# Seafuel

Seafuel

Seafuel™ Robert Hargraves

Biofuels are a failing synthetic fuel attempt to reduce CO2 emissions. Growing corn absorbs CO2 from the air, once expected to offset emissions from burning the ethanol derived from the corn. US gasoline is blended with 10% ethanol, but studies[175] show that farming and manufacturing processes emit more CO2 than is offset. Sustainable aviation fuels (SAF)[176] and other biofuels are too expensive because they use widely dispersed crops for energy sources. Biofuels compete with food for farmland. The US DOE SAF use goal is 71 million bbl/year by 2030. World airlines consume 5.6 million bbl/day. SAF consumption in 2022 was about 400,000 bbl/year, roughly 1,000 bbl/day.

New nuclear fission power plants generate energy inexpensively because they achieve high temperatures, opening up more options. Besides seawater desalination and district heating, what can be done with a ThorCon style reactor?

What else can we do with cheap fission energy?
Heat @ $0.01/kWh, Electricity @ $0.03/kWh; Investment $1 billion/GW(e)
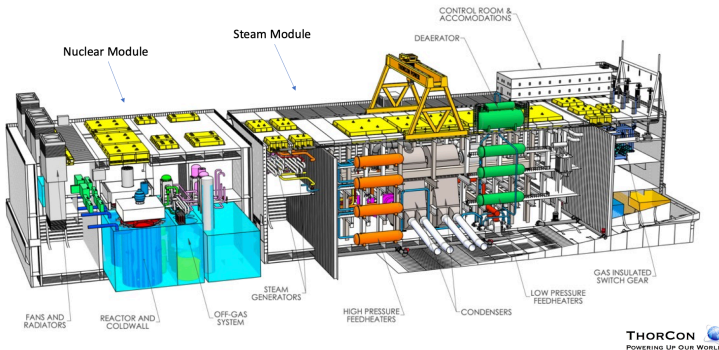
ThorCon 500 fission power plant

The transportation sector emits about as much CO2 as does the electric power sector. Can cheap nuclear power make synthetic fuels?

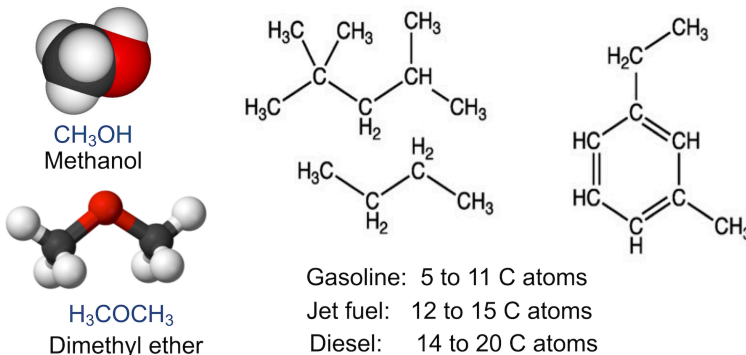| Fuel weight and volume are critical for vehicles.		
Fuel	**kWh/kg**	**kWh/L**
Gasoline, Diesel	13	11
Hydrogen liquid, -253°C	33	2.4
Hydrogen gas, 700 bar	33	1.2
Methane, CH4, 250 bar	15	9
Methanol, CH3OH	6	5
Dimethyl ether, CH3OCH3	9	7
Lithium ion battery, kWh(e)	0.2	

https://en.wikipedia.org/wiki/Energy_density

Long chain hydrocarbon fuels have the best energy density.

It is difficult for vehicles such as airplanes or heavy trucks to be powered by batteries. They are much heavier per unit of energy delivered, even though battery-electric-motors can be 90% work efficient, twice that of internal combustion engines.

Here are typical hydrocarbon fuels used today to propel vehicles.

CH_3OH
Methanol

H_3COCH_3
Dimethyl ether

Gasoline: 5 to 11 C atoms
Jet fuel: 12 to 15 C atoms
Diesel: 14 to 20 C atoms

Transportation is fueled by hydrocarbons.

A nuclear power plant such as the ThorCon 500 can deliver heat energy below $0.01/kWh, much cheaper than electric energy at $0.03/kWh. The power plant generates fully 1,100 MW(t) of heat energy to run the supercritical turbine-generator that generates 500 MW(e). A purpose built nuclear heat plant would not need the very expensive supercritical steam turbine generator.

New nuclear power plant supplies cheap energy on site.

Electric energy	**$0.03/kWh**
Heat energy	**$0.01/kWh**

Portable energy sells at a premium.

Gasoline	**$3.00/gallon =**
Heat energy	**$0.09/kWh**
Premium	**$ 0.08/kWh**

Premium is paid for vehicles' portable hydrocarbon energy.

When you buy $3 gasoline, you are paying for the heat that gasoline combustion can deliver within your vehicle's engine, or $0.09/kWh. The engineering challenge is to repackage inexpensive heat and electricity from a nuclear power plant into gasoline, or diesel, or jet fuel worth about $0.08/kWh more. Here is the general strategy.
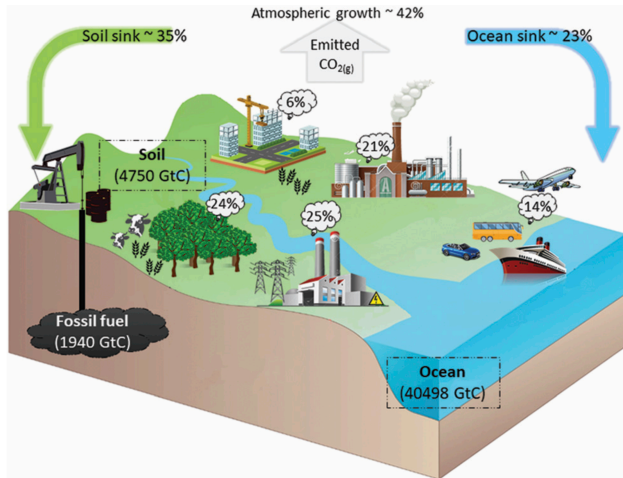

Captured Carbon

Water split Hydrogen

Cheap Energy

Seaside refinery, paid by fuel premium
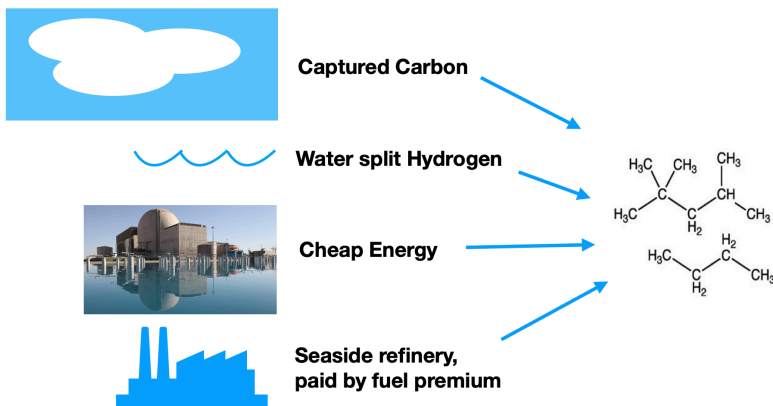
Seaside nuke captures CO2, electrolyzes water for H2, makes fuel

CO2 in seawater

CO2 emitted into the atmosphere also dissolves into the ocean until the air/sea CO2 partial pressures balance.

