REMEDY- Reducing Emissions of Methane Every Day of the Year

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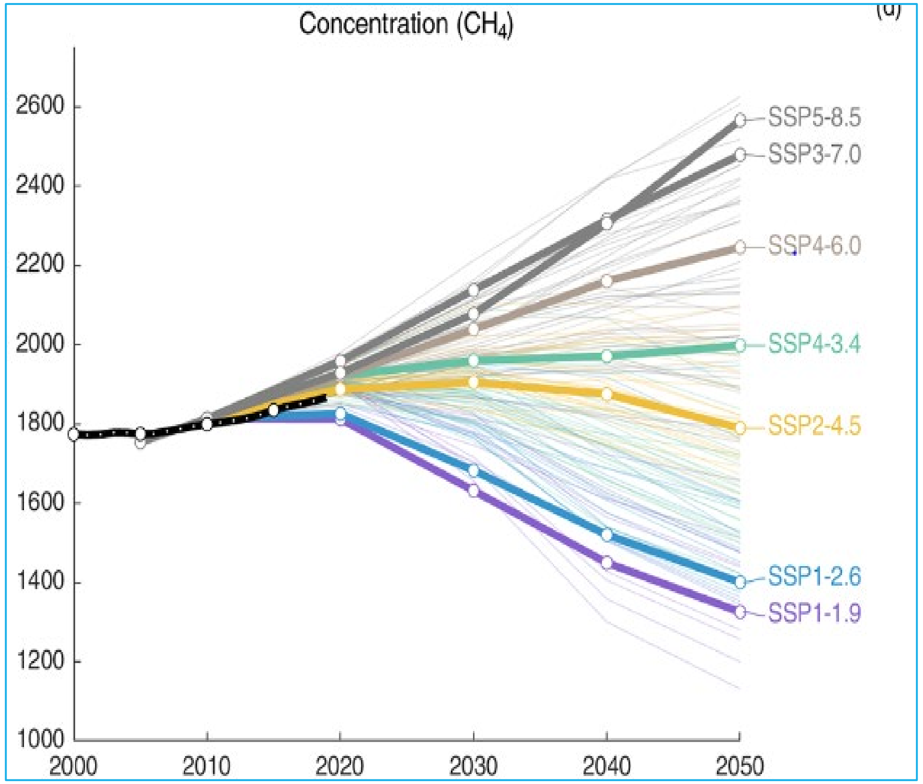
What problem are we trying to solve?

- Reverse methane accumulation in atmosphere
  - Prevent methane emissions
  - Reduce methane emissions at source
  - Remove methane from air
- Decreasing atmospheric methane concentration is possible with 10 -30% reduction in anthropogenic CH_4 emissions, due to natural methane sinks
- Addressing methane emissions complements CO_2 capture/sequestration programs, and may be faster/cheaper



Saunois, *et al*., Earth Syst. Sci. Data, 12, 1561–1623

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Decreasing the Atmospheric Methane Inventory

