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Life-Cycle Analysis of Green Ammonia and its Application as Fertilizer Building Block

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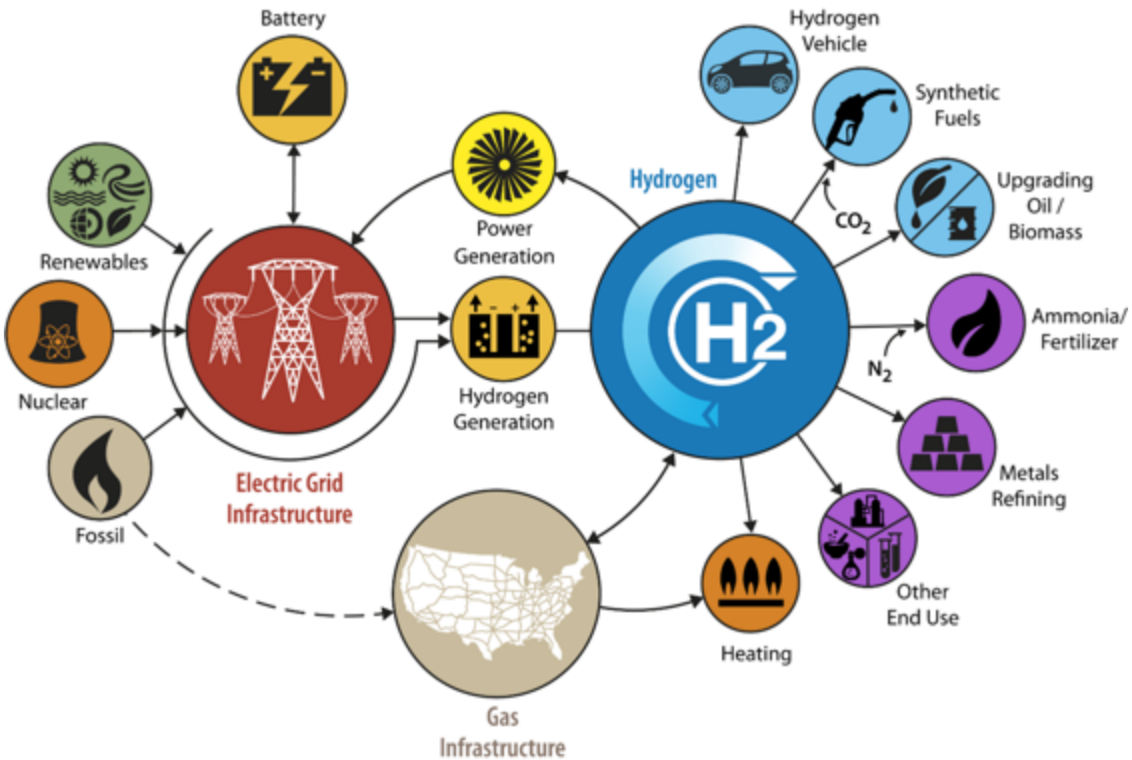
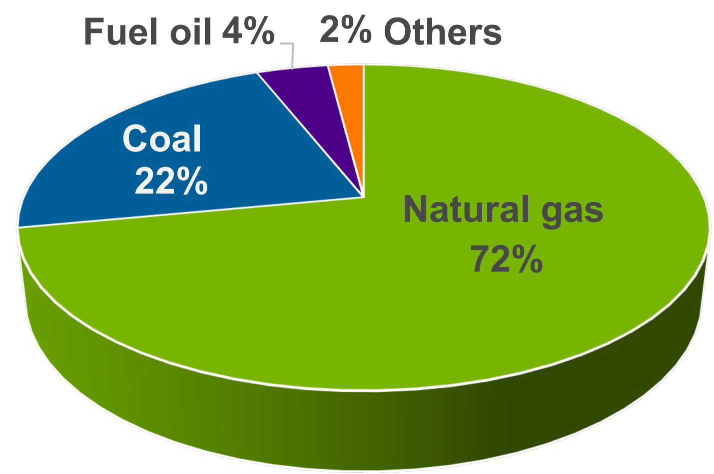
H_2 @ Scale and NH_3 as fertilizer



