Enabling industrial fermentation of one-carbon compounds via a completely new concept

FeedstocksUnited

Jan Wery

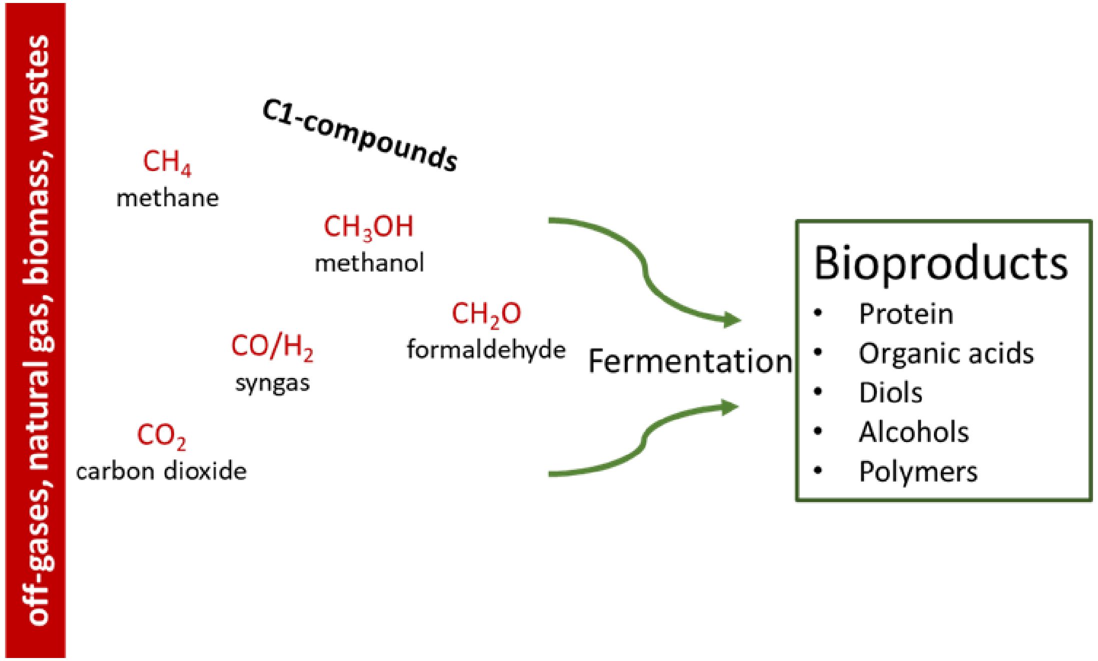
janwery@feedstocksunited.com

FSC Conference 2020

June 23-25

Why one-carbon compounds as feedstock for bioproduction?

- Generally much cheaper than sugar
- Abundantly available
- Decoupling production from agriculture, no land-use, less water use
- Possibility to integrate with renewable electrification processes
- Great CO_2-reduction potential



Selection of bioproducts considered on the basis of C1-compounds

Bioproduct	C1-substrate	Reference
Single Cell Protein (SCP)	Methane	Feedkind.com (Calysta/BP/Cargill), Unibio.dk
Lactic acid/PLA	Methane	Calysta/Natureworksllc.com
Butanediols, Isobutanol, etc.	Methane	MBP Titan (Formerly Intrexon)
Single Cell Protein (Pruteen)	Methanol	Imperial Chemical Industries
Lysine and other amino acids	Methanol	Brautaset *et al.* 2007
Amino acids, dicarboxylic acids, etc.	Methanol	Pfeifenschneider *et al.* 2017
Ethanol and others	Syngas	lanzatech.com
Polyhydroxyalkanoates (PHA)	Methane	Strong *et al.* 2016
Methionine and other amino acids	H2 and CO2	trelystech.com

