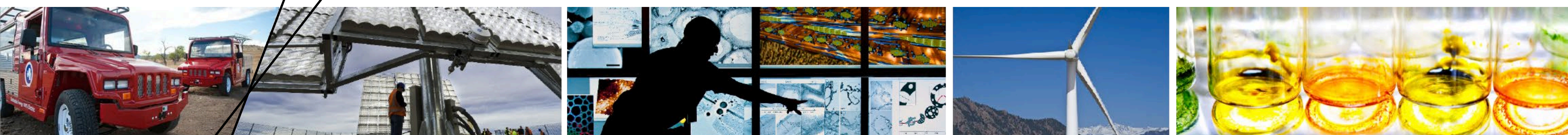
Benefits and Hurdles for Biological Methane Upgrading



Fei, Qiang

Sustainable Chemicals & Plastics Adoption & Applications Summit

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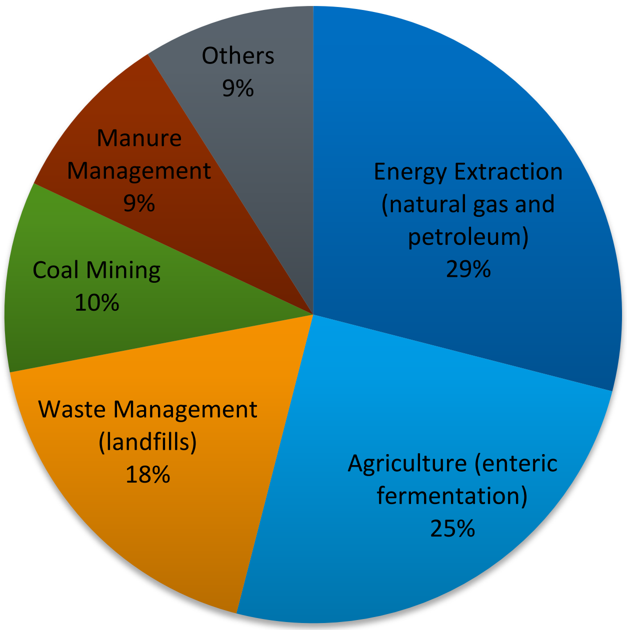
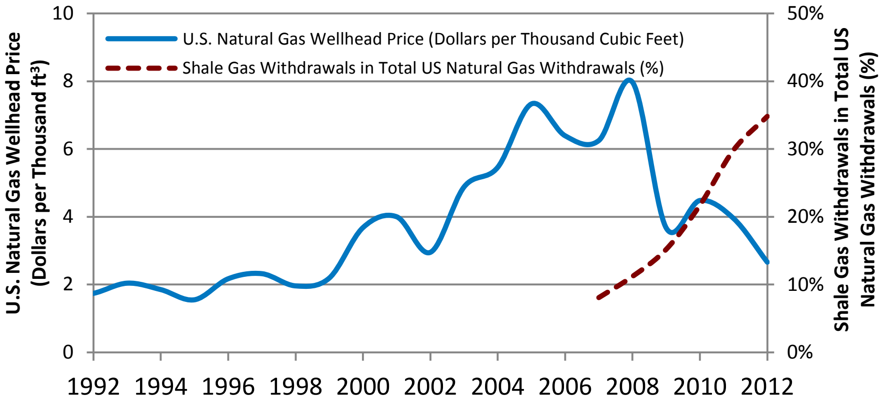
NREL/PR-5100-64878
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Methane Source

- **Most energy dense alkane: 55 MJ/kg**
- **Extraction: Natural gas (90% CH4)**
- **Anaerobic digestion: Biogas (60% CH4)**
- **Global-warming potential (GWP) of CH4 :**
  - CH4 lifetime is 12 years
  - 100-year GWP: 21 times of CO2
  - 20-year GWP: 72 times of CO2
- **Methane Cost**
  - Natural gas: pipeline NG vs. industrial waste stream (flaring gas)
  - Biogas: associates with plant size

U.S. Methane emissions by sources from 1990-2012 (US_EPA 2015)





Source: U.S. Energy Information Administration.

