Carbon absorption in silages: a novel approach in silage microbiology

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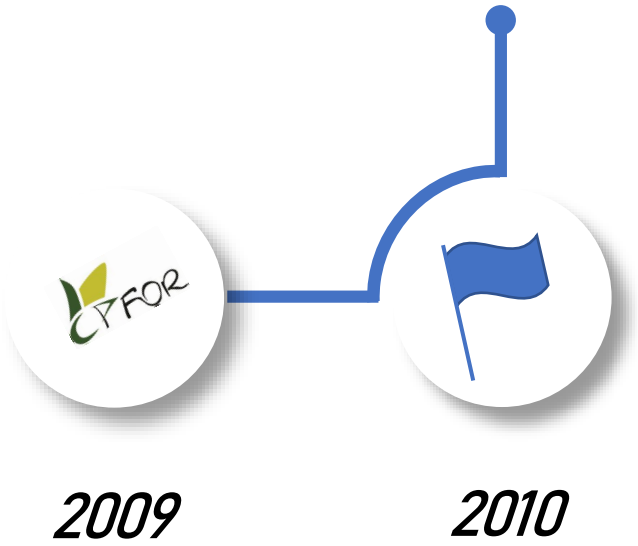


Development of a methodology for collecting all gases from fermentation

2012

2009

2010

Schmidt et al. Greenhouse gas emissions from fermentation of corn silage

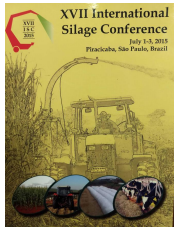
2009

2010

2012

2015

Souza et al. Does the silage absorb air during its fermentation? A lab trial on maize silages added with natamycin.



