A next-generation toolset for the life-cycle analysis of electricity use

Solutions for Today | Options for Tomorrow

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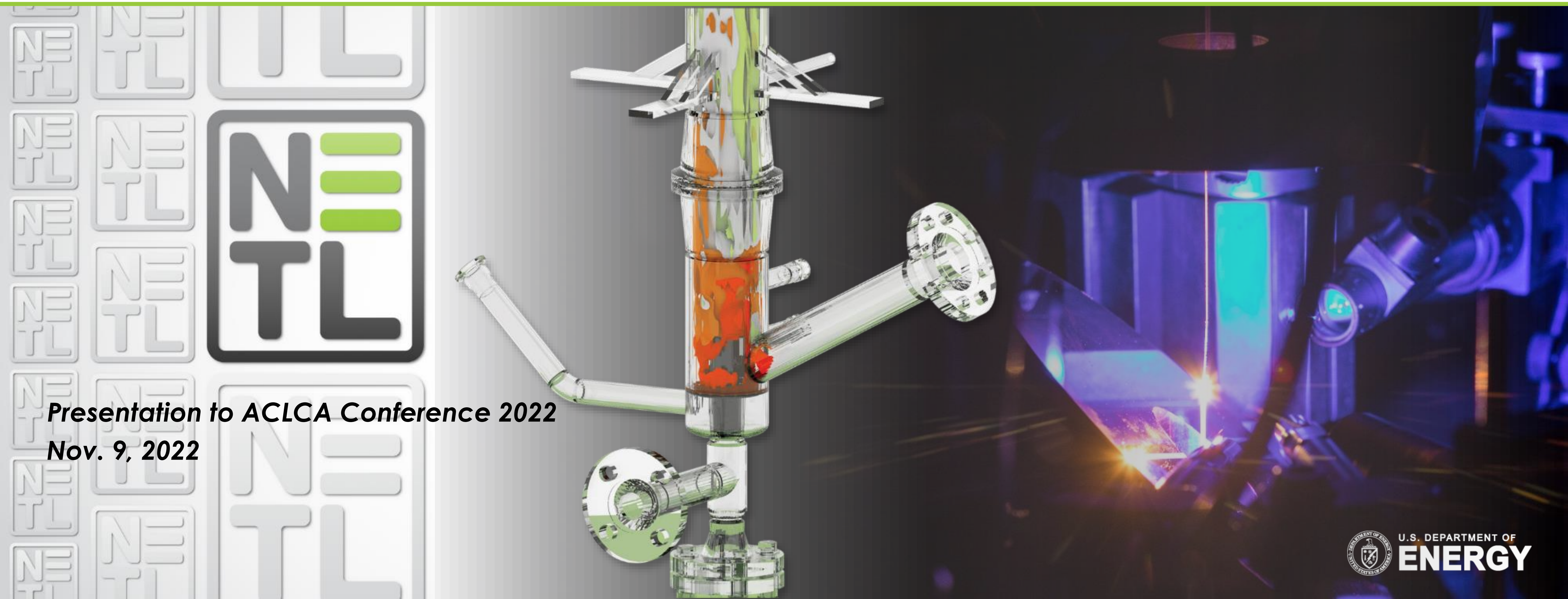

Presentation to ACLCA Conference 2022

Nov. 9, 2022

Motivation

- To demonstrate a diversified and holistic view of electricity generation impacts using cutting-edge methods and sophisticated tools.
- To leverage the power of plant-level life-cycle inventory in evaluating impacts from electricity using spatially-relevant impact assessment such as air quality pollutant exposures and regional water stress.
- To develop a tool for forward-looking evaluations of impacts by allowing users to define generation mixes or plant-level changes in future scenarios.

Background

A Brief (and Incomplete) History

- 2011–2020: Development of the U.S. electricity baseline.
- 2017–2021: Development of the ElectricityLCI Python package.
- 2020: Release of Grid Mix Explorer (v.4.2).
- 2021–2022: Impact assessment Python packages.
- 2022: Scenario modeler and visualization framework toolset.

Background

The Electricity Baseline

- Formatted for the Federal LCA Commons.
- Powered by data science for automated processing.

Goals

- High-quality data for technology evaluation.
- Assessment of regional impacts and benefits.
- Consistent national baseline.

