

HYDROGEN AND SYNTHETIC HYDROCARBON FUELS – A NATURAL SYNERGY*

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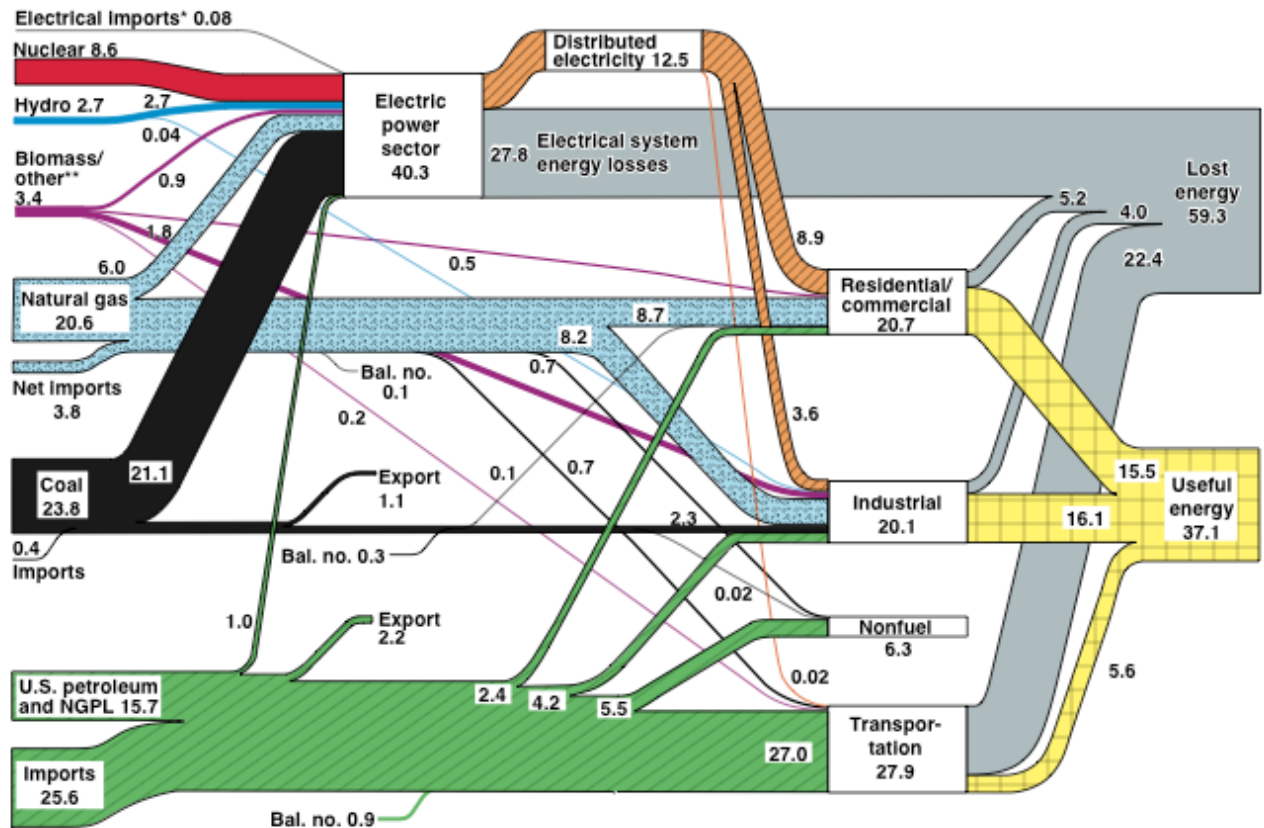
* Work supported by General Atomics

We currently rely heavily on fossil energy, especially oil

- Oil 40%
- Gas 23%
- Coal 23%
- Total Fossil 86%

- Nuclear 8%
- Hydro 2.8%
- Biomass 2.8%
- Geothermal 0.4%
- Wind 0.1%
- Solar 0.06%

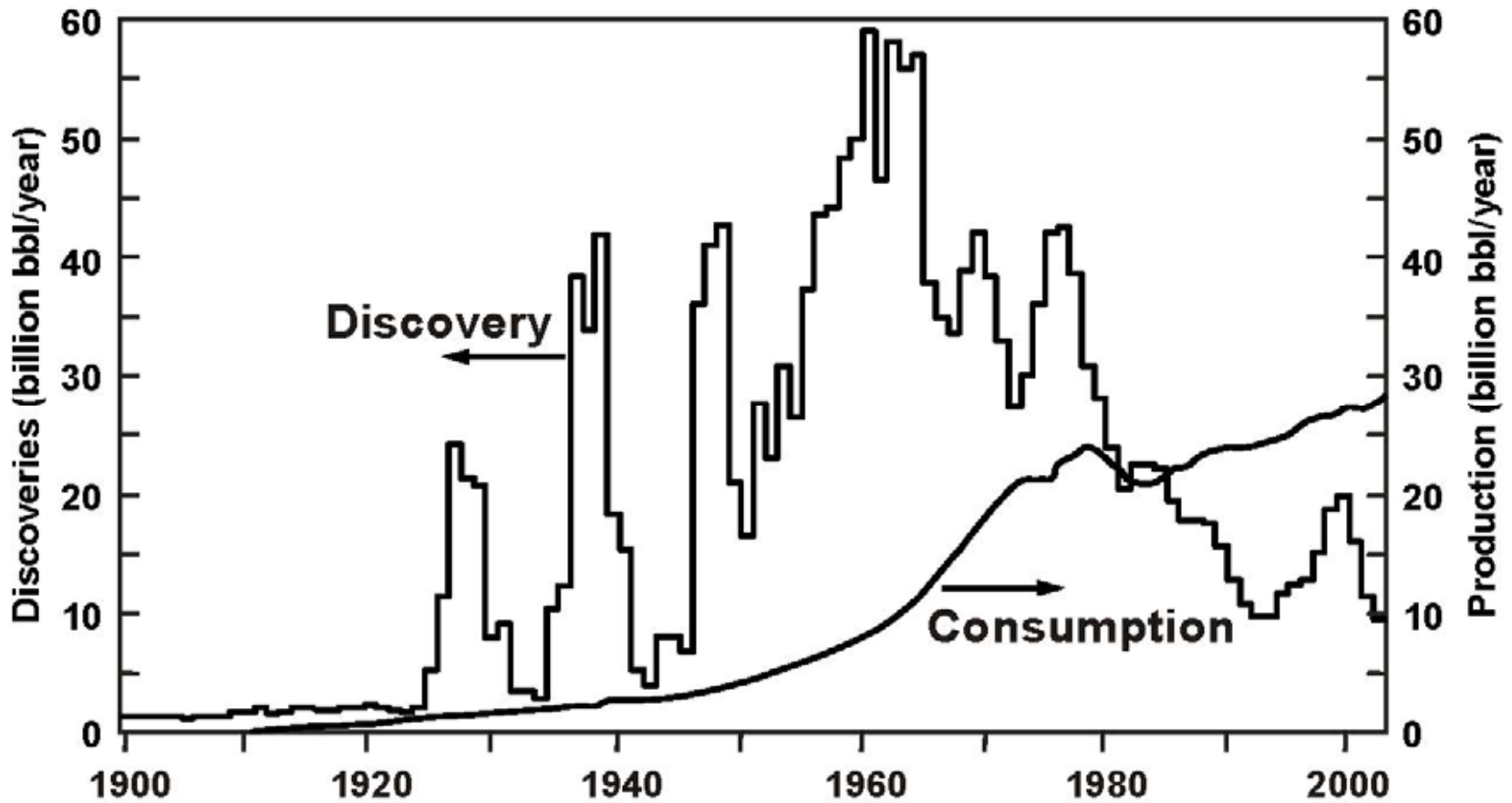
U.S. Energy Flow Trends – 2002
Net Primary Resource Consumption ~103 Exajoules