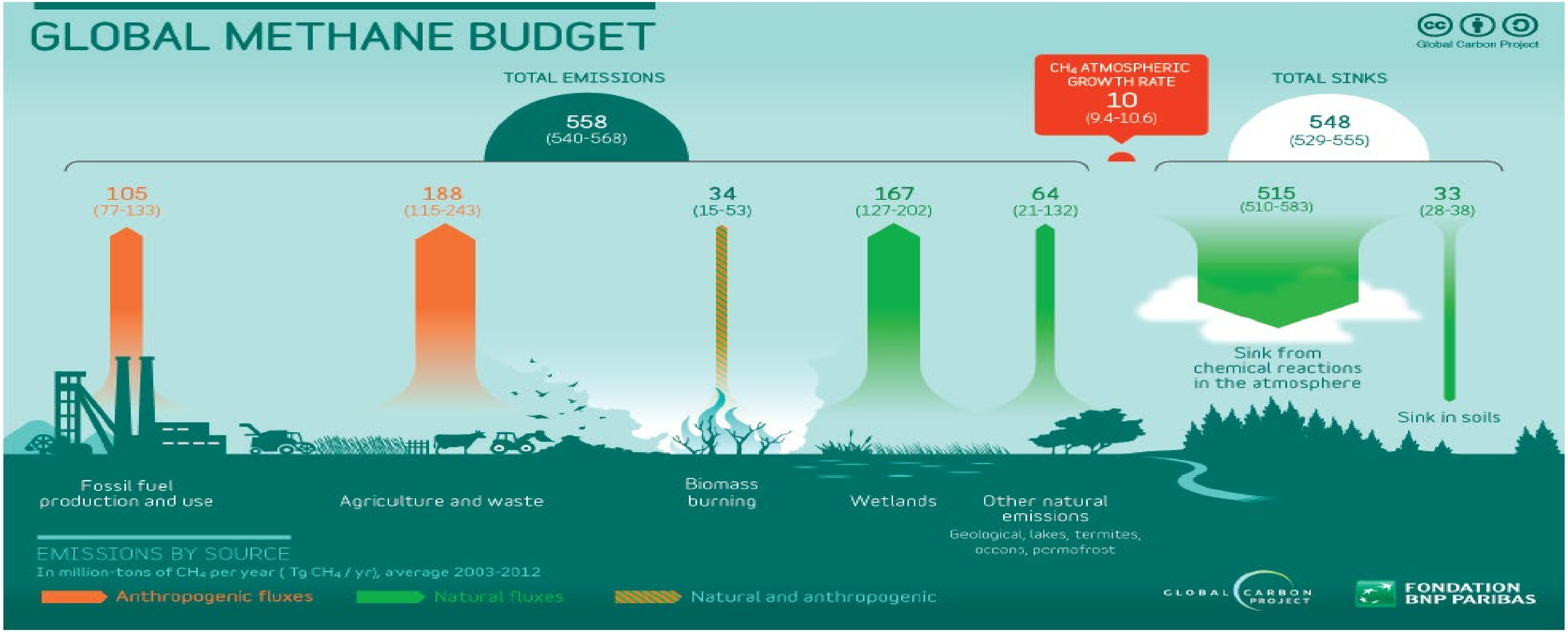

FIGURE S.1 Schematic of sources and sinks of methane globally. SOURCE: Global Carbon Project, http://www.globalcarbonproject.org/.

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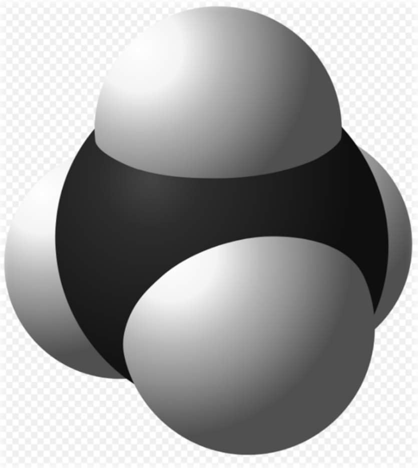
- Develop integrated systems that
  - Eliminate methane emissions
    - Oxidizing to CO_2 is acceptable
    - Capture for use or conversion to higher-value products is allowed, but not a focus
    - Must ensure no harmful products are produced (e.g., formaldehyde)
  - Quantify inlet and outlet methane fluxes
    - Needed for control, since many sources have variable methane flow rates and/or concentration
    - Required to quantify methane reductions in future carbon credit programs
- Seek flexible and robust processes
    - Many approaches will be required, given diversity of methane sources
    - Multi-step processes allowed
    - Need to define emission space where proposed technology could work
- Interested in novel biological, chemical, and/or mechanical approaches; equipment designs, and/or process configurations
- Economics predicated on carbon reduction, not making a salable product

Why is this hard?