Objectives

- Complete inventory for U.S. power consumption in 2016.
- Open-source data.
- Transparent model approach.
- Coordination with EPA and DOE.

(Cooney et al., 2019; Ingwersen et al., 2017)

Background

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Implementation With Existing Technologies

Life Cycle Assessment Practice

Federal LCA Commons
- JSON-LD and ILCD exports.
- Choose selected region and export full product system to openLCA for connection with rest of system.

https://lcacommons.gov/lca-collaboration/

Energy and Environ. Analysis

Grid Mix Explorer v4.2
- Customized technology mix and inventory.
- Explore inventory and TRACI impacts for selected region.
- Add advanced technologies.

https://netl.doe.gov/LCA

Research and Development

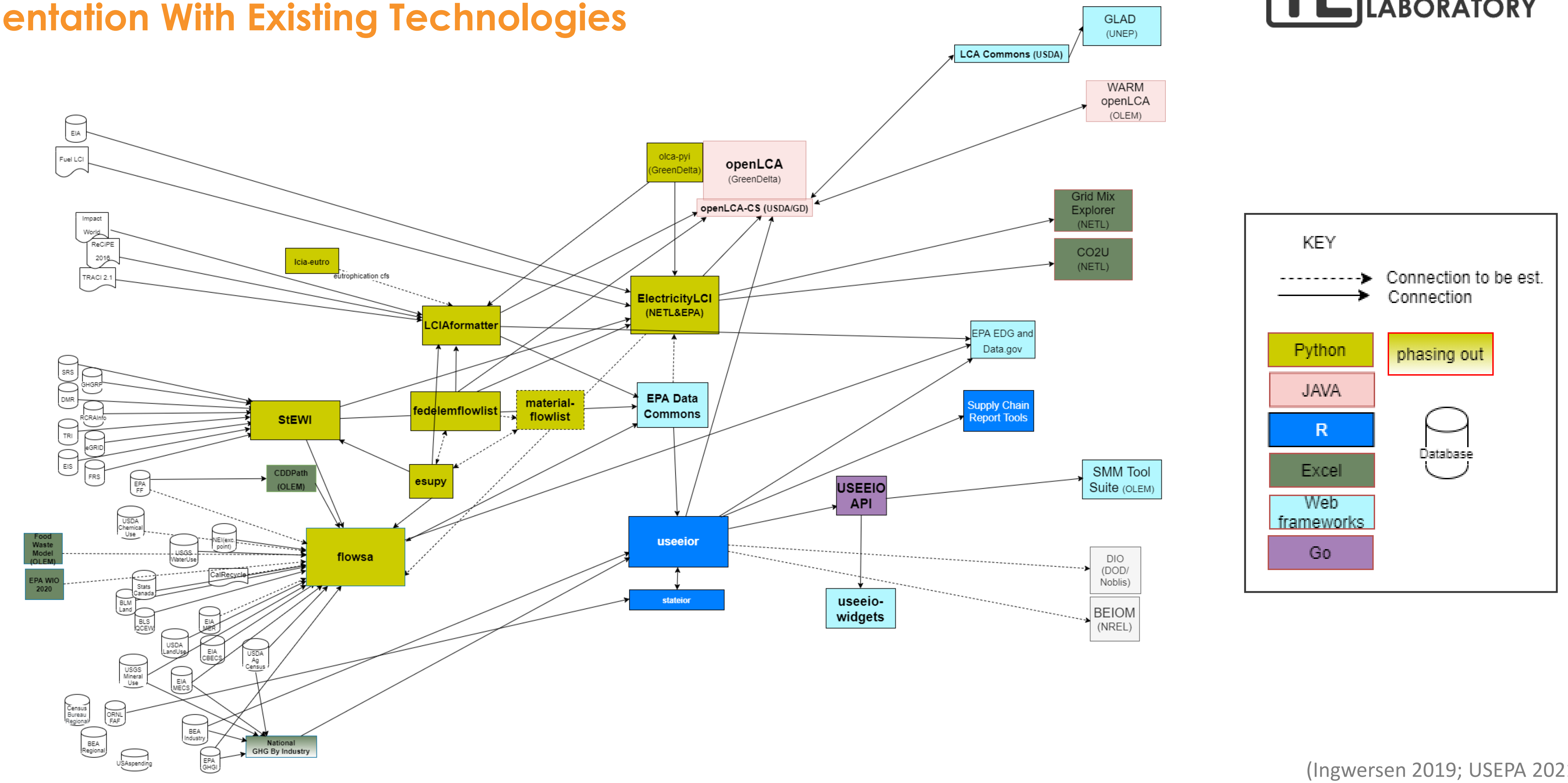
ElectricityLCI
- Complete transparency into inventory development.
- Flexibility to adjust model parameters.
- Integration into other frameworks.

