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SODIUM BOROHYDRIDE AS HYDROGEN CARRIER

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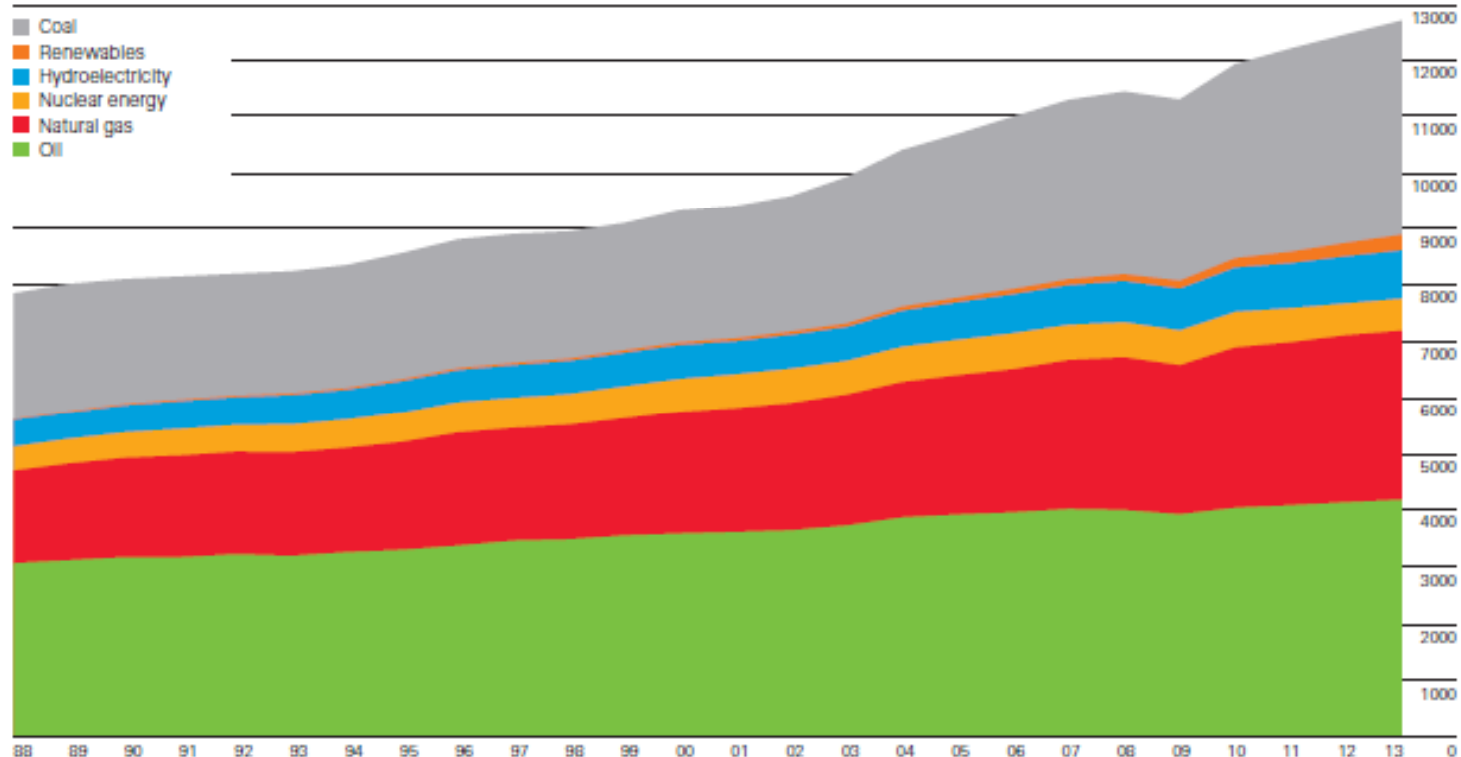
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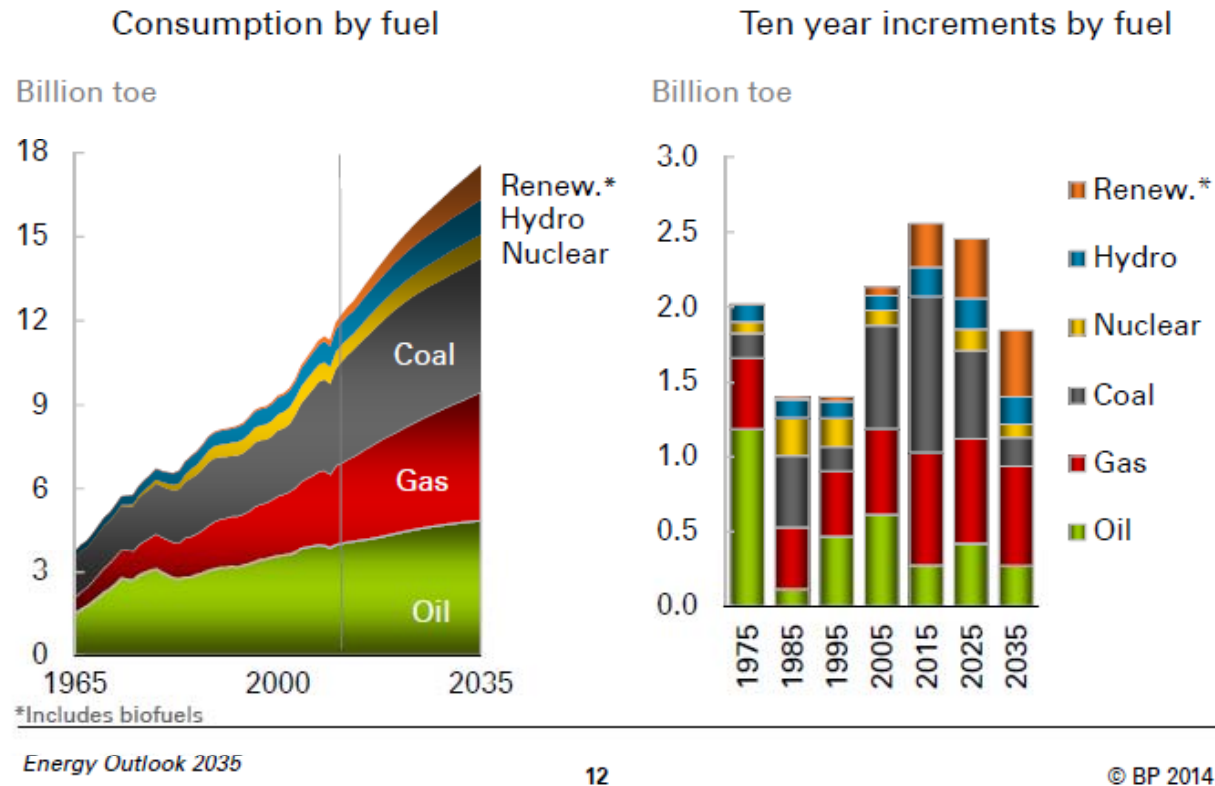
Global Energy Outlook

