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CelloFuel
Portable Biomass Refinery

Protein from Natural Gas

- 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
- The world has a lot of low-cost natural gas.
- It’s possible to make low-cost protein for fish feed and chicken feed from natural gas by fermenting Methylococcus capsulatus
- A foam fermenter is the most efficient way to produce this protein at large scale
- A foam fermenter can do nitrogen fixing from the atmosphere while using Methylococcus capsulatus, resulting in contamination control and thus allowing efficient continuous fermentation.

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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

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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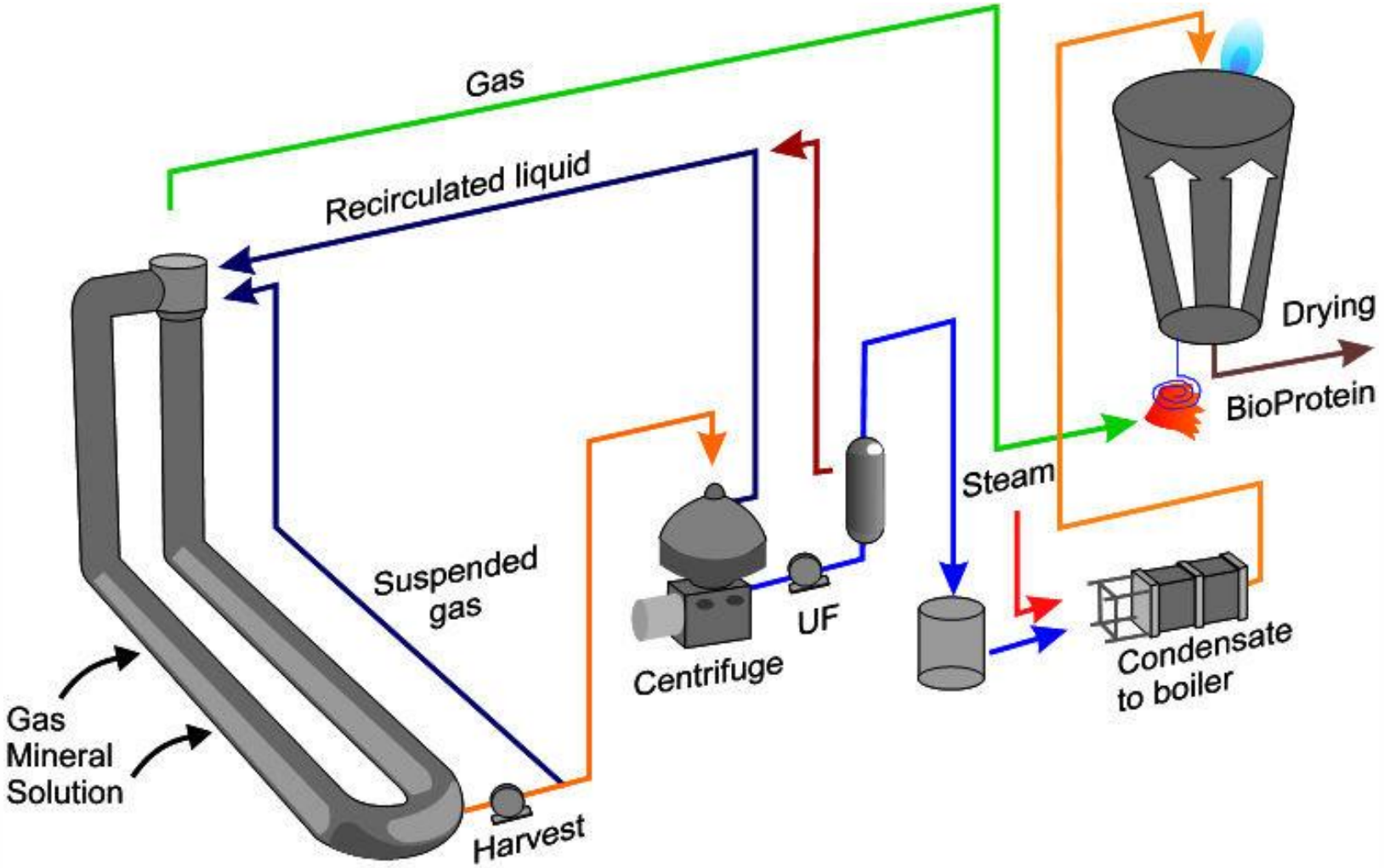
Protein from Natural Gas - Norferm



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Protein from Natural Gas - Norferm

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Protein from Natural Gas - Protelux