https://github.com/USEPA/ElectricityLCI

(Cooney et al., 2019; Skone 2020)

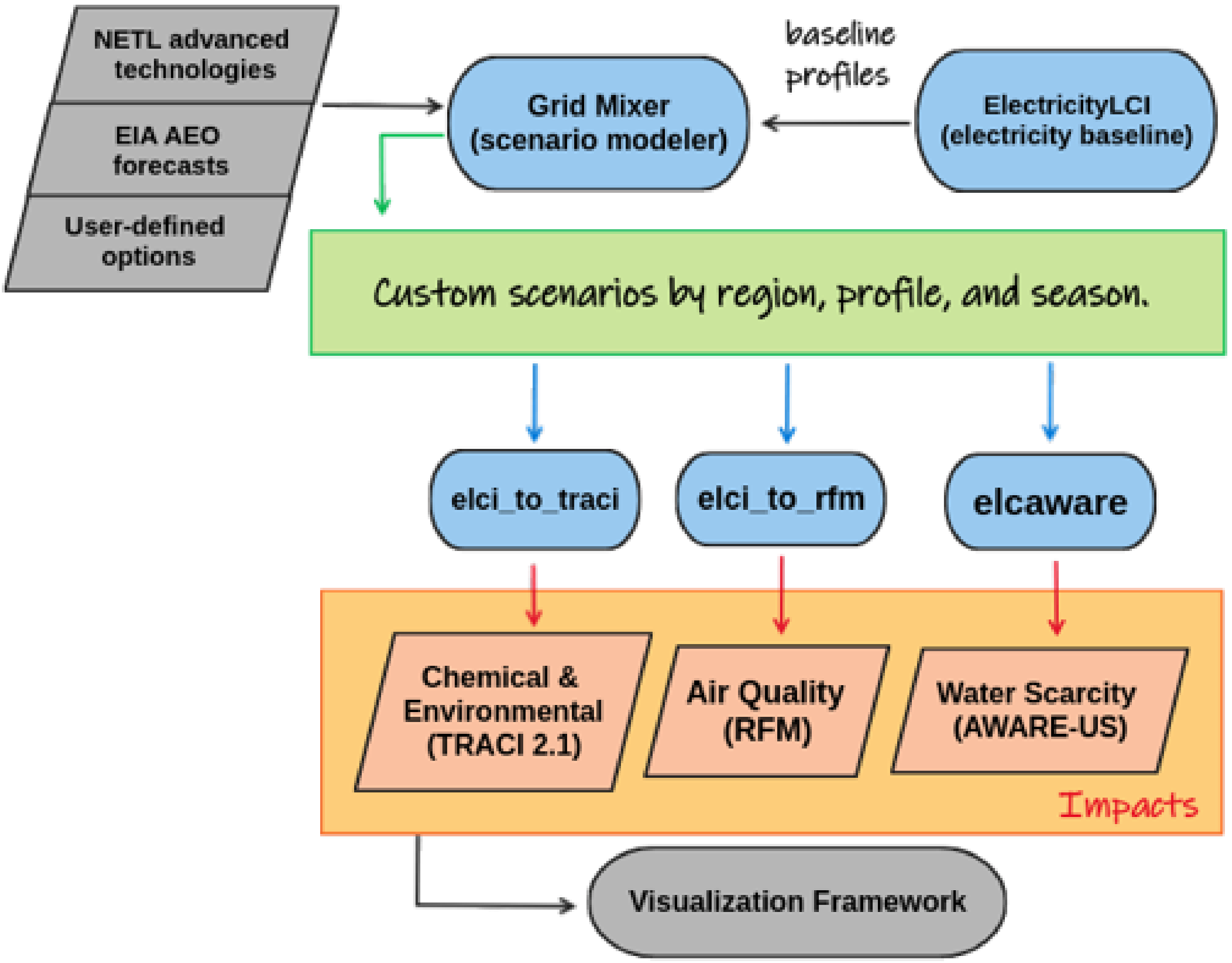
Background

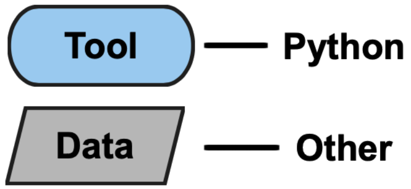
Implementation With Existing Technologies



