Thirteenth Annual Conference on Carbon Capture, Utilization & Storage

3-G: Capture/Utilization of CO_2 from & for Liquid Fuel Production

Conversion of CH_4 and CO_2 from Flare Gas and Flue Gas to Butanol for Use as a Synthetic Chemical and/or Liquid Fuel

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Acknowledgements & Disclaimer

This is preliminary analysis that has not gone through peer-review yet.

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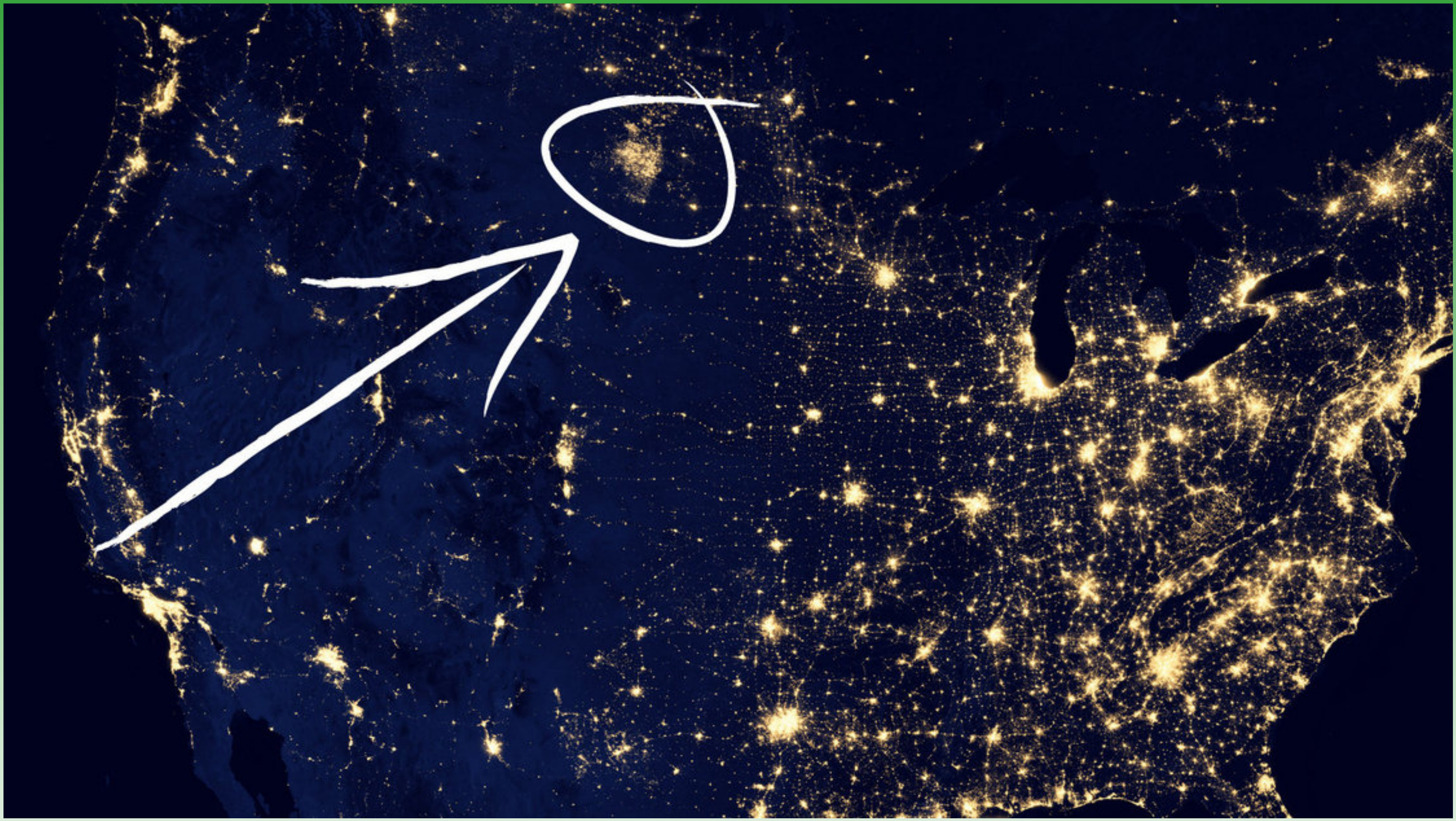
North Dakota from Space: Wasted flare gas is both an economic & environmental problem



