Life Cycle Analysis of Renewable Hydrogen from Waste

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Renewable H_2 is from reformation of renewable NG produced by anaerobic digestion of biomass from:

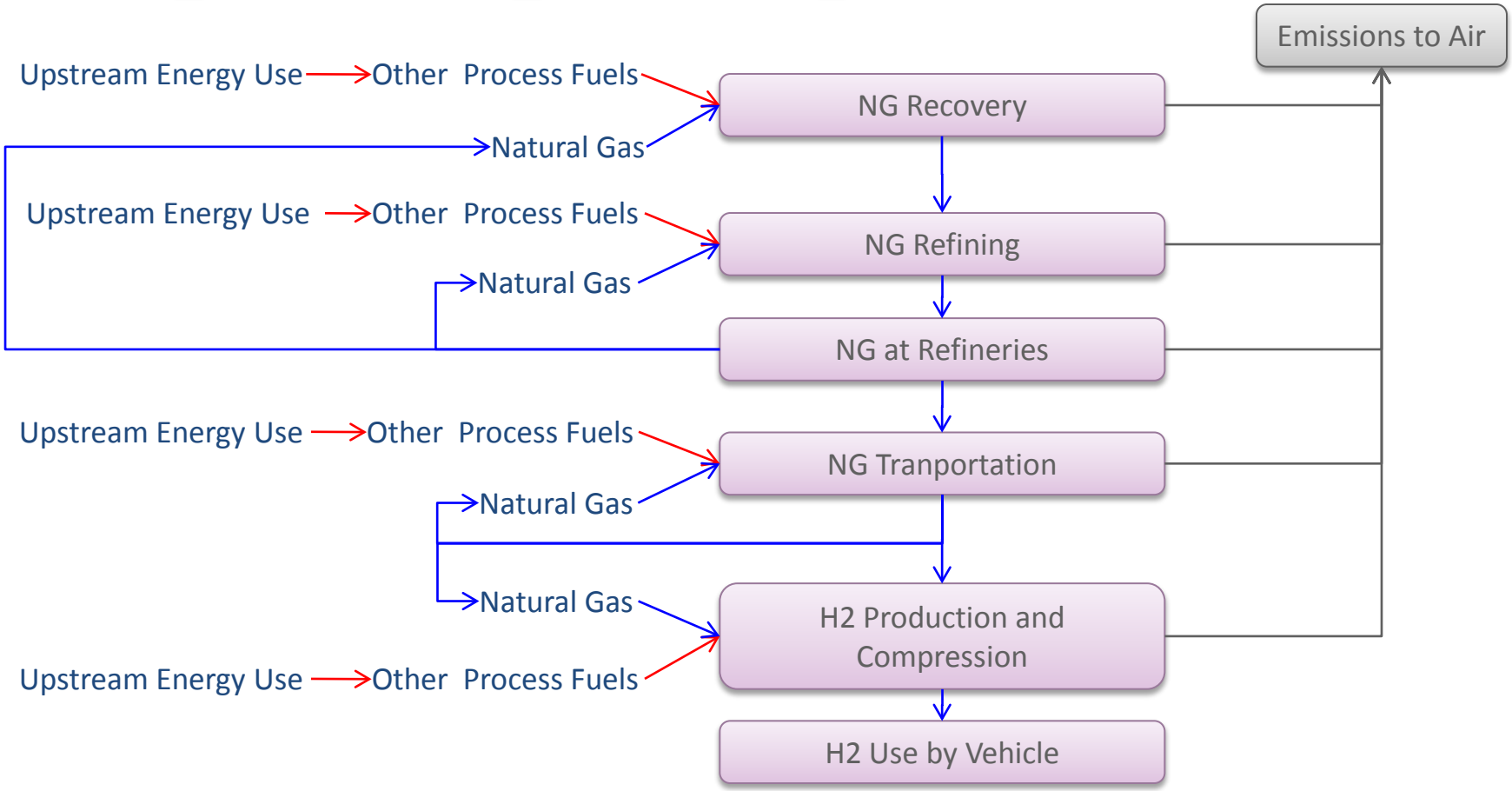
- Landfills (LFG)
- Organic matter from plants or animals
- Wastewater
- Food waste

Renewable H_2: Benefits and Issues

- Candidate LFG for NG Production is 580mmscfd that could be converted into 3500 metric tonne of H2 per day, accounting for 12% of U.S. H_2 production
- Methane emission from livestock manure mangement in U.S. for 2009 (recoverable or unrecoverable) is 293 mmscfd that could be converted into 1772 metric tonne per day, accounting for 6% of U.S. H_2 production
- Animal waste anaerobic digestion (AWAD) can reduce unrecoverable methane emission and increase recoverable methane production in addition to other environmental benefits
- Renewable NG is required more purification than most fossil-based NG before reformed into H_2