(Ingwersen 2019; USEPA 2021)

Next-Generation Toolset





Impact Assessment

elci_to_traci → Chemical and environmental impacts.

- TRACI 2.1 (traditional).
- TRACI 2.1 (NETL).

elci_to_rfm → Air quality impacts.

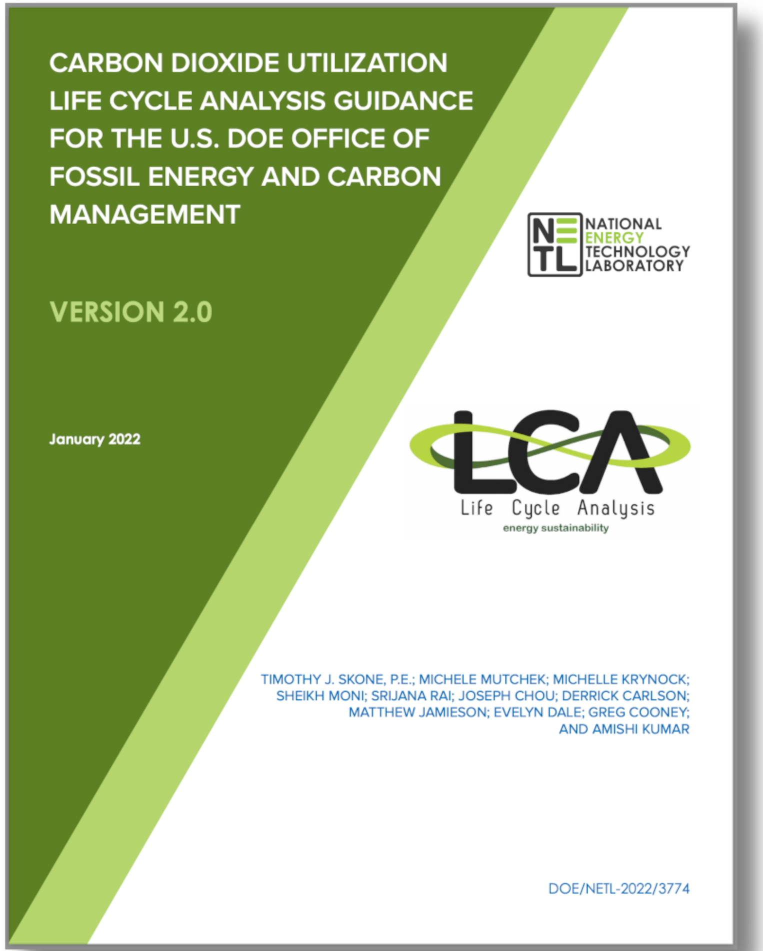
- EASIUR.
- InMAP.
- AP3/AP4.

elcaware → Water scarcity impacts.

- AWARE-US.

Impact Assessment

TRACI 2.1 (NETL)


CARBON DIOXIDE UTILIZATION LIFE CYCLE ANALYSIS GUIDANCE FOR THE U.S. DOE OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT

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VERSION 2.0

January 2022

LCA Life Cycle Analysis energy sustainability

TIMOTHY J. SKONE, P.E.; MICHELE MUTCHEK; MICHELLE KRYNOCK; SHEIKH MONI; SRIJANA RAI; JOSEPH CHOU; DERRICK CARLSON; MATTHEW JAMIESON; EVELYN DALE; GREG COONEY; AND AMISHI KUMAR

DOE/NETL-2022/3774

https://www.osti.gov/biblio/1872564

elci_to_traci

This package provides the assessment method for converting inventory-level data (e.g., from ElectricityLCI) into TRACI 2.1 midpoint impacts (e.g., acidification, eutrophication, particulate matter formation, photochemical smog formation, global warming, and ozone depletion potential) using either traditional or NETL-modified characterization factors as provided by USEPA's Federal LCA Commons Elementary Flow List Python package.