North Dakota flares 190 **million** ft^3 per **day** = 69 billion ft^3 per year (69 BCF/yr)
World flares 7 **trillion** ft^3 (TCF) per **year** (7,000 BCF/yr)

Alberta, Canada from Space: Similar Situation

Alberta, Canada flares 1.1 **billion** cubic **meters** per year ……. 39 BCF/yr
North Dakota flares 69 billion ft^3 per year ……………………… 69 BCF/yr
World flares 7 **trillion** ft^3 (TCF) per year …………………… 7,000 BCF/yr

Meanwhile, world's liquid fuel needs are rising…

- **Growth of the worlds economy has given a huge rise to demand for liquid fuels for transportation and chemicals for industry using clean technologies.**

- **Ethanol production from fermentation addresses this demand in part.**

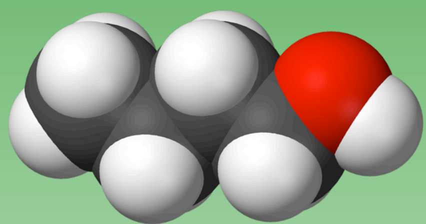
- **<u>But:</u> Ethanol has a lower calorific value than gasoline, yielding lower mileage. It can only be used in high concentration in flex fuel cars. It cannot be transported in gasoline pipelines. It is made from food crops, limiting its resource base and increasing its price.**

- **What is needed is a synthetic fuel that has comparable energy to gasoline, can be used in unmodified automobiles, can be transported in gasoline pipelines, and can be made from abundant, non-food resources.**

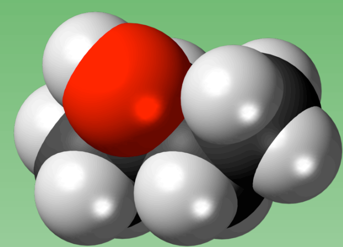
- **Butanol is an answer.**

What is Butanol?

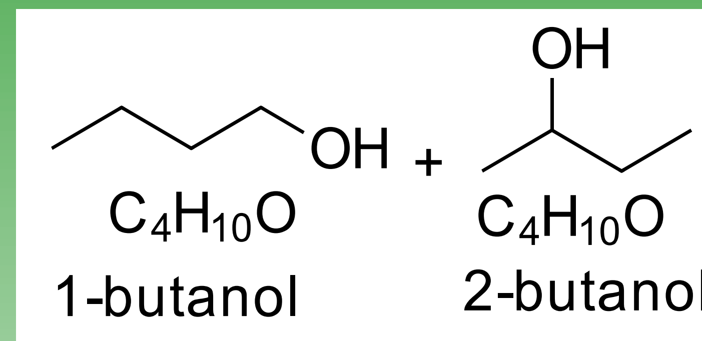
- **Butanol is an alcohol containing 4 carbons**
- **Chemical formula C_4H_9OH**
- **Has 80% the energy content of gasoline**



