2020 DOE Hydrogen and Fuel Cells Program
Annual Merit Review

Argonne NATIONAL LABORATORY

Synthetic Fuels Technoeconomic Analysis and Life Cycle Analysis

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SA174

Overview

Timeline

- Start: October 2019
- End: Determined by DOE
- % complete (FY20): 80%

Budget

- Funding for FY20: $150K

Barriers to Address

A: Future Market Behavior

- ➢ Potential market for low value energy and potential hydrogen markets beyond transportation

D: Insufficient Suite of Models & Tools

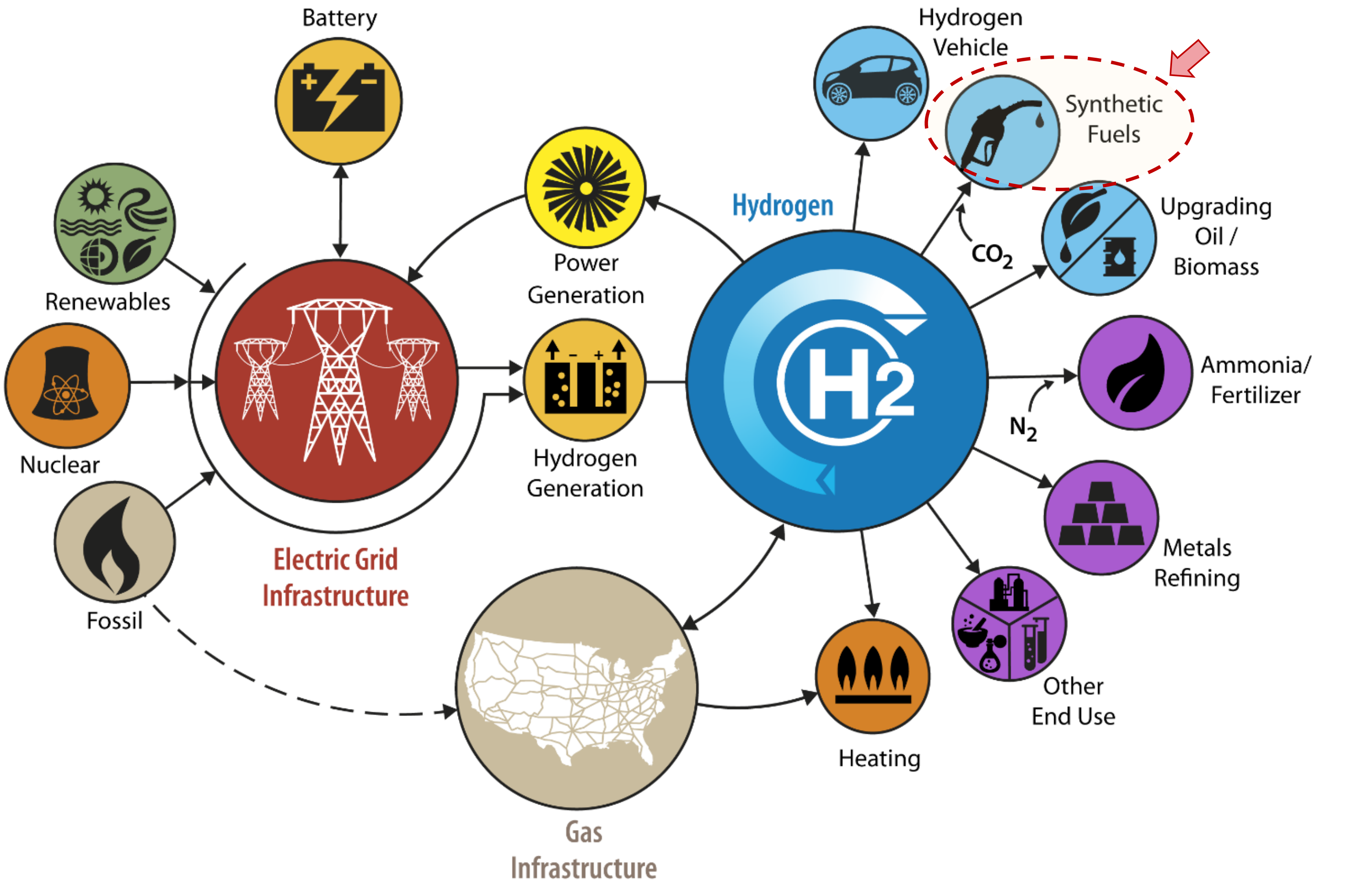
E: Unplanned Studies and Analysis

- ➢ H2@Scale is a new concept and requires analysis of its potential impacts

Partners/Collaborators

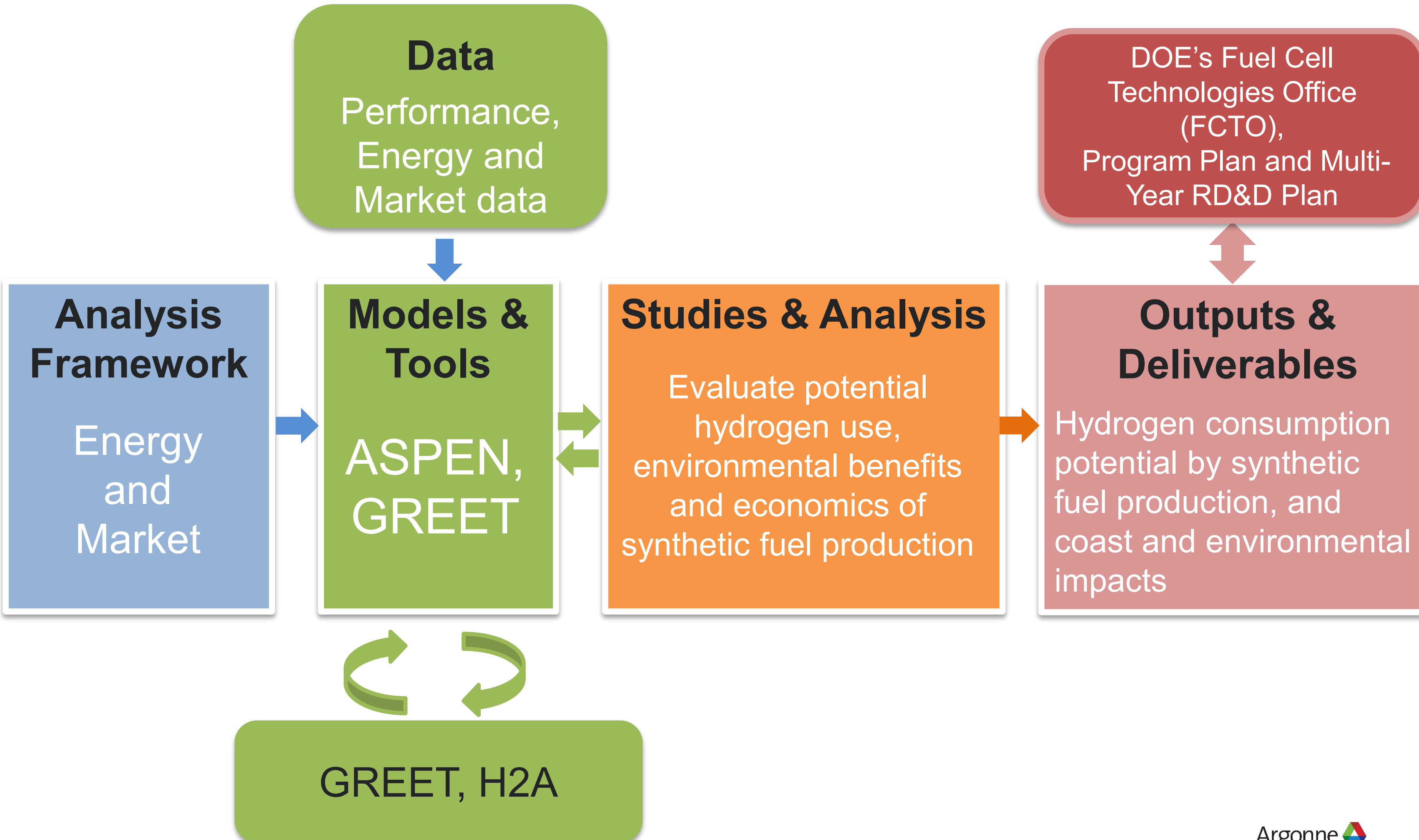
- NREL and INL
- DOE NE Office

H2@SCALE EXPANDS HYDROGEN UTILIZATION BEYOND CURRENT MARKETS – *Relevance/Impact*



- Synthetic fuels production can contribute to large scale hydrogen demand
- Need to evaluate potential hydrogen demand and associated cost