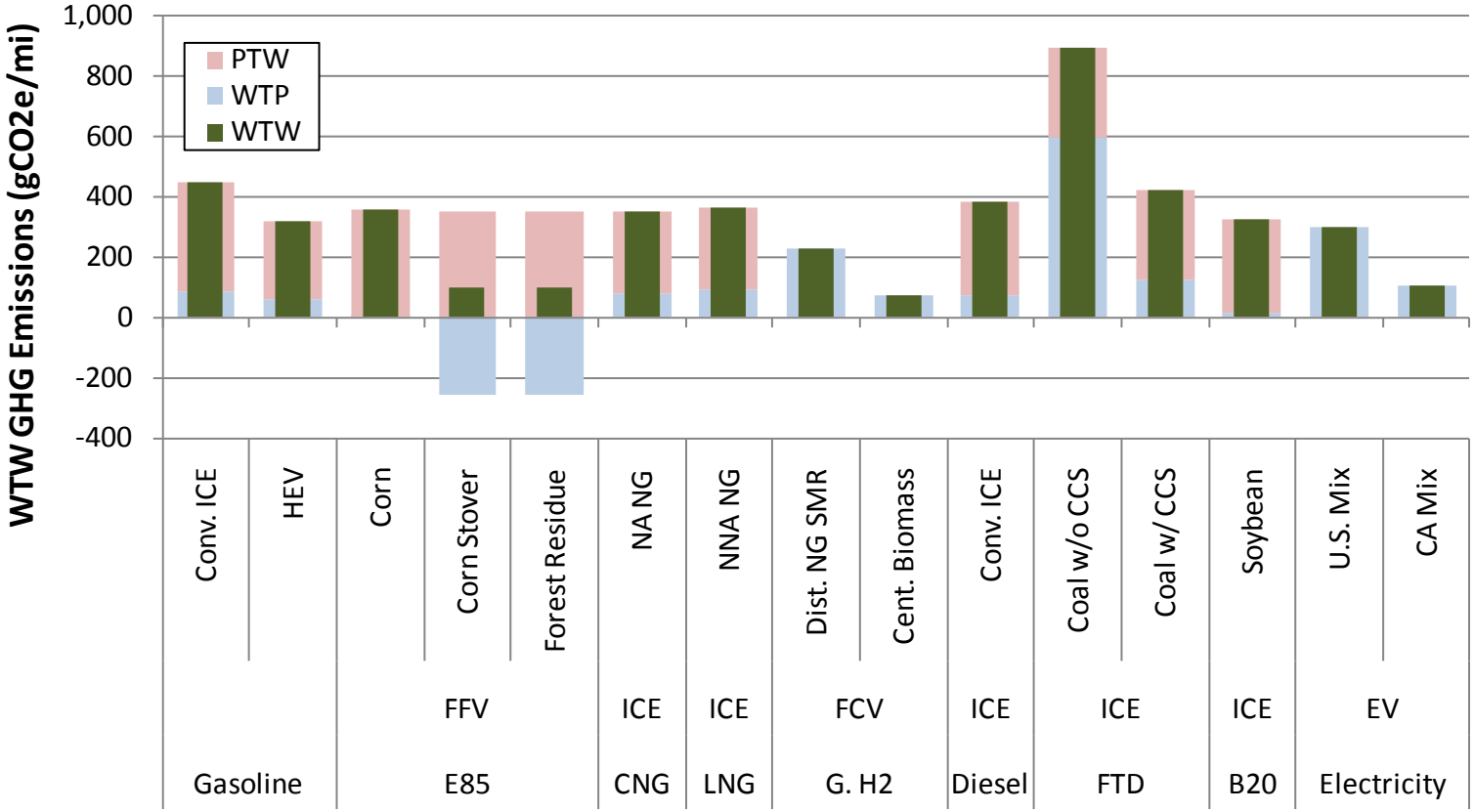
Parameter		Unit	LFG	AD-Based Biogas	NA NG	NNA NG	Pipeline NG in US
Source					(Segeler 1965)		
LHV:	avg. range	Btu/ft^3	450	584	1081 835–1336	1145 627–1717	1049 945–1121
CH_4:	avg. range	vol %	36–55	63 53-70	51.5 84.7–98.8	77.0 22.8–98.0	89.4 72.8–95.2
CO_2:	avg. range	vol %	20–45	47 30-47	0.55 0–6.0	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