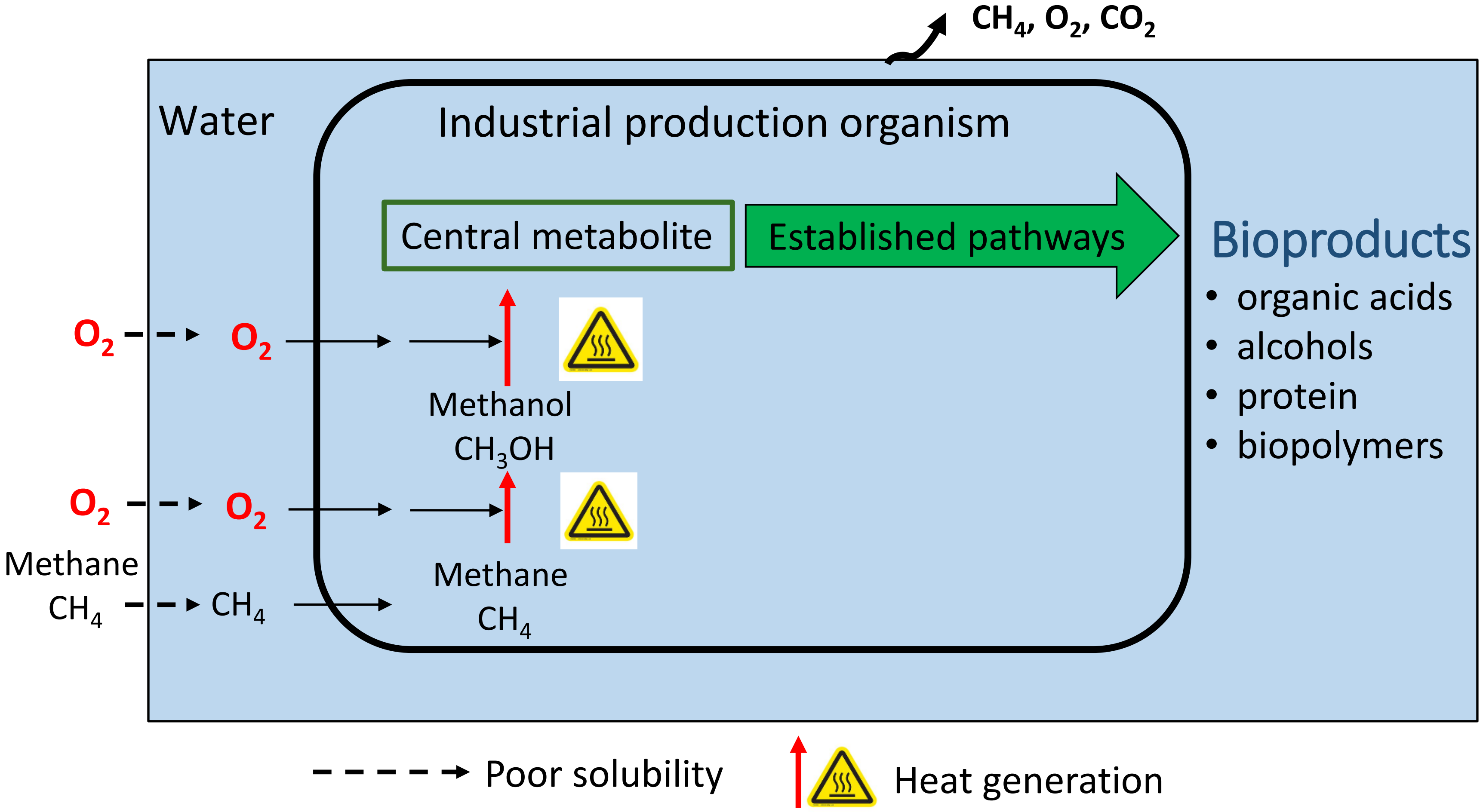
Addressable market for C1-compounds as fermentation feedstocks