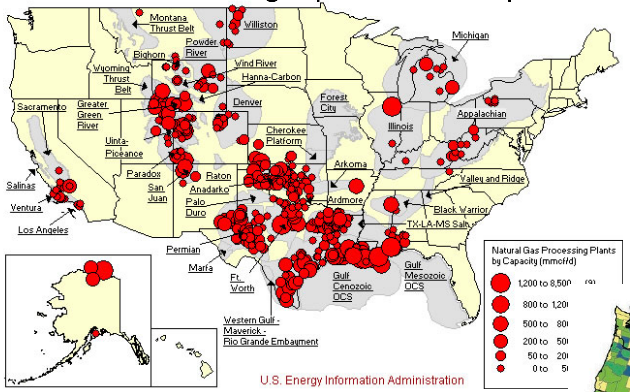
Biogas source	$/MMBTU	Reference
Landfill	2-4	California Energy Commission, 2012
Livestock manure	6-10	CALSTART, 2010
Wastewater treatment plants	2-8	Nicholas Institute report,2014
Biomass	6-8	Nicholas Institute report,2014
Dairy farm	11	NRRL report, 2010

Methane Production and Use in the US

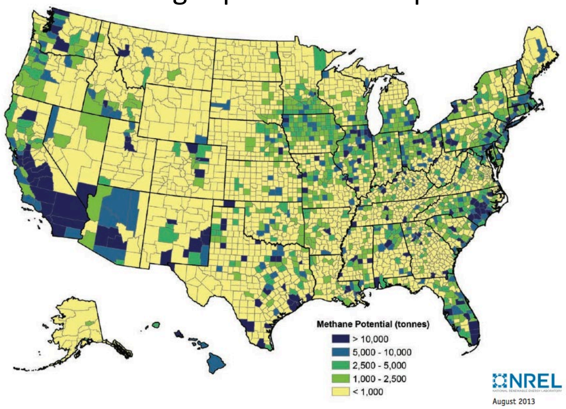
- **Methane production**
  - Natural gas: 65.9 billion Bcf/d
  - Biogas: 1.79 billion Bcf/d

- **Methane use**
  - Boiler: 85% heat and 15% lost
  - Combined heat and power (CHP):
    - 50% heat, 35% electricity and 15% lost
    - 1m3 biogas=2 kWh (35% ECE)
  - Upgrading (chemical and biological): chemical, nutrient and transportation fuel

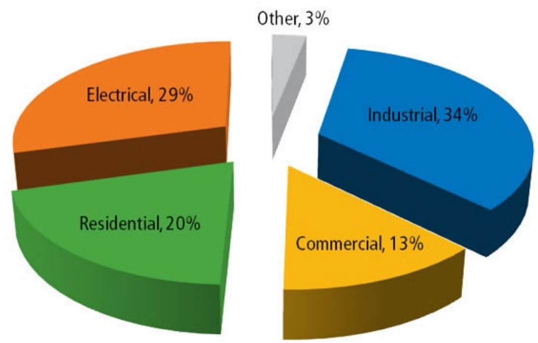
Natural gas production map



Biogas production map

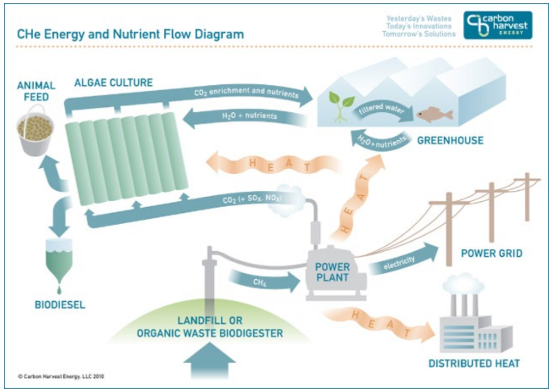


NG use

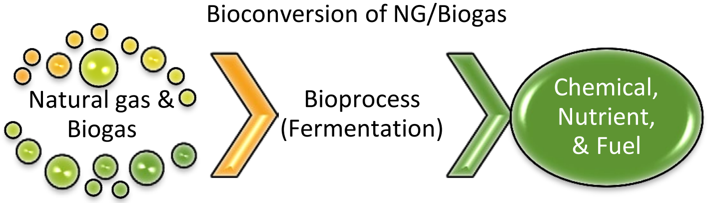


Source: Modern Shale Gas Development in the United States, US Department of Energy