1-butanol



2-butanol

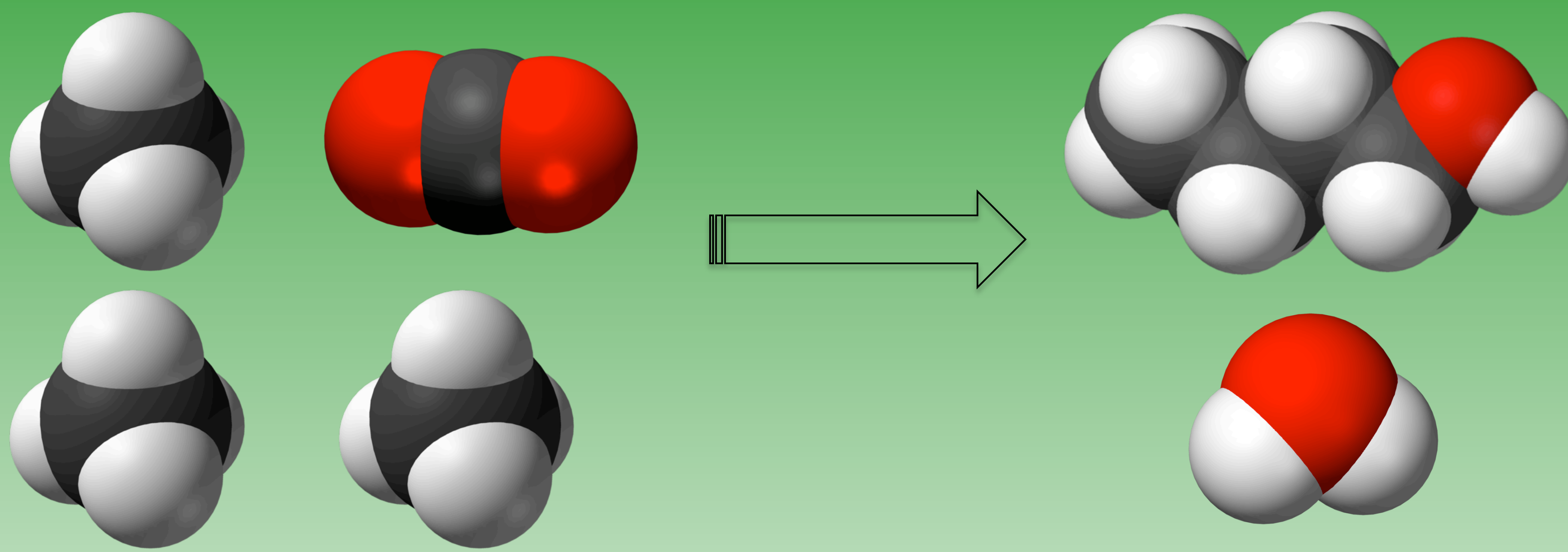


Energy Density: ~36 MJ/kg

- **Fully compatible with existing automobiles and pipelines**
- **Currently made from petrochemical sources, it is an important industrial chemical with an estimated market of over $5 billion**
- **Pioneer Energy has developed a process to make butanol from flare gas and CO_2**

The Basic Chemistry of Our Process

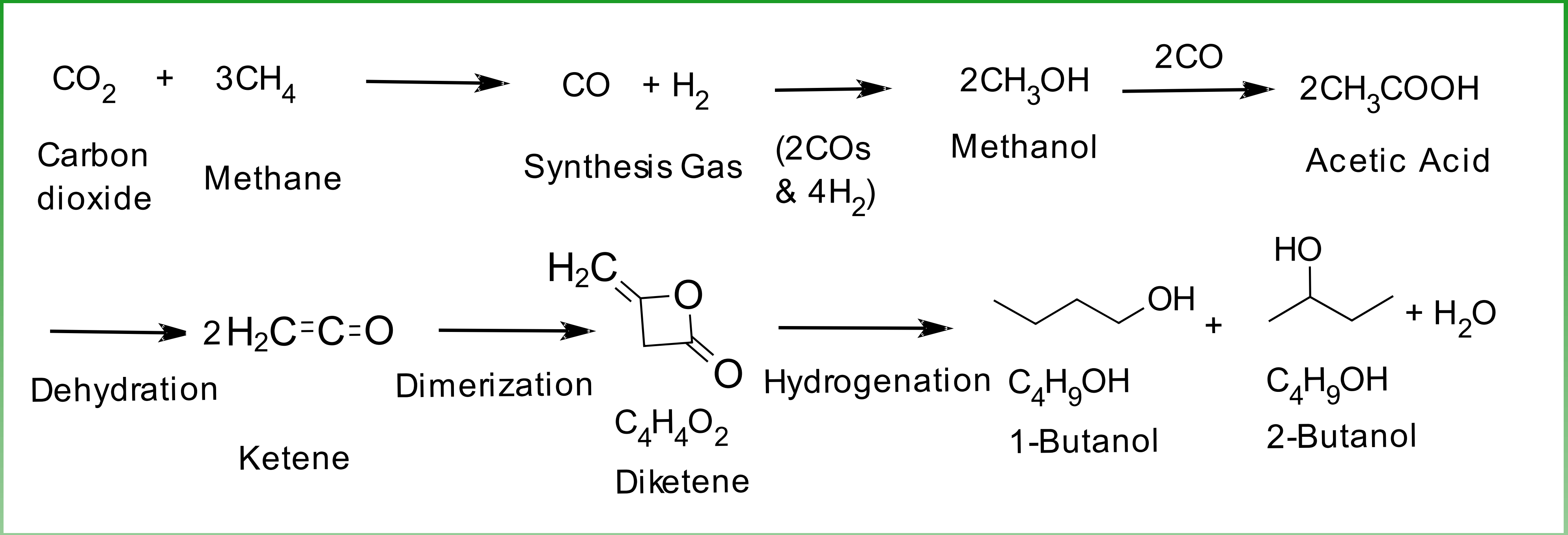
$$3CH_4 + CO_2 \rightarrow C_4H_9OH + H_2O$$



