Affordable CO_2-free Hydrogen Production from Methane ? and/or Nuclear Power ?

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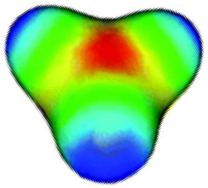
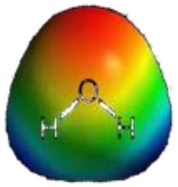
Energy and Specific Feedstocks Are Required To Produce Hydrogen

The only two H_2 feedstocks on earth are Water $(H^{+1})_2O^{-2}$ and/or Hydrocarbons $(C^{-n}H^{+1})$



CH_4

Electricity
+/- Heat



H_2O

H_2

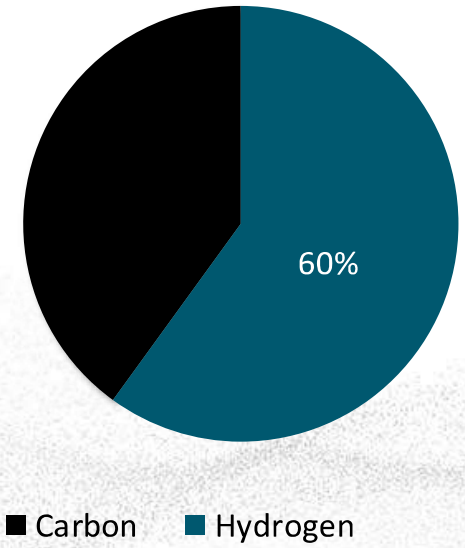
Without a sustained price on CO_2 emissions it is not possible to compete with SMR.

C||ZERO

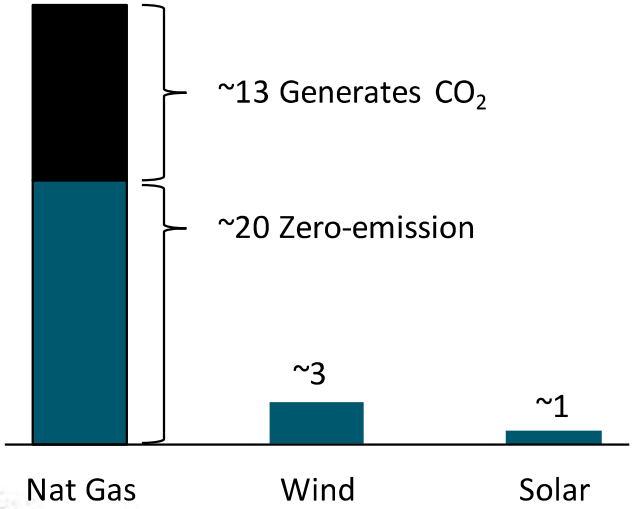
Decarbonizing Natural Gas

Turquoise Hydrogen ($CH_4 \rightarrow C + 2H_2$) extracts only the hydrogen associated energy from hydrocarbons

Energy from natural gas combustion, by reactant



2020 US Energy Production (in Quadrillion BTUs)



Opportunity = 5x current wind and solar production

Methane Pyrolysis Primarily Produces Carbon and is already commercially deployed for high value carbon production *(>$3-500/kg C)*

Not cost-effective for CO_2 free H_2 fuel production

$CH_4 \rightarrow 2H_2$ + Carbon Black

MONOLITH

NU:IONIC

HiiROC

Nanoplazz TECHNOLOGIES

spark

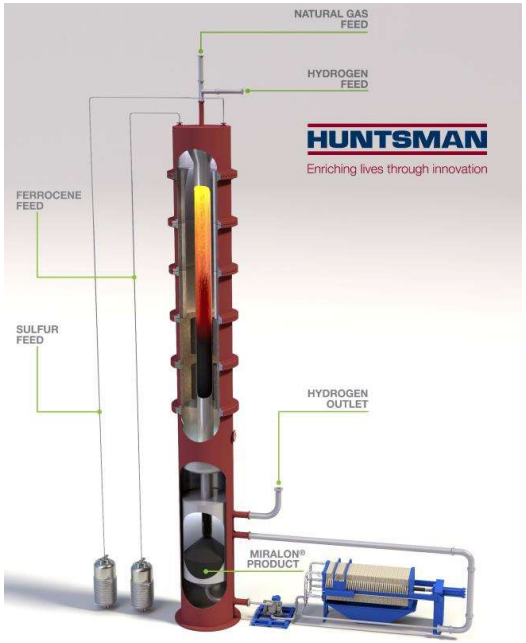
MAAT ENERGY

Low P Plasma

Global Market for C ~ 100 Mta

https://carbonblack.monolith-corp.com/methane-pyrolysis

$Fe + nCH_4 \rightarrow 2nH_2 + C_nFe$ (CNT's)



Global Market for CNT's ~ 0.1 Mta

https://www.huntsman.com/docs/Documents/Miralon%20Pulp_US_e.pdf

For A Sustainable Impact in the Power Sector, Scale is Everything!

