RNG WORKS | THE COALITION FOR RENEWABLE NATURAL GAS

Gasification to RNG

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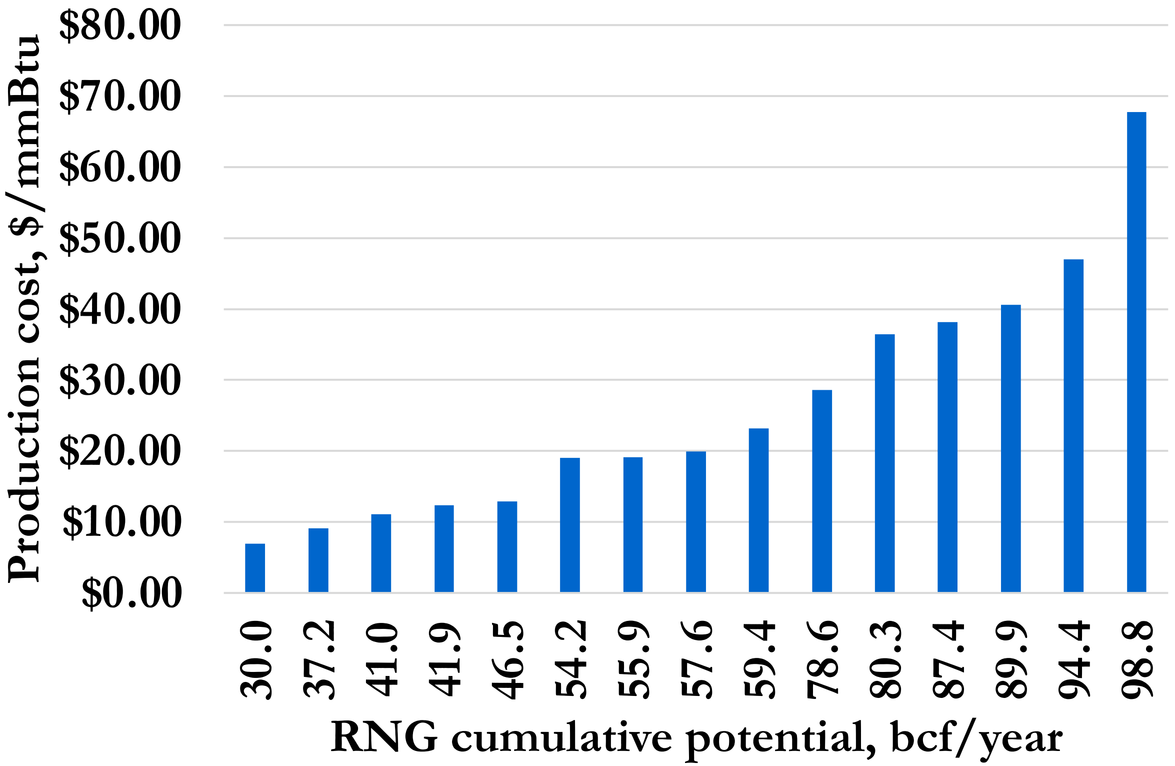
RNG from California Resources

- Center for Renewable Natural Gas
- Part of CE-CERT (Center for Environmental Research and Technology), University of California, Riverside
- Recently released study on RNG potential from in-state resources*
  - Estimate of wet feedstock availability: landfill gas, animal manure, biosolids, food and green waste
  - Pipeline grade RNG volume potential, production costs, GHG reduction & carbon abatement costs
- Compare with established baseline
  - Long term Renewable Portfolio Standard (RPS) modeling
  - 50-80% RPS scenarios using Resolve model
  - GHG reduction, electricity and carbon abatement costs