EVALUATE ECONOMIC AND ENVIRONMENTAL IMPACTS OF PRODUCING SYNTHETIC FUELS FROM ZERO-CARBON HYDROGEN – Approach



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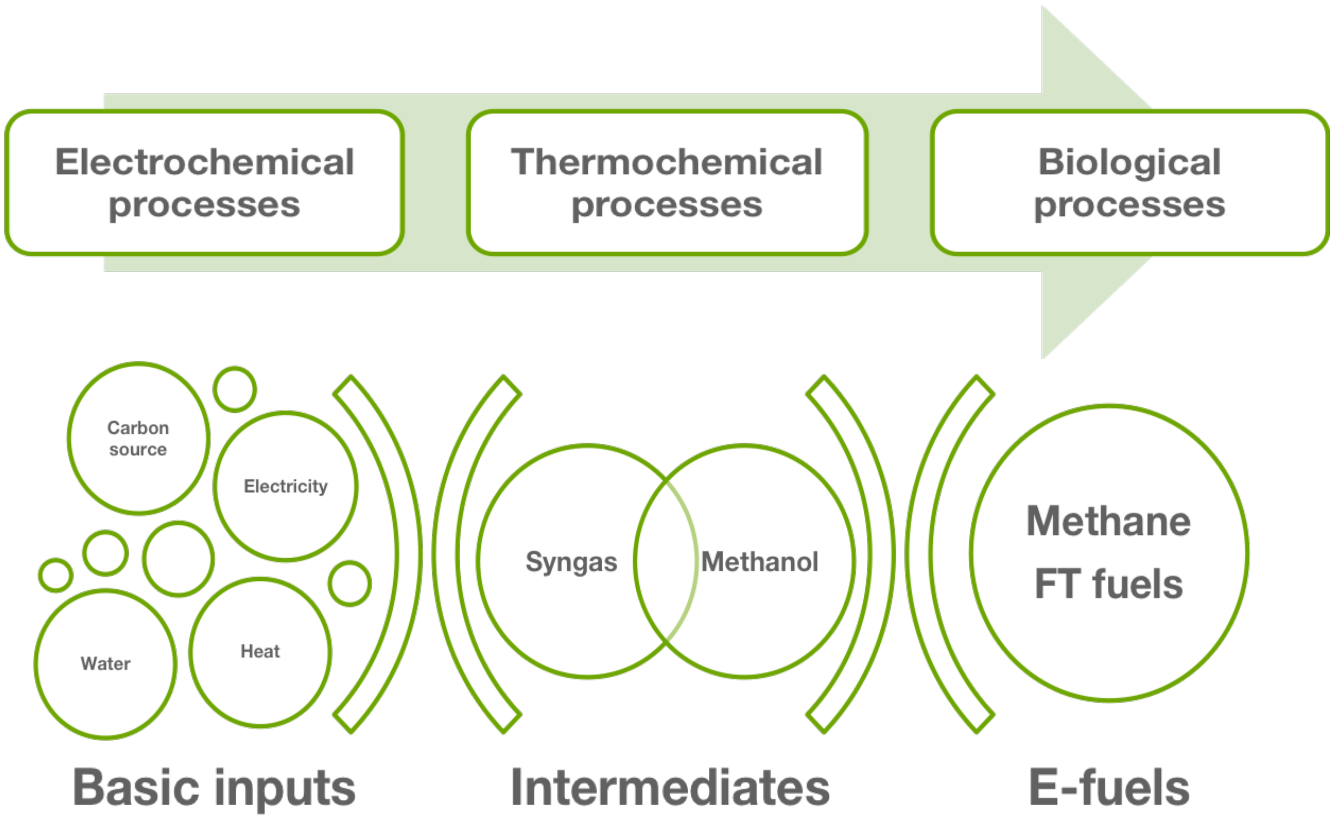
$H_2+CO_2 \rightarrow$ LIQUID HYDROCARBON FUELS AND CHEMICALS – Relevance

- Electrofuels or “e-fuels” encompass energy carriers and their intermediates synthesized primarily using a carbon source and electricity (for hydrogen)



MAJOR CO_2 AND ZERO–CARBON ELECTRICITY SOURCES TO CONSIDER – Approach

Carbon Sources

Bio-derived CO_2

- Ethanol plants
- Waste streams (MSW, residues, etc.)

Fossil- derived CO_2

- Ammonia plants
- NG processing plants
- NG SMR plants
- Cement plants
- Iron & Steel mills
- Fossil power plants