$$I_{k,y} = \sum_j \sum_i c_{i,y} \times e_{i,j,k} \times m_{j,k} \times l_k$$

where:

- I is TRACI impact for region k and factor y
- c is TRACI characterization factor y
- e is emission factor i
- m is mix fraction for fuel technology j
- l is transmission and distribution loss factor

Impact Assessment

Air Quality / Air Pollution Emissions

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InMAP

INTERVENTION MODEL FOR AIR POLLUTION

Health Impacts of Air Pollution: A Tool to Understand the Consequences

Christopher Tessum | Jason Hill | Julian Marshall

Publication: Tessum, C. W.; Hill, J. D.; Marshall, J. D. InMAP: A model for air pollution interventions. *PLoS ONE* **2017**, *12* (4), e0176131 DOI: 10.1371/journal.pone.0176131.

EASIUR: Marginal Social Costs of Emissions in the United States

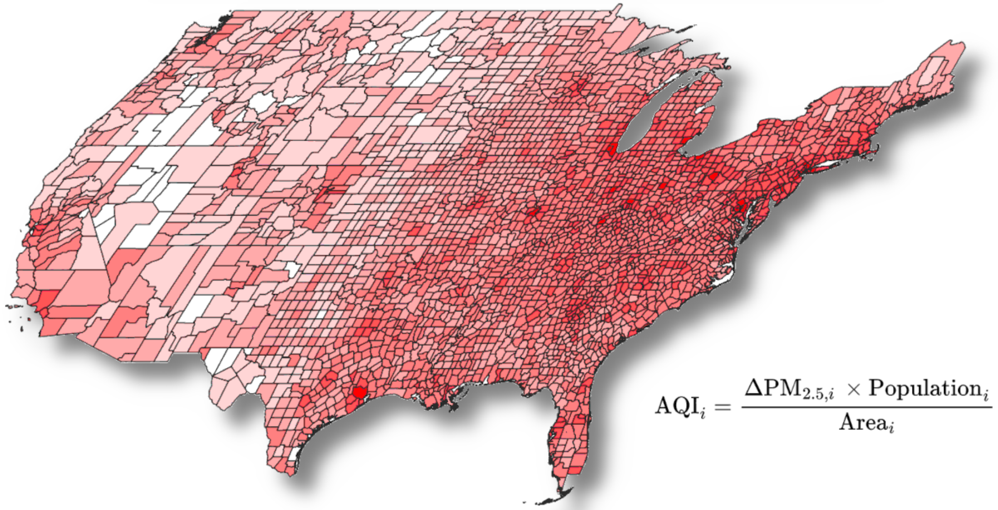
The Estimating Air pollution Social Impact Using Regression (EASIUR) model is an easy-to-use tool estimating the social cost (or public health cost) of emissions in the United States. The EASIUR model was derived using regression on a large dataset created by CAMx, a state-of-the-art chemical transport model. The EASIUR closely reproduce the social costs of emissions predicted by full CAMx simulations but without the high computational costs.

AP3 (AP2, APEEP) Model

The Air Pollution Emission Experiments and Policy analysis (APEEP) model is an integrated assessment model that links emissions of air pollution to exposures, physical effects, and monetary damages in the contiguous United States. The model and its updated version, AP2, have been used in many peer-reviewed publications (see Current CV). A new, updated version of the model (AP3) is now available soon (early 2018).The primary distinctions between the model years are the data in the model: emissions, population, mortality rates, for example.