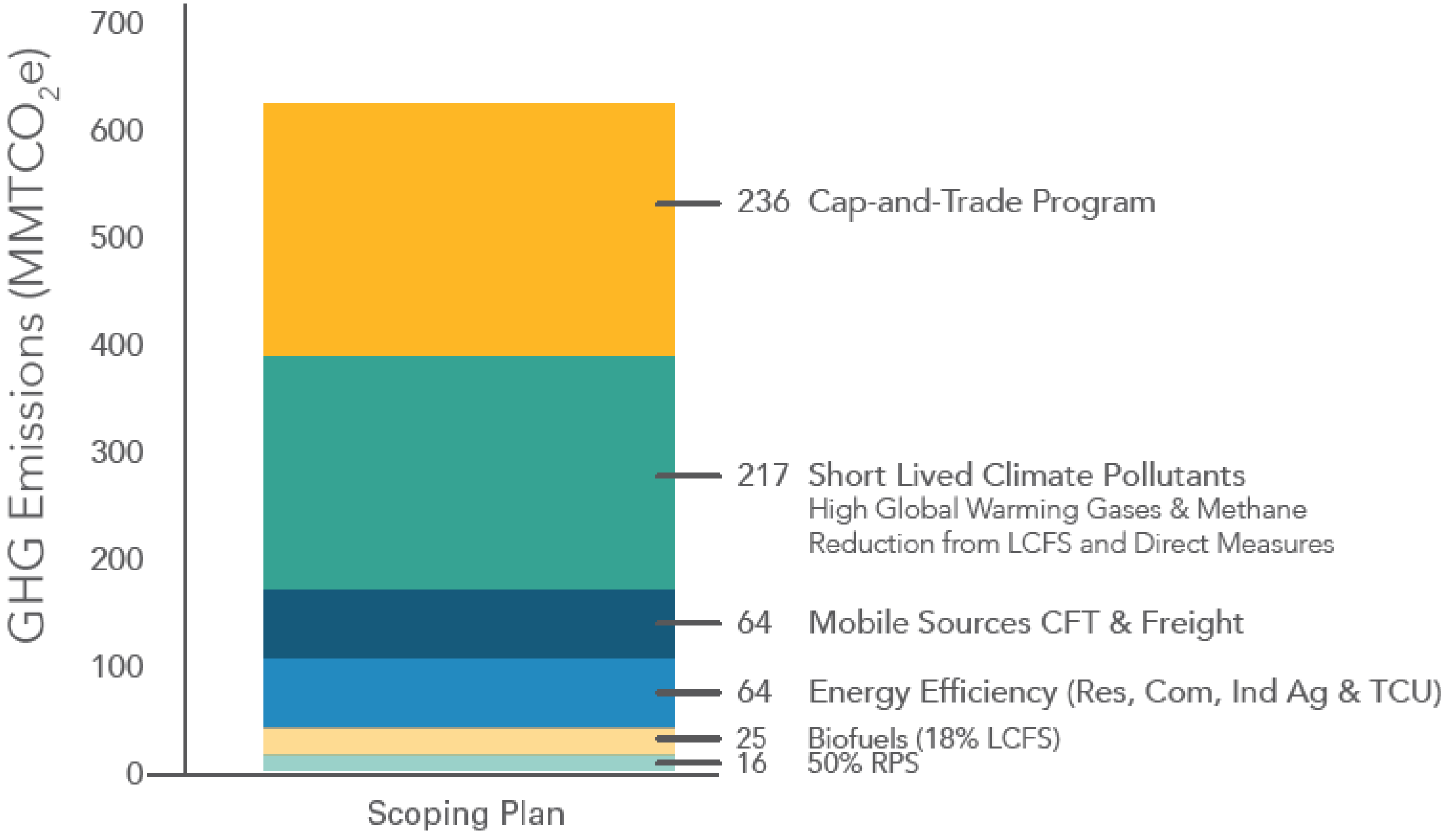


* http://www.cert.ucr.edu/crng/Optimal_Pathways_Report.pdf

GHG Reduction Potential

- RNG utilization would result in meaningful and sustained GHG emission reductions