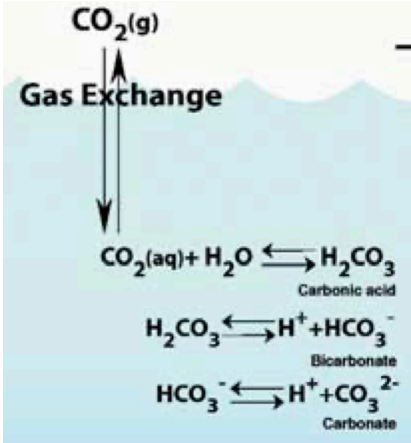**Balance in ~ 1 year**

Add 9 Gt-CO2/year to ocean

A third of emitted CO2 is absorbed by ocean water.[177]

The vast ocean surface absorbs CO2 from the atmosphere.[178] The concentration of CO2 in seawater varies as it flows. Cool water absorbs more CO2; warm water releases it. Given a pulse of CO2 into the atmosphere, about a third will dissolve into the ocean in about one year. That's now 9 gigatons annually.
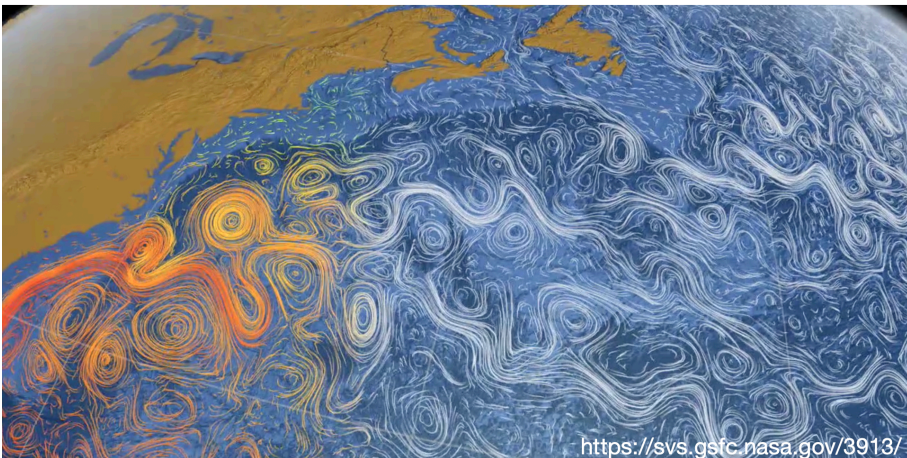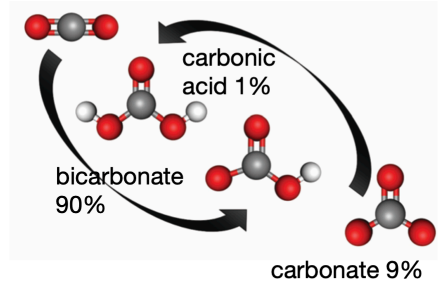

Ocean currents distribute dissolved CO2 worldwide.[179]

In ocean water the CO2 gas quickly becomes carbonic acid, H2CO3. Then an equilibrium is established[180] with bicarbonate ion HCO3- and carbonate ion CO3[2-]. 90% of ocean water CO2 is in bicarbonate form.

$$CO_2(aq) + H_2O \rightleftharpoons H_2CO_3$$
Carbonic acid

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$
Bicarbonate

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$
Carbonate

carbonic acid 1%

bicarbonate 90%

carbonate 9%

<< Acidic pH . . . . Basic pH >>

Increasing acidity reverts dissolved bicarbonate back to CO2, that can be bubbled out by vacuum pumps.

90% of ocean water CO2 is in bicarbonate form[181].

The ocean is becoming more acidic as it absorbs about 9 Gt/year of CO2; ocean pH drops as the water becomes more saturated with CO2. If we could somehow make a batch of ocean water even more acidic (lower pH) the carbonic acid concentration increases at the expense of the bicarbonate and carbonate ions. Then lowering the partial pressure of CO2 gas above the water surface causes the H2CO3 carbonic acid to release CO2 bubbles which can be removed from the water by vacuum pumping. Then we restore the water batch pH before putting it back in the ocean.

Seaside power plant CO2 opportunity

A seaside nuclear power plant pumps seawater through it for cooling its steam condensers.
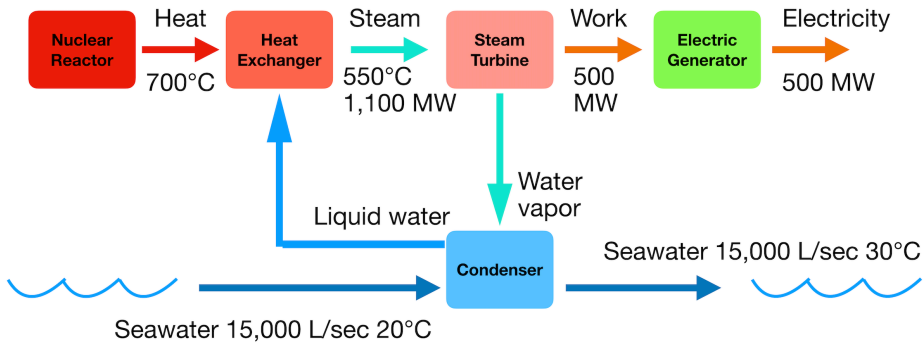
A seawater cooled, hot, new nuclear power plant

Above is a sketch of ThorCon power plant energy flows. Other high temperature reactors may work similarly. The fissioning fuel heats the reactor's molten salt to 700°C and transfers 1100 MW of heat through a series of heat exchangers to make supercritical 550°C steam. The high, 46% efficient turbine converts steam's heat energy to work energy, turning the electric generator to produce 500 MW of electric power.

The used steam transfers its remaining heat to the condenser, where it condenses to water and is pumped at high pressure back into the steam generator portion of the heat exchangers. The heated condenser is cooled by seawater pumped through it, raising seawater temperature by 10°C.

The large volumes of seawater flowing through the condenser provide an opportunity to harvest CO2 absorbed by the sea from the air. Desalination company Lenntech[182] estimates seawater contains 140 mg-HCO_3^-/L of bicarbonate. That amounts to 1.5 kg/sec of CO2 flowing through the power plant.

