Low-cost production of protein from methane in Russia

Alex Ablaev
NanoTaiga
Moscow, Russia
info@nanotaiga.ru

Edward B. Hamrick
Hamrick Engineering
Miami, FL USA
info@cellofuel.com

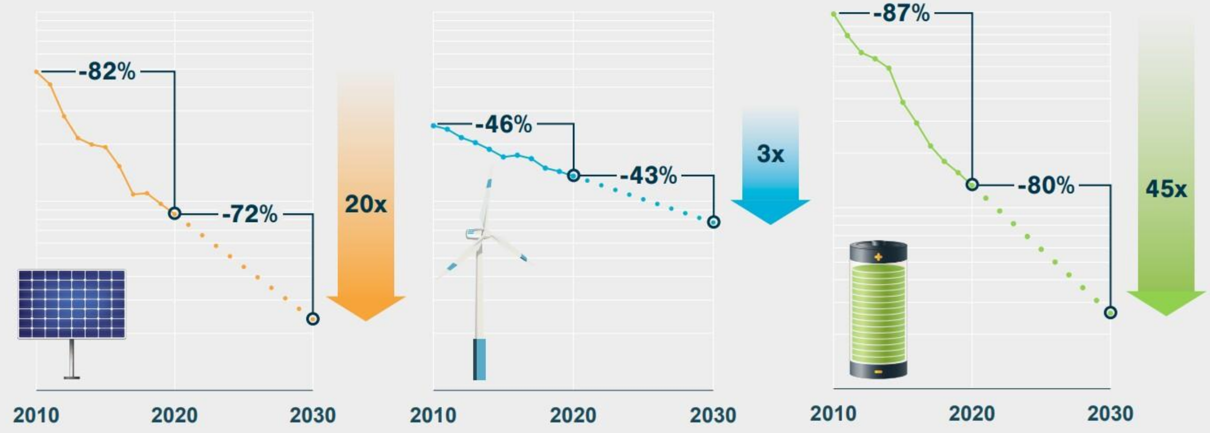
Global Electricity Trends (from Tony Seba at rethinkx.com)

China leading this technology disruption Possible resource limitations for solar panels Less cost effective in northern latitudes

100% Solar, Wind, and Batteries is the Cheapest System by 2030

Falling costs drive technology disruptions. Solar and wind are already the cheapest new generation options, and cost less than existing coal, gas, and nuclear power plants in many areas. The cost of SWB systems will fall another 70% by 2030, making disruption inevitable.

$/kWh (logarithmic plot)



- **We are beyond the rupture point, and the bulk of disruption will unfold rapidly over the next decade.**
- **Electricity from a 100% SWB system in 2030 will cost less than 3 cents per kilowatt-hour.**
- **New investments in coal, gas, or nuclear power is financially unviable.**
- **Existing coal, gas, and nuclear assets will be stranded.**

Market Disruption

5th AVE NYC 1900

WHERE IS THE CAR?

Market Disruption – Phase Change

5^{th} AVE NYC 1913

WHERE IS THE HORSE?

Global Trends
in Transportation Fuels

- 50% of oil use in the world is for road transportation today 5% additional is ethanol for blending
- Road transportation is switching to Battery Electric Vehicles (BEV)
  - *China and Tesla dominate the market*
  - *Most new cars in China are BEV*
  - *In 10 years, most Internal Combustion Engine car makers will be bankrupt*
  - *VW, GM, Ford, Toyota have huge debts, circling the drain*

- 129 Mt/year fuel ethanol produced from 256 Mt/year sugars & starch eventually could produce 129 Mt/year protein from these sugars & starch
- Population will increase from 8 B to 10 B in the next 20 years at 80 g protein/person/day, need at least 160 Mt/year additional protein

Global Trends in Electricity Production

- Natural gas produces 6,300 TWh electricity per year worldwide consumes 891 Mt/year natural gas
- Solar power is now less expensive to produce electricity than natural gas
  China leads the world in Photovoltaic (PV) solar, 15% growth per year
- As electricity generation switches to PV, excess natural gas in next 20 years eventually could produce 450 Mt/year protein from this natural gas
- Excess gas from NordStream 1&2 is 110 B m^3 (75 Mt/year)
  Russia flaring $10 M/day ($3.6 B/year) excess Nordstream gas could produce $75-150 B/year revenue from Single Cell Protein (SCP)