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
 *Net fossil-fuel electrical imports.
 **Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

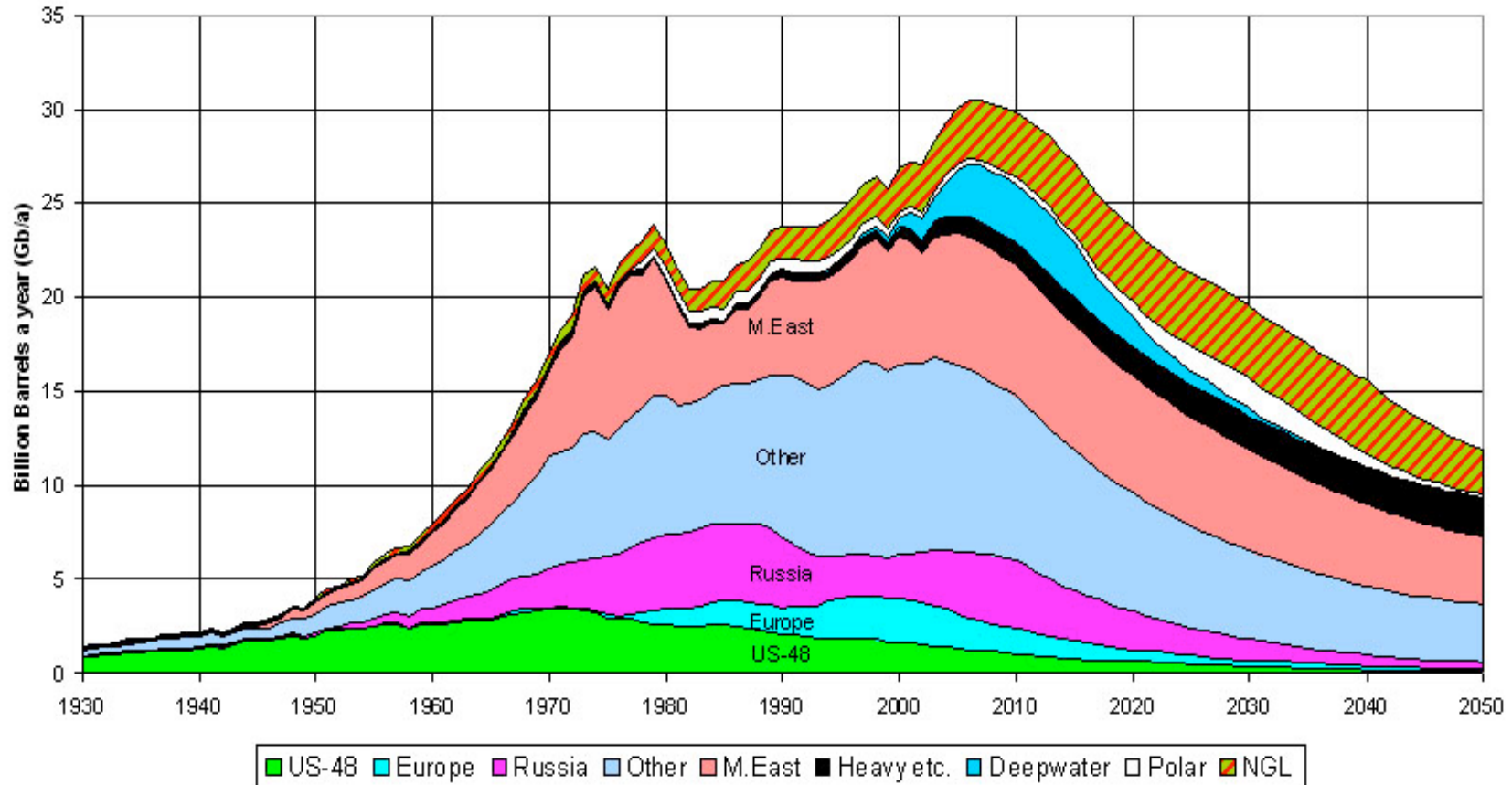
June 2004
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Oil consumption has outpaced discovery for 20 years



Some predict the global oil supply may peak soon

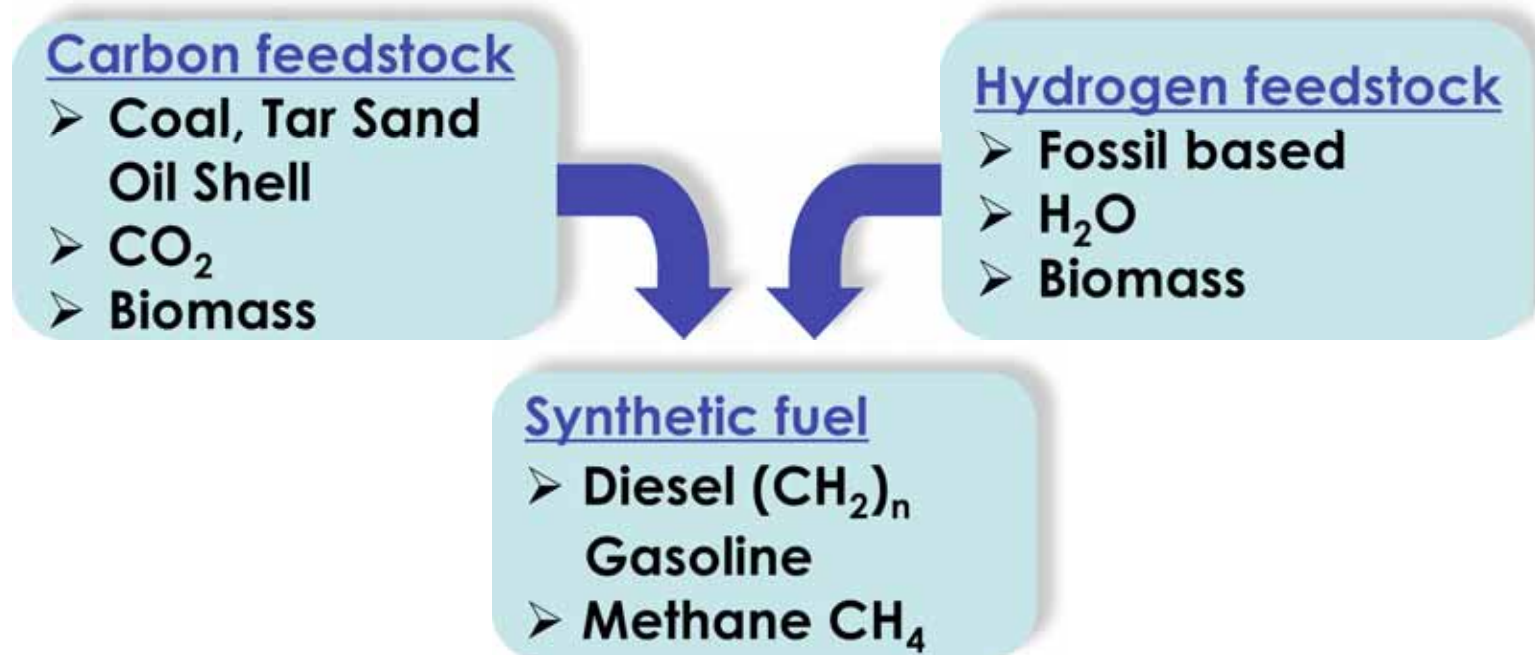
Oil production in billion barrels per year