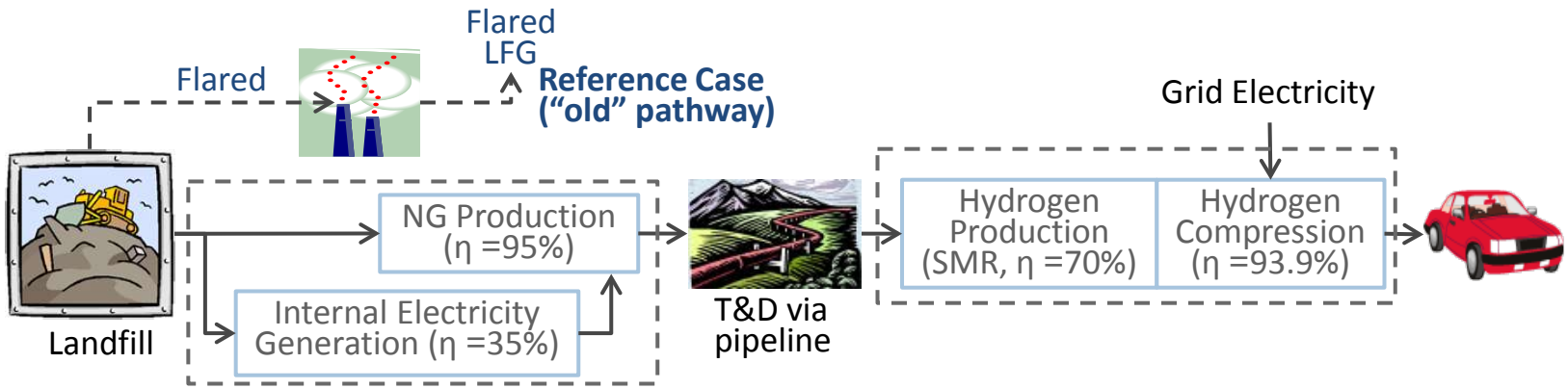
- WTW analysis of fuel systems covers activities for fuel production and vehicle use
- WTW analysis takes into account the direct fuel use and its upstream energy use and associated emissions

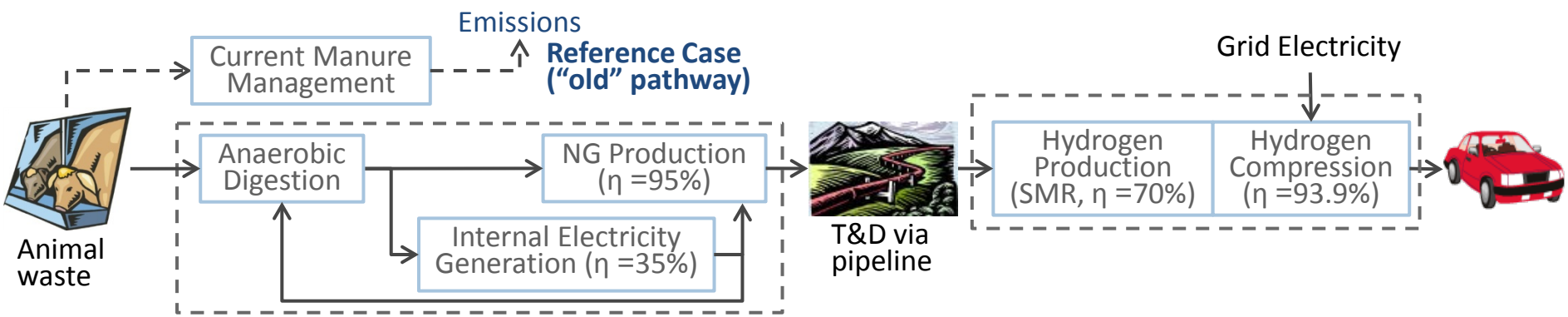
WTW Analysis is a Complete Energy/Emissions Comparison



- 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 waste-to-H_2 pathways and compares LCA results with conventional fuels

Pathway starts from collected methane for LFG, but from collected animal waste for AD-based biogas





- Pipeline-quality of methane from LFG or AD-based biogas is produced
- Energy and emission credits from avoided emissions are accounted for
- Local demand is assumed: renewable methane is transported 50 miles from landfill or manure management site to refueling stations (for on-site H_2 production)

Additional Issues in AD-based Renewable H_2

- AD residue needs to be disposed
  - AD residue is assumed to be disposed in the same way as the waste in the reference case (such as composting, soil application, …)
  - No loss of nutrients is assumed
  - The same amount of carbon sequestration as the reference case is assumed
  - Additional impacts of AD residue as soil amendment are not taken into account
- Co-digestion can boost methane yield
  - Co-digestion is not considered
- Emissions in reference cases depend on
  - Livestock,
  - Climate condition
  - Current manure management system, …
- Methane conversion factor and energy requirement of anaerobic digester can vary widely
  - Methane conversion factor of anaerobic digester is assumed 45%

Key Parameters for AD-based Renewable H_2

- (Methane production per volatile solid)
  = (Maximum amount of methane from manure)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
- Methane conversion factors depend on the manure management system and temperature

