Life-cycle Analysis of Renewable Natural Gas Pathways with the GREET Model

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Renewable Natural Gas Is Processed Bio-methane Produced from

- Landfills (LFG)
- Manure and other plant or animal waste
- Wastewater
- Food waste

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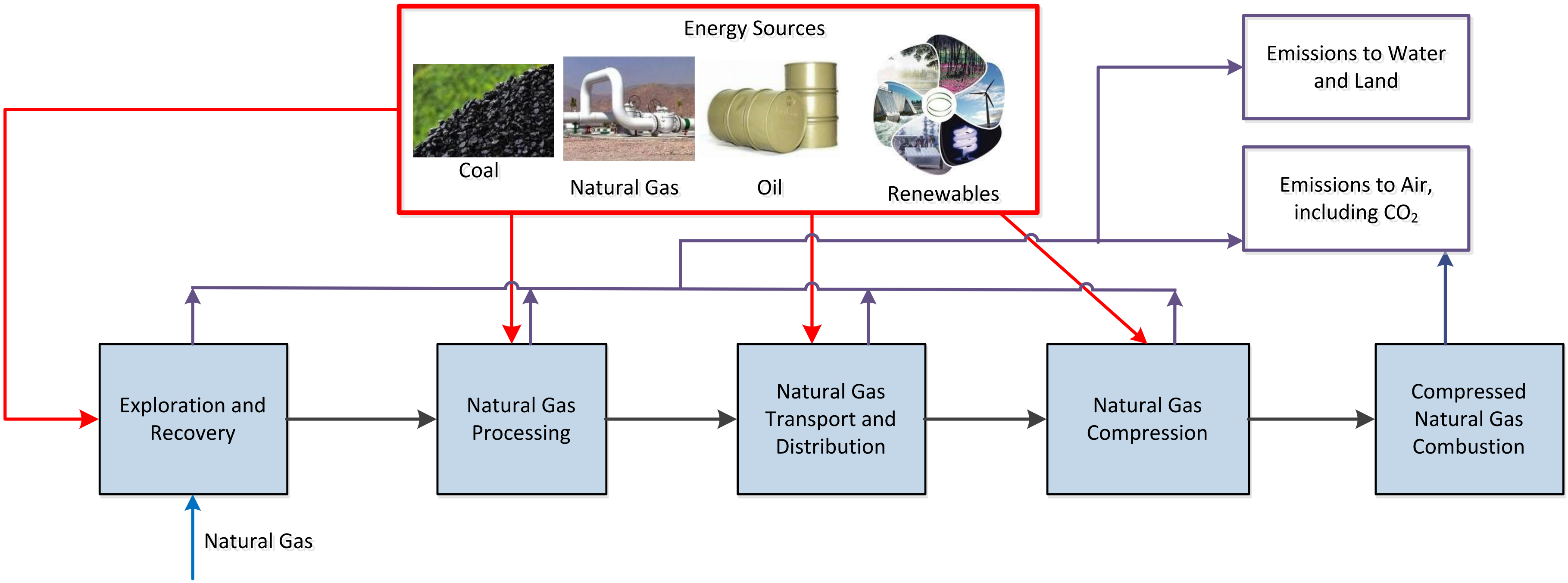
RNG: Opportunities and Processing Needs

- Candidate LFG for NG Production is 580 mmscfd while methane emission from livestock manure management in U.S. for 2009 is 293 mmscfd
  - U.S. natural gas consumption: 23.4 quadrillion Btu or 65,218 mmscfd
- EPA estimates that in 2009 over 190 MMT of CO2e emissions came from landfills, animal manure and wastewater treatment facilities
- Recovering LFG and manure-based AD gas can reduce unrecoverable methane emission and increase recoverable methane production in addition to other environmental benefits