Association for the Study of Peak Oil, available at <http://www.peakoil.net>

Synthetic Hydrocarbon Fuel (Synfuel) could replace oil

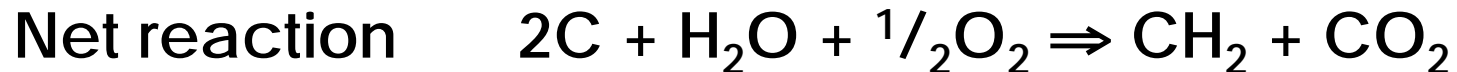
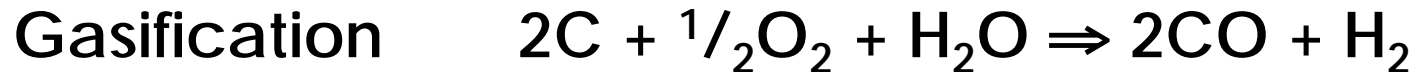
- Fuel can be manufactured by combining carbon and hydrogen into combustible hydrocarbons



- This technology has been used for almost a century. Synfuel made (Sasol) from coal and natural gas supports 30% of South Africa's transportation need

Coal is a possible source of synfuel

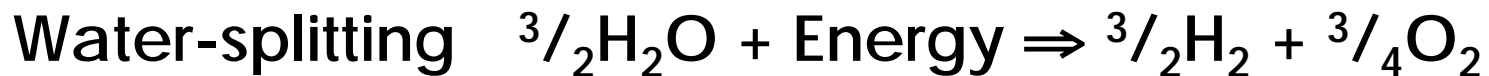
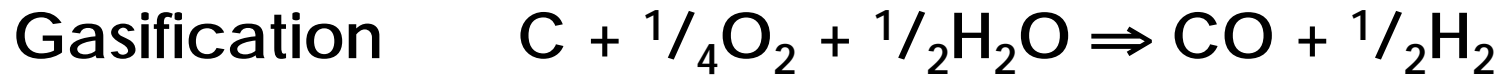
- Synfuel by Coal Gasification:



- Process uses 2 C and half an O₂ and makes one CO₂ for every CH₂ produced
- Replacing oil with coal synfuel would triple current coal use and double current CO₂ production

Addition of H₂ improves the coal synfuel process

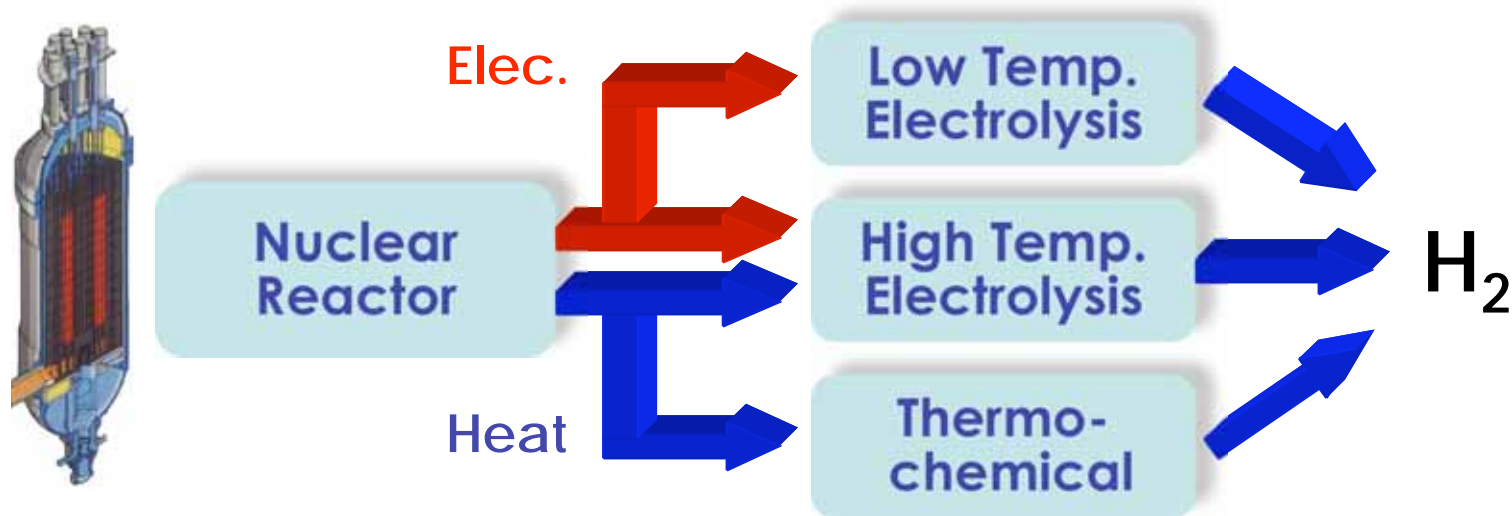
- Synfuel by Coal Gasification + H₂ from Water-splitting:



- Carbon need cut in half compared to synfuel from standard coal gasification, and no CO₂ is produced.