MCF of major manure management system in North America

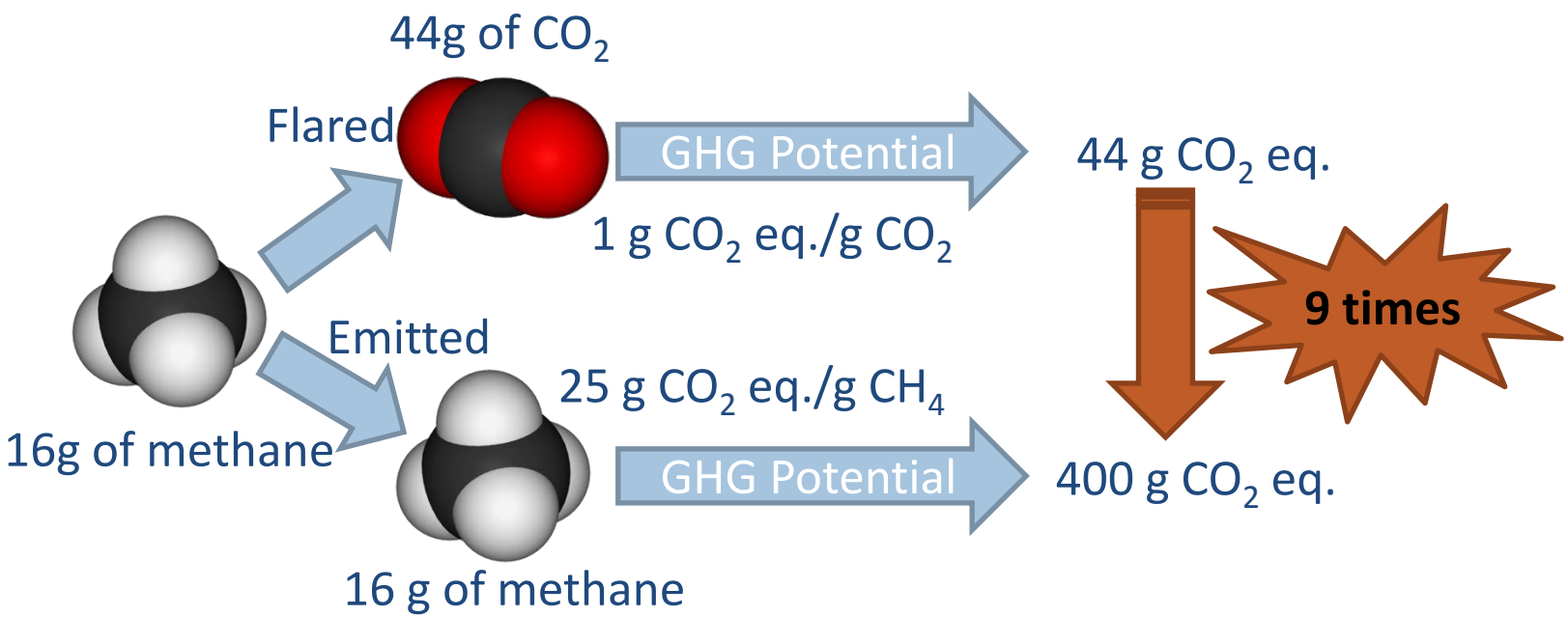
Temp.		Lagoon	Liquid/Slurry	Solid Storage	Pit>1mn	Daily Spread
11°C	52°F	68%	19%	2%	19%	0.1%
16°C	60°F	75%	29%	4%	29%	0.5%
22°C	72°F	78%	50%	4%	50%	0.5%

Share of manure management systems in North America

Livestock	Lagoon	Liquid/Slurry	Solid Storage	Pit>1mn	Daily Spread	Other
Market Swine	33%	19%	4%	41%	0%	3%
Dairy Cow	15%	27%	26%	0%	18%	14%

