

# Building a Primary Product-Level Emissions Data Platform



Irving Fisher Committee on  
Central Bank Statistics



13 & 14 October

# Day 1 – Monday 13 October 2025

11:30 – 12:30 | Guided tour @ De Nederlandsche Bank (optional)

13:00 – 14:00 | Arrival, Registration, and Lunch

14:00 – 14:10 | Introductory Remarks: Framing the Vision

14:10 – 15:30 | **Working Session 1:** Accounting Principles for Product-level Embedded Emissions

15:30 – 15:45 | Break

15:45 – 17:15 | **Working Session 2:** Statistical Methods for Aggregate and Top-down Emissions Analysis

17:30 – 19:00 | Boat Tour (incl. drinks and appetizers)

19:00 | Hosted Dinner

# Day 2 – Tuesday 14 October 2025

08:30 – 09:00 | Morning Coffee and Networking

09:00 – 10:30 | **Working Session 3:** Calculating Primary Data in Practice

10:30 – 11:00 | Break

11:00 – 12:30 | **Working Session 4:** Computational Principles and Design of a Global Product-Level Primary Data Hub

12:30 – 13:30 | Lunch

13:30 – 15:00 | **Working Session 5:** Governance Models for the Product-level Emissions Data Hub

15:00 – 15:30 | Closing Remarks and Next Steps

15:30 – 16:00 | Farewell Networking

16:00 – 17:00 | Guided tour @ De Nederlandsche Bank (optional)

# Introductory Remarks: Framing the Vision

Fabienne Fortanier – De Nederlandsche Bank (DNB)  
Karthik Ramanna – Blavatnik School of Government, Oxford University



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# Working Session 1: Accounting Principles for Product-level Embedded Emissions

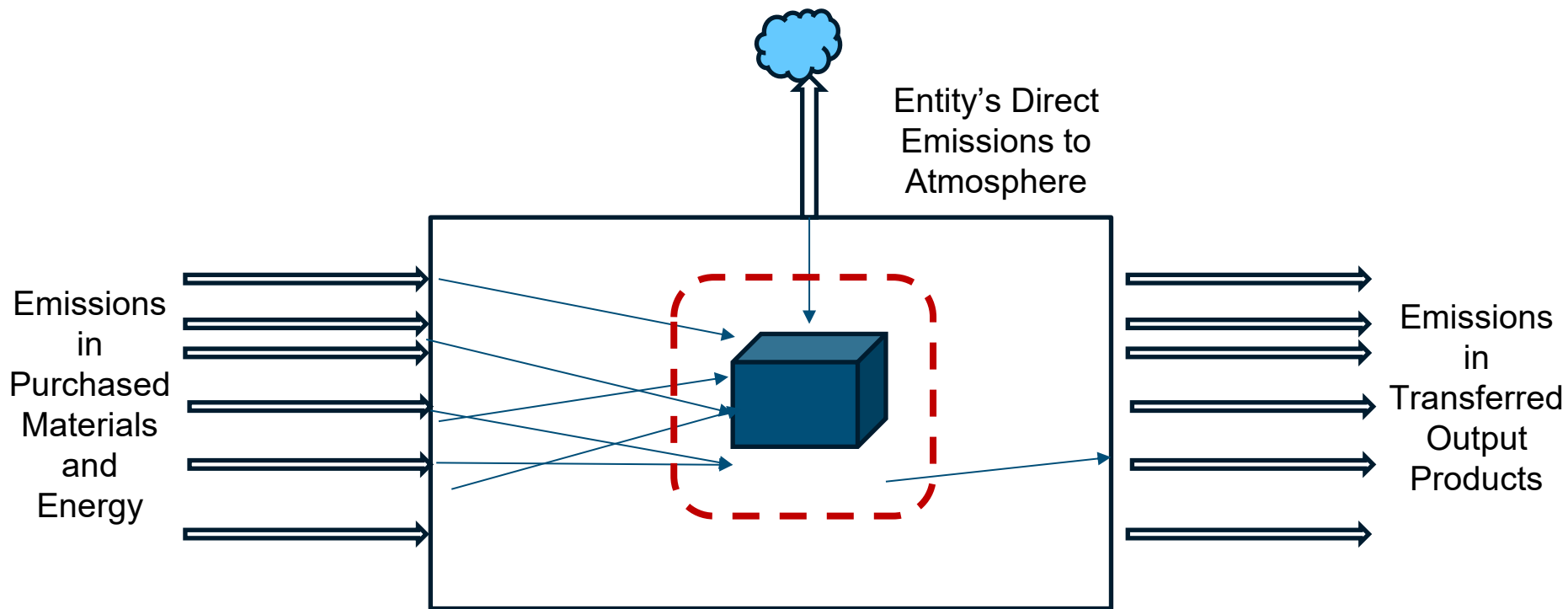
Bob Kaplan – E-ledgers Institute & Harvard Business School  
Miranda Ballentine – former and founding CEO, Clean Energy  
Buyers Alliance (CEBA)



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## 1. Allocation of Current Period Direct and Purchased Emissions (including electricity)

### ☐ Causal

- Input-Output analysis for CO<sub>2</sub> released from combustion and other chemical reactions (e.g., ICE, cement, steel)
- Electricity
  - Minutes of machine time × kw/minute × kgCO<sub>2</sub>/kw
- Materials scrap and waste
- Disposal of used products
- Incoming and outgoing transportation

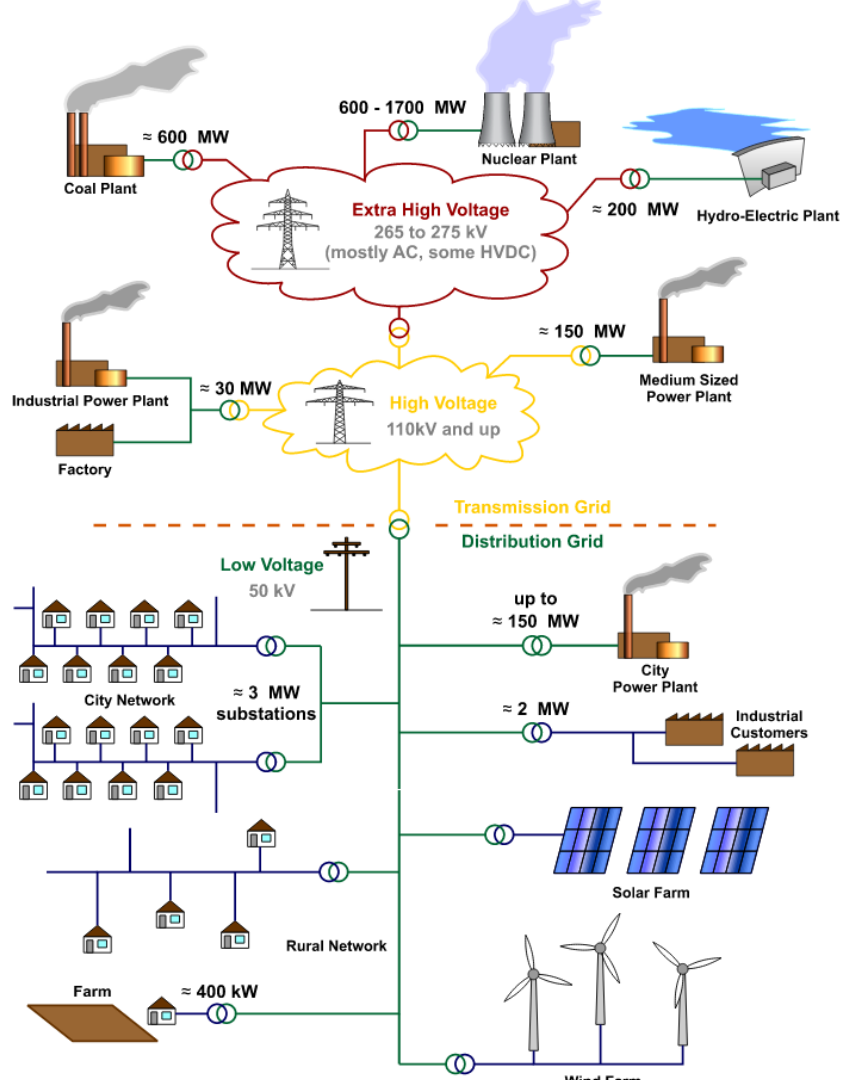
### ☐ Somewhat Arbitrary

- Conversion of single input to multiple outputs
  - Head of cattle, barrel of oil, harvested tree
- Emissions unrelated to products: G&A

## 2. Current Period Amortization of Past and Future Emissions

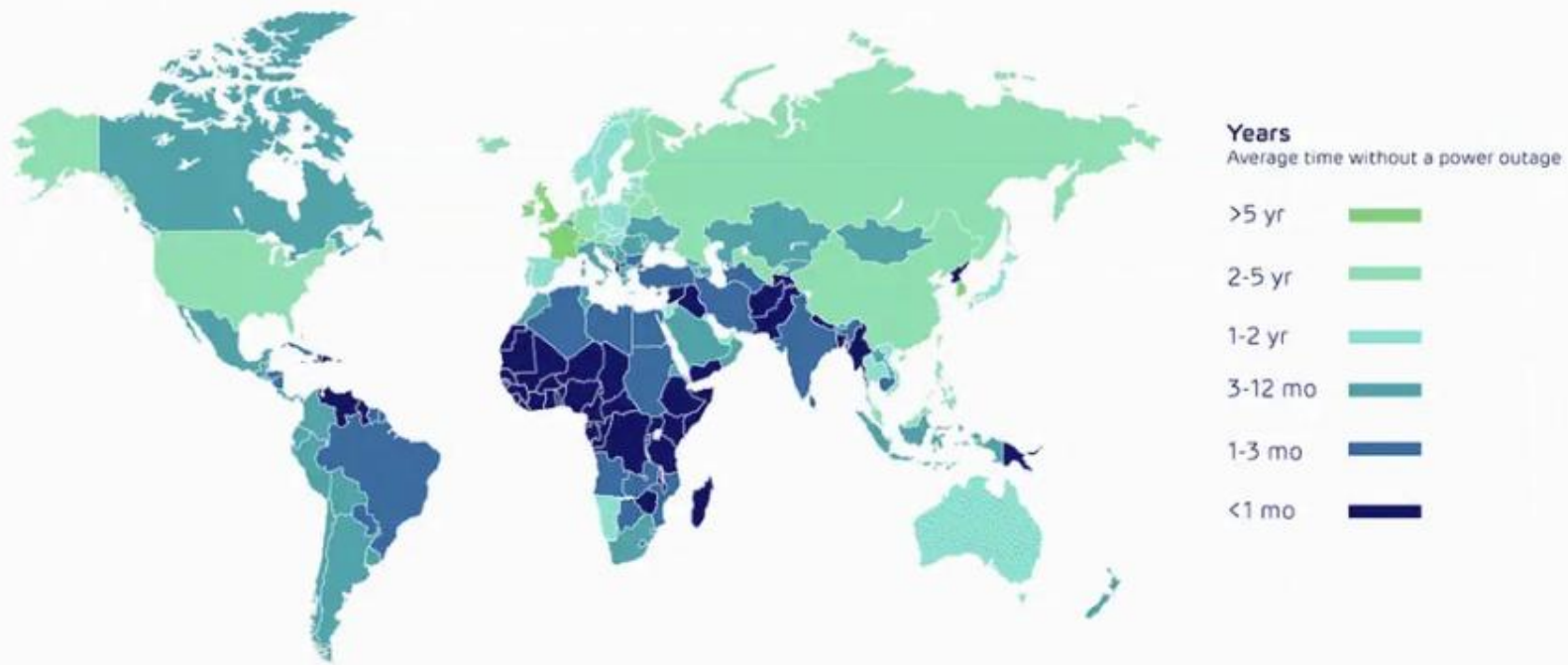
- Capitalized Emissions in PP&E
- End-of-Life Emissions from Decommissioning & Salvage

