Liquid Organic Hydrogen Carrier Technology:

from energy storage to fuel cell applications

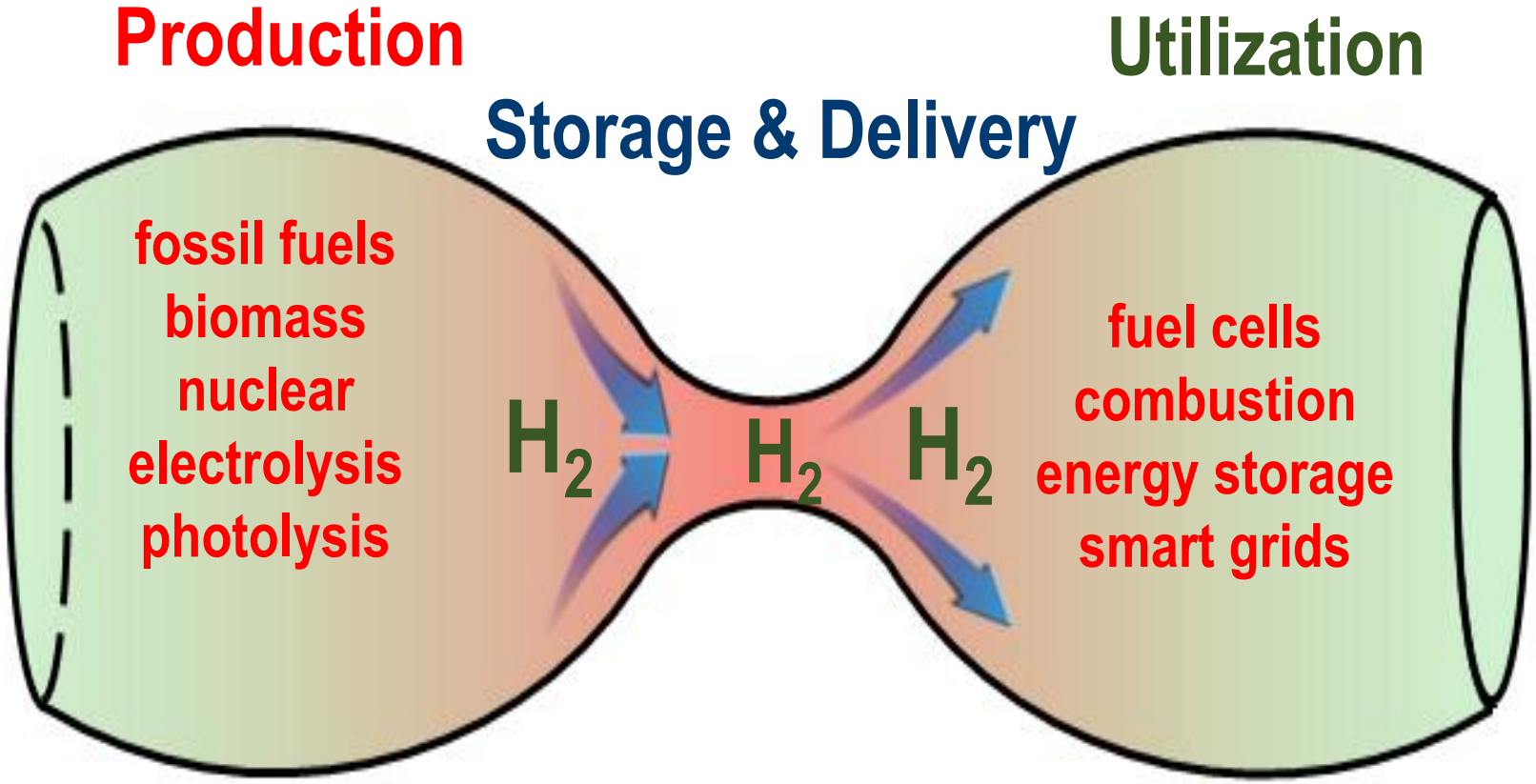
Outline

- Liquid organic hydrogen carrier (LOHC) technology
- Applications
- Outlook

Grand Challenges for Hydrogen Economy

- Do we have a sufficient amount of hydrogen to support commercial scale applications?
- Are the current PEM fuel cells good enough?
- Can we store and deliver hydrogen at ambient conditions with high capacity?
- What infrastructure is needed?

Hydrogen Technologies



LOHC in China

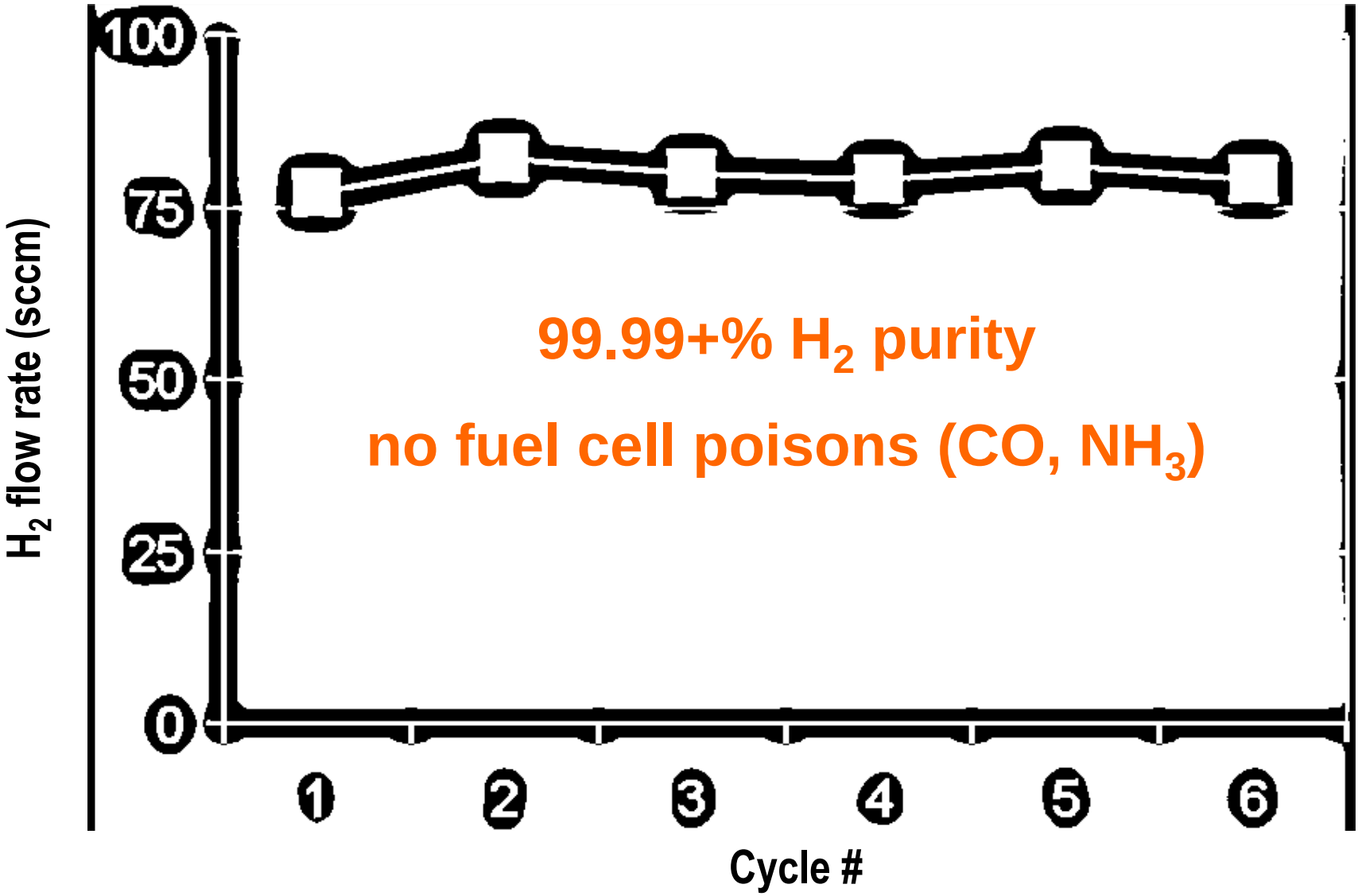
LOHC

$+ H_2$ catalyst ⟷

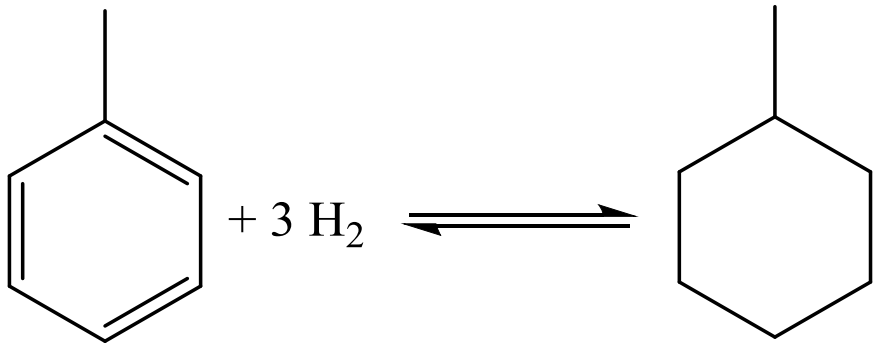
hydrogen oil

- Low melting point (> -20°C)
- High boiling point (> 300°C)
- Chemically stable
- Highly reversible
- High storage capacity

High Reversibility



LOHC: Toluene (Chiyoda Corporation)



enthalpy of reaction：

-16.3 kcal/mol.H_2

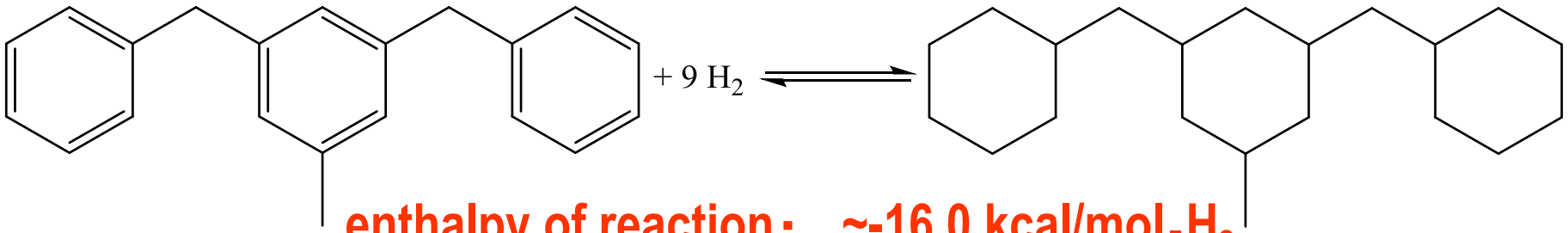
Pros:

- facile to hydrogenate
- easy to obtain
- convenient for delivery

Cons:

- difficult to release H_2 (>400°C)
- heavy use of precious metals as catalyst
- slow kinetics
- severe side reactions
- poor gas purity

LOHC: Dibenzyltoluene (Hydrogenious)



enthalpy of reaction： ~-16.0 kcal/mol.H_2

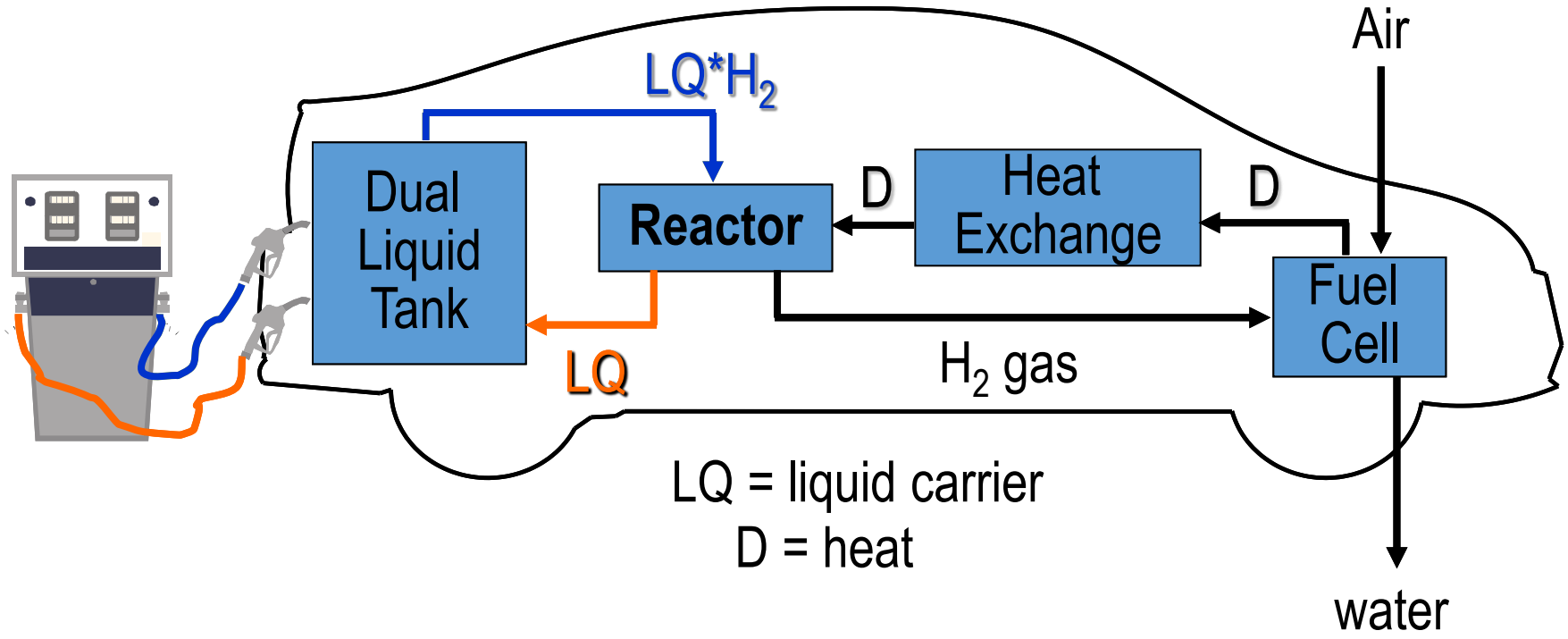
Pros:

- facile to hydrogenate
- wide temperature range in liquid
- convenient for delivery
- easy to obtain

Cons:

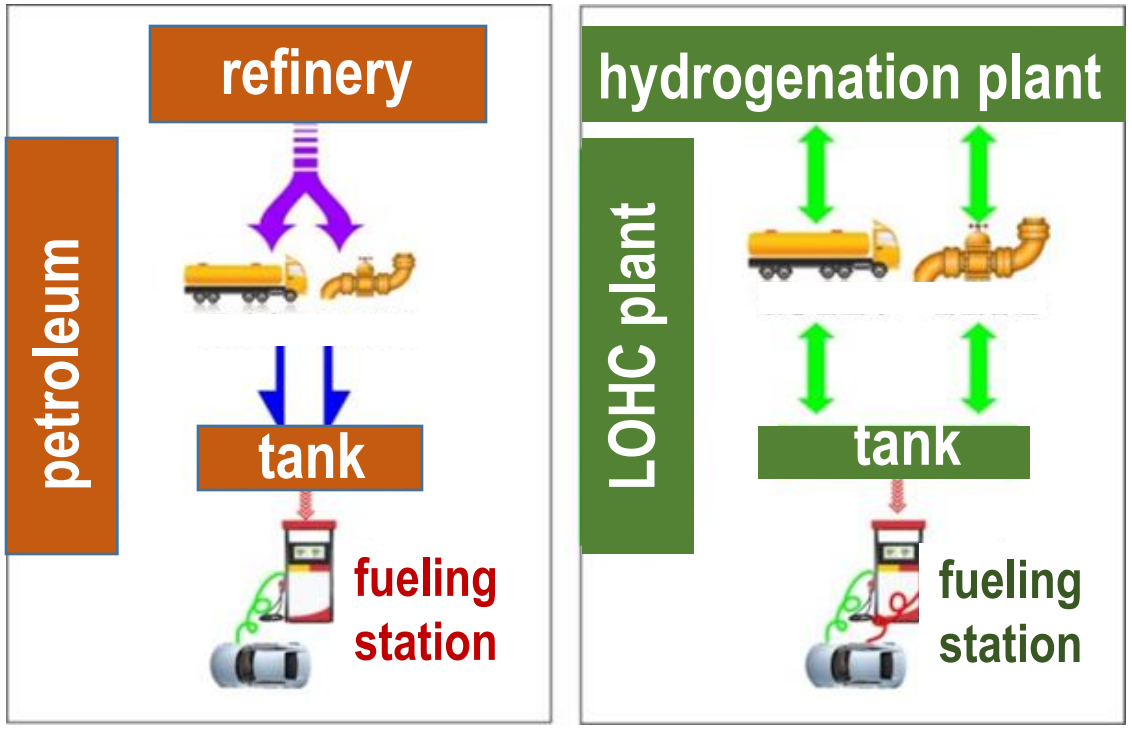
- relatively difficult to dehydrogenate (280-320°C)
- heavy use of platinum
- slow kinetics (0.7L H_2/kW)
- disproportionational reactions
- relatively poor gas purity

Onboard LOHC & Fuel Cell Integration



Hynertech LOHC:	~55-60 g/L
Liquefied (-253 °C):	70 g/L
Compressed (70 MPa):	39 g/L

Advantages LOHC Technology



- Compatible with the existing infrastructure
- Low cost
- Excellent safety
- Suitable for long time storage and long distance delivery