Global Sources of Inexpensive Natural Gas

- Russia has large amount of surplus natural gas and flare gas even more stranded natural gas – pipelines are expensive
- Qatar and Bahrain have large amounts of surplus natural gas limited by liquefaction capacity
- USA has large amounts of stranded natural gas – pipelines are expensive
- Together, natural gas can meet the entire world's requirement for protein
- People prefer fish and chicken to texturized protein
  SCP has a very good Feed Conversion Ratio with fish and chicken
- Beyond Meat – protein from peas, mung beans, faba beans, brown rice doesn't taste as good as salmon and chicken

It sounds easy – what's the problem

- Soviet Union had thousands of world-class engineers working on making SCP (Gaprin) from natural gas
- Denmark and Norway have worked decades on making SCP from methane
- Germany made SCP from spent sulfite liquor in 1930's and 1940's
- Russia currently making SCP from natural gas (Protelux)
- WHY HAVE ALL THESE PROJECTS FAILED? Soy protein is cheaper - $2/kg

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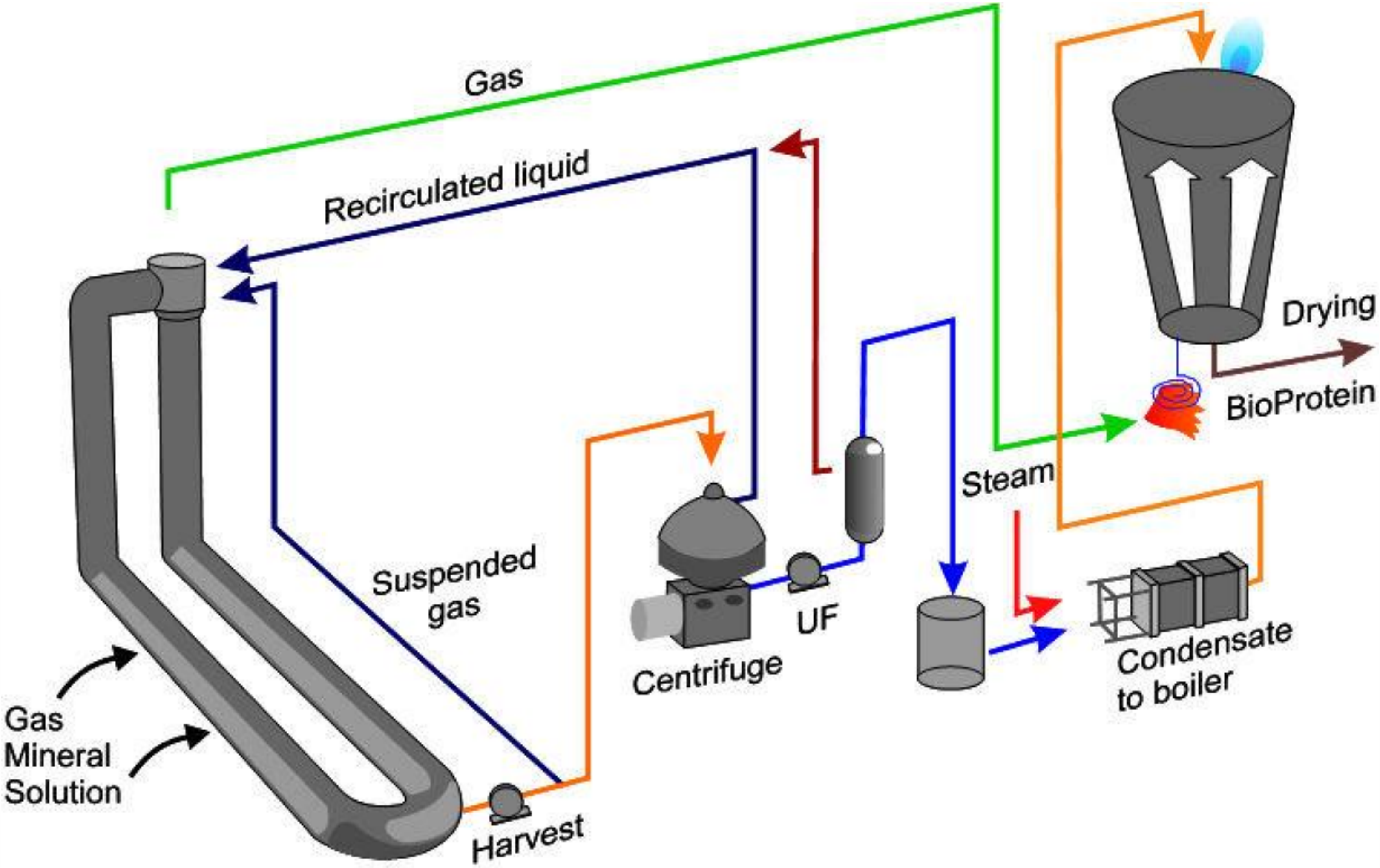
Protein from Natural Gas - Norferm