# E-liability Accounting Allocations of Emissions to Output Products





## Average time between power outages



Source: World Bank, CEER and EIA

**Table 4.1 Comparing market-based and location-based methods**

|                                        | <b>Market-Based Method</b>                                                                                                                                                                                                                                                                 | <b>Location-Based Method</b>                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Definition</b>                      | A method to quantify the scope 2 GHG emissions of a reporter based on GHG emissions emitted by the generators from which the reporter contractually purchases electricity bundled with contractual instruments, or contractual instruments on their own                                    | A method to quantify scope 2 GHG emissions based on average energy generation emission factors for defined geographic locations, including local, subnational, or national boundaries                                                                                                                                                                                       |
| <b>How method allocates emissions:</b> | Emission factors derived from the GHG emission rate represented in the contractual instruments that meet Scope 2 Quality Criteria                                                                                                                                                          | Emission factors representing average emissions from energy generation occurring within a defined geographic area and a defined time period                                                                                                                                                                                                                                 |
| <b>Where method applies:</b>           | To any operations in markets providing consumer choice of differentiated electricity products or supplier-specific data, in the form of contractual instruments                                                                                                                            | To all electricity grids                                                                                                                                                                                                                                                                                                                                                    |
| <b>Most useful for showing:</b>        | <ul style="list-style-type: none"><li>• Individual corporate procurement actions</li><li>• Opportunities to influence electricity suppliers and supply</li><li>• Risks/opportunities conveyed by contractual relationships, including sometimes legally enforceable claims rules</li></ul> | <ul style="list-style-type: none"><li>• GHG intensity of grids where operations occur, regardless of market type</li><li>• The aggregate GHG performance of energy-intensive sectors (for example, comparing electric train transportation with gasoline or diesel vehicle transit)</li><li>• Risks/opportunities aligned with local grid resources and emissions</li></ul> |
| <b>What the method's results omit:</b> | <ul style="list-style-type: none"><li>• Average emissions in the location where electricity use occurs</li></ul>                                                                                                                                                                           | <ul style="list-style-type: none"><li>• Emissions from differentiated electricity purchases or supplier offerings, or other contracts</li></ul>                                                                                                                                                                                                                             |

## Working Session 2: Statistical Methods for Aggregate and Top-down Emissions Analysis

Caroline Willeke – European Central Bank (ECB)  
Michael Wang – Argonne National Laboratory



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13 & 14 October

Symposium on Building a Primary Product-level Emissions Data Platform  
Amsterdam, the Netherlands, Oct. 13-14, 2025



# R&D GREET Life-Cycle Analysis (LCA) Model and Its Data

**Michael Wang, Ph.D, Director**

Life Cycle Analysis and Technology Assessment Department  
Energy Systems and Infrastructure Assessment Division  
Argonne National Laboratory

# R&D GREET life cycle analysis model covers fuels, materials, and technologies

Fuel cycle + vehicle cycle = cradle-to-grave (C2G) (GREET1 + GREET2 models)

Fuel production cycle (WTP) + vehicle operation (PTW) =  
well to wheels fuel cycle (WTW) (GREET1)

Fuel Production Cycle  
(Well-to-Pump, WTP)

Vehicle Operation:  
Pump-to-Wheels (PTW)

Material Cycle:  
Vehicle Manufacturing cycle as example (GREET2)

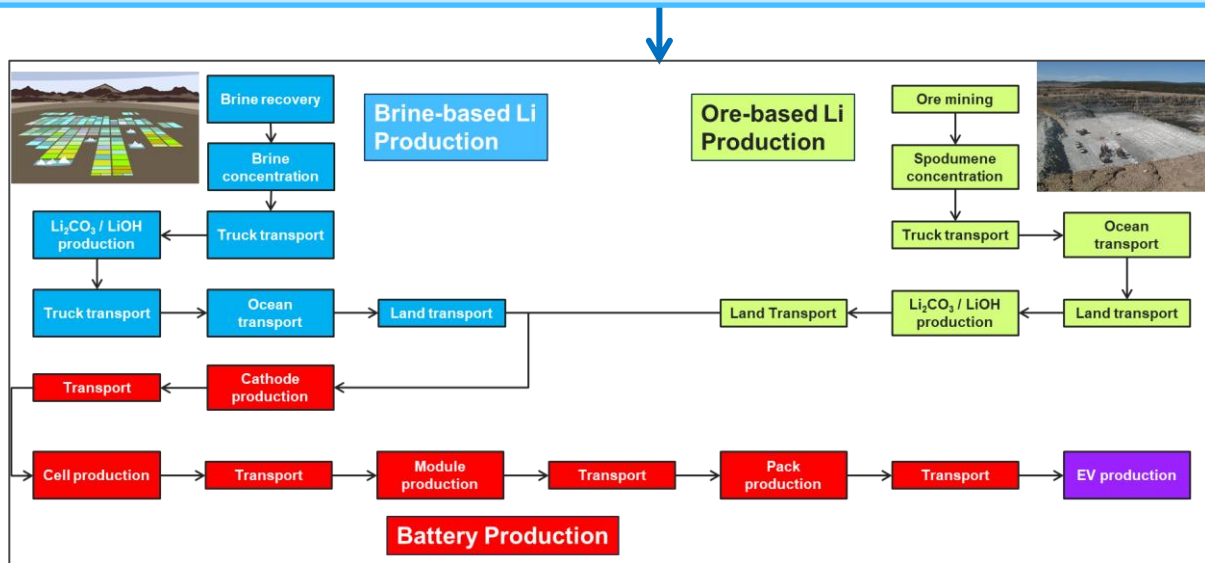
Vehicle Manufacturing  
Cycle (VMC)  
Battery  
Manufacturing Cycle

Vehicle End of  
Life (EOL)

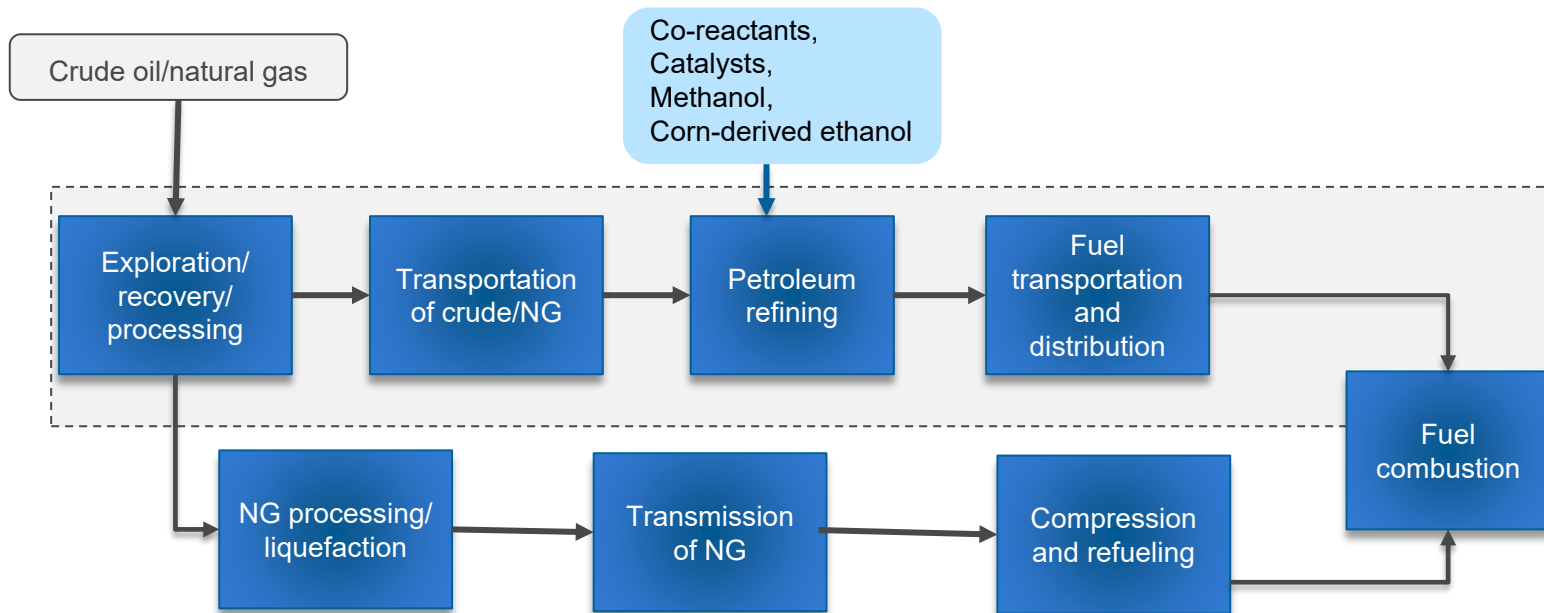
- **R&D GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies)**

examines life-cycle impacts  
of technologies and  
products

- It has been developed  
since 1995; publicly  
available at [greet.anl.gov](http://greet.anl.gov)

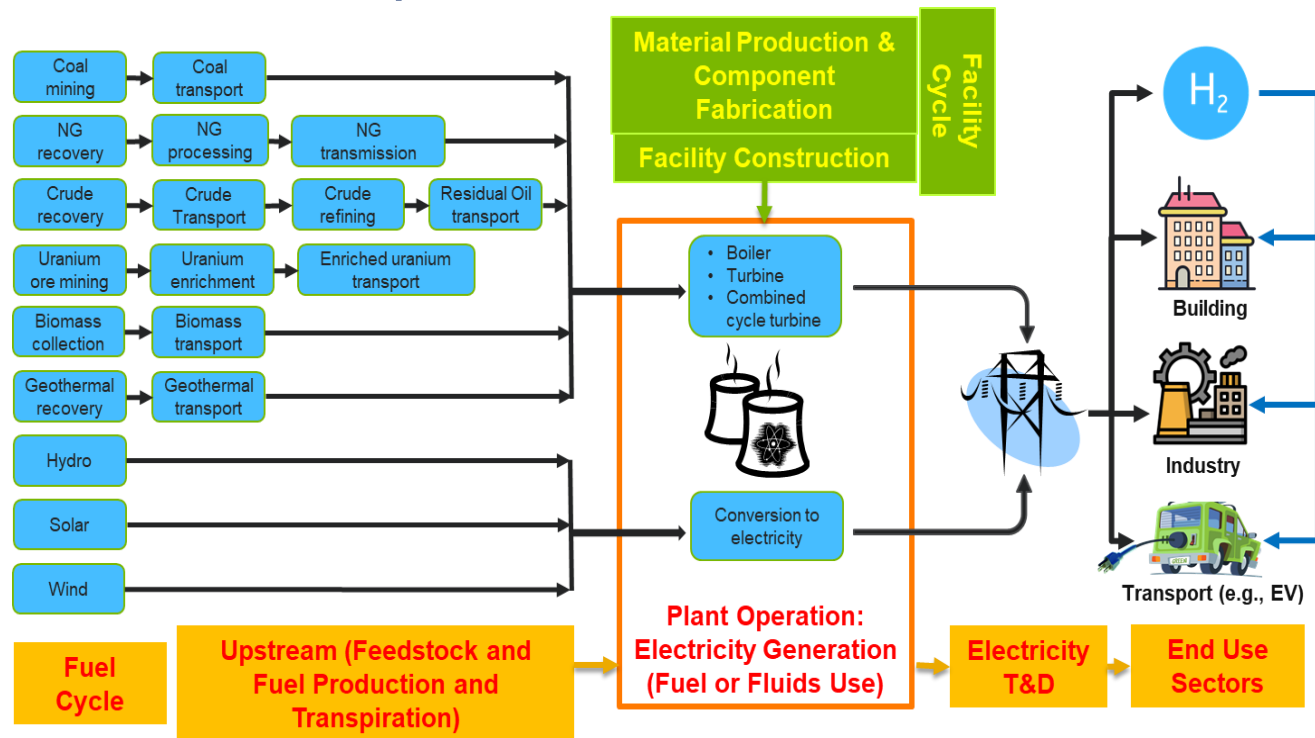


# Life cycle of fuels from petroleum and natural gas



- All direct activities and emissions in the above flowcharts are included
- **Land disturbance** of oil/NG recovery was assessed and included in R&D GREET (up to 2 g/MJ)
- Methane leakage of the NG supply chain is based on combined bottom-up (EPA GHG Inventory) and top-down (individual studies) approach