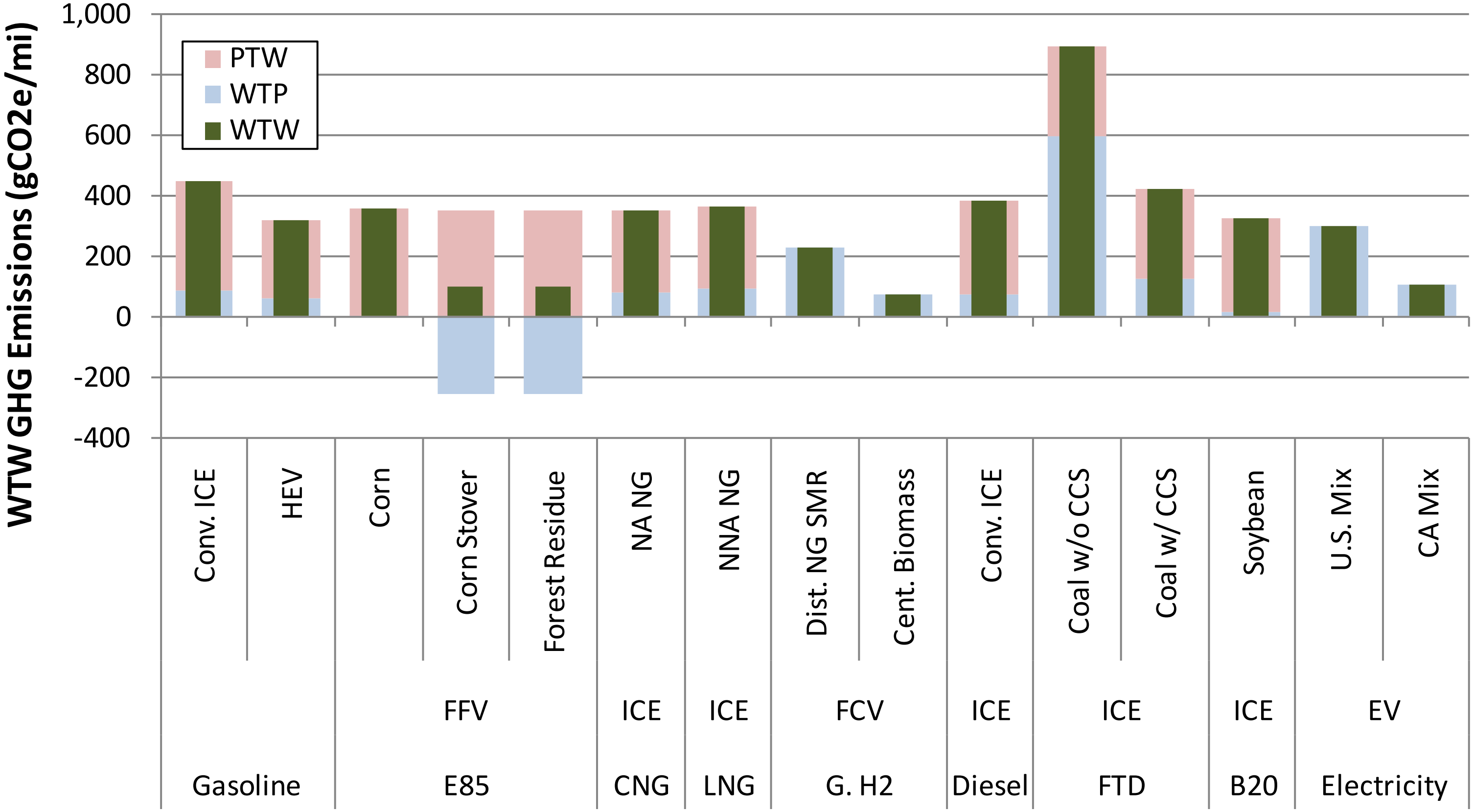
Parameter	Unit	LFG	AD-Based Biogas	NA NG	NNA NG	Pipeline NG in US
Source				(Segeler 1965)		
LHV: avg. range	Btu/ft3	450	584	1081 835–1336	1145 627–1717	1049 945–1121
CH_4: avg. range	vol %	 36–55	63 53-70	51.5 84.7–98.8	77.0 22.8–98.0	89.4 72.8–95.2
CO_2: avg. range	**vol %**	 **20–45**	**47 30-47**	0.55 0–6.0	4.1 0–29.0	**0.7 0–2.0**
N_2: avg. range	**vol %**	 **2–45**	**0.2 –**	4.03 0–29.4	1.7 0–12.1	**2.9 0–17.1**
O_2: avg. range	**vol %**	 **0–5**	**0 –**	0.06 0–0.4	0.1 0–1.4	**0.0 0–0.4**
H_2S: avg. range	**ppmv**	 **20–500**	**≤ 1000 0–10000**	100 0–3100	400 0–5200	**–**
Siloxane	**ppm**	**0.2-10**	–	–	–	**–**

Well-to-Wheels (WTW) Analysis by the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model