Biogas use



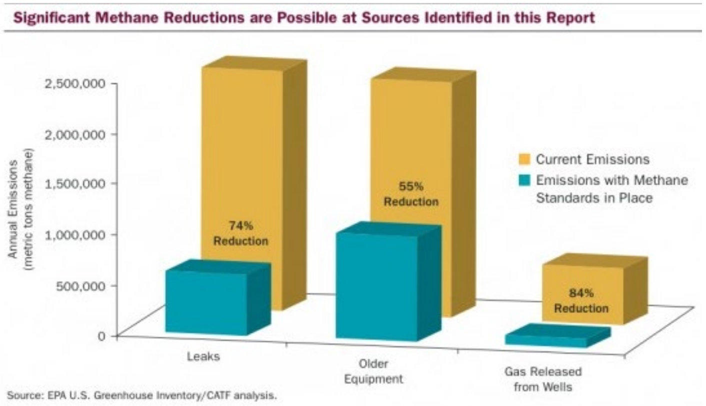
Bioconversion of NG/Biogas

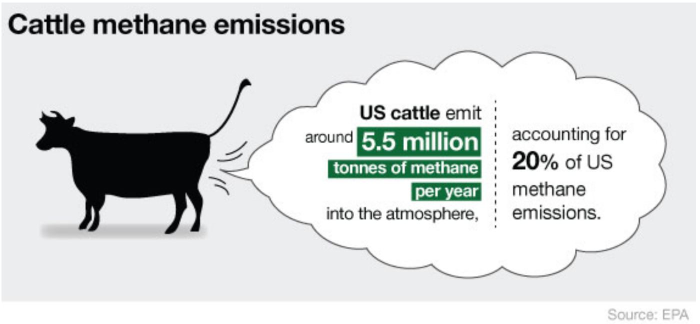


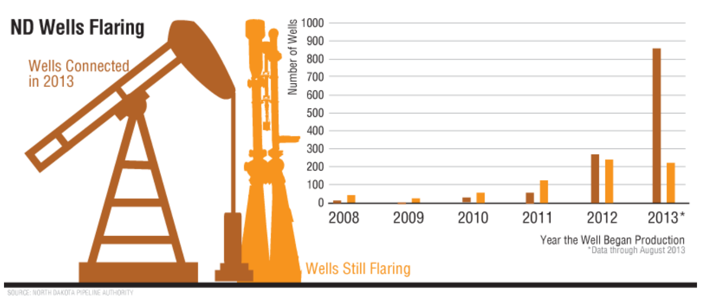
Rule of Methane Production and Use

❖ Regulation

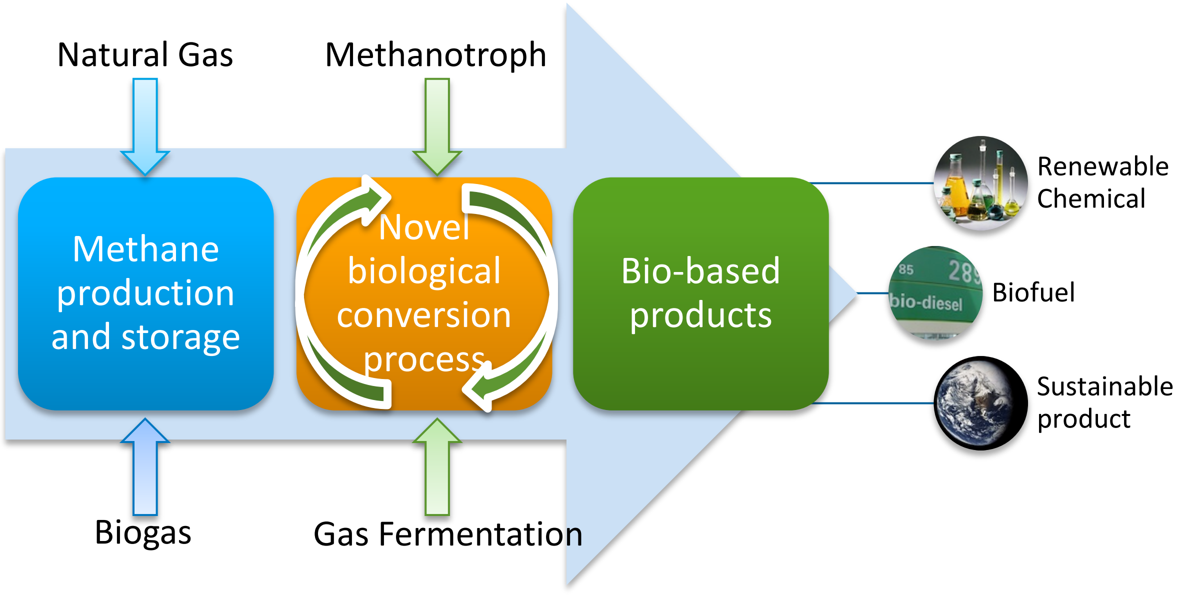
- Methane availability: Control and Storage
- Technology demand: Conversion Process
- Product: Bio-base Fuel and Chemical
- Player: EPA, USDA, DOE, American Biogas Council, DOD, State government, North Dakota Industrial Commission (NDIC), etc.
- Rule: Renewable Fuel Standard II, Low Carbon Fuel Standard, 2007 Energy Bill, Farm Bill, Treasury Grants, Clean Air Act, Climate Action Plan, etc.