2009

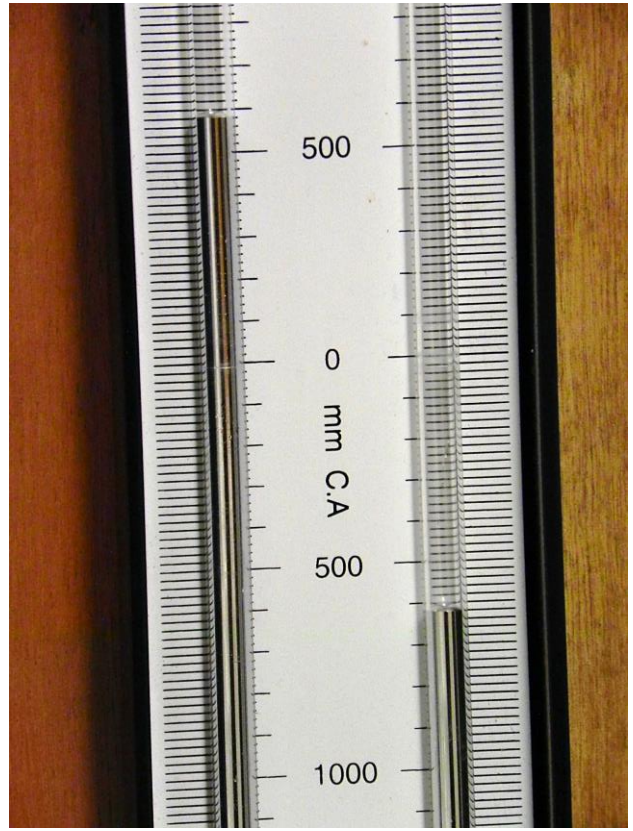
2010

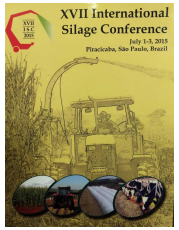
2012

2015

2016

Pilot trial:
Internal pressure and gas absorption





Ph.D. student dedicated to this project

2009

2010

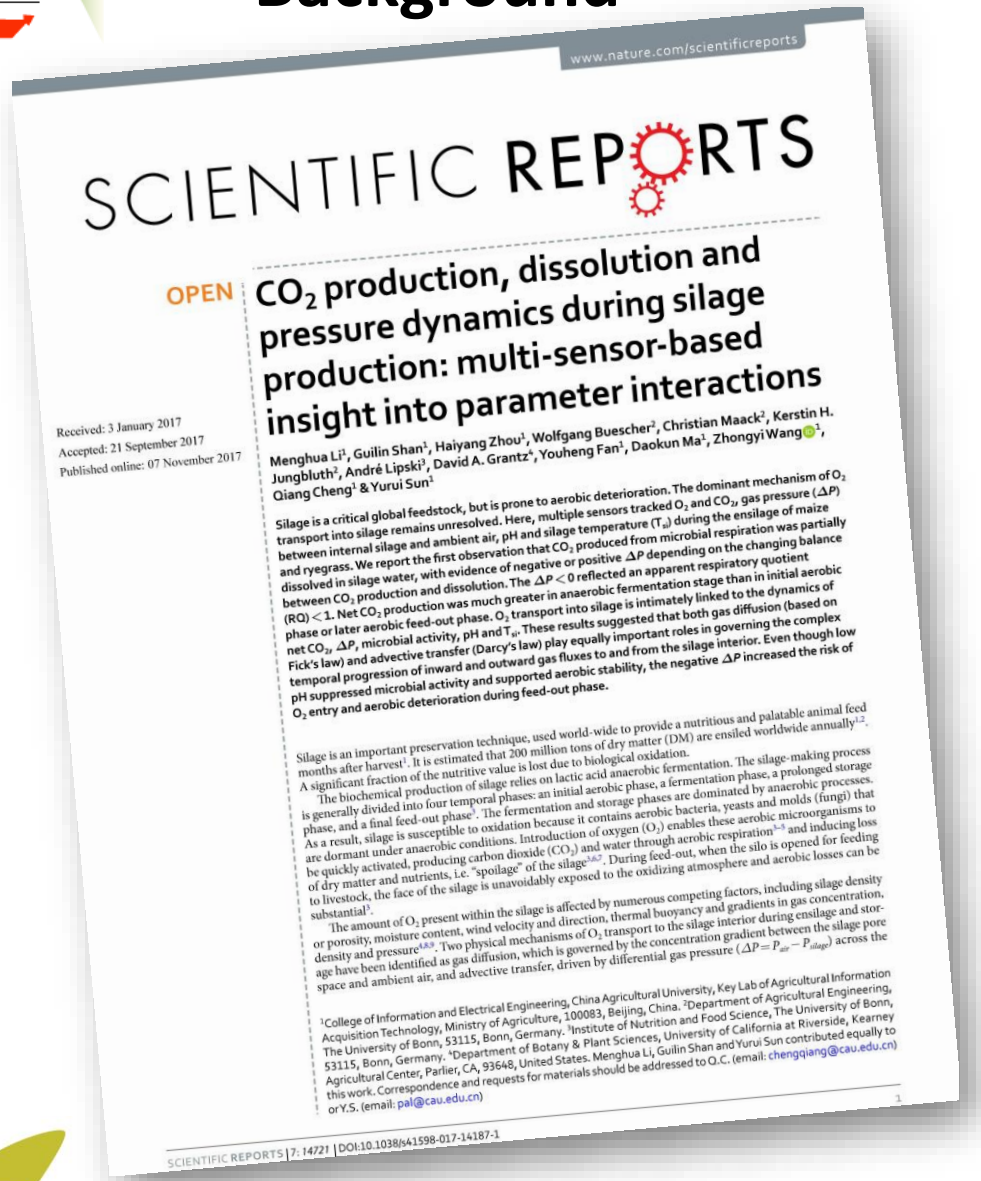
2012

2015

2016

2018

Background



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SCIENTIFIC REPORTS

OPEN

CO_2 production, dissolution and pressure dynamics during silage production: multi-sensor-based insight into parameter interactions

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Silage is a critical global feedstock, but is prone to aerobic deterioration. The dominant mechanism of O_2 transport into silage remains unresolved. Here, multiple sensors tracked O_2 and CO_2, gas pressure (ΔP) between internal silage and ambient air, pH and silage temperature (T_{si}) during the ensilage of maize and ryegrass. We report the first observation that CO_2 produced from microbial respiration was partially dissolved in silage water, with evidence of negative or positive ΔP depending on the changing balance between CO_2 production and dissolution. The $\Delta P < 0$ reflected an apparent respiratory quotient (RQ) < 1. Net CO_2 production was much greater in anaerobic fermentation stage than in initial aerobic phase or later aerobic feed-out phase. O_2 transport into silage is intimately linked to the dynamics of net CO_2, ΔP, microbial activity, pH and T_{si}. These results suggested that both gas diffusion (based on Fick's law) and advective transfer (Darcy's law) play equally important roles in governing the complex temporal progression of inward and outward gas fluxes to and from the silage interior. Even though low pH suppressed microbial activity and supported aerobic stability, the negative ΔP increased the risk of O_2 entry and aerobic deterioration during feed-out phase.

Silage is an important preservation technique, used world-wide to provide a nutritious and palatable animal feed months after harvest[1]. It is estimated that 200 million tons of dry matter (DM) are ensiled worldwide annually[1,2]. A significant fraction of the nutritive value is lost due to biological oxidation.