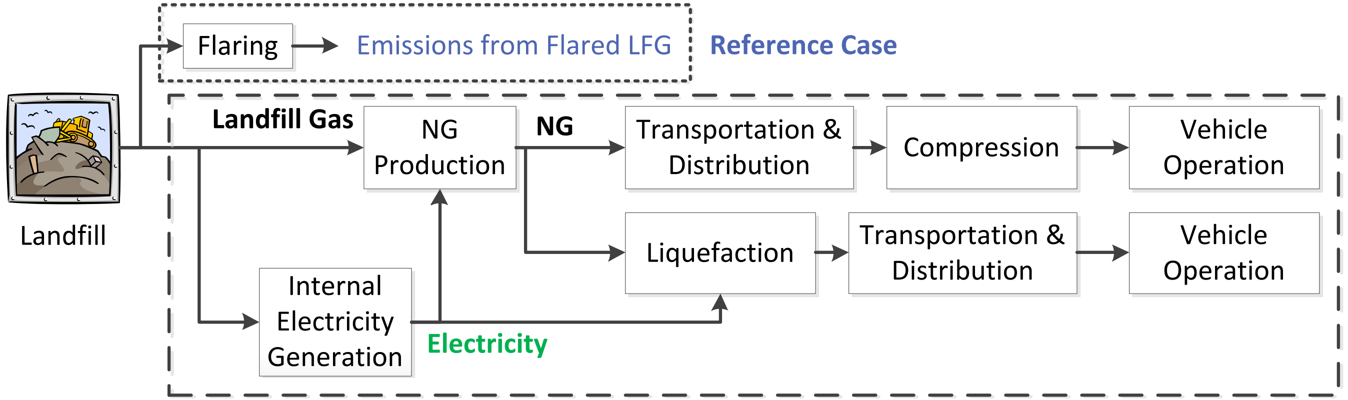
- WTW analysis of fuel systems covers activities for fuel production and vehicle use
- WTW analysis takes into account the direct fuel use and its upstream energy use and associated emissions

WTW Analysis is a Complete Energy/Emissions Comparison



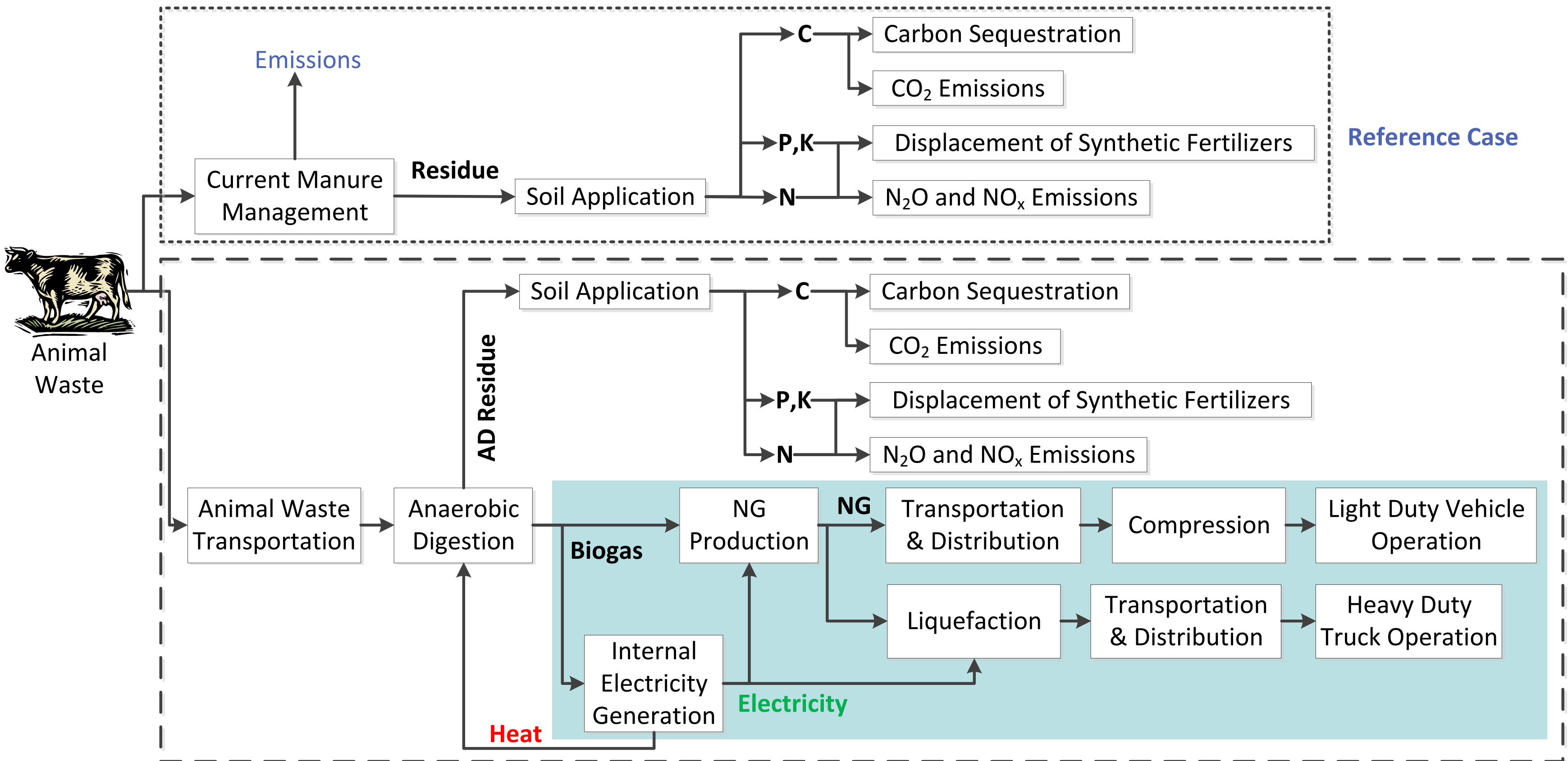
- As an example, greenhouse gases emissions are illustrated here
- In addition, energy (total, renewable, fossil, coal, NG and petroleum) and emissions of six criteria pollutants can be estimated
- This study expands GREET to RNG pathways and compares LCA results with conventional fuels