World consumption
 Million tonnes oil equivalent



World primary energy consumption grew by a below-average 2.3% in 2013, a third consecutive below-average increase. Growth was below average in all regions except North America. All fuels except oil, nuclear and renewables grew at below-average rates. Oil remains the world's dominant fuel, but has lost market share for 14 years in a row. Hydroelectric and other renewables in power generation both reached record shares of global primary energy consumption (6.7% and 2.2%, respectively).

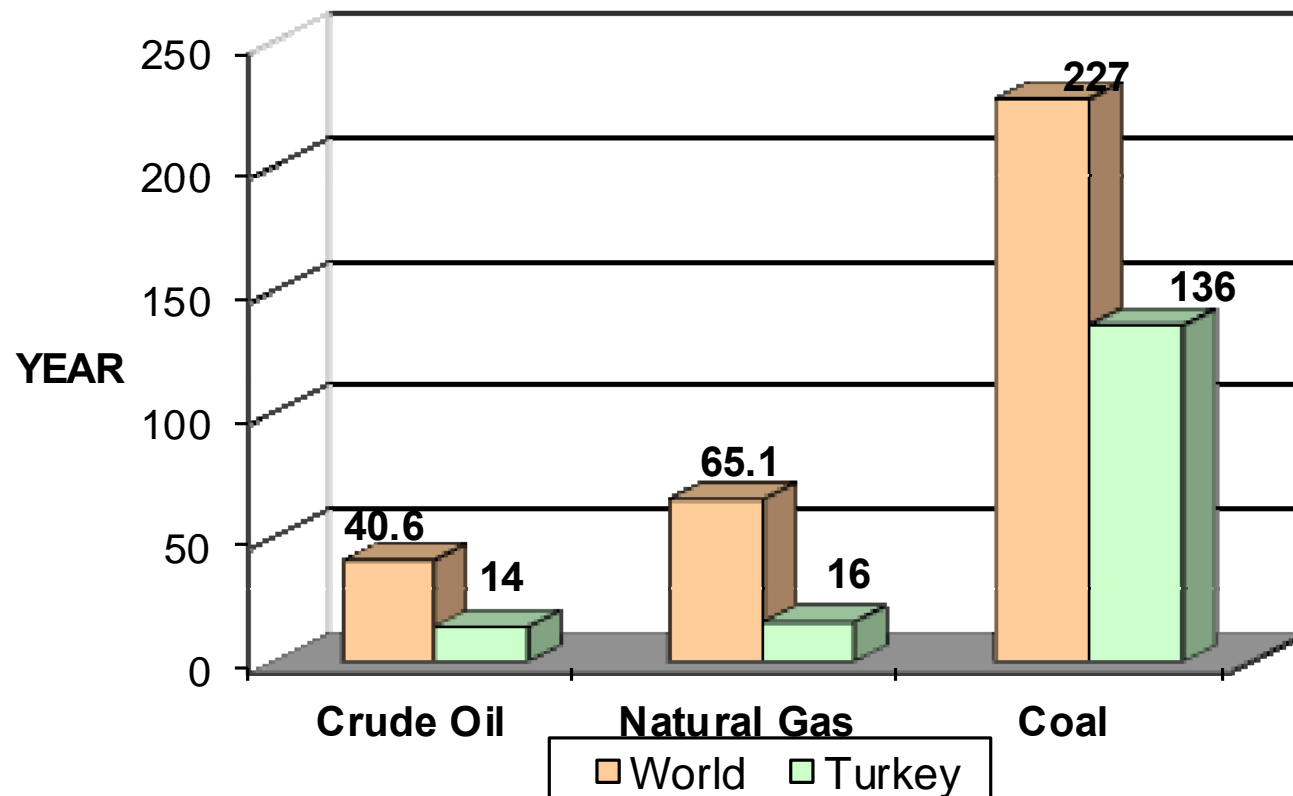
Fossil fuels have been the primary energy source so far.