The biochemical production of silage relies on lactic acid anaerobic fermentation. The silage-making process is generally divided into four temporal phases: an initial aerobic phase, a fermentation phase, a prolonged storage phase, and a final feed-out phase[3]. The fermentation and storage phases are dominated by anaerobic processes. As a result, silage is susceptible to oxidation because it contains aerobic bacteria, yeasts and molds (fungi) that are dormant under anaerobic conditions. Introduction of oxygen (O_2) enables these aerobic microorganisms to be quickly activated, producing carbon dioxide (CO_2) and water through aerobic respiration[4–6] and inducing loss of dry matter and nutrients, i.e. "spoilage" of the silage[5,6,7]. During feed-out, when the silo is opened for feeding to livestock, the face of the silage is unavoidably exposed to the oxidizing atmosphere and aerobic losses can be substantial[3].

The amount of O_2 present within the silage is affected by numerous competing factors, including silage density or porosity, moisture content, wind velocity and direction, thermal buoyancy and gradients in gas concentration, density and pressure[4,8,9]. Two physical mechanisms of O_2 transport to the silage interior during ensilage and storage have been identified as gas diffusion, which is governed by the concentration gradient between the silage pore space and ambient air, and advective transfer, driven by differential gas pressure ($\Delta P = P_{air} - P_{silage}$) across the

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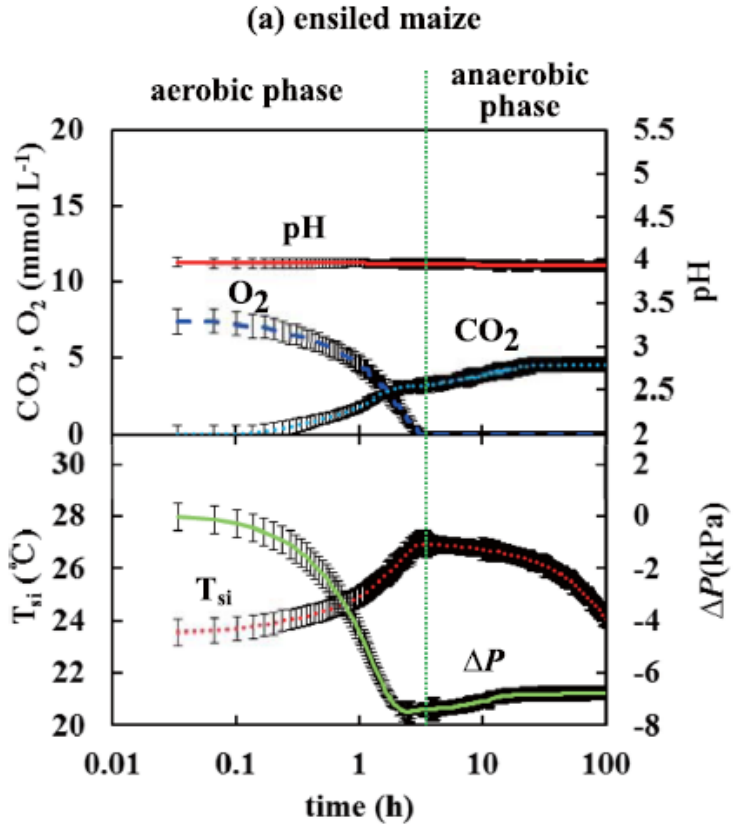
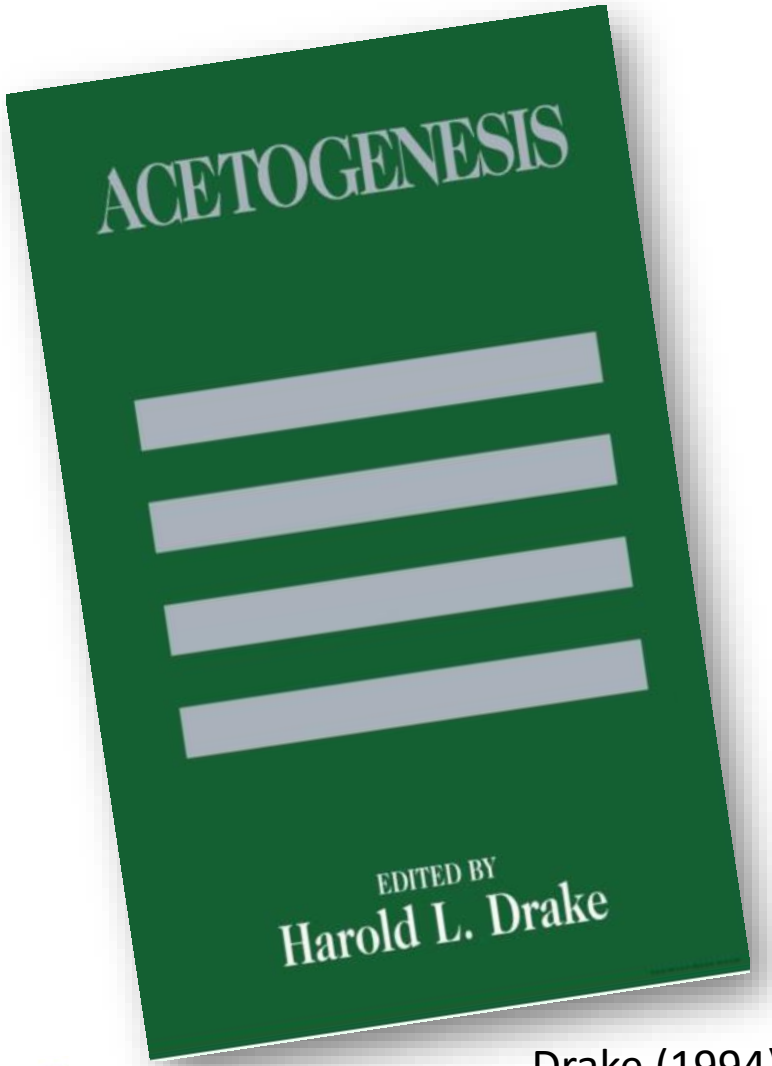
Li et al. (2017) reported an unknown behaviour of negative pressure inside silos