Net zero Seafuel for combustion engines
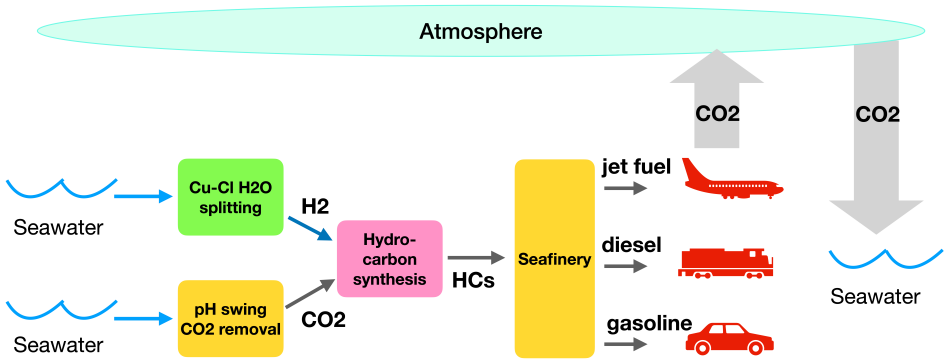
Sea re-absorbs CO2 removed a year before.

The components of hydrocarbon fuels are hydrogen and carbon. Seawater contains hydrogen in its H2O and carbon in its dissolved CO2. Pairing a Seafinery with a *new nuclear* power plant takes advantage of its high temperature heat energy and low cost electricity.

The Cu-Cl box represents hydrogen generation with 530°C copper-chlorine mediated water splitting, 2H2O —> 2H2 + O2. The cycle uses both electrolysis energy and less expensive hydrolysis energy.

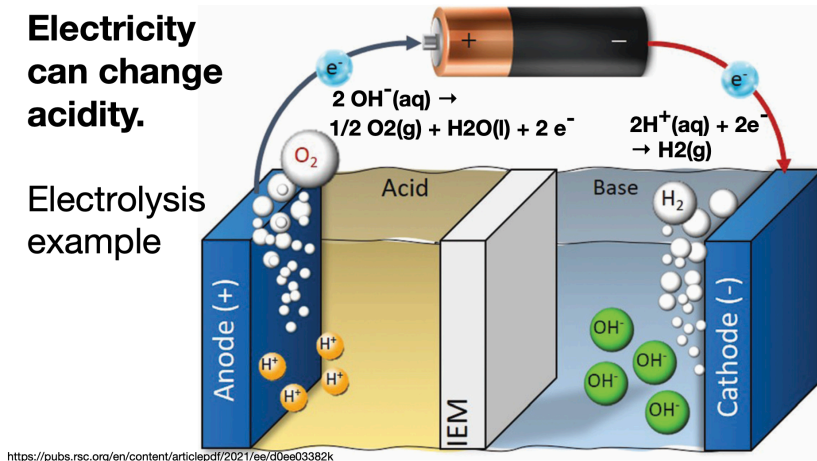The pH box stands for emerging pH swing chemistry to lower pH, pump off CO2, then restore CO2.

The valuable CO2 and H2 are combined into long-chain hydrocarbon molecules using mature refinery technologies and distilled into the separate fuels to power existing planes, trains, and automobiles.

Their combustion engines release CO2 back into the atmosphere, where it is re-absorbed by ocean water previously CO2-depleted, restoring concentrations in sea and air to the previous equilibrium state.

The Seafinery Cu-Cl process also emits waste product O2 into the atmosphere, in trivially small relative amounts.

pH swing electrochemistry

The pH swing process relies on lowering ocean water pH 8 down to acidic pH 4, pumping off CO2, then swinging pH back to 8 before returning water to the sea. We can use electricity to alter pH.

Electricity can change acidity.

Electrolysis example

$2\,OH^-(aq) \rightarrow$
$1/2\,O_2(g) + H_2O(l) + 2\,e^-$

$2H^+(aq) + 2e^- \rightarrow H_2(g)$

https://pubs.rsc.org/en/content/articlepdf/2021/ee/d0ee03382k

Electrolysis, with ion exchange membrane

In this diagram you see electrolysis of water as explained in a freshman chemistry course. On the right, electrons from the battery merge with waterborne H+ protons to make H2 gas bubbles, leaving OH- hydroxyl ions behind.

On the left electrons are pulled by the battery from OH- hydroxyl ions, leaving proton H+ ions behind. The ion exchange membrane (IEM) passes protons but not hydroxyl molecules, so alkalinity builds up near the cathode and acidity near the anode.

This pH swing technology is under intensive R&D. This review article by Sharifian et al, *Electrochemical carbon dioxide capture to close the carbon cycle*[183], provides more information than can be presented here.

CO2 via pH swing
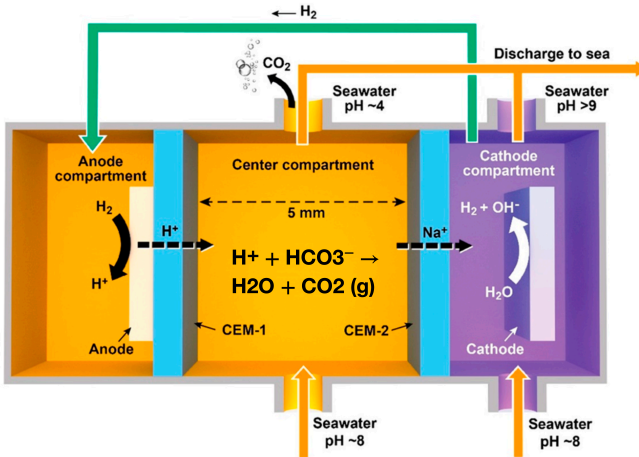
Increasing acidity reverts dissolved bicarbonate to CO2.

$H+ + HCO3^- \rightarrow H2O + CO2 (g)$
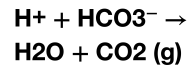
CO2 bubbled out by vacuum pumps.

Electrolysis energy

0.66 kWh(e)/kg-CO2

@ $0.03/kWh

$20.00/ton-CO2

CO2 removal by pH swing (Yan)[184]

In the abstract of *An Electrochemical Hydrogen-Looping System for Low-Cost CO2 Capture from Seawater* Yan et al write

> "We have demonstrated that the electrochemical hydrogen-looping flow cell can remove CO2 from simulated seawater at a record low electric energy consumption of 660 kWh ton^{-1} CO2, which is a significant reduction of 56% compared with the currently used bipolar membrane electrodialysis technology. The electrochemical hydrogen-looping flow cell with its much lower energy consumption provides an economical approach for direct removal of CO2 from seawater at practical scale."
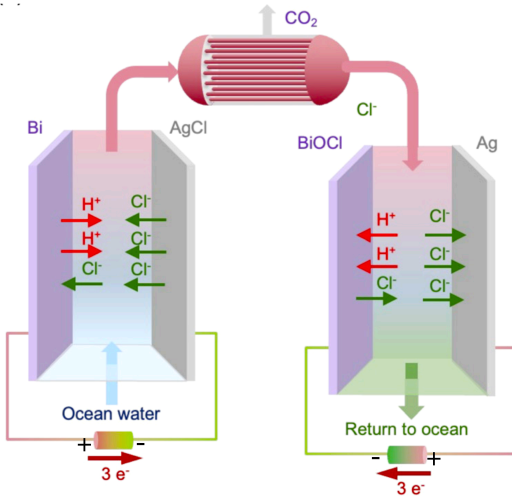
Electrolysis energy

122 kJ	per 44 g-CO2
2.77 MJ	per kg-CO2
0.77 kWh	per kg-CO2
@ $0.03	per kWh
$23	per ton-CO2
System	**energy** (Kim)
$56	ton-CO2

CO2 removal without bipolar ion exchange membranes (Kim)[185]

In *Asymmetric electrochemical system for chloride-mediated CO2 removal from ocean water* by Kim et al write,

> "With two silver–bismuth systems operating in tandem in a cyclic process, one acidifying the ocean water, and the other regenerating the electrodes through alkalization of the treated stream, CO2 can be continuously removed from simulated oceanwater with a relatively low energy consumption of 122 kJ mol^{-1}, and high electron efficiency."