RFM

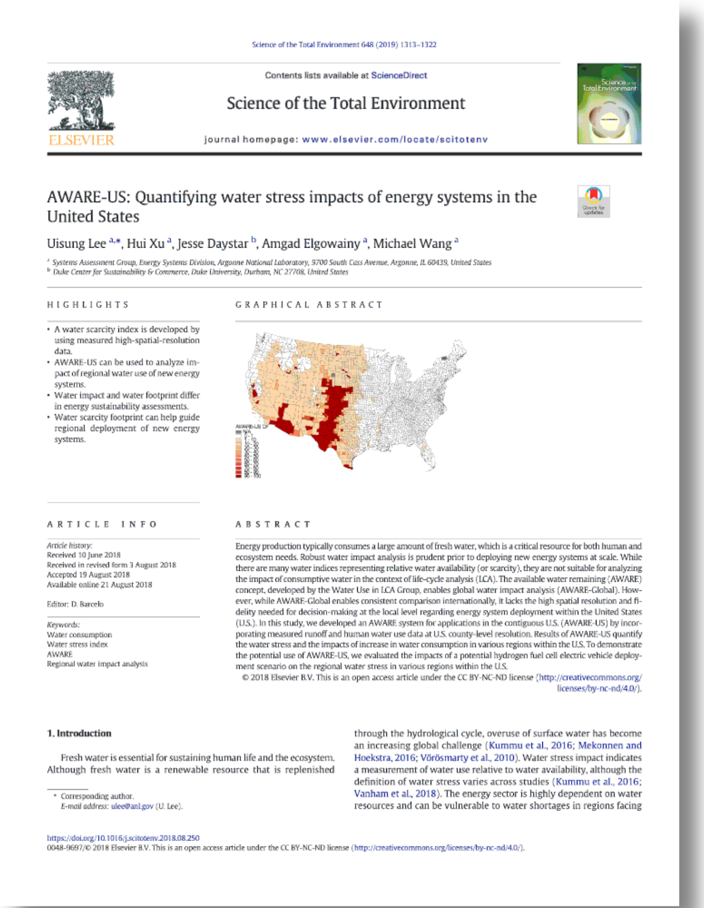
eLCI-to-RFM is an add-on package that converts life cycle emission data to inputs for reduced form air pollution models (RFMs) and runs publicly available RFMs to calculate the particulate matter (PM) impacts associated with electricity generation. Life cycle inventories are generated using the U.S. EPA's electricityLCI. Users can modify the configuration file to generate custom inventories for different geographical sizes or years. Three RFMs are available, including EASIUR, InMAP, and AP3. Impacts are quantified in a population-weighted exposure criterion called the Air Quality Index, defined as the population density of a region multiplied by the concentration of $PM_{2.5}$.



$$\mathrm{AQI}_i = \frac{\Delta \mathrm{PM}_{2.5,i} \times \mathrm{Population}_i}{\mathrm{Area}_i}$$

Impact Assessment

AWARE-US



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journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

AWARE-US: Quantifying water stress impacts of energy systems in the United States

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HIGHLIGHTS

- A water scarcity index is developed by using measured high-spatial-resolution data.
- AWARE-US can be used to analyze impact of regional water use of new energy systems.
- Water impact and water footprint differ in energy sustainability assessments.
- Water scarcity footprint can help guide regional deployment of new energy systems.

GRAPHICAL ABSTRACT

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ABSTRACT

Energy production typically consumes a large amount of fresh water, which is a critical resource for both human and ecosystem needs. Robust water impact analysis is prudent prior to deploying new energy systems at scale. While there are many water indices representing relative water availability (or scarcity), they are not suitable for analyzing the impact of consumptive water in the context of life-cycle analysis (LCA). The available water remaining (AWARE) concept, developed by the Water Use in LCA Group, enables global water impact analysis (AWARE-Global). However, while AWARE-Global enables consistent comparison internationally, it lacks the high spatial resolution and fidelity needed for decision-making at the local level regarding energy system deployment within the United States (U.S.). In this study, we developed an AWARE system for applications in the contiguous U.S. (AWARE-US) by incorporating measured runoff and human water use data at U.S. county-level resolution. Results of AWARE-US quantify the water stress and the impacts of increase in water consumption in various regions within the U.S. To demonstrate the potential use of AWARE-US, we evaluated the impacts of a potential hydrogen fuel cell electric vehicle deployment scenario on the regional water stress in various regions within the U.S.