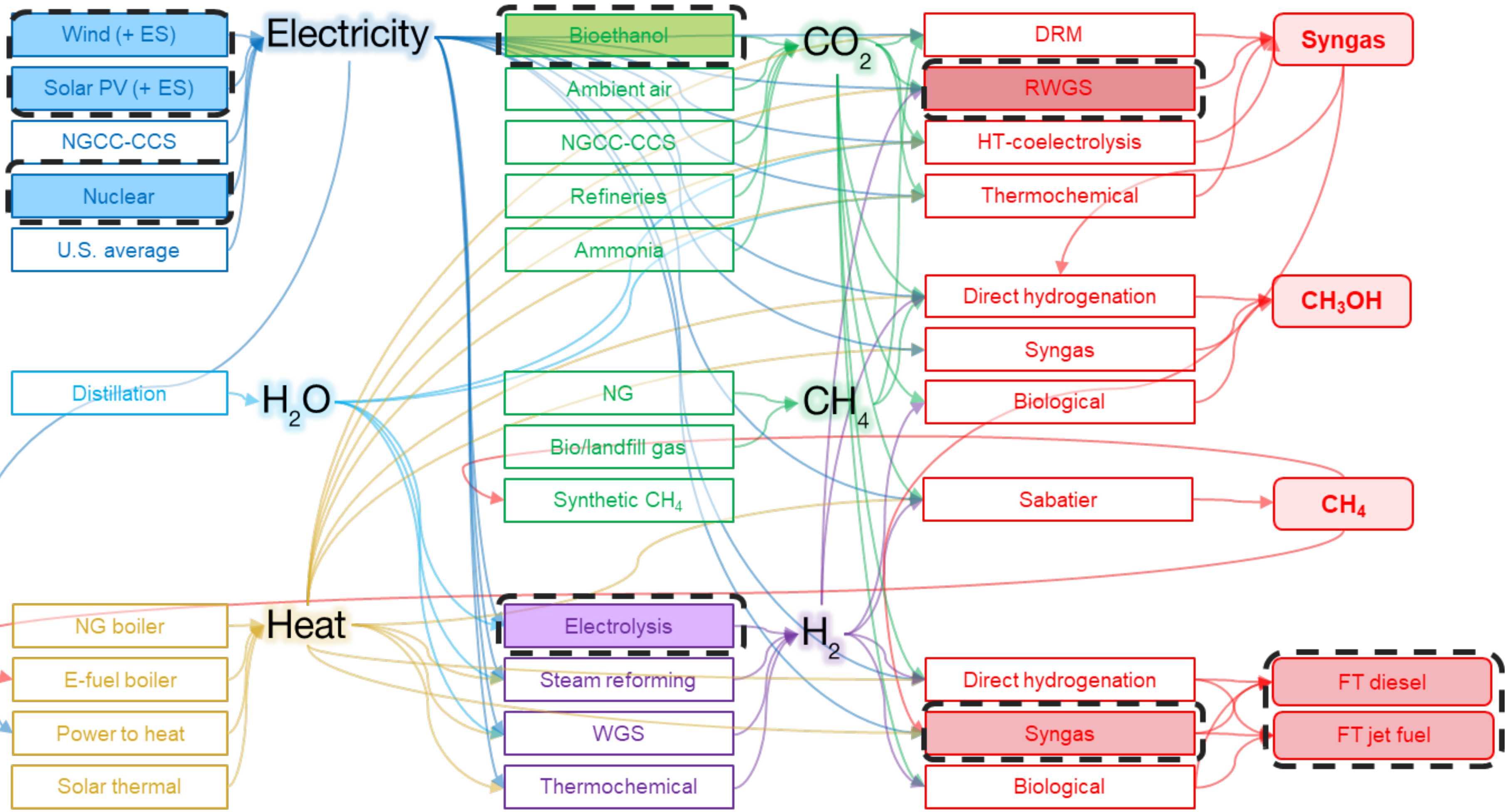
Zero-Carbon Electricity Sources

Wind

Solar

Nuclear

LARGE NUMBER OF SYNTHETIC CHEMICALS AND FUELS PATHWAYS ARE POSSIBLE – Approach



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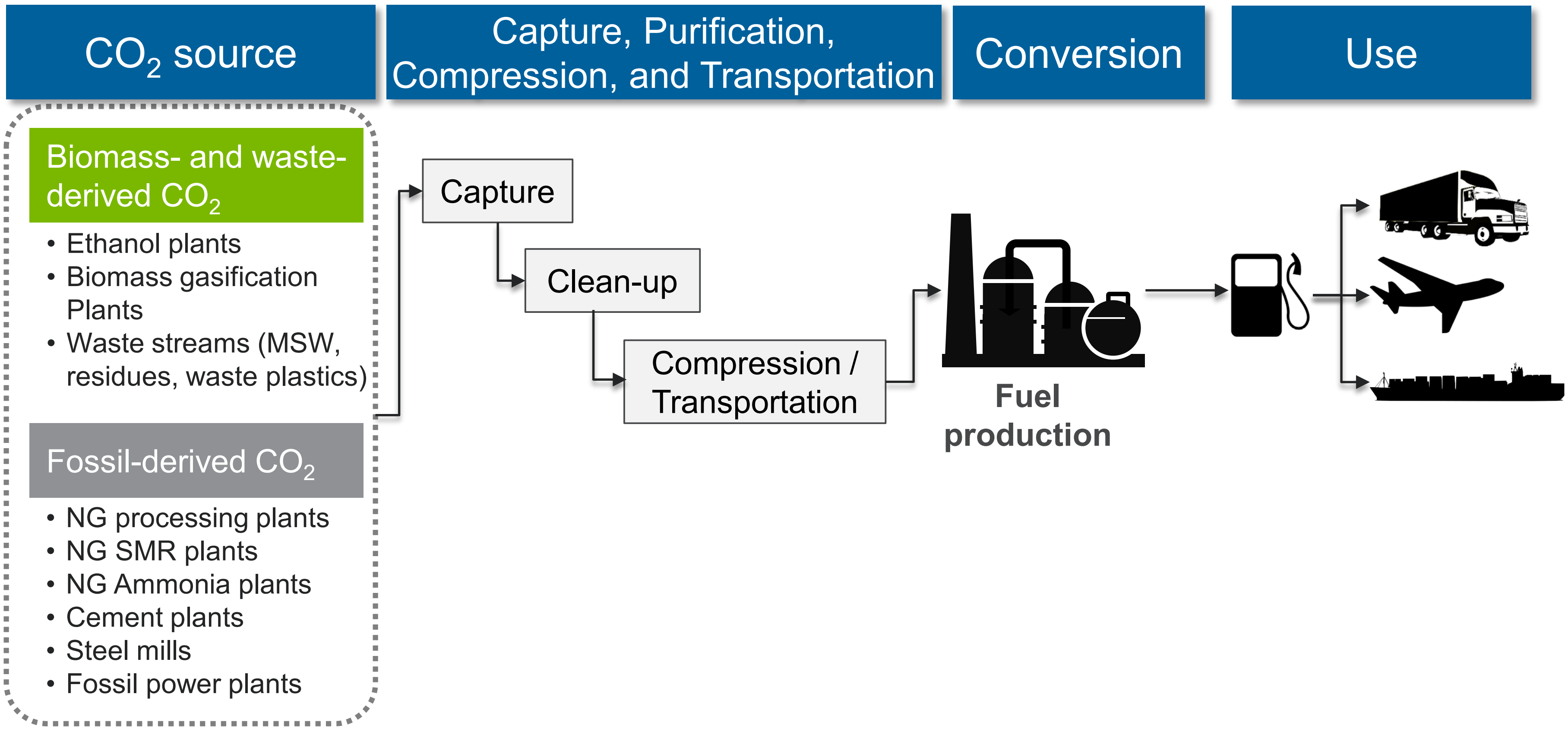
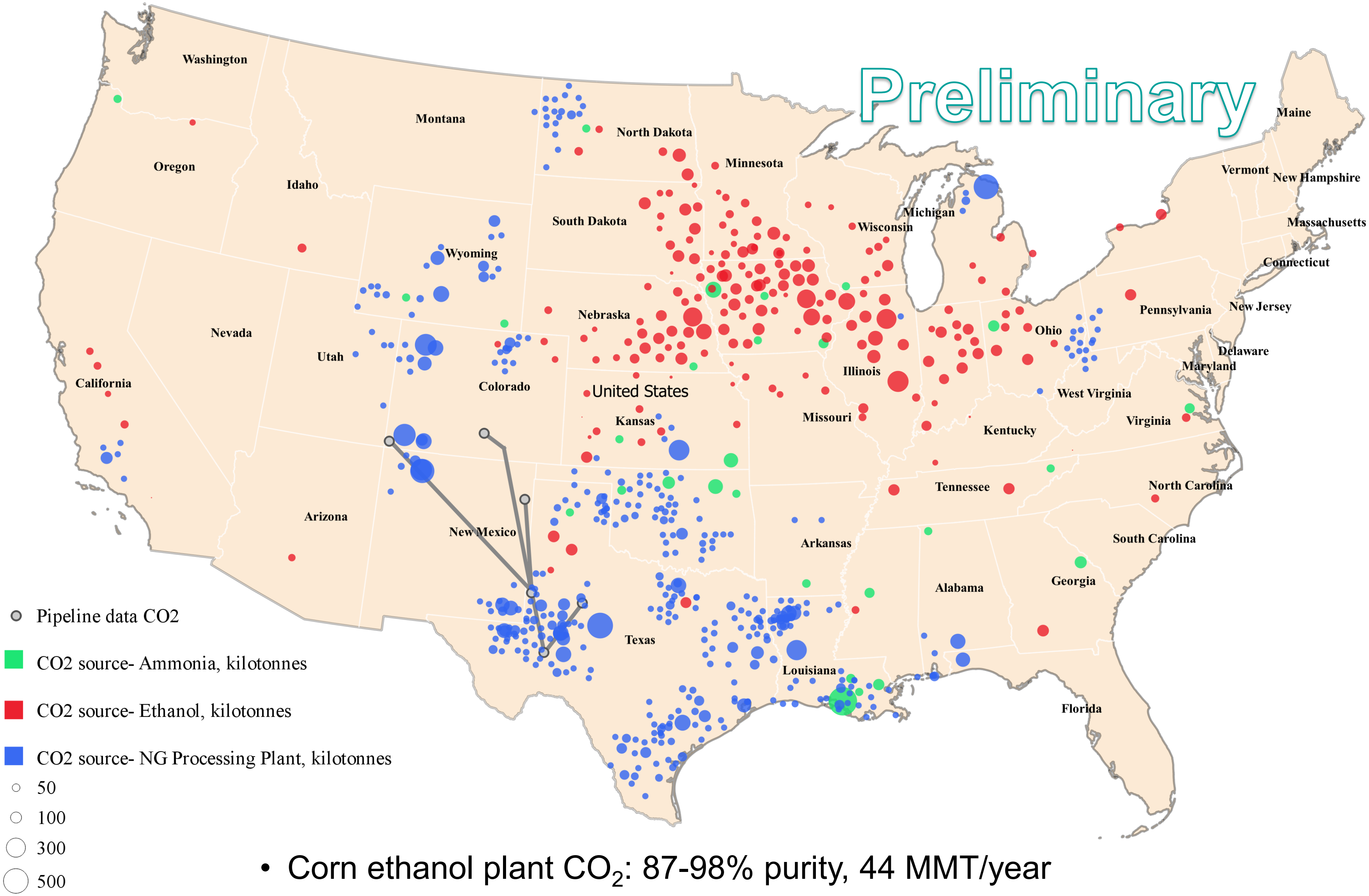
LCA of CO_2–BASED FUELS: SYSTEM BOUNDARY – *Approach*