Source: https://www.energy.gov/eere/fuelcells/h2scale



Feedstock for global ammonia production

Source:10.1021/acssuschemeng.7b02219

- Ammonia stays in a liquid form at room temperature and ~10 bar pressure
- The handling and shipping infrastructure of ammonia including regulations for transportation are already in place
- Ammonia can be synthesized from carbon-free sources: water, air and renewable- or nuclear based electricity

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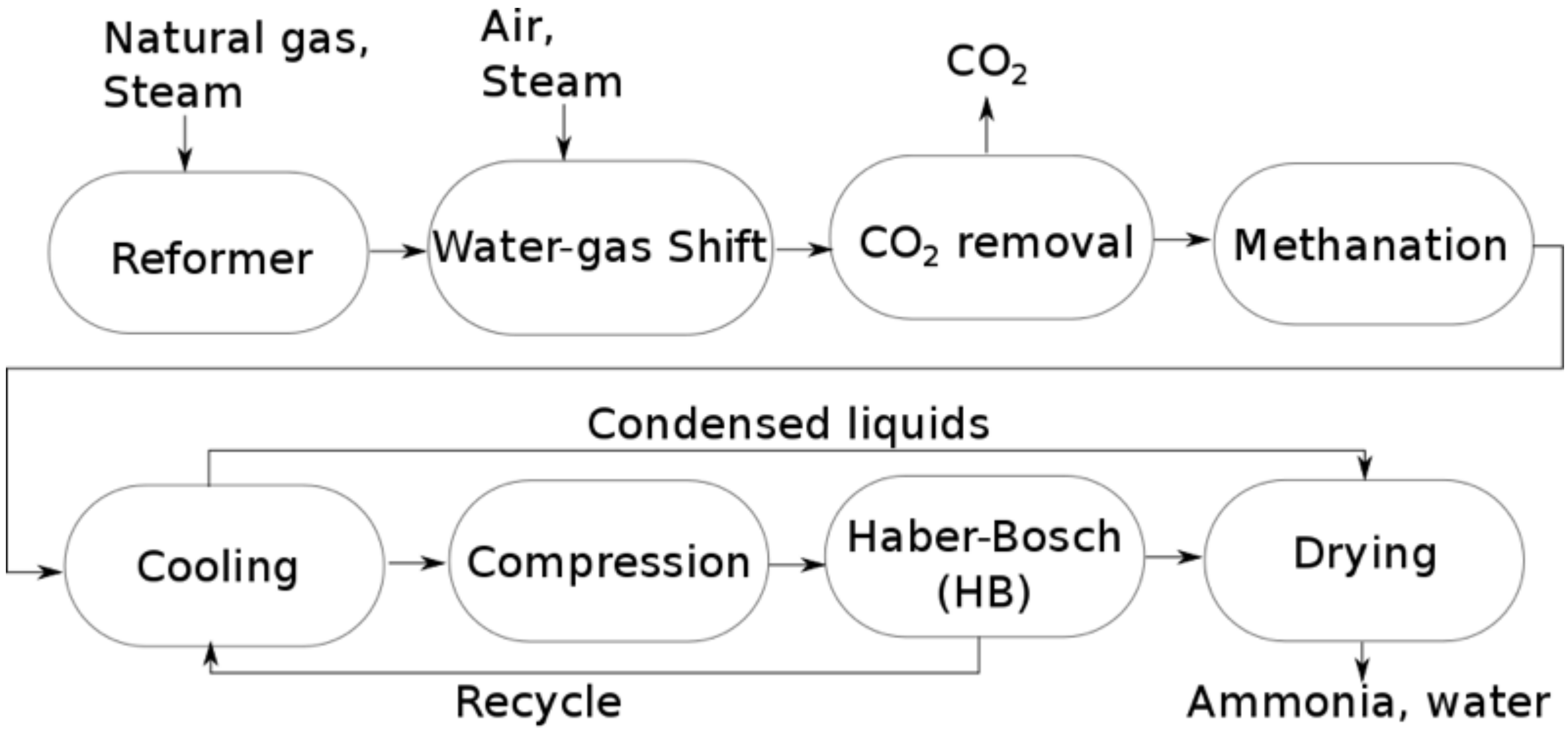
Conventional ammonia life-cycle analysis (LCA)

