CHANGING WHAT'S POSSIBLE

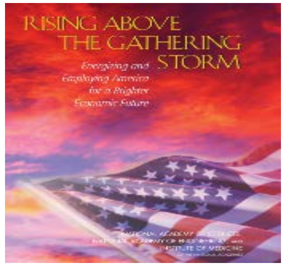
ARPA-E proposed REMEDY Program: Prevention and Abatement of Anthropogenic Methane Emissions

Jack Lewnard, ARPA-E Program Director
Jack.lewnard@hq.doe.gov

October 29, 2020

ARPA-E History

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy to fund advanced energy R&D.



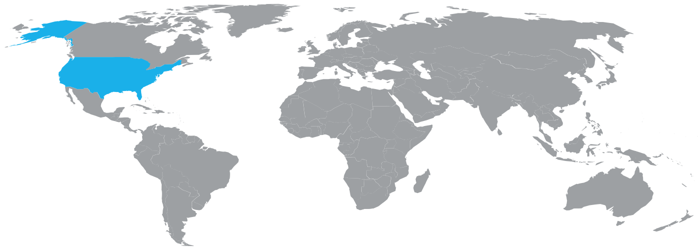
Rising Above the Gathering Storm **Published** - warning policymakers that U.S. advantages in science and technology had begun to erode

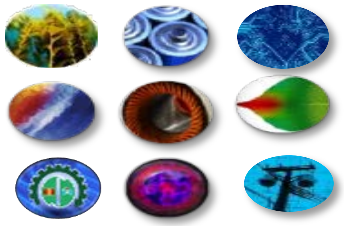
America COMPETES Act **Signed** – authorizing the creation of ARPA-E

2007

American Recovery & Reinvestment Act **Signed** – Providing ARPA-E its first appropriations of $400 million, which funded ARPA-E's first projects

2009





2020

850+ Awards
54 Programs

Current Funding: **$425M** (FY20)

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Built on DARPA foundation

ARPA-E Mission

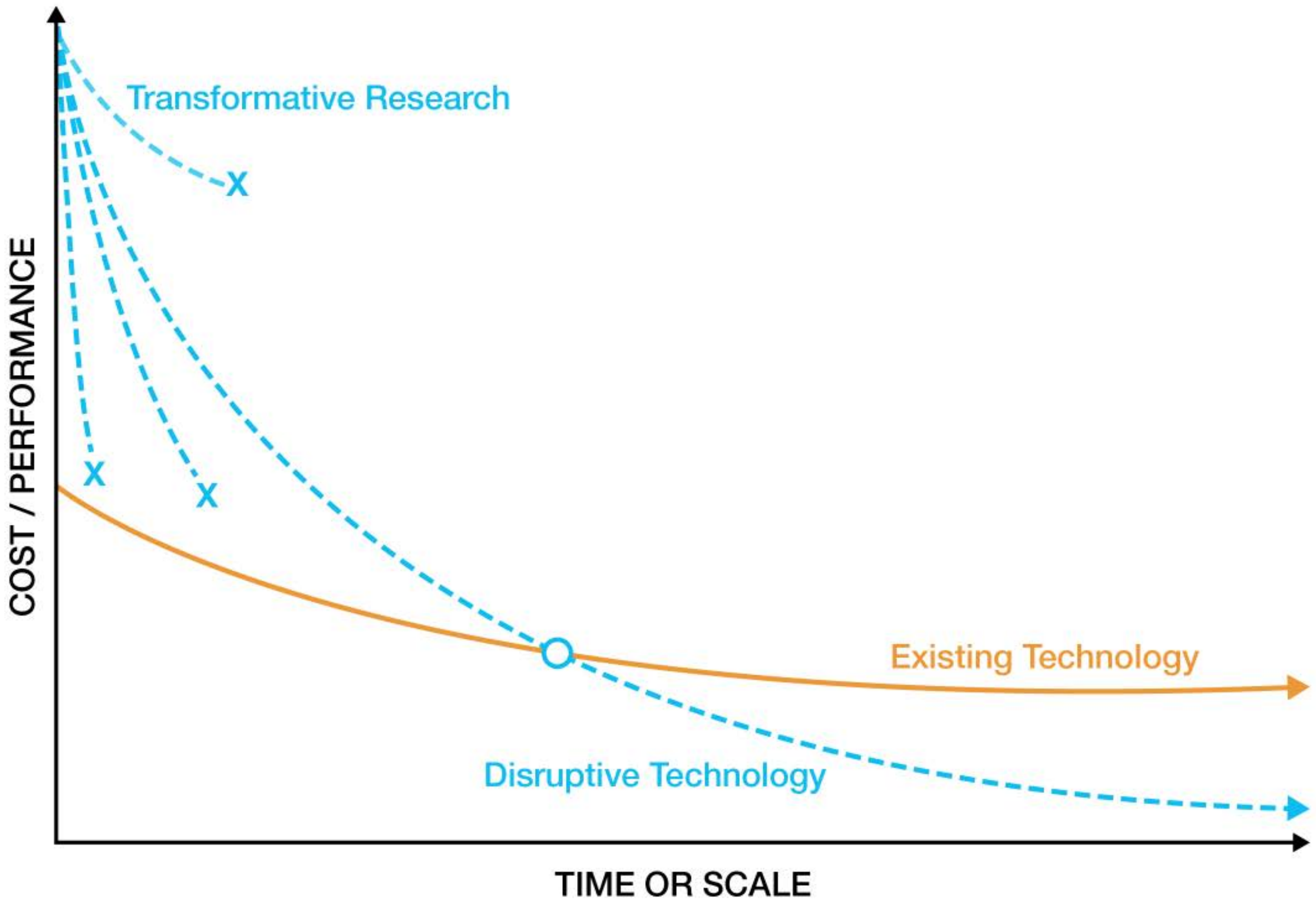
Goal 1: Overcome long-term and high-risk technological barriers in the development of energy technologies that…