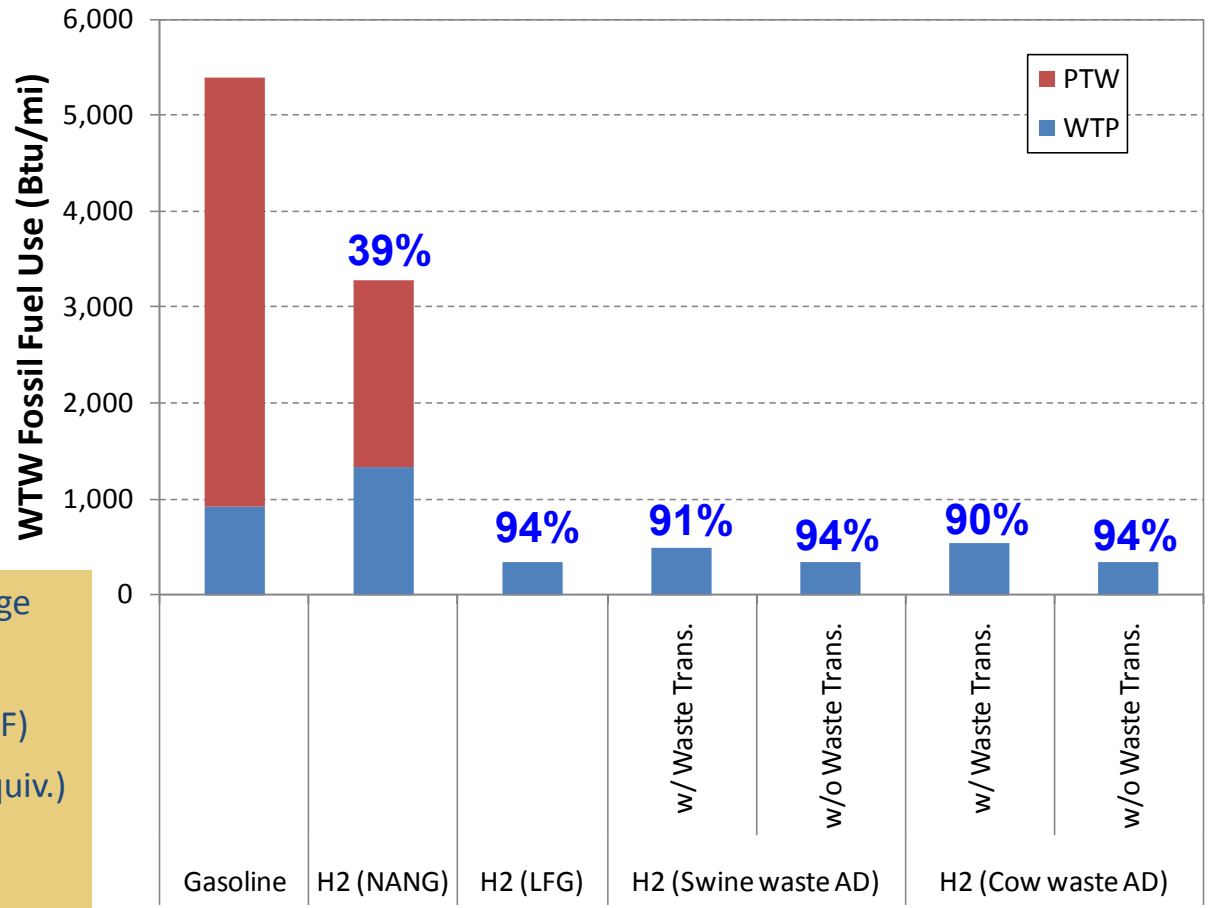
- Animal waste can be transported to a central AD plant by truck for 3 miles

Flaring methane can reduce GHG emissions by 9 fold



- If reference manure managements do not flare methane emissions, emission credit for the avoided emissions would be significant
- As default, 95% of methane is assumed to be flared

FCV fueled by renewable H_2 can reduce fossil fuel use by 90%—94% relative to gasoline ICE vehicle



Reference manure management: Average

Reference share of flaring CH_4: 95%

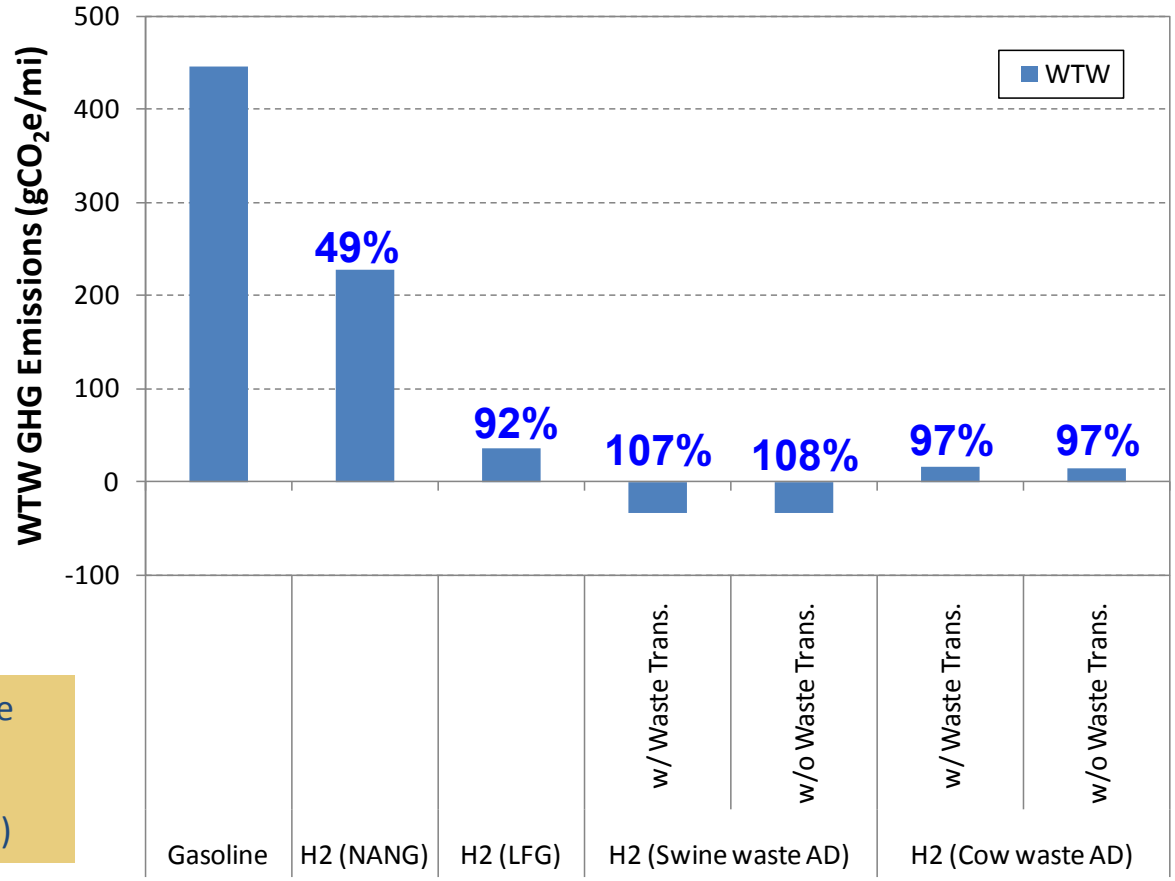
Annual average temperature: 16°C (60°F)