- Sources
  - Millions of point sources; many diffuse sources (e.g., landfills)
  - Concentrations range over >4 orders of magnitude
    - Concentration of most sources below LEL – won't "burn"
    - Ambient concentration 1.9 ppm; CO_2 410 ppm
  - Flow rates range over >6 orders of magnitude
  - Concentration and/or flow rate can vary with time, esp for high-impact point sources
- Methane chemistry
  - Symmetric, and consequently stable, molecule
    - Activation energy 359 kJ/mol in air; heat of combustion 889 kJ/mol
    - Auto-ignition temperature 540 C (theoretical), 600 C (experimental) at ambient pressure; 390 C at 1100 bar
    - Flammable (explosive) limits 4.4% (LEL) –17% (UEL) vol% in air
- No "Silver Bullet"
  - Wells/mines – millennium time scales, numerous subsurface geologies
  - Oxidation – Temperature; catalysts (photocatalysts, NEMCA effect); reactants (H_2, ethane, oxygen, ozone, hydroxyl radicals); mechanical designs (engines, flares, reactors); and combinations
  - Biology – consortia populations; nutrients; poisons; enzyme stabilization



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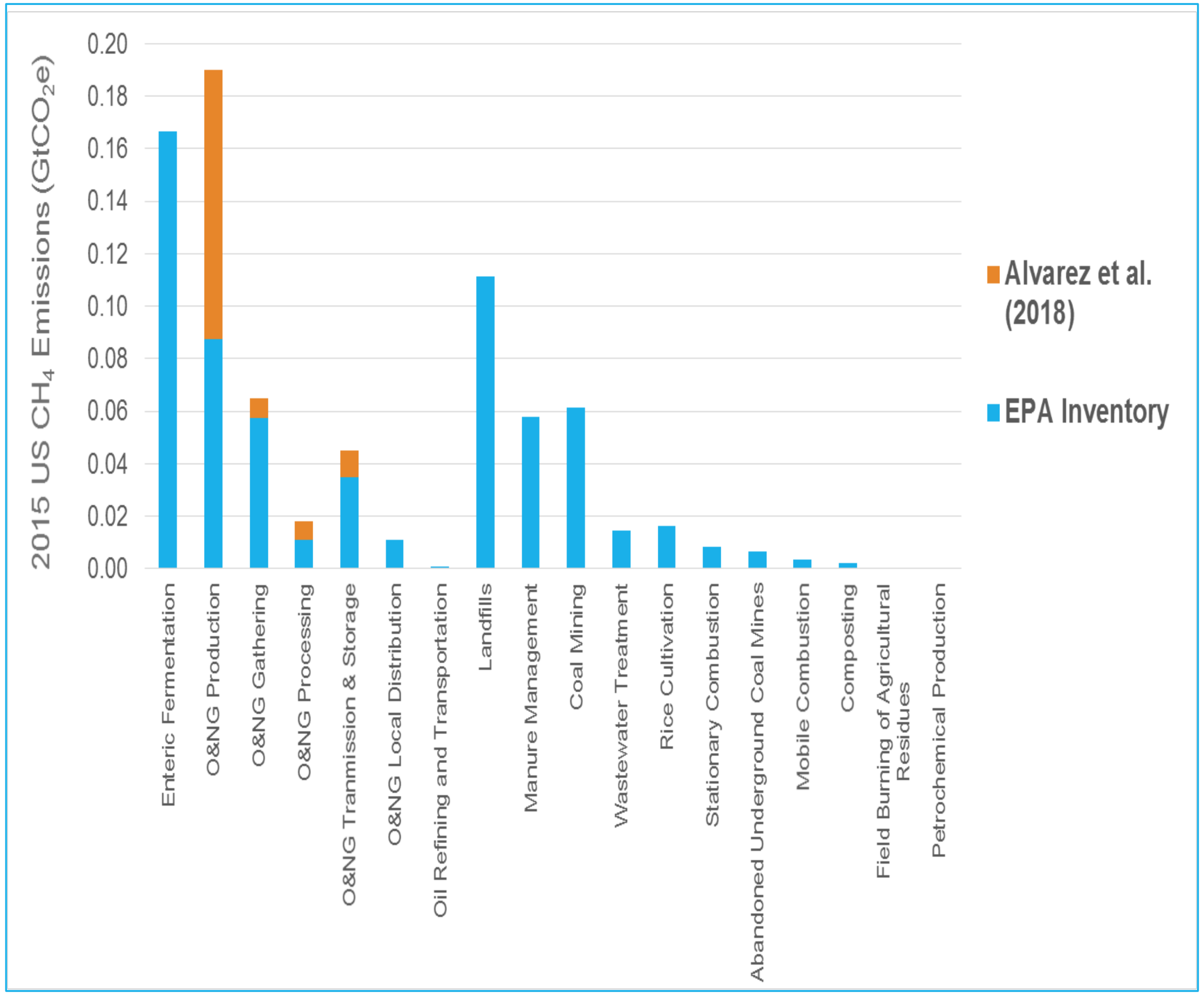
Sources– Diverse and Numerous