LFG Pathways Start with LFG Collected at Landfills



- Pipeline-quality RNG (bio-methane) is produced from LFG or AD-based biogas
- NG production efficiency: 94%
- 2% of produced RNG is assumed to be leaked during NG Production
- Internal electricity generation efficiency: 35%
- Compression efficiency: 97%
- Small-scale liquefaction efficiency: 89%
- Energy and emission credits from avoided emissions are accounted for
  - The reference case could be 1) flaring LFG, 2) generating LFG-based electricity or 3) mixture of flaring LFG and generating LFG-based electricity.
  - This study assumes flaring LFG is the reference case.
- Local demand is assumed: RNG is transported 50 miles from the facility where RNG is produced.

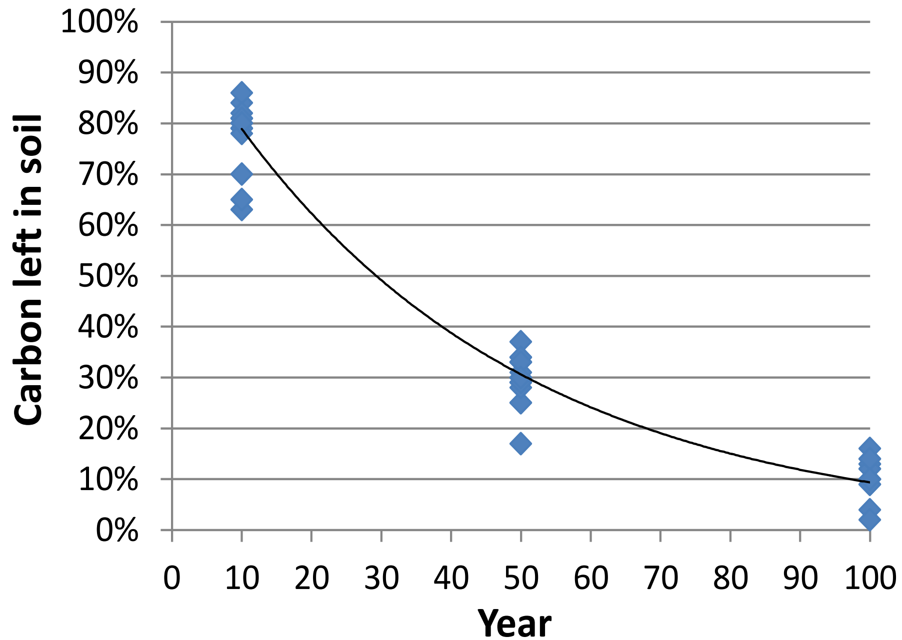
Manure-based AD Gas Pathways Start with Animal Waste Collected at Anaerobic Digesters



- Complex reference case
- Impacts of AD residue application to soil
- Operation of anaerobic digesters
- Animal waste transportation

Major Issues in Manure-based AD Gas

- Reference case emissions can be highly site-specific, depending on:
  - Livestock (species, diet)
  - Climate (temperature, precipitation)
  - Current manure management system (open lagoon, other)
- Residue from both current manure management system and anaerobic digesters is applied to soil
  - No loss of nutrients (N, P, K) by manure management or AD is assumed
  - Applied nutrients displace synthetic fertilizers
  - Applied nitrogen is converted into N_2O and NO_X emissions
  - Among carbon applied to soil, 14–37%, 63 – 83% and 84 – 98% of C applied becomes CO2 in 10, 50 and 100 years.
  - Averaging over 100 year, 62% of the C in the residue is assumed to become CO2, and the rest (38%) is assumed to remain stored in the soil.