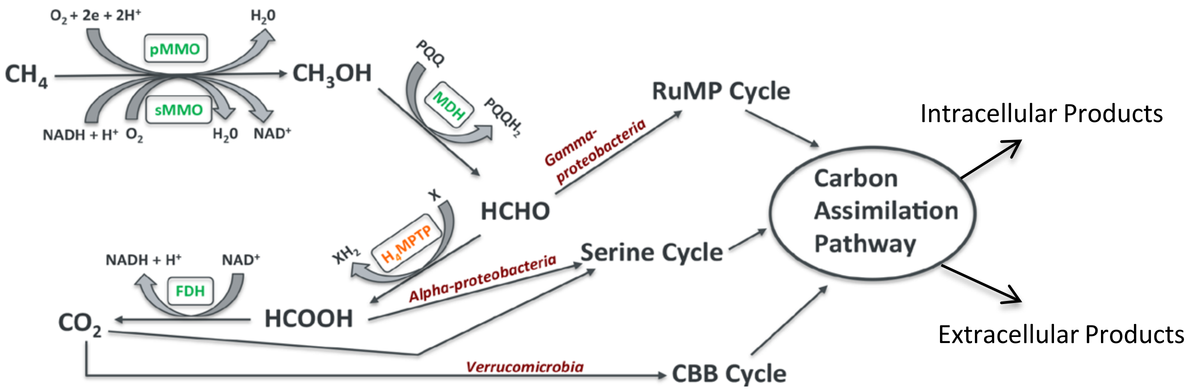


Source: North Dakota Petroleum Council



Biological Conversion of Methane

❖ Methanotrophic bacteria (Aerobic cultivation)

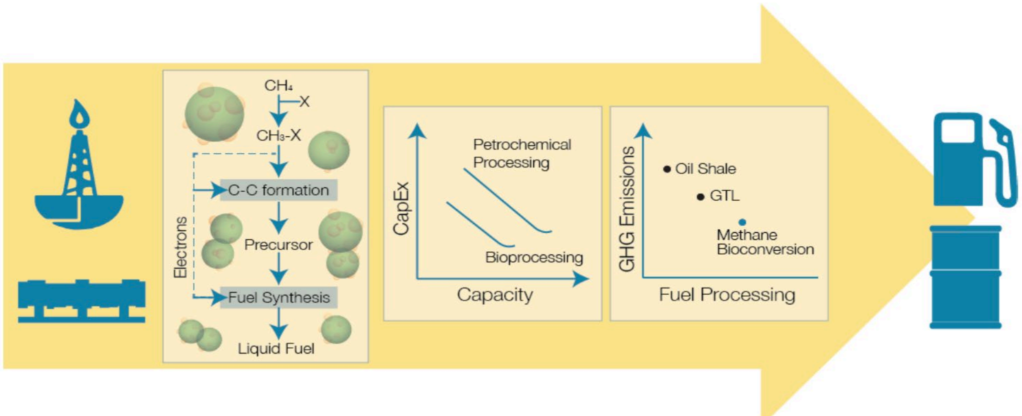


❖ Selected products

Product	Formula	Application
Fomate	CH_2O_2	Chemical
Glycogen	$C_6H_{12}O_6$	Chemical
Ectoine	$C_6H_{10}N_2O_2$	Healthy care
Astaxanthin	$C_{40}H_{52}O_4$	Healthy care
Sucrose	$C_{12}H_{22}O_{11}$	Chemical
Isoprene	C_5H_8	Fuel/Rubber
Lactic acid	$C_3H_6O_3$	Chemical
Lipid	C_{15}-C_{18}	Fuel
PHB	$C_4H_8O_2$	Fuel/plastic
Single cell protein*		Nutrient

*, including glutamic acid, aspartic acid, alanine, leucine, valine, glycine, lysine, isoleucine, threonine, serine etc.

❖ Biological routes chemical route for fuel



Source: Conrado & Gonzalez, 2014. Science, 343: 621/Haynes & Gonzalez, 2014. Nat. Chem. Biol. 10: 331

Hurdles of Bioconversion of Methane

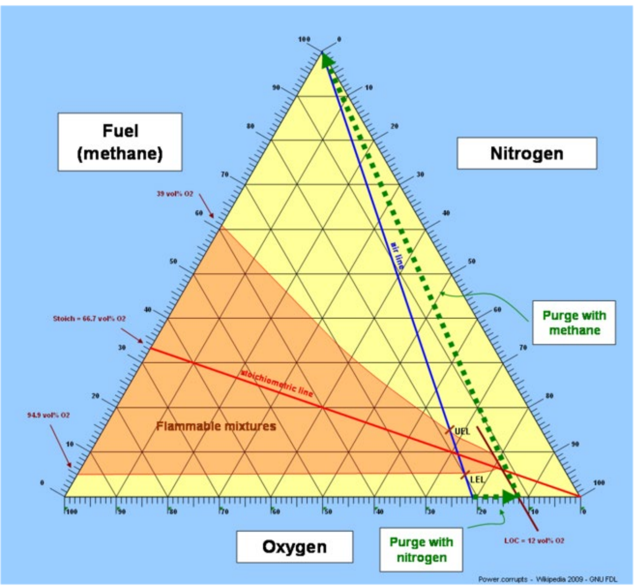
❖ Safety consideration

Limiting Oxygen Concentration (LOC) = 12 vol % O_2

UEL of CH_4: 15% in Air (v/v)