For every three methane molecules taken from flare gas, we consume one CO_2 taken from flue gas and produce one butanol and one water.

We put carbon that would otherwise be released as CO_2 from flare gas & flue gas back into liquid fuels!

The Detailed Chemistry



1. Syngas production	Known
2. Methanol production	Known
3. Reverse water gas shift	Pioneered by us for NASA
4. Acetic acid production	Known
5. Ketene production	Pioneered by Pioneer Energy
6. Ketene dimerization to diketene	Pioneered by Pioneer Energy
7. Reduction of diketene to butanols	Pioneered by Pioneer Energy

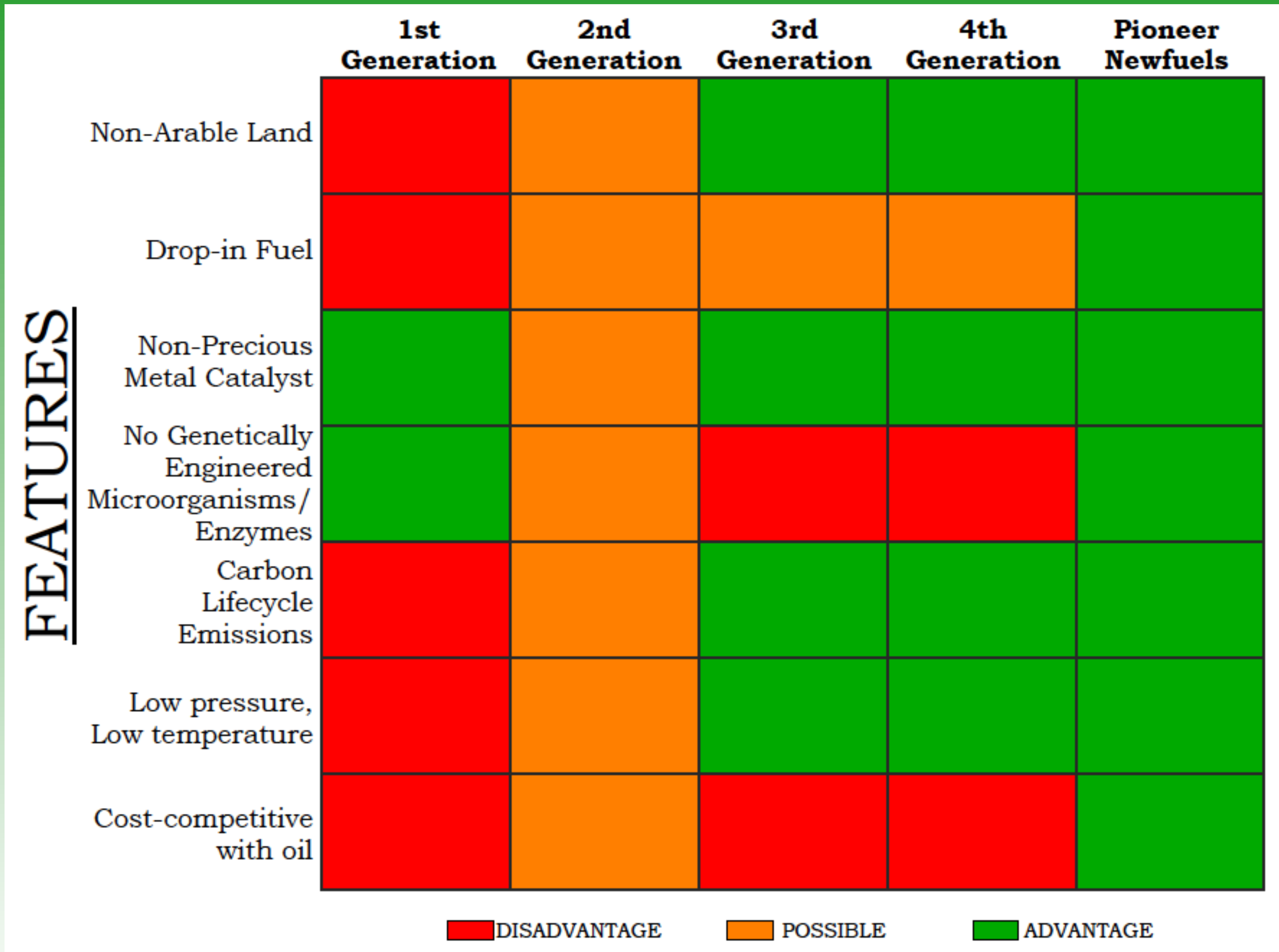
Our Process: A Combination of New and Established Chemical Steps