Cumulative RNG production potential, bcf/year	GHG reduction, CO_{2e} MMT
56	3
80	5.1
99	11.4



https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

Carbon Abatement Cost

- Carbon abatement costs are comparable to other pathways
  - Scoping Plan has very high cost estimates for RNG

Cumulative RNG production potential, bcf/year	Cost of avoided CO_2, $/metric ton
55.2	$93
75.4	$202
98.8	$434

UCR estimates based on feedstock estimates, availability & specific LCFS CI values*

Measure	Cost/metric ton in 2030	Cost/metric ton 2021-2030
50% RPS	$175	$100 - $200
Liquid Biofuels (18% CI Reduction Target LCFS)	$150	$100 - $200
Short-Lived Climate Pollutant Strategy	$25	$25
10% incr. RPS + 10 GW btm solar PV	$350	$250 - $450
Liquid Biofuels (25% CI Reduction Target for LCFS)	$900	$550 - $975
5% Increased RNG	$1500	$1350 -$3000

https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

California RNG Potential

- CA annual RNG potential from wet feedstocks ~ 99 bcf (5% of 2030 gas consumption)
  - landfill gas, animal manure, biosolids, food and green waste
  - Production cost range \$6 – 68 /mmbtu
  - Up to 46 bcf under \$13/mmbtu
  - Up to 80 bcf under \$30/mmbtu
- GHG reduction potential ~ 11.4 CO_{2e} MMT
- RNG can play a key role in helping the state achieve climate goals
- Reaching beyond 99 bcf requires thermochemical conversion

UCR | College of Engineering- Center for Environmental Research & Technology — **KEY FINDINGS**

99 Billion cubic feet — In-State RNG Resource Potential

11.4 Million Metric Tonnes — Total CO_{2E} GHG Reduction from RNG Use

Cumulative RNG production potential BCF/Year	Cost of avoided CO_2 \$/tonne
55.2	\$93
75.4	\$202
98.8	\$434

Estimated CO_2 Avoidance Cost Range from CARB 2017 Scoping Plan Measures = -\$300 to \$200 per Metric Ton*

*https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

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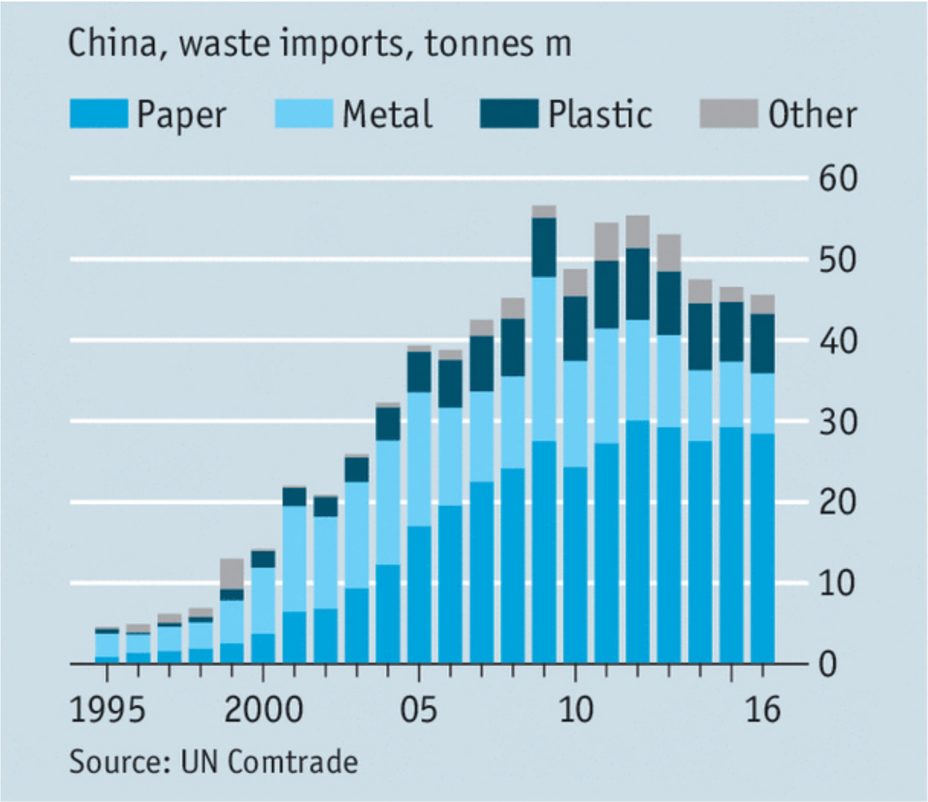
Resources