CO2 removal, at the top of the graphic, was done with a thin-wall, high area straws instead of a vacuum pump.

US Navy seawater to synfuel demonstration

The trick of cyclic role reversal for the two cells in order to restore electrodes is also a basis of the work of Willauer et al. The US Navy Research Labs work was inspired by the potential of generating jet fuel at sea for airplanes based on nuclear powered aircraft carriers. The work advanced beyond lab bench chemistry to skid scale, continuous demonstration.

US Navy Research Lab electrolysis cell frees both CO2 and H2 from seawater.
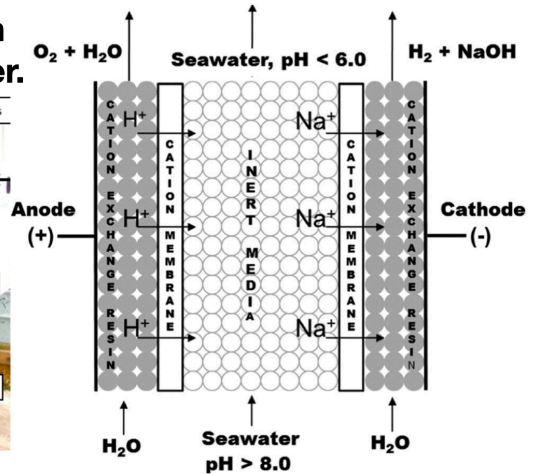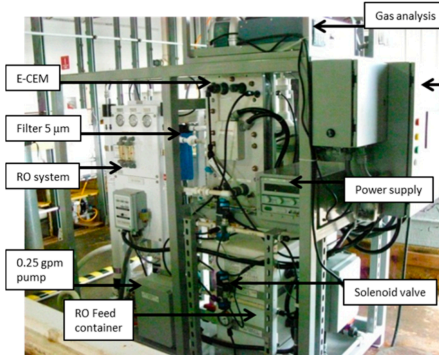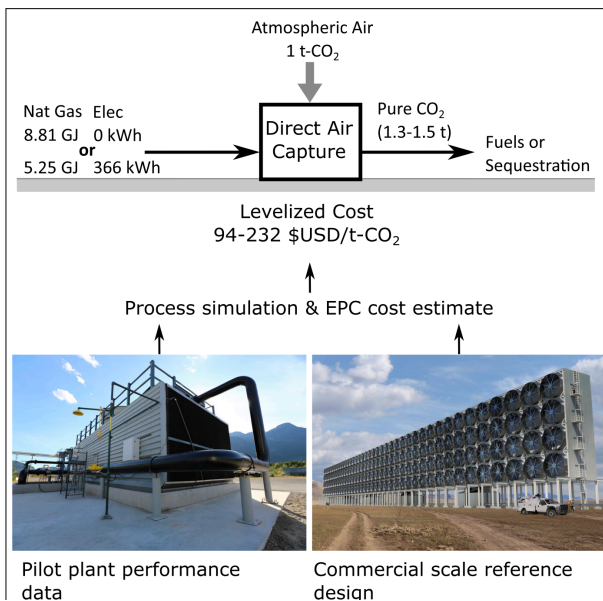

Nuclear powered carrier might fuel its jet fighters from seawater.[186]

Their cell design produces both CO2 and H2. In the Willauer et al 2010 article *The Feasibility and Current Estimated Capital Costs of Producing Jet Fuel at Sea Using Carbon Dioxide and Hydrogen* they estimated jet fuel costs of $5.78/gallon, based on nuclear power electricity cost of $0.07/kWh.

Cost of CO2

The Yan and Kim articles estimate costs of $20 to $56 per ton of CO2 captured from seawater. These are emerging technologies, not yet validated by pilot scale demonstrations.

Direct air capture (DAC) is another option, demonstrated by MIT Prof David Keith. He led a DAC project to demonstrate the process with existing commercial technologies, not necessarily at the lowest cost, to gain experience. Keith founded Carbon Engineering to test this idea. The plant used natural gas and electricity, and for every 1 ton of atmospheric CO2 captured, produced about 1.4 tons of pure CO2, at a cost of $94 to $232 per ton[187].

Atmospheric Air
1 t-CO_2

Nat Gas Elec
8.81 GJ 0 kWh
or
5.25 GJ 366 kWh

Direct Air Capture

Pure CO_2
(1.3-1.5 t)

Fuels or Sequestration

Levelized Cost
94-232 $USD/t-$CO_2$

Process simulation & EPC cost estimate

Pilot plant performance data

Commercial scale reference design

David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel

keith@carbonengineering.com

HIGHLIGHTS
Detailed engineering and cost analysis for a 1 Mt-CO_2/year direct air capture plant

Levelized costs of $94 to $232 per ton CO_2 from the atmosphere

First DAC paper with commercial engineering cost breakdown

Full mass and energy balance with pilot plant data for each unit operation

Pilot plant for Direct Air Capture of CO2

Keith's MIT colleague Howard Herzog projected[188] $180 to $1,000 per ton for DAC.

Occidental Petroleum purchased Carbon Engineering for $1.1 billion.

Keith was recruited by University of Chicago.

Hydrogen from electric AND heat energy

Water electrolysis is a mature technology for hydrogen production, using electric energy. Cheap, onsite electricity can lower costs. Unexplored commercially, high temperature heat can help break H-O bonds.

The sulfur-iodine cycle process, invented in the 1970s by General Atomics, is alluring but requires temperatures of 850 to 1000°C, and it requires expensive materials to guard agains corrosion.

The copper-chlorine cycle was demonstrated in Canada in 1976, and much of Cu-Cl research is published by Canadians. There are many variants of the Cu-Cl cycle, and the more efficient ones operate at higher temperatures. The copper and chlorine are not consumed in this process. They are oxidized and reduced and re-cycled within the process.
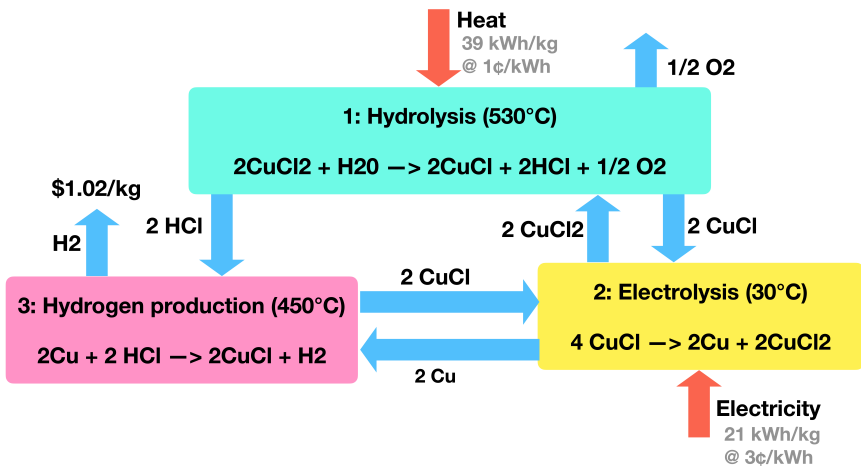
Hydrogen from three step Cu-Cl water splitting (Razi)[189]

The process in Box 1 is energized with 530°C heat. The heat and CuCl2, copper(II) chloride, break the oxygen away from the water molecule. "II" symbolizes 2 valence electrons. Another product is CuCl, cuprous(I) chloride.