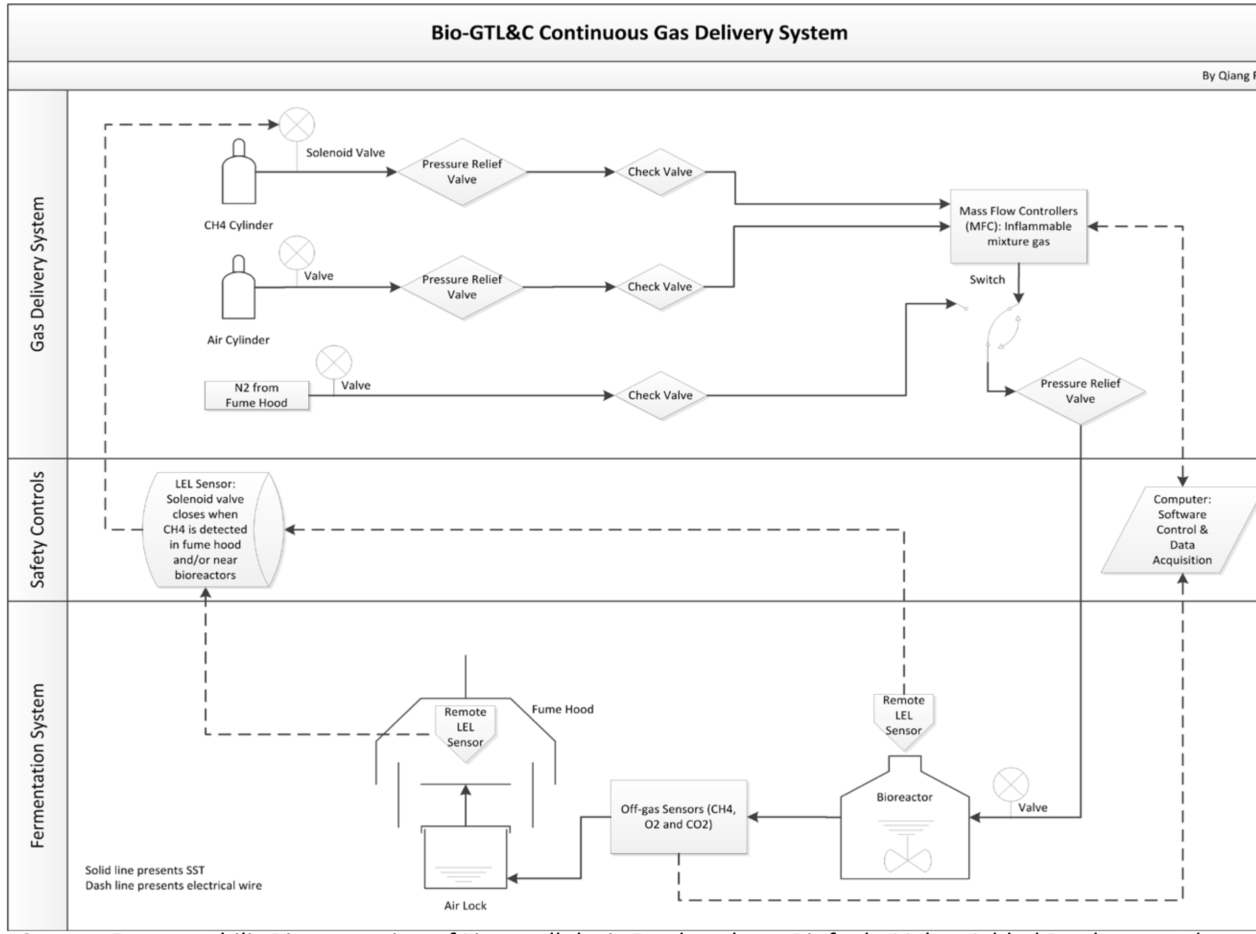
LEL of CH_4: 5% in Air (v/v)