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Protein from Natural Gas - Norferm

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Protein from Natural Gas - Protelux

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Protein from Natural Gas – project status worldwide

- BioProtein (Methylococcus capsulatus) was produced from 1997-2005 at the Norferm plant in Tjeldbergodden, north of Trondheim, Norway
- Built in 1997, produced 20,000 tons/year of BioProtein, closed in 2005 after losing $9M/year – couldn't compete with price of soy protein
- Protelux produced Bioprotein since 2018 at plant in Ivangorod, Leningrad Region, near Estonian border
- Plant cost 3.5 billion rubles to build, Protelux has never been profitable – can't compete with price of soy protein
- Cargill and Calysta announced joint venture using same technology as Protelux, started construction in 2017. Current satellite view shows a large empty plot of land – couldn't compete with price of soy protein
- Lesson – must produce protein at less than $2/kg to compete with soy protein

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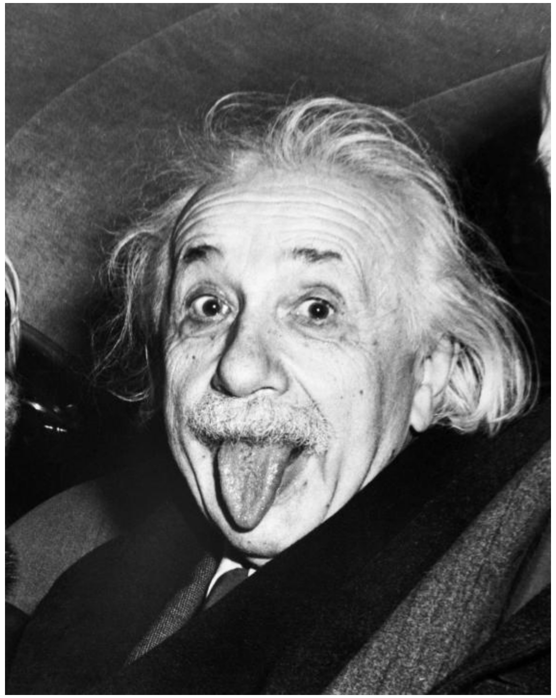
Protein from Natural Gas – How to Succeed

Albert Einstein

The definition of insanity is doing the same thing over and over again and expecting different results

Альберт Эйнштейн

Безумие - это делать одно и то же снова и снова и ожидать при этом иного результата



Single Cell Protein from Carbohydrates and Methane – Stoichiometry

SCP from carbohydrates

$$CH_2O + 0.33\ O_2 + 0.133\ NH_4 \text{ -> } 0.333\ CO_2 + 0.666\ H_2O + 0.1333\ C_5H_{10}O_{2.5}N$$

$$1\text{ kg } CH_2O \text{ -> } 0.55\text{ kg SCP}$$

SCP from methane

$$CH_4 + 1.20\ O_2 + 0.064\ N_2 \text{ -> } 0.360\ CO_2 + 1.424\ H_2O + 0.1280\ C_5H_9O_2N$$

$$1\text{ kg } CH_4\ (\$0.18) + 2.4\text{ kg } O_2\ (\$0.36) \text{ -> } 0.92\text{ kg SCP } (\$0.92)$$

