Sustainability Analysis: Hydrogen Regional Sustainability (HyReS)

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Project ID SA059

NREL/PR-5400-71334

Overview

Timeline

Start: September, 2015

End: September, 2018

80% complete

Barriers

4.5 A. Future Market Behavior

- Consumer preferences for green hydrogen

4.5 B. Stove-piped/Siloed Analytical Capability

- Integration of metrics from internal (DOE) and external models

4.5 D. Insufficient Suite of Models and Tools

- More complete analytics across all aspects of sustainability

Budget

Total Project Funding: $500k

- FY15: $200K
- FY16: $200k
- FY17: $100k

Total DOE funds received to date: $500k

Partners

Argonne National Laboratory (GREET)

Collaborative Reviewers

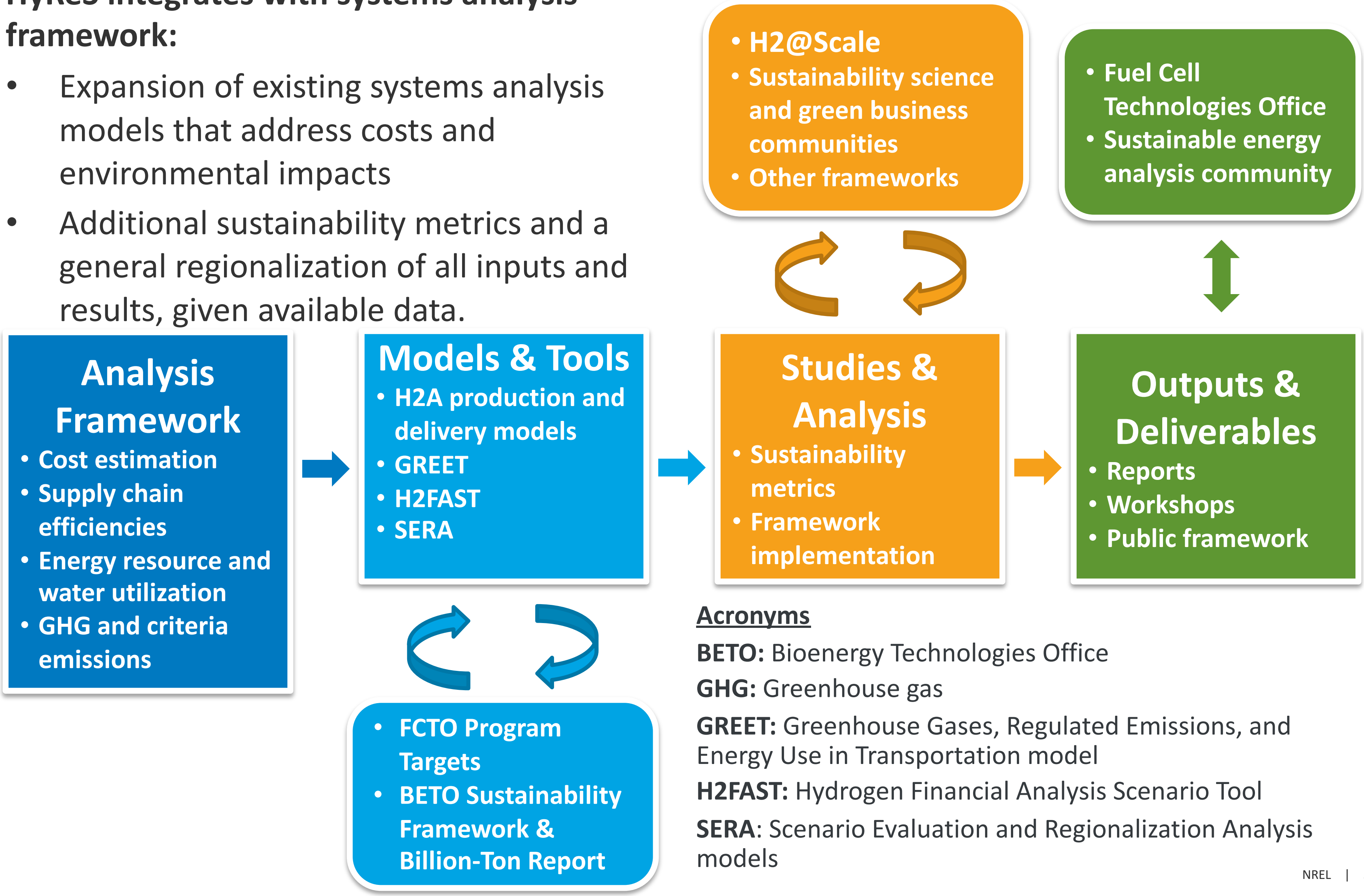
- Ford
- Louis Berger
- E4Tech
- LBST (Ludwig-Bölkow-Systemtechnik)

FCTO Systems Analysis Framework

Relevance 1

HyReS integrates with systems analysis framework:

- Expansion of existing systems analysis models that address costs and environmental impacts
- Additional sustainability metrics and a general regionalization of all inputs and results, given available data.



Analysis Framework

- Cost estimation
- Supply chain efficiencies
- Energy resource and water utilization
- GHG and criteria emissions

Models & Tools

- H2A production and delivery models
- GREET
- H2FAST
- SERA

- FCTO Program Targets
- BETO Sustainability Framework & Billion-Ton Report

Studies & Analysis

- Sustainability metrics
- Framework implementation

- H2@Scale
- Sustainability science and green business communities
- Other frameworks

Outputs & Deliverables

- Reports
- Workshops
- Public framework

- Fuel Cell Technologies Office
- Sustainable energy analysis community

Acronyms

BETO: Bioenergy Technologies Office

GHG: Greenhouse gas

GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model

H2FAST: Hydrogen Financial Analysis Scenario Tool

SERA: Scenario Evaluation and Regionalization Analysis models

HyReS Objectives

Relevance 2

Overall Objectives:

- To provide industry, government, and non-government ***stakeholders*** with readily accessible and transparent analytic tools needed to make ***informed investments*** with respect to hydrogen supply, fuel cell systems, and ***sustainable development***
- To examine ***environmental*** burdens in an integrated regional assessment approach that also takes into account the ***economic*** and ***social*** aspects of hydrogen supply chains and the FCEV life cycle

FY18 Objectives:

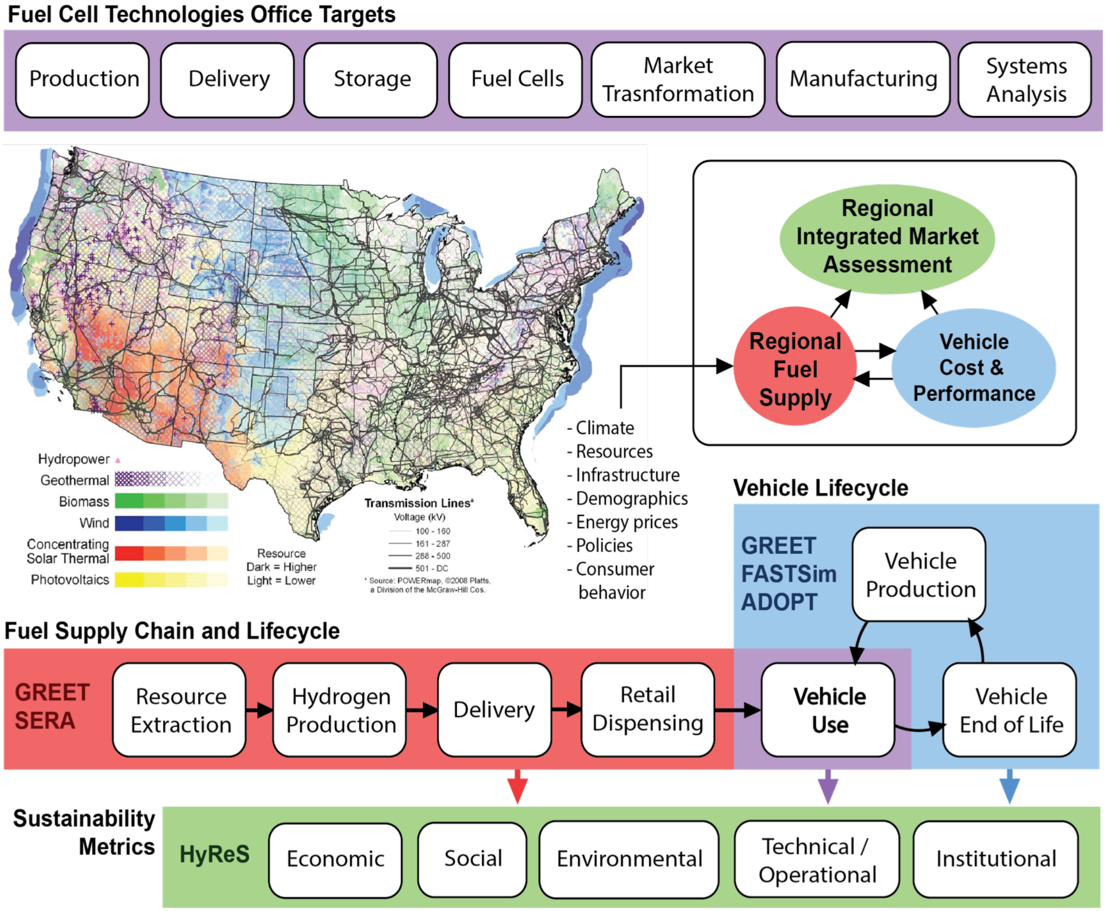
- Model various future ***scenarios*** of hydrogen infrastructure build-out based on uncertain ***political, technological, and economic*** conditions
- Develop and publish online ***visualization tool*** of scenario results

The Hydrogen Regional Sustainability (HyReS) framework will integrate existing sustainability metrics and indicators to examine environmental, economic and social impacts of hydrogen supply chains and FCEVs

Modeling Approach Builds on SERA Framework

Approach 1

- The ***Scenario Evaluation and Regionalization Analysis*** (SERA) modeling framework develops optimized hydrogen supply networks in response to hydrogen demands
- Spatially explicit: accounts for the geography of resource availability, supply chain costs, and HyReS will include supply chain sustainability
- Identifies optimal supply chain configuration (least-cost or most-sustainable) options both temporally and regionally



Fuel Cell Technologies Office Targets

Production | Delivery | Storage | Fuel Cells | Market Trasnformation | Manufacturing | Systems Analysis

- Climate
- Resources
- Infrastructure
- Demographics
- Energy prices
- Policies
- Consumer behavior

Regional Integrated Market Assessment

Regional Fuel Supply

Vehicle Cost & Performance

Vehicle Lifecycle

GREET
FASTSim
ADOPT

Vehicle Production

Fuel Supply Chain and Lifecycle

GREET
SERA

Resource Extraction → Hydrogen Production → Delivery → Retail Dispensing → **Vehicle Use** → Vehicle End of Life

Sustainability Metrics

HyReS

Economic | Social | Environmental | Technical / Operational | Institutional

The HyReS/SERA framework will identify optimal hydrogen supply chains considering spatially- and temporally-based constraints and aspects of sustainability

Metrics for Comparison of Alternative Hydrogen Supply Pathways

Approach 2

The HyReS framework will track information related to selected sustainability indicators, maintaining compatibility with existing frameworks to guide a broad range of decision makers

- Business perspective: focus on issues that are ***material*** to the company's long-term value
  - System energy efficiency
  - Water management
  - Emissions
- Government perspective:
  - Energy security
  - Resource conservation
  - Human health
  - Cost to consumers

Framework Alignment

Sustainability Accounting Standards Board (SASB) – material sustainability metrics

Global Reporting Initiative (GRI) – comprehensive sustainability reporting standards

MSCI – ESG factors related to UN Principles for Responsible Investment

ENVISION – certification for sustainable infrastructure

Natural Capital Coalition – protocol for business managers and decision makers

Bioenergy Technologies Office (BETO) sustainability program (social, economic, environmental)

Modeling Approach Leverages GREET2017 and FASTSim Models

Approach 3

Feedstocks	Delivery	Outputs
Natural Gas	Gaseous or Liquid	Energy Consumption
Coal	Tube Trailer	Water Consumption
Nuclear	Pipeline	Emissions
Solar	Barge	
Biomass	Rail	
⋮		

Vehicle Cycle GREET2

Material recovery and production

Vehicle component fabrication

Vehicle Assembly

Vehicle Operation: PTW

Vehicle Disposal and Recycling

FASTSim is used to model future vehicles with comparable driving ranges (400 miles) and, when possible, acceleration.

Inputs to GREET include vehicle weight, battery size, and fuel economy.

Fuel Cycle GREET1

Feedstock Production & Transportation — **Fuel Production & Transportation** —

Well-to-Pump (WTP)

Incorporating GREET 2017 data:

- Updated water consumption factors
- Updated the emission factors of criteria air pollutant (combustion and non-combustion emissions) for SMR hydrogen
- Updated U.S. electricity generation mix

The HyReS analysis combines GREET environmental impacts with FASTSim modeling of future vehicle attributes