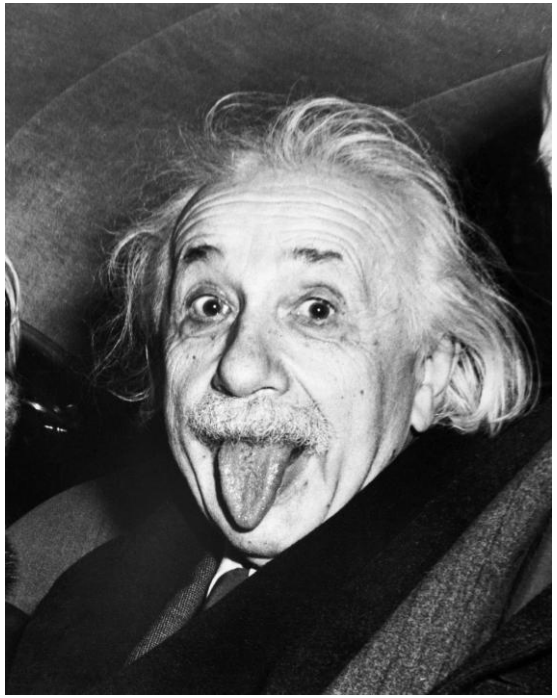
Protein from Natural Gas – project status worldwide

- 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

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



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Single Cell Protein from Carbohydrates and Methane – Stoichiometry

SCP from carbohydrates

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

1 kg CH_2O -> 0.55 kg SCP

SCP from methane

$CH_4 + 1.20\ O_2 + 0.064\ N_2 \rightarrow 0.360\ CO_2 + 1.424\ H_2O + 0.1280\ C_5H_9O_2N$

1 kg CH_4 ($0.18) + 2.4 kg O_2 ($0.36) -> 0.92 kg SCP ($0.92)

Burning methane

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Single Cell Protein from Carbohydrates and Methane – Stoichiometry

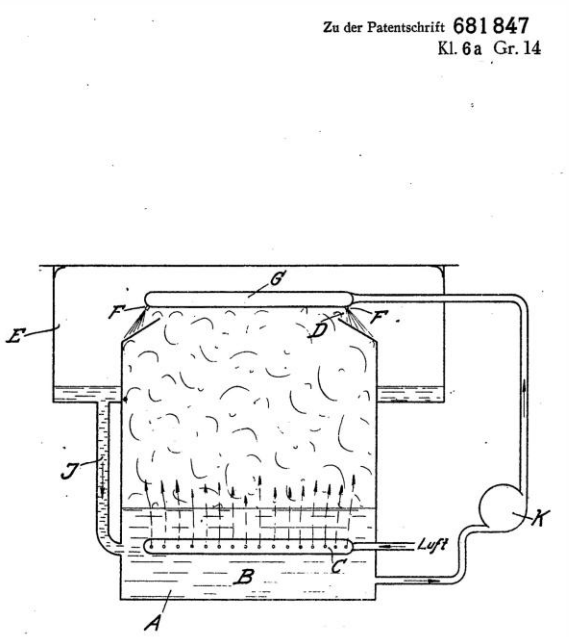
IMPORTANT CONCLUSIONS:

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

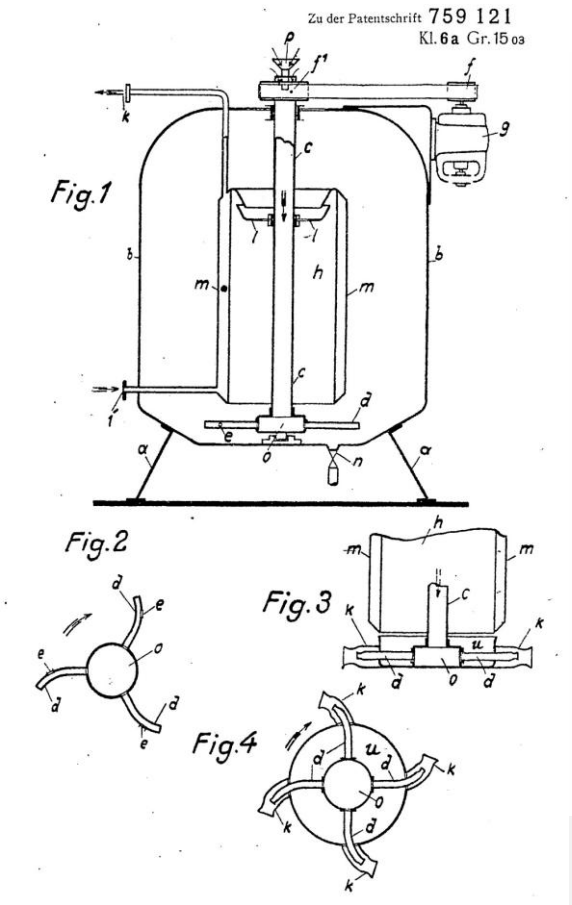
2. SCP from methane produces 1/3 as much CO_2 as from burning methane
   Good way to reduce the carbon footprint of methane