CH_4 Flammability Diagram



❖ *Source: wikipedia.com*

NREL lab-scale continuous gas delivery system

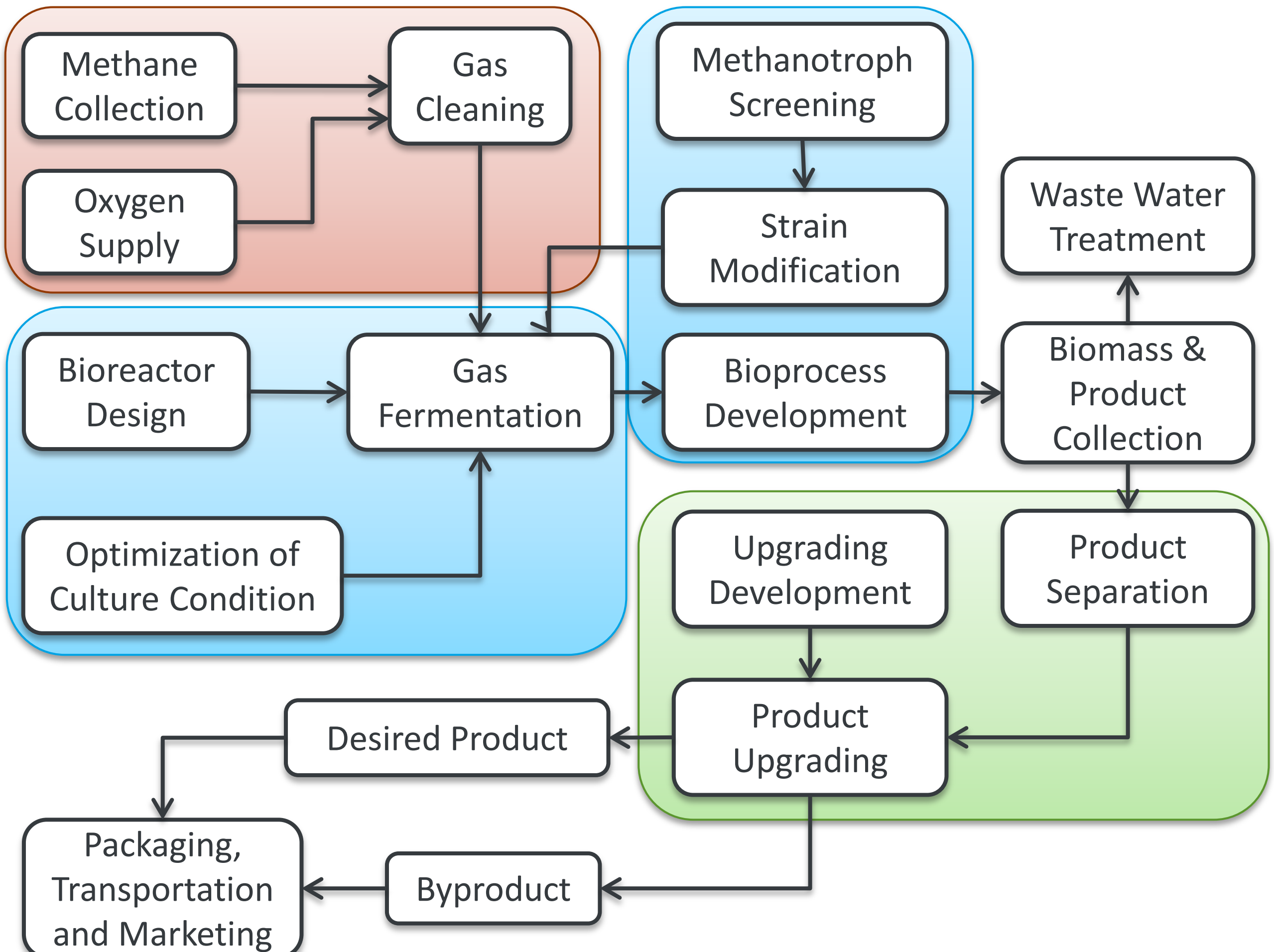


Source: Extremophilic Bioprocessing of Lignocellulosic Feedstocks to Biofuels, Value-Added Products, and Usable Power. Chapter: Bioconversion of Methane for Value Added Products

Hurdles of Bioconversion of Methane

❖ **Technical hurdles (R&D Map for Bioconversion of Methane)**

- ➢ Gas Supply & Cleaning
- ➢ Bioprocess Development
- ➢ Product Separation & Upgrading