- Fossil fuels will continue to be the primary energy source in the coming decades.
- Growth rate in global primary energy consumption: **+2.3%**
- Currently, share of renewables: **5.3%**
- But, considering the increase in the TOTAL consumption of fuels by 2035, it is anticipated that coal's and oil's relative shares will decrease and **renewables will increase.**

Sustainability of Energy Supply

LIFE SPAN OF FOSSIL FUELS Reserves to Production (R/P, Yr)



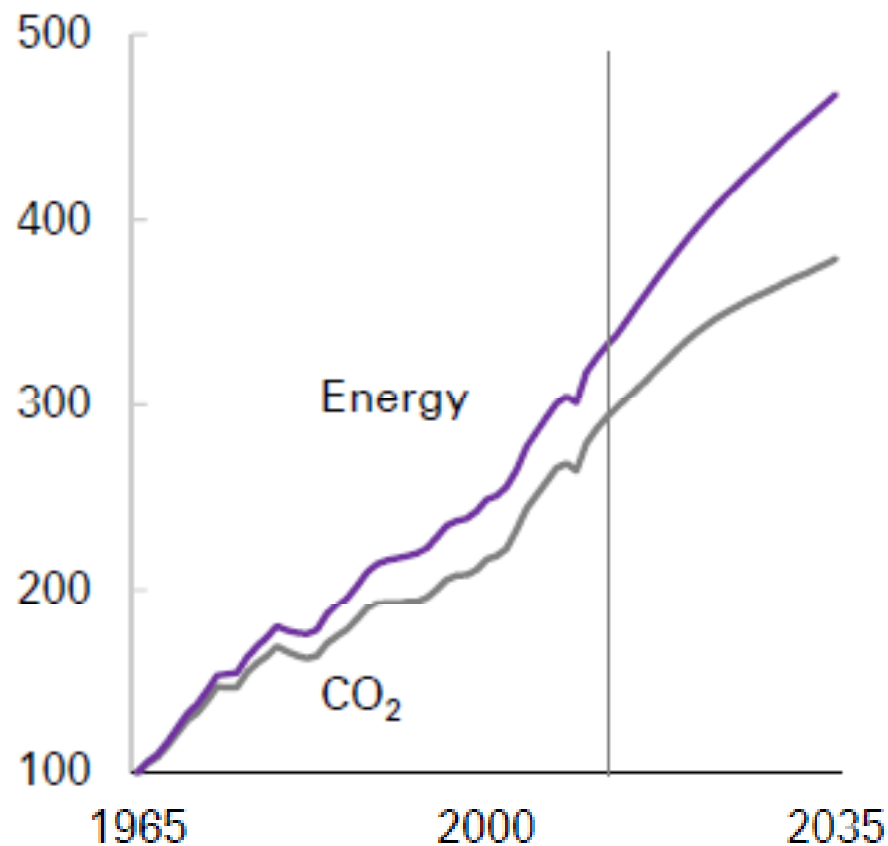
Kaynak:

BP Statical World Review of Energy, June 2006
Türkiye petrol ve doğalgaz rakamları 2003 verisidir.



Energy and CO₂ emissions

Index: 1965 = 100



With the fossil fuels continuing to have the greatest share in energy portfolio in the coming decades, **global warming and the associated challenges should be faced.**