# *R&D GREET covers electricity generation from various sources and more than 30 generation technologies; it also includes facility cycle (embodied emissions)*



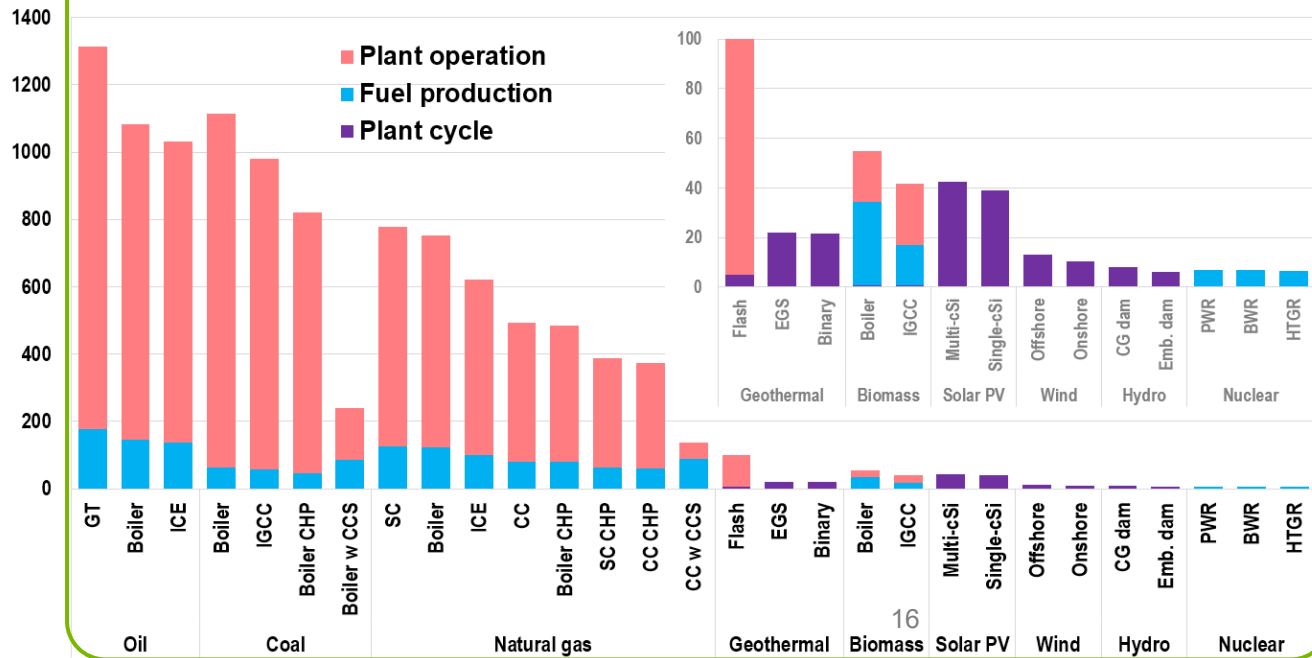


# Life-cycle GHG emissions of electricity vary among technologies

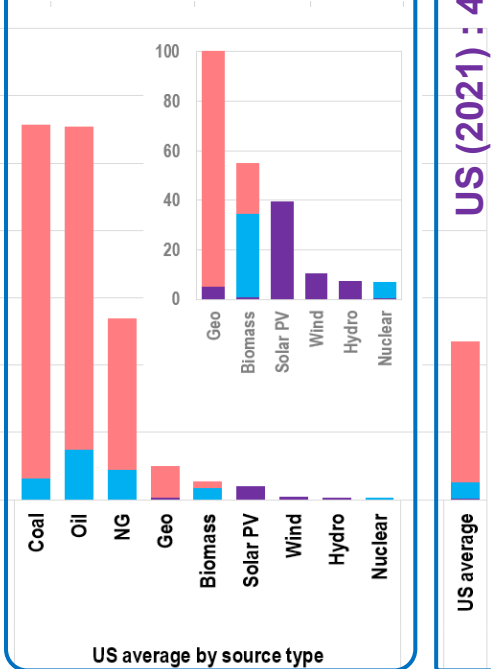
- Thermal power plants (coal, gas, oil, biomass) results are dominated by GHG emissions from plant operation and plant fuel production stages
- Facility cycle GHG emissions of renewable power infrastructure are higher than those of fossil-fired and nuclear plants

g CO<sub>2eq</sub>/kWh

By power generation technology



US By source



US (2021) : 470

US average

US average by source type



# *R&D GREET emission calculation: energy inputs as an example*

$$EM_{cm,i} = \left( \sum_j \sum_k EF_{i,j,k} \times EC_{j,k} \right) \div 1,000,000$$

$EM_{cm,i}$  = Combustion emissions of pollutant  $i$  in  $\text{g}/10^6$  Btu of fuel throughput,

$EF_{i,j,k}$  = Emission factor of pollutant  $i$  for process fuel  $j$  with combustion technology  $k$  ( $\text{g}/10^6$  Btu of fuel burned), and

$EC_{j,k}$  = Consumption of process fuel  $j$  with combustion technology  $k$  ( $\text{Btu}/10^6$  Btu of fuel throughput).

Key input data at process (or stage) level of the supply chain of a product

- Materials inputs
- Emissions per unit of material inputs

(In Wang [1999])

# *LCA is data intensive; data, as well as methodology, drive LCA results*

- ❑ **Background vs. foreground data:** in relation to specific technology under LCA
  - Background data: reflect background systems
    - ✓ Improvements of the rest of economy on specific technology under LCA
    - ✓ Consistency and up-to-date are key
  - Foreground data: reflect the state of the technology under LCA
    - ✓ Spatial representation: regional differences where technologies will be deployed
    - ✓ Temporal representation: past, present, and future performance of technologies
    - ✓ Data verification is key
  
- ❑ **Primary vs. secondary data:** related mainly to foreground data
  - Primary data: data from facility operations (surveys, etc.)
  - Secondary/proxy:
    - ✓ Simulations with process engineering modeling (techno-economic analysis)
    - ✓ Literature data
    - ✓ Approximation
  
- ❑ **Data quality:** affecting LCA reliability
  - Quality rating is usually subjective
  - Technologies at different TRLs affect data availability, thus data quality

# ***R&D GREET relies on a variety of data sources to address the challenge of data availability, representation, and reliability***

## **Background data for baseline technologies and systems**

- Energy Information Administration's data and its Annual Energy Outlook projections
- EPA eGrid for electric systems, GHGRP, and many others
- US Geology Services for water data
- USDA agricultural sector statistics

## **Field operation data (primary sources for foreground data)**

- Oil sands and shale oil operations
- Ethanol plants energy use
- Farming operations, facility operations, etc.

## **Simulations with models (secondary sources for foreground data)**

- ASPEN Plus for technologies at facility level
- Argonne Autonomie for fuel economy of vehicle operations
- EPA MOVES for vehicle emissions, EPA CAMPD for stationary equipment emissions
- Linear programming models for petroleum refinery operations
- Electric utility dispatch models for marginal electricity analysis of EV recharging

## **Collaboration with universities, national labs (primary/secondary sources for foreground data)**

## **Industry inputs (primary sources for foreground data)**

- Fuel producers and technology developers on fuels
- Automakers and system components producers on vehicles and materials

# ***R&D GREET includes extensive lists of critical materials/minerals: examples for EVs and batteries***

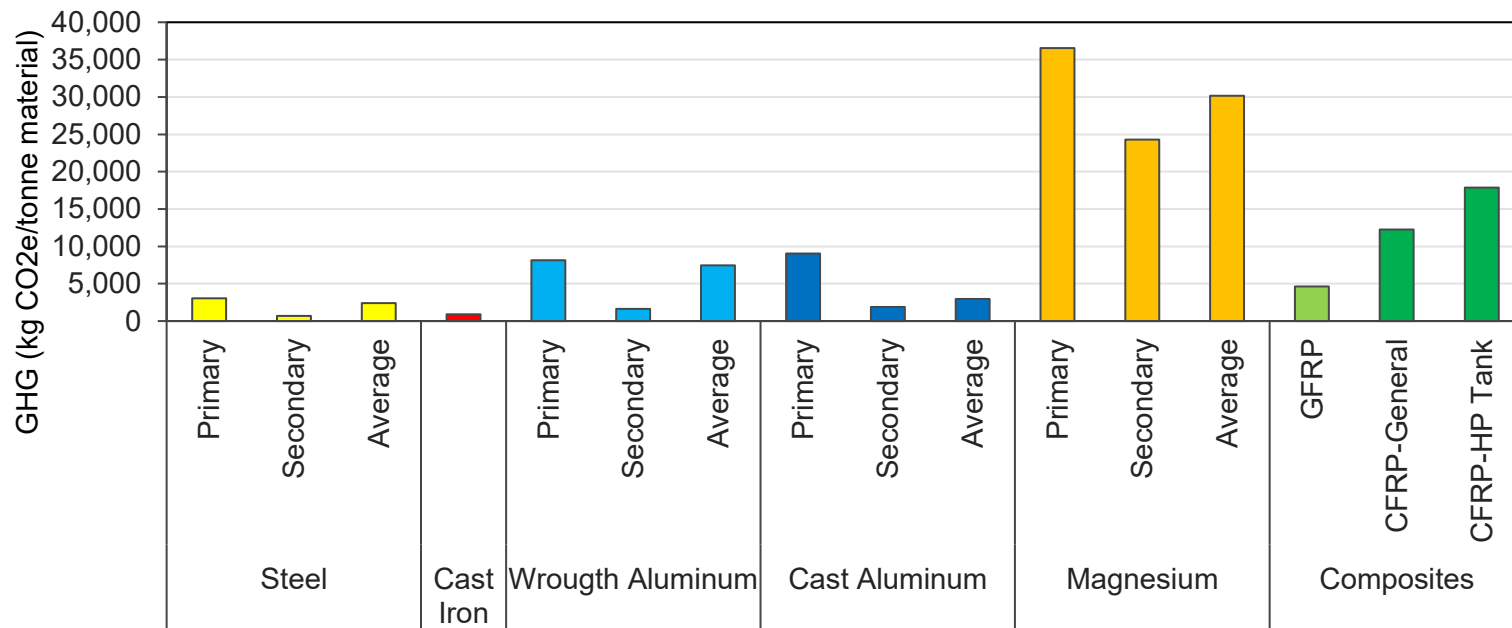
## **EVs**

- **Copper**
- **Aluminum**
- **Steel**
- **Magnesium**
- **Carbon Fiber**
- **Glass Fiber**
- **Plastics**
- **Titanium**
- **PGM for fuel cells**

## **Battery**

- **Nickel**
- **Lithium**
- **Manganese**
- **Cobalt**
- **LiPF<sub>6</sub>**
- **Ethylene carbonate**
- **Dimethyl carbonate**
- **Phosphorous**
- **PVDF**
- **NMP**
- **Graphite**
- **Silicon**
- **Li metal**

# Life cycle GHG emissions for selected materials



- **Steel:**
  - ✓ BOF vs. EAF steel; with different recycled steel inputs
  - ✓ Usage difference in different vehicle parts
- **Aluminum:**
  - ✓ Wrought vs. cast; with different recycled aluminum inputs
  - ✓ Usage difference in different vehicle parts
    - Die cast vs. extrusions vs. sheets
- **Steel and aluminum alloys:**
  - ✓ What elements?
  - ✓ How much?