- Many bottom up/top down studies
  - New and improved detection tools/quantification methods
  - “Super-emitters” following log-normal distributions
- Ruminants – 100 MM cattle
- Oil and gas examples
  - Sources across supply chain
    - “Orphaned” and leaking “plugged and abandoned” wells – 0.5-2MM
    - Gas-fired compressors – 30K
    - Methane slip from flares ->50K
- Coal – Operating and abandoned mines ->3K
- Landfills ->1000 operating; >5000 closed



(US EPA) Green House Gas Inventory, 2018.
Alvarez *et al*.., *Science*, 361, 186-188, 2018.

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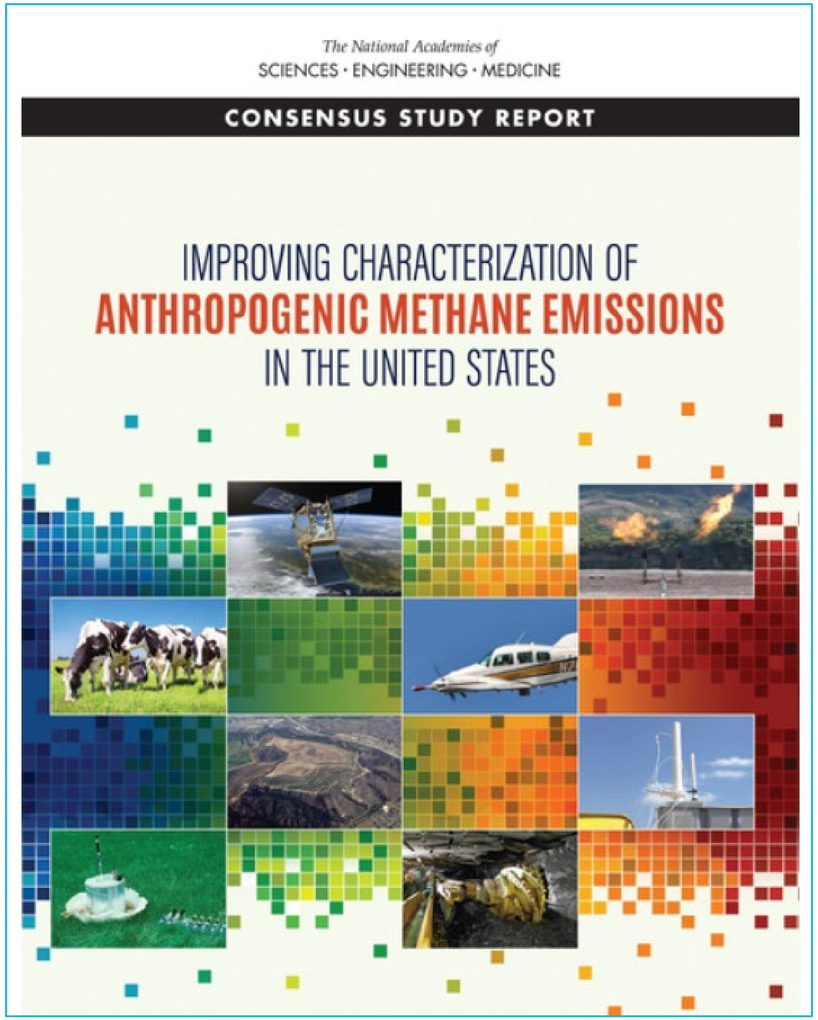
https://www.nap.edu/read/24987/chapter/1