Health Impact Assessment with EASIUR

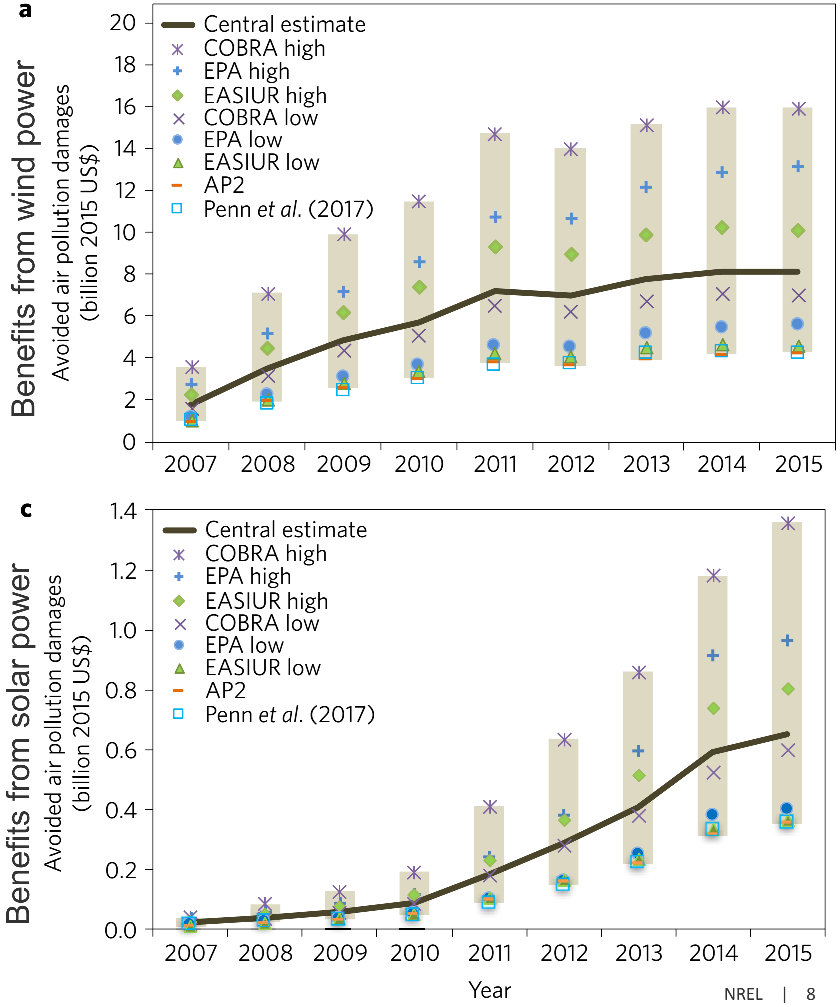
Approach 4

The HyReS framework will assess social sustainability, such as health benefits from changes in air pollutants using existing tools

As opposed to BenMAP or COBRA, the Estimating Air pollution Social Impact Using Regression (EASIUR) *(Carnegie Mellon, 2016)* model will be used for monetizing health benefits from changes in air pollution emissions

- More straightforward integration with SERA/HyReS model
- Chemical transport model as opposed to Gaussian dispersion model
- Marginal benefits calculations similar to EPA models (see figure)
- Applied to GREET emissions factors by year

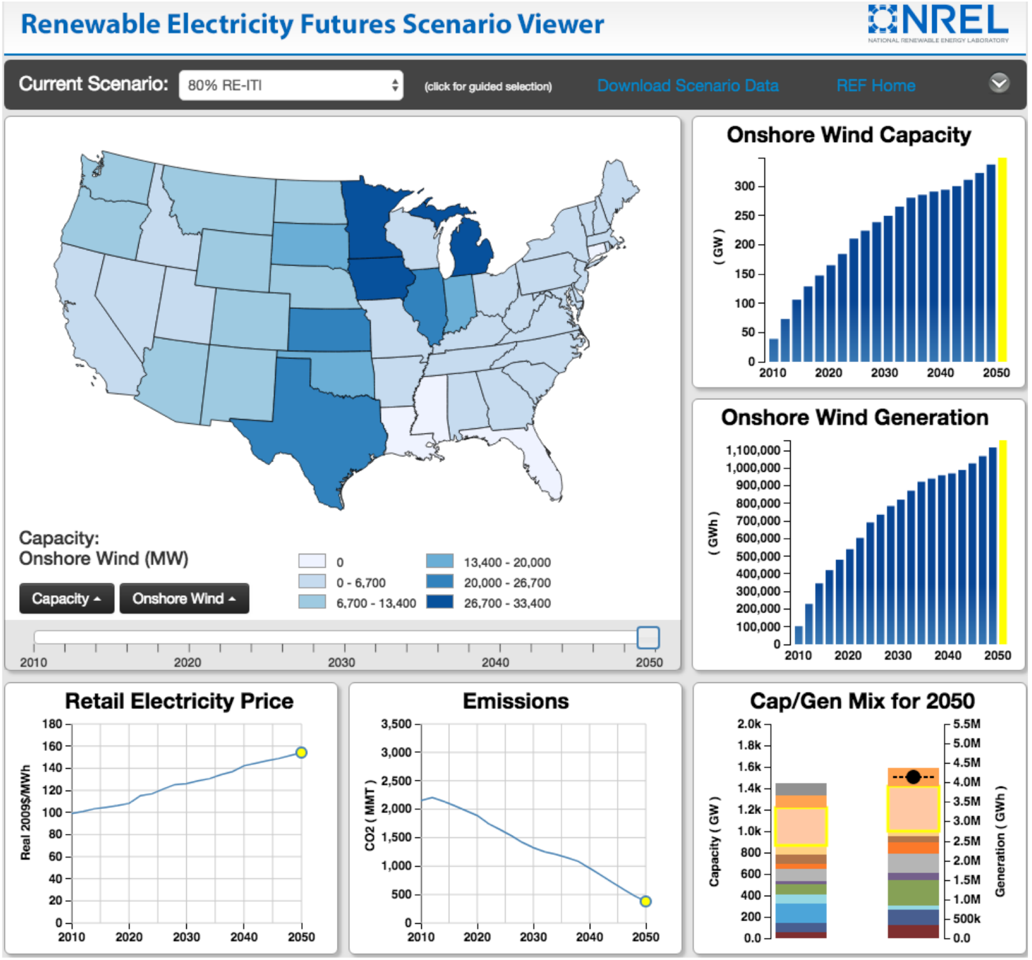
Reprinted by permission from Springer: Nature Energy, "The Climate and Air-Quality Benefits of Wind and Solar Power in the United States, "Millstein, D., R. Wiser, M. Bolinger, and G. Barbose. 2017 https://doi.org/10.1038/nenergy.2017.134.



Scenario and Sensitivity Analysis

Approach 5

The HyReS framework will consider a number of scenarios related to political, technological, and economic conditions



Renewable Electricity Futures Scenario Viewer

Current Scenario: 80% RE-ITI

Source: NREL - https://www.nrel.gov/analysis/re_futures/data_viewer/

Scenarios varying based on:

- Future grid mix –
  - GREET /EIA projections
  - NREL Renewable Electricity Futures Study
- H2@Scale and H2USA demand scenarios
- FCTO program goals
  - Electrolyzer efficiency
  - Biomass gasification efficiency