- We have developed a novel method to synthesize butanol using scalable industrial chemistry.
- The first 2/3-part of this process, taking methane to synthesis gas to methanol and then to acetic acid, is already proven in industry on large scale.
- The final 1/3-part of this process, taking acetic acid to diketene to butanol, has been demonstrated by Pioneer Energy at laboratory-scale and scale-up modeling is being performed.

Competing approaches to butanol production

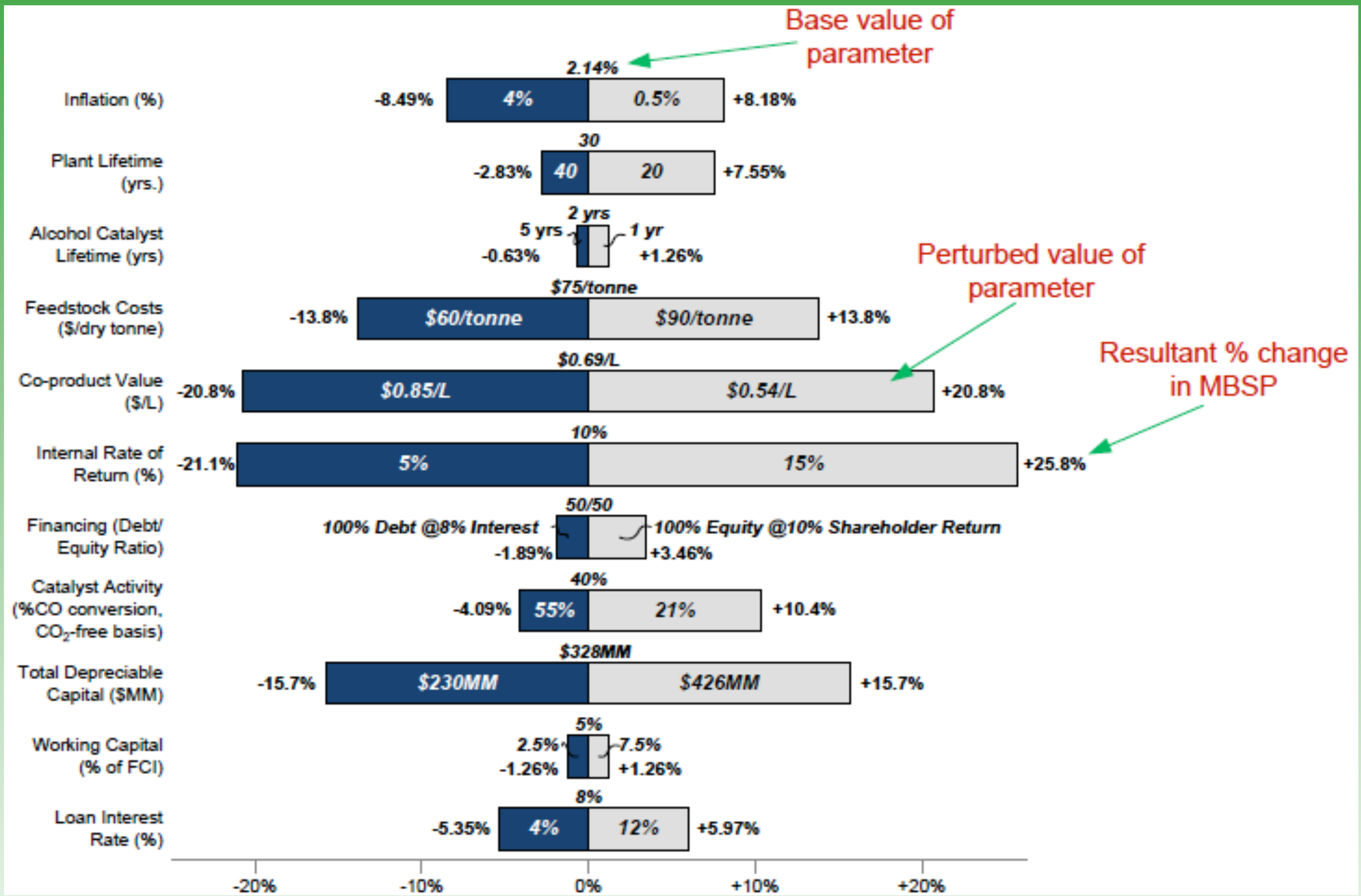
- Other companies are developing methods to make butanol using microbial fermentation.
- The time required for each fermentation cycle, large water consumption, and difficulty of isolation of butanol from broths due to its toxicity to microbes are serious challenges to fermentation process economics.
- Furthermore, such fermentation approaches must use food for feedstock.
- In contrast, the Pioneer Energy approach can use flare gas and flue gas, as well as cellulosic biomass, for feedstock.
- ***Instead of burning food, we turn pollution into fuel.***