HIGH-CONCENTRATION CO_2 SOURCES – Accomplishment



- Corn ethanol plant CO_2: 87-98% purity, 44 MMT/year
- Ammonia plant CO_2: >98% purity, 19 MMT/year
- NG processing plant CO_2: >96% purity, 17 MMT/year

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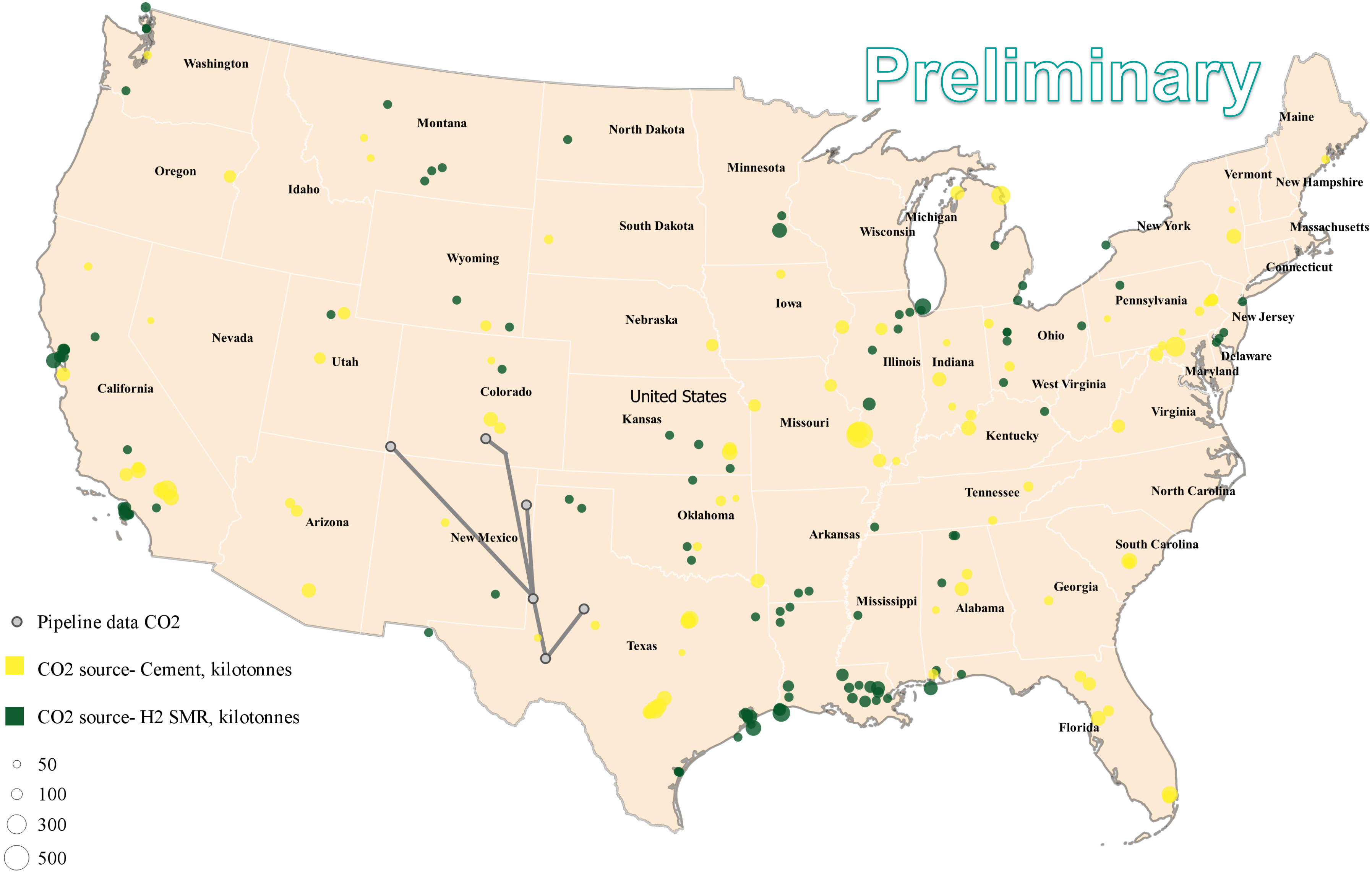
OTHER LOWER-CONCENTRATION CO_2 SOURCES – Accomplishment



- H2 SMR plant CO_2: 28% purity, 44 MMT/year
- Cement plant CO_2: 14-33% purity, 65 MMT /year