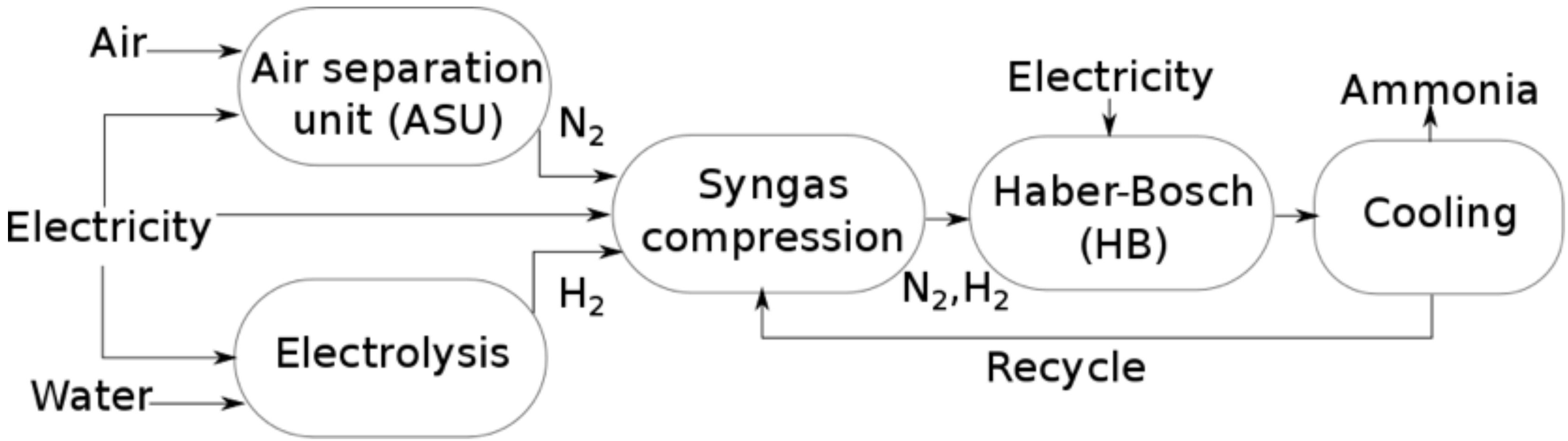


Source: Modified from 10.1016/j.algal.2013.08.003

- Natural gas as feedstock → 2.3 ton CO_{2e}/ton ammonia (well-to-plant gate)[1]

[1]GREET 2019 model

Green ammonia LCA



- Ammonia from renewable/nuclear electricity, air and water
- Need to evaluate CO_{2e} per ton of green ammonia?

GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

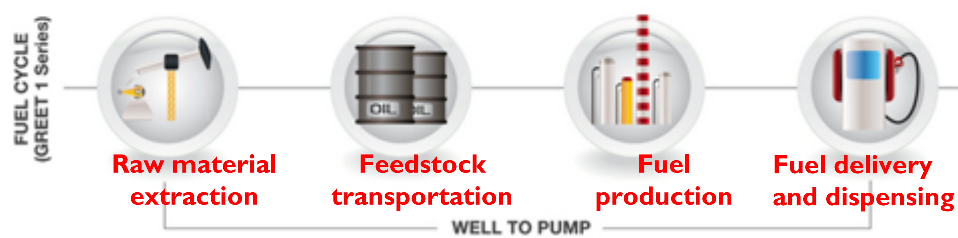
- Argonne has been developing the GREET LCA model since 1995 with annual updates and expansions
- GREET is available free of charge at https://greet.es.anl.gov