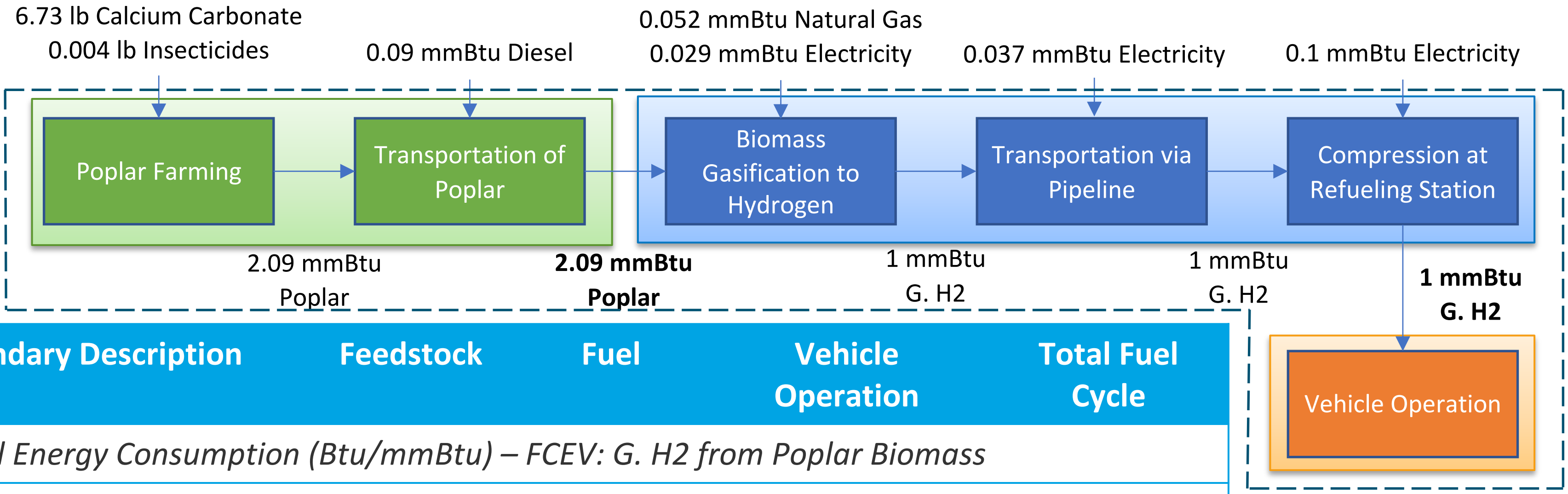
Modified GREET System Boundaries for Energy Accounting

Accomplishments 1

Example: Hydrogen from Poplar
Pathway is adjusted so that the poplar biomass is not counted as part of the fuel cycle energy use

COORDINATING MODIFICATIONS WITH AMGAD ELGOWAINY (ANL, GREET)

Feedstock
Fuel } WTP
Vehicle Operation - PTW } Fuel Cycle



0.035 mmBtu Diesel
0.56 lb Nitrogen
0.17 lb Phosphoric Acid
0.15 lb Potassium Oxide
0.02 lb Herbicides
6.73 lb Calcium Carbonate
0.004 lb Insecticides
→ Poplar Farming

0.09 mmBtu Diesel
→ Transportation of Poplar

0.052 mmBtu Natural Gas
0.029 mmBtu Electricity
→ Biomass Gasification to Hydrogen

0.037 mmBtu Electricity
→ Transportation via Pipeline

0.1 mmBtu Electricity
→ Compression at Refueling Station

→ Vehicle Operation

2.09 mmBtu Poplar

2.09 mmBtu Poplar

1 mmBtu G. H2

1 mmBtu G. H2

1 mmBtu G. H2

Boundary Description	Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle
Total Energy Consumption (Btu/mmBtu) – FCEV: G. H2 from Poplar Biomass				
GREET Default (Solid Background Blocks)	41,000	1,557,000	1,000,000	2,598,000
Adjusted (Dotted Line)	41,000	424,000	0	465,000

System boundaries adjusted to: (1) avoid double counting between WTP and PTW stages; (2) consider biomass as being generated and used within the system

Modeled 400-Mile Range Vehicles in FASTSim

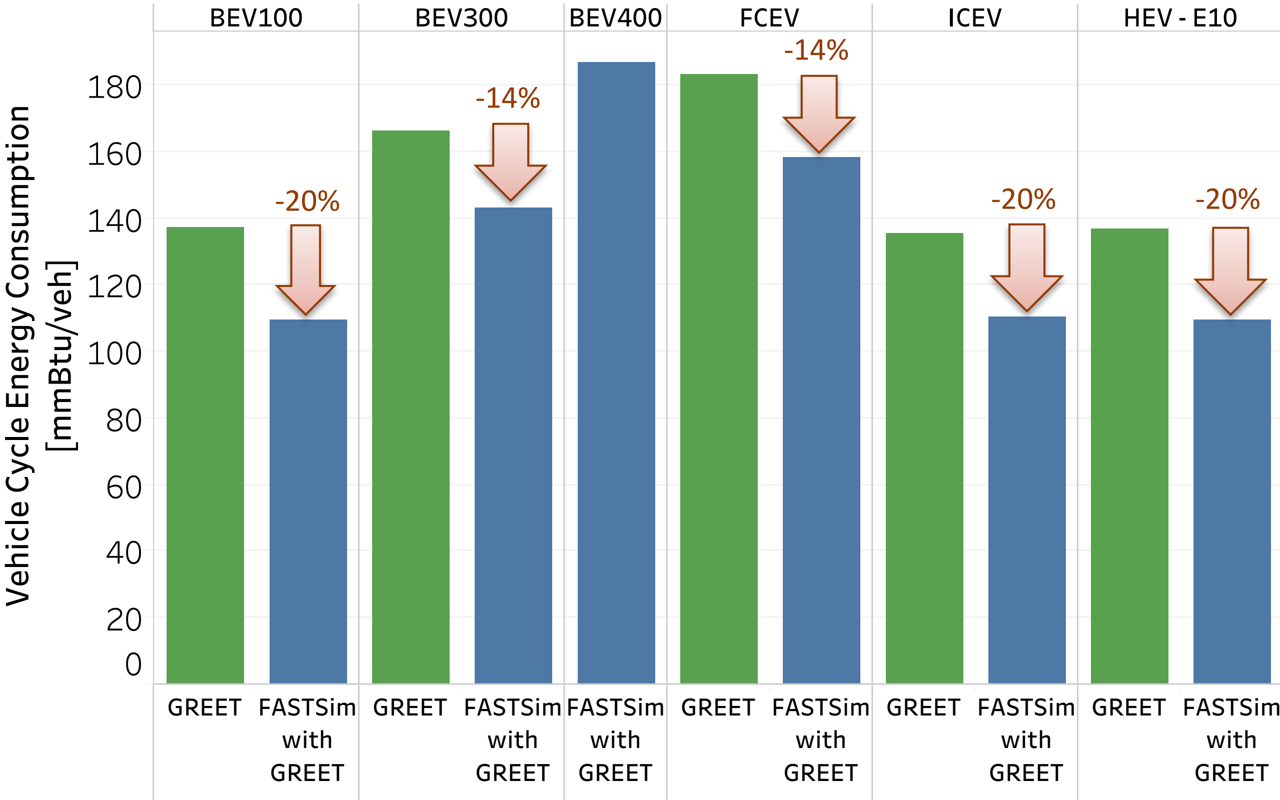
Vehicle Cycle Results

Accomplishments 2

FASTSim-modeled vehicles tend to have lower vehicle cycle energy impacts than the GREET lightweight default vehicles