Goal 2: Technological lead in developing and deploying advanced energy tech.

Means:

- Identify and promote revolutionary advances in fundamental and applied sciences;
- Translate scientific discoveries and cutting-edge inventions into technological innovations; and
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty.

Creating New Learning Curves



ARPA-E Program Portfolio

ELECTRICITY GENERATION & DELIVERY

Active

INTEGRATE, GRID DATA, IONICS, MOSAIC, GENSETS, NODES, ALPHA, CHARGES, MEITNER, DAYS, ATLANTIS, BETHE, PERFORM, GEMINA

Alumni

REBELS, GRIDS, GENI, HEATS, SOLAR ADEPT, IMPACCT, FOCUS

EFFICIENCY

Active

SENSOR, CIRCUITS, PNDIODES, ROOTS, ENLITENED, SHIELD, MONITOR, ARID, DELTA, BREAKERS, HITEMMP, DIFFERENTIATE, FLECCS, REPAIR

Alumni

SWITCHES, METALS, BEETIT, REACT, ADEPT

TRANSPORTATION

Active

MARINER, REFUEL, NEXTCAR, REMOTE, TERRA, RANGE

Alumni

MOVE, PETRO, TRANSNET, ELECTROFUELS, AMPED, BEEST

OPEN 2009, 2012, 2015 & 2018 Solicitations Complement Focused Programs

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ARPA-E Impact Indicators 2020

Since 2009 ARPA-E has provided **$2.4 billion** in R&D funding to more than **950 projects**

166 Projects have attracted more than **$3.3 billion** in private-sector follow-on funding

86 companies formed by **ARPA-E projects**

229 projects have **partnered with other government agencies** for further development