Fuel economy (miles per gal gasoline equiv.)

- Gasoline ICE vehicle: 24.8 mpgge
- H_2 fuel cell vehicle: 58.7 mpgge

- Waste transportation decreases reduction in fossil fuel use by 3—4%
- Renewable H_2 from swine and cow waste consumes similar amount of fossil fuels

FCV fueled by renewable H_2 can reduce GHG emissions by 92%—108% relative to gasoline ICE vehicle



Reference manure management: Average

Reference share of flaring CH_4: 95%

Annual average temperature: 16°C (60°F)

- Renewable H_2 from swine waste reduces GHG emissions more than other renewable H_2
  - The reference swine case has a larger amount of un-flared CH_4 emissions
- Waste transportation provides little impacts on GHG emissions

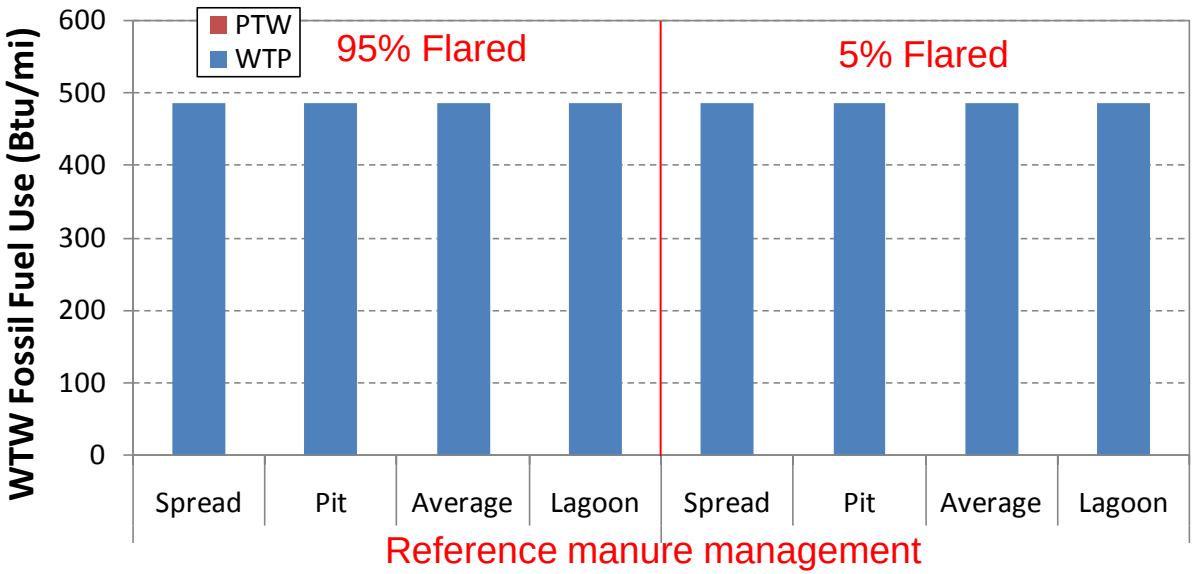
Impacts of Difference Reference Cases in AD-based Renewable H_2

- Shares of flared methane
  - 95%
  - 50%
  - 5%
- Manure management systems
  - Average
  - Pit
  - Lagoon
  - Daily spread
- Annual average temperature
  - 11°C (52°F)
  - 16°C (60°F)
  - 22°C (72°F)

Reference cases make little impacts on fossil energy use

- Similarly, reference cases make little impacts on other energy-related measures, such as total energy, NG savings