FASTSim was used to model vehicle specifications for MY2025 vehicles with a 400-mile range

- Adjustments to existing vehicles made with respect to vehicle weight and fuel storage to result in 400-mile range
- GPRA targets used to adjust glider weight, motor power, and battery energy density for MY2025 vehicles
- Resulting vehicles lighter than GREET vehicles and thus have lower vehicle cycle impacts
- BEV400 is not modeled by GREET; BEV400 vehicle cycle energy intensity is 13% higher than GREET BEV300



		BEV100	BEV300	BEV400	FCEV	ICEV	HEV - E10
Total Vehicle Weight (lbs)	GREET	2700	3500		2900	2700	2800
	FASTSim	2100	2900	3700	2400	2100	2100
Fuel Economy (mpgge)	GREET	140	120		80	40	60
	FASTSim	140	120	110	80	50	50

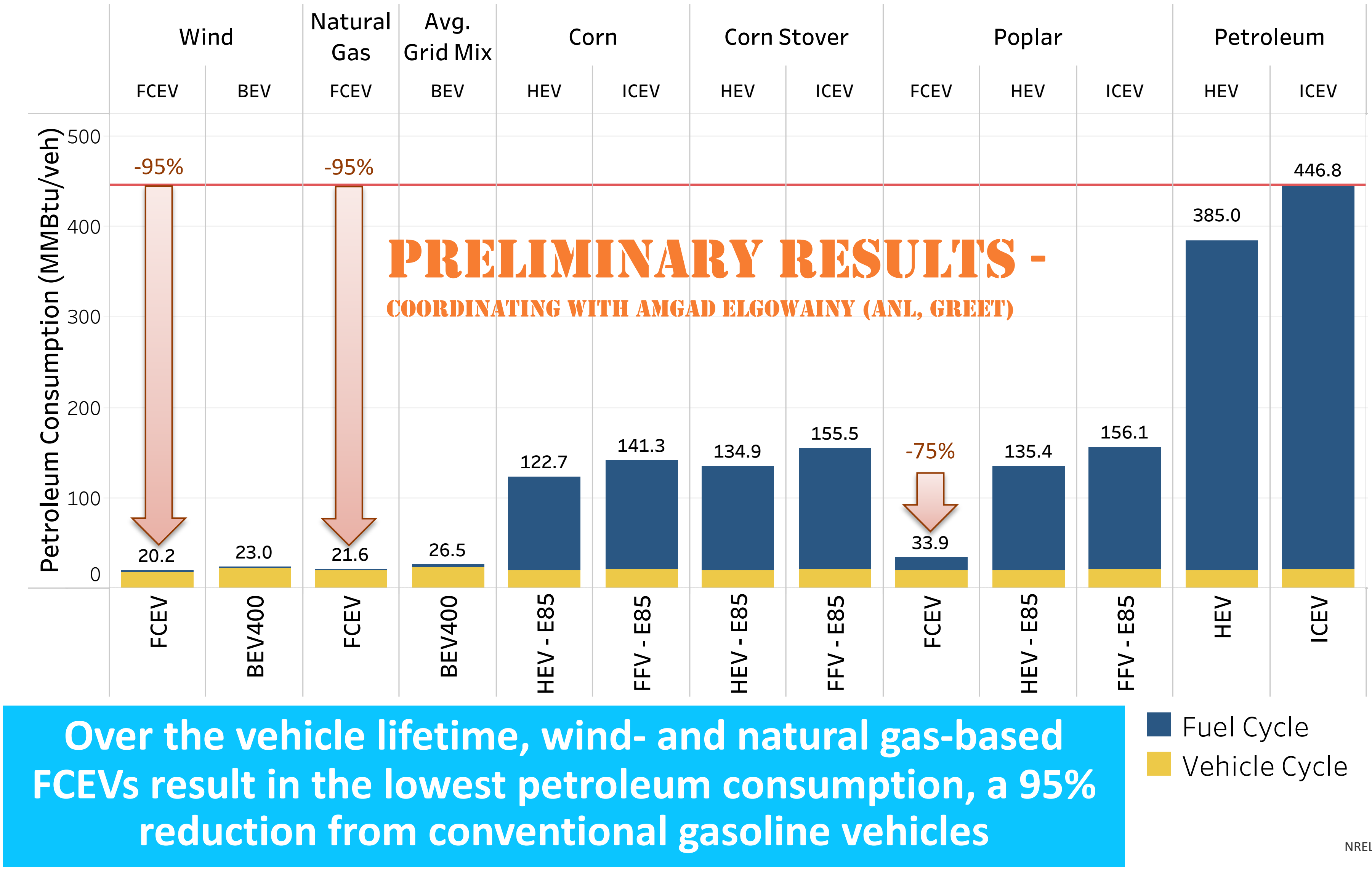
BEVs, FCEVs, and HEVs shown above are assumed to have li-ion batteries

Analyzed Life Cycle Petroleum Consumption of FASTSim-Based Vehicles

Accomplishments 3

Life Cycle Petroleum Consumption

per vehicle lifetime



PRELIMINARY RESULTS -

COORDINATING WITH AMGAD ELGOWAINY (ANL, GREET)

Over the vehicle lifetime, wind- and natural gas-based FCEVs result in the lowest petroleum consumption, a 95% reduction from conventional gasoline vehicles

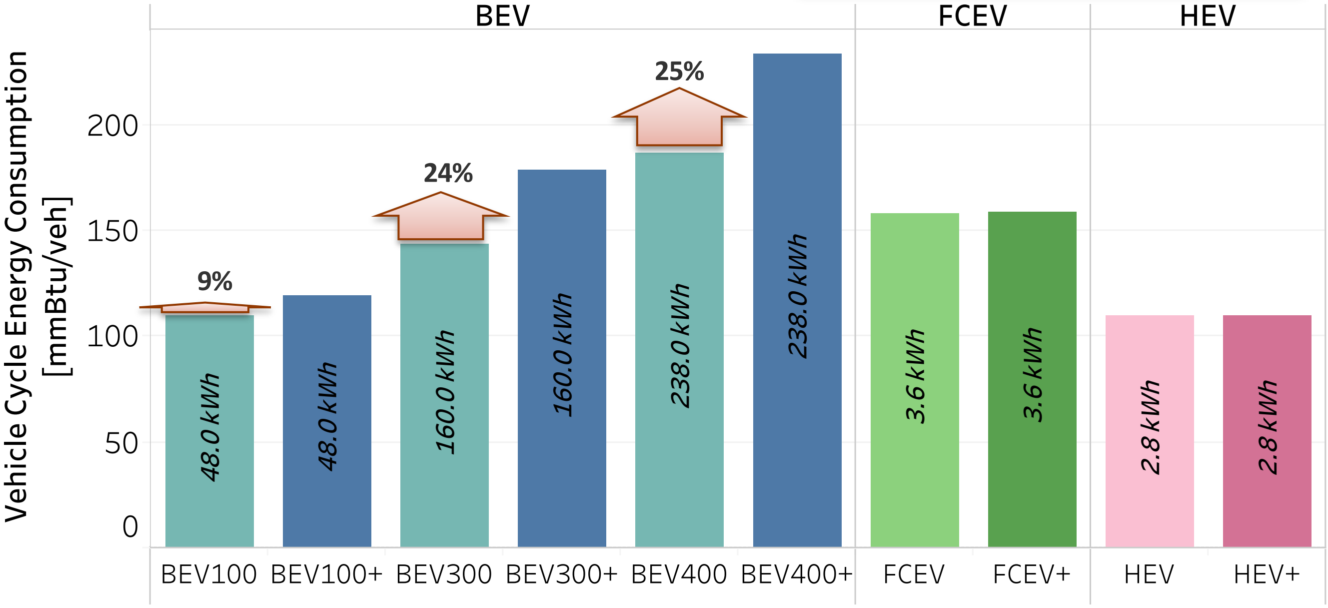
Revised Energy Intensity of Li-Ion Batteries