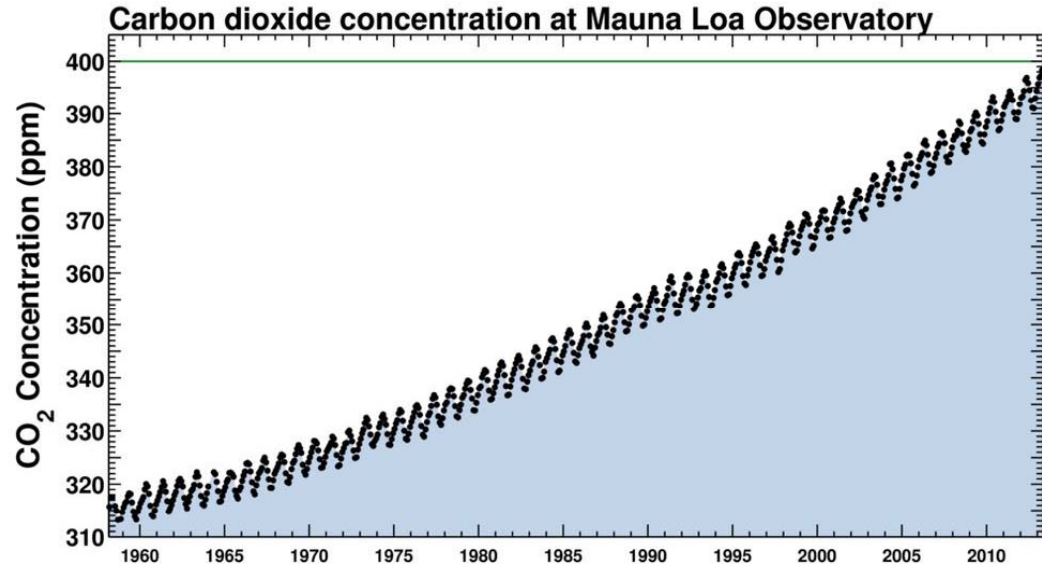
Mauna Loa Observatory in Hawaii



400 ppm is exceeded!

Global CO₂ emission values
forecasted for 2035 are
nearly double the 1990 level.

IEA's 450 Scenario: The goal is to limit the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO₂.



ENERGY OUTLOOK - Summary



- Not every country is equally lucky to have enough fossil fuel.
- Harsh and ruthless attack on oil and natural gas continues towards depletion of their reserves.
- Coal will continue to be one of the major primary source of energy; though its share will tend to decrease in favor of **renewables**.
- Avoidance of global warming requires to increase the share of **renewables** in energy generation.

STRATEGIC PLANNING FOR FUTURE

- 1) Rehabilitation and renovation of energy systems using fossil fuels and abatement of the damage to the environment.
 - Improvement of combustion and gasification systems
 - Reducing SO₂, NO_x, Hg and CO₂ emissions

- 2) Development and adaptation of renewable energy systems

- Hydroelectric
- Wind
- Solar
- Biomass

⇒ Suitable for distributed energy generation (DEG)

- 3) Energy storage

- Use of H₂ as energy carrier

⇒ Suitable for distributed energy generation (DEG)



Distributed Energy Supply on Demand and on Spot

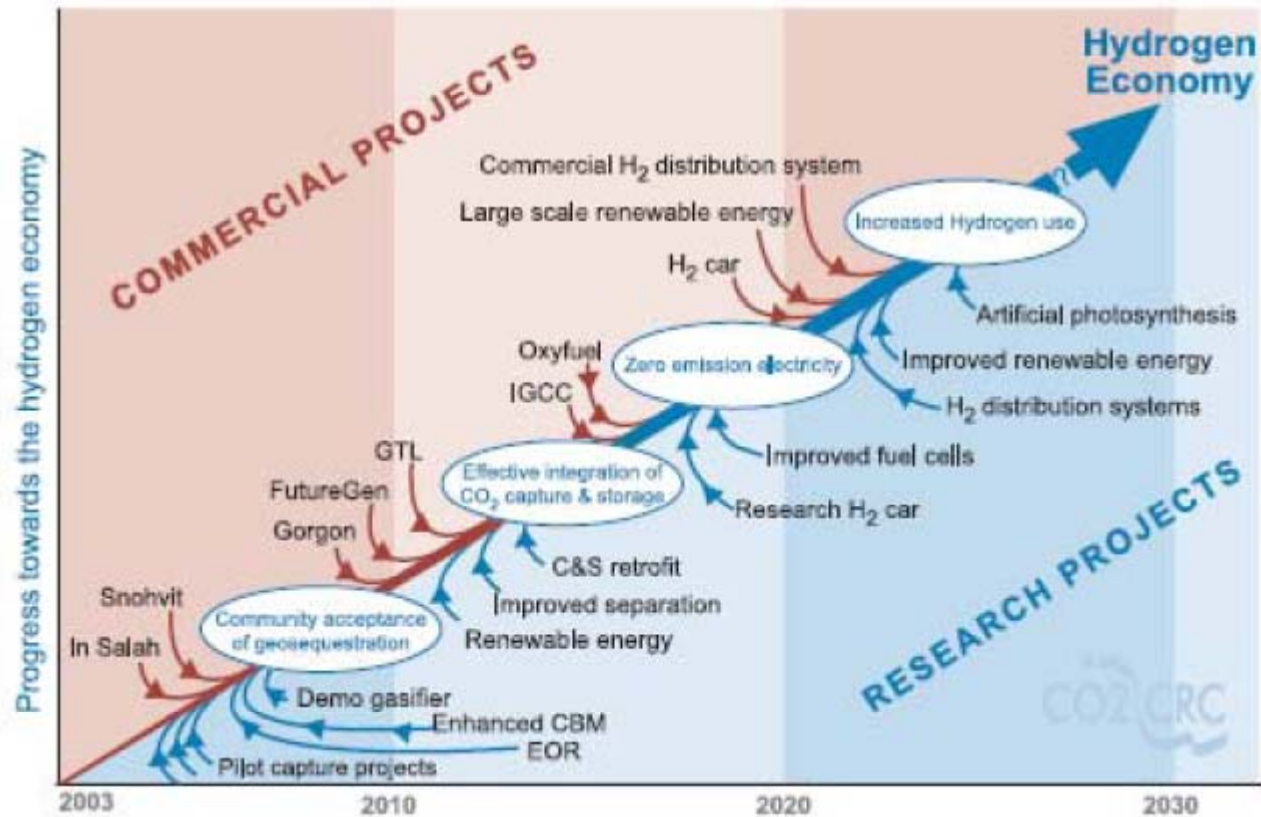
Distributed energy consists of a range of small-scale and modular devices designed to provide electricity, and sometimes also thermal energy, in locations close to consumers. They include renewable energy technologies (e.g., photovoltaic arrays, wind turbines, microturbines, reciprocating engines, fuel cells, combustion turbines, and steam turbines); energy storage devices (e.g., batteries and flywheels); and combined heat and power systems.