FeedstocksUnited

Product	Main players	Market size (M$)	CAGR (%)	Price range ($/ton)	Current feedstock	Alternative feedstock	Developed by
Lactic acid/PLA	Corbion, NatureWorks	700 (LA), 250 (PLA)	15	1.300 - 1.600 (LA) 1.800 - 2.800 (PLA)	sugar	methane	Calysta
Aquafeed (fish meal)	Alpha Feed, BioMar	40.000	4 - 7	1.200 - 1.900	wild fish	methane	Calysta/BP/Cargill, Calysseo, UniBio
Lysine (for feed)	CJ Group, Ajinomoto, ADM, Evonik	3.100	3 - 4	1.200 - 1.500	sugar	methanol	Academic groups
Glutamic acid (for feed)	Ajinomoto	4.000	5	1.500	sugar	methanol	Academic groups
Butadiene	BASF, SABIC, Exxon, Shell	22.000	6	1.000 - 2.000	alkanes	methane	MBP Titan
Ethanol	ADM, Copersugar, POET, Valero, Odebrecht	50.000	5	230 - 1.000*	corn, sugarcane	Syngas	Lanzatech

Direct fermentation of C1-compounds is challenging!

FeedstocksUnited



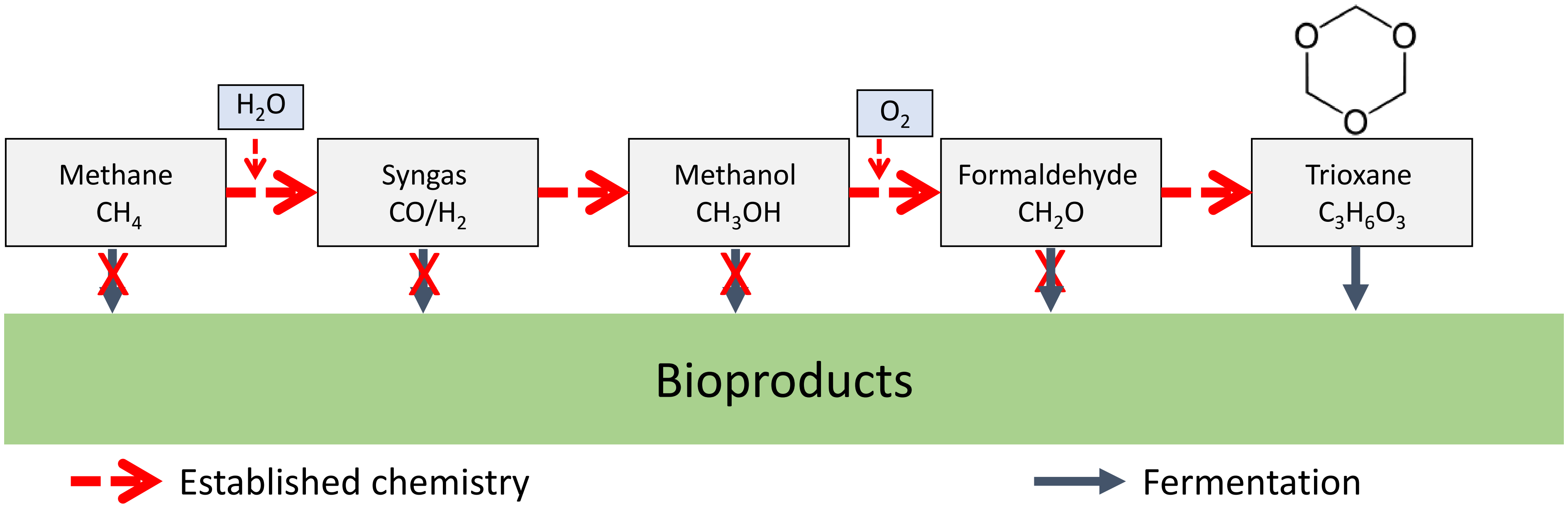
Key issues

- Oxygen supply* and cooling
- Limited volumetric productivity due to limitations in substrate and oxygen transfer
- Excess unwanted biomass and by-product formation
- Safety (explosion limits, handling)

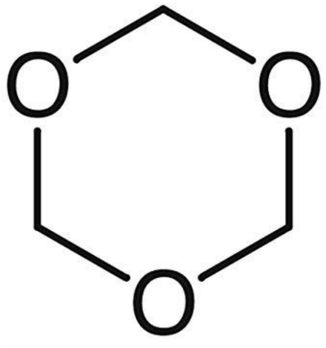
→ No commercial large scale process implemented after 40 years of work on the topic