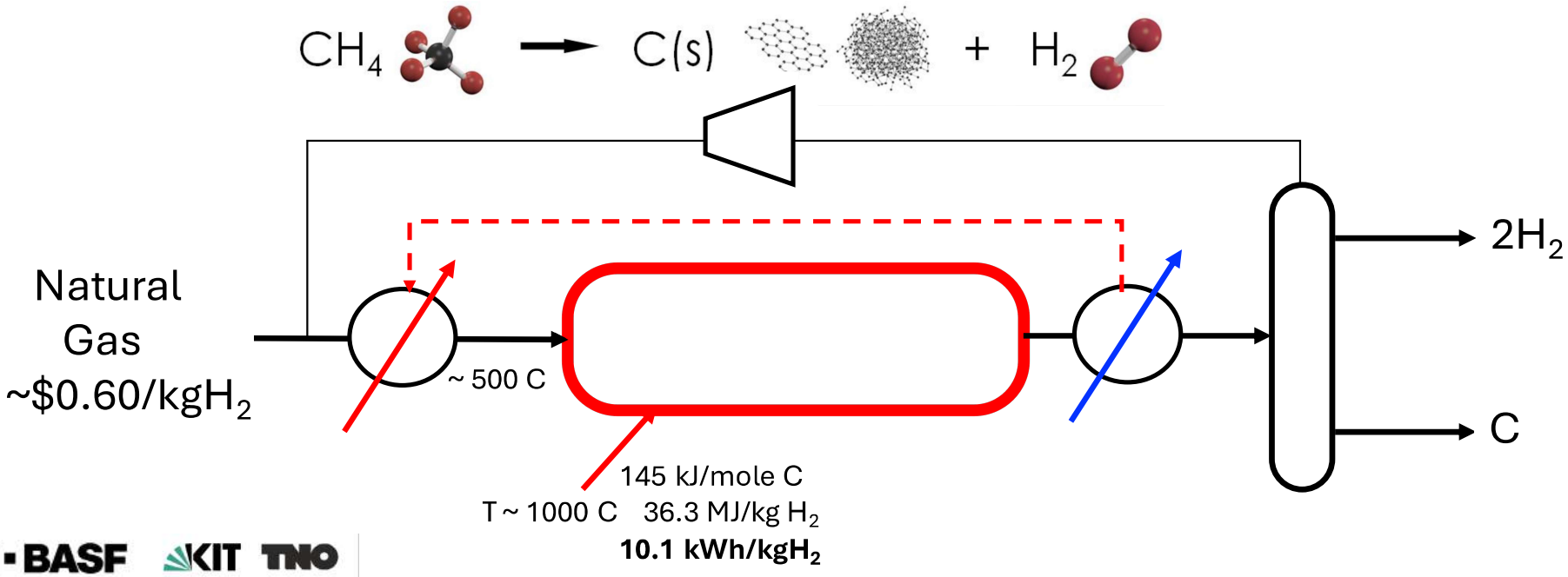


We build ~ 300 GW of new power systems each year GLOBALLY.
Last year this included a large fraction of renewable power generation capacity.
At present there are ~ 180 GW of new coal plants under construction
~ 50 GW of new natural gas power plants under construction
~ 70 GW new nuclear plants under construction

To be ”important” as a fuel source we will need to bring on
~ 30 GW of CO_2-free hydrogen capacity per year
~ 60 new 100 kta facilities per year and find the extra of CO_2-free heat/power to operate them.

WITHOUT A CO_2 TAX: ALL CO2-free HYDROGEN PRODUCTION PROCESSES WILL BE MORE EXPENSIVE THAN SMR’s

Challenges For Low-Value H_2 as the Primary Product



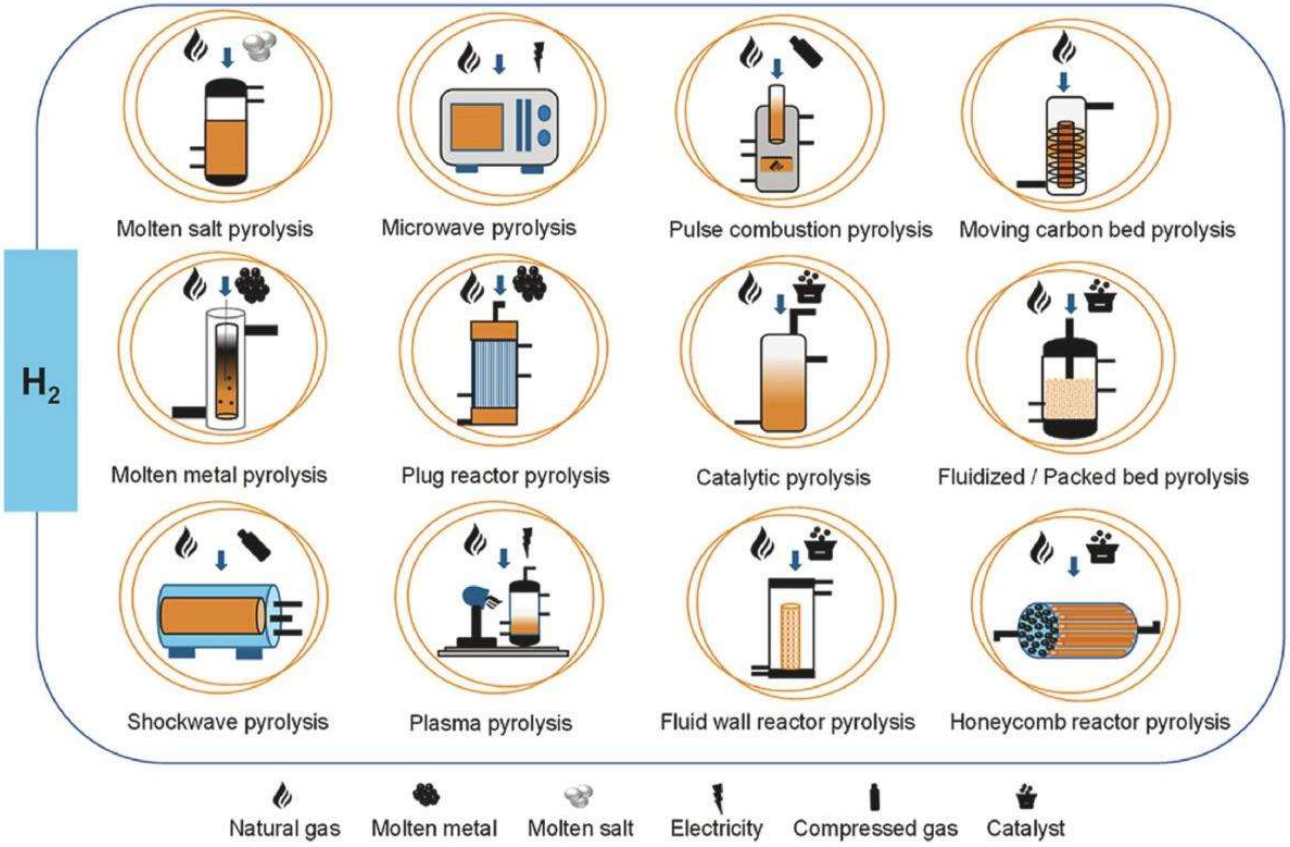
BASF · KIT · TNO · EKONA · ExxonMobil · C|ZERO · THERMOCATALYTIC · Shell · HazerGroup · LIQUID METAL CONDENSING · hycamite · parc