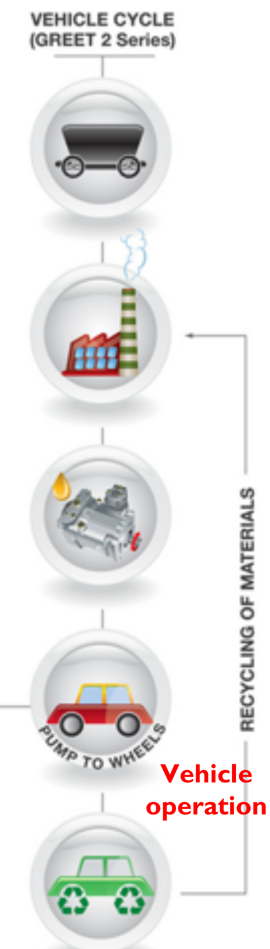
Stochastic Simulation Tool

Carbon Calculator for Land Use Change from Biofuels (CCLUB)

GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems

GREET 2 model:
Vehicle cycle modeling for vehicles





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GREET® sponsors and major users

Sponsors

- Vehicle Technology Office (VTO)
- Fuel-Cell Technology Office (FCTO)
- Advanced Research Projects Agency-Energy (ARPA-E)
- Building Technologies Office (BTO)
- Bioenergy Technology Office (BETO)
- Strategic Priorities & Impact Analysis (SPIA)

Examples of major uses of GREET

- DOE, USDA, and the Navy use GREET for R&D decisions
- US EPA used GREET for RFS and vehicle GHG standard developments
- CARB developed CA-GREET for its Low-Carbon Fuel Standard compliance
- DOD DLA-Energy uses GREET for alternative fuel purchase requirements
- International Civil Aviation Organization (ICAO) uses GREET to develop carbon intensities of aviation fuel pathways
- Energy industry (especially new fuel companies) uses it for addressing sustainability of R&D investments
- Auto industry uses it for R&D screening of vehicle/fuel system combinations
- Universities uses GREET for education on technology sustainability of various fuels