Previous Solutions – Foam Fermenters

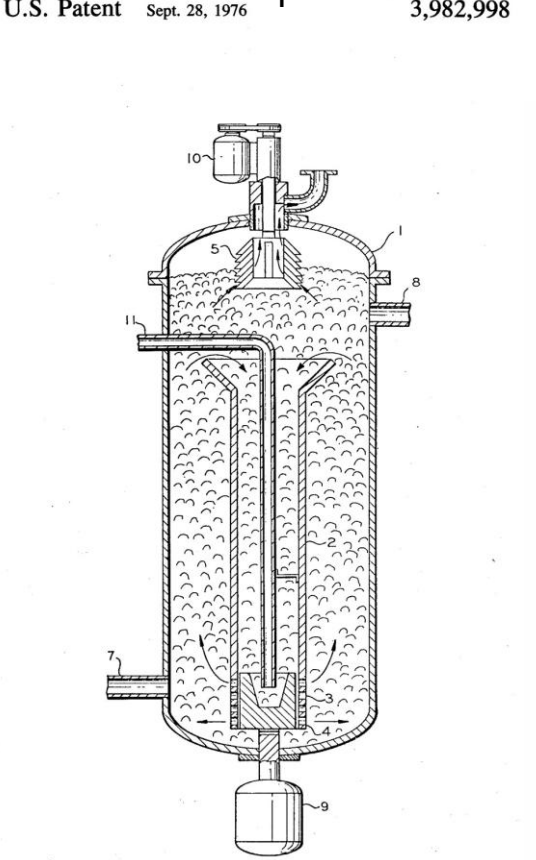
1937 – Stob Fermenter



1940 – Waldhof Fermenter



1976 – Phillips Petroleum



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