*For each ton of methane utilized, two tons of oxygen (10 tons of air) are required

FeedstocksUnited proposes to use trioxane in fermentations rather than other C1-feedstocks



1,3,5-TRIOXANE

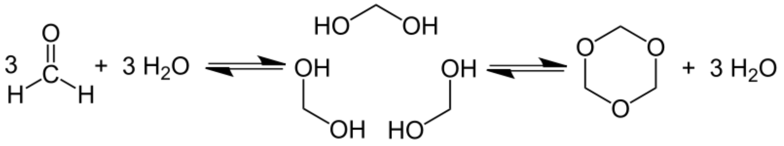


$C_3H_6O_3$

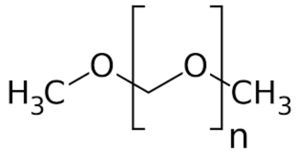
Cyclic acetal

Trioxane production from formaldehyde

- Trioxane is currently produced as a monomeric compound for the manufacture of polyoxymethylene (POM):



1,3,5-Trioxane is synthesized under acidic conditions from formaldehyde



POM is a high performance industrial polymer

- Current production of POM is ~500,000 tons/year

Trioxane as a fermentation feedstock?

FeedstocksUnited

Physical properties:

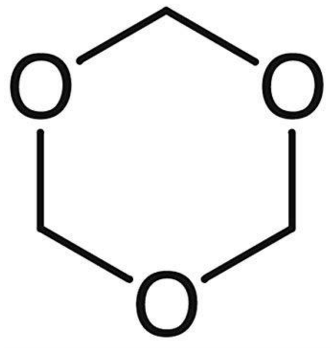
- Good solubility in water of up to 800 g/l (depending on temperature)
- Stable in water
- Volatility no issue

Bioprocess advantages:

- Not toxic to microbes
- Limited problems in combatting contaminations
- Clean stream which is very beneficial in downstream processing of bioproducts

Biological aspects:

- The oxidation/reduction levels of trioxane and sugars are the same



$C_3H_6O_3$

Trioxane could be used like a sugar in fermentations, PROVIDED it can be utilized **(our technology)**