- Significantly larger quantities of resources are available
- Wet feedstocks (LFG and AD): 99 bcf/year
- Potential for an additional 10-20% of throughput:
  - Landfilled organics
  - Biomass
- State goal is 75 % of solid waste to be source reduced, recycled, or composted by 2020 (AB 341)
- Recyclables export is facing challenges
  - Plastics (polyethylene, propylene, styrene)
- RNG is attractive both technologically and economically



Economist.com

https://www.economist.com/china/2017/08/03/china-tries-to-keep-foreign-rubbish-out

Technology Options

- AD is commercially mature and widely used but for limited feedstock options
- Low to medium efficiencies – complete carbon conversion not achieved
- Often used for power generation
- Gasification offers high carbon conversion and thermal efficiencies
- Can convert most carbonaceous matter

	Thermochemical	Biological
Reaction rates; g/L/h	10^3 - 10^4	10^1 - 10^2
Feedstock flexibility	High	Low
Thermal efficiency	High	Medium/low
Temperature, °C	~1000	~30
Pressure, atm	20-50	1

J. J. Spivey and A. Egbebi, H_2 from coal-derived syngas: catalytic synthesis of ethanol as a H_2 carrier, ACS National Meeting, Apr 2008

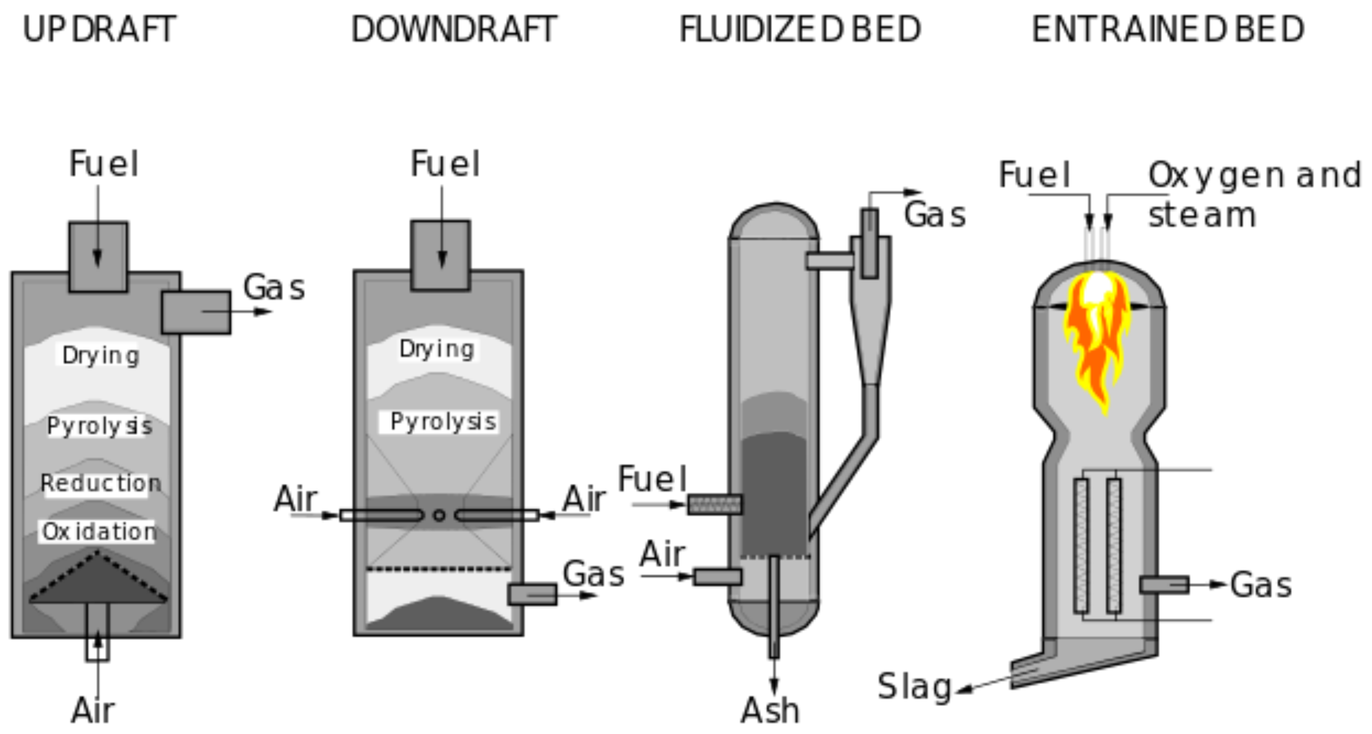
Gasification

C + Gasifying agent + Heat (700-1400 °C) ⟶ Gases (H_2, CO…) + ash

- Partial oxidation (O_2)
- Hydrogasification (H_2)
- Steam pyrolysis (H_2O)

r_{O_2}	>>	r_{H_2O}	>	r_{CO_2}	>	r_{H_2}
10^5		3		1		3.1^{-3}

At 1073 K and 0.1 atm*



* Gas reactions of carbon, Advanced Catalysis XI, 133, 1959; https://en.wikipedia.org/wiki/Gasification

Gasification to RNG

- High Efficiency
- Feedstock Flexibility
  - Accept most carbonaceous matter
  - Waste conversion
- Product Flexibility
  - Syngas is a versatile feedstock
- Environmental Benefits
  - GHG and criteria pollutant mitigation
- High capital costs
  - Distributed facilities
- Technology maturity
  - Innovative solutions needed
  - Demonstration & pre-commercial activity
- Policy barriers