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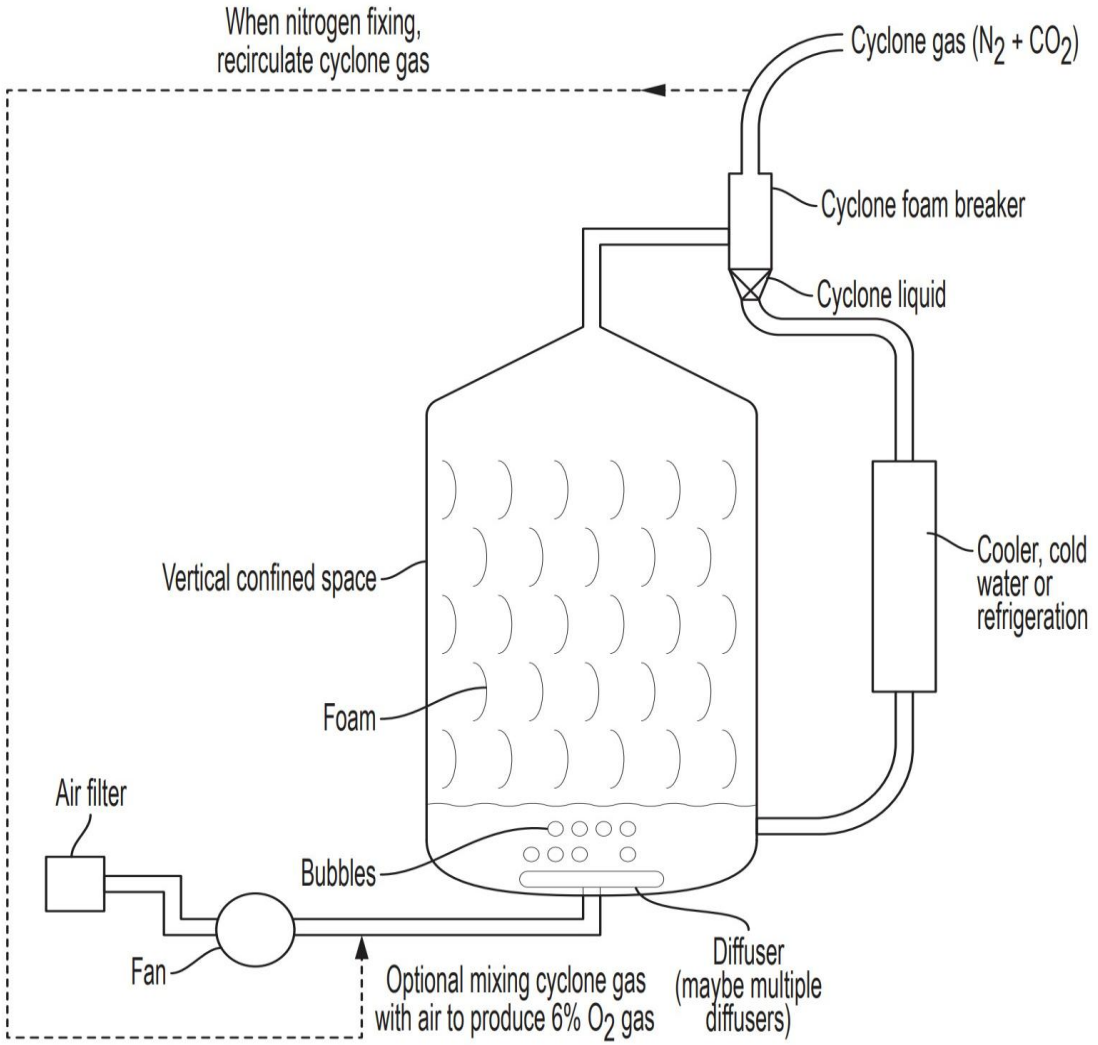
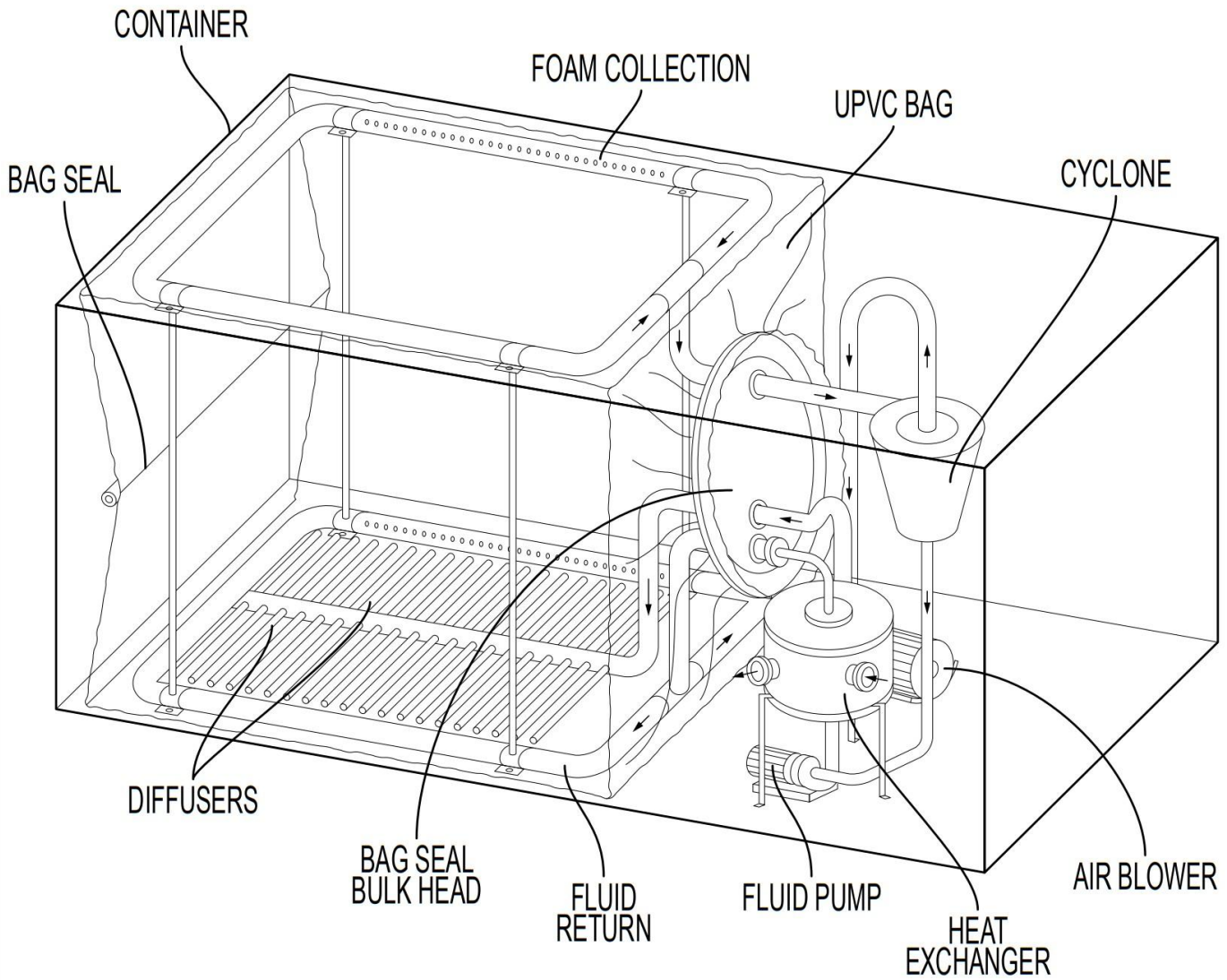
Protein from Natural Gas - CelloFuel