Carbon left in soil after AD residue is applied to soil (Bruun et al. 2006)

Key Parameters for Manure-based AD Gas

- (Methane production per volatile solid [VS])
  = (Maximum amount of methane)x(Methane conversion factor)
- Maximum amount of methane from manure depends on animal species and feed regimen
  - Market Swine in North America: 0.48 m^3 CH_4/kg VS
  - Dairy Cow in North America: 0.24 m^3 CH_4/kg VS
- Animal waste can be transported to a central AD plant by truck for 3 miles
- Anaerobic Digesters Assumptions

AD Type	Covered Lagoon	Complete Mix	Horizontal Plug Flow	Mixed Plug Flow
MCF of Anaerobic Digester	69.7%	85.2%	86.8%	81.7%
Electricity required for AD (kWh/mmBtu)	0.0	19.0	19.0	19.0
Heat required for AD (Btu/mmBtu)	91,997	183,993	183,993	183,993

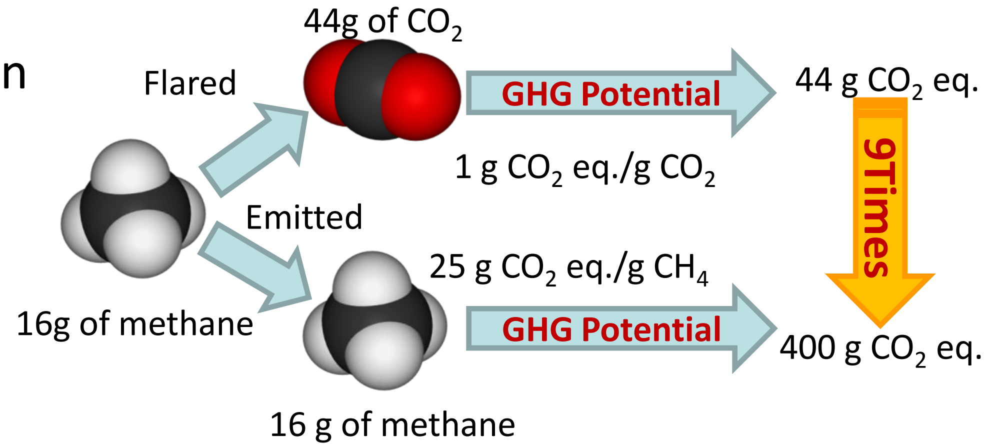
  - MCFs are based on AgStar 2011
  - Process electricity and heat inputs for complete mix, horizontal plug flow and mixed plug flow reactors are based on Frost and Gilkinson (2011), Berglund and Börjesson (2006) and Börjesson and Berglund (2006).
  - For covered lagoon process heat input is assumed to be the half of what the other reactors require, no electricity input is assumed.

Key Parameters for Manure-based AD Gas (Reference Case)

- Methane conversion factor (MCF) depends on manure management system and temperature