Major Challenges

1) **High methane conversion at P > 5bar**
2) **Heat transfer and materials at T~1000 C**
3) **Efficient high T energy integration Q_{net} < 12 kWh/kgH_2**
4) **Efficient removal of clean solid carbon**

Many Reactor Options Under Investigation

none deployed for commercial H2 production



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Renewable and Sustainable Energy Reviews
Volume 181, July 2023, 113323

We are focused on catalytic pyrolysis in scalable fluidized solid bed reactors

World's largest single-train methanol-to-olefins plant now operating

March 2, 2018 | By Scott Jenkins

Honeywell today announced that Jiangsu Sailboat Petrochemical Company, Ltd. has accepted a new methanol-to-olefins (MTO) unit provided by Honeywell UOP (Des Plaines, Ill.; www.uop.com), and that the plant is operating and has met all guarantees. With a production capacity of 833,000 metric tons per year, the unit is the largest single-train MTO unit in the world. The new plant converts methanol from domestic coal into olefins for plastics production.

The Sailboat facility in Lianyungang City in Jiangsu Province manufactures propylene to make acrylonitrile for clothing and fabrics, and high-performance polymers used in automotive parts, hard hats and other hard plastic products. The plant also produces ethylene for ethylene vinyl acetate copolymers that are used to make adhesives, foams, medical devices, photovoltaic cells, and other products, and C4 olefins for butadiene, an ingredient in synthetic rubber.

Honeywell UOP started its first MTO unit for China's Wison Clean Energy in 2013 *photo credit: Honeywell UOP*

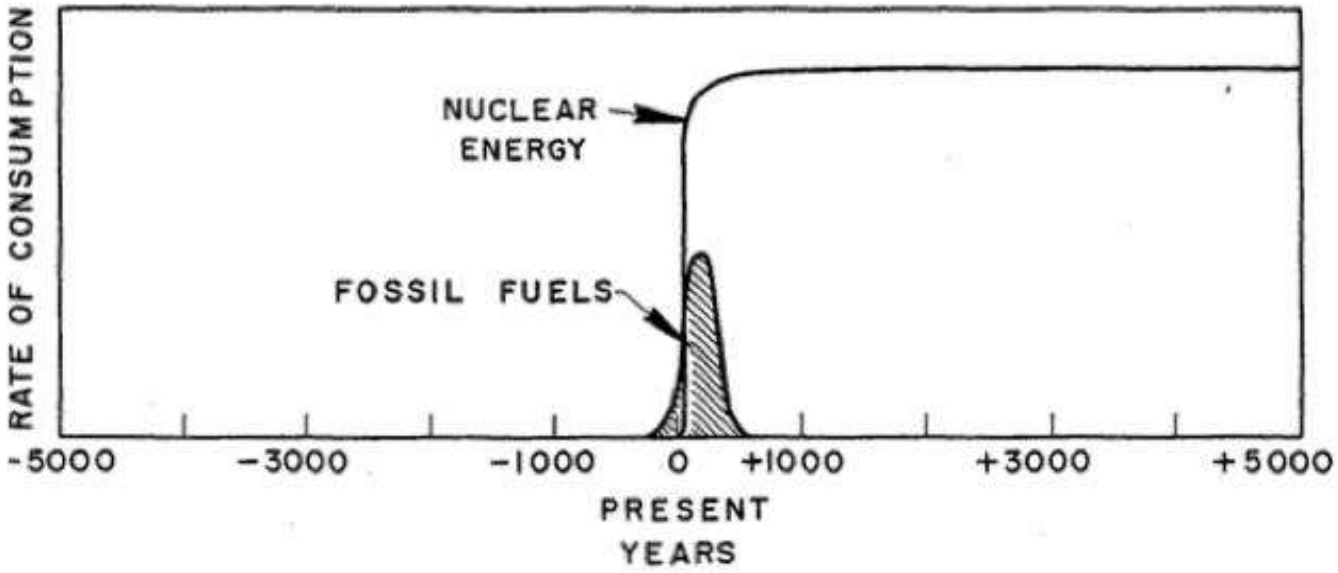
<u>Catalytic Solid Fluidized Bed</u>

- < 1000 C
- Commercially available materials
- High Heat transfer coefficients.
- Clean Graphitic Carbon
- Many operating commercial analogs.
- Direct scaling to 100+ kta.