# REET LCA Co-Product Handling Methods

- Displacement (system boundary expansion)
- Process level allocation based on purposes of processes within a facility
- Mass allocation
- Energy allocation
- Market revenue allocation

# Argonne documented different co-product methods in a 2011 journal article



Contents lists available at ScienceDirect

Energy Policy

journal homepage: [www.elsevier.com/locate/enpol](http://www.elsevier.com/locate/enpol)



Methods of dealing with co-products of biofuels in life-cycle analysis and consequent results within the U.S. context

Michael Wang<sup>a,\*</sup>, Hong Huo<sup>b</sup>, Salil Arora<sup>a</sup>

<sup>a</sup> Center for Transportation Research, Argonne National Laboratory, Argonne, IL 60439, USA

the choice of co-product method can significantly influence the WTW results of biofuels. Of the five methods examined in this study, ISO 14040 advocates use of the displacement method. As we discussed in principle and simulated in practice, the displacement method can generate distorted LCA results if the co-products are actually main products (for the cases of biodiesel and renewable diesel from soybeans). It is far from settled whether use of a given method should be uniformly and automatically recommended for LCA studies. We suggest that a generally agreed-upon method should be applied for a given fuel production pathway. Consistency in choice of co-product method may not serve the purpose of providing reliable LCA results. On this note, the transparency of LCA method(s) selected is important in given LCA studies and sensitive cases with multiple co-product methods may be warranted in LCA studies where co-products can significantly impact study outcomes.

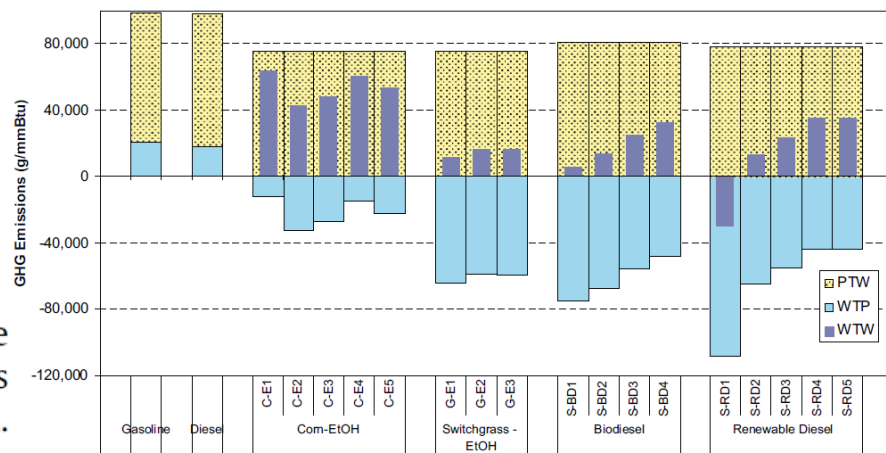
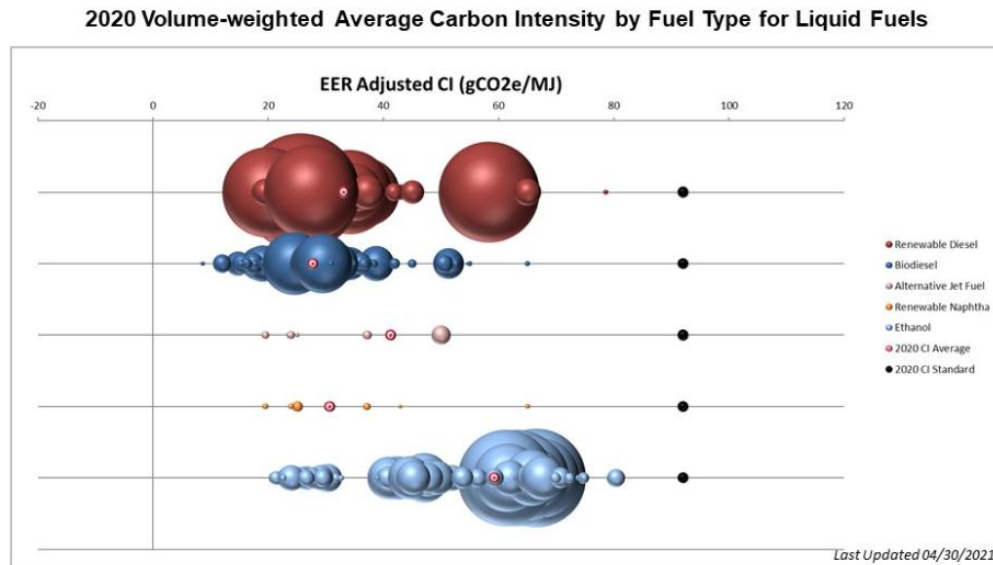


Fig. 9. WTW Greenhouse Gas Emissions of Petroleum Fuels and Biofuels (grams of CO<sub>2</sub>e/ million Btu).

| Biofuel Pathway              | Method of Dealing with Multiple Products | Case Number |
|------------------------------|------------------------------------------|-------------|
| Corn to ethanol              | Displacement                             | C-E1        |
|                              | Mass                                     | C-E2        |
|                              | Energy content                           | C-E3        |
|                              | Market value                             | C-E4        |
|                              | Process purpose                          | C-E5        |
| Switchgrass to ethanol       | Displacement                             | G-E1        |
|                              | Energy content                           | G-E2        |
|                              | Market value                             | G-E3        |
| Soybeans to biodiesel        | Displacement                             | S-BD1       |
|                              | Mass                                     | S-BD2       |
|                              | Energy content                           | S-BD3       |
|                              | Market value                             | S-BD4       |
| Soybeans to renewable diesel | Displacement                             | S-RD1       |
|                              | Mass                                     | S-RD2       |
|                              | Energy content                           | S-RD3       |
|                              | Market value                             | S-RD4       |
|                              | Hybrid allocation                        | S-RD5       |

# California LCFS certifies transportation fuels with different tiers

- **Tier 1 CI default lookup tables:**  
developed by CARB for different pathways by CARB without certification
- **Tier 2 pathway CIs:** allow for project-specific, lower CIs with at least 3-month operations data to certify and verify
- **Tier 3 pathway CIs:** for pathways such as electricity and hydrogen without operations data to certify
- **Tier 4 (or temporary) pathway CIs:** provisional based on engineering modeling with a customized GREET



Source: CARB (2022) (<https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard>)

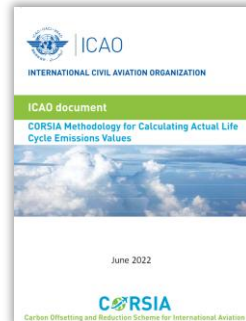
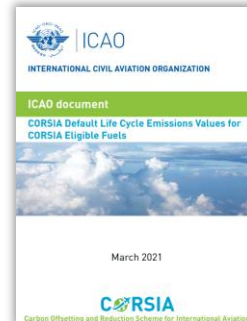
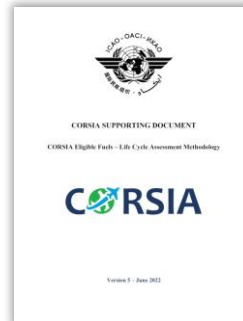


# International Civil Aviation Organization's CORSIA approach

## CORSIA Pathways

| Conversion Technology | Feedstocks                 | Conversion Technology | Feedstocks            |
|-----------------------|----------------------------|-----------------------|-----------------------|
| FT                    | Agricultural residues      | SIP                   | Sugarbeet             |
|                       | Forestry residues          |                       | Sugarcane             |
|                       | Municipal solid waste      | ATJ-isobutanol        | Agricultural residues |
|                       | Short-rotation woody crops |                       | Forestry residues     |
|                       | Herbaceous energy crops    |                       | Corn grain            |
| HEFA                  | Tallow                     |                       | Switchgrass           |
|                       | Used cooking oil           |                       | Miscanthus            |
|                       | Palm fatty acid distillate |                       | Molasses              |
|                       | Corn oil                   | ATJ-ethanol           | Sugarcane             |
|                       | Soybean oil                |                       | Corn grain            |
|                       | Rapeseed oil               |                       | Agricultural residues |
|                       | Camelina                   |                       | Forestry residues     |
|                       | Palm oil                   |                       | Switchgrass           |
|                       | Brassica carinata          |                       | Miscanthus            |
|                       | Sugarcane                  |                       | Waste gases           |

- Argonne has been a member of ICAO's Fuels Task Group (FTG) since 2014
- Argonne's GREET was used to calculate the core LCA values of SAFs for CORSIA
- Default** LCA values and **Actual** LCA value calculation methods are available in CORSIA documents.



FT: Fischer-Tropsch | HEFA: hydroprocessed esters and fatty acids

SIP: Synthesized iso-paraffins | Iso-BuOH: Iso-butanol

ATJ: Alcohol-to-jet | ETJ: Ethanol-to-jet | NBC: non-biomass carbon

# ***International Maritime Organization's LCA approach***

- ❑ IMO LCA Guidelines published in 2024
  - Well to tank
  - Tank to wake
  - Detailed parameters specified along the marine fuel supply chain
- ❑ The LCA Review Working Group of GESAMP (Joint Groups of Experts on the Scientific Aspects of Marine Environmental Protection) was established
  - To review marine fuel WTW CI values to be proposed by member states
- ❑ Default lookup CI tables and actual method CIs

# ***LCA and regulation compliance: default vs. actual methods***

- ❑ Most (if not all) regulations relying on LCA allow default and actual method
- ❑ Default method is generic; does not need company-specific data to certify CIs
- ❑ Actual method, with lowered CIs, is company/project-specific, and requires company proprietary data
- ❑ Data for actual method has not been made public, thus has not helped public data building yet
- ❑ What can we learn among LCA, regulation, and corporate account?
  - Consistency: system boundary, co-product allocation
  - Transparency: data made publicly available; to what extent?
  - Verification and auditing

# Summary

- ❑ LCA is a major step to holistically evaluate environmental performance of technologies and products
  - From singular stages to the complete supply chain; shift in environmental burdens from one stage to another is not missed
- ❑ Recent trends of LCA applications
  - US domestic regulations and programs
    - ✓ Regulations such as the CA LCFS (and several other states), EPA RFS, and IRA/OBBBA
  - International activities
    - ✓ International Civil Aviation Organization's CORSIA program
    - ✓ International Marine Organization's LCA Guidelines
    - ✓ EU Renewable Fuel Directive
    - ✓ Canadian Clean Fuel Regulation
- ❑ LCA practices and regulations have helped accumulation of emission data
- ❑ Further improvements are still needed
  - LCA methodologies need to be consistent
  - Models and data need to be open and transparent
  - Data representation and reliability
    - ✓ Temporal and geographic/spatial variations
    - ✓ New data gathering protocols/technologies will help

The R&D GREET effort at Argonne National Laboratory is supported by the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, the Office of Clean Energy Demonstration, the Office of Technology Commercialization, the Office of Nuclear Energy, and ARPA-E of the US Department of Energy (DOE) under contract DE-AC02-06CH11357. The views and opinions expressed herein do not necessarily state or reflect those of the US government or any agency thereof. Neither the US government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Argonne's R&D GREET is to inform the life cycle analysis of technical community. Not all pathways and data in R&D GREET are appropriate for use in circumstances where a high level of quantitative certainty or precision is required. GREET is referenced in numerous independent state and federal compliance and incentive programs (including solicitations, rulemakings, and tax incentives), but it is important to note that R&D GREET is not the version used by any of these specific programs. Argonne does not warrant that use of R&D GREET is consistent with the requirements of any particular regulatory or incentive program.