"...partial CO_2 dissolution in interstitial silage water"

Background



Drake (1994)

First acetogenic bacteria (*Clostridium aceticum*) described by Wieringa in 1936:

$$4H_2 + 2CO_2 \rightarrow CH_3COOH + 2H_2O$$

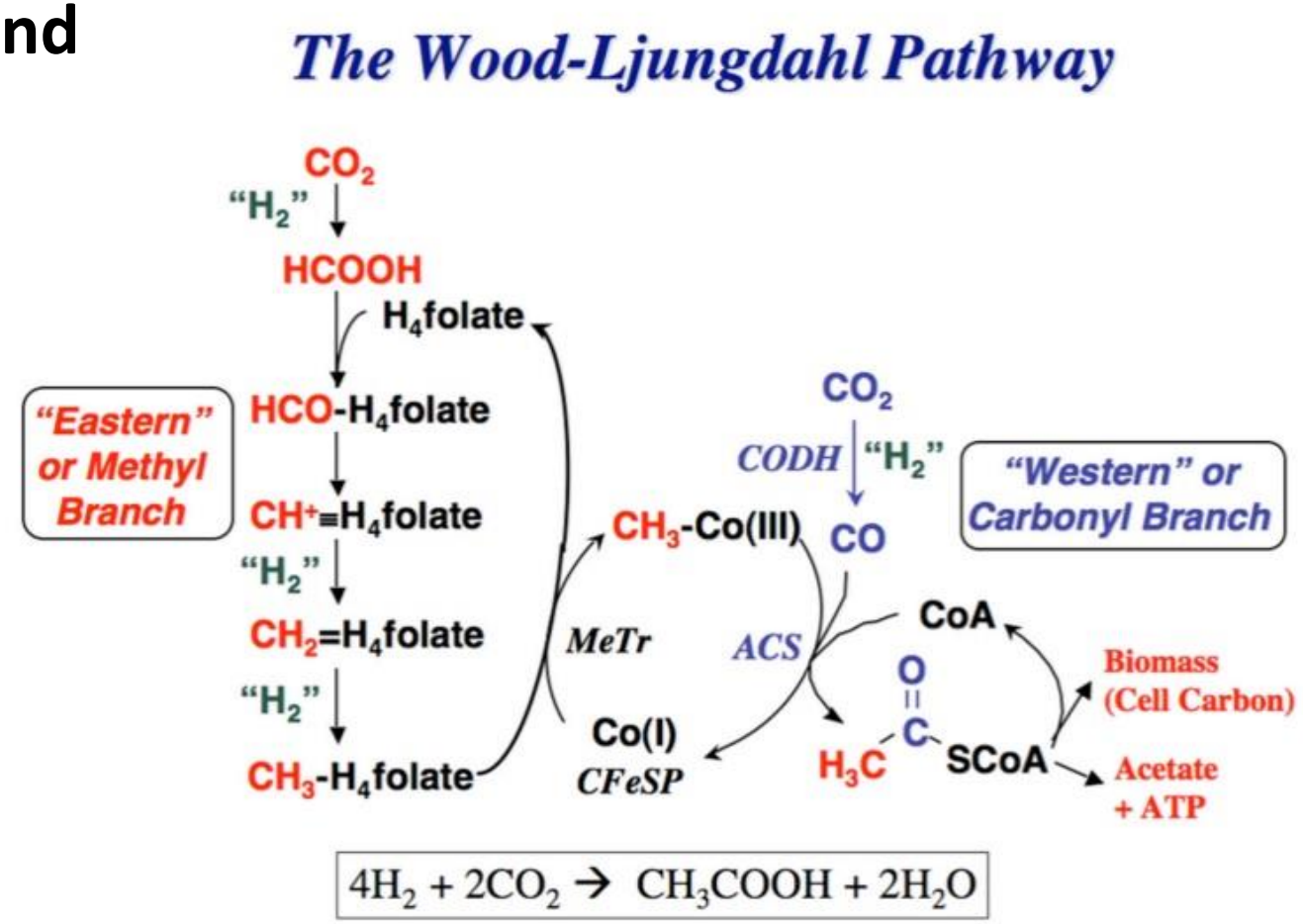
Harland G. Wood - entire career dedicated to CO_2 fixation

Wood (1952) - first study with $^{13}CO_2$ proving incorporation of CO_2 during acetate formation

Autotrophic Acetyl-CoA pathway of CO_2 fixation only established in the 90´s.