4,021 peer-reviewed **journal articles** from ARPA-E projects

609 patents issued by U.S. Patent and Trademark Office

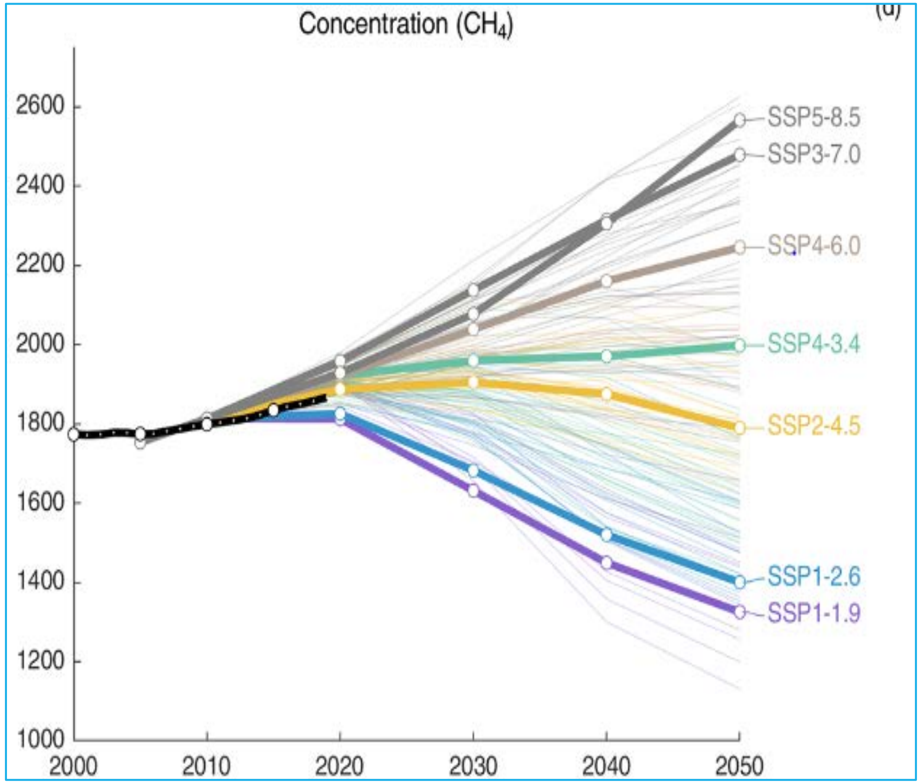
As of September 2020

REMEDY
Reducing Emissions of Methane Every Day of the Year

- 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