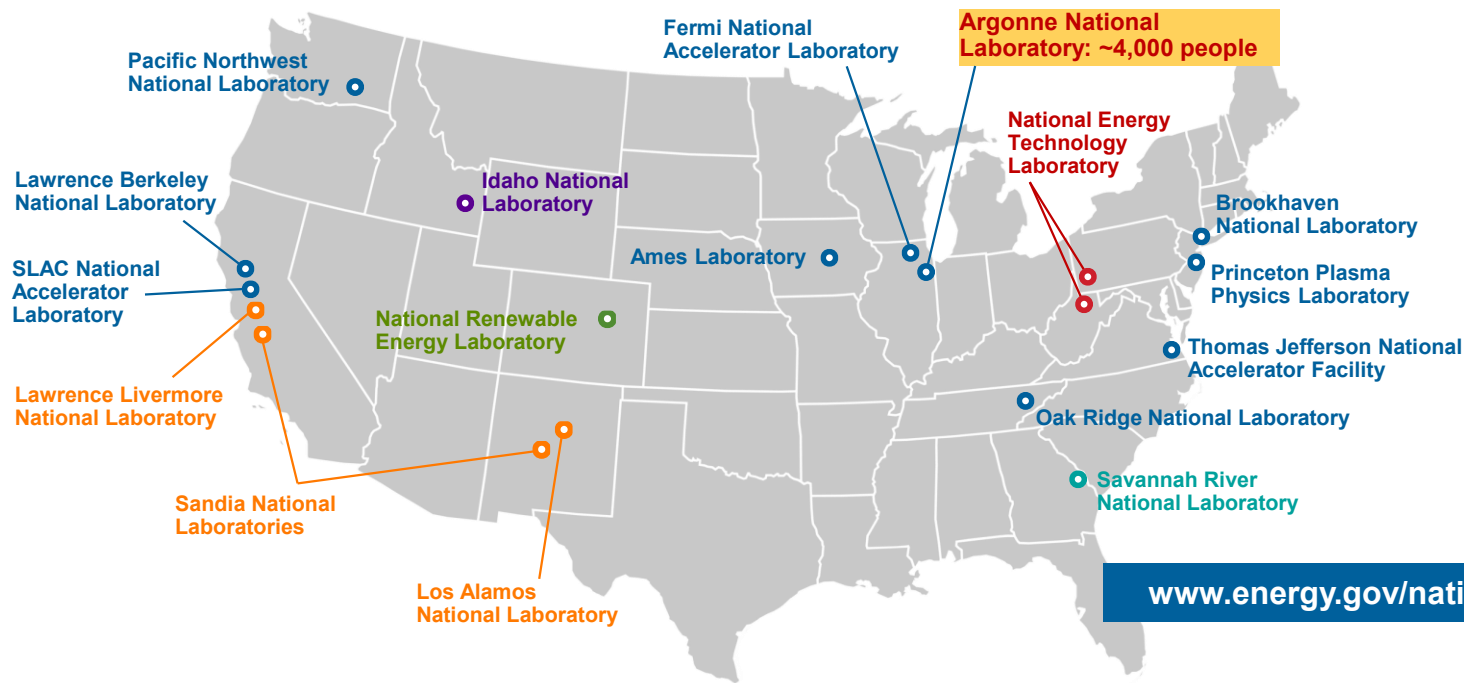


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U.S. DEPARTMENT OF  
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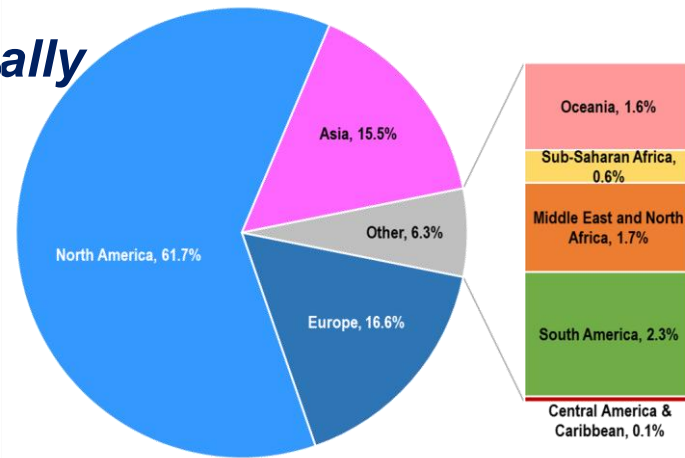
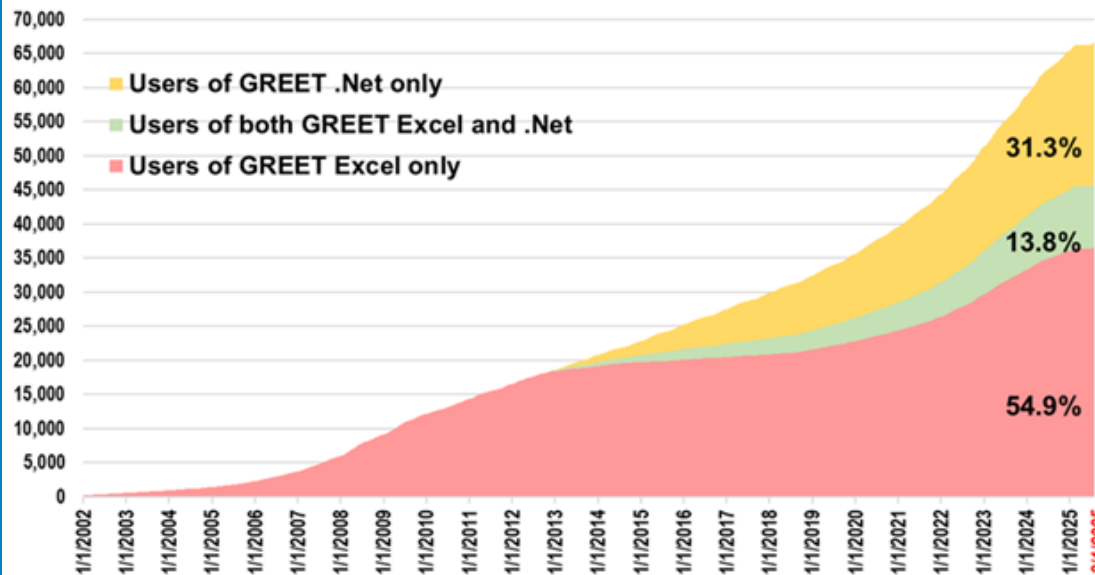


## LABORATORIES BY OFFICE OR ADMINISTRATION

- Office of Science
- National Nuclear Security Administration
- Office of Fossil Energy and Carbon Management
- Office of Energy Efficiency and Renewable Energy
- Office of Nuclear Energy
- Office of Environmental Management

[www.energy.gov/national-laboratories](http://www.energy.gov/national-laboratories)

# >66,000 Registered R&D GREET Users Globally



International Energy Agency



California Environmental Protection Agency  
Air Resources Board



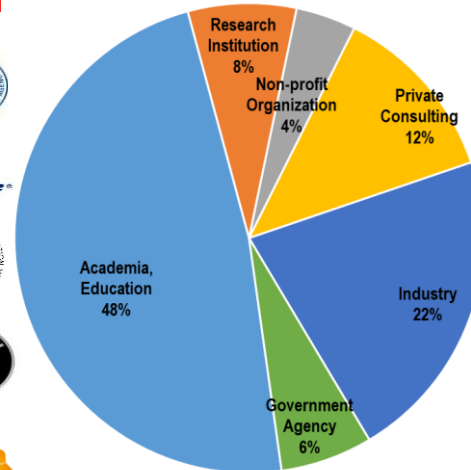
UC DAVIS  
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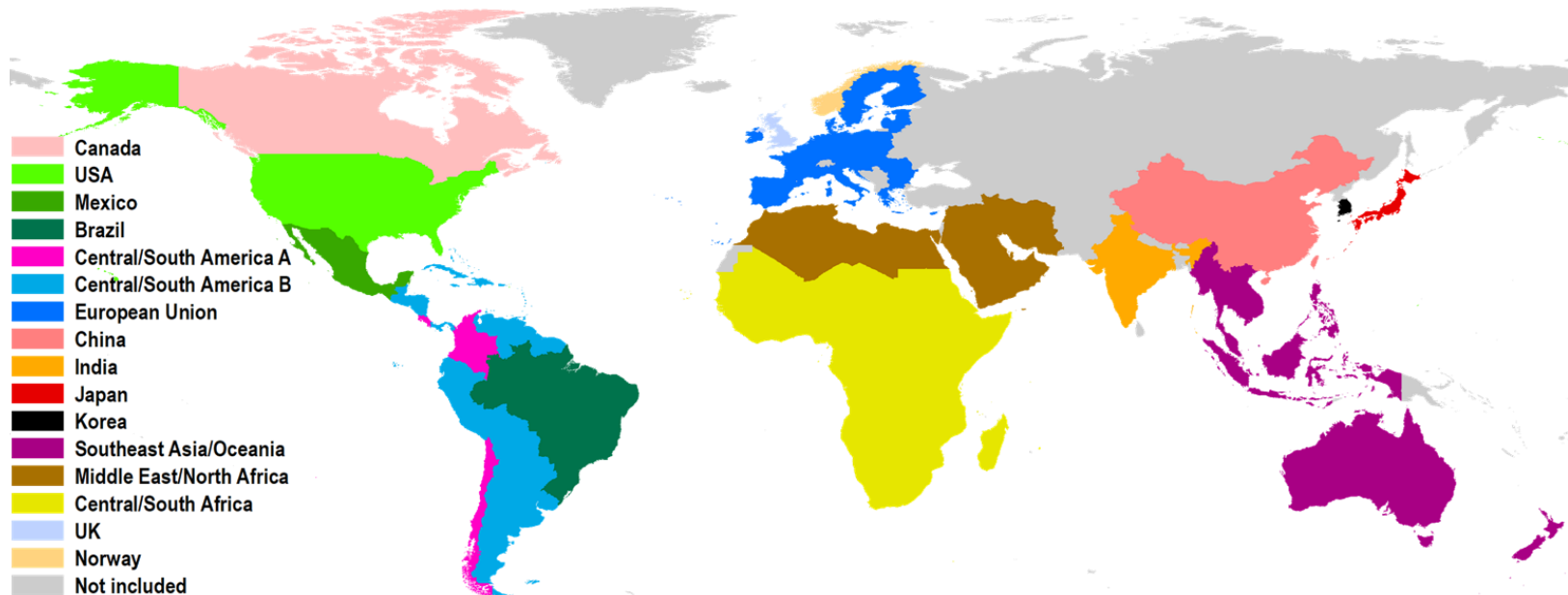
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# Development of the GREET+ Model

Analyze life-cycle energy use and GHG emissions for vehicle/fuel systems and technologies in 16 world regions

- Develop a consistent and comparable LCA modeling platform for different world regions
  - based on the well-established GREET® for the US and previous derivatives of China-GREET and MENA-GREET
- GREET+ is currently developed based on Excel platform of GREET® 2022 rev1
- Time period: 2005 to 2050





# Argonne GREET website has R&D GREET, technical reports, journal articles, and technical memos.

ANL/ESIA-24/20

## Summary of Expansions and Updates in R&D GREET® 2024

Prepared by

Michael Wang, Hao Cai, Longwen Ou, Amgad Elgowainy, Md Rakibul Alam, Thathiana Benavides, Livia Benvenuti, Andrew Burnham, Thai Ngan Do, Masum Farhad, Yu Gan, Ulises Gracida, Troy Hawkins, Rakesh Krishnamoorthy Iyer, Saurajyoti Kar, Jarod Kelly, Taemin Kim, Christopher Kolodziej, Hoyoung Kwon, Uisung Lee, Juin Yau Lim, Xinyu Liu, Zifeng Lu, Michele Morales, Clarence Ng, Ishan Pandey, Siddharth Shukla, Nazib Siddique, Pingping Sun, Thomas Sykora, Pradeep Vyawahare, Jo Zhou

Systems Assessment Center  
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Argonne National Laboratory

January 2025



Argonne's R&D REET Model  
<https://greet.anl.gov>

## Energy Systems and Infrastructure Analysis



RESEARCH CAPABILITIES PUBLICATIONS NEWS

### R&D GREET®

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Fuel-Cycle Model

Vehicle-Cycle Model

GREET Tools

R&D GREET Building  
Module

R&D GREET Marine  
Module

R&D GREET Rail Module

R&D GREET Battery  
Module

ICAO-GREET Model

GREET+ Model

FD-CIC Tool

WTW Calculator

AFLEET Tool

**This is Argonne National Laboratory's R&D version of GREET.**  
For GREET versions used for determining tax credits, please [click here](#).  
A brief introduction to R&D GREET can be found [here](#).