Major Remaining Question: Ultimate Energy Efficiency, H_2 Yield, Best Use of Solid Carbon

At Best, Hydrogen from Natural Gas will only be helpful during a transition period

Fact: Low-cost fossil resources are finite and can not be used indefinitely for fuel.



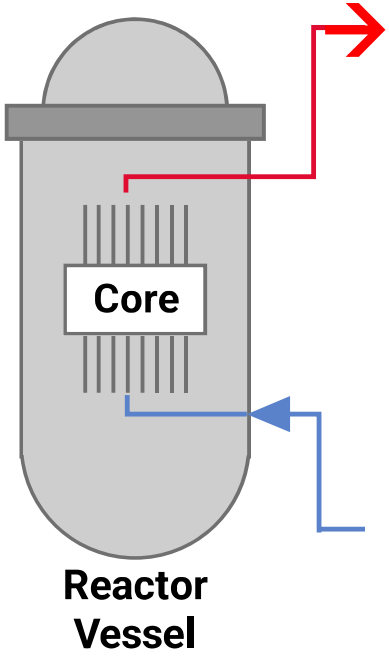
– Relative magnitudes of possible fossil-fuel and nuclear-energy consumption seen in time perspective of minus to plus 5000 years.

Source: M. K. Hubbert, *Nuclear Energy and the Fossil Fuels*, 1956.

Eventually – hydrogen must be made from water using nuclear reactions

Hydrogen Generation from the heat of Nuclear Fission (Pink Hydrogen)

A nuclear reactor generates Heat from fission of Heavy Elements (U, Pu) 24,000,000 kWh/kg U^{235}



→ Steam → Electricity → Electrolysis (Green H_2)

→ Steam + Electricity → High Temp Electrolysis

→ Thermochemical Water Splitting

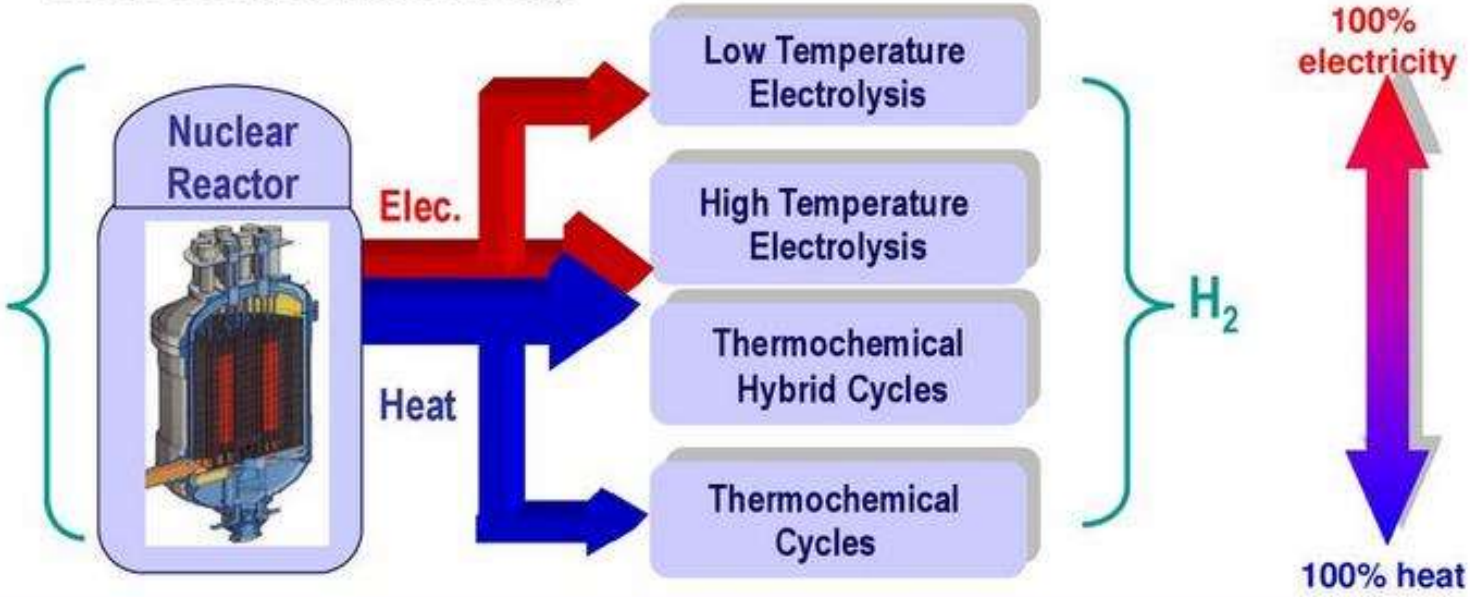
Cost = Cost of the Producing the Heat + Cost of Converting the Heat to Hydrogen