The "Wood-Ljungdahl Pathway" (1991)

Background



(Rasgdale and Pierce, 2008)

Figure 1.
The Wood-Ljungdahl pathway. "H_2" is used in a very general sense to designate the requirement for two electrons and two protons in the reaction.

Objectives

1. To evaluate the pressure inside the silos of maize silage.

2. To quantify the CO_2 absorption throughout the storage period.

Material and methods

Eight PVC silos (8.8 L) properly sealed.
Maize forage (332 g kg^{-1} DM)
Storage at controlled-temperature room (24 ±1 ºC) for 5 months

Silos attached to a 3-way valve and to a 1-L chamber made of low-density polyethylene, for collecting all gases. Chamber immersed in water

Pressure inside the silos assessed using a mercury column manometer

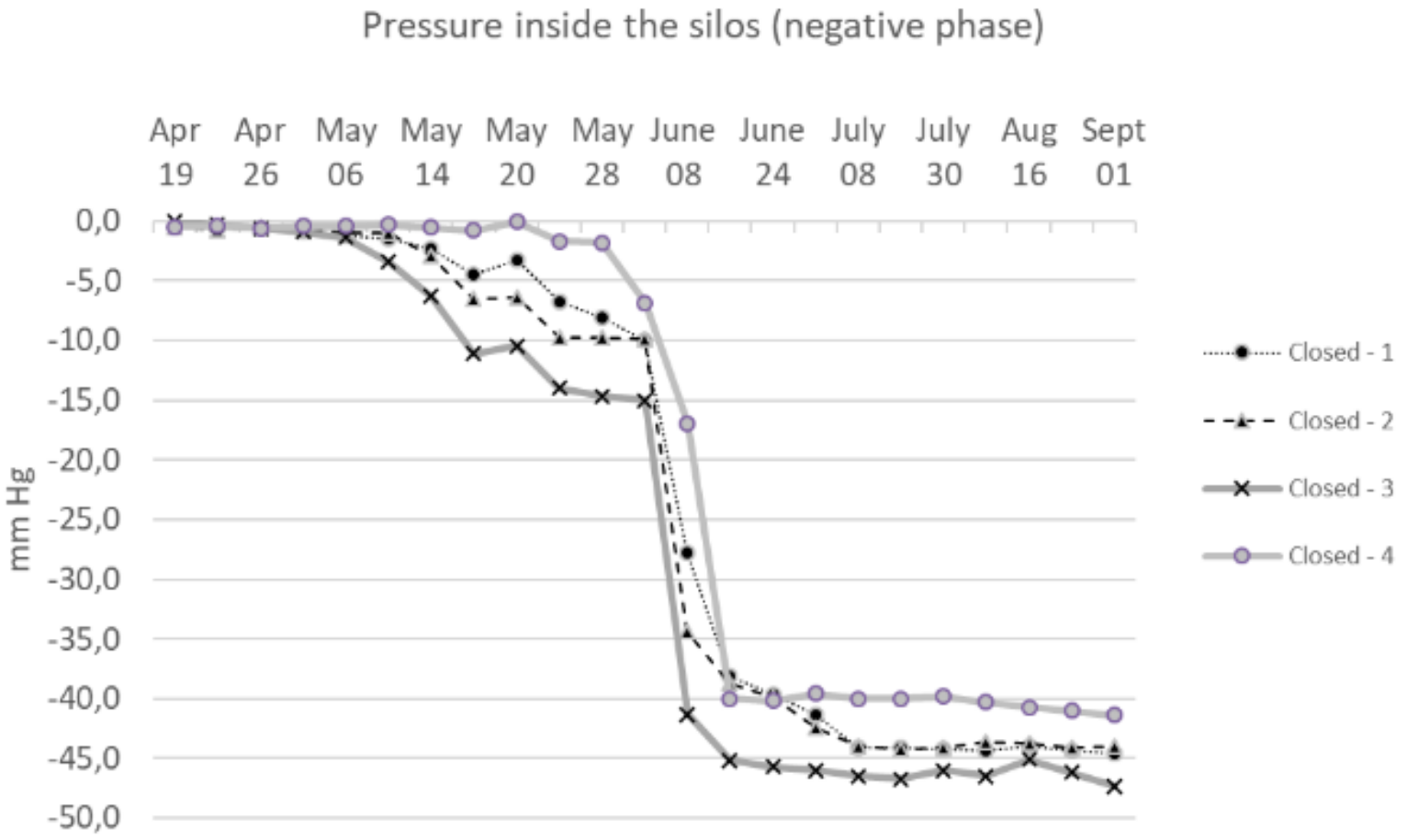
Once the pressure become negative, four silos were weekly fed with pure CO_2. The gas was not forced inside the silos!