H₂ can be manufactured cleanly by using nuclear energy for water-splitting

- US currently produces 11 million tons of H₂ annually through steam reformation of CH₄
 - Process is fossil dependent and produces 100 million tons/yr of CO₂
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- Using nuclear power to produce H₂ is efficient and eliminates greenhouse gases



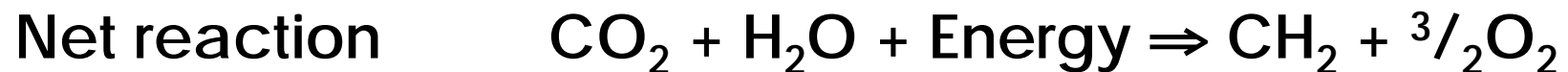
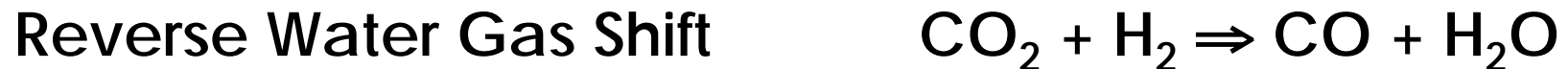
Nuclear H₂ can be economical if an efficient process is implemented

	LWR Low Temp. Electrolysis	HTGR High Temp. Electrolysis	HTGR Thermo- chemical
Efficiency	24-36%	50%	50%
Production Cost	\$2.7- 1.9/kg	\$1.8/kg	\$1.5/kg

- Production can be implemented today using low temperature electrolysis
- A 1100MW electric plant can produce 360 tonne of H₂/day at 24% efficiency, ~1000 nuclear plants needed to support production of transportation synfuel.
- A 50% efficient process can cut the number of power plants needed by half

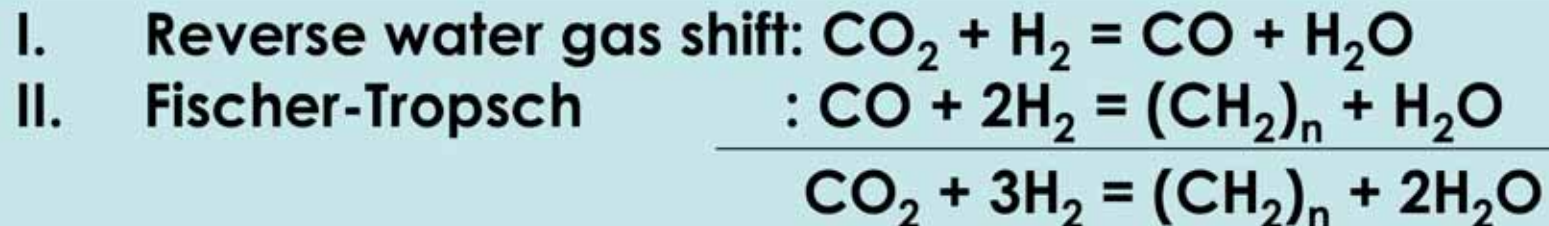
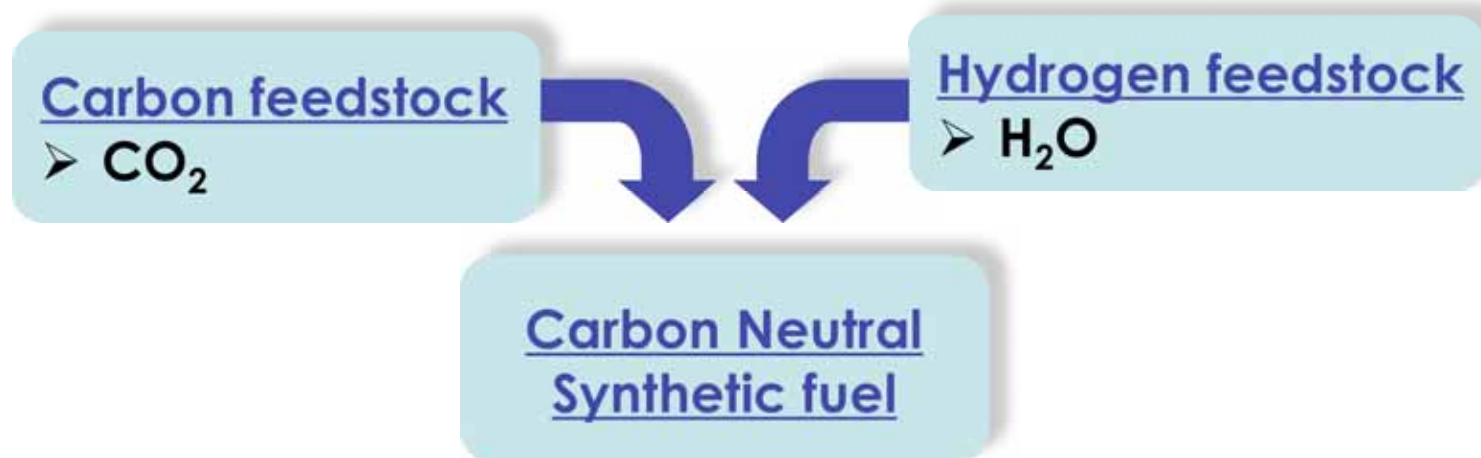
A source of CO₂ would make synfuel very attractive

- Synfuel by CO₂ Capture + H₂ from Water-splitting:



- No coal is needed and one CO₂ is consumed for each CH₂ produced
- When the CH₂ is burned, the process is carbon-neutral

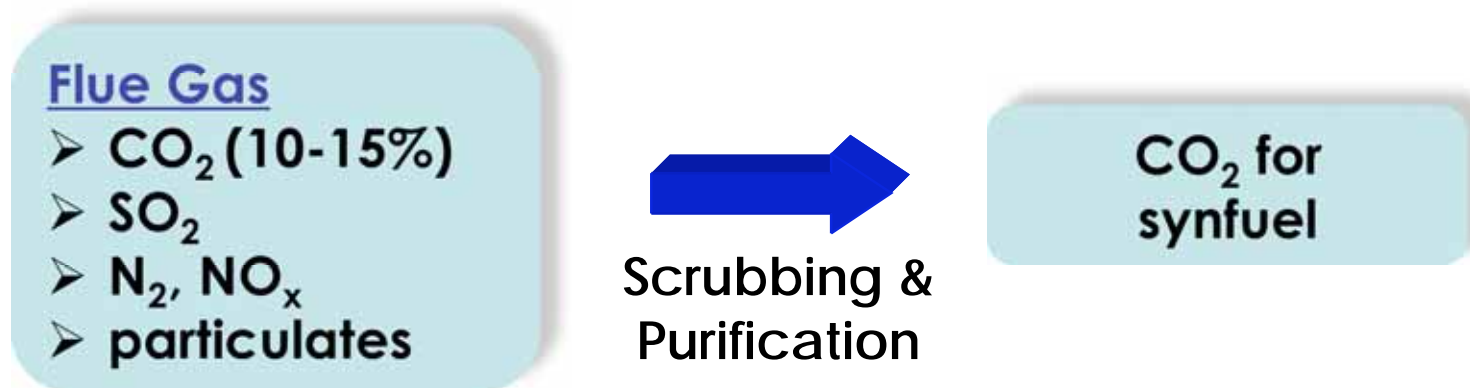
Synfuel can be a self sustainable and environmentally friendly transportation fuel