Benefits of our approach over 1st, 2nd, 3rd, and even 4th generation bio-fuels



Estimated Economics of the Proposed Process

- **Biomass feedstock: $0.84/liter ($3.18/gallon) OR $3.34/gasoline-gallon-equivalent**
- **GHG feedstock: $0.51/liter ($1.94/gallon) OR $2.03/gasoline-gallon-equivalent**
- **Current spot-price of butanol for chemical use: ~$6/gallon**

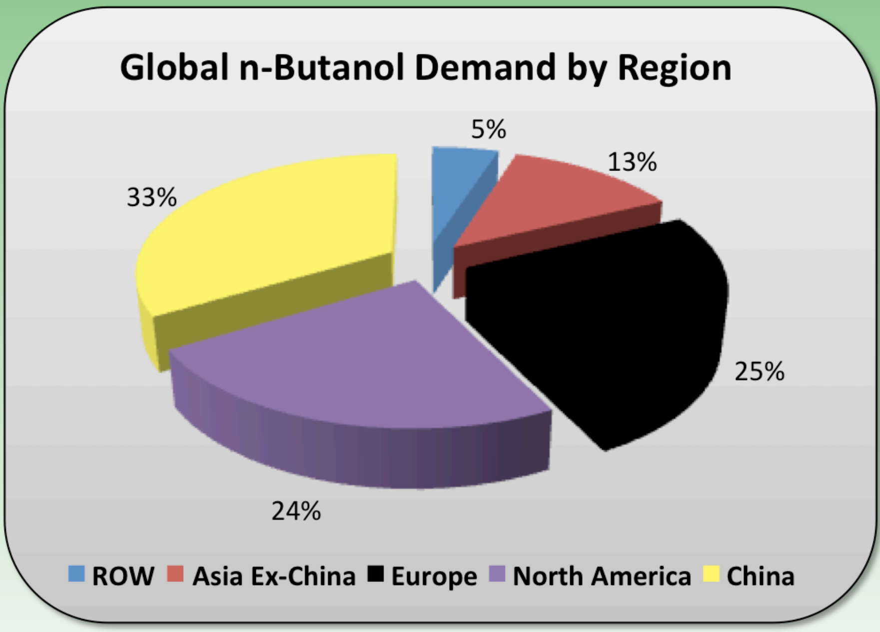


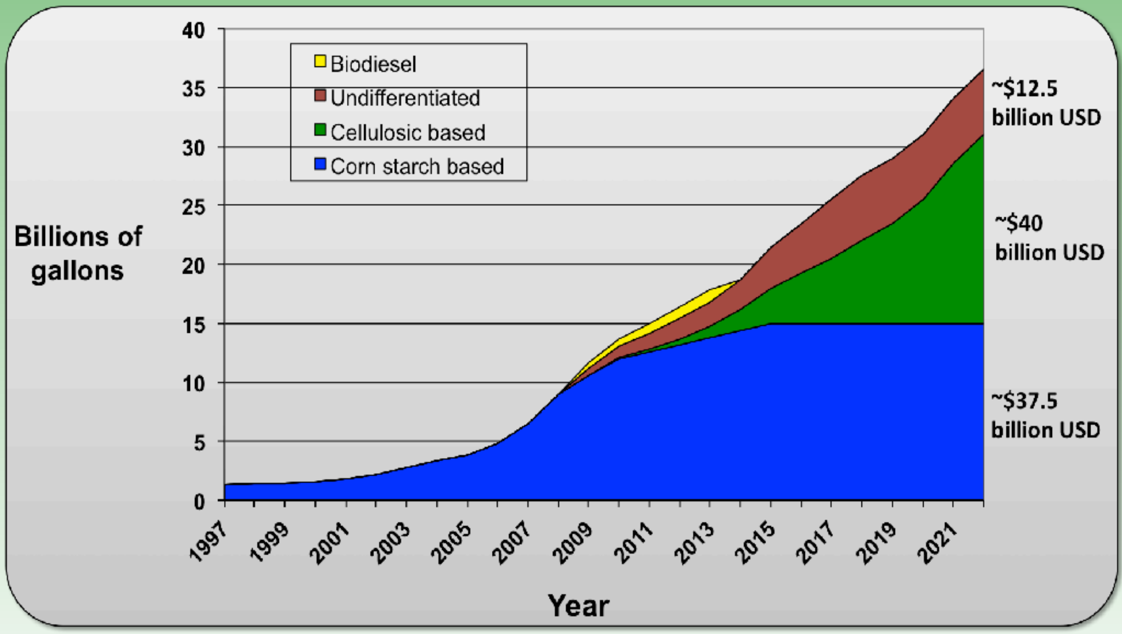
% Change in MBSP from the Base Case ($0.51/L)

Butanol Price Full-Scale Plant Sensitivity Analysis

Market for Butanol

- **The market for butanol in the pharmaceutical, chemical, and polymer industries is estimated at over $5B per year.**
- **As a gasoline blender or extender, butanol can access a >$100B per year market. Automobiles can and have been driven on 100% butanol, so any legal limits can be raised when butanol production and use rise to warrant an increase.**
- **Ethanol use has reached a “blend-wall.”**





Our technology transforms currently-wasted gas into a valuable resource

Ex: Flaring in Alberta today

2.1	%	of Alberta's GHGs originate from flaring & venting
868	million m^3	gas flared/year
333	million m^3	gas vented/year
6-8	million tons	CO_2-e/year

It could be used to produce:

1,440,000 tons Butanol

Worth $1,150,00,000

Concluding Remarks

- **Butanol from Greenhouse Gases turns pollution into fuel**