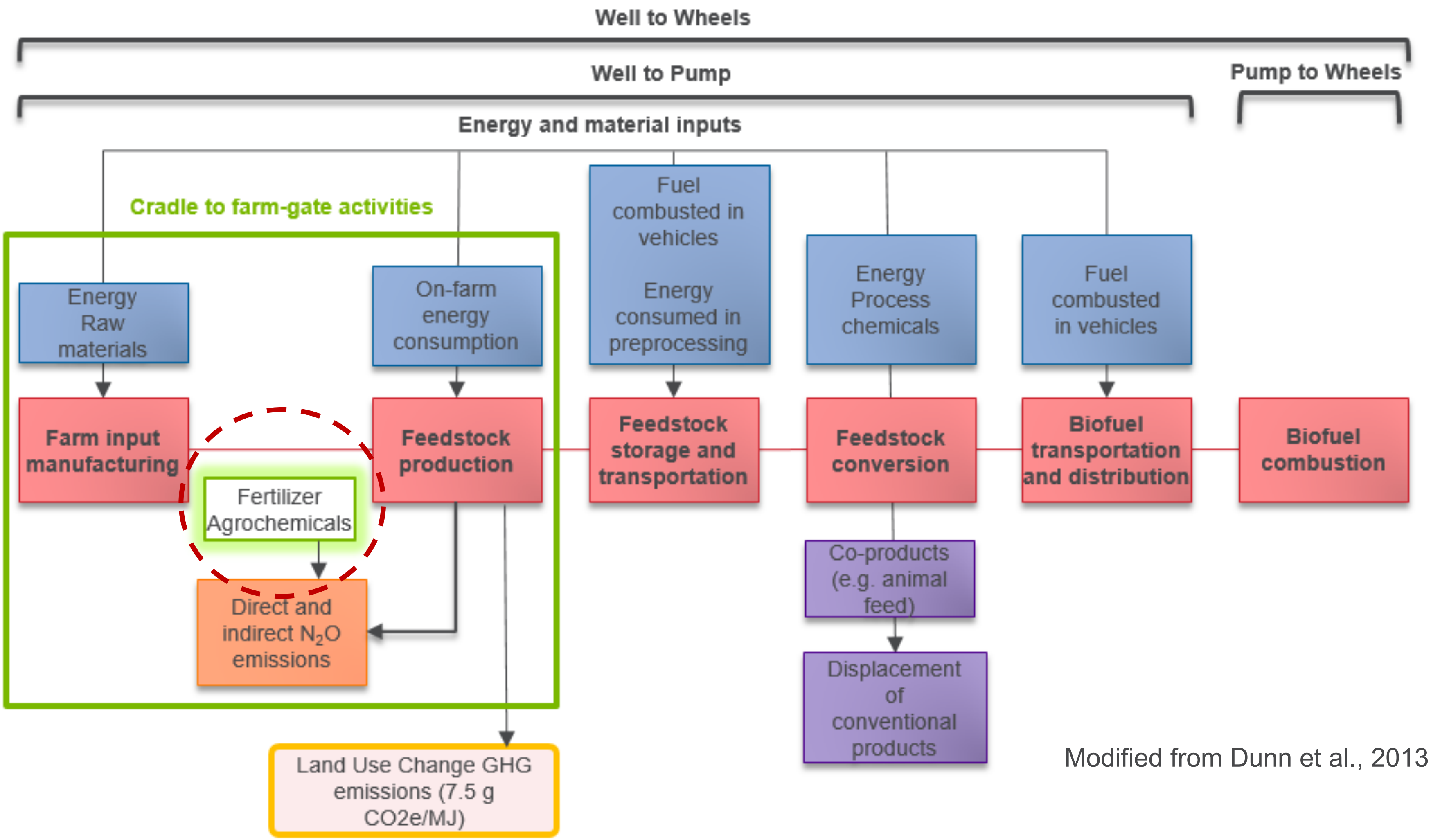
GREET® outputs include energy use, criteria pollutants, greenhouse gases, and water consumption

- Energy use – addressing energy diversity/security
  - Total energy: fossil energy and renewable energy
    - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
    - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy
- Air pollutants – addressing air pollution
  - VOC, CO, NOx, PM_{10}, $PM_{2.5}$, and SO_x
- Greenhouse gases (GHGs) – addressing climate change
  - CO_2, CH_4, N_2O, black carbon, and albedo
- Water consumption – addressing water supply and demand (energy-water nexus)

GREET® includes more than 100 fuel production pathways from various energy feedstock sources

Feedstock	Fuel
Petroleum Conventional Oil Sands	Gasoline Diesel Jet Fuel Liquefied Petroleum Gas Naphtha Residual Oil
Coal	Hydrogen Fischer-Tropsch Diesel Fischer-Tropsch Jet Methanol Dimethyl Ether
Natural Gas North American Non-North American Shale gas **Renewable Natural Gas** Landfill Gas Animal Waste Waste water treatment	Compressed Natural Gas Liquefied Natural Gas Liquefied Petroleum Gas Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fischer-Tropsch Naphtha Hydrogen
Coke Oven Gas Petroleum Coke Nuclear Energy	Hydrogen
Corn	Ethanol Butanol
Sugarcane	Ethanol
Soybeans Palm Rapeseed Jatropha Camelina Algae	Biodiesel Renewable Diesel Renewable Gasoline Renewable Jet
Cellulosic Biomass Switchgrass Crop Residues Forest Residues Miscanthus Willow/Poplar	Ethanol Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Pyro Gasoline/Diesel/Jet
Residual Oil Coal Natural Gas Biomass Other Renewables	**Electricity** → Hydrogen

Ammonia based nitrogen fertilizer impacts corn ethanol carbon intensity (CI)