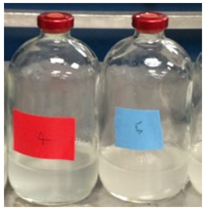


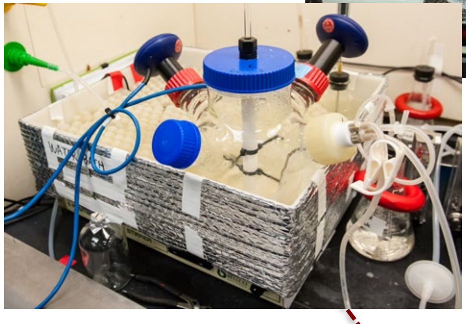
Hurdles of Bioconversion of Methane

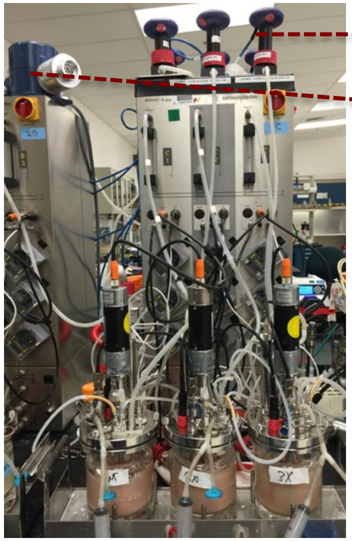
- **Gas Supply & Cleaning**
  - Flow rate:
    - Plant capacity and productivity
    - Biogas: 20-11000 (1000m3/hr)
    - Natural gas:
  - Location: transportation and water availability
  - Impurity and cleaning method:
    - Natural gas vs. Biogas
    - CO2, H2S, higher chain hydrocarbons (in NG)
  - Oxygen supply: Pure oxygen costs as mush as methane on final product price
  - Gas cleaning: Adsorption (PSA) vs. Membrane vs. Absorption vs. Cryogenic
- **Bioprocess Development**
  - Strain modification: carbon conversion efficiency, growth rate, pathway modification
  - Culture condition: pH, T, Cu^{2+}, CH4/O2 ratio, pO2,
  - Bioreactor design (gas transfer efficiency): CSTR/micro-bubble, loop/air-lift, bubble column, trickle-bed, membrane-based, nanoparticles gas substrate carrier
- **Product Separation and Upgrading**
  - Intercellular product (single cell protein, lipid/fatty acid, PHB): S/L separation, extraction, and upgrading
  - Extracellular product (lactic acid, butanol, isoprene): purification, extraction (harvesting), and upgrading

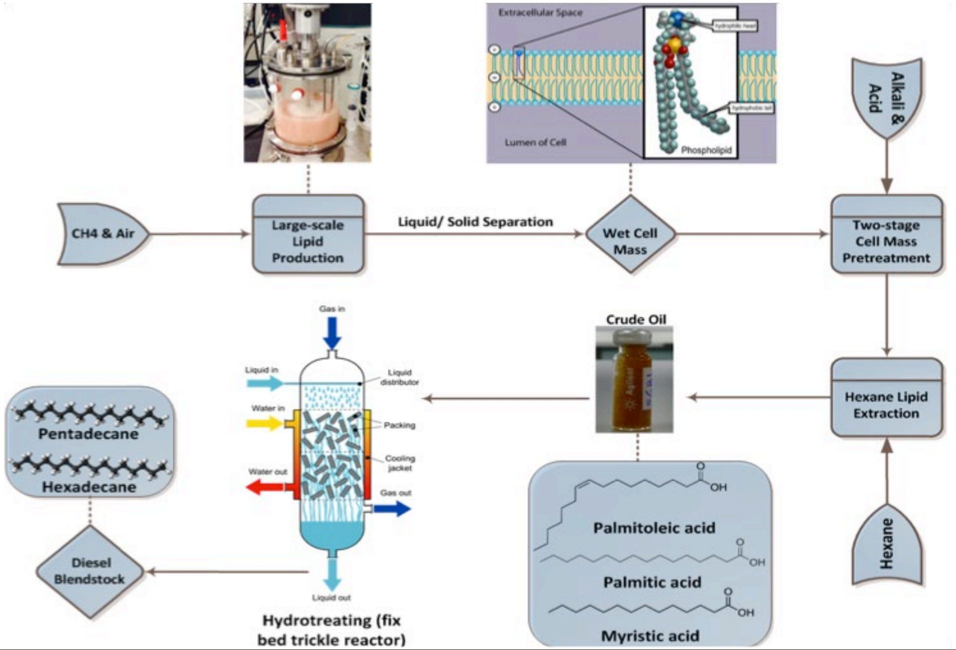
Bioconversion of Methane at NREL

- **Methane source:** Natural gas and Biogas
- **Product**: Lipid, Carbohydrate, Lactic acid & Muconic acid
- **Bioprocess**:
  - Safety control system
  - Strain screening with continuous gas delivery
  - Seed train development
  - Batch production culture with continuous gas delivery
  - High cell density culture: Dry cell density up to 20 g/L
  - Scale up of fermentation: 50 mL to 5L