Burning methane

$$CH_4 + 2O_2 \text{ -> } CO_2 + 2H_2O$$

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Single Cell Protein from Carbohydrates and Methane – Stoichiometry

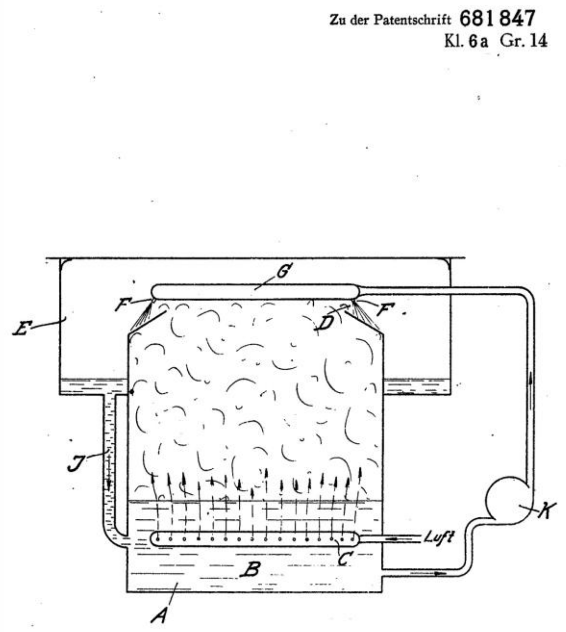
IMPORTANT CONCLUSIONS:

1. SCP from methane needs 3.6 times as much O_2 as from carbohydrates
   This is a big problem since O_2 isn't very soluble in water

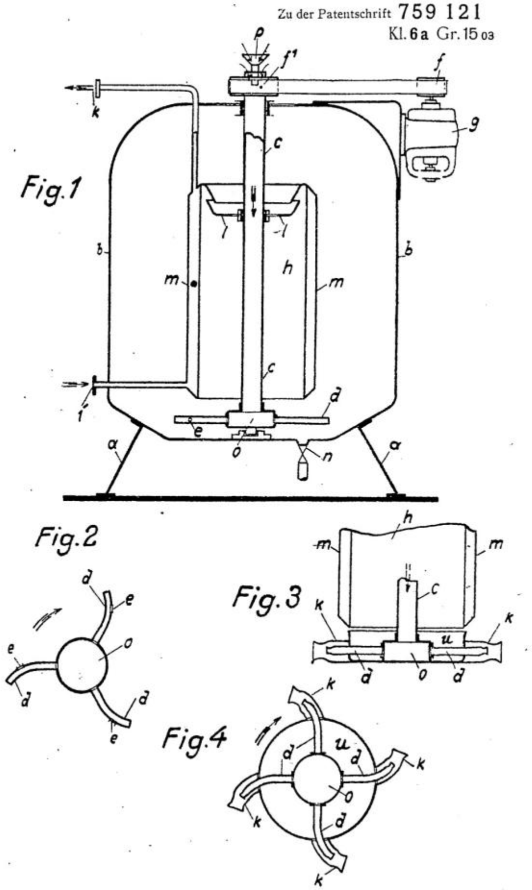
2. SCP from methane produces 1/3 as much CO_2 as from burning methane
   Good way to reduce the carbon footprint of methane

Previous Solutions – Foam Fermenters

1937 – Stob Fermenter

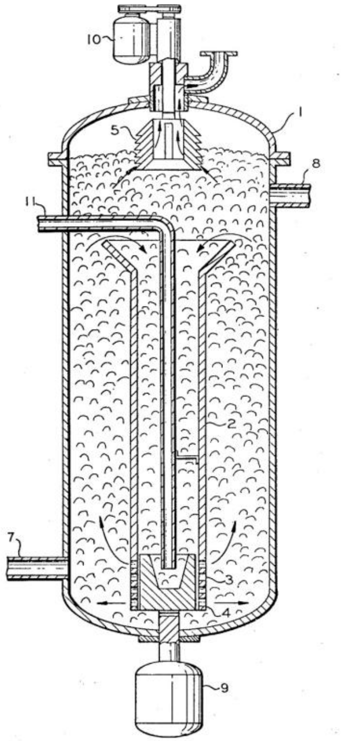


1940 – Waldhof Fermenter



1976 – Phillips Petroleum

U.S. Patent Sept. 28, 1976 3,982,998



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Protein from Natural Gas – How to Succeed

- Use diluted atmospheric (6%) oxygen instead of pure oxygen (100%).