After 147 days, silos were opened. Samples taken for pH measuring.

Material and methods

Material and methods

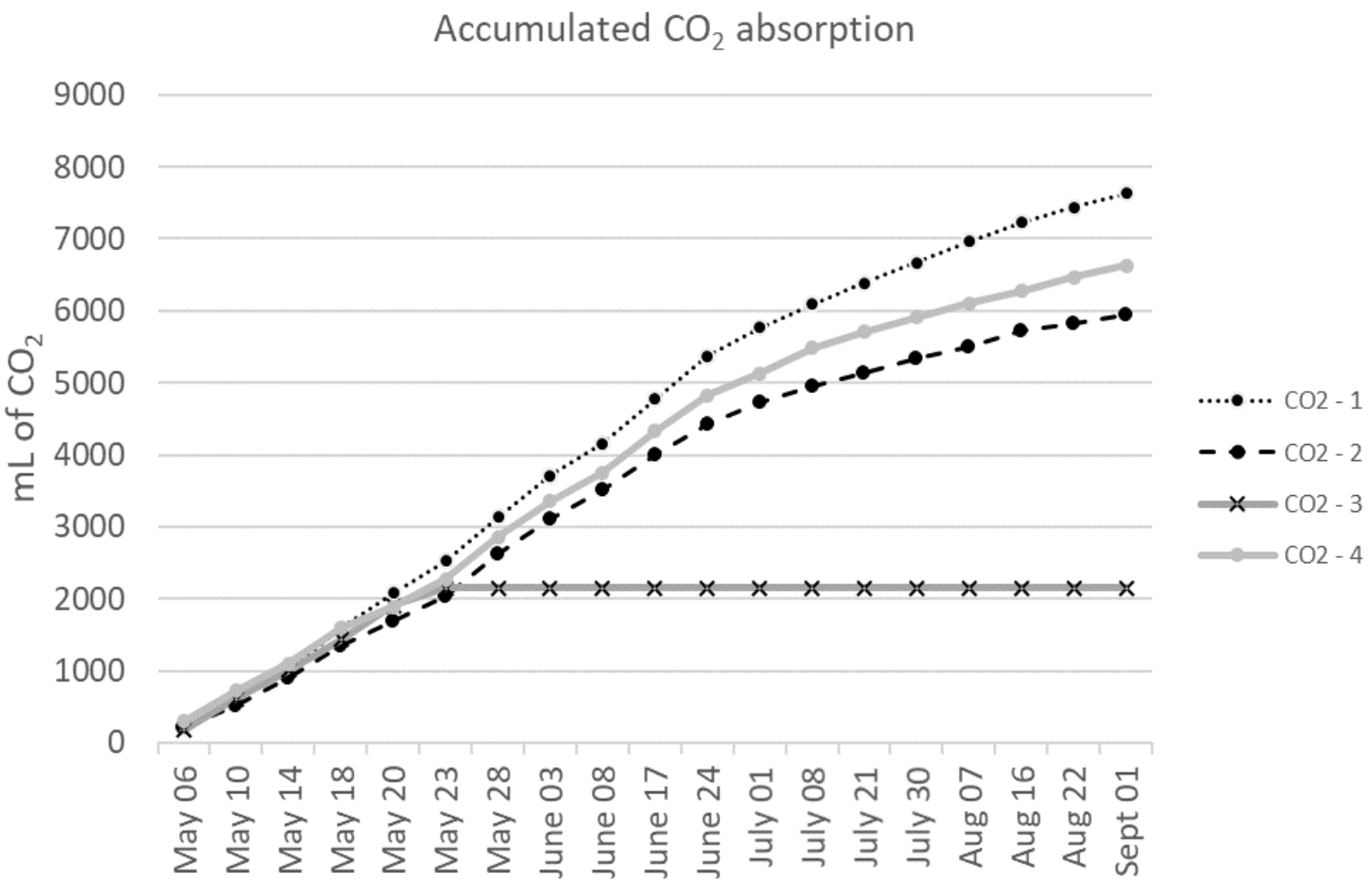
Results



11 days of gas production
3,235 ± 388 mL kg^{-1} DM

Increased negative pressure until 101 days for silos kept closed
-43 ± 2.6 mm Hg (-5.7 kPa)