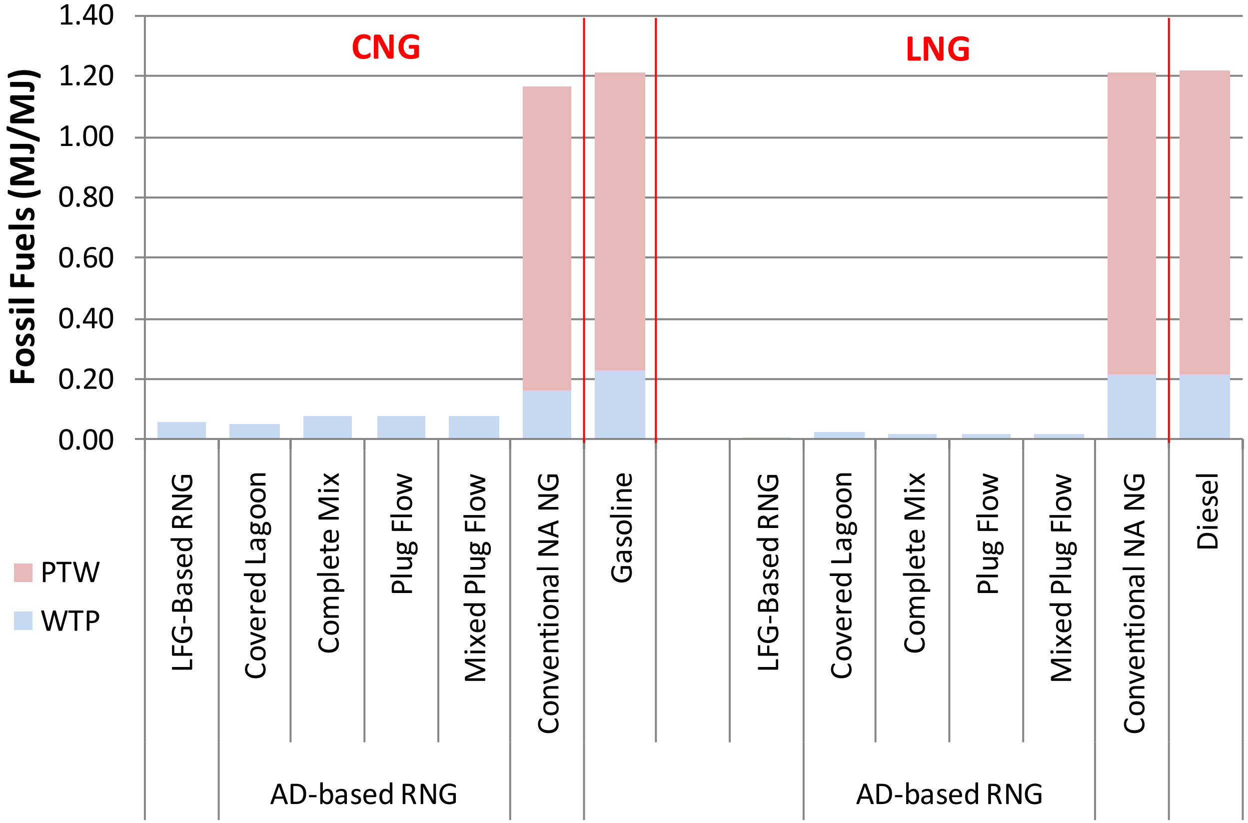
	Pasture	Daily Spread	Solid Storage	Liquid/Slurry	Anaerobic Lagoon	Deep Pit
Manure Share (MS) by system						
U.S. Average	7%	15%	23%	21%	32%	2%
California	1%	11%	9%	21%	58%	0%
Wisconsin	7%	12%	42%	24%	12%	4%
Methane Conversion Factor (MCF) by system and location						
U.S. Average	1.2%	0.2%	2.6%	28.6%	69.9%	28.6%
California	1.5%	0.5%	4.0%	35%	75%	35%
Wisconsin	1.0%	0.1%	2.0%	22%	66%	22%

- If manure management system in reference case does not flare methane emissions, emission credit for the avoided emissions would be significant



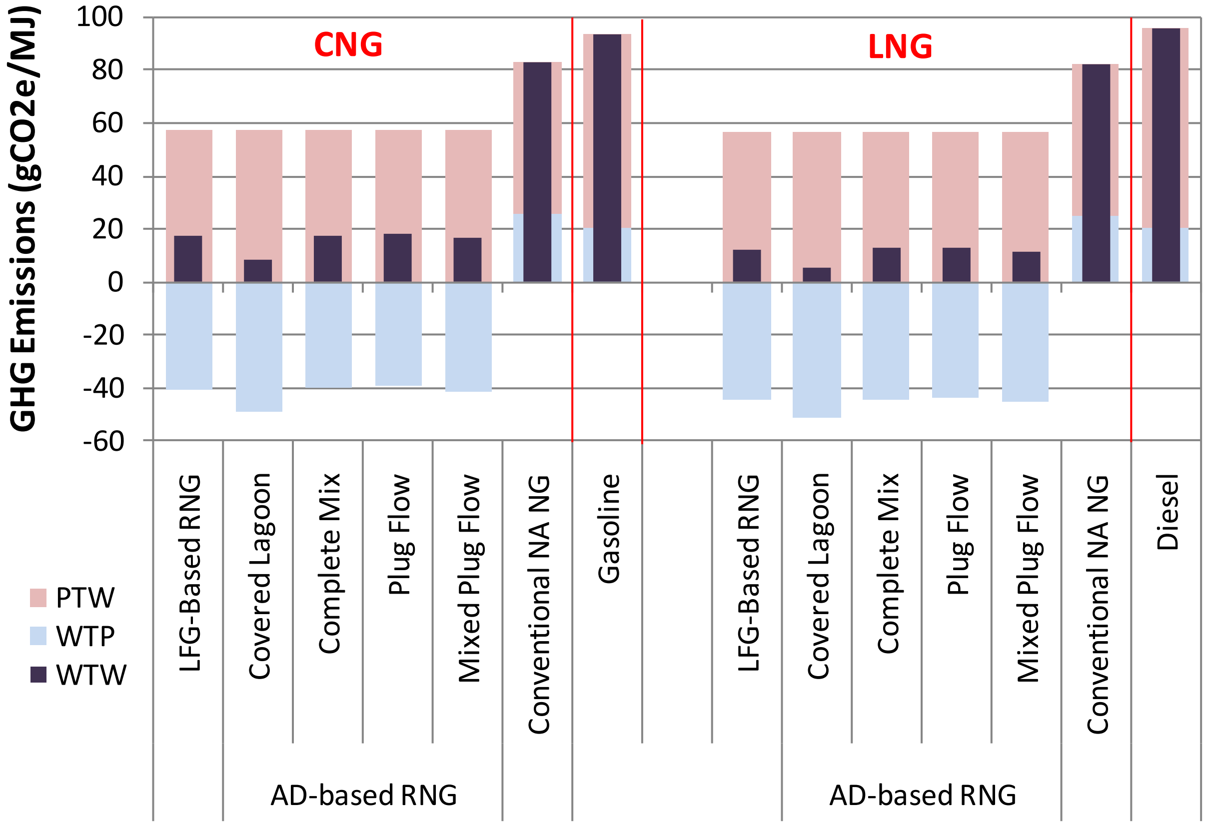
- As default, 90% of controllable methane (from solid storage, liquid/slurry, anaerobic lagoon and deep pit) is assumed to be flared in the reference case