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

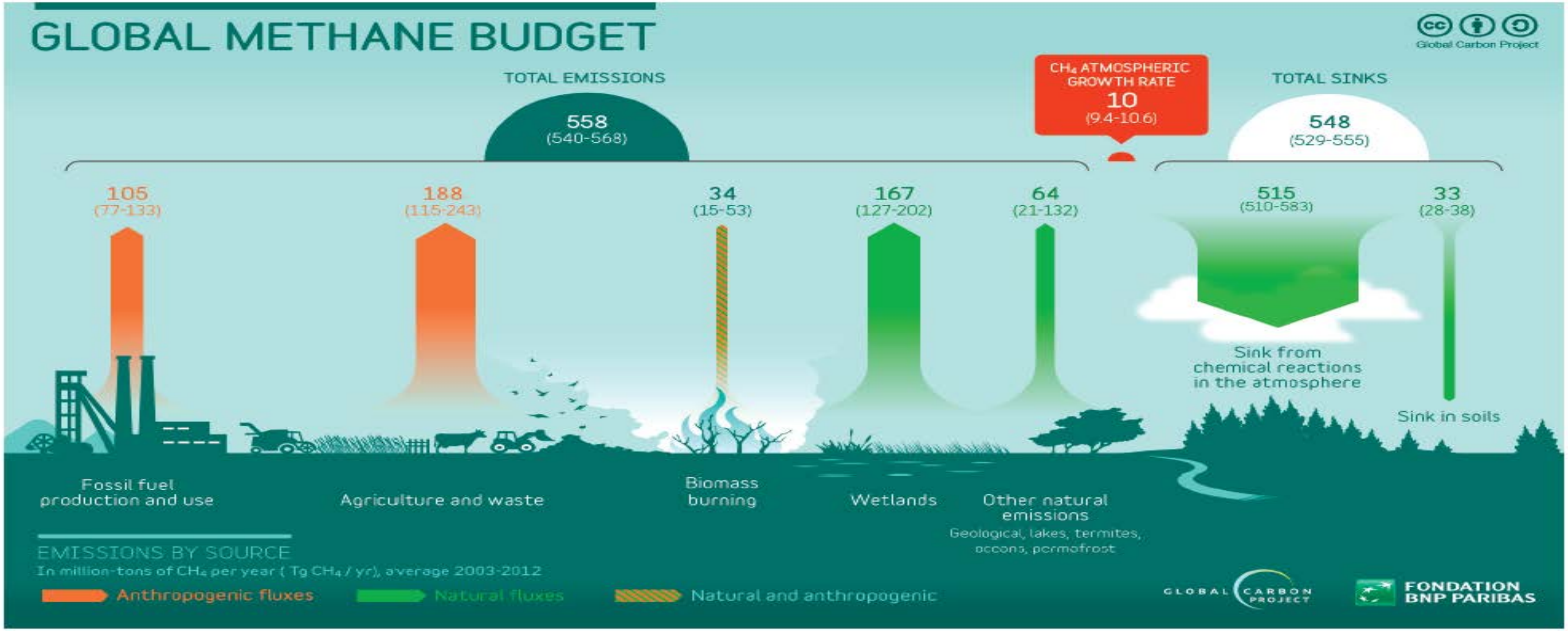
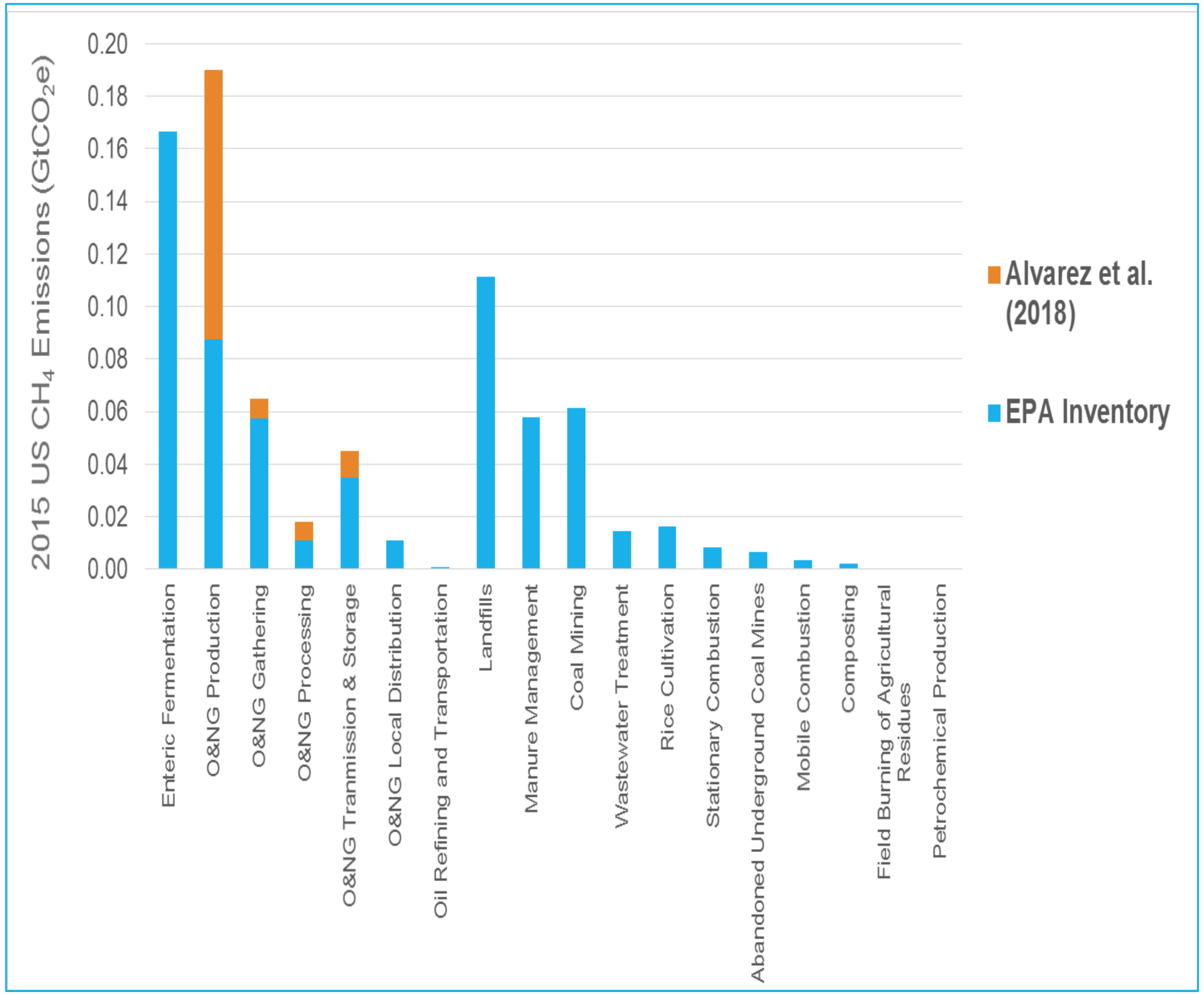


FIGURE S.1 Schematic of sources and sinks of methane globally. SOURCE: Global Carbon Project, http://www.globalcarbonproject.org/.