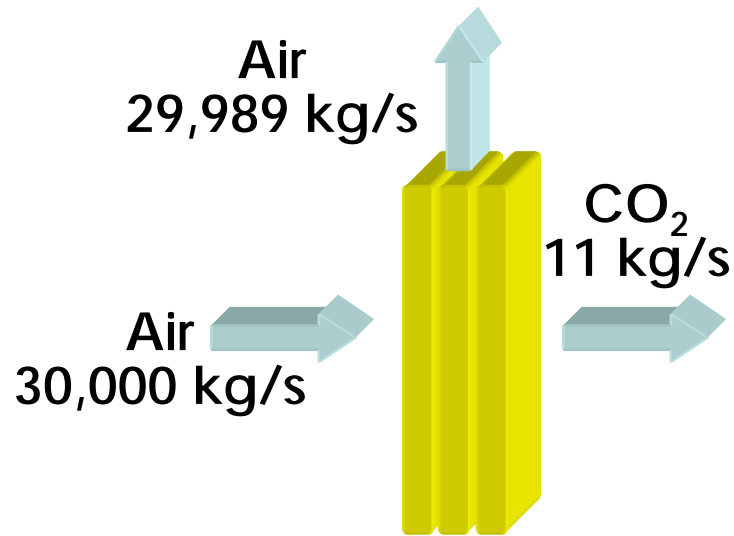
- This cycle is carbon neutral and does not produce any greenhouse gas. Replacing oil, it would cut CO₂ in half.

A readily available source of CO₂ is flue gas from fossil power plants

- A 1000MW coal-fired power plant produces 5.5 million tons of CO₂/yr. (14,500 tons/day)
- Coal-fired plants account for 53% (0.38TWh) of US electricity generation \approx 2 billion tons of CO₂/yr – *meets total annual CO₂ requirement to make synfuel for US transportation needs*
- Recycling the flue gas to make synfuel will cut CO₂ emission by 50%.



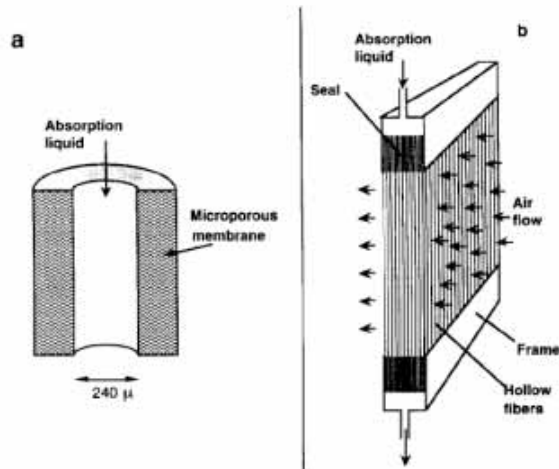
CO₂ could be captured from the atmosphere



Membrane separation of CO₂ from air followed by absorption of CO₂ by either amine or inorganic solvents

- CO₂ absorption technology has been demonstrated on a laboratory scale
- Large airflow is required due to low concentration of CO₂ in air
- CO₂ extracted from air will cost \$0.10/kg (~ \$1.0/gallon of synfuel)

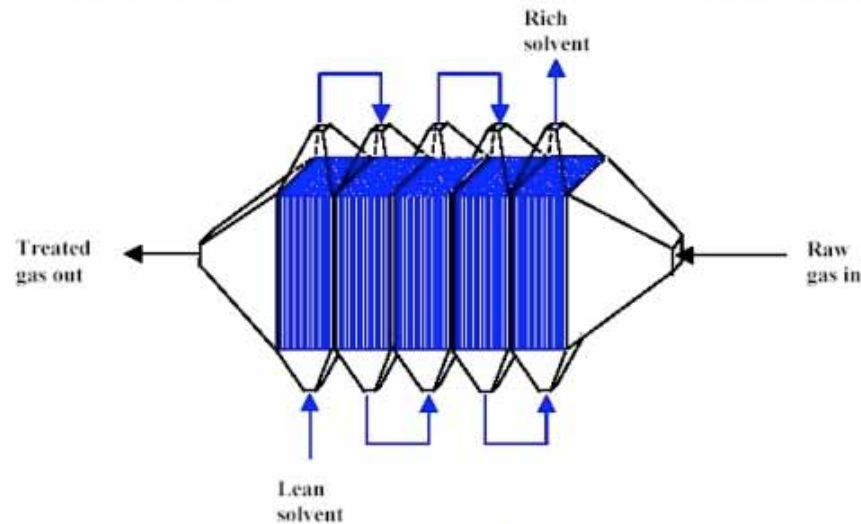
CO₂ capture by Membrane Gas Absorption is an emerging technology