Protein from Natural Gas – 20 ft. CelloFuel Container



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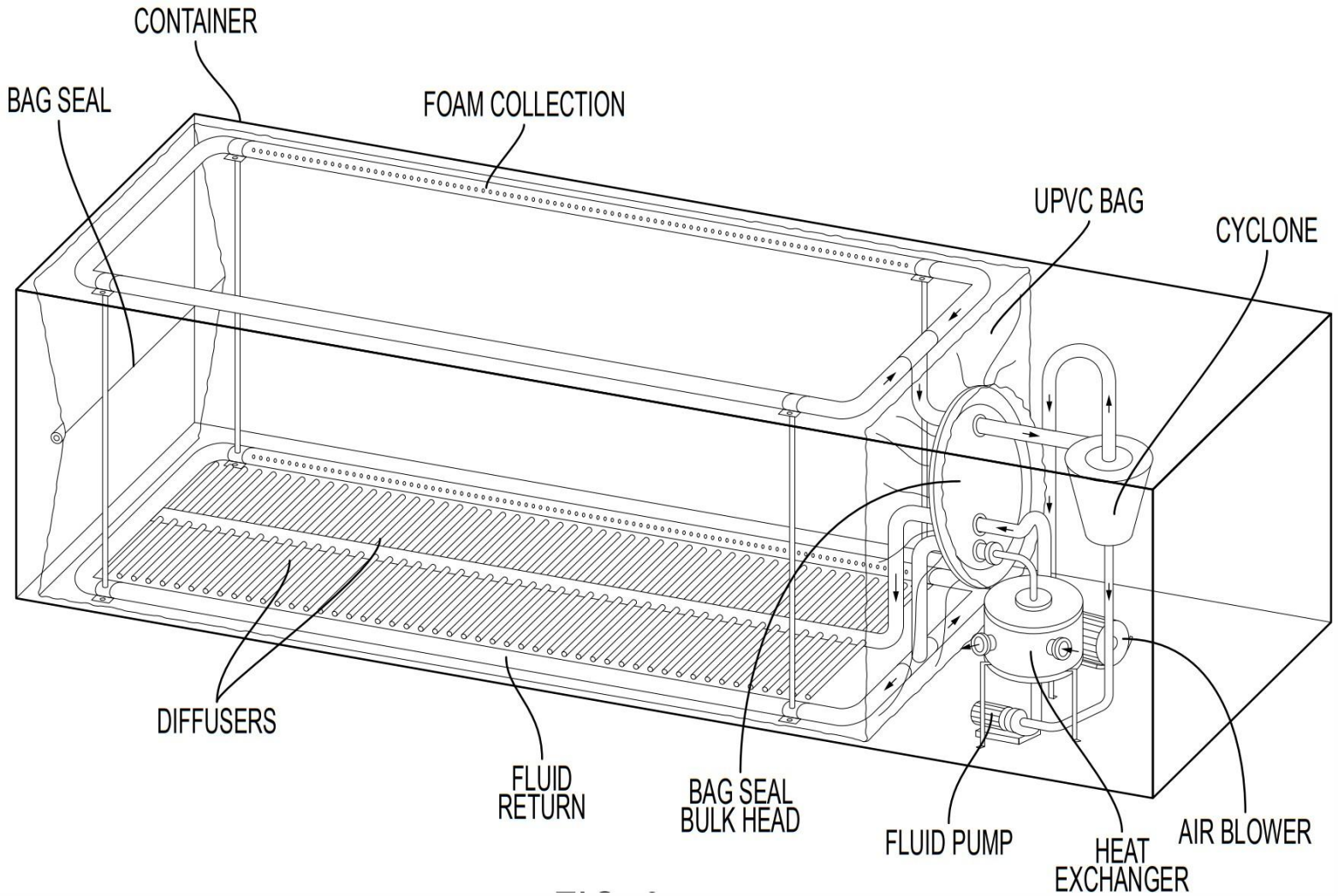
Protein from Natural Gas – 40 ft. CelloFuel Container



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

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