Livestock: Swine
Trans. of animal waste is included
Annual ave. temp.: 16°C (60°F)



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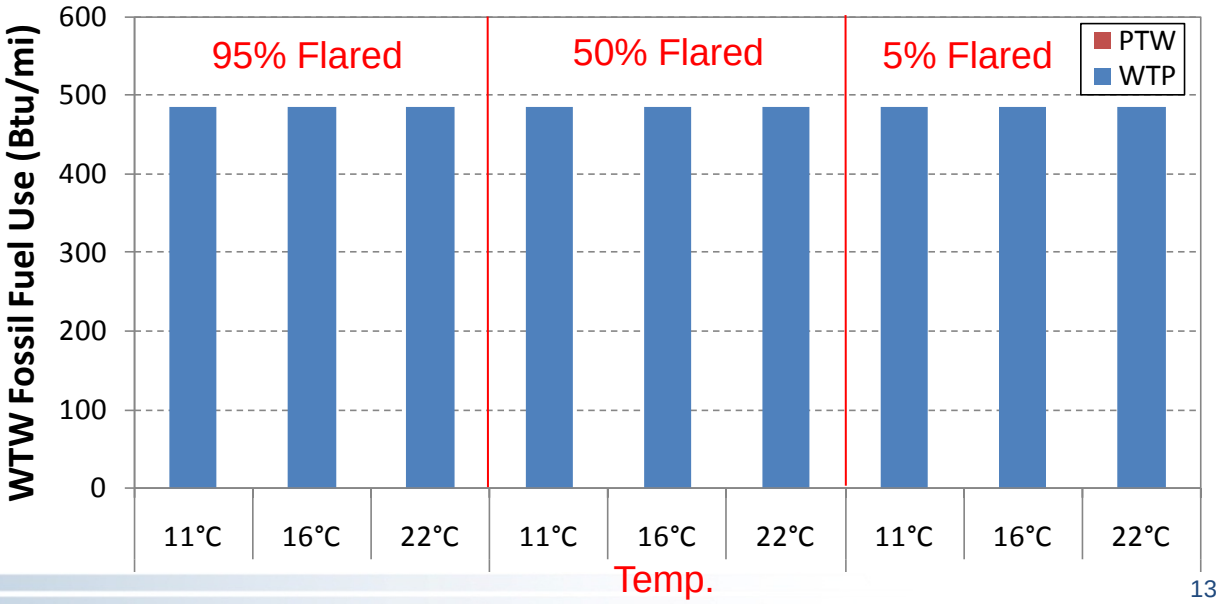
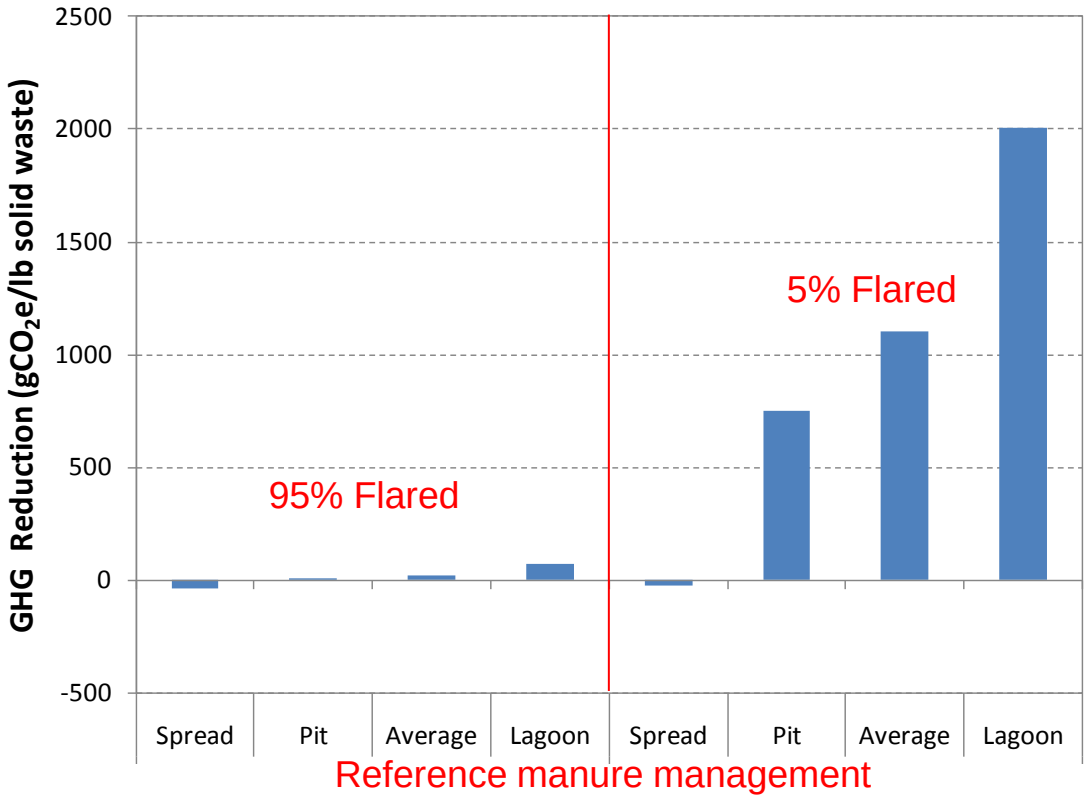