Modified from Dunn et al., 2013

Approximately 8% of corn ethanol CI are due to nitrogen fertilizer manufacturing

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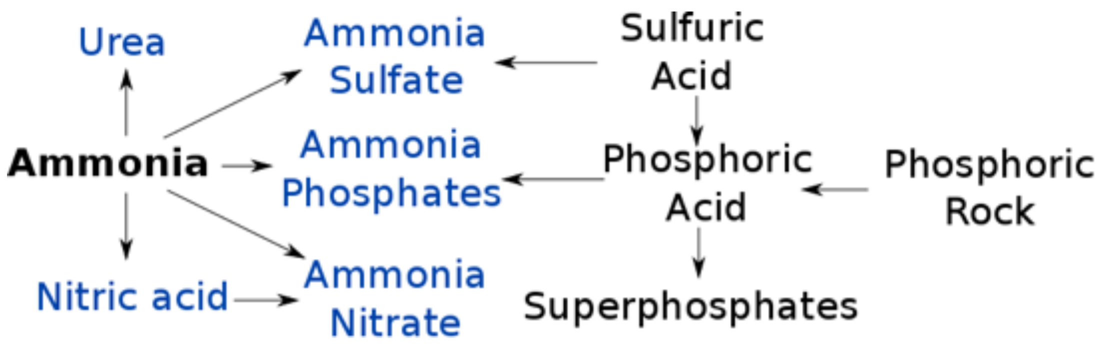
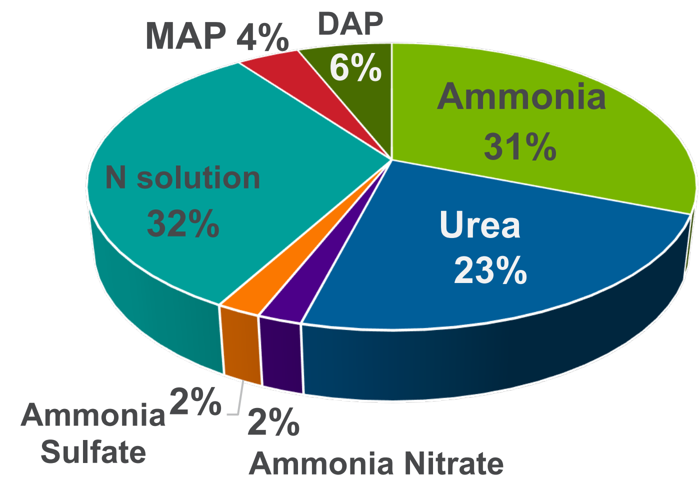
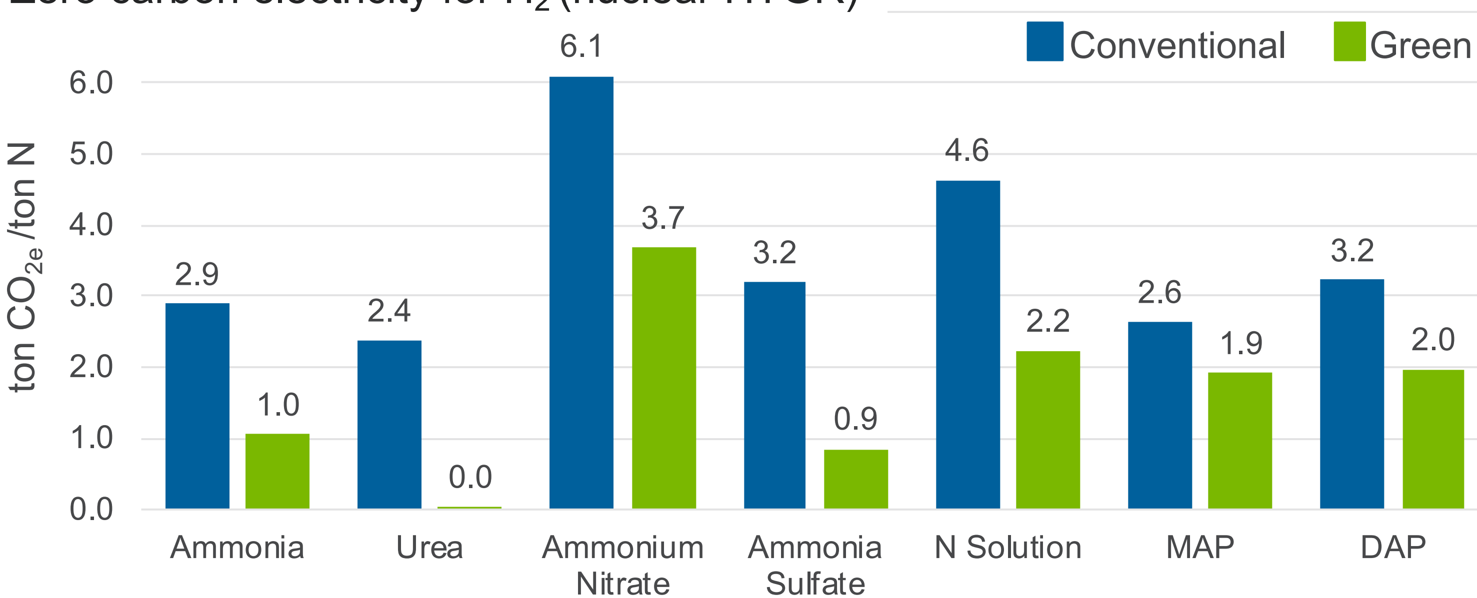
Green ammonia reduces nitrogen fertilizer CO_2 emissions