### R&D GREET® Model

The **Greenhouse** gases, **Regulated Emissions**, and **Energy** use in **Technologies** Model

### GREET News

#### R&D GREET 2024 Release

January 10, 2025

The Argonne National Laboratory's Systems Assessment Center is pleased to announce the 2024 release of the suite of **R&D GREET Models**. Please read [Summary of Expansions and Updates in R&D GREET® 2024](#) (451KB pdf) for more details on updates in this version.

### DISCLAIMER

R&D GREET 2024 is being released, consistent with Argonne National Laboratory's routine annual R&D GREET update process. Consistent with annual updates since 1995, R&D GREET (also historically called "ANL GREET") includes representation of new fuel pathways and updates to underlying assumptions. Pathways represented in the tool include two major categories: A) those that have been rigorously evaluated and have high certainty; and B) those that are preliminary, which could include pathways that have not recently been evaluated; those where there is still a gap in the science or data, and/or those that are currently under internal or external peer review. Argonne's annual releases of R&D GREET are comprehensive in order to inform the life cycle analysis technical community and elicit stakeholder feedback. These annual releases are meant to share the early-stage perspectives in life-cycle analysis, particularly in preliminary form, so as to gather feedback from the academic and technical expert community and determine where additional research, analysis and data are needed. Not all pathways and data in R&D GREET are appropriate for use in circumstances where a high level of quantitative certainty or precision is required. Inclusion of a pathway or module in R&D GREET does not necessarily represent U.S. Government concurrence for any specific use, but instead is intended to gather technical feedback and advance the science of life-cycle analysis.

# GREET informs policies and regulations



Environment and  
Climate Change Canada



- **California Low-Carbon Fuel Standard** uses CA-GREET, an adaptation of Argonne GREET model
- **Oregon Clean Fuels Program** uses an adaptation of Argonne's GREET model
- **State of Washington Clean Fuel Regulation** relies on CA-GREET
- **State of New Mexico Clean Transportation Fuel Program** relies on Argonne's GREET
- **U.S. EPA** uses GREET with other sources for **Renewable Fuels Standard** pathway evaluations
- **National Highway Traffic Safety Administration** for fuel economy regulation
- **Federal Aviation Administration** and **International Civil Aviation Organization** using GREET to evaluate aviation fuel pathways
- **Canadian Clean Fuel Regulation** for Environment and Climate Change Canada fuel pathways
- LCA results for use in different provisions of the 2021 **Bipartisan Infrastructure Law** and the 2022 **Inflation Reduction Act** and 2025 **One Big Beautiful Bill Act** in the U.S.



U.S. DEPARTMENT OF  
**ENERGY**

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# R&D GREET has an extensive list of energy systems

## Petroleum



- Gasoline
- Diesel
- Jet fuel
- Etc.

## Natural gas

- Conventional
- Shale gas
- Renewable natural gas
- Coal mine methane



- Electricity/Heat
- Hydrogen
- Methanol
- Ammonia
- Diesel/jet fuel

- Natural gas
- Coal
- Nuclear
- Hydro
- Wind
- Solar
- etc.



## Electricity:

- national,
- NERC,
- State
- And different countries

## 1<sup>st</sup> Gen Feedstocks:

- Corn
- Soybeans
- Sugarcane
- Etc.

## 2<sup>nd</sup> Gen Feedstocks:

- Energy crops
- Crop/forest residues
- Wastes (MSW, animals)



## Biofuels

- Ethanol
- Biodiesel
- Renewable diesel
- Sustainable aviation fuels (SAF)

- Natural gas
- Renewable natural gas
- Coal mine methane
- Coal
- Electricity (solar, wind, nuclear, grid, etc.)



## Hydrogen:

- gaseous
- liquid

## Renewable Hydrogen via low-C electricity:

- Wind
- Solar
- Nuclear



- CO<sub>2</sub> Sources
- Biogenic
- Point sources
- Direct air capture



## Electro-fuels:

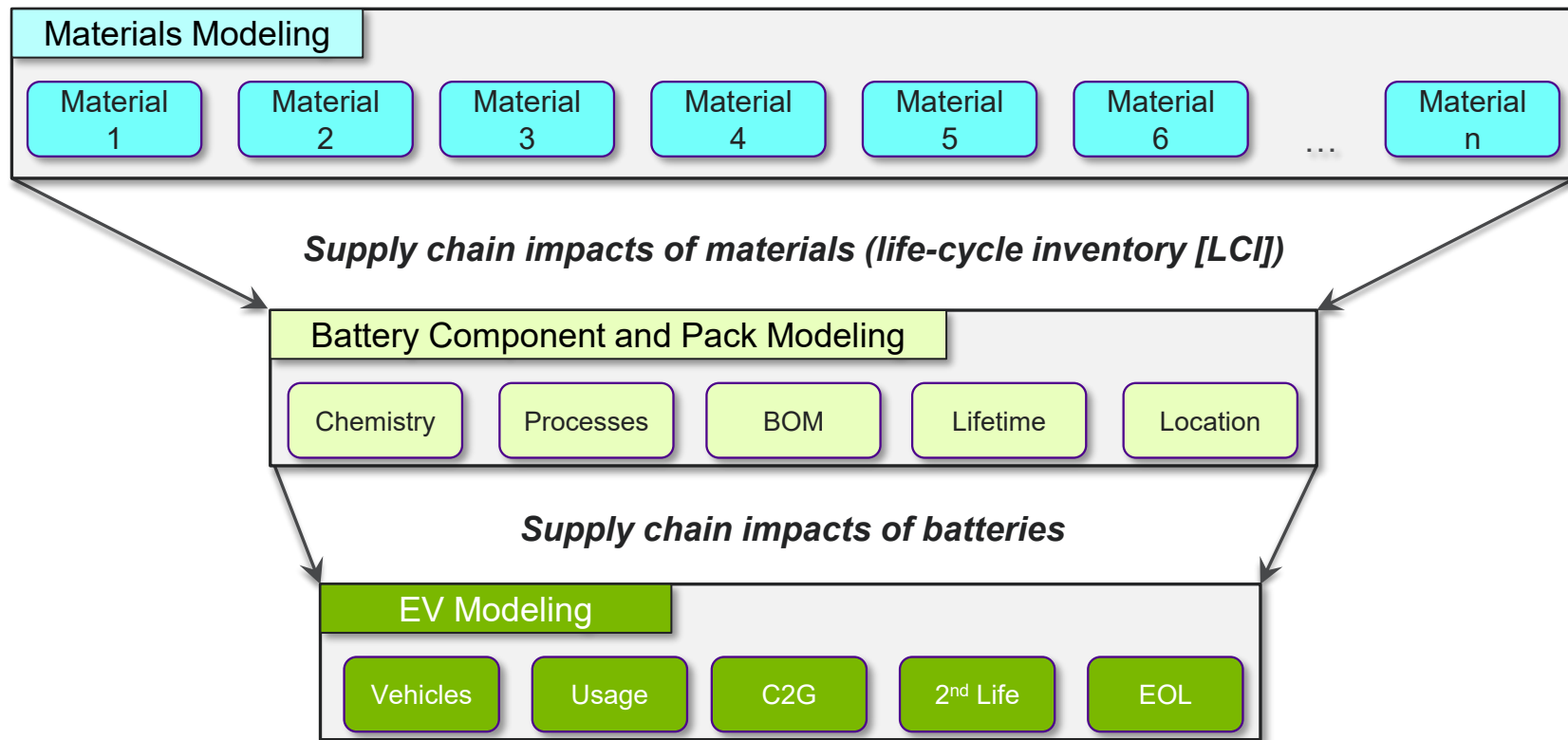
- Gasoline
- Diesel
- Jet fuel
- Methanol



# ***GREET covers materials and chemicals, besides energy systems***



# Framework of vehicle cycle analysis: example of electric vehicles – from materials, to batteries, and to EVs



**Impacts of EV production, use, and EOL**

# Life cycles of 60+ materials are included in R&D GREET2

| Material Type      | Number in GREET | Examples                                              |
|--------------------|-----------------|-------------------------------------------------------|
| Ferrous Metals     | 3               | Steel, stainless steel, iron                          |
| Non-Ferrous Metals | 12              | Aluminum, copper, nickel, magnesium                   |
| Plastics           | 23              | Polypropylene, nylon, carbon fiber reinforced plastic |
| Vehicle Fluids     | 7               | Engine oil, windshield fluid                          |
| Others             | 17              | Glass, graphite, silicon, cement                      |
| <b>Total</b>       | <b>62</b>       |                                                       |

- ❑ Several important lightweighting materials included in GREET 2
  - Aluminum, magnesium, carbon fiber reinforced plastics, and high strength steel (comparable to steel)
  - They currently have high GHG impacts; GREET 1 & 2 address trade-offs between high embodied material GHGs (R&D GREET2) and vehicle lightweighting efficiency (R&D GREET1)
- ❑ Life-cycle inventory (LCI) data for the materials reside in R&D GREET2; data sources for vehicle materials
  - Argonne's detailed analysis of materials supply chains (steel, aluminum, battery critical materials, etc.)
  - Collaboration with universities and other national labs
  - Collaboration with companies and industry associations

# ***R&D GREET includes extensive lists of critical materials/minerals: examples for EVs and batteries***

## **EVs**

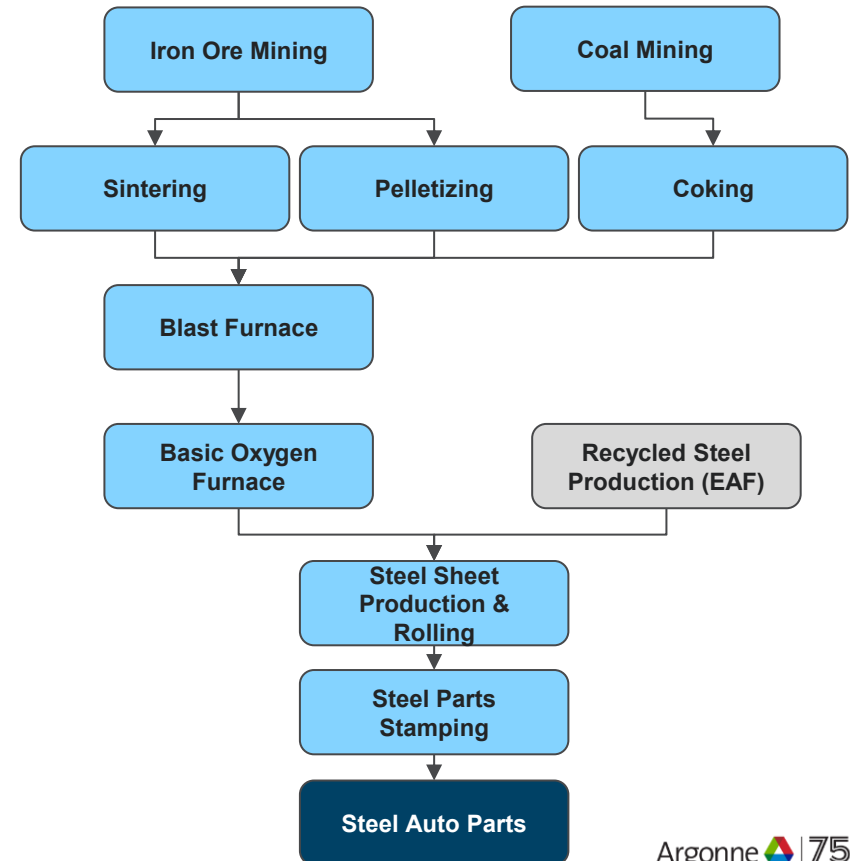
- **Copper**
- **Aluminum**
- **Steel**
- **Magnesium**
- **Carbon Fiber**
- **Glass Fiber**
- **Plastics**
- **Titanium**
- **PGM for fuel cells**