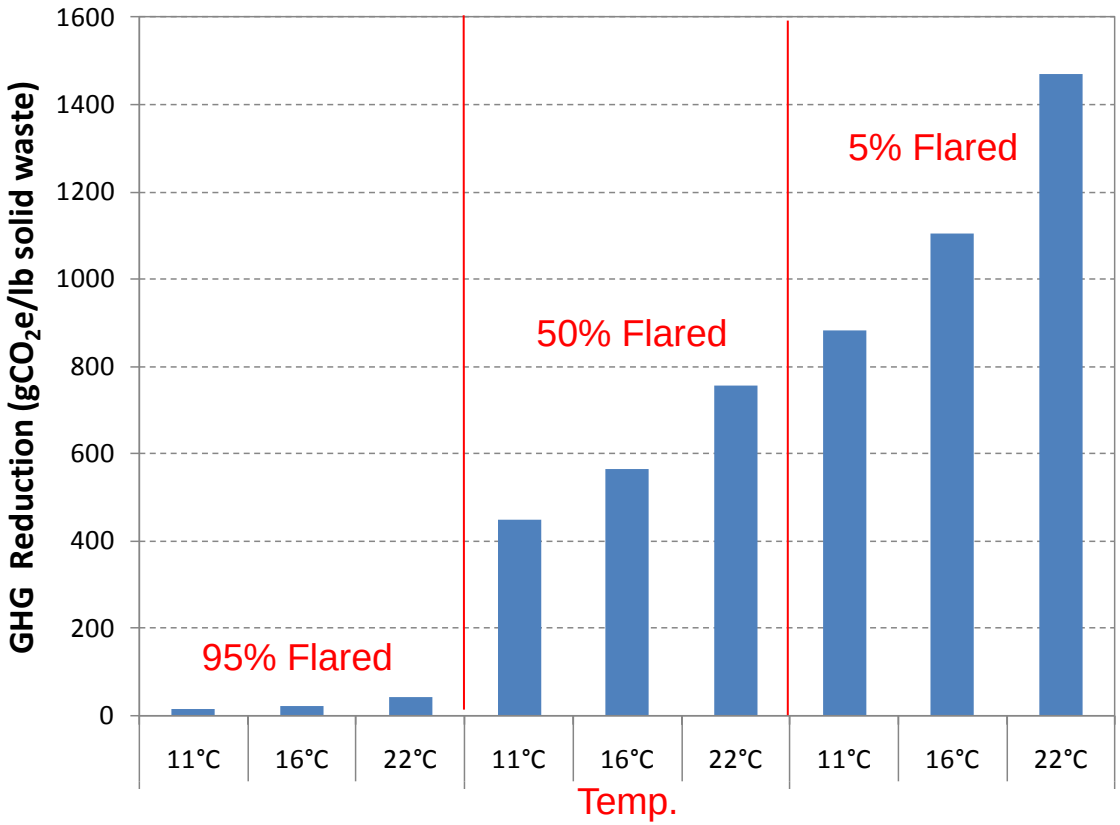
GHG reductions relative to reference cases depend on share of flaring and reference manure management



Livestock: Swine
Trans. of animal waste is included
Annual ave. temp.: 16°C (60°F)

- With aerobic management as reference (e.g daily spread), AD generates a small amount of GHG emissions regardless flaring
- Otherwise, flaring provide great impacts on GHG reduction

GHG reductions relative to reference cases depend on ambient temperature



Livestock: Swine
Trans. of animal waste is included
Reference manure management: Average

- Benefits of AD on GHG emission are greater in warmer climate

Conclusions

- FCV fueled by renewable H_2 from LFG can reduce fossil fuel use and GHG emissions by 94% and 92%, respectively, relative to gasoline ICE vehicle
  - For AD-based renewable H_2, the reductions are 90%—94% and 92%—108%, respectively, with reference share of flaring CH_4 is 95%
- GHG reductions relative to reference cases depend on reference share of flaring, reference manure management and annual average temperature
- Reference cases make little impacts on fossil energy use as well as other energy-related measures, such as total energy, NG savings
- Outstanding Issues
  - Anaerobic digestion of waste water treatment
  - Co-digestion
  - Other emissions (such as N_2O and VOC) in reference cases and AD
  - Nutrient loss in AD residue and waste
  - Carbon sequestration in AD residue and waste
  - Impacts of AD residue and waste as soil amendment

Questions/Comments

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