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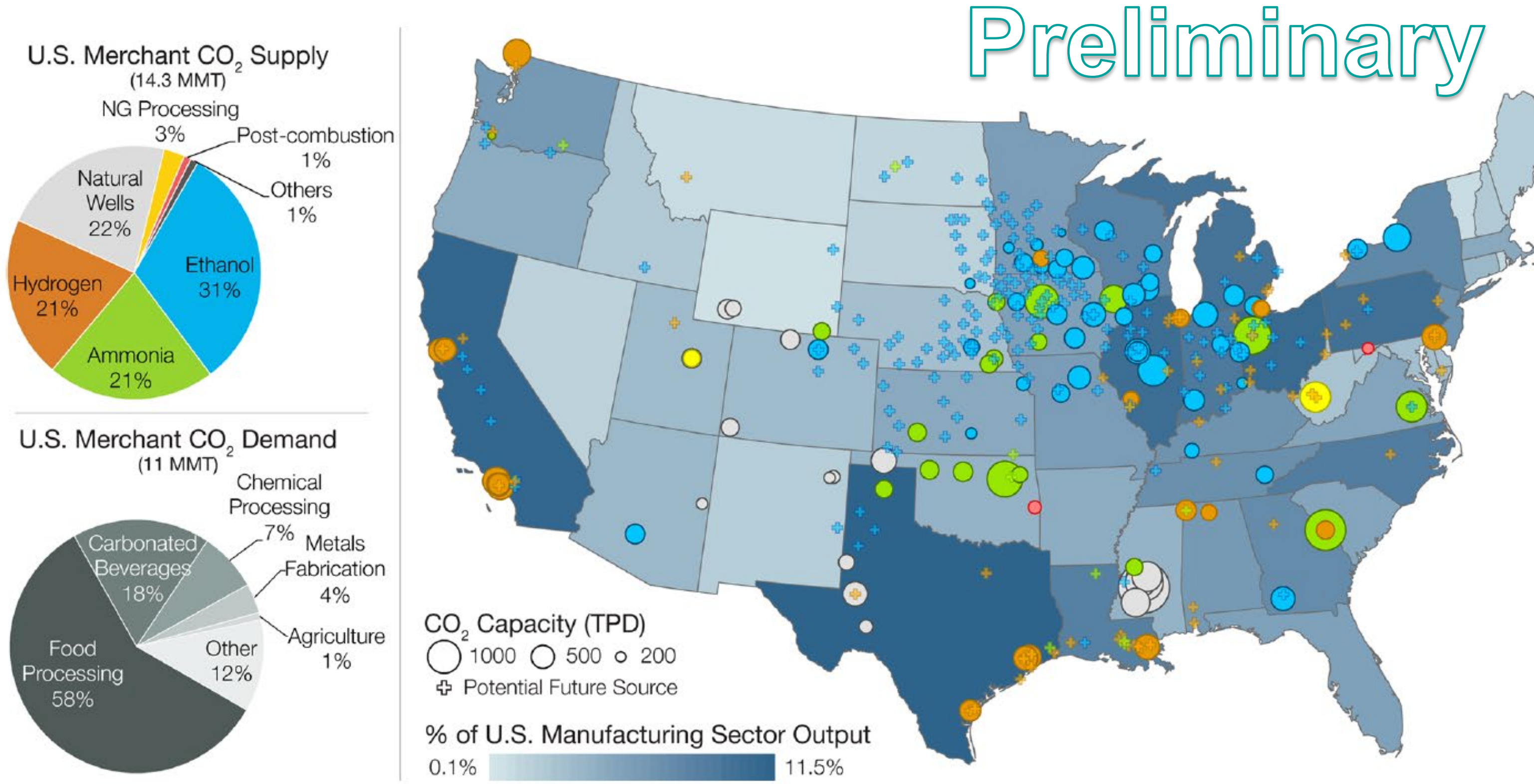
POTENTIAL H_2 DEMAND FOR SYNTHETIC HYDROCARBON PRODUCTION FROM CONCENTRATED CO_2 SOURCES – Accomplishment

- ~100 MMT of concentrated CO_2 sources are considered (out of total~ 5 GT CO_2)
  - 44 million MT from ethanol plants
    - ✓ Current CO_2 supply capacity of 14 MMT, and market demand of 11 MMT
  - Remainder from hydrogen SMR (refineries) and ammonia plants

Preliminary



Source: Supekar and Skerlos, ES&T (2014)

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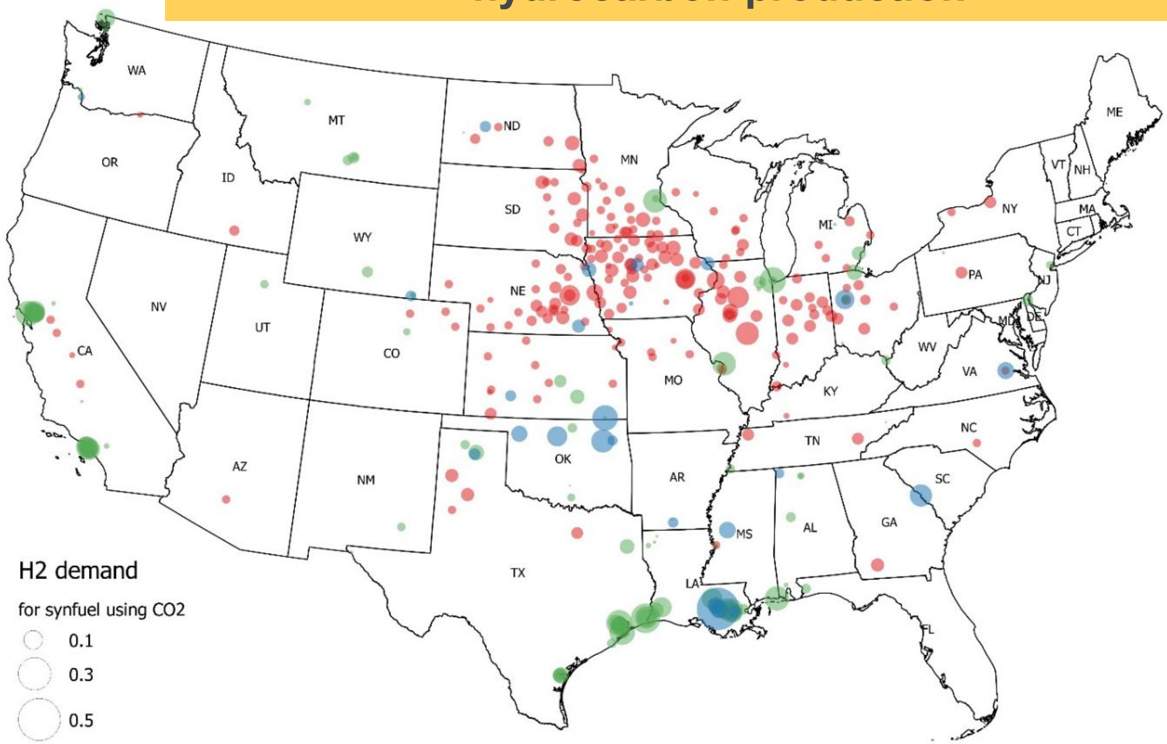
14 MMT POTENTIAL H_2 DEMAND WITH 100MMT CONCENTRATED CO_2 ANNULAY – *Accomplishment*

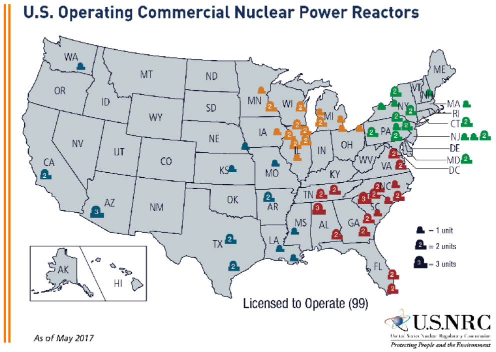
*__Assumption__: CO_2/H_2 mole ratio 1:3 for synthetic hydrocarbon production



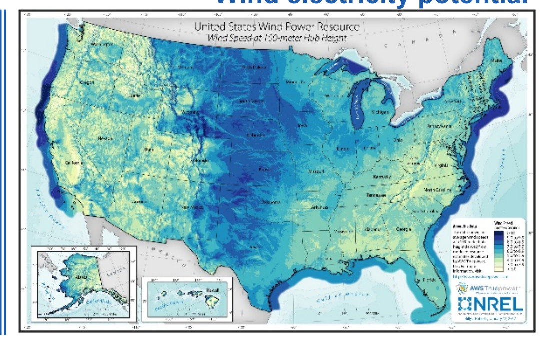
Recovered CO_2 from
- Ethanol plants
- H_2 plants
- Ammonia plants