1. Introduction

Fresh water is essential for sustaining human life and the ecosystem. Although fresh water is a renewable resource that is replenished through the hydrological cycle, overuse of surface water has become an increasing global challenge (Kummu et al., 2016; Mekonnen and Hoekstra, 2016; Vörösmarty et al., 2010). Water stress impact indicates a measurement of water use relative to water availability, although the definition of water stress varies across studies (Kummu et al., 2016; Vanham et al., 2018). The energy sector is highly dependent on water resources and can be vulnerable to water shortages in regions facing

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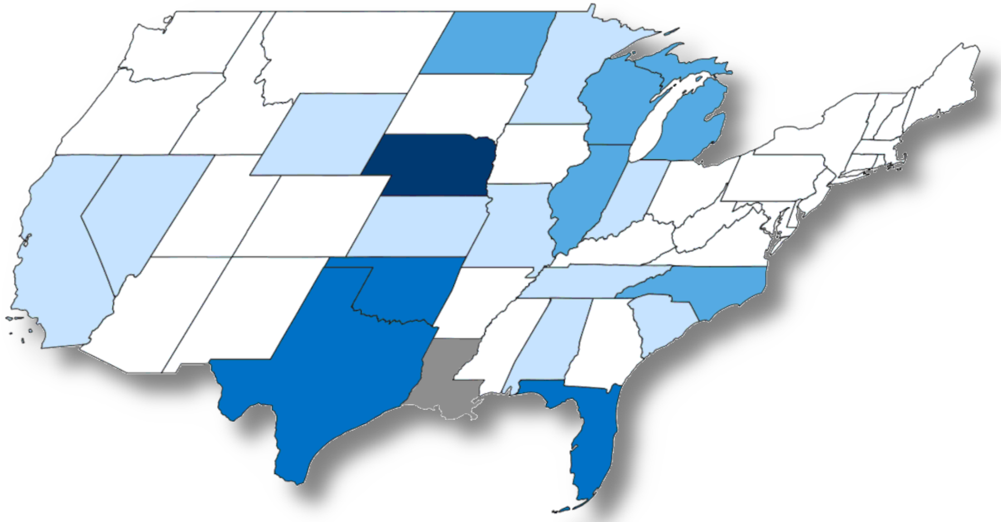
https://doi.org/10.1016/j.scitotenv.2018.08.250

(Lee et al., 2019; NETL 2020)

elcaware

This package converts results from the US electricityLCI to inputs for the U.S. AWARE model, and calculates the life cycle impact of generation on water scarcity at both a county and state level of detail. It is primarily an add-on package that should be used with the electricityLCI.



$$\text{Water Scarcity Footprint } (\mathrm{m}^3)_i = \text{Water consumption } (\mathrm{m}^3)_i \times \mathrm{CF}_i$$


New Capability
NETL advanced technology inventories
Facility level

New Capability – Example 1

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How does a sample combined-cycle natural gas power plant (from eLCI) compare with the same plant using NETL's advanced technology inventory?

Indicator*	NGCC (eLCI)	NGCC (NETL)	Units
Acidification Potential	2.11	0.417	kg SO_2 eq/MWh
Eutrophication Potential	0.145	0.0284	kg N eq/MWh
Global Warming Potential (AR5, 100-yr)	768	467	kg CO_2 eq/MWh
Particulate Matter Formation Potential	3.33e–2	5.49e–3	PM 2.5 eq/MWh
Ozone Depletion Potential	1.09e–6	3.86e–9	kg CFC-11 eq/MWh
Photochemical Smog Formation Potential	73.8	14.6	kg O_3 eq/MWh

*Indicators are based on NETL-modified TRACI 2.1 characterization factors.


New Capability
NETL advanced technology inventories
Aggregate level

New Capability – Example 2

Overview – PowerSouth Energy Cooperative (Alabama and Florida, USA)

Region Code	Name	Primary Fuel	Electricity (MWh)
AEC	PowerSouth Energy Cooperative	Various	5,644,564
53	Gantt	Hydro-electric	5,718
55	Point A	Hydro-electric	14,113
56	Charles R. Lowman	Coal	1,470,743
533	McWilliams	Natural gas	3,816,551
7063	McIntosh	Natural gas	308,865
56522	Springhill Gas Recovery Plant	Biomass	28,573