PSI, Switzerland

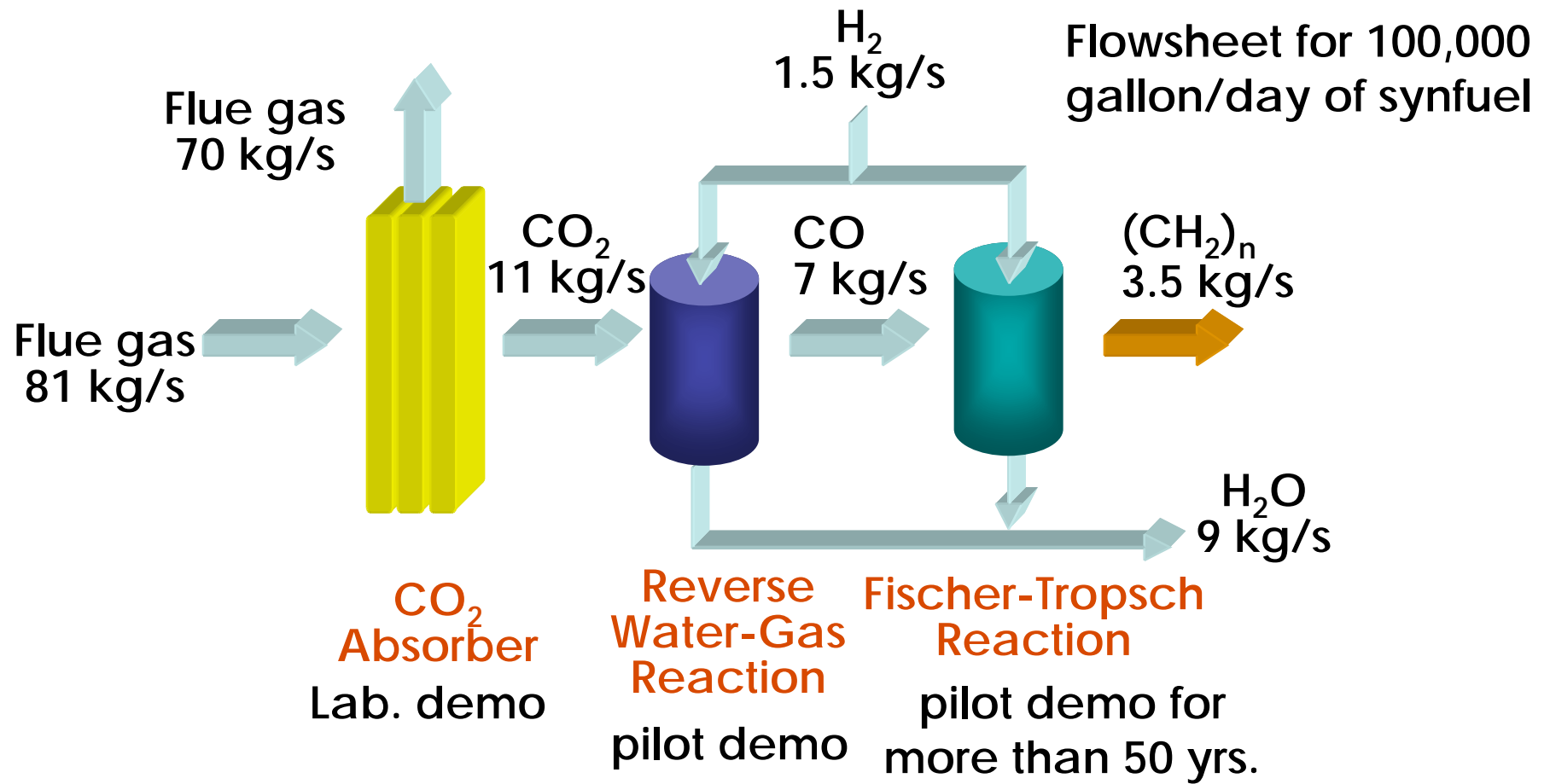


TNO, Netherlands



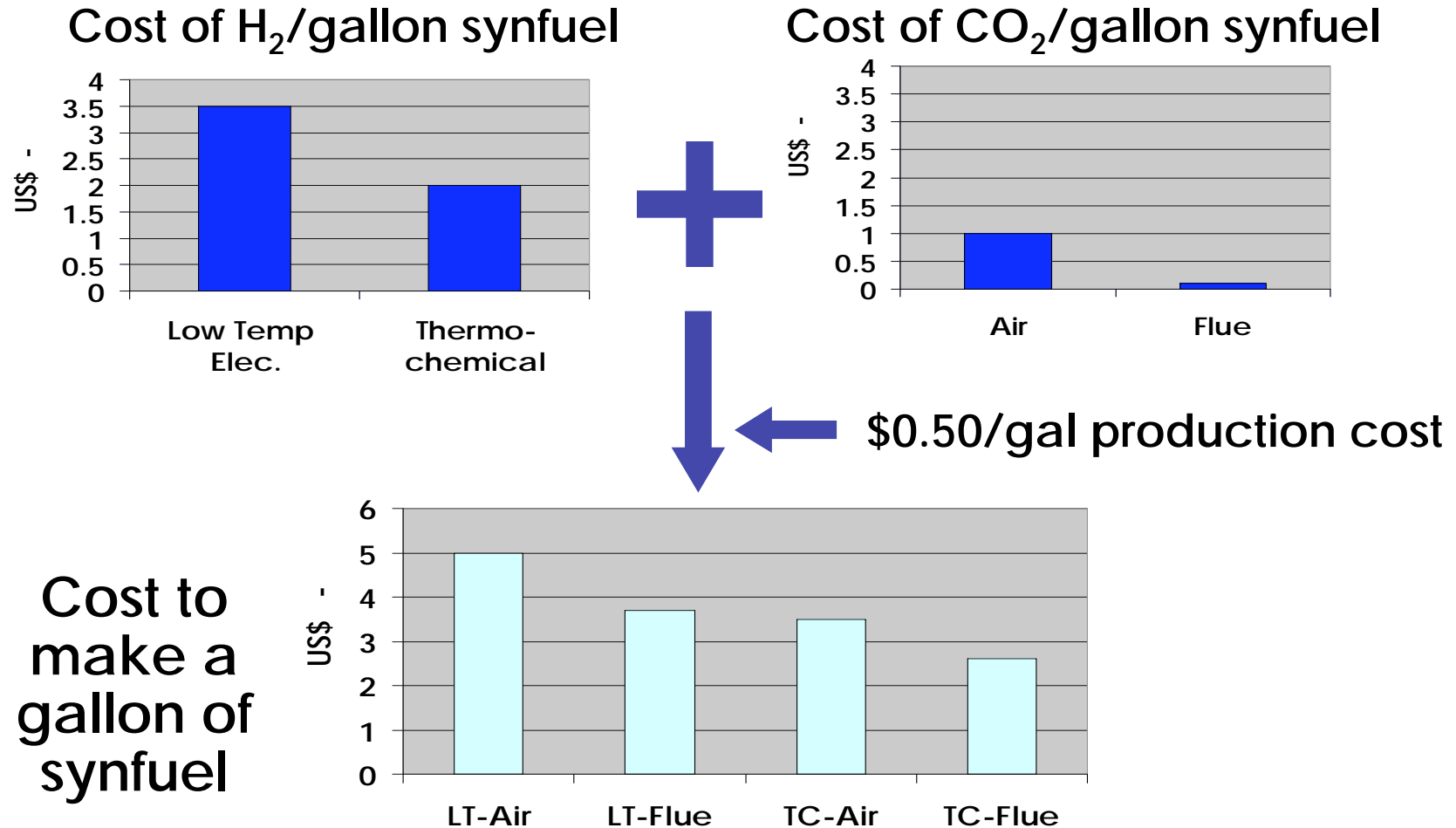
Aker Kvaerner, Norway

All the reaction steps have been demonstrated



- An integrated demo is needed

Using CO₂ from flue gas can reduce the price per gallon of synfuel compared to air capture