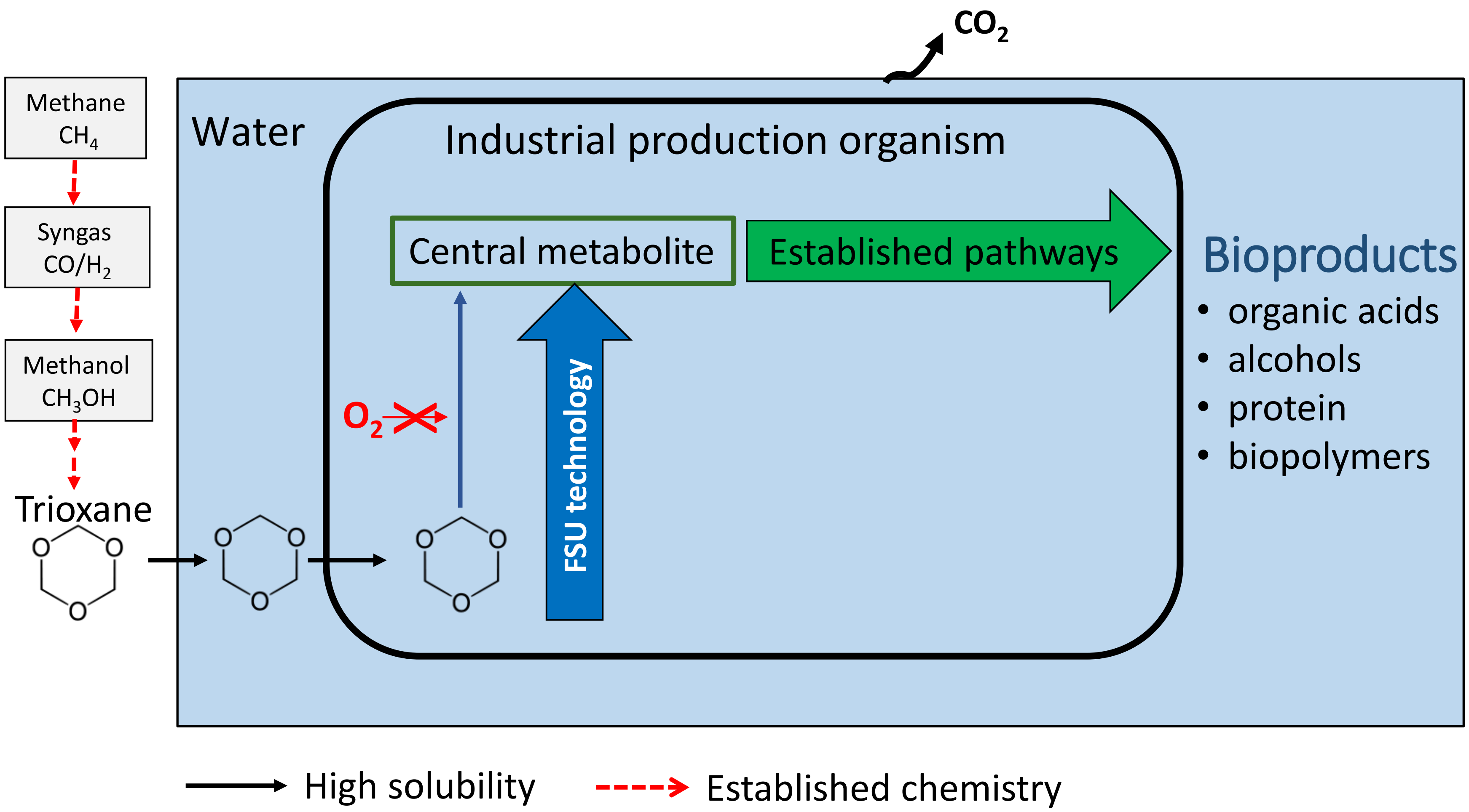
Trioxane versus other (C1) feedstocks projected in industrial fermentations

FeedstocksUnited

Parameter	Methane	Syngas	Methanol	Trioxane	Sugar
Non-food feedstock	yes	yes	yes	yes	no
Mass transfer issues	very high	very high	high	normal	normal
Oxygen requirement	very high	not applicable	high	normal	normal
Cooling requirement	very high	low	high	normal	normal
Water solubility	very low	very low	good	good	good
Toxicity	not	medium	medium	not	not
Safety issues	very high	high	medium	low	low
Greenhouse gas mitigation	yes	yes	yes	yes	medium
Growth/production rate	limited	limited	medium	high	high
Organisms and tools	reasonable	reasonable	good	good	good
Contamination risk	high	low	high	very low	medium
Options for new IP (FTO)	limited	limited	limited	ample	limited

The FeedstocksUnited technology allows trioxane to be used like sugar in bioproduction of commodities

FeedstocksUnited

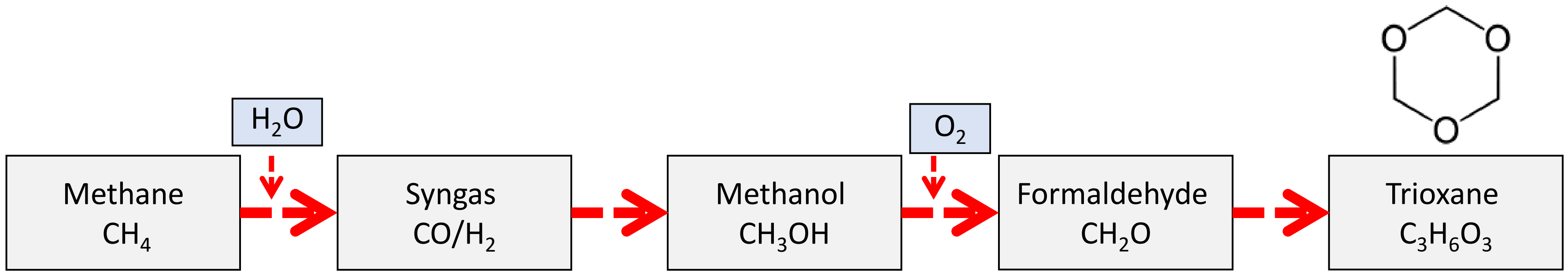


Key advantages of the technology

- Enzymatic conversion of trioxane into central metabolite
- No extra oxygen supply and cooling needed
- Limited mass transfer issues
- High volumetric productivities possible