  This results in nitrogen fixing (no ammonia) and lower costs for oxygen.
- Ferment inside foam instead of submerged fermentation

  results in liquid with 10% SCP instead of 1-2% with U-loop

  much lower costs for separation
- Use plastic inside shipping containers for fermenter.

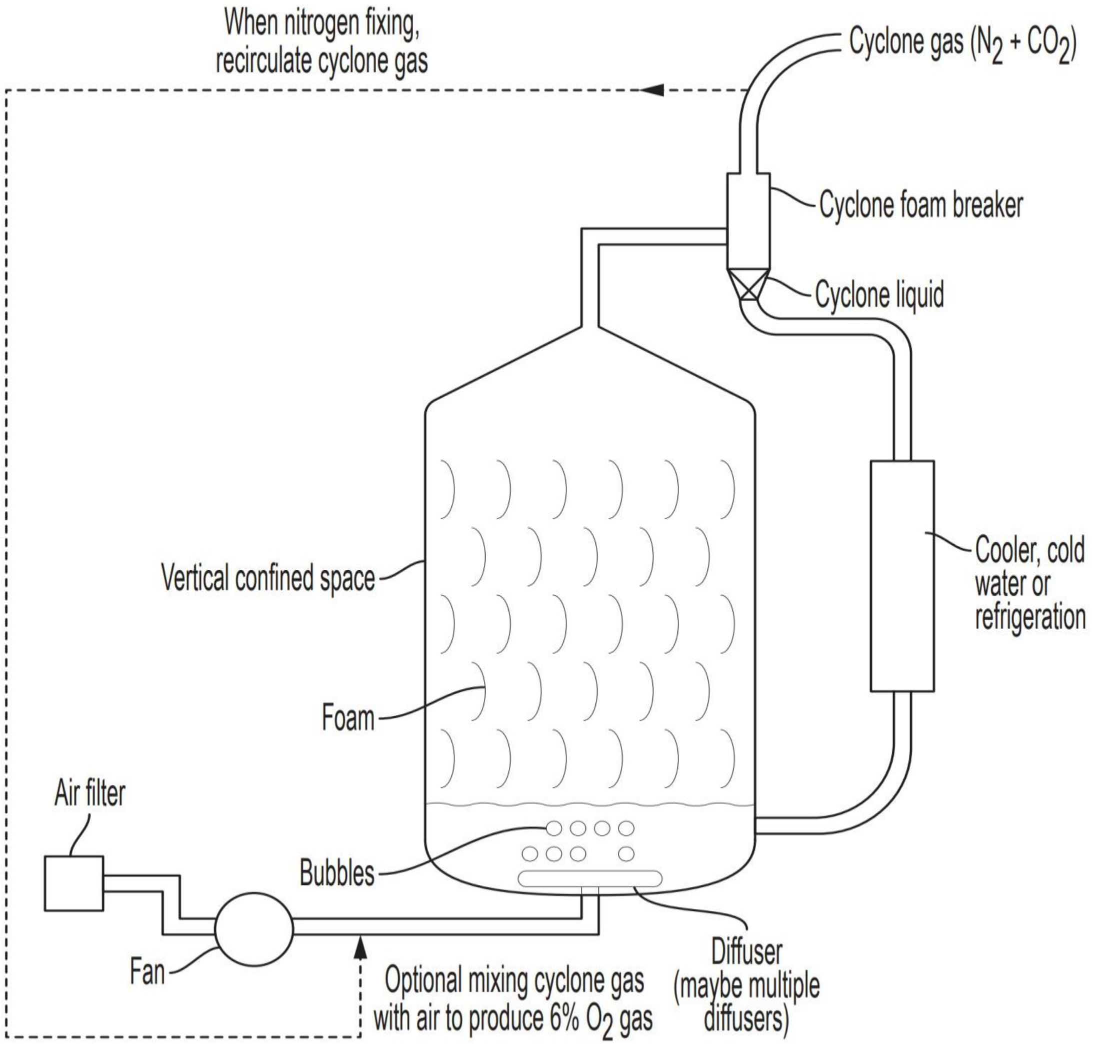
  Fermenter is less than $1000/m^3 compared with $200,000/m^3 for U-loop
- Scale up to industrial scale by using modular solution (containers)