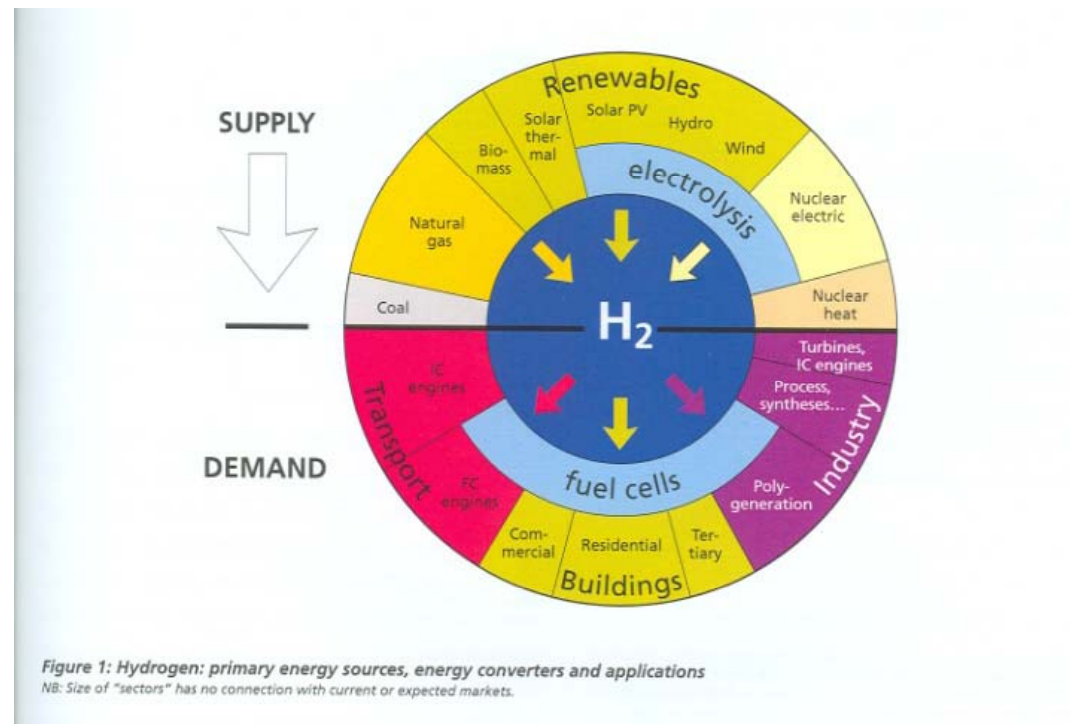
Hydrogen as Energy Carrier

ROAD MAP

Future of Energy Trends



Energy storage - Use of H₂ as energy carrier





HYDROGEN STORAGE

Physical Storage

- 1) Thick wall tanks (High pressure, very heavy, not very practical)
- 2) Metal hydride/carbon nanotubes/graphene canisters
(Adsorption capacity limitation, difficulties associated with P & T variations)