U.S. DEPARTMENT OF ENERGY

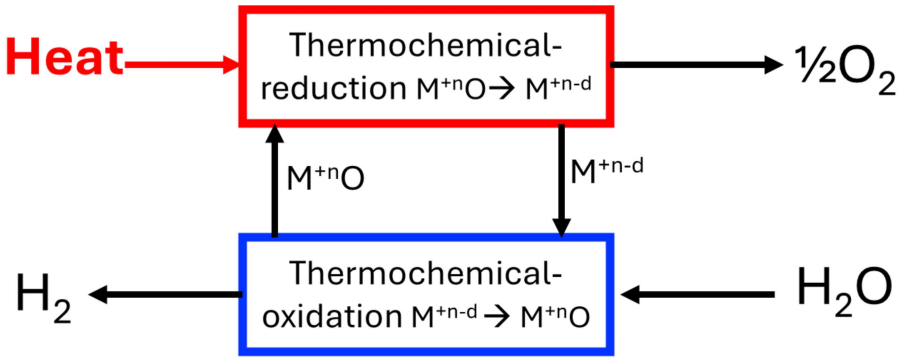
Nuclear Energy

Nuclear Hydrogen Production

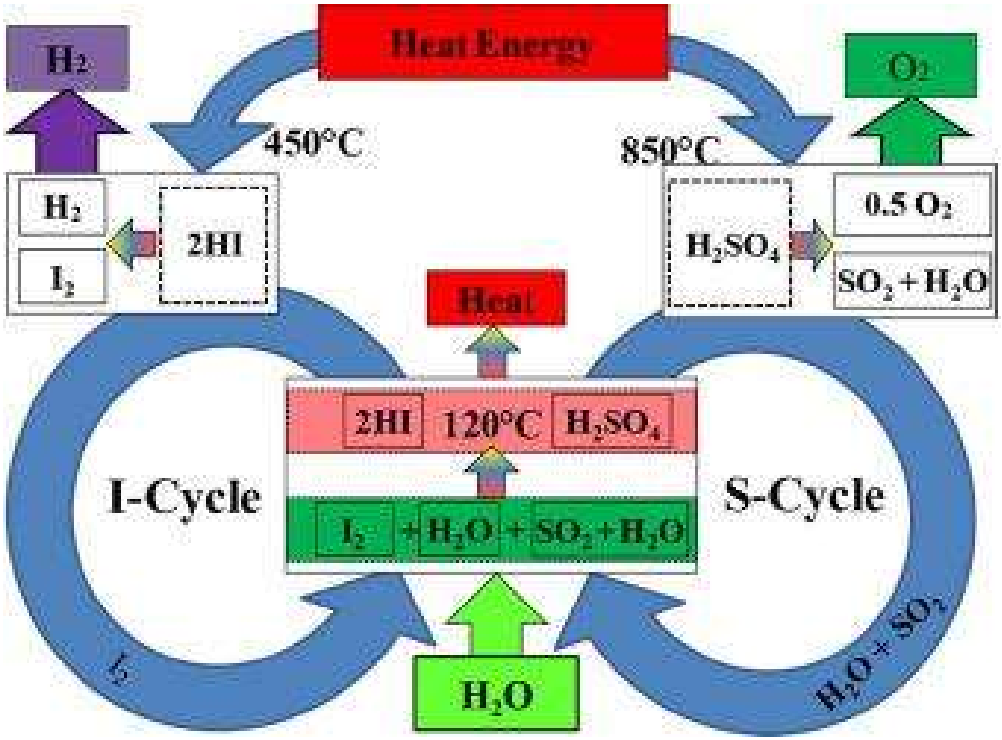
The Nuclear Hydrogen Production Program is focused on demonstrating the economic, commercial-scale production of hydrogen using process heat derived from nuclear energy.



Thermochemical water decomposition relies on separate thermochemical oxidation/reduction (chemical looping): Identical Thermodynamics as Electrolysis



I-S Cycles Proposed for Nuclear Heat



Potential Advantages

1) **Scalable, low-cost reactors**
2) **High Reaction Rates**
3) **High Energy Efficiency**

Both Electrochemical and Thermochemical Processes Nearing Commercial Deployment
→ At what cost? How fast can the technology be deployed?

RECHARGE
Global news and intelligence for the Energy Transition

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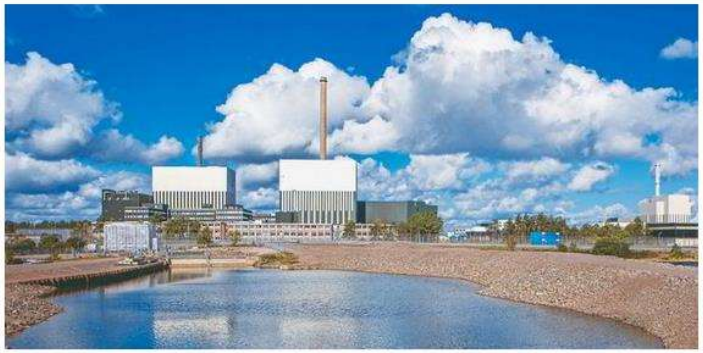


The Oskarshamn nuclear power plant in Sweden, where the hydrogen will be produced. Photo: Nuclear Energy Agency

World first for nuclear-powered pink hydrogen as commercial deal signed in Sweden

Industrial gases giant Linde to buy an undisclosed amount of the H2 produced at the Oskarshamn atomic power station owned by Uniper and Fortum

25 January 2022 13:10 GMT *UPDATED 25 January 2022 13:14 GMT*

By **Leigh Collins**

A Swedish nuclear power plant owned by Uniper and Fortum is to sell pink hydrogen to industrial gases giant Linde in the first-ever commercial deal for nuclear-derived H_2.

OKG, which operates the Oskarshamn 3 power station, has been producing hydrogen from electrolysers powered by its own electricity since 1992 — for use in reactor coolant.