- 2019 US grid electricity for ASU and HB
- Zero carbon electricity for H_2 (nuclear HTGR)



Green ammonia with current N fertilizer shares, reduces CI per ton of N fertilizer from 3.4 ton CO_{2e} to 1.3 ton CO_{2e}, a 61% reduction

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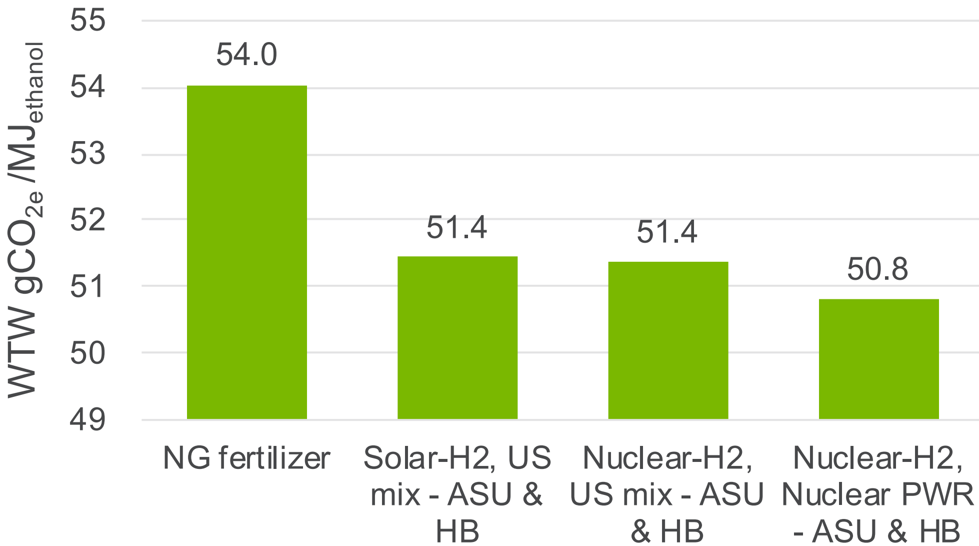
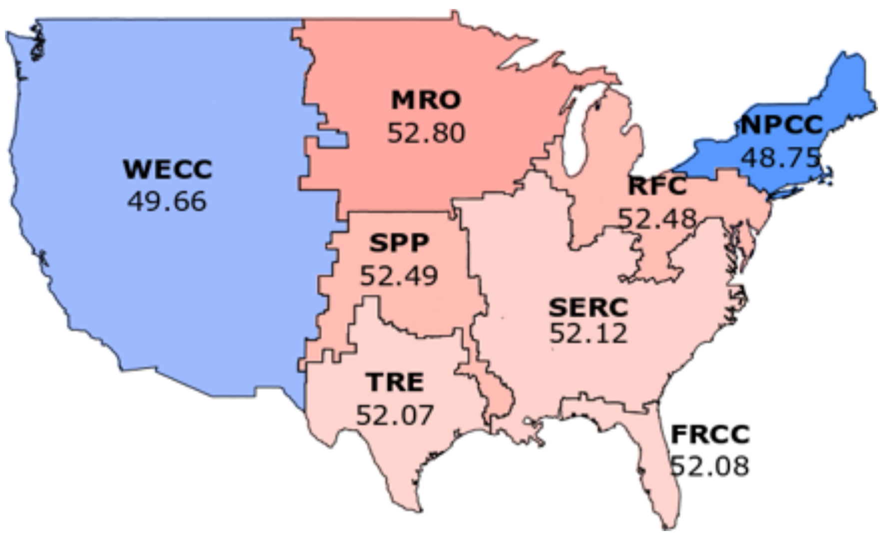
Corn ethanol CI reduces with green ammonia