Difficulty involved led to **Hydrogen-on-demand** projects

3) Chemical storage



Sodium Borohydride (SBH) as Hydrogen Carrier

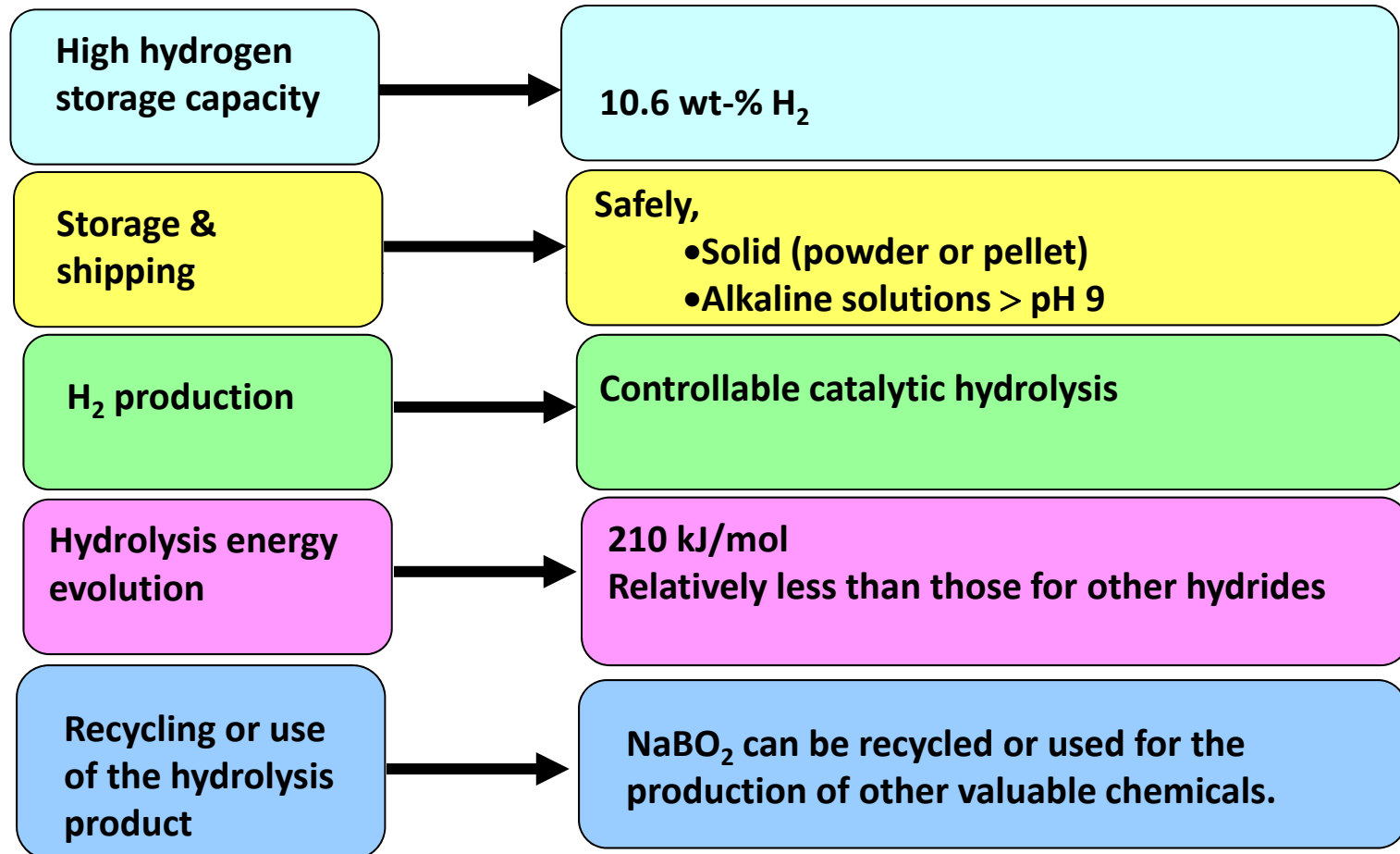
SBH can be used to produce

- i) electricity (DC) using “Direct Sodium Borohydride Fuel Cell”
- ii) **hydrogen** on demand. (Inception by Millenium Cell Inc.)

Hydrogen can then be used in

1. fuel cells to generate electricity (DC)
2. internal combustion engines for power
3. combined heat and power systems

Why NaBH₄ ?