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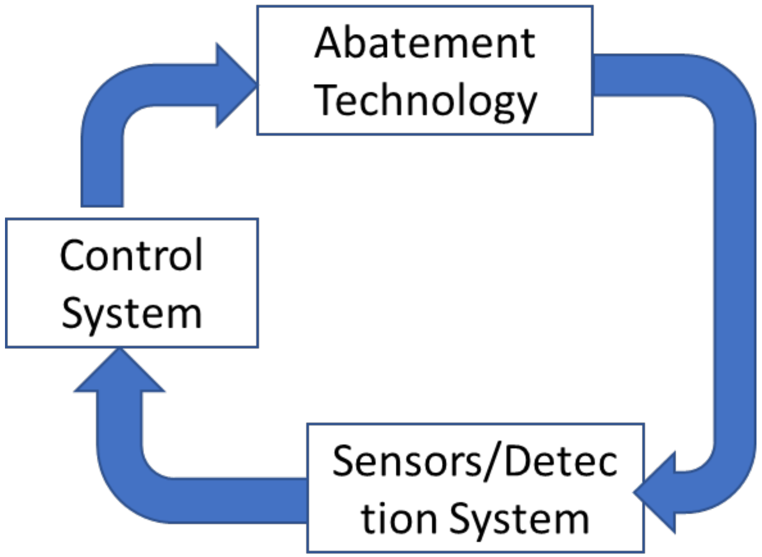
Example Potential Approaches
Not Intended to Limit or Direct

- Ruminants
  - Novel genetics, nutrients, enteric consortia modification
- Wells/mines
  - New abandonment/plugging techniques; novel pliable, chemical resistant materials
  - Downhole biological intervention to prevent methane emissions
- Post-combustion methane slip (gas -fired engines, flares)
  - New hardware designs; recuperation; catalysts; additives
- "Geo-engineering"
  - Accelerate tropospheric reactions
  - Accelerate soil/methanotroph reactions

Evaluation Criteria

- Disruptive, transformative technologies
  - Novel biology, chemistry, mechanical approaches; not incremental advances
- Systems Engineering Solution
  - Core prevention/abatement technology
  - Integrated detection/quantification sensors/measurement protocol
  - Control system with feedback to the prevention/abatement technology
  - Measurement protocol consistent with carbon credit markets
- Team
  - Diverse and complementary skills
  - Commercialization plan, and ideally partner
- End goal
  - De-risk proposed system with relevant lab-scale, or ideally field test



Contacts/More information

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- Maruthi Devarakonda, Tech SETA, Booz Allen Hamilton, Support Contractor to ARPA-E maruthi.devarakonda@hq.doe.gov
- Link to October 20th workshop - https://arpa-e.energy.gov/events/preventing-abating-anthropogenic-methane-emissions-workshop
- Teaming Partner List – https://arpa-e-foa.energy.gov/#FoaId93b90253-21d8-414a-a110-0facd1518f83
- Link to Blog – https://arpa-e.energy.gov/news-and-media/blog-posts/prevention-and-abatement-methane-emissions
- ARPA-E FAQs - http://arpa-e.energy.gov/faq.
- Contract questions - ARPA-E-CO@hq.doe.gov

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