Fossil Fuel Use Drops 94—100% for RNG Pathways Relative to Gasoline Pathways



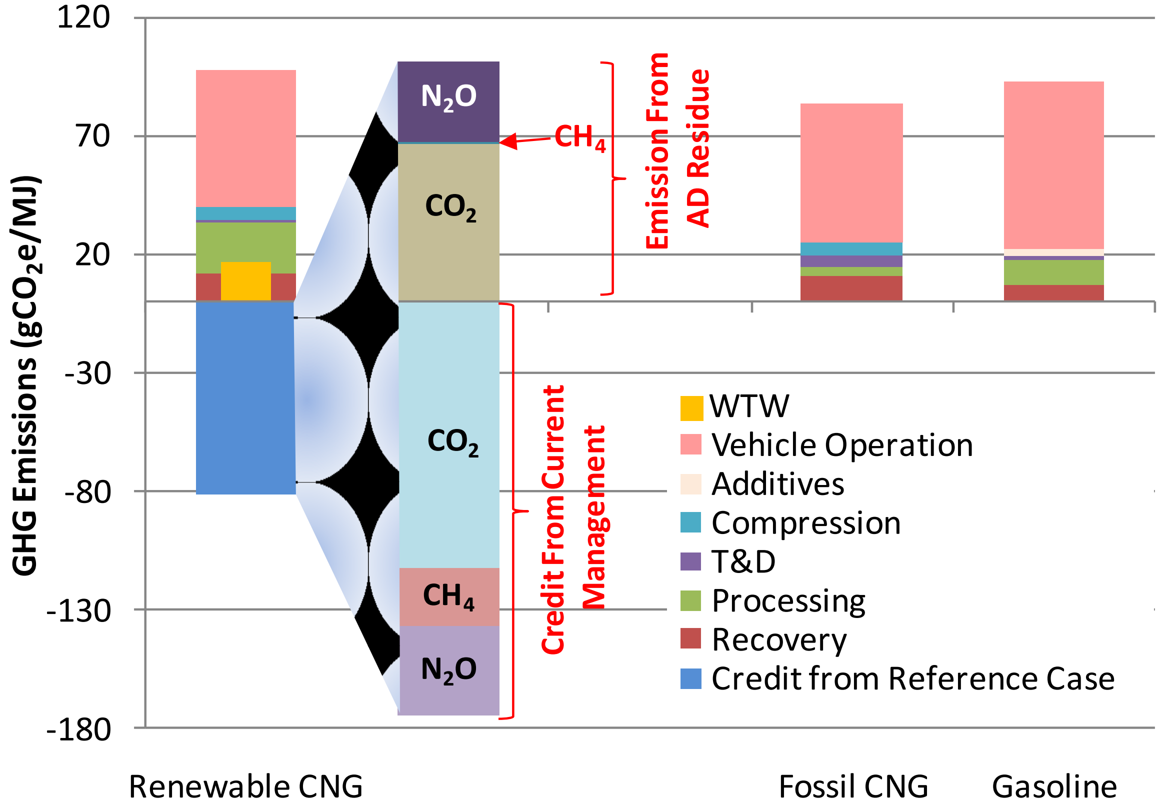
- Renewable LNG consumes less fossil fuels than Renewable CNG does because liquefaction is done by RNG while compression energy is from fossil sources