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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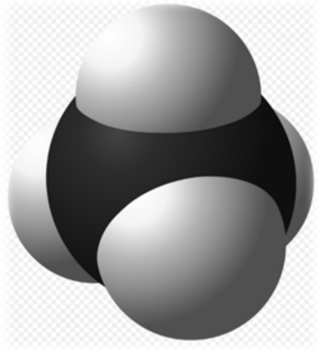
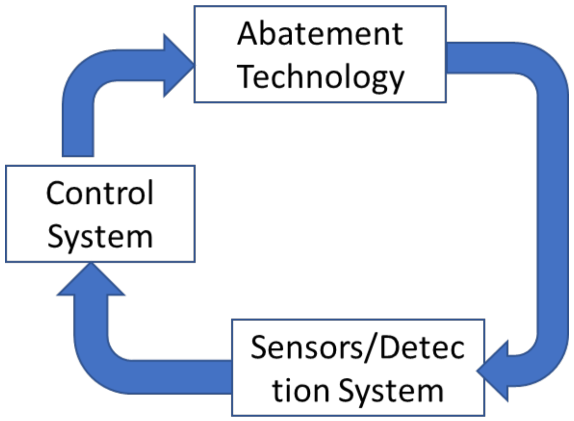
Why is this problem ARPA-E hard?

- Sources
  - Millions of point sources; thousands of 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
  - 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



- Seeking system-level 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
- No "Silver Bullet"
  - Diversity of sources will require diverse set of solutions
  - Which tools to take from the toolsbox?



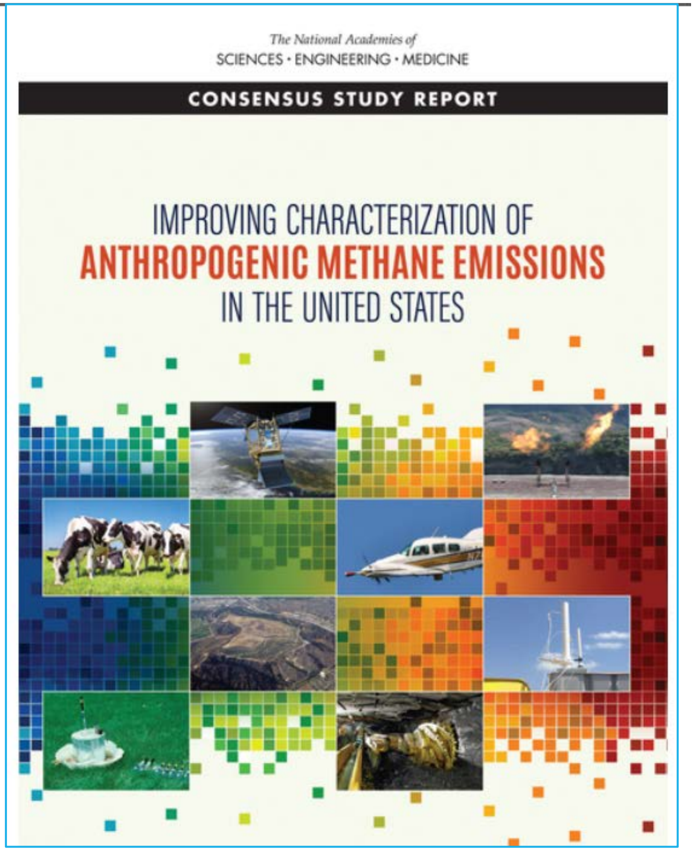
Contacts/More information

- Jack Lewnard, Program Director jack.lewnard@hq.doe.gov
- Maruthi Devarakonda, Tech SETA, Booz Allen Hamilton, Support Contractor to ARPA-E maruthi.devarakonda@hq.doe.gov
- Link to REMEDY Request for Information https://arpa-e-foa.energy.gov/Default.aspx#FoaId70a4dc16-ae6b-409e-8f2f-75f4d4e063df
- Link to Blog – https://arpa-e.energy.gov/news-and-media/blog-posts/prevention-and-abatement-methane-emissions
- Teaming Partner List – https://arpa-e-foa.energy.gov/ - soon
- Link to October 20th workshop - https://arpa-e.energy.gov/events/workshops - soon
- ARPA-E FAQs - http://arpa-e.energy.gov/faq.
- Contract questions - ARPA-E-CO@hq.doe.gov

Possible Connection with NASA

- REMEDY
  - Methane emission quantification
    - Drones, fixed wing, tower-based scanners, satellites, other (?)
    - Indirect measures – flares, soil/ground cover, possibly old coal/oil /gas fields?
  - Atmospheric chemistry (?)
- Other ARPA-E Programs
  - Non CO_2 GHG emissions
  - Terra/Roots (carbon sequestration)

- Other DOE – Hoyt Battey – Hydropower Office



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

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Methane and Reservoirs: A (very) Quick Summary