Japan's High Temperature Test Reactor in Ibaraki prefecture, near Tokyo. Photo: JAEA

Japan plans hydrogen production with next-generation nuclear reactor – using heat and only minimal electricity

National research agency schedules field tests for 2028 ahead of a demonstration project planned by the end of the decade

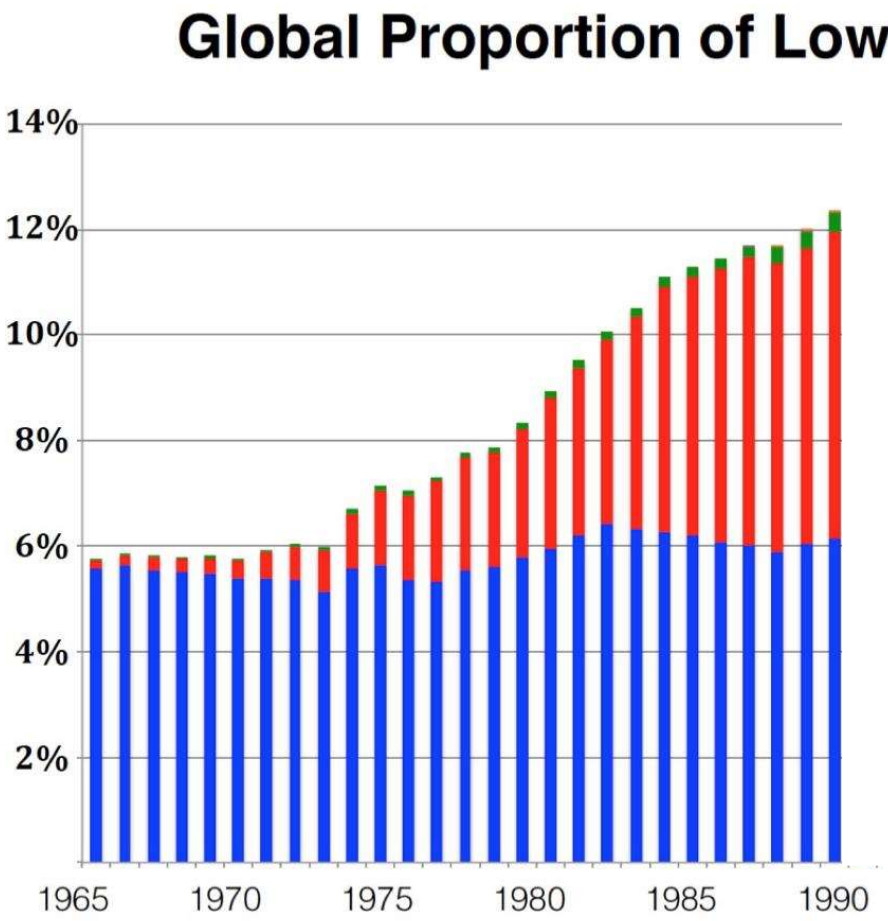
4 April 2024 12:53 GMT *UPDATED 4 April 2024 12:57 GMT*

Japan is planning to field-test a novel method of producing hydrogen fro a next-generation nuclear reactor — in which H_2 is produced almost entirely from waste heat.

The country's nuclear research agency, the Japan Atomic Energy Agency (JAEA), last week passed a safety test on its novel High Temperature Gas Cooled Reactor (HTGR), and is now planning hydrogen production field trials using waste heat from the plant as soon as 2028, Japanese daily *Nikkei* reported.

The process uses waste heat in a thermochemical reaction called the sulphur-iodine cycle, in which hydrogen and oxygen are extracted from water as part of a three-step chemical process.

When We Want To Do Big Things They Can Get Done Fast



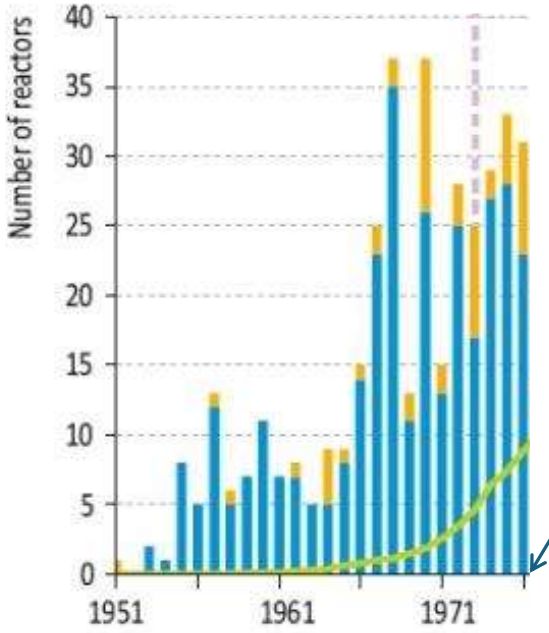
New Nuclear Power Plants

~ 1 new plant every 15-30 days producing zero carbon dioxide power!

When cost competitive alternatives are available significant changes in energy production can occur.

New Nuclear Reactor Construction

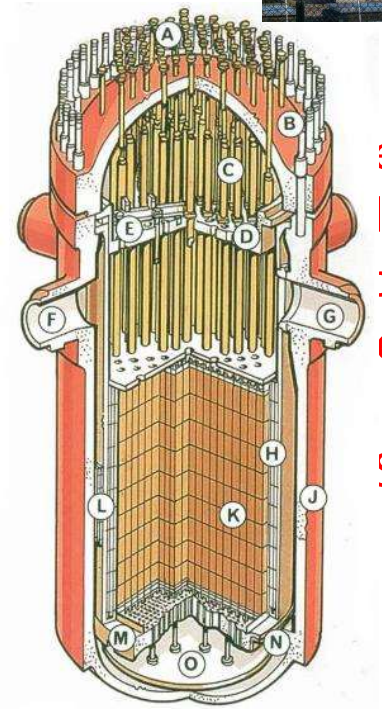
addressing uncertain supplies and increasing oil prices