  if one container is economical, 10,000 containers are also economical

  can transport to stranded natural gas
- Use water cooling for fermenter, optimally sea water cooling

  cold water is free in Russia ☺
- Objective –produce protein at less than $1/kg

Protein from Natural Gas - CelloFuel



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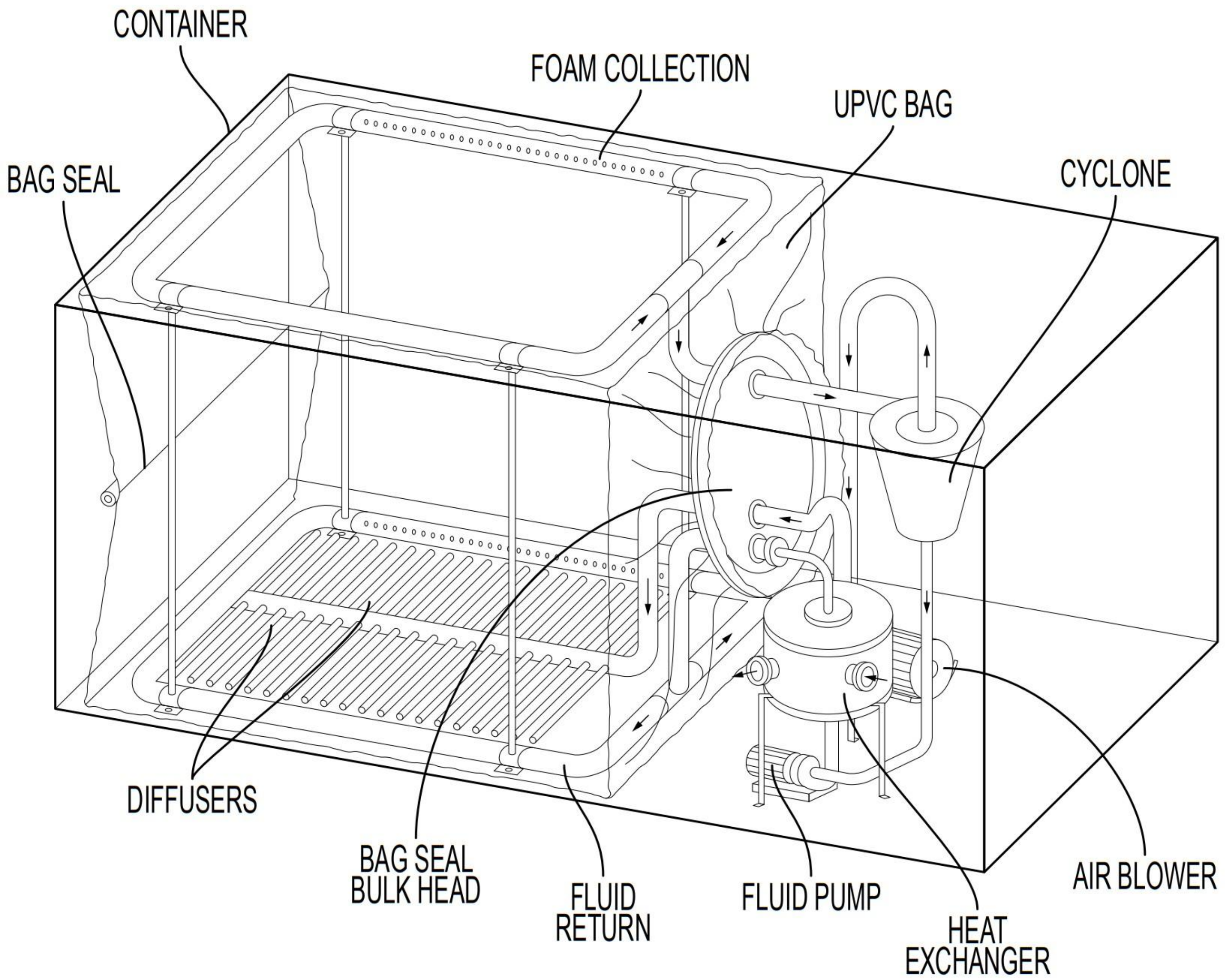
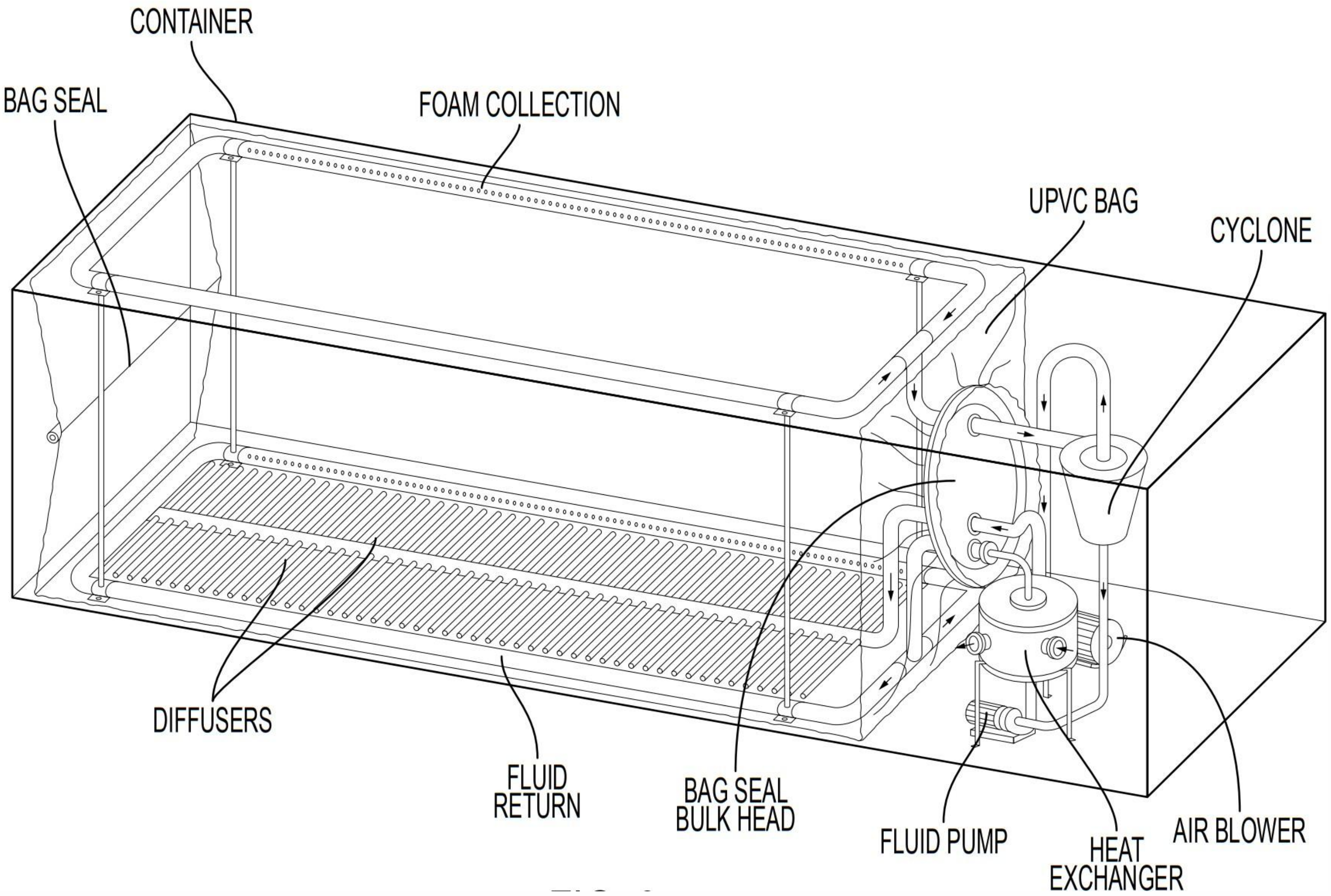
Protein from Natural Gas – 20 ft. CelloFuel Container