Hoyt Battey – Program Manager for Strategy, Analysis and Outreach
Water Power Technologies Office

October 29, 2020

Introduction

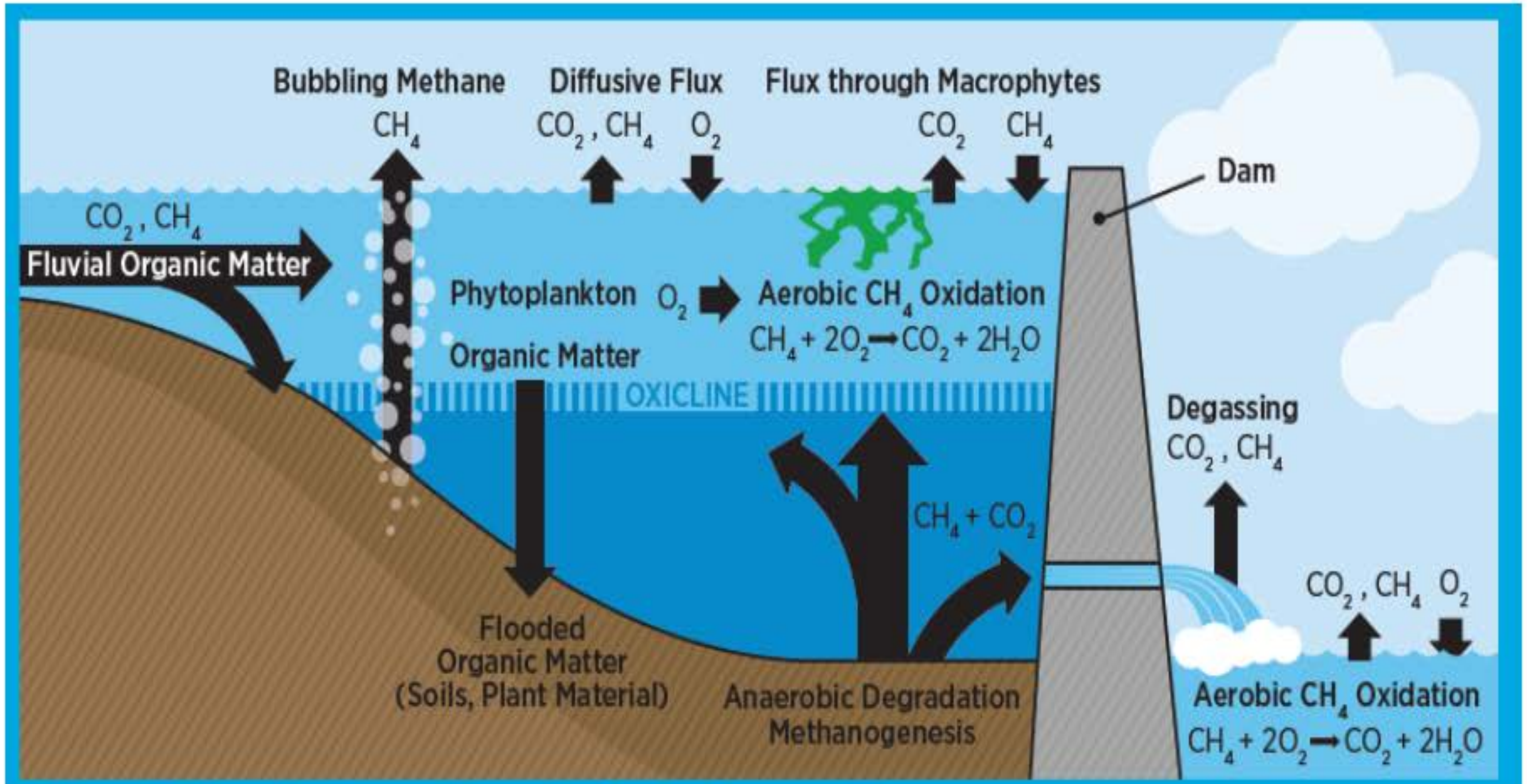
-Methane* production in reservoirs and waterbodies has been a significant concern

-Significant emissions at many reservoirs (but 100s of reservoirs also sampled with insignificant or zero emissions)

-Most sampling has been conducted with limited spatial coverage and over limited periods of time

-Limited uses thus far of newer remote sensing technologies for longer-term assessments over larger spatial scales

-Know from some longer-term more detailed studies that emissions can be extremely temporally and spatially "spotty"



Carbon dioxide and methane pathways in a freshwater reservoir.