- Butanol is a drop-in automotive fuel, compatible with existing pipelines
- Process eliminates flaring; reduces existing CO_2 emissions
- Essentially free feedstock
- No use of food sources
- Global applications
- Variants can use trash, cellulosic biomass, natural gas, etc.

- **Thank you to Canada's Climate Change Emissions Management Corporation (CCEMC) for agreeing to fund this work going forward!**

Additional Support Slides

Methodology

- **We used Alberta as a case study, and these results will be generalized to Bakken and other locations in Future Work.**

- **A baseline was established for existing conditions. The baseline included:**
  - **Gasoline produced from Average Alberta Oil**
  - **Flare gas emissions**
  - **Flue gas (CO_2) emissions from stationary sources**

- **This baseline was compared to the GHG emissions associated with the system. The system emissions included:**
  - **Butanol production**
  - **Butanol combustion**
  - **All energy needed for the process comes from the flare gas itself**

Baseline Emission Data

- **Flare Gas Emissions:** **2.75 g CO_2e / g CH_4**
- **Flue Gas Emissions:** **1 g CO_2e / g CO2**
- **Alberta Average Gasoline Production:** **25.5 g CO_2e / MJ**
- **Gasoline Combustion:** **64.6 g CO_2e / MJ**

System Emission Data

▪ **Flare Gas Capture:**	**99%**
▪ **Flue Gas Capture:**	**90%**
▪ **Butanol Combustion:**	**58.5 g CO_2e / MJ**
▪ **Fugitive System CO_2 Emissions:**	**10%**