Accomplishments 4

Peters and Weil (2018) review the existing literature on the LCA of Li-Ion batteries (LIBs), unifying assumptions across studies.

HyReS analysis considers both GREET default values and higher energy intensity of LIB manufacturing.

	Electricity for LIB manufacturing (kWh/kg)	Heat for LIB manufacturing (MJ/kg)
Peters and Weil (2018) unified assumptions	9.0	20.0
GREET2017 default assumptions	1.1	18.7



Due to large LIB size, BEV400 vehicle cycle energy intensity increases by 25% using unified manufacturing assumptions

Considering FCEVs and HEVs with LIBs based on reviewer feedback

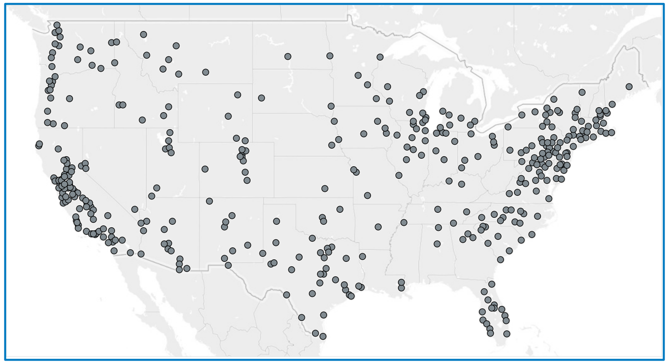
Reference: Peters, Jens F., and Marcel Weil. 2018. “Providing a Common Base for Life Cycle Assessments of Li-Ion Batteries.” *Journal of Cleaner Production* 171 (Supplement C): 704–13. https://doi.org/10.1016/j.jclepro.2017.10.016.

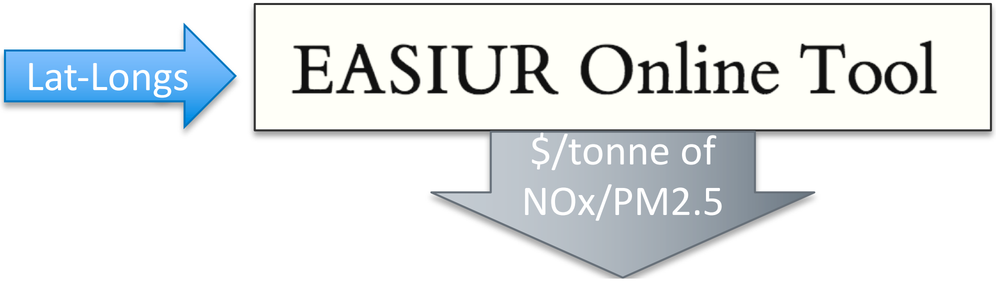
Integrated EASIUR into HyReS Framework

Accomplishments 5

Extracted marginal benefits of reducing NOx and PM2.5 emissions from EASIUR *(Carnegie Mellon, 2016)* for network of over 600 nodes used in SERA

Urban area network based on H2USA LDV demand for hydrogen and existing electrolysis, SMR, and nuclear facilities (H2@Scale)





Lat-Longs

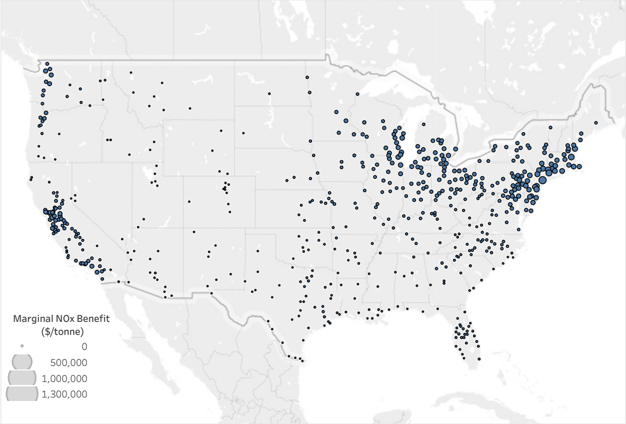
EASIUR Online Tool

$/tonne of NOx/PM2.5

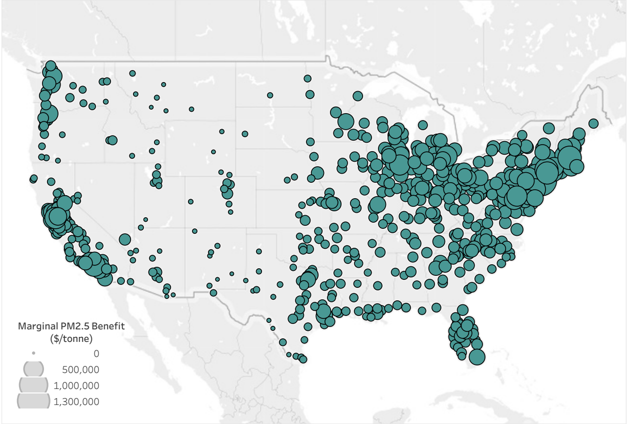
	NOx	PM2.5
Minimum Marginal Benefit (2010$/tonne & location)	$654 Alamogordo, NM	$18,477 Roswell, NM
Maximum Marginal Benefit (2010$/tonne & location)	$205,866 New York, NY	$1,250,410 New York, NY

Areas with higher population density have greater marginal benefits from air pollution reductions; PM2.5 marginal benefits are greater than those for NOx