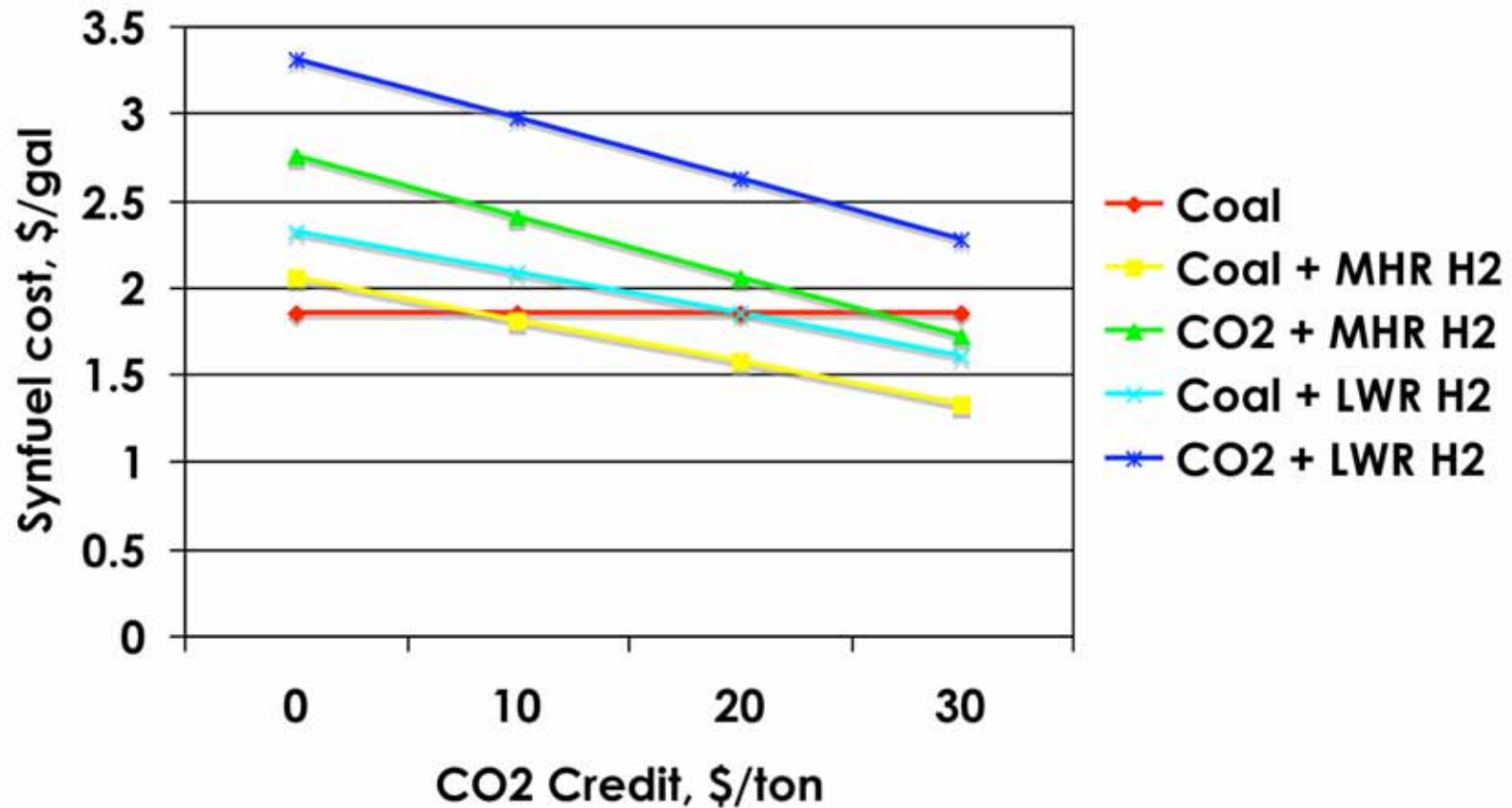
Synfuel Cost estimates are encouraging

Estimated Cost of Synfuel, \$/gallon (with/without \$30/ton CO₂ credit)

Process	External Hydrogen Source		
	None	Modular Helium Reactor + S-I Process	Light Water Reactor + Electrolysis
Coal gasification + F-T	1.85*	-	-
Coal gasification + H ₂ from water + F-T	-	1.32 / 2.06	1.61 / 2.36
CO ₂ capture + H ₂ from water + F-T	-	1.72 / 2.75	2.28 / 3.31

*: Coal gasification synfuel cost estimated from Rentech study
(<http://www.rentechinc.com/process-technical-publications.htm>)
but with \$30/ton coal and 10% interest rate,

The CO₂ credit is a key parameter



- A modest CO₂ credit allows H₂ synfuel to compete with coal synfuel

Large amounts of CO₂ and H₂ are required to support synfuel manufacturing for US transportation need

Synfuel
Production



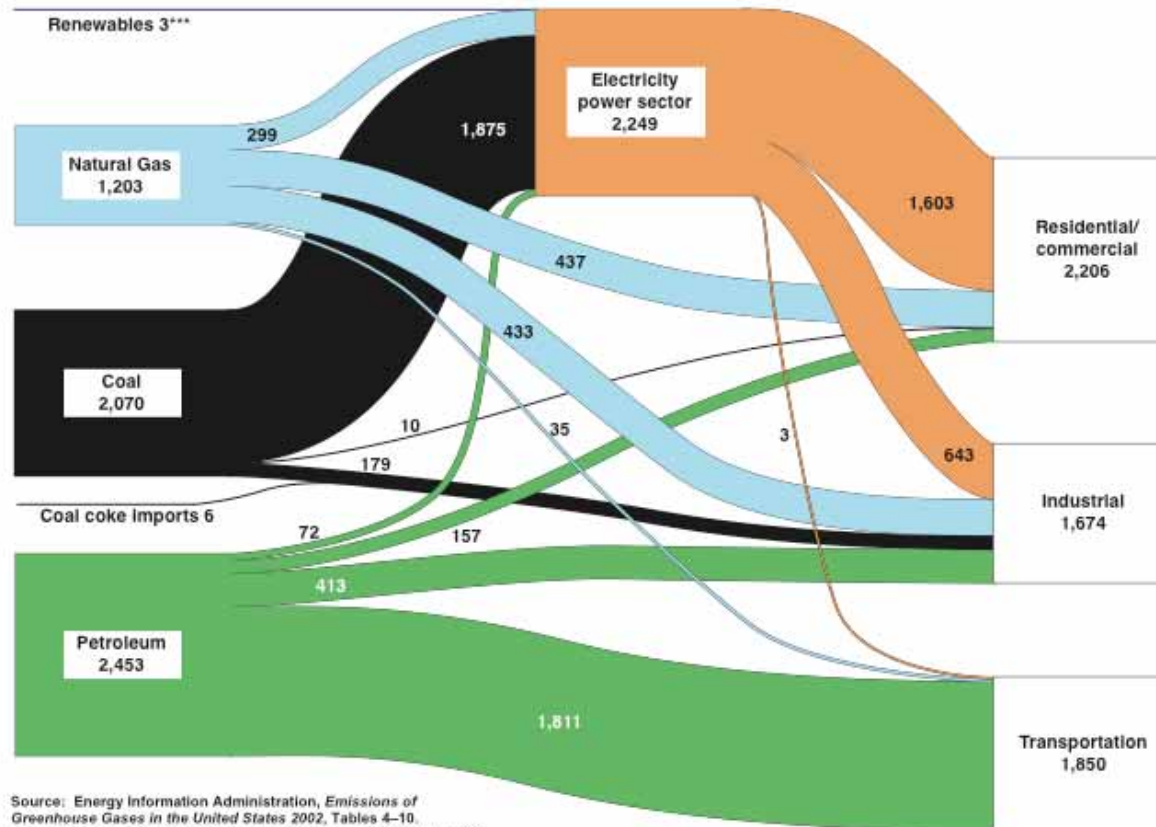
$$9.5\text{kg} + 1.3\text{kg} \rightarrow 3.1\text{kg} + 7.7\text{kg}$$

(1 gallon of fuel)

-
- US consumes 260 million gallons of transportation fuel per day. (13 million barrels of crude)
 - 2.5 million tonne of CO₂ (2.5 billion kg) and 0.35 million tonne of H₂ (350 million kg) per day are required to make synfuel to replace crude
 - Economical and dependable supply of H₂ and CO₂ will be the key driver for successful manufacturing of synfuel.

CO₂ release from coal for electricity and transportation are similar

U.S. 2002 Carbon Dioxide Emissions from Energy Consumption — 5,682* Million Metric Tons of CO₂**



Source: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2002*, Tables 4–10.
 *Includes adjustments of 42.9 million metric tons of carbon dioxide from U.S. territories, less 90.2 MtCO₂ from international and military bunker fuels.
 **Previous versions of this chart showed emissions in metric tons of carbon, not of CO₂.
 ***Municipal solid waste and geothermal energy.
 Note: Numbers may not equal sum of components because of independent rounding.

Lawrence Livermore National Laboratory, May 2004
<http://eed.llnl.gov/flow/>

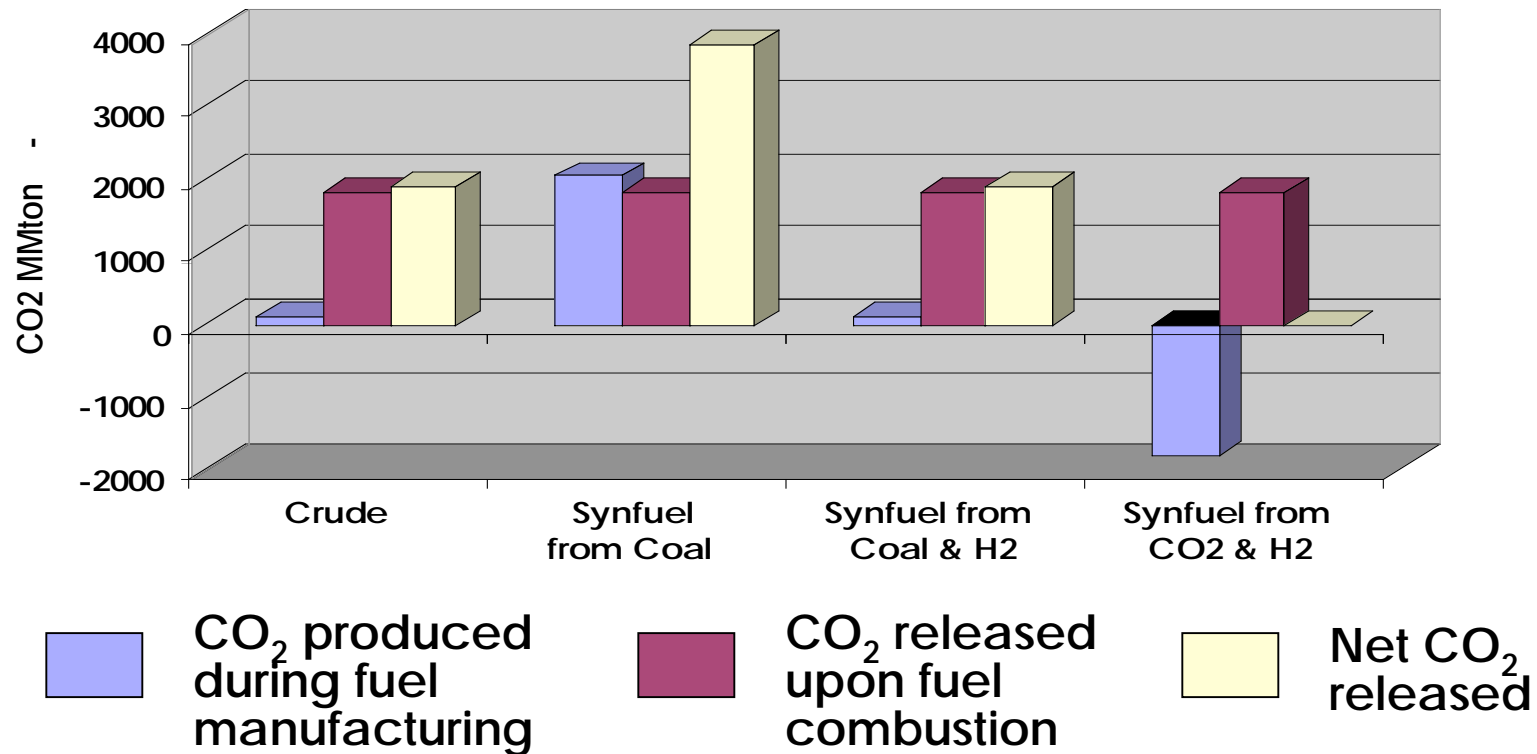
CO₂ from coal could provide all the carbon needed for synfuel to replace oil and cut CO₂ in half

H₂ would make synfuel environmentally attractive

MMT/year	Transportation Fuel From:			
	Oil	Coal	H ₂ + Coal	H ₂ + CO ₂ Capture
Oil needed	612	-	-	-
Coal carbon needed	-	1113	556	0
H ₂ from water-splitting	-	-	130	260
CO ₂ produced	~100	2046	104	-1811
CO ₂ release on use	1811	1811	1811	1811
Net CO ₂ released:	1911	3857	1915	0
Current carbon used/CO ₂ produced from coal: 565/2076 MMT/yr, H ₂ use: 10 MMT/yr				

Burning synfuel made from captured CO₂ results in ZERO CO₂ net release

Annual production of CO₂ from manufacturing and combustion of synfuel from various sources



Synfuel from CO₂ and H₂ reduces greenhouse effect

Hydrogen and Synfuel have Natural Synergy

- Addition of H₂ to the synfuel process can eliminate CO₂ production, allowing coal-based synfuel to replace oil with no increase in CO₂
- H₂ plus capture of CO₂ can allow synfuel production and use while cutting CO₂ release in half
- With modest CO₂ credit, H₂ can save money over conventional synfuel processes
- H₂ use in synfuels can be a bridge to the Hydrogen Economy