Preliminary

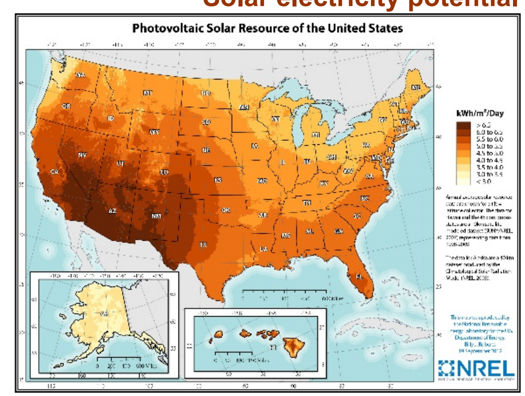
Installed nuclear plants



Wind electricity potential



Solar electricity potential



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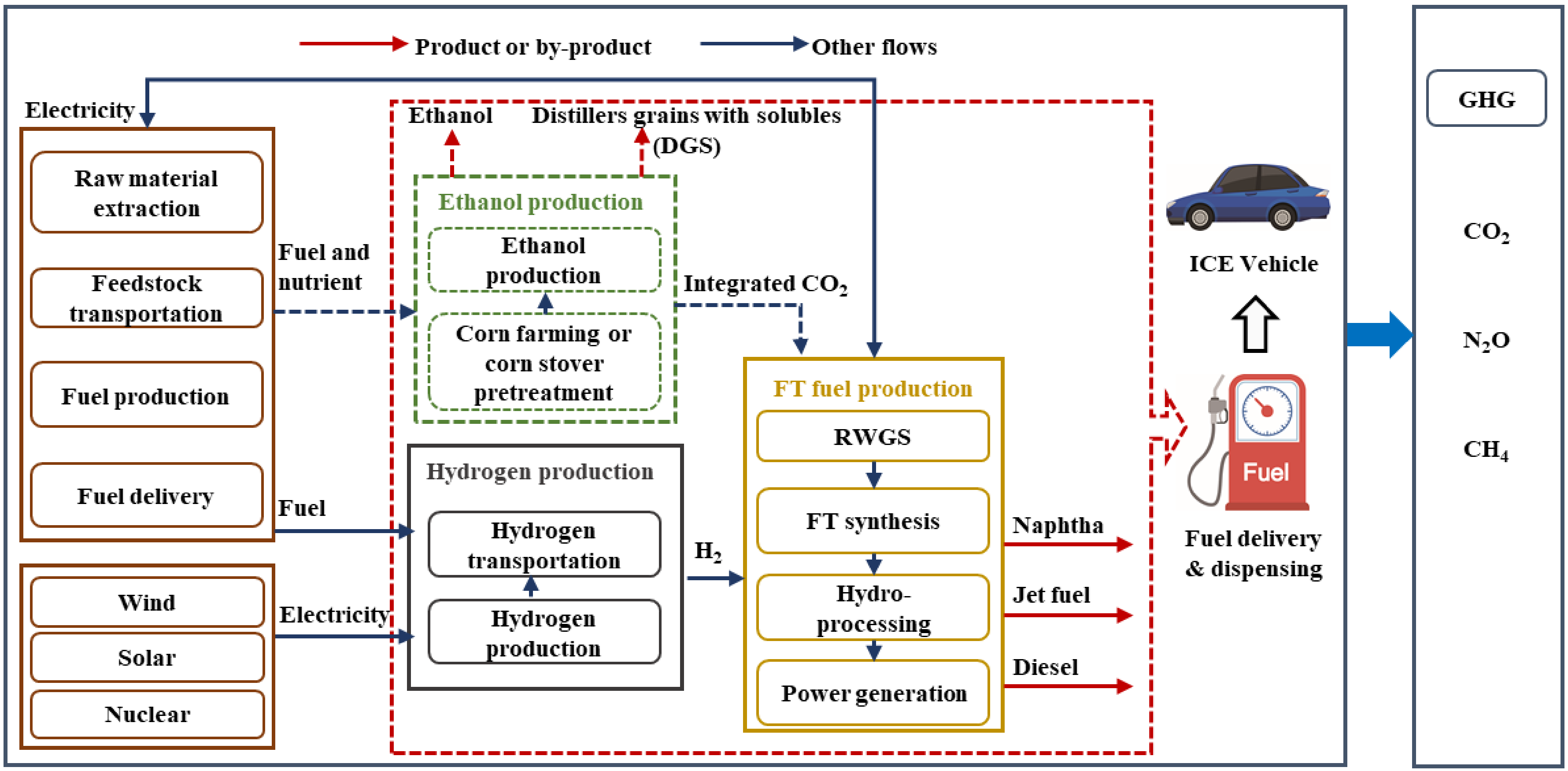
MODELED H_2 DEMAND FOR SYNTHETIC FISCHER-TROPSCH (FT) HYDROCARBON PRODUCTION – *Accomplishment*

Preliminary



Well to wheel (WTW) boundary of FT fuel production from electrolysis hydrogen and ethanol plant by-product CO_2

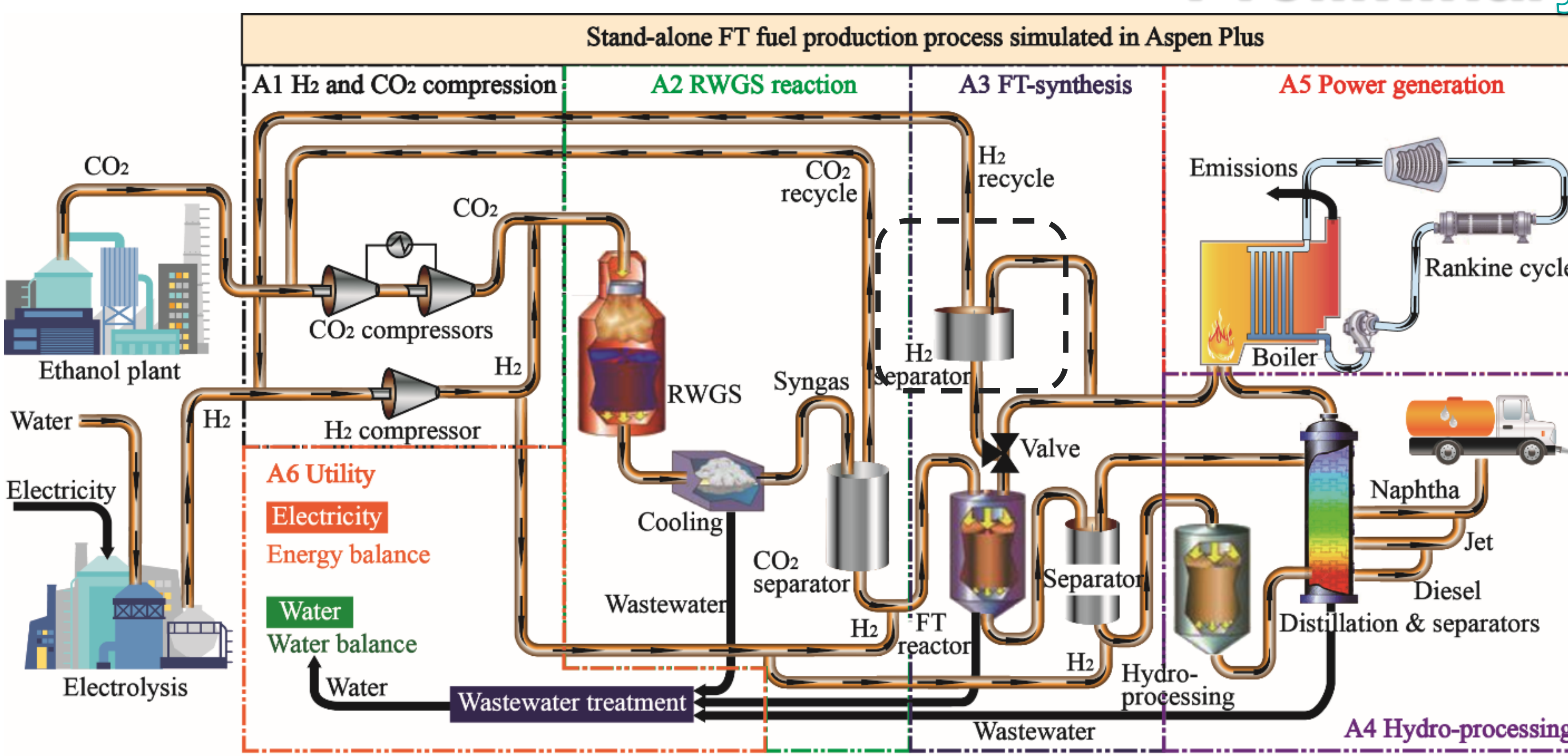
Life cycle emissions

(Forthcoming by Zang et al.)