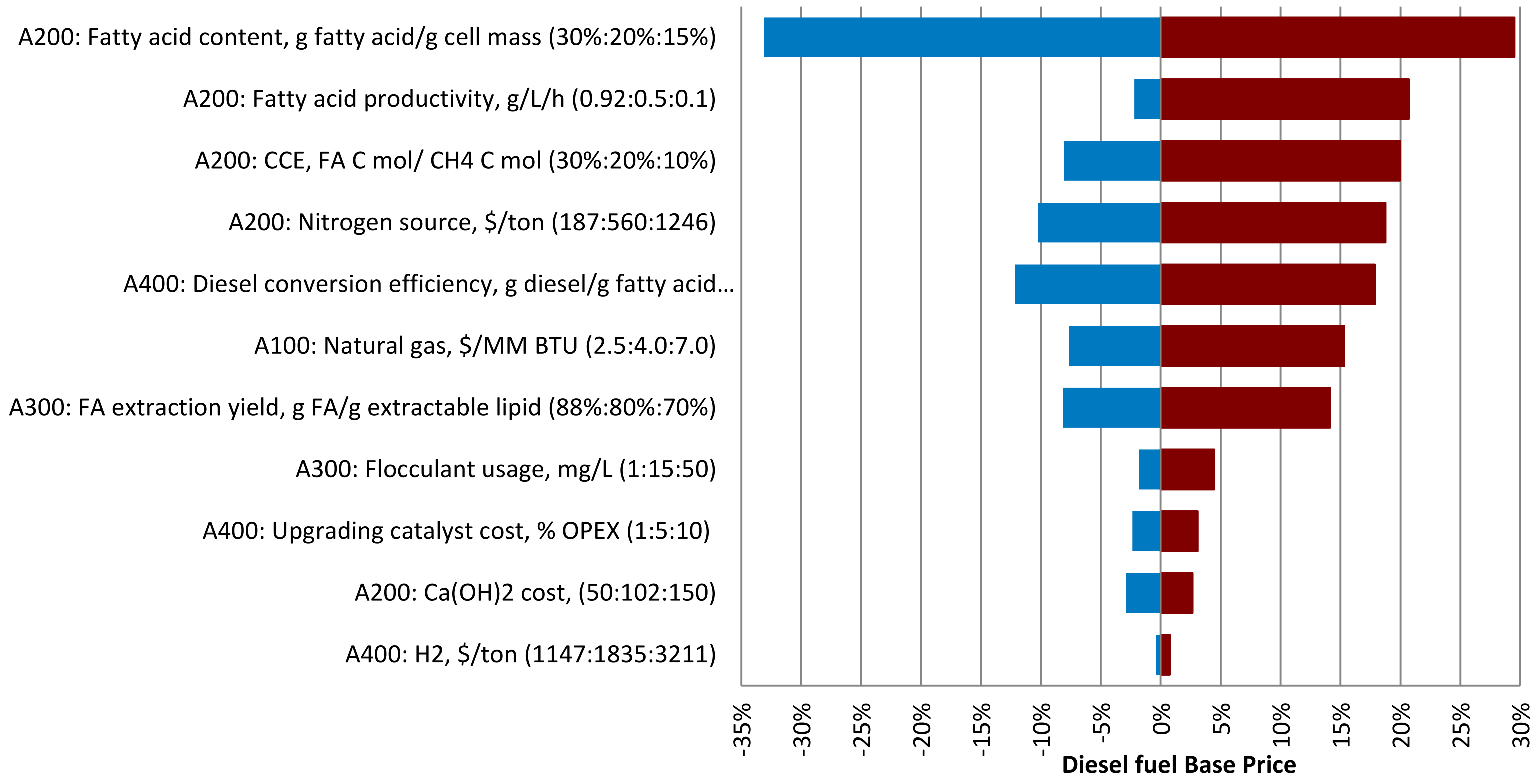








Techno-economic Analysis at NREL



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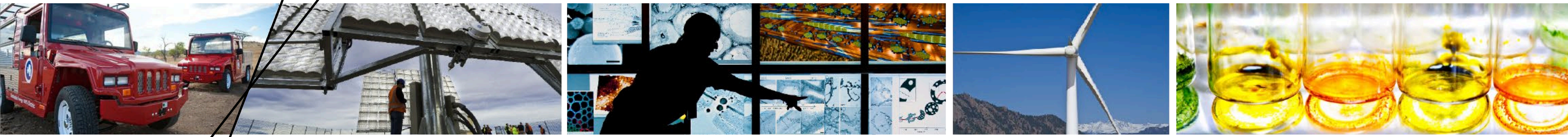
Thank you for your time



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