## **Battery**

- **Nickel**
- **Lithium**
- **Manganese**
- **Cobalt**
- **LiPF<sub>6</sub>**
- **Ethylene carbonate**
- **Dimethyl carbonate**
- **Phosphorous**
- **PVDF**
- **NMP**
- **Graphite**
- **Silicon**
- **Li metal**

# Key parameters for material production: steel

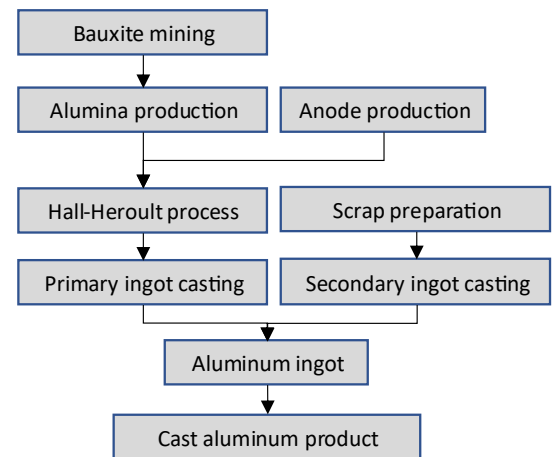
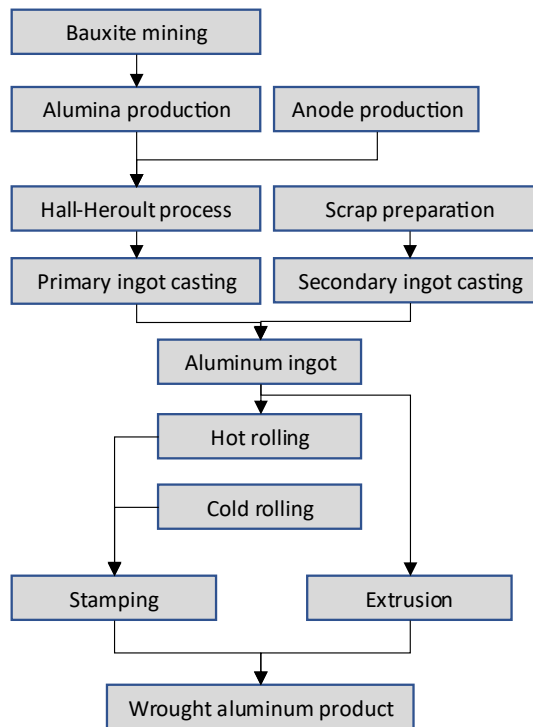
- Materials are modeled step-by-step from ore mining to part production
- Many materials can be, and are, produced in multiple ways
  - Blend of known production approaches when data are available
- Most steel is produced via either a Basic Oxygen Furnace (BOF) or an Electric Arc Furnace (EAF)
  - BOF steel is generally primary
  - EAF steel is generally secondary



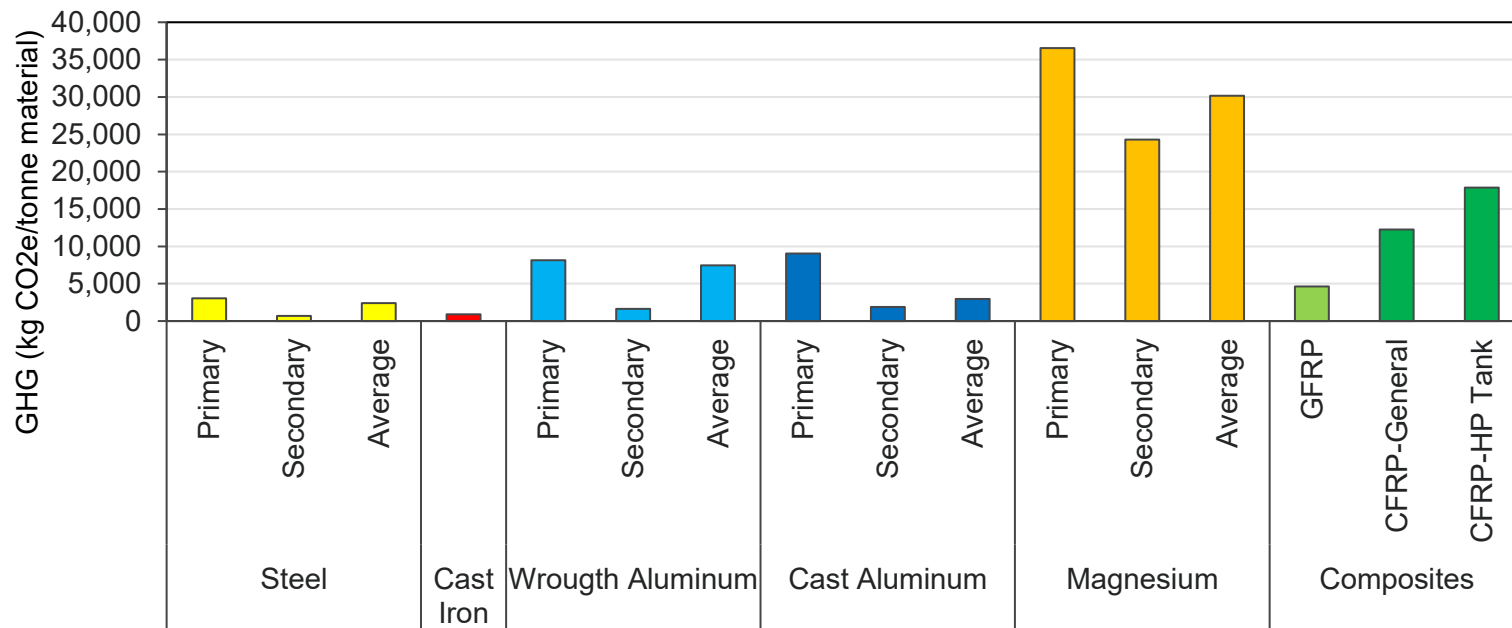


# Key parameters for material production: aluminum

- **Consider all aluminum process flows**
- **Evaluate processes using GREET background data**
  - Energy and environmental burdens associated with all energy and material inputs
- **Leverage industry data**
  - Aluminum Association and others



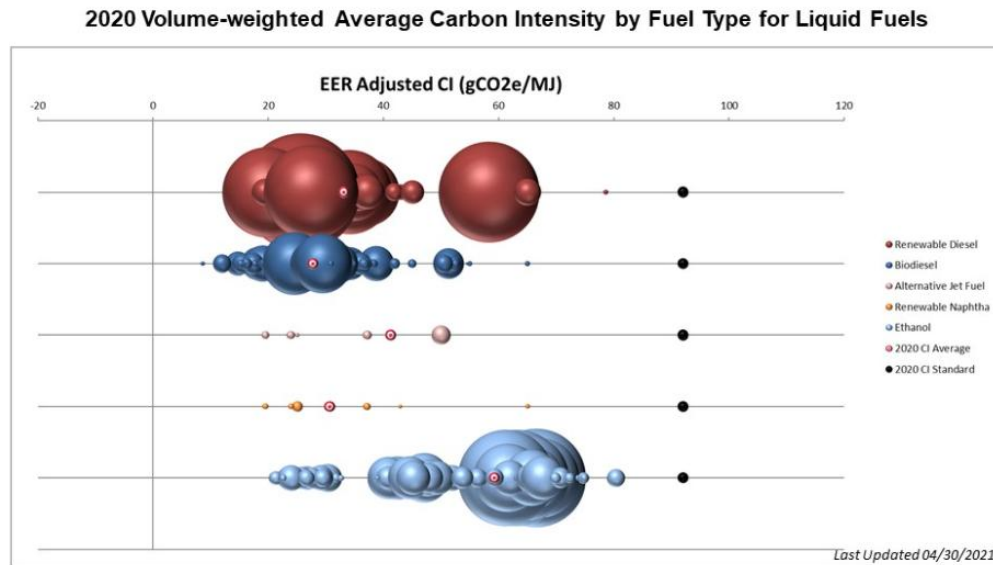
# Life cycle GHG emissions for selected materials



- **Steel:**
  - ✓ BOF vs. EAF steel; with different recycled steel inputs
  - ✓ Usage difference in different vehicle parts
- **Aluminum:**
  - ✓ Wrought vs. cast; with different recycled aluminum inputs
  - ✓ Usage difference in different vehicle parts
    - Die cast vs. extrusions vs. sheets
- **Steel and aluminum alloys:**
  - ✓ What elements?
  - ✓ How much?

# California LCFS certifies transportation fuels with different tiers

- **Tier 1 CI default lookup tables:**  
developed by CARB for different pathways by CARB without certification
- **Tier 2 pathway CIs:** allow for project-specific, lower CIs with at least 3-month operations data to certify and verify
- **Tier 3 pathway CIs:** for pathways such as electricity and hydrogen without operations data to certify
- **Tier 4 (or temporary) pathway CIs:** provisional based on engineering modeling with a customized GREET



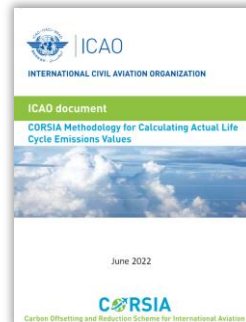
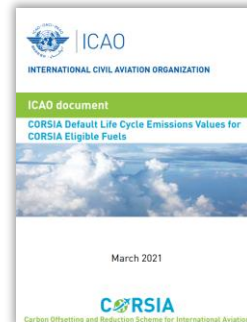
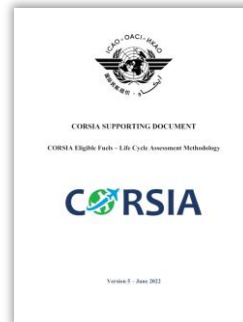
Source: CARB (2022) (<https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard>)

# International Civil Aviation Organization's CORSIA approach

## CORSIA Pathways

| Conversion Technology | Feedstocks                 | Conversion Technology | Feedstocks            |
|-----------------------|----------------------------|-----------------------|-----------------------|
| FT                    | Agricultural residues      | SIP                   | Sugarbeet             |
|                       | Forestry residues          |                       | Sugarcane             |
|                       | Municipal solid waste      | ATJ-isobutanol        | Agricultural residues |
|                       | Short-rotation woody crops |                       | Forestry residues     |
|                       | Herbaceous energy crops    |                       | Corn grain            |
| HEFA                  | Tallow                     |                       | Switchgrass           |
|                       | Used cooking oil           |                       | Miscanthus            |
|                       | Palm fatty acid distillate |                       | Molasses              |
|                       | Corn oil                   | ATJ-ethanol           | Sugarcane             |
|                       | Soybean oil                |                       | Corn grain            |
|                       | Rapeseed oil               |                       | Agricultural residues |
|                       | Camelina                   |                       | Forestry residues     |
|                       | Palm oil                   |                       | Switchgrass           |
|                       | Brassica carinata          |                       | Miscanthus            |
|                       | Sugarcane                  |                       | Waste gases           |

- Argonne has been a member of ICAO's Fuels Task Group (FTG) since 2014
- Argonne's GREET was used to calculate the core LCA values of SAFs for CORSIA
- Default** LCA values and **Actual** LCA value calculation methods are available in CORSIA documents.