FT FUEL PROCESS SIMULATION USING ASPEN PLUS – Accomplishment

- Six process areas were simulated
- Two systems were evaluated:
  - with H_2 recycle
  - without H_2 recycle (with electricity export)

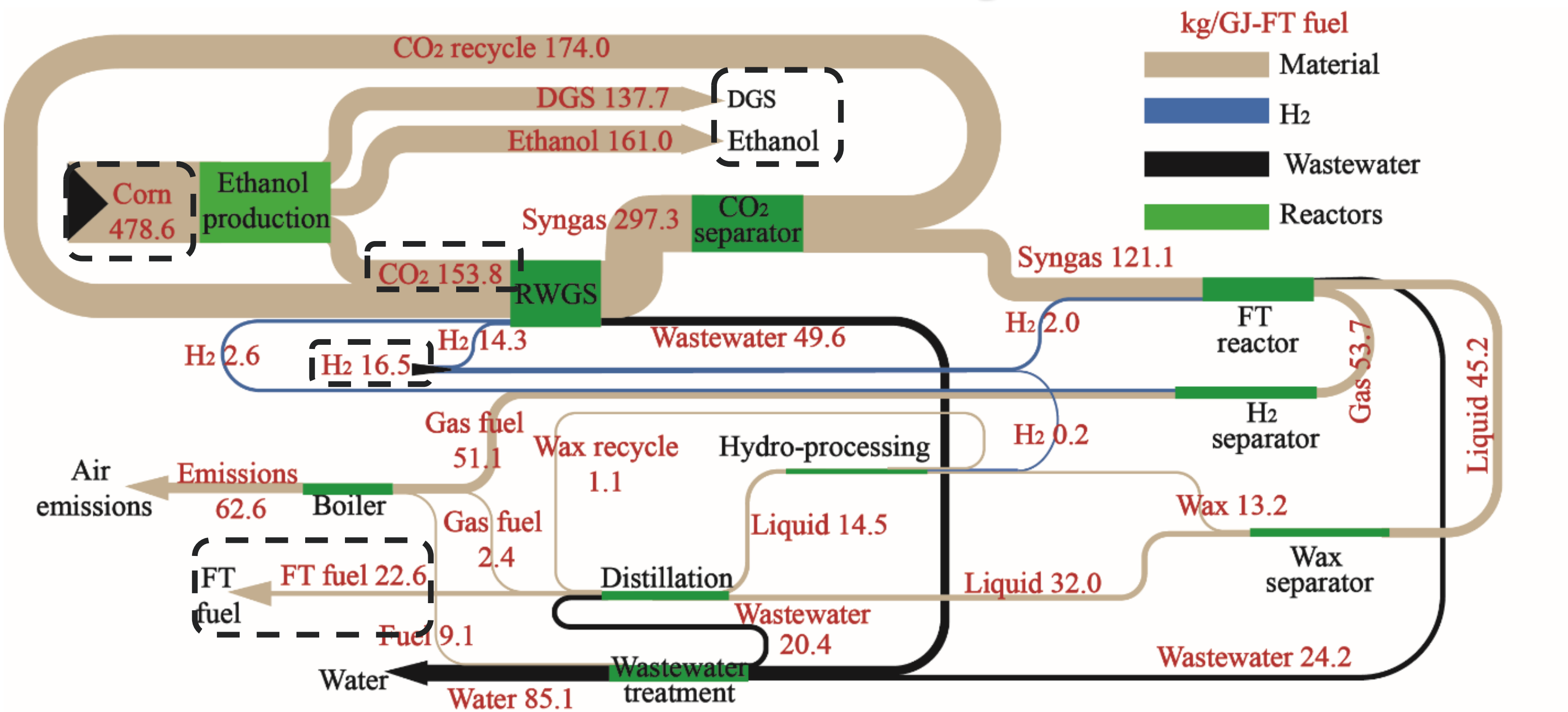
Preliminary



INTEGRATED ETHANOL AND FT FUEL MASS CONVERSION – Accomplishment

- FT fuel production is integrated with the dry milling corn ethanol production via 154 kg CO_2
- 479 kg corn and 17 kg H_2 are converted into 161 kg ethanol, 138 kg DGS, and 23 kg FT fuel

Preliminary



- **CO_2/H_2 mole ratio 1:2.4 for synthetic FT fuel production**
- **Carbon conversion efficiency ~ 46%**