BORON

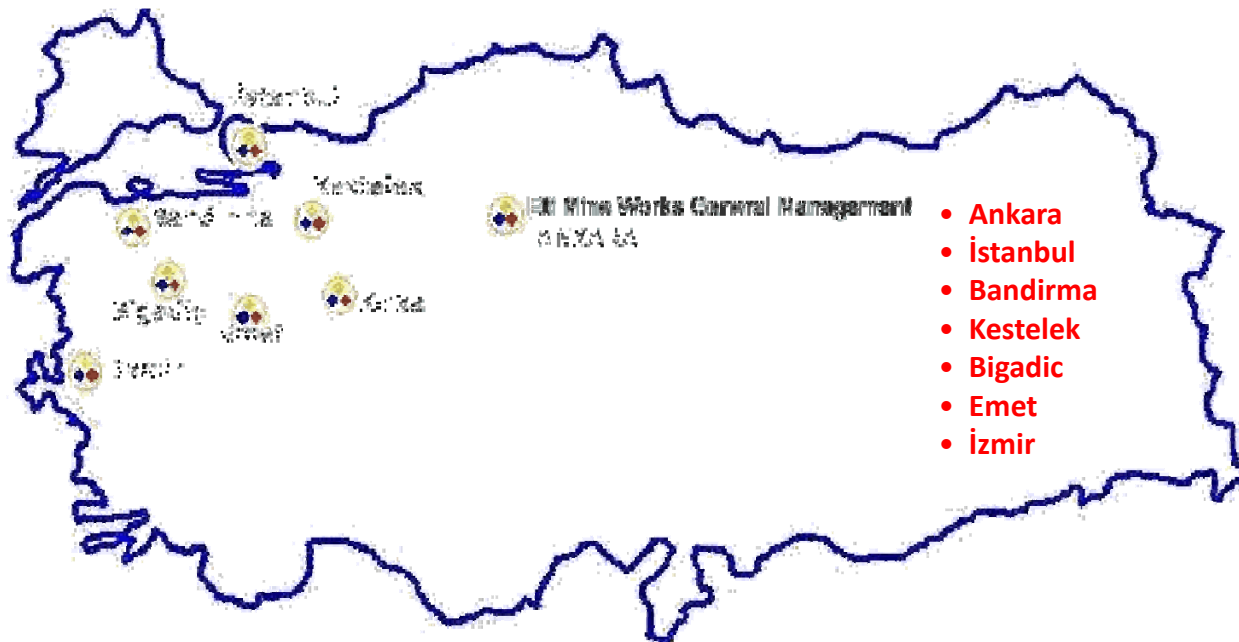
Türkiye has about 73% of world's reserves.

Tincal ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$)

Colemanite ($2\text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$)

Ulexite ($\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 16\text{H}_2\text{O}$)

► NaBH_4 can be produced using these raw materials.





Hydrogen can be generated by
hydrolysis of sodium borohydride.





SBH Production

Commonly used **INDUSTRIAL** sodium borohydride production processes;

1. Rohm&Haas Process,



2. Bayer Process,

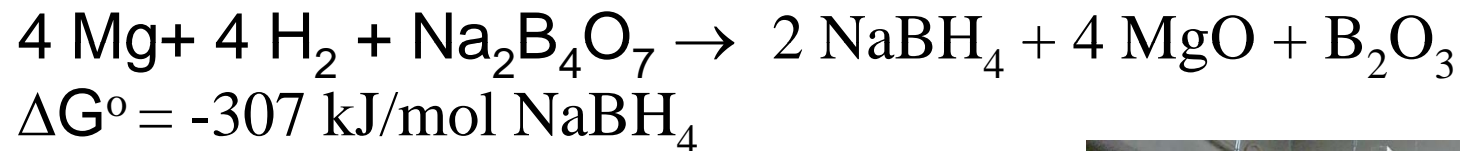




ALTERNATIVE METHODS FOR SBH PRODUCTION

PRODUCTION OF SODIUM BOROHYDRIDE BY HYDROGENATION OF ANHYDROUS BORAX AT HIGH TEMPERATURE AND PRESSURE IN THE PRESENCE OF MAGNESIUM

OUR RELATED WORK



The highest yield was obtained **as 93 %** in the experiment performed at a reactor temperature of **550°C**, reaction time of 4 hours, the hydrogen gas given to the reactor at **25 bar** and 400°C and using a stoichiometric mixture of anhydrous borax with 200 % excess amount Mg.

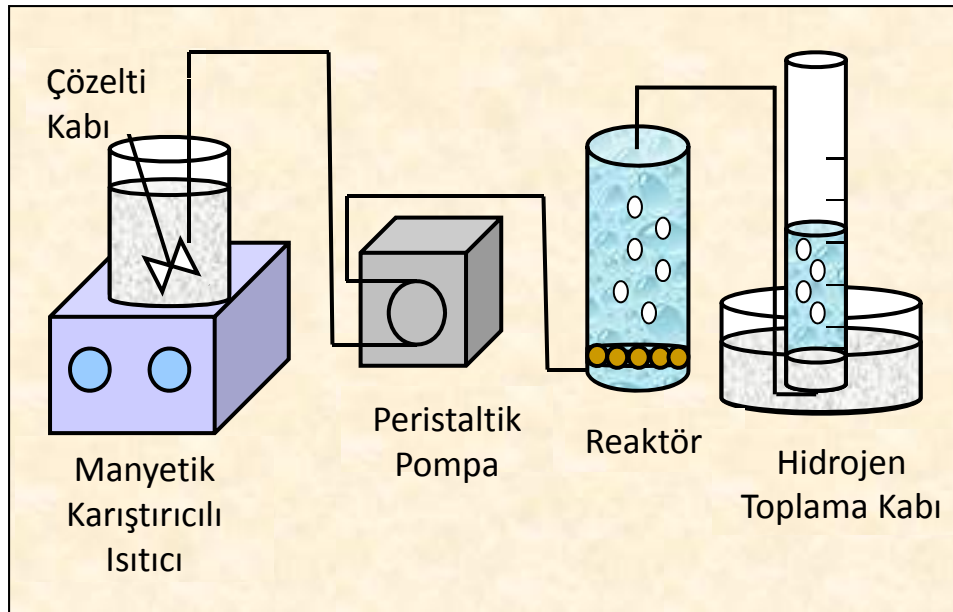


Hydrogen production from Sodium Borohydride



Sodium borohydride should be kept in alkaline medium (e.g. NaOH solution) in order to be stable for a long time.