Results



19 supplies of CO_2

5,590±2492 mL of CO_2 were absorbed

Absorption continued throughout the trial!

pH closed - 3.76±0.03

pH CO_2 - 3.63±0.02

Discussion

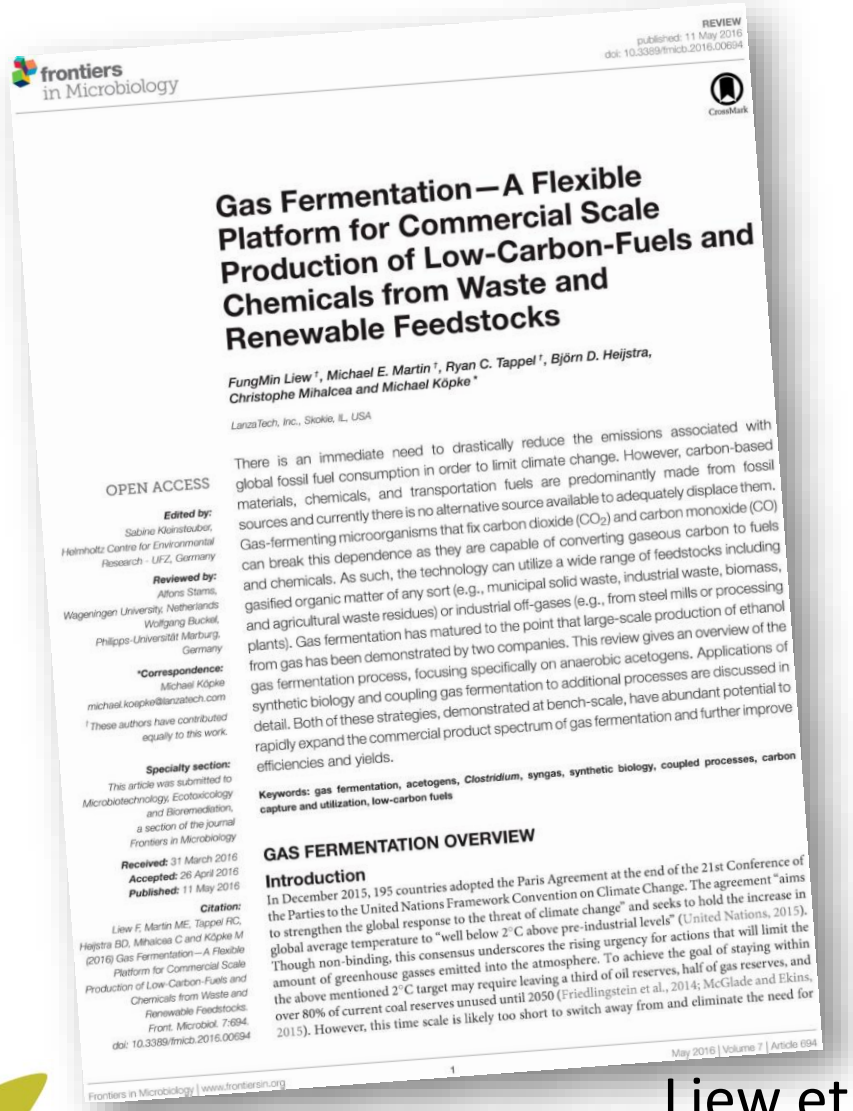
The Wood-Ljungdahl pathway is an energy-generating process of reducing CO_2 to acetate under anaerobiosis

22 bacterial genera are described (Drake at al, 2008)

This process has never been described for silages!

In the future silos can become bioreactors fixing pollutant gases from farm activities (CO, CO_2, N_2O) into high quality nutritive compounds of feed

Where can we go?



frontiers in Microbiology

REVIEW
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Gas Fermentation—A Flexible Platform for Commercial Scale Production of Low-Carbon-Fuels and Chemicals from Waste and Renewable Feedstocks