NOx Marginal Benefits



PM2.5 Marginal Benefits



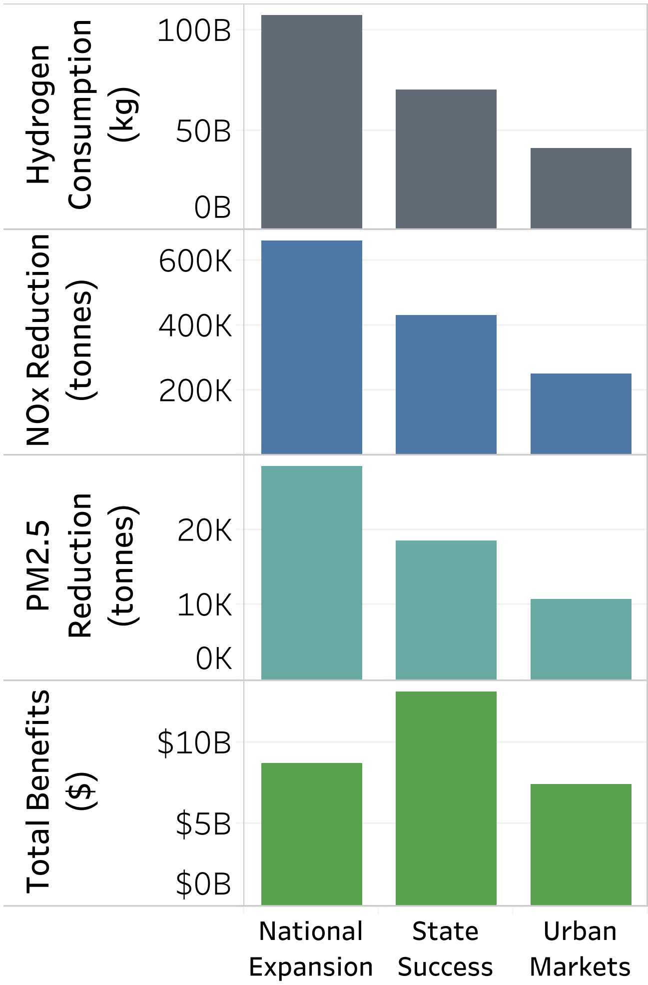
Monetized Benefits Air Pollution Emissions Reductions for H2USA Scenarios

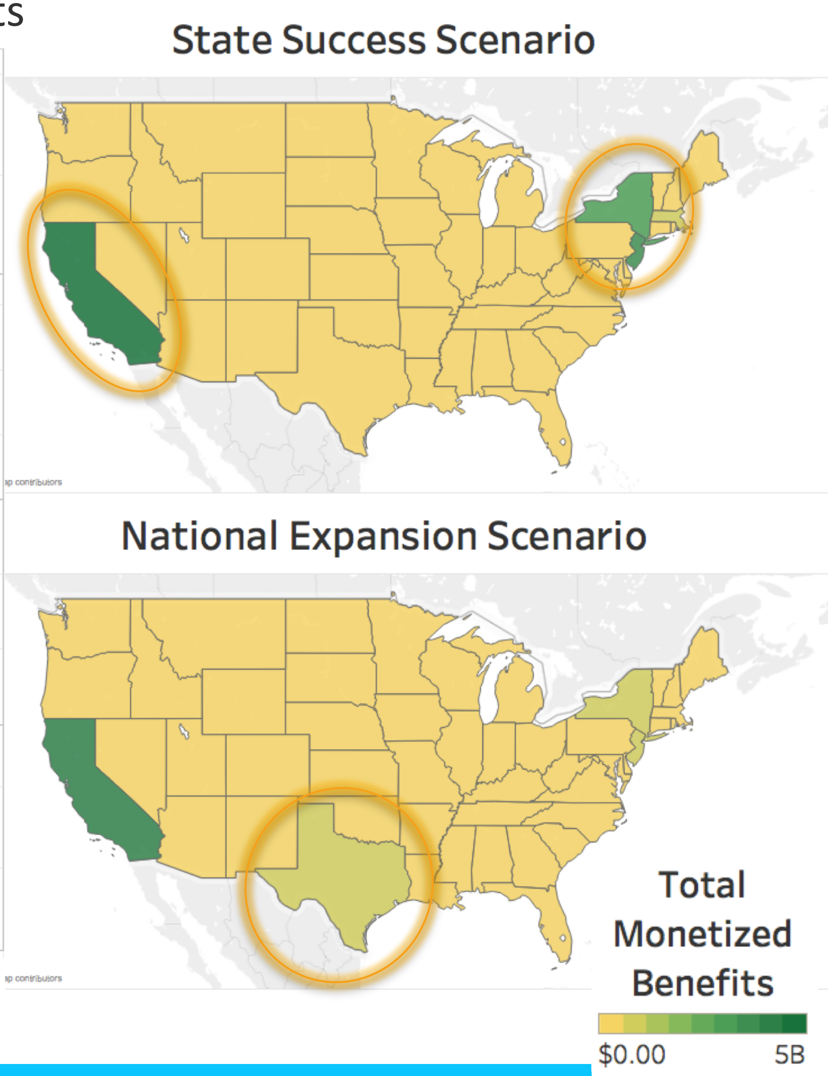
Accomplishments 6

The National Expansion scenario has greatest FCEV adoption (hydrogen consumption), yet 33% lower cumulative air pollution benefits than in the State Success scenario.

The Urban Markets scenario requires only 40% of the hydrogen consumed in the National Expansion scenario, but results in 85% of the air pollution benefits.

Cumulative (2015 to 2050) Results





Scenario analysis highlights that spatial pattern of FCEV adoption determines magnitude of monetized air pollution benefits

Responses to Reviewers' Comments: Pathways and Costs

Responses 1

Comment 1: Biomass gasification is not relevant (not being developed by DOE), would be more appropriate to use pyrolysis or hydrothermal liquefaction

Response: For consistency with DOE models, we base our pathways on those from the H2A production models. At this time, biomass gasification is the only biomass pathway modeled.