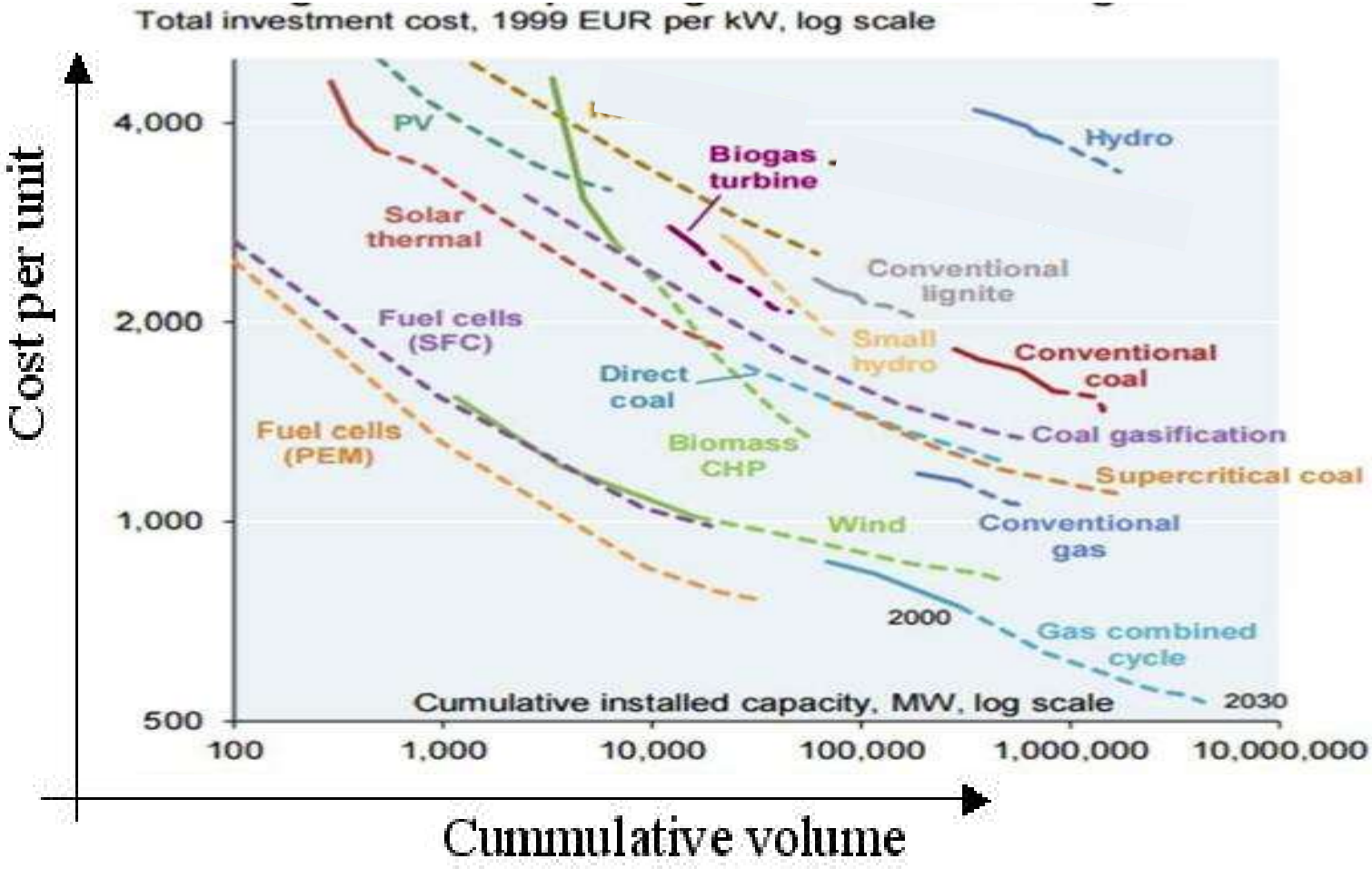
Future Resource Shortages

Oil Prices

McFarland enters UCB to study Nuclear Physics and Engineering Exciting Times !!