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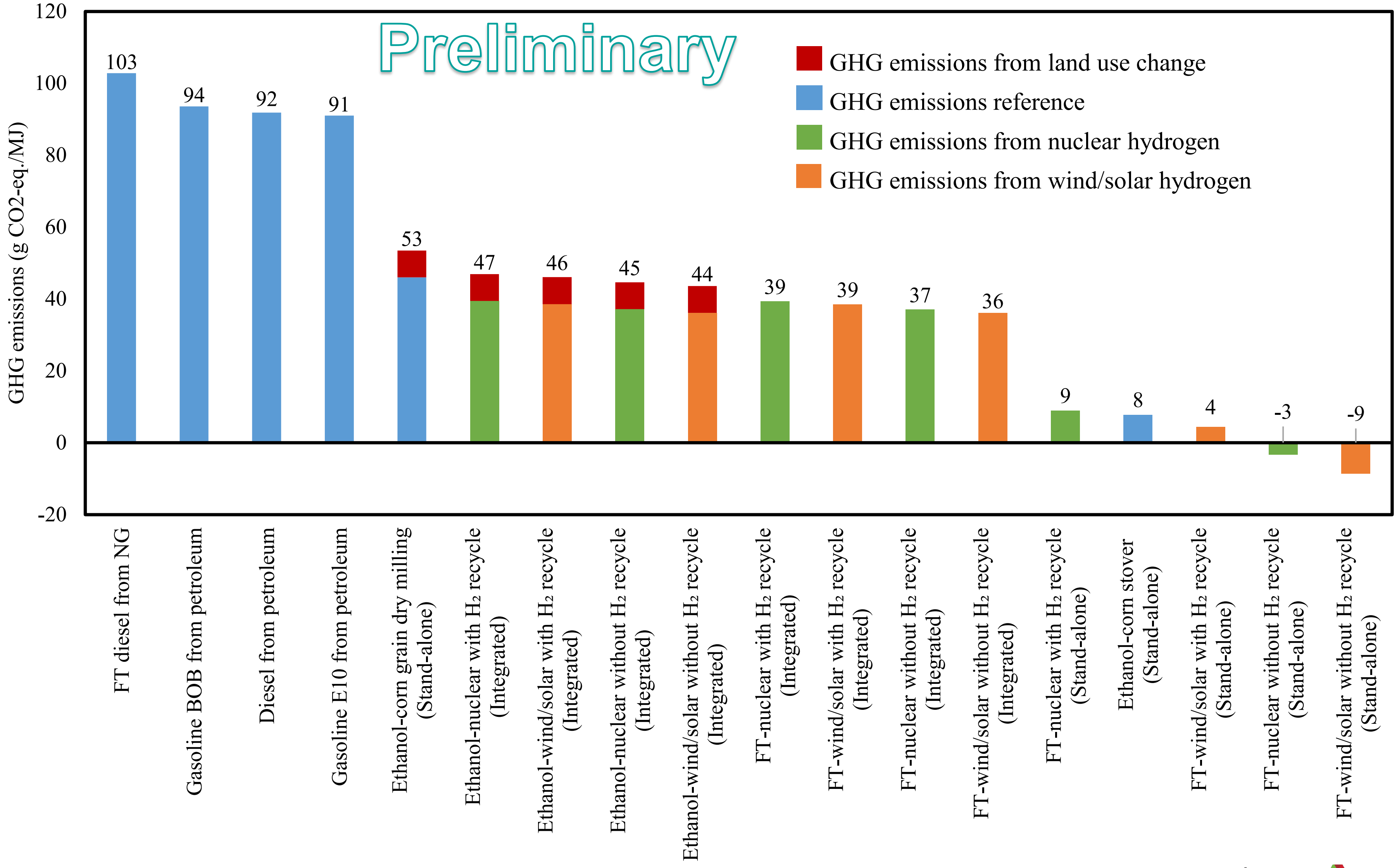
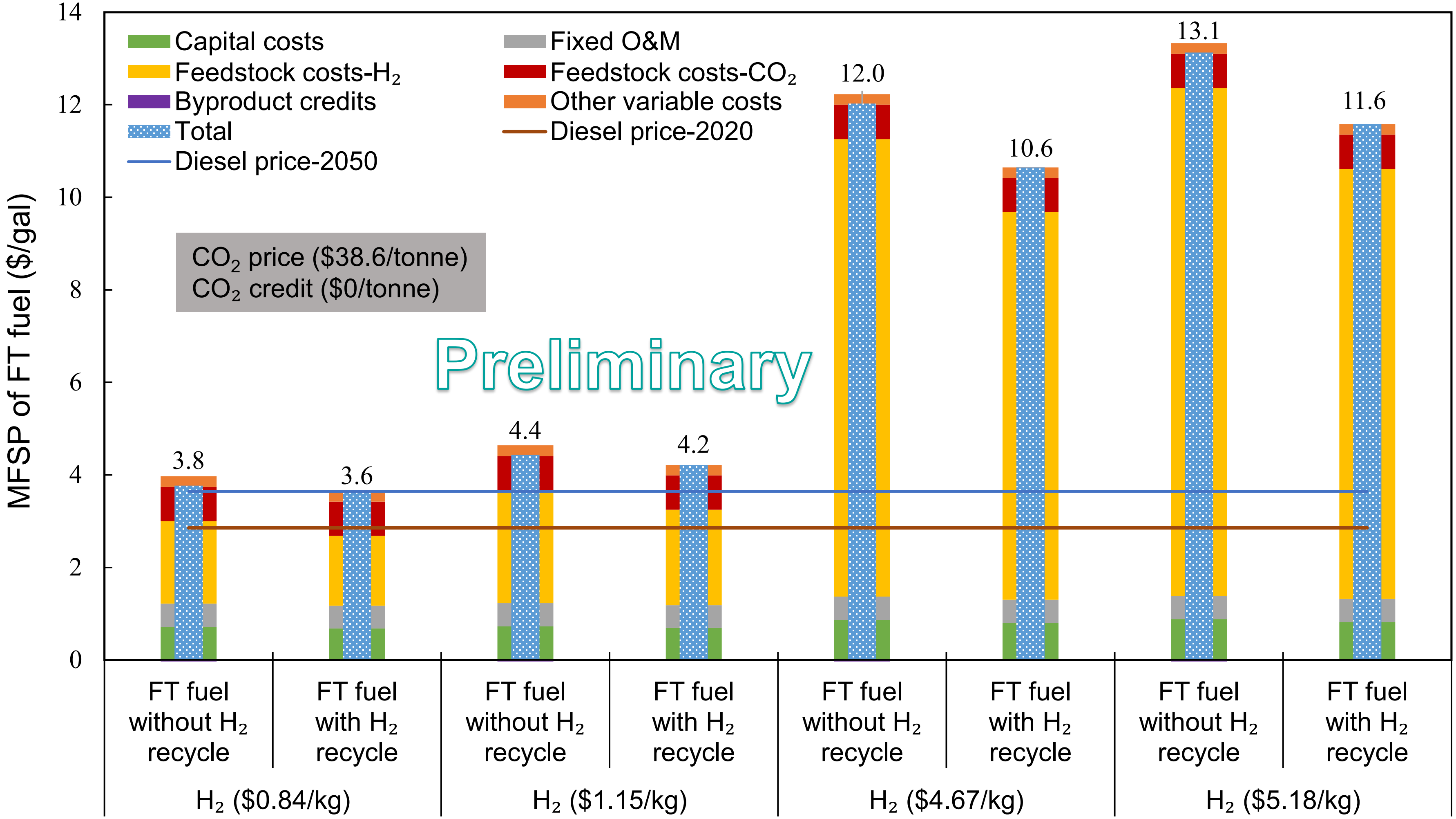
CARBON-NEUTRAL HYDROGEN PRODUCES NET ZERO CARBON FT FUELS – *Accomplishment*



(Forthcoming by Zang et al.)

HYDROGEN COST < $1/kg FOR FT FUEL TO BREAKEVEN WITH $3.6/gal DIESEL – *Accomplishment*



(Forthcoming by Zang et al.)

SUMMARY – Accomplishment

- Modeled hydrogen demand and product yield for synthetic FT production
- Simulated two FT plant designs, with and without recycling of hydrogen, using Aspen Plus
- Conducted life cycle analysis with GREET® model
  - Evaluated two co-product allocation methods
  - More than 90% CO_{2e} emission reduction compared to petroleum fuels
- Conducted techno-economic analysis using H2A framework to determine cost of hydrogen for FT fuels to breakeven with petroleum fuels
  - Hydrogen cost < $1/kg for FT to breakeven with $3.6/gal Diesel
- Documented data sources, modeling approach and analysis in two papers
  - Currently under review
  - Publication pending

Collaborations and Acknowledgments

H2@Scale is a multi-national laboratory effort with collaboration across DOE national lab complex

– Mark Ruth and Paige Jadun: NREL

– Richard Boardman: INL

Future Work

- Consider additional CO_2 sources for synthetic hydrocarbon production
  - e.g., natural gas processing plants, cement plants, power plants and direct air capture
- Conduct economic and environmental analysis of other synthetic fuels and chemicals
  - e.g., methanol and methanol-to-gasoline, etc.
  - Determine potential CO_2 reduction for each fuel and chemical pathway compared to baseline current technologies
  - Determine H_2 cost for synthetic hydrocarbon to breakeven with baseline technology pathway
- Conduct regional analysis considering proximity of CO_2 and H_2 supplies
  - Evaluate economics of delivered H_2 vs. onsite production
  - Evaluate economics of CO_2 capture and transportation

Project Summary

- **Relevance**: Hydrogen from clean energy sources can be used with available CO_2 sources to produce near zero-carbon synthetic hydrocarbon chemicals and fuels
- **Approach**: Evaluate economic and environmental impacts of synthetic fuel production using Aspen, H2A framework and GREET models
- **Collaborations**: H2@Scale is a multi-national laboratory effort with collaboration across DOE national lab complex
- **Technical accomplishments and progress**:
  - Modeled hydrogen demand and product yield for synthetic FT production
  - Evaluated two FT plant designs, with and without recycling of hydrogen
  - Conducted life cycle analysis with GREET® model
    - Evaluated two co-product allocation methods
    - More than 90% CO_{2e} emission reduction compared to petroleum fuels
  - Conducted techno-economic analysis to determine cost of hydrogen for FT fuels to breakeven with petroleum fuels
    - Hhydrogen cost < $1/kg for FT to breakeven with $3.6/gal Diesel
  - Documented data sources, modeling approach and analysis in two papers
- **Future Research**:
  - Consider additional CO_2 sources for synthetic hydrocarbon production
  - Conduct economic and environmental analysis of other synthetic fuels and chemicals
  - Conduct regional analysis considering proximity of CO_2 and H_2 supplies
  - Evaluate economics of delivered H_2 vs. onsite production
  - Evaluate economics of CO_2 capture and transportation

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