FT: Fischer-Tropsch | HEFA: hydroprocessed esters and fatty acids

SIP: Synthesized iso-paraffins | Iso-BuOH: Iso-butanol

ATJ: Alcohol-to-jet | ETJ: Ethanol-to-jet | NBC: non-biomass carbon

# ***International Maritime Organization's LCA approach***

- ❑ IMO LCA Guidelines published in 2024
  - Well to tank
  - Tank to wake
  - Detailed parameters specified along the marine fuel supply chain
- ❑ The LCA Review Working Group of GESAMP (Joint Groups of Experts on the Scientific Aspects of Marine Environmental Protection) was established
  - To review marine fuel WTW CI values to be proposed by member states
- ❑ Default lookup CI tables and actual method CIs

# *Regulation compliance: default vs. actual methods for LCA*

- ☐ Most (if not all) regulations relying on LCA allow default and actual method
- ☐ Default method is generic, does not need company-specific data to certify CIs
- ☐ Actual method, with lowered CIs, is company/project-specific, and requires company proprietary data
- ☐ Data for actual method has not been made public, thus has not helped public data building yet

# Summary

- ❑ LCA is a major step to holistically evaluate environmental performance of technologies and products
  - From singular stages to the complete supply chain; shift in environmental burdens from one stage to another is not missed
- ❑ Recent trends of LCA applications
  - US domestic regulations and programs
    - ✓ Regulations such as the CA LCFS (and several other states), EPA RFS, and IRA/OBBBA
  - International activities
    - ✓ International Civil Aviation Organization's CORSIA program
    - ✓ International Marine Organization's LCA Guidelines
    - ✓ EU Renewable Fuel Directive
    - ✓ Canadian Clean Fuel Regulation
- ❑ LCA practices and regulations have helped accumulation of emission data
- ❑ Further improvements are still needed
  - LCA methodologies need to be consistent;
  - Models and data need to be open and transparent
  - Data representation and reliability
    - ✓ Temporal and geographic/spatial variations
    - ✓ New data gathering protocols/technologies will help

## Working Session 3: Calculating Primary Data in Practice

Pratik Chatterjee – Tata Steel

James Johnson – Capital+SAFI

Vijay Swarup – Exxon Mobil Cooperation



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# Direct Measurement of Methane Emissions from Enteric Fermentation

James Johnson  
Capital SAFI  
Bolivia

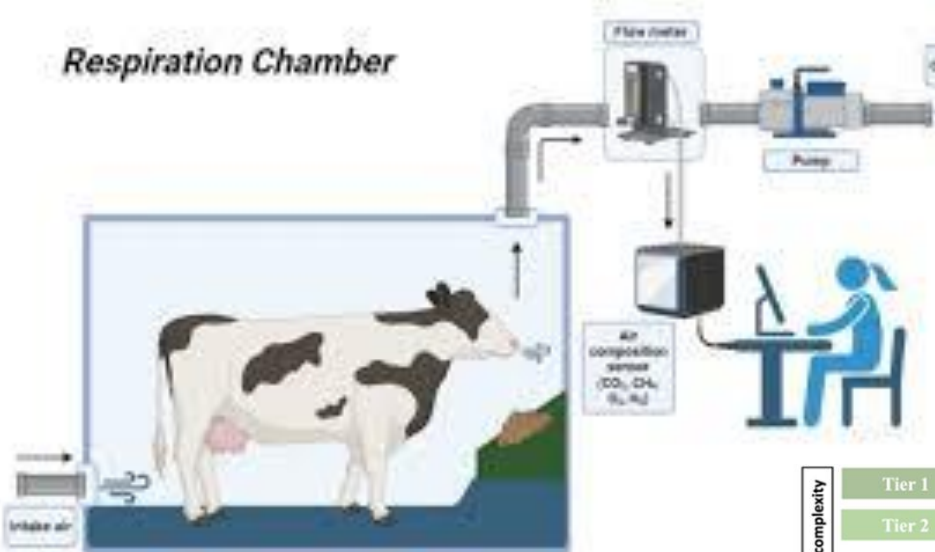


**CAPITAL**

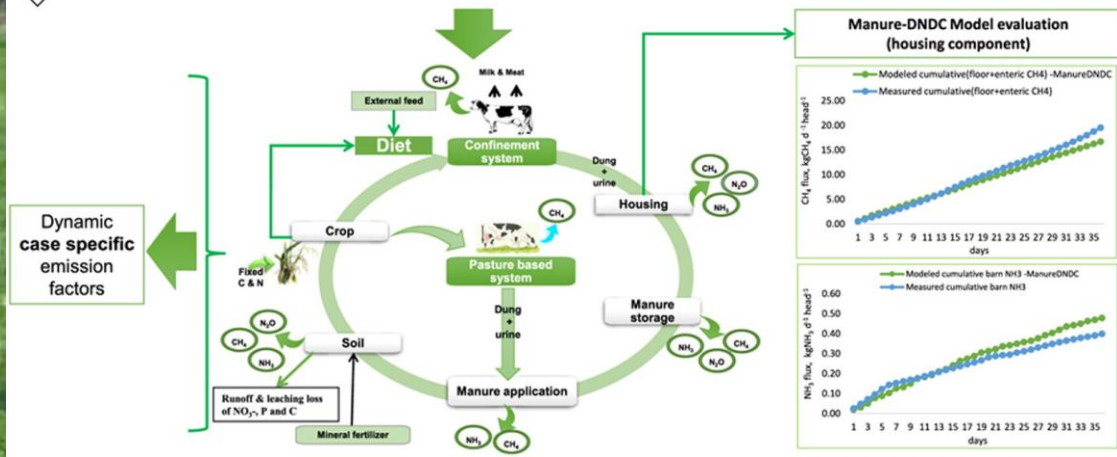
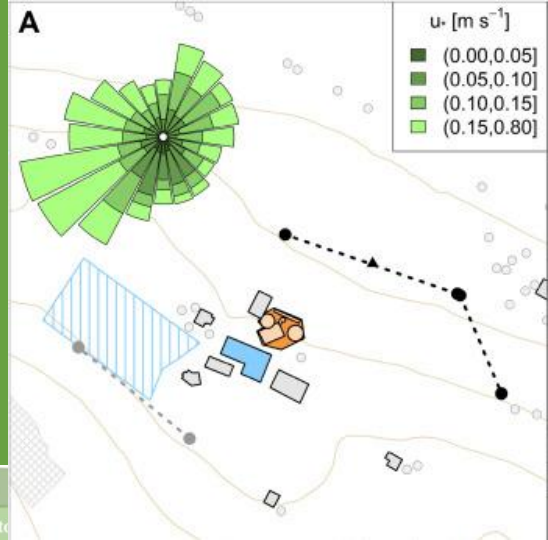
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## Respiration Chamber



## State of the Art







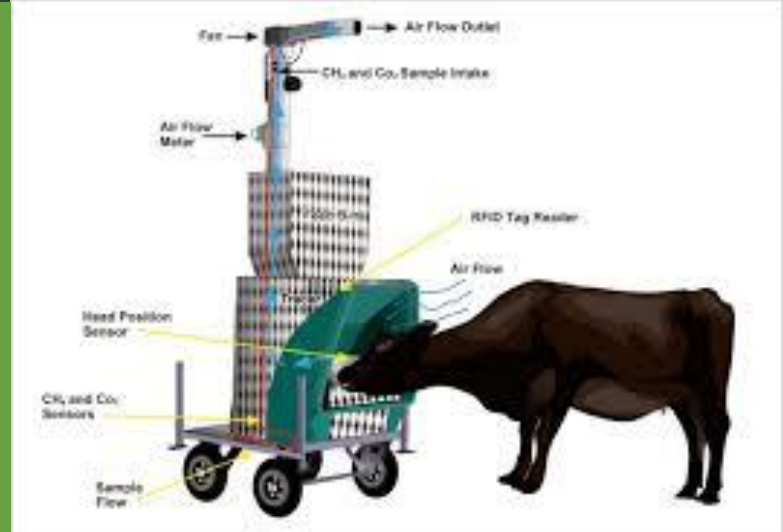
# Challenges







# Unanswered Questions?



## Working Session 4: Computational Principles and Design of a Global Product-Level Primary Data Hub

Abhishek Sankritik – Finternet Labs  
Salil Pradhan – Google X (Alphabet)



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## Working Session 5: Governance Models for the Product-level Emissions Data Hub

Christian Schmieder – Bank for International Settlements (BIS)

Nathan Cole – CDP

Omid Harraf, Stanford Law School, formerly Public Company  
Accounting Oversight Board



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## The potential case for a data hub

- Thoughts for discussion by Christian Schmieder (Bank for International Settlements)
- *Note that the views expressed herein are those of the authors and do not necessarily reflect the views of the Bank for International Settlements (BIS) or its member central banks.*

## The potential case for a data hub: Overarching issues

- **Substance → need conceptual clarity**

- We want a repository of product-level data on emissions
- Key questions:
  - Which data at which aggregation level? (start with modelled data (IO / LCA); later: reporting; direct / indirect emissions)
  - Stepwise approach: start simple, then improve, keep materiality principles in mind

- **Governance → need institutional neutrality**

- Prerequisite: neutrality, transparency, and trust
- → needs support by a broad coalition of international stakeholders

- **Need operational transparency**, to make the hub credible, durable, and globally legitimate



## The “how”? Possible benchmark: NGFS Data Directory 2.0

- Objective from work that started in 2021:
  - Create public centralised repository for relevant data sources (meta data) to enable evidence-based decision to deal with financial stability risks.
  - Need reliable, consistent climate data to assess exposure to associated risks.
  - Key principles: availability, quality and comparability of climate-related data.
- In 2022, the NGFS released the **Data Directory 1.0**, a catalogue of climate-related metrics (~1,200) and datasets (~750).
- Useful start, but need concerted effort to make the repository truly useful
- In 2024 and early 2025, the NGFS developed the **NGFS Data Directory 2.0**: a **collaborative website** where information can be **crowdsourced** and **curated** by a **community of users**.

## The “how”? Possible benchmark: NGFS Data Directory 2.0 (cont)

- Directory v2.0: Tangible project to make the directory operational: A concerted effort by the Bank of France, BIS Innovation Hub, the MAS and NGFS.
  - Three core elements
    - Focus on substance collection (ie input), but no strong objective for standardisation
    - Collaborative approach, anchored in solid “home”
    - Attractive design

## Comparison with NGFS Data Repository

| Dimension                             | NGFS data repository                                                                                                                                                  | Data hub for product-level emissions data                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Purpose                               | Make available meta data (→ help stakeholders to find data)                                                                                                           | <ul style="list-style-type: none"> <li>First step <ul style="list-style-type: none"> <li>Solicit the use of a common concept (→ publish relevant information in an accessible format)</li> <li>Facilitate search of available data (in a preferably structured manner)</li> </ul> </li> <li>Ultimate goal <ul style="list-style-type: none"> <li>Use of agreed common concept</li> <li>Facilitate the generation of new data and publish those in a systematic manner (blockchain system?)</li> </ul> </li> </ul> |
| Governance and operational principles | <ul style="list-style-type: none"> <li>Hosting by a group of public sector institutions</li> <li>Random voluntary contributions (self-governance approach)</li> </ul> | <ul style="list-style-type: none"> <li>Hosting by a representative group of stakeholders</li> <li>Ensure structured contributions and quality control</li> <li>Facilitate growth of data over time, achieve meaningful market coverage (materiality principle)</li> <li>How to create incentives to have inputs?</li> </ul>                                                                                                                                                                                       |
| Funding                               | <ul style="list-style-type: none"> <li>Commitment by the hosts to fund the undertaking</li> </ul>                                                                     | <ul style="list-style-type: none"> <li>Commitment by the hosts to fund the undertaking</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                 |

## Relevant issues to discuss

- What is the purpose of the data? (Is there a commitment to use a carbon ledger?)
  - How to convince stakeholders (companies and authorities) of the concept?
  - Why should firms contribute to and the use the data?
- How to build trust in the data? (Quality control, transparency)
- How to deal with data gaps? (Modelled data at the beginning)
- How to maintain the data? (Infrastructure, ownership)
- How to manage expenses? (Implementation and running costs)

## Closing Remarks and Next Steps

Fabienne Fortanier – De Nederlandsche Bank (DNB)

Karthik Ramanna – Blavatnik School of Government, Oxford University



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