Hybrid Nuclear-Fossil Systems for Low-Emission Production of Synthetic Fuels

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Traditional synthetic fuel processes

Fossil resource  100 units of C mass

Oxidation

Chemical upgrading

energy

Product fuel

CO₂

30 units of C mass
Example: Traditional Coal to Liquid

Coal 14,600 tons/day → Gasifier → Water-Gas Shift

CO + H₂O → CO₂ + H₂

Gas Cleanup → Fischer-Tropsch Synthesis

Fischer-Tropsch Synthesis → Product Upgrade

Synfuel 25,000 barrels/day

Sulfur Product → H₂S

Over 65% of carbon in feed is lost

CO₂ (25,000 tpd)

Gas Cleanup → Vent or Sequester

Example: Traditional Coal to Liquid
Uses 70% less coal
Virtually no CO₂ emissions
Over 95% of carbon in feed is converted to product
What do low emissions cost?

- Comparable to conventional CTL with CO₂ cost of $50/ton
- Major nuclear cost is capital cost of reactors (2002 costs)
- Only nuclear has a clearly lower carbon emission than the baseline of conventional light crude oil
• Uses renewables, but intermittency requires operating flexibility or storage of hydrogen and oxygen
• Can be smaller scale than with a dedicated nuclear plant
Hybrid systems can use multiple feeds

**Energy Sources**
- Nuclear (Gen 3 and 4)
- Geothermal
- Biomass/MSW
- Supplemental wind/solar

**Energy Forms**
- Heat at various levels
- Electricity
- Shaft work
- Steam
- Water splitting ($H_2$)
- Air separation ($N_2 / O_2$)
- Desalination
- Waste heat recovery, nonevaporative cooling

**Carbon Sources**
- Biomass
- Coal / pet coke
- Oil shale / oil sands
- Heavy petroleum
- Carbon dioxide

**Processes**
- Synthetic diesel / gasoline
- Methanol / dimethyl ether
- Synthetic natural gas
- Ethylene / propylene
- Ammonia / fertilizers

**Hydrogen Sources**
- Methane
- Water

Secure, low CO$_2$, domestic supplies
Nuclear Energy for Upgrading

Water splitting cycle

Water

Brayton cycle

Nuclear fission (high level heat)

Fossil energy upgrading

Unconventional carbon resource

H₂ and O₂

Compression

Synthetic vehicle fuel

Minimal CO₂ production

Electricity to grid

Rankine cycle

midlevel heat

Waste heat

Low level heat
Why conversion flexibility?

Demand, alternatives, and relative costs change faster than facilities do.

Typical plant lifetime is well over 30 years.

Source: EIA Monthly Energy Review
Synfuel + O$_2$

CO$_2$ + H$_2$O

+ energy
Carbon dioxide → Syngas

Coal → Methanol

Biomass → Methane

→ Fischer Tropsch fuel (CH₂)
Assumptions

• Reactions at standard conditions of 25 C and 1 atm

• Thermal input/recovery efficiency is 70%

• Electrolysis efficiency is 75% based on electricity. Power generation is 33%, for 25% overall thermal efficiency
All synfuels require similar energy input when starting from CO$_2$. 

<table>
<thead>
<tr>
<th>Synfuel</th>
<th>Energy input (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syngas</td>
<td>3000</td>
</tr>
<tr>
<td>Methanol</td>
<td>3500</td>
</tr>
<tr>
<td>Methane</td>
<td>4000</td>
</tr>
<tr>
<td>FT synfuel</td>
<td>4500</td>
</tr>
</tbody>
</table>

Graph showing energy input for different synfuels.
Syngas

Carbon dioxide
Coal (CH)
Biomass (CHOH)

Methanol
Methane
Fischer Tropsch fuel (CH₂)
**CO₂-to-methanol requires much energy**

Why is CO₂ so different?

- Largest need for H₂
- Low production efficiency
  - Electrolysis 75%
  - Power generation 33%
Alternative water-splitting routes to make H$_2$
High Temp Electrolysis looks better

Data from J. O'Brien/INL
Nuclear energy’s potential roles

**Hydrogen**
- Near term
  - natural gas
  - coal
  - biomass
  - electrolysis
- Long term
  - high temperature electrolysis
  - thermo-chemical water splitting
  - gas hydrates

**Carbon**
- Near term
  - natural gas
  - coal / petcoke
  - unconventional fossil
  - biomass
- Long term
  - coal
  - biomass
  - unconventional fossil
  - gas hydrates
  - CO₂ recycling

**Energy**
- Near term
  - coal
  - natural gas
  - nuclear
- Long term
  - nuclear
  - renewables
  - gas hydrates
  - coal with CO₂ capture

*Courtesy Dr. R. Carrington*
**Conclusions**

- When making synfuels, consider the sources of carbon, hydrogen, and energy individually.

- Nuclear systems provide a low CO$_2$ source of energy, but the conversion efficiency between energy forms (heat, electricity, hydrogen, others) is important.