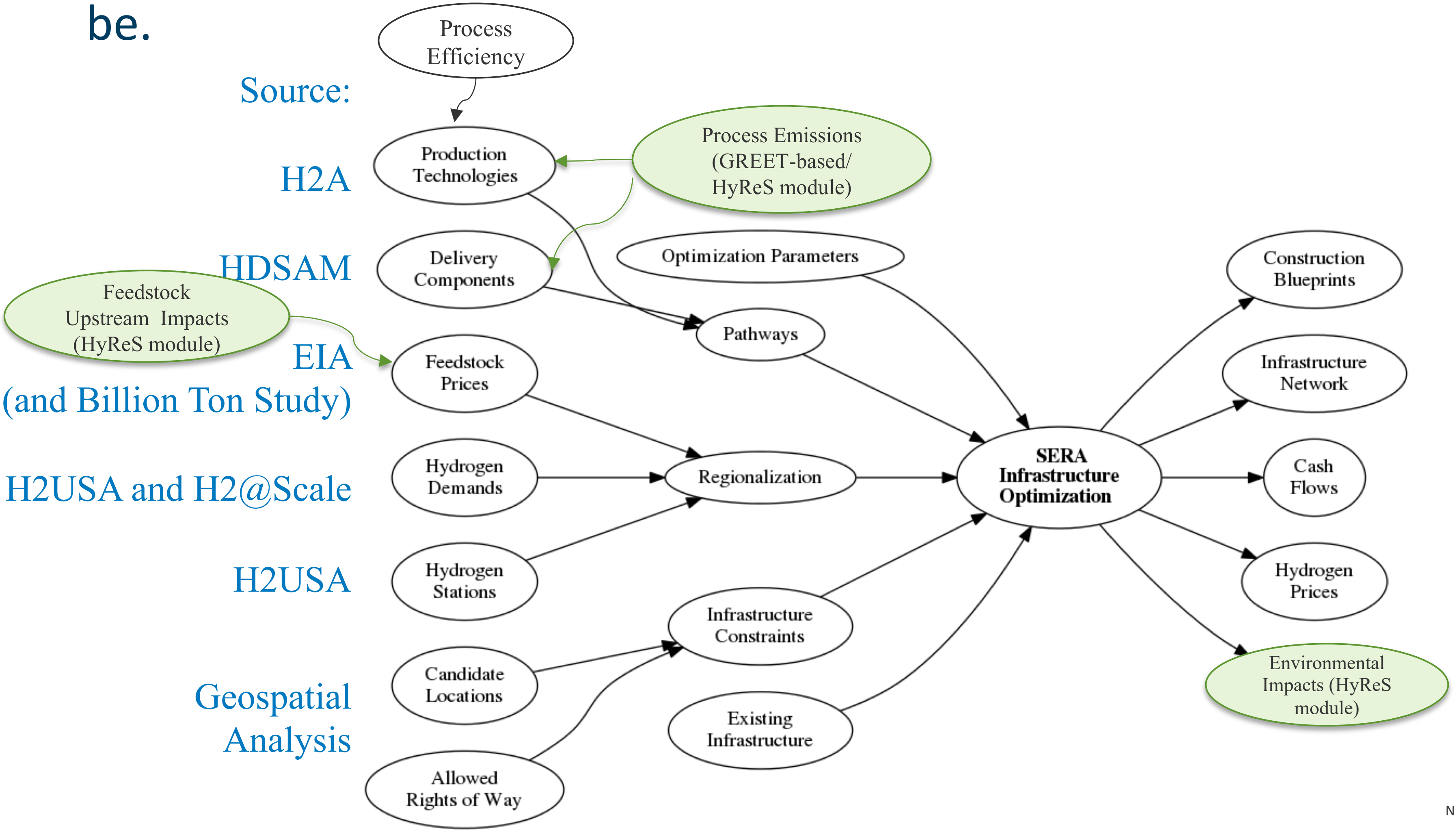
Comment 2: The project is using the Hydrogen Analysis (H2A) model for the hydrogen levelized cost. This hydrogen cost is not a price. Price is set by the market.

Response: SERA calculates the cost of producing hydrogen based on the H2A capital costs and resource efficiency. SERA also uses energy and other resource prices (mainly from EIA). Transportation and distribution costs are based on the HDSAM model. Thus, the outputs include the cost of hydrogen from individual units with a 10% IRR (minimum required selling price). Future work will implement the H2FAST approach for cost analysis. A market-based pricing strategy is outside the scope of this project.

Responses to Reviewers' Comments: Model Inputs and Outputs

Responses 2

Comment 3: It is not clear what the final model will look like when the project is done, and what possible inputs and outputs would be.



Source:

H2A

HDSAM

EIA

(and Billion Ton Study)

H2USA and H2@Scale

H2USA

Geospatial Analysis

Process Efficiency

Production Technologies

Process Emissions (GREET-based/ HyReS module)

Delivery Components

Feedstock Upstream Impacts (HyReS module)

Feedstock Prices

Hydrogen Demands

Hydrogen Stations

Candidate Locations

Allowed Rights of Way

Optimization Parameters

Pathways

Regionalization

Infrastructure Constraints

Existing Infrastructure

SERA Infrastructure Optimization

Construction Blueprints

Infrastructure Network

Cash Flows

Hydrogen Prices

Environmental Impacts (HyReS module)

Collaboration and Coordination

- Argonne National Laboratory – *Modeling*
  - GREET Model

- Collaborative Reviewers – *Metric Visualization*
  - Ford
  - Louis Berger
  - E4Tech
  - LBST (Ludwig-Bölkow-Systemtechnik)
  - Academic institutions
- H2@Scale Project Team – *Scenario Analysis*

Remaining Challenges and Barriers

Finalizing Model

- Implementation of resource supply curves in SERA model
- Modeling impacts from existing production facilities (used in H2@Scale scenarios)
- Calculating H2 prices

Relevance to Stakeholders

- Additional stakeholder input from hydrogen producers and/or fueling station owners
- Limited mapping capabilities with Tableau Public

Future Work

Project Plan

Year One

- Subject Review ☑
- Steering Team ☑
- Expand Framework ☑

Year Two

- Additional Expansion ☑
- Framework Application ☑
- Corporate-Level Alignment ☑
- Beta Version ☑

Year Three

Ongoing iterative process

- *Reviewer Feedback* ☐
- *Refine Framework* ☐
- Implement Framework ☐

Model Updates

- Implement supply curves for hydrogen feedstocks to reflect actual resource availability
  - Biomass – prepared using Billion Ton Study (✓)
  - Solar – NREL maps (see Hydrogen Resource Report)
  - Wind – NREL maps (see Hydrogen Resource Report)
- Expand production pathways outside of those in H2A
- Compare sustainability of vehicle technologies across non-LDV market segments

Visualizations

Finalize and publish Tableau public visualizations of future scenarios

- Based on iterative stakeholder feedback

Project Coordination

Continue coordination with H2@Scale team to understand sustainability implications of H2@Scale scenarios

- Requires additional inputs/model restructuring to account for existing production infrastructure

Any proposed future work is subject to change based on funding levels.

Some proposed work (in orange) is outside the current project scope.

Technology Transfer Activities

- Licensing of SERA model is being considered
- Presently publically available:
    - FASTSim: https://www.nrel.gov/transportation/fastsim.html
    - GREET: https://greet.es.anl.gov/
    - H2A Case Studies: https://www.hydrogen.energy.gov/h2a_prod_studies.html
    - HDSAM Model: https://hdsam.es.anl.gov/index.php?content=hdsam
    - EASIUR: http://barney.ce.cmu.edu/~jinhyok/easiur/online/

Summary

Relevance

- Expansion of existing systems analysis models that address costs and environmental impacts
- Addresses industry and other stakeholder preferences

Approach

- Modifying GREET fuel system boundary for energy accounting, coordinating with ANL
- Comparing vehicles with 400-mile range

Accomplishments and Progress

- FASTSim-based vehicle cycle results show BEV400 vehicle cycle with 15% higher energy consumption than FCEV with 400-mile range
- FCEVs can reduce life cycle petroleum consumption by 95% compared to conventional gasoline vehicles
- H2USA "State Success" scenario results in the largest monetized benefits due to air pollution reductions concentrated in densely populated areas

Collaboration

- GREET model developers; H2@Scale project team; Steering committee

Proposed Future Research

- Final refinements of model and implementation to analyze H2@Scale and other sensitivity scenarios
- Tableau Public for visualization of results

Thank You

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