Protein from Natural Gas – 40 ft. CelloFuel Container



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Portable Biomass Refinery

Microorganism and nitrogen source	Candida utilis + urea	Methylococcus capsulatus + NH3	Methylococcus capsulatus + N2
Doubling time (min)	105	120	140
Heat (MJ/mol_O2)	0.40	0.47	0.47
Fermentation temperature (C)	30	45	45
Substrate (sub)	CH2O	CH4	CH4
Molar mass of substrate (g/mol_sub)	30	16	16
Cell composition (cell)	C5H10O2.5N	C5H9O2N	C5H9O2N
Molar mass of cells (g/mol_cell)	124	115	115
Molar yield from substrate (mol_cell/mol_sub)	0.13	0.13	0.13
Mass yield from substrate (g_cell/g_sub)	0.55	0.92	0.92
Cell yield from O2 (mol_cell / mol_O2)	0.40	0.11	0.11
Ratio of substrate to O2 (mol_sub/mol_O2)	3.03	0.83	0.83
Cell yield from O2 (g_cell/mol_O2)	50.09	12.27	12.27
Oxygen concentration (mol_O2/mol_gas)	0.21	0.21	0.08
Fermenter width (m)	2.40	2.40	2.40
Fermenter height (m)	2.40	2.40	2.40
Fermenter length (m)	4.00	4.00	4.00
Fermenter volume (m3)	23.04	23.04	23.04
Cell density in liquid (g_cell/g_liquid)	0.10	0.07	0.04
Liquid fraction (fraction)	0.10	0.10	0.10
Fermenter liquid (kg)	2,304.00	2,304.00	2,304.00
Fermenter gas (L)	20,736.00	20,736.00	20,736.00
Fermenter cells (kg_cell)	230.40	161.28	80.64
Fermenter gas (mol_gas)	833.56	794.26	794.26
Fermenter O2 (mol_O2)	174.60	166.37	63.54
Cell mass grown if all O2 used (kg)	8.75	2.04	0.78
Heat generated if all O2 used (kJ)	69,839	77,693	29,673
Temperature rise in water (C)	7.24	8.06	3.08
Time to use all O2 (min)	3.99	1.52	1.35
Fan airflow (m3/h)	312.17	819.38	919.43
Fan power needed (kW)	2.60	6.83	7.66
Cooling needed (kW)	292.05	852.78	365.48
Cooling water temperature (C)	20.00	20.00	20.00
Cooling water mass flow (kg/s)	6.98	8.15	3.49
Cooling water volume flow (m3/hr)	25.12	29.34	12.57
Cooling water heat exchanger area (m2)	10.82	12.63	5.41
Yearly substrate (ton_sub/year)	2,093.23	767.83	329.07
Yearly productivity (ton_cell/year)	1,153.32	706.41	302.75
Hourly productivity (kg/hr)	131.66	80.64	34.56
Cost of substrate ($/ton_sub)	500.00	110.00	110.00
Cost of nitrogen ($/ton_cell)	46.28	28.02	-
Cost of electricity ($/ton_cell)	7.67	17.77	43.87
Sale of cells ($/ton_cell)	1,500.00	1,500.00	1,500.00
Profit/year ($)	621,000.00	943,000.00	405,000.00
CAPEX ($)	50,000.00	50,000.00	50,000.00

Patent Status

Patent pending at U.S. Patent Office,

“AEROBIC FERMENTATION USING PNEUMATIC FOAM”

application number 63/530,954, priority date of 5 August 2023

“CONTAMINATION CONTROL WHEN GROWING YEASTS”

Application number 63/534,123, priority data of 23 August 2023

Planned PCT submission to RU, US, CN, IN, BR, EU, QA

Спасибо за внимание!

Задавайте любой вопрос

Alex Ablaev
NanoTaiga
Moscow, Russia
info@nanotaiga.ru

Edward B. Hamrick
Hamrick Engineering
Miami, FL USA
info@cellofuel.com