint
- Large amount of water used for boiler feed

RECOMMENDATIONS

Recommendation	Outcome
High Efficiency (95%) boiler	- 6% reduction in carbon footprint due to natural gas - 3% reduction in overall carbon footprint - Annual savings of $13,000
Updating of carbon footprint projection	- More accurate carbon footprint to reflect changes in production
Manipulate control of compressor	- Reduced use of backup compressor - Reduced electricity waste

CONCLUSIONS & FUTURE WORK

- Environmental footprint assessment is an important step toward sustainable practices
- Estimated footprint of 31,000 mt/year CO_2 eq.
- Simple actions can reduce impact
- Improve upon projections using additional data
- Apply methods to other processes on site

ACKNOWLEDGMENTS

The Xellia team: Kruttika Patel, Frank Medina, and Jeffrey Bores

CWRU advisors: Prof. Uziel Landau and Prof. Daniel Lacks

Others: Joe Yurko

REFERENCES

B. R. Bakshi, *Sustainable engineering: principles and practice*. Cambridge, United Kingdom: Cambridge University Press, 2019.

Emissions & Generation Resource Integrated Database. EPA, 2015

2020 Capstone Internship Certificate

xellia
PHARMACEUTICALS

The Cleveland, Ohio Manufacturing Facility of

Xellia Pharmaceuticals USA, INC.

Is pleased to recognize and present

Nathan Ewell

For the 2020 Spring Semester Internship of the Senior Class CWRUcible Team performing

Sustainable Engineering Carbon Footprint LCA Project

supervised by Joseph Yurko, P.E.
in conjunction with
AIChE and the Department of Chemical and Biomolecular Engineering at

Case Western Reserve University School of Engineering

this 18th day of April, 2020

Joseph Yurko, P.E.
Associate Project Lead

Rafael Rios Delgado, P.E.
Engineering & Maintenance Director

Brenda Shuler
Formulations SME

Barton Farmer, P.E.
Automation SME

Certificate of Achievement

AIChE
The Global Home of Chemical Engineers

The Cleveland Section 017 of the

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

Takes Great Pleasure in Recognizing

Nathan Ewell

with the award of

Academic Excellence

Upon recommendation by the faculty of Case Western Reserve University
School of Engineering Department of Chemical and Biomolecular Engineering
this day of 15th April, 2020

Chrarles Roe, PhD.
Charles Roe, PhD, FAIChE
SECTION PAST CHAIRMAN

Michael Galgoczy, P.E.
Michael Galgoczy, P.E.
SECTION CHAIRMAN

Joseph Spagnuolo, P.E.
Joseph Spagnuolo, P.E., FAIChE
VICE CHAIRMAN

Sources

- B. R. Bakshi, *Sustainable engineering: principles and practice*. Cambridge, United Kingdom: Cambridge University Press, 2019.
- *Emissions & Generation Resource Integrated Database*, EPA, 2018