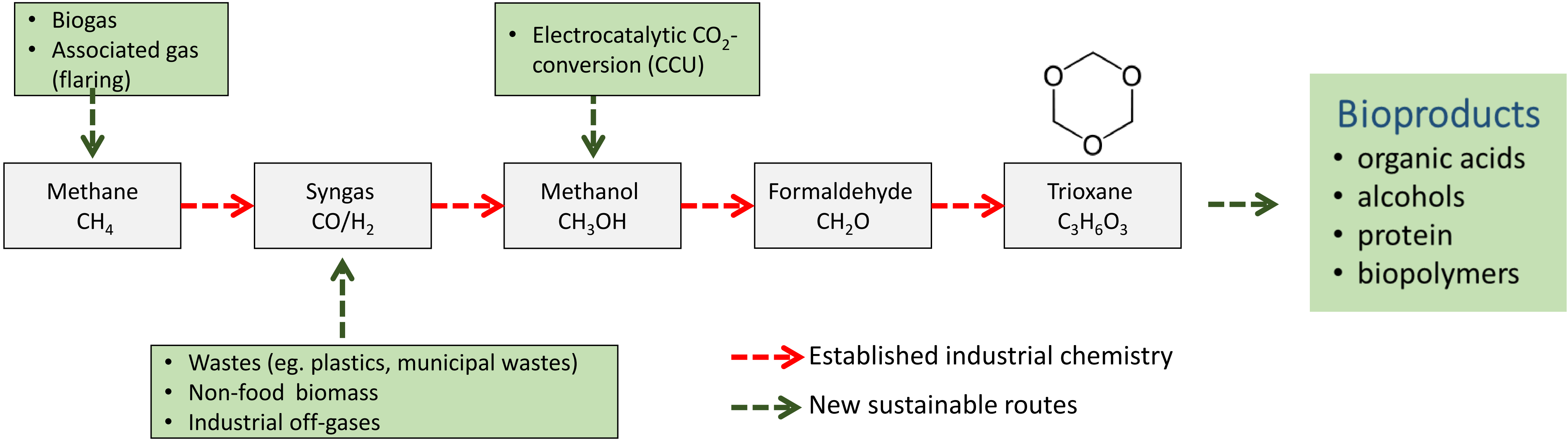
➡ Existing large scale fermentation infrastructure can be used

Economics of trioxane production for fermentation purposes



- Production chain of formaldehyde, via methane and methanol is mature and efficient
- Market prices of trioxane-intermediates are generally below sugar price
- Trioxane for POM production has to be ultra-pure and free of water
- Trioxane for fermentations can be less pure, and water obviously is no issue
- Hence, the cost price of trioxane production at fermentation specs will be substantially lower (target = sugar price-range)
- Collaboration with Prof. Hans Hasse, University Kaiserslautern

Trioxane-based fermentation offers great sustainability potential



- Move away from agriculture (sugar) for bioproduction of commodities.
- Utilization of a range of wastes and by-products is possible via trioxane