ECN
MILENA gasification

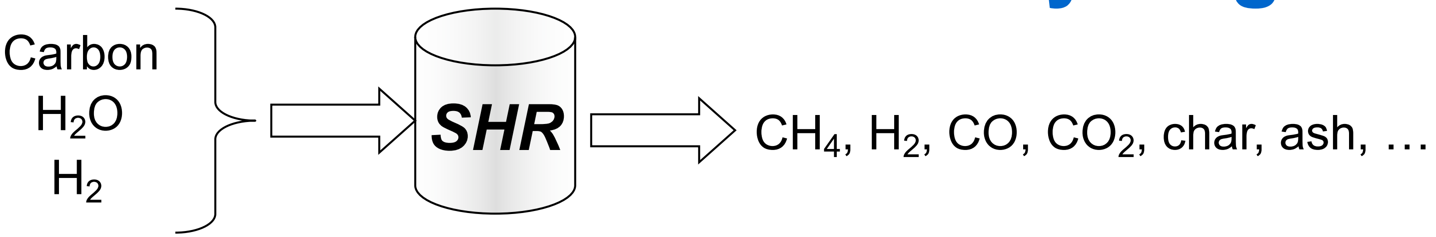
CORTUS ENERGY

SIERRA ENERGY

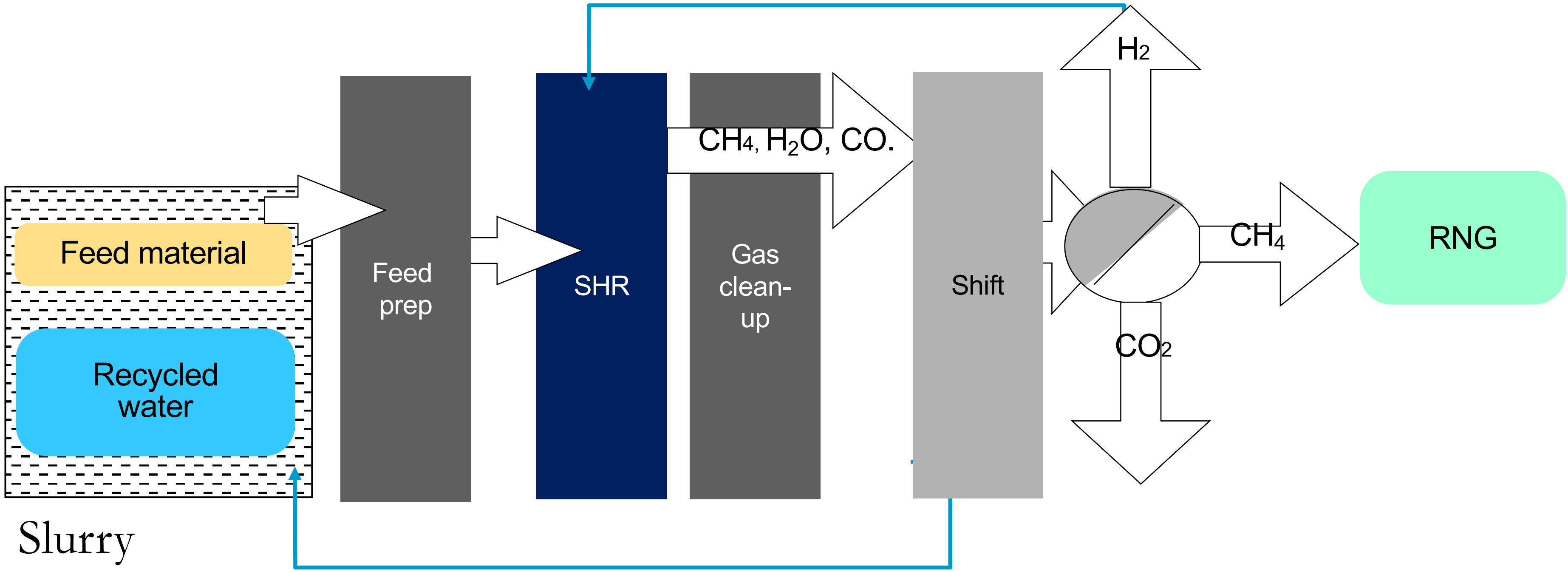
CARBONA

WESTBIOFUELS

Steam Hydrogasification



$$C + \mathbf{H_2O} + 2H_2 \rightarrow CH_4 + \mathbf{H_2O} + 75kJ/mol + others$$



SHR Gasifier

- Fluidized bed gasifier
- 200 lb/day throughput (dry basis)
- Slurry feed system – hydrothermal pretreatment
- Gas cleanup & water gas shift

	Performance Data
Product gas yield	1200 - 1500 kg/ ton feed
Energy content	12 - 15 GJ/ton feed
CO content	5-20 Vol%
CH_4 content	60-80 Vol%
Sulfur, Tar, NH_3	< 0.01 ppm

Partial Oxidation Gasification

- Taylor Energy Gasification technology
  - Pilot - 3 TPD gasifier
    - Partial oxidation with pulse detonation
  - Add Fischer-Tropsch reactor
  - Planned RNG production – methanation catalyst development ongoing
  - MSW feedstock
  - Net thermal efficiency ~ 50%

Gasification to RNG

- California RNG potential from LFG & AD at 100 bcf per year*
- Gasification will significantly increase potential from in-state resources
  - Improved waste management
- Higher efficiencies and feedstock flexibility at higher costs
- Pilot scale demonstration ongoing
  - Commercial deployment timeframe 5-10 years

* http://www.cert.ucr.edu/crng/Optimal_Pathways_Report.pdf