OUR RELATED WORK



EFFECTS OF

- CATALYST, (Pt, Ru, Rd)
- NaOH CONCENTRATION,
- TEMPERATURE,

Pt- %0,5

T=20 °C

NaOH : 10 wt-%

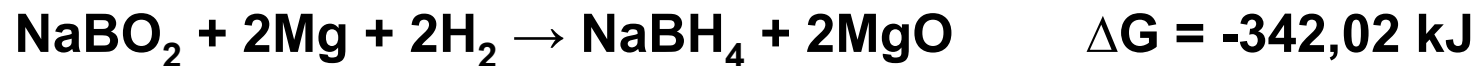
Efficiency ≈ 64-85%

Recycling SMB to SBH

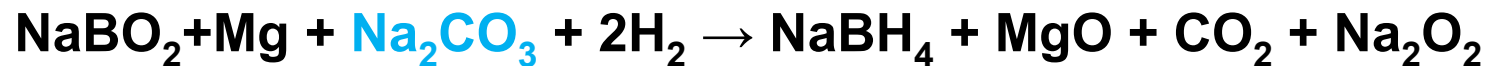
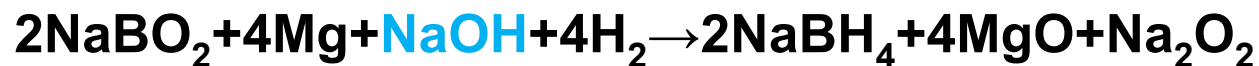


RECOVERY OF SODIUM BOROHYDRIDE FROM SODIUM METABORATE at HIGH TEMPERATURE AND HIGH HYDROGEN PRESSURE

OUR RELATED WORK

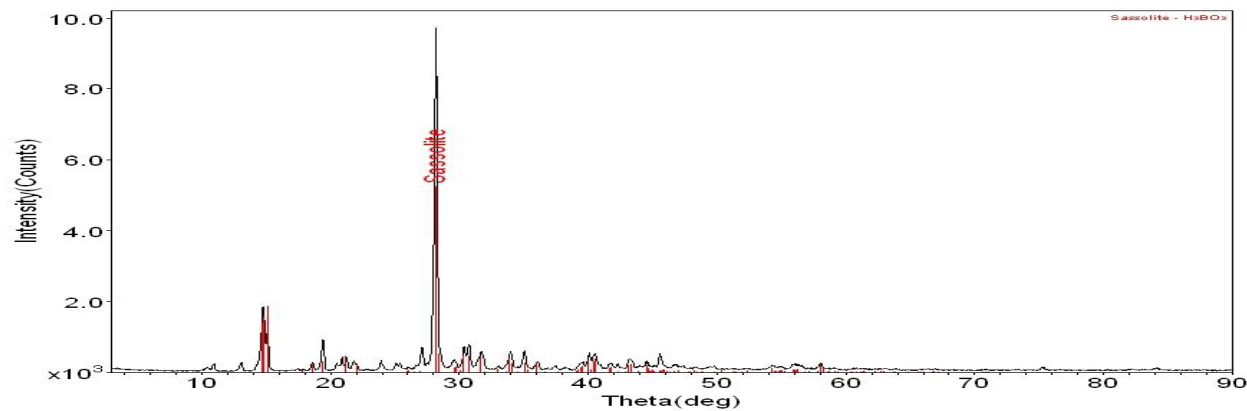


Effect of additional Na sources:



At 650°C, 28 atm hydrogen pressure and with hydrogen fed to the reactor at 400°C, 43,1 % product yield was achieved by using a stoichiometric mixture of NaBO₂ and Mg, 34 % yield was achieved by using 100 % excess Mg, 46 % yield was achieved by using 100 % excess Mg and carbon coated platinum and **53,3 % yield of sodium borohydride was achieved by using 200 % excess Mg and 100 % excess NaOH.**

Recycling Sodium Metaborate Via Boric Acid



XRD analysis of the solid product

Purity achieved : 100%



CONCLUSIONS

Sodium borohydride is a suitable chemical for **hydrogen on demand** and thus for **distributed energy generation on demand and on spot.**

Though, efforts should continue to lower its cost.



SOLAR-HYDROGEN-ELECTRICITY ENERGY CYCLE

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SOME OF OUR RELATED WORK



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INTERUNIVERSITY SOLAR CAR COMPETITION – Gazi University's team

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THANK YOU

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