Note: The light tan represents soils present prior to constructing the reservoir. The above processes illustrate gross GHG emissions. Many of these pathways would have been active without the reservoir, but the reservoir could increase and accelerate these pathways.

Source: Intergovernmental Panel on Climate Change

The light tan represents soils and organic matter present prior to reservoir construction, while the darker brown represents organic matter and sediments being added to the reservoir over time.

Measurements

Most measurement techniques are focused on in-situ sampling of diffusive and ebullitive gases at a handful of locations across a water body.

(images taken from the 'GHG Measurement Guidelines for Freshwater Reservoirs' document, produced under a UNESCO / International Hydropower Association research project)

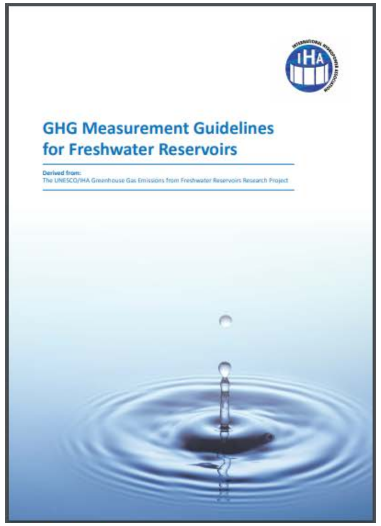


Figure 3.27: Example of chamber design

Source: Environnement Illimité Inc.