FeedstocksUnited technology: status and next steps

Status

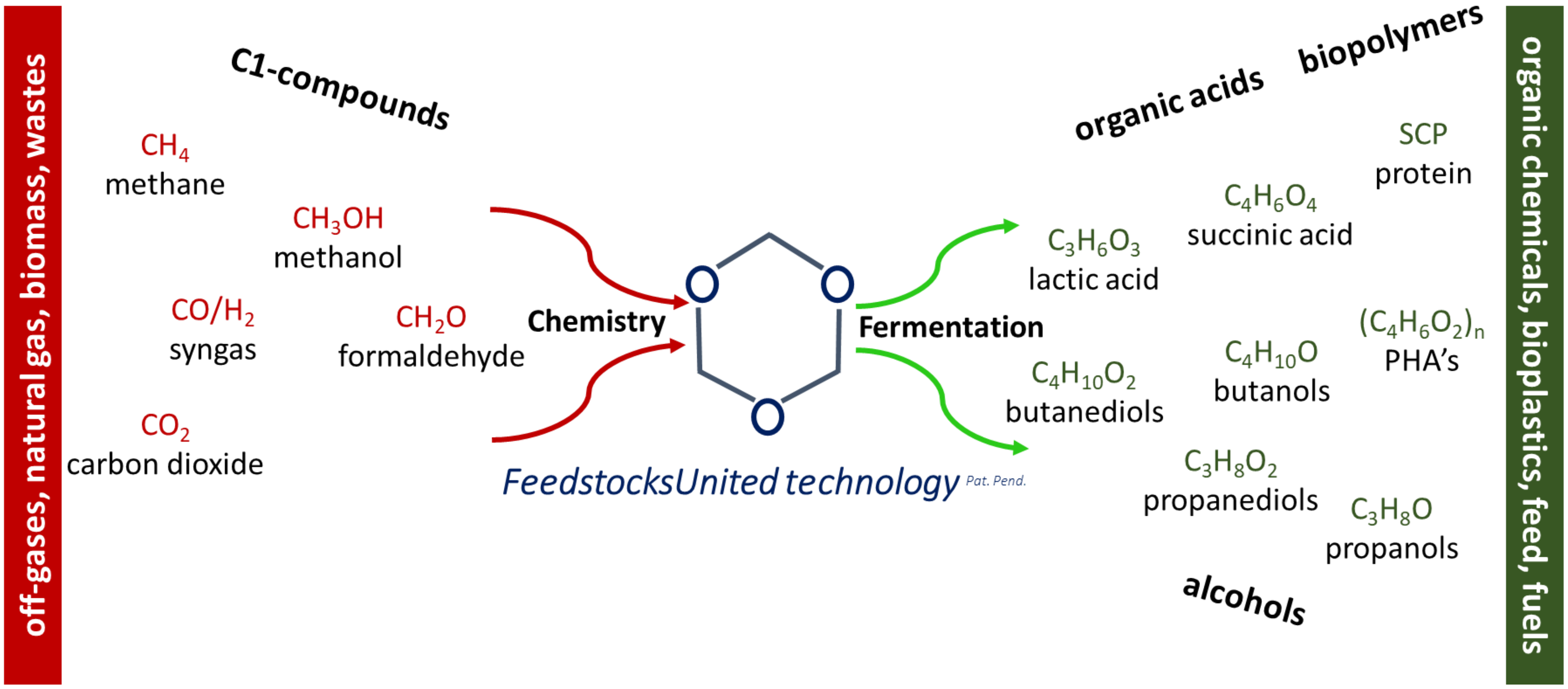
- ✓ Bacterial anoxic degradation of trioxane demonstrated.
- ✓ The genome of one strain has been sequenced.
- ✓ Genes encoding trioxane degrading enzymes have been identified.
- ✓ A patent application has been filed with claims covering enzymes, organisms and processes.
- ✓ Preliminary techno-economic evaluation performed

Next steps technology development

- Produce desired product from trioxane by expression of our enzymes in a production host.
- Demonstrate potential of the technology by achieving target KPI’s: target yield, titer, rate.
- Evaluate the economic and sustainability potential in detail.
- Broaden IP position.

In conclusion

FeedstocksUnited



The new technology presents great opportunities:

- Completely novel bioproduction processes for various commodity chemicals which form a multibillion market
- Extremely good sustainability profile since non-food biomass, municipal wastes, industrial off-gases such as CO, CO2 and associated natural gas (methane) can be funneled into the production chain
- Patented technology and freedom to operate

Team FeedstocksUnited

Founders:

Jan de Bont
Managing Director

Jan Wery
R&D Advisor

Bart Swinkels
IP Director

Advisors:

Ger Bemer
Business

Hans Hasse
Chemical Process Engineering