GHG Emissions Drops 81—94% for RNG Pathways Relative to Gasoline Pathways



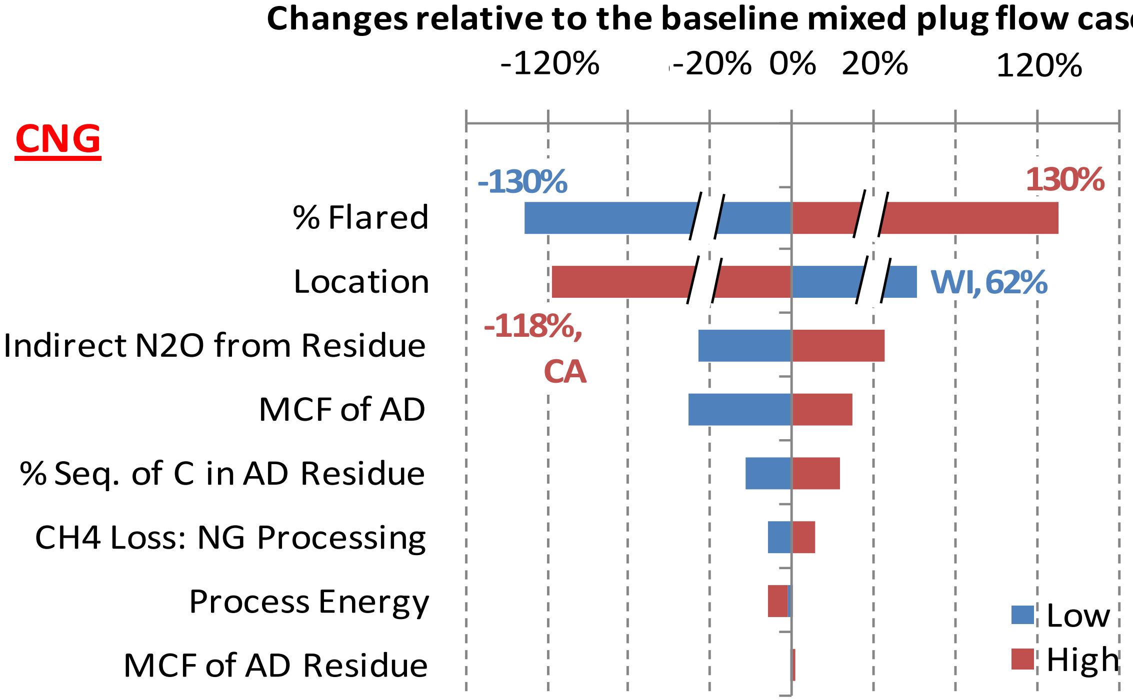
- Smaller process heat and electricity inputs for covered lagoon result in smaller GHG emissions
- Manure-based AD gas pathways generates equal or less GHG emissions than LFG pathways

Significant GHG Emission Credits are from the Reference Case (Mixed Plug Flow)



- CH_4 emissions are reduced significantly
- CO_2 emissions are also reduced because a smaller amount of carbon is applied to soil.
- N_2O emissions are also slightly reduced.

Assumptions for Reference Case are the Most Critical to WTW GHG Emissions



Low: -10% of the average value
High: +10% of the average value

- A small change in the percent of flaring controllable CH_4 in the reference case results in a significant change in WTW GHG emissions
- Location, determining MS and MCF of reference case is also important
  - High MCFs of California results in more credit from the reference case, which in turn results in lower GHG emissions

Conclusions

- RNG from LFG can cut fossil fuel use and GHG emissions by 95-100% and 82-87%, respectively, relative to gasoline
- RNG from manure-based AD gas can cut fossil fuel use and GHG emissions by 94-98% and 81-94%, respectively, relative to gasoline
- For manure-based AD gas, assumptions for reference case are the most critical to WTW GHG Emissions.
  - % of flaring controllable CH_4 in the reference case (Uncertainty)
  - Location
- Outstanding Issues:
  - Conversion of AD gas from waste water treatment plants
  - Co-digestion
  - Carbon sequestration in AD residue and waste
  - Impacts of AD residue and waste as soil amendments

Questions/Comments

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