Source: SINTEF

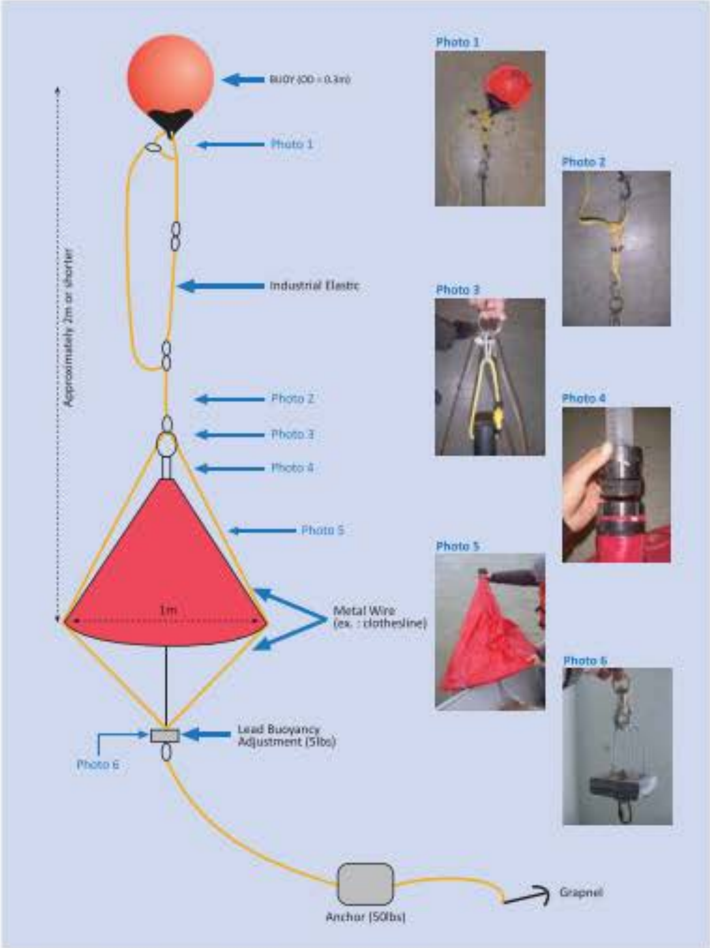
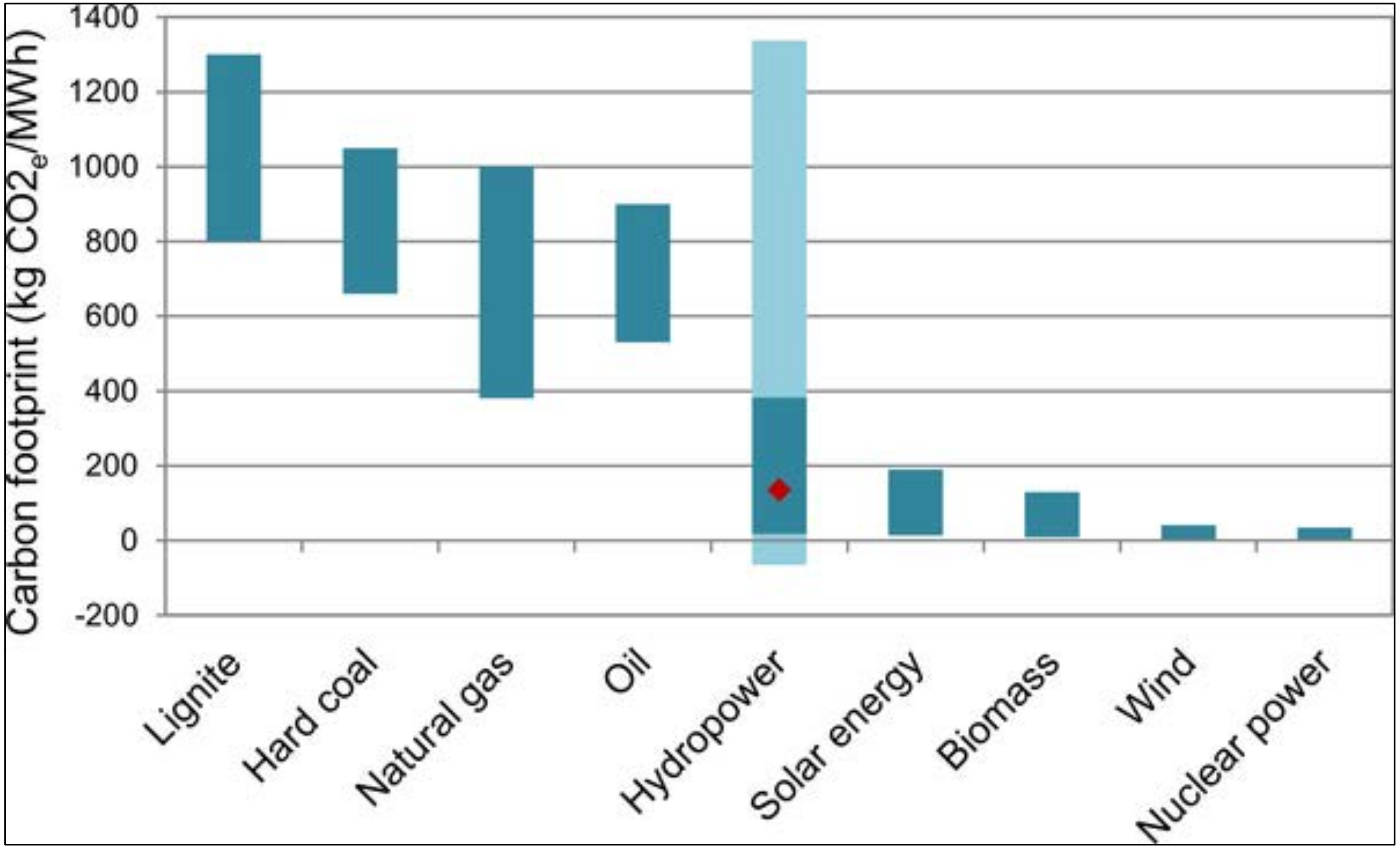


Figure 3.32: Schematic representation of a gas-collecting funnel

Extrapolations



Hydropower's Biogenic Carbon Footprint – PLOS One
Laura Scherer, Stephan Pfister Published: September 14, 2016
https://doi.org/10.1371/journal.pone.0161947

Fig 2. Carbon footprints of various energy sources (based on [32] for all energy sources other than hydropower). The lower and upper value of the dark bar for hydropower are the lower and upper quartiles for the corrected model average (Model AC). The light extensions represent the 10 and 90% quantiles and the red diamond marks the median.

Conclusions

- **”Spottiness” of emissions throws into question previous studies / measurements, various extrapolations, and what is really occurring “in-the-big-picture”**

- **So…where does this leave us??**

  1. Need to improve ability to know what is actually being emitted (and have confidence in assessments)

  2. Need to know what variables are important in driving emissions in some locations / cases and not others (temperature, water depth, nutrient input, anoxic zones, organic carbon/sediment input)

  3. To what extent are man-made reservoirs creating conditions that transform organic Carbon into methane, as opposed to other types of fluvial systems / waterbodies (like wetlands, estuaries or lakes)

  4. Assuming one can get a handle on #1-3 above, how are any methane emissions attributed to the many different purposes of a reservoir? (hydropower generation, for instance, is not usually the main purposes for large reservoirs…flood control, irrigation, navigation, water supply are also major drivers)