If nuclear-based electricity is used to produce H_2 via electrolysis and to power ASU and HB reactor, the CI of corn ethanol is 50.8 g CO_{2e}/MJ, representing a 6% decrease compared to NG pathway

WTW gCO_{2e} /$MJ_{ethanol}$



	MRO Mix	NPCC Mix	U.S. Mix
Natural gas	10.30%	41.96%	33.44%
Coal	47.71%	2.68%	28.96%
Nuclear power	10.60%	32.59%	20.31%
Others	31.38%	22.78%	17.29%

The reduction in corn-ethanol CI may translate into monetary credits depending on pathway

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Conclusions

- Ammonia can be synthesized from carbon-free sources: water, air, and renewable or nuclear-based electricity
- Impacts of shifting from conventional ammonia to green ammonia-based nitrogen fertilizer on corn ethanol CI are assessed
- Using renewable and carbon-free resources to produce green ammonia can reduce corn ethanol CI by 6%, which may translate into monetary credits depending on pathway

Acknowledgement

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Thank you!

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Inventory

	Electricity	Unit	H_2	Unit
N_2 via cryogenic air separation unit	**0.875**	**GJ/metric ton N_2**		
N_2 via cryogenic air separation unit	**0.720**	**GJ/metric ton NH_3**		
Haber Bosch (HB) process	**2.304**	**GJ/metric ton NH_3**	0.177	ton H_2/ ton NH_3

	Electricity	Unit	H_2	Unit
N_2 via cryogenic air separation unit	0.619	mmbtu / short ton NH_3		
Haber Bosch process	1.981	mmbtu / short ton NH_3	0.177	ton H_2/ ton NH_3
Total energy	**2.6**	**mmbtu / short ton NH_3**		

- The more conservative numbers are taken if there are differences
- Assuming linear scaling up of processes, and HB process obtains its energy through reaction heat

California Low-Carbon Fuel Standard (LCFS) evaluates low-carbon fuels based on their CI

- Adopted in 2009 by the State of California to reduce California's transportation fuel carbon intensity (CI) by 10% in 2020 relative to 2010; and by another 10% in 2030
- CI for various fuels are determined on LCA basis
  - GREET was adapted to CA-GREET to decide fuel's LCA GHG intensity (or well-to-wheels CI)
- There is a certification scheme in LCFS to score CI of individual bio-refineries that creates an incentive for each bio-refinery to minimize its CI
- Even though there is currently no such certification scheme for the feedstock production sector, the substantial improvements in sensor technologies have made the field-level monitoring and verification possible
- Green ammonia and its fertilizer derivatives can play an important role in reducing the feedstock CI