New Capability – Example 2

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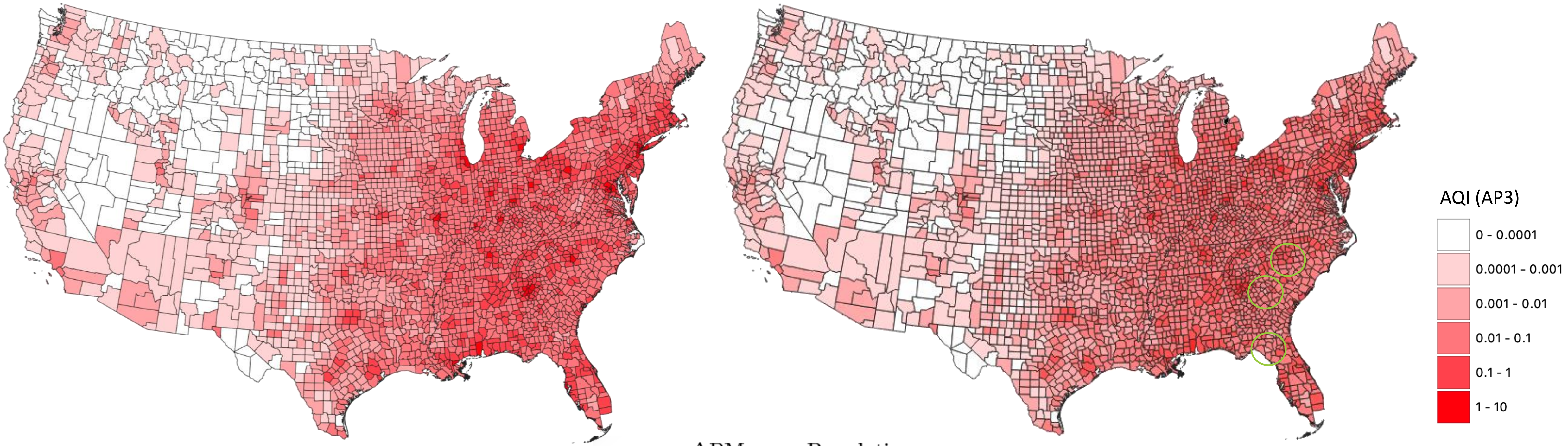
Are there impact-based incentives to implementing capture at the McWilliams and McIntosh natural gas power plants using natural gas combined cycle technology as a proxy?



Base scenario

$$AQI_i = \frac{\Delta PM_{2.5,i} \times Population_i}{Area_i}$$

NGCC w/ CCS

New Capability
Forecasting regional profiles

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U.S. DEPARTMENT OF ENERGY

New Capability – Example 3

What is the AEO outlook for the SERC Reliability Corporation Southeastern electricity market module region for the year 2050?

Fuel	Reference 2022	Low oil and gas supply	Low renewable cost	Low growth
Hydro	0.0329	0.0336	0.0309	0.0354
Coal	0.0736	0.2031	0.0556	0.0785
Biomass	0.0044	0.0046	0.0044	0.0047
Natural gas	0.3934	0.1810	0.3943	0.3701
Nuclear	0.2047	0.2156	0.1035	0.2192
Petroleum	0.0003	0.0008	0.0002	0.0003
Solar	0.2827	0.3627	0.4126	0.2844
Wind	0.0001	0.0004	0.0004	0.0001

New Capability – Example 3

Implementation Challenges of AEO Forecast Profiles

- National Energy Modeling System (NEMS) electricity market module regions (EMMRs) are based on eGRID subregions that differ from eLCI balancing authority areas (BAAs) and requires some modeling choices:
  - EMMR mixes are apportioned among contained BAAs or, in some cases, combined to represent larger BAAs.
  - Regions without technologies that are not currently expected to deploy (e.g., nuclear and coal) do not add those technologies. Shares in the mix of those technology are accounted for by increasing the share in the BAAs that do have them.
  - Solar and wind can be added using regionally similar profiles as proxies.
  - Consumption mixes are held constant because trading between BAAs cannot be predicted.
- This is a work in progress – next steps are to develop the algorithms to implement the AEO mixes.

Future Work

- Develop algorithms for implementing AEO forecast profiles.
- Improve customization to include temporal-scale analysis.
- Implement additional geospatial processes in the model (e.g., nearest neighbor and spatial interpolation methods for undefined regional profiles).
- Expand impact assessments (e.g., Environmental Justice40).
- Incorporate the latest Canadian profiles (i.e., assess the North American electricity profile).
- Consider both electricity generation and consumption profiles.
- Provide life cycle assessments at the stage level.
- Design and build the web-based visualization framework.

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