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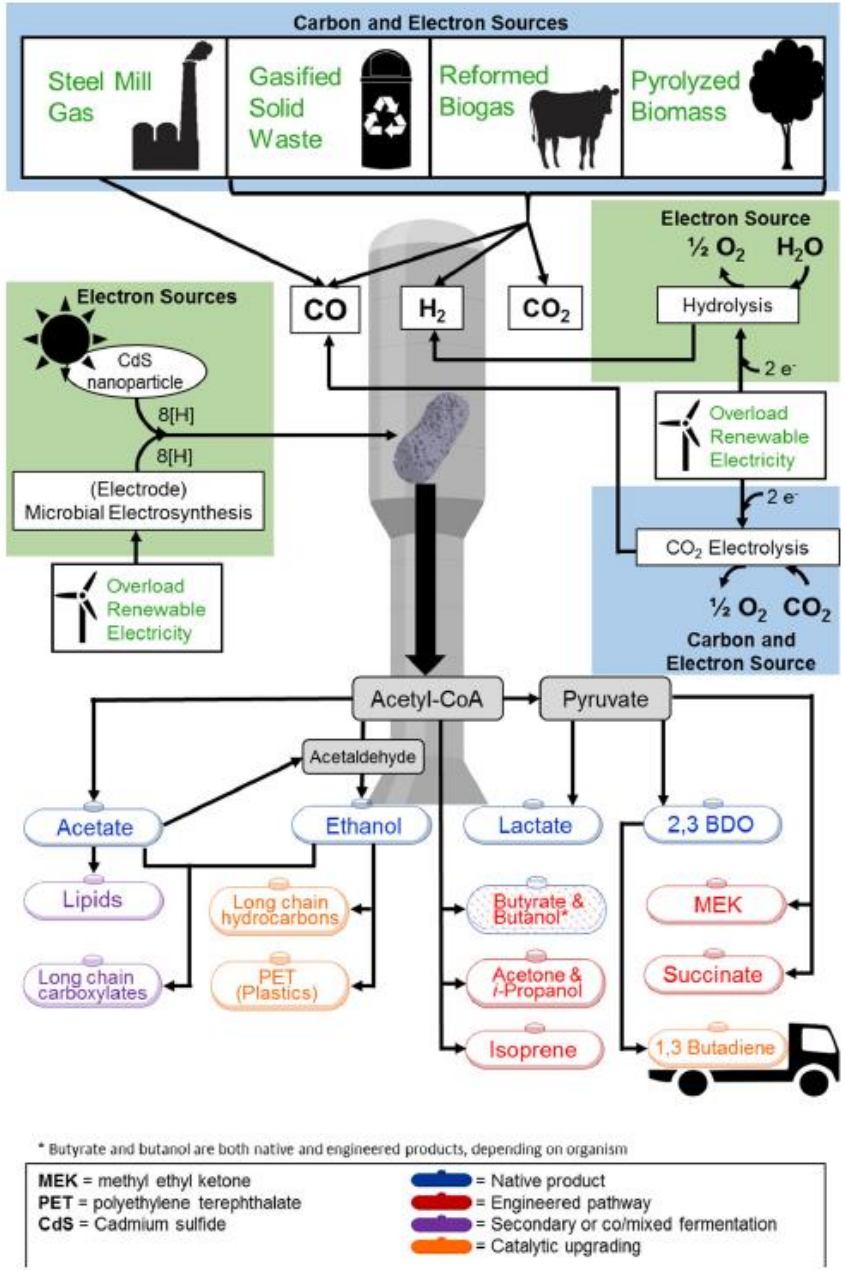
There is an immediate need to drastically reduce the emissions associated with global fossil fuel consumption in order to limit climate change. However, carbon-based materials, chemicals, and transportation fuels are predominantly made from fossil sources and currently there is no alternative source available to adequately displace them. Gas-fermenting microorganisms that fix carbon dioxide (CO_2) and carbon monoxide (CO) can break this dependence as they are capable of converting gaseous carbon to fuels and chemicals. As such, the technology can utilize a wide range of feedstocks including gasified organic matter of any sort (e.g., municipal solid waste, industrial waste, biomass, and agricultural waste residues) or industrial off-gases (e.g., from steel mills or processing plants). Gas fermentation has matured to the point that large-scale production of ethanol from gas has been demonstrated by two companies. This review gives an overview of the gas fermentation process, focusing specifically on anaerobic acetogens. Applications of synthetic biology and coupling gas fermentation to additional processes are discussed in detail. Both of these strategies, demonstrated at bench-scale, have abundant potential to rapidly expand the commercial product spectrum of gas fermentation and further improve efficiencies and yields.

Keywords: gas fermentation, acetogens, *Clostridium*, syngas, synthetic biology, coupled processes, carbon capture and utilization, low-carbon fuels

GAS FERMENTATION OVERVIEW

Introduction

In December 2015, 195 countries adopted the Paris Agreement at the end of the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. The agreement "aims to strengthen the global response to the threat of climate change" and seeks to hold the increase in global average temperature to "well below 2°C above pre-industrial levels" (United Nations, 2015). Though non-binding, this consensus underscores the rising urgency for actions that will limit the amount of greenhouse gasses emitted into the atmosphere. To achieve the goal of staying within the above mentioned 2°C target may require leaving a third of oil reserves, half of gas reserves, and over 80% of current coal reserves unused until 2050 (Friedlingstein et al., 2014; McGlade and Ekins, 2015). However, this time scale is likely too short to switch away from and eliminate the need for



Liew et al. (2016)

Conclusion

Maize silage seems to be able for absorbing and fixing CO_2 by the Wood-Ljungdahl pathway.

Thank you!

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