Innovation Drives Cost Down

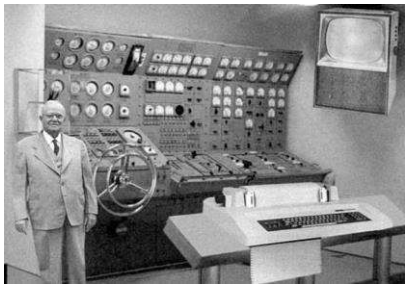


Imaginative Engineering and Science

1940

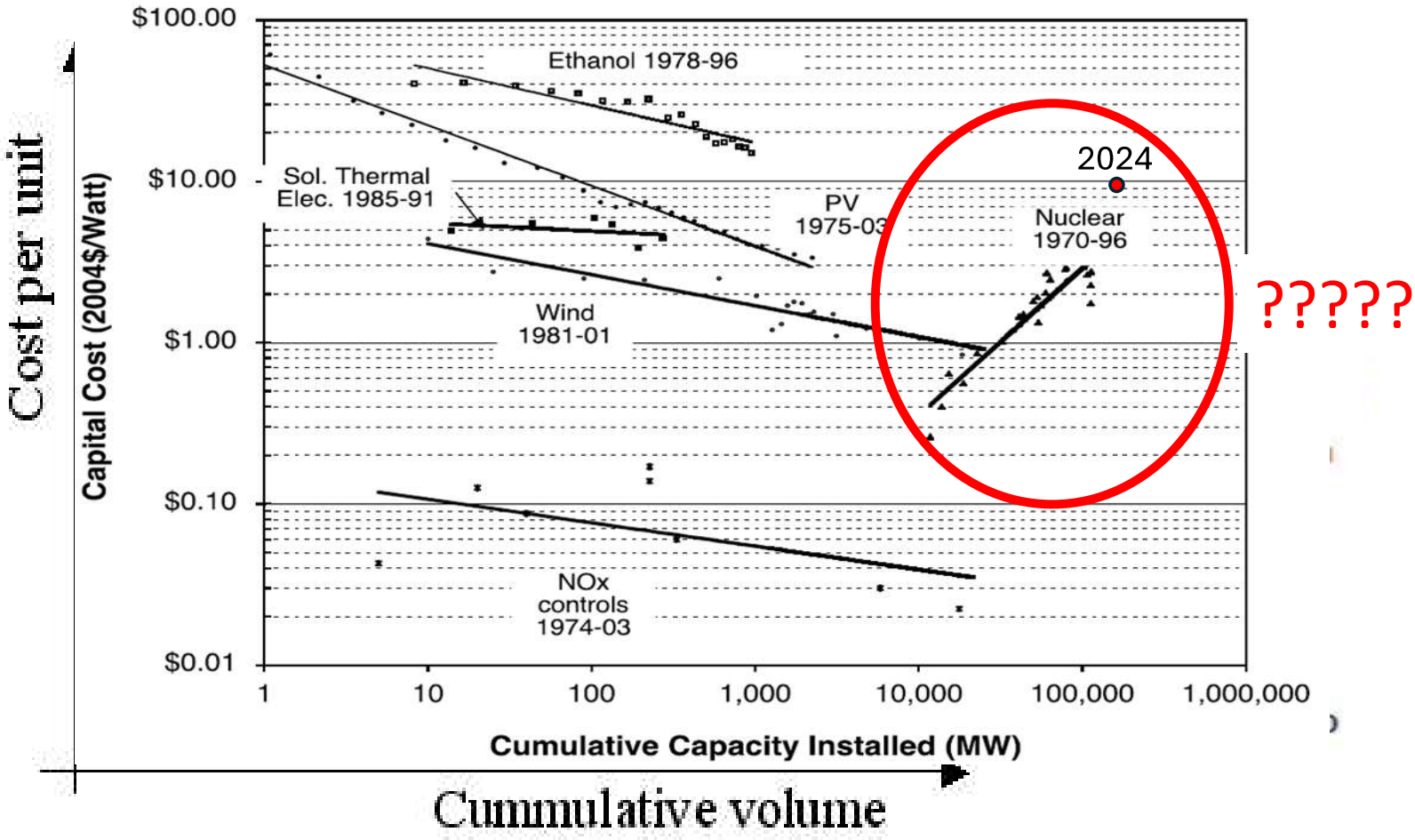
1970

2000



Safer, Cheaper, Better

Innovation Drives Cost Down ?



2009-2024 $31 billion !

March 1, 2024.

Vogtle Unit 4 Connects to Electric Grid for the First Time

PUBLISHED 5 HOURS AGO SUBMITTED BY SOUTHERN COMPANY

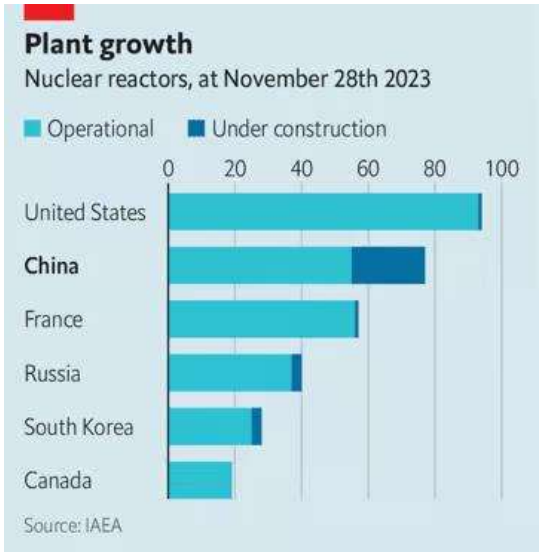
NOW READING

Vogtle Unit 4 Connects to Electric Grid for the First Time

Southern Company

Georgia Power announced on March 1 that Unit 4 at the Vogtle nuclear expansion project near Waynesboro, Georgia, has achieved another major milestone in startup testing by generating electricity and successfully synchronizing and connecting to the electric grid for the first time. This

Democratic Nations Are Lagging In Nuclear Technology !
We MUST do better.



The Economist

Menu

My Economist

China | Going fission (and fusion)

China is building nuclear reactors faster than any other country

Can its scientists solve the fusion problem?

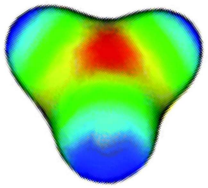
PHOTOGRAPH: LIN SHANCHUAN/XINHUA/EYEVINE

Nov 30th 2023

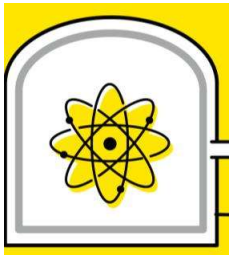
Save Share Give

Nuclear Power in China
→ $0.07/kWh$_{elec}$

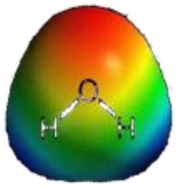
While low-cost methane is available it can be used for the cheapest zero-CO_2 hydrogen, eventually we will use water and nuclear power.



CH_4



Electricity
+/- Heat



H_2O

Turquoise

$$CH_4 \rightleftharpoons C + 2H_2 \quad > 6 \frac{kWh}{kgH_2}$$

Sequestration

Blue

$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2 \quad > 9.2 \frac{kWh}{kg\ H_2}$$

Green

$$H_2O \rightleftharpoons \frac{1}{2}O_2 + H_2 \quad > 50 \frac{kWh}{kg\ H_2}$$

H_2