The Box 2 process uses electricity to reduce cuprous(I) chloride back to copper(II) chloride, and also to copper metal.
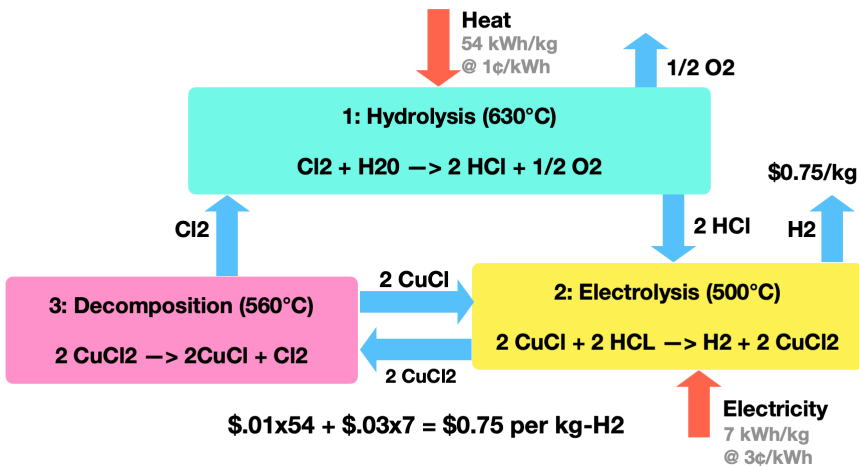
In Box 3 the copper regains the chlorine from HCl, hydrochloric acid, and releases hydrogen.

Electric energy and heat energy have different costs. The energy cost for hydrogen production of $.01x39 + $.03x21 = $1.02 per kg.

New nuclear reactors generate the needed high temperature heat. For example, Cu-Cl water splitting is compatible with ThorCon technology, which delivers 550°C steam.

Hydrogen fuel delivers 39 kWh/kg-H2. At a cost of $1/kg-H2, hydrogen energy costs just $0.026/kWh, compared to gasoline's energy at $0.09/kWh, at the pump.

A alternative, hotter Cu-Cl cycle might deliver even less expensive hydrogen if redesigned heat exchangers could transfer heat from ThorCon's 700°C radioactive molten fuel salt to intermediate molten salt to drive hydrolysis efficiently at the higher 630°C temperature.

Heat
54 kWh/kg
@ 1¢/kWh   **1/2 O2**

1: Hydrolysis (630°C)

Cl2 + H20 —> 2 HCl + 1/2 O2   **$0.75/kg**

Cl2   **2 HCl**   **H2**

2 CuCl

3: Decomposition (560°C)   **2: Electrolysis (500°C)**

2 CuCl2 —> 2CuCl + Cl2   **2 CuCl + 2 HCL —> H2 + 2 CuCl2**

2 CuCl2

Electricity
$.01x54 + $.03x7 = $0.75 per kg-H2   7 kWh/kg
@ 3¢/kWh

Hydrogen from hotter, 630°C Cu-Cl water splitting (Razi)

This 630°C Cu-Cl cycle also has the advantage that all process take place at similar temperatures, not requiring the 500°C temperature reduction for Box 2 of the 530°C Cu-Cl cycle.

Conclusion
New nuclear energy coupled with Cu-Cl water splitting can supply economic hydrogen, a transportable energy carrier. A cost of $1/kg-H2 is achievable, relying on both electricity and cheap, hot heat from *new nuclear* power.

Hydrogen fuel

Hydrogen is hard to transport. Toyota sells some hydrogen-fueled autos that use fuel cells to convert compressed hydrogen to electricity to power wheel motors. Hydrogen refueling stations are a limiting factor, now selling hydrogen for $36/kg[190], for fuel that is two-thirds from natural gas. Nikola has not succeeded in its venture to power long-haul truck with compressed hydrogen.

For autos and trucks, hydrogen must be compressed to 350 or 700 bar, requiring 8-16% of energy value, plus strong containment tanks. The strongly reinforced tanks would be too heavy for aircraft, so chilled, liquified hydrogen can be used for airplane fuel. Liquefaction of hydrogen to -253°C costs 30% of its energy value. That temperature is only 20°C above absolute zero!


Russia's Tupolev-155 with liquid hydrogen fuel flew in 1988.

Russia developed and flew its hydrogen-fueled Tupolev-155 aircraft 36 years ago. The cost was too high, and the aircraft was converted to run on LNG (liquified natural gas).

Hydrogen frees carbon from CO2

Hydrogen will always be a niche fuel because it is difficult to transport. It must be highly compressed or deeply chilled. Instead we can use it at the point of generation to manufacture carbon based fuels.
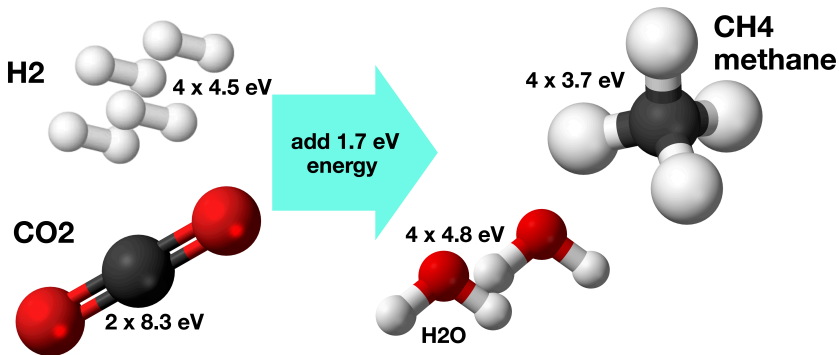

Hydrogen frees carbon from oxygen's bonds.

In this example, half the hydrogen becomes combustion fuel transported in the methane molecule, and half the hydrogen is used to free one carbon atom from two oxygens in a CO2 molecule. (The bonding energies don't quite sum because of rounding; 1 eV = 96 kJ/mol.) The Fischer-Tropsch[191] process is one scheme for creating methane from hydrogen and carbon dioxide.
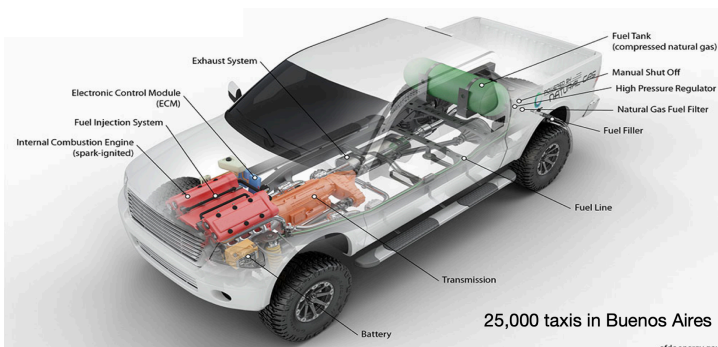
23 million vehicles run on methane fuel.[192]

Methane (natural gas) fuel is suitable for many vehicles. It's 24% cheaper than gasoline in the US, where natural gas is cheap. However methane is pressurized and the methane tank takes up more space than a gasoline tank.

Methanol fuel from CO2
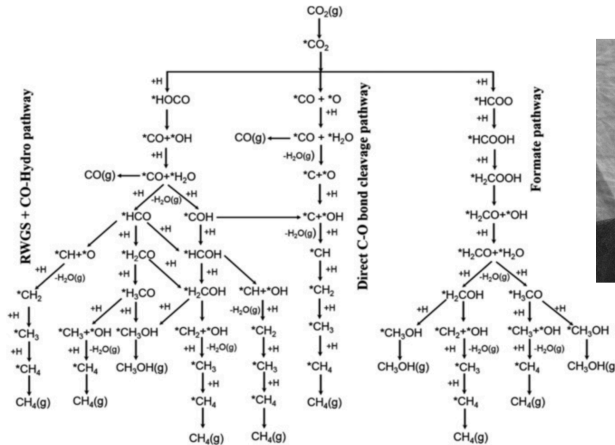
Many reaction paths for CO2 + 4 H2 —> CH4 + 2 H2O[193]

What happens in a chemical reactor to synthesize methane is complex. George Olah won the Nobel prize for his contributions to carbon chemistry. In his acceptance essay he wrote, emphasis added.

"As **atmospheric carbon dioxide** is available to all people on the Earth this will **enable mankind to liberate itself from dependence on fossil fuels**. Substantial energy is of course necessary to generate the needed hydrogen for methanol production. This **energy could come from safe nuclear power plants** as well as all alternative energy sources such as sunlight, wind, geothermal, etc. At the same time, this approach will also diminish the danger of global warming by removing and recycling the rising carbon dioxide content of the atmosphere."
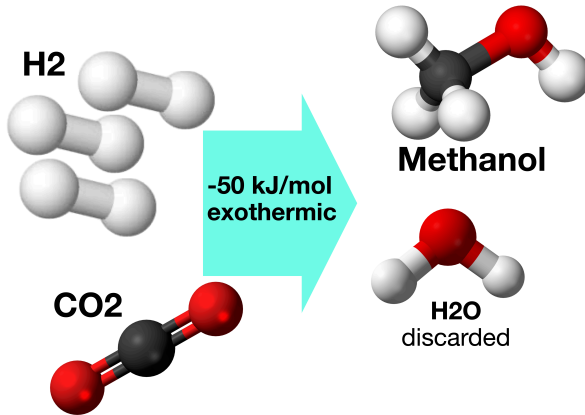
George Olah envisioned our economy powered by methanol fuel.[194]

Svartsengi, Iceland: 4,000 tons/year   China: 110,000 tons/year

*Carbon Recycling International built two CO2-to-methanol plants.[195]*

The first of these plants was build near a geothermal electric power plant in Iceland. The aptly named George Olah power plant removes CO2 rising with the volcanic heated steam and supplies it to the methanol plant built by Carbon Recycling International. The methanol product is termed "Green" it is sold in Germany at about twice the normal market price.

In Anyan, Henan province, China, the Henan Shuncheng Group metallurgical coke oven emits CO2, hydrogen, and methane gasses that are now transformed into methanol by the Shunli plant built by Carbon Recycling International.

Methanol fuel does not need to be pressurized for storage. Methanol combustion emits less CO2 than bunkers, the viscous product left from

refining crude oil, used to power most large ocean transport vessels. About 8% of the 205 ships ordered in 2023 include the capability to use methanol fuel.[196]

Dimethyl ether fuel
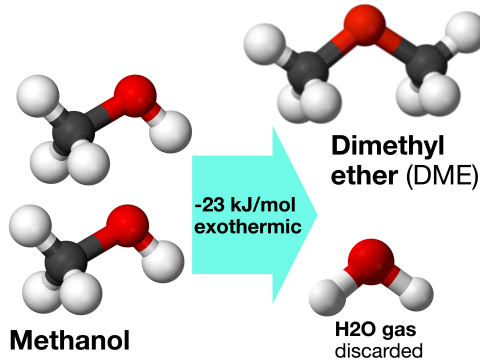
Dimethyl ether can fuel existing diesel engines.

Another proposal from George Olah is to make methanol into dimethyl ether (DME), which can be a drop-in substitute for diesel fuel. DME delivers 10 kWh/kg, compared to 13 kWh/kg for diesel fuel. However DME takes up 57% more tank space at 6.5 L/kWh.

Synthetic gasoline

Cut off from oil supplies during World War II, Germany relied on its 1920s Fischer Tropsch (FT) process to convert coal to vehicle fuels. South Africa also relied on the FT process when its oil supplies were cut because of apartheid. SASOL has expended its refineries and produces many chemical products often derived from petroleum.
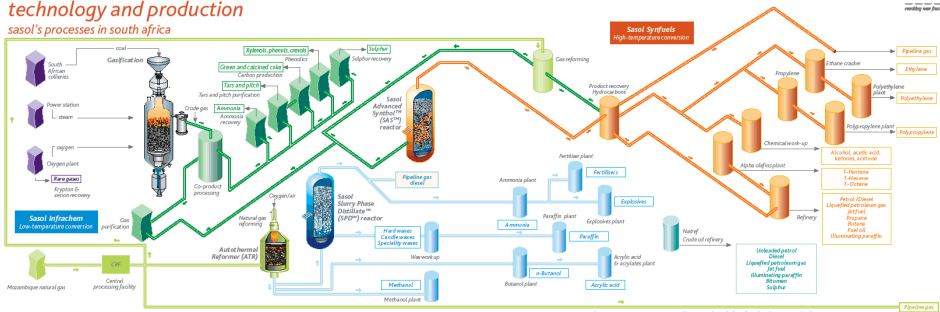

SASOL Fischer Tropsch plants, Secunda, South Africa[197]

The FT process is presented here, not for it ability to use coal, but as an illustration of the capabilities of the chemical industry to transform simple molecules like CO2, CO, and H2 to long-chain hydrocarbon fuels.


FT process, starting with coal gasification, C + H2O —> CO + H2

I remember "city gas" at my grandparents' home in Concord NH. The gas plant sprayed water on hot coal to generate hydrogen and carbon monoxide gases distributed by pipes and used in cook stoves. When methane became available it is was renamed "natural gas" because it came from natural wells, not a city gas plant. US National Energy Technology Laboratory *OVERVIEW OF COAL-TO-LIQUIDS: A HISTORICAL PERSPECTIVE*[198] is a good introduction to FT technology.

Methanol to gasoline
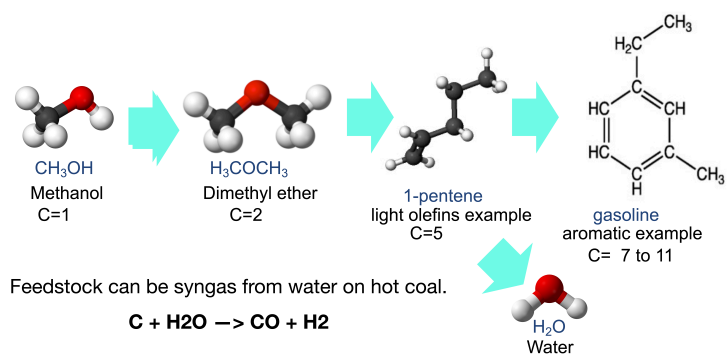
ExxonMobil methanol-to-gasoline process[199]

ExxonMobil developed a methanol-to-gasoline process in the 1970s, as the Arab oil embargo tightened oil supplies. New Zealand used it to convert natural gas to gasoline at 15,000 bbl/day in the 1980s. It ceased operation after a decade, unable to compete with returning low oil prices.

An ExxonMobil fixed bed reactor has produced 12,500 bbl/day in China since 2016. ExxonMobil now promotes its more efficient, fluid bed reactor design, not yet prototyped. Alternative process designs are described here.[200]

Haldor Topsoe also provides syngas to gasoline technology.

Synthetic Fuels | Methane-rich gas to gasoline

TIGAS™ (Topsoe Improved Gasoline Synthesis) makes it possible to produce high-quality, high-value gasoline from natural gas, shale gas, or associated gas.

After the 1973 oil crisis sparked a surge of interest in synthetic fuels, that interest soon waned as oil prices began to fall. However, today's high energy prices and a volatile energy supply have rejuvenated interest in synthetic fuels. And, as gasoline specifications reach new levels of stringency, Topsoe has responded to the needs of the market with TIGAS™ – Topsoe Improved Gasoline Synthesis.
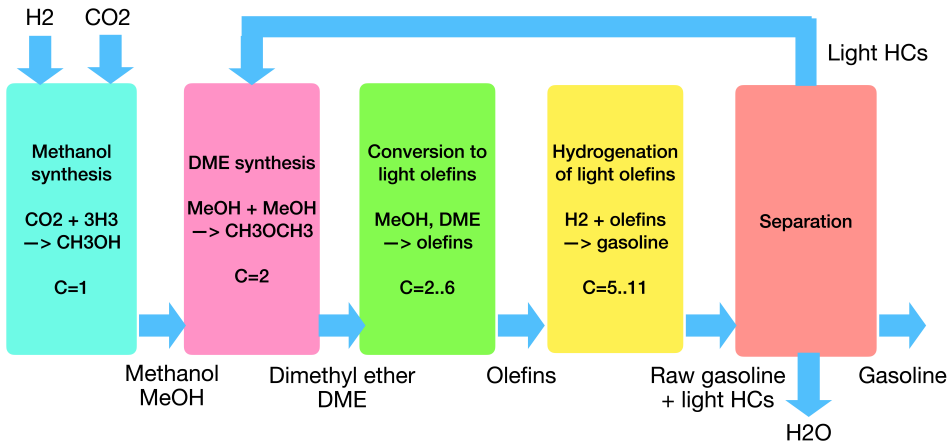
Haldor Topsoe gas-to-gasoline process[201]

Haldor Topsoe offers a dimethyl ether (DME) process, and also its TIGAS™ process to convert DME and methanol to multiple products:

(MeOH/DME) → C1-2 + C3-4 (LPG) + C5+ (Gasoline) + H20 + Heat

"The all-new Gasoline Upgrade Unit (GUU) comprises an additional catalytic step in which the heavy fraction gasoline is isomerized to produce a high-octane gasoline fraction. Blending this with the remaining gasoline results in high-value gasoline such as the Euro V gasoline."

Seafinery

Chemical engineers know[202] how to build a "seafinery" that convert CO2 and H2 into gasoline, jet fuel, and diesel liquid fuels for vehicles. Below is such a conceptual, synthesizing refinery with chemical reactors.

H2   CO2

Light HCs

Methanol synthesis	DME synthesis	Conversion to light olefins	Hydrogenation of light olefins	Separation
CO2 + 3H3 —> CH3OH	MeOH + MeOH —> CH3OCH3	MeOH, DME —> olefins	H2 + olefins —> gasoline	
C=1	C=2	C=2..6	C=5..11	

Methanol   Dimethyl ether   Olefins   Raw gasoline   Gasoline
MeOH   DME   + light HCs

H2O

Conceptual Seafinery to convert H2 + CO2 —> gasoline

The first two boxes synthesize methane, methanol, and DME, already discussed. Olefins are chains of 2 to 6 or more carbon atoms, with one or more double bonds between carbons. The fourth box displaces double bonds by bonding hydrogen, making raw gasoline and other hydrocarbons. They are separated into wanted products by distillation. Unreacted hydrogen and short-chain hydrocarbons can be fed back for reprocessing.

The methanol synthesis is the only chemical reactor requiring energy. Reactions in the other reactors are exothermic. Engineers are skilled at developing heat exchangers that take heat from hot reactions and use it to drive endothermic ones.

Engineers would design the seafinery to control the temperatures and pressures and flow rates for the reactants in each individual reactor. Key technologies to speed up reactions are catalyst materials and their substrates. Such materials may be managed in fixed bed, slurry bed, fluid bed mechanisms.

In some ways, a seafinery may be simpler than a petroleum refinery. There is no sulfur in the input stream to be removed or disable catalysts. There is no need to build a "cracker" to break apart longer-chain molecules present in crude oil. The seafinery already makes the antiknock additive methanol, obviating the need for biomass farming for ethanol. There is no requirement for accepting crude oil by ship.

Cost of Seafuel

What will be the cost of Seafuel compared to gasoline at the pump?

Refineries can't precisely control exactly the molecules being constructed. Gasoline might have over 100. We estimate the energy value and energy cost of Seafuel by looking at a typical molecule, octene.
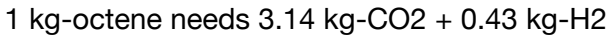

8 x (CO_2 + 3H_2) —> 16 H_2O + C_8H_{16}
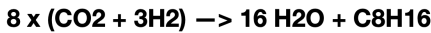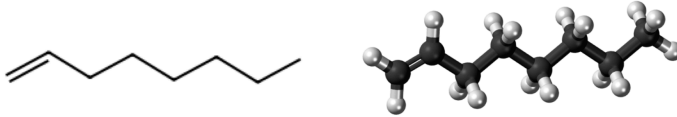
Models of octene molecule, formed from CO_2 and H_2O

Octene has 8 carbon atoms and 16 hydrogen atoms. The two leftmost carbons share a double bond that could be replaced by two more hydrogens. Octene is an olefin.

If we write the chemical equation in gram-mols we get

$$8x44 \text{ g-}CO_2 + 8x6 \text{ g-}H_2 \longrightarrow 16x18 \text{ g-}H_2O + 112 \text{ g-}C_8H_{16}$$
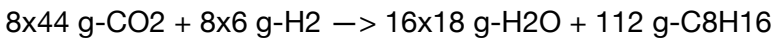
and solving the algebra for octene, C_8H_{16}, we get

$$1 \text{ kg-octene needs } 3.14 \text{ kg-}CO_2 + 0.43 \text{ kg-}H_2$$

Octene Ingredients	Quantity kg	Electricity kWh(e)/kg	kWh(e)	Elect Cost $/kWh @0.03	Heat kWh(t)/kg	kWh(t)	Heat cost $/kWh @ 0.01	Energy cost
CO_2	3.14	0.66 (Yan)	2	$0.06	0			$0.06
H_2	0.43	21 (Razi)	9	$0.27	39 (Razi)	17	$0.17	$0.44
Totals, per kg-octene			11	$0.33		17	$0.17	$0.50

Seafuel energy cost is $0.50/kg.

Making hydrogen involves both electric energy and heat energy costs. In the table above we add the cost of CO_2 from Yan and the cost of H_2 from Razi to get $0.50/kg-$H_2$. The H_2 cost dominates, so we could afford to spend more on CO_2 capture.

The Seafuel heat of combustion is about 13 kWh/kg-octene, costing about \$0.04/kWh. The Seafuel energy cost is about the same as the cost of crude oil at a petroleum refinery, typically operating at 88% energy efficiency. Seafuel economics are encouraging because \$3/gal gasoline sells energy for \$0.09/kWh.

Bosch[203] estimated CO2-sourced synfuel costs at \$4 to \$6 per gallon.

Willauer's US Navy project above estimated \$6 per gallon.

Seafuel cost is not going to be a big problem.

Scale
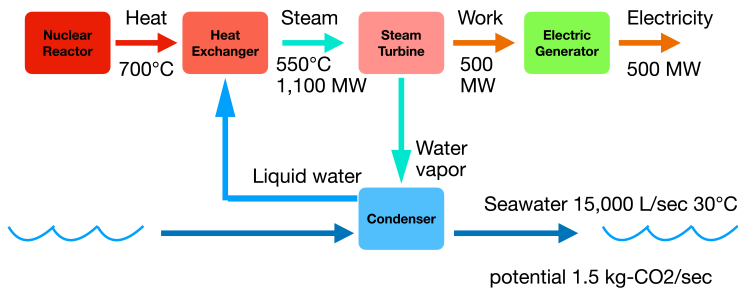
1.5 kg-CO2/sec seawater flow constrains Seafuel production.

Our example 500 MW *new nuclear* power plant cools its condenser with 15,000 L/sec-seawater, carrying potentially 1.5 kg/sec-CO2. Let's assume 67% extraction efficiency, or 1 kg/sec-CO2. The prior table indicates 3.14 kg-CO2 is required for 1 kg-Seafuel, so the plant produces 1/3.14 = 0.32 kg-Seafuel/sec.

Another perspective is that the 500 MW(e) plant could produce 15 MW of Seafuel power using 13 MW of electric power and 20 MW of heat.

	Flow rate kg/sec	Electricity kWh(e)/kg	MW(e)	Heat kWh(t)/kg	MW(t)
CO2 in	1.00	0.66 (Yan)	2.4	0	0
H2 in	0.14	21 (Razi)	10.6	39 (Razi)	20
Seafuel out	0.32				-15

Seafinery output: 15 MW(t)   Input: 13 MW(e) + 20 MW(t)

We conclude that Seafuel can be a byproduct of a 500 MW *new nuclear* electric power plant. At a typical fuel density of 119 kg/bbl, the plant makes 230 bbl/day. Unfortunately, global demand is much larger.

• World refineries today produce 93,000,000 bbl/day.
• Airlines alone use 5,600,000 bbl/day.

We might dedicate all the energy capacity of a *new nuclear* plant to Seafuel production, including pumping to increase seawater flow by a factor of 25. This could raise Seafuel output to 5,800 bbl/day. Satisfying airline needs alone would require 970 such ThorCon 500 scale plants, costing in total perhaps $500 billion, at ThorCon costs.

Replacing all of the world's 93,000,000 bbl/day would require 16,000 small plants for the energy, costing **$8 trillion** at ThorCon costs.

Dangote petroleum refinery

This is an example of a new plant that converts crude oil into vehicle fuels and other products, using best available modern technology.

Begun in 2016 this complex, multi-product refinery began production at the end of 2023. The Wikipedia Dangote article[204] source is a great tutorial on how petroleum refineries work.

Africa's largest, world's newest, Dangote refinery in Nigeria

Dangote Capacities
650,000 bbl/day crude input
10.4 Mt/year gasoline
4.6 Mt/year diesel fuel
4.0 Mt/year jet fuel
27 GW-fuels power out

Capital measures
$19 billion investment
$29,000/(bbl/day)
$2/bbl (if 40 year lifetime)
$700/kW fuels power out
$0.001/kWh

Shell Pearl gas-to-liquids refinery

Pearl Gas to Liquids plant in Qatar[205]

This plant uses gas-to-liquid technology that might produce liquid hydrocarbon Seafuel from CO_2 and H_2 gases.

Shell completed this plant in 2012 and operates this plant owned by Qatar. Offshore wells, connected by pipelines, deliver natural gas that is purified, then distilled to separate saleable light NGL (natural gas liquids) products such as butane and propane. The remaining, pure methane goes to the gas-to-liquids plant where it is combined with oxygen then converted into liquid hydrocarbon fuels by Shell's *Middle Distillate Synthesis* process, proprietary, with 3,500 patents.

The plant has 24 chemical reactors, each 1,200 tons with 26,000 tubes of cobalt synthesis catalyst. The catalyst surface area is 18 times the land area of Qatar.

Pearl Capacities
1.6 billion cu ft per day gas in
120,000 bbl/day NGL out
140,000 bbl/day fuels out
3 billion bbl lifetime out
8 GW-NGL power out
10 GW-GTL fuels power out

Capital measures
$19 billion investment
$73,000/(bbl/day)
$6/bbl (60 year lifetime)
$1,000/kW-power out
$0.004/kWh-out (60 years)

Global refinery costs

697 global oil refineries, tallies oilmap.xyz[206]

By 2030 there will be 697 oil refineries, with refining capacity of 105 million bbl/day. Larger refineries are more economic.

Nearly 700 oil refineries like these power our world.

Based on the cost of the new Dangote $29,000 per bbl/day of capacity, we roughly estimate capital in world crude oil refineries is at least

  • $29,000/(bbl/day) x 105 million bbl/day ~ $3 trillion.

Based on the Shell Pearl pioneering experience in gas-to-liquids, we estimate capital to provide Seafuel worldwide would be

  • $73,000/(bbl/day) x 105 million bbl/day ~ **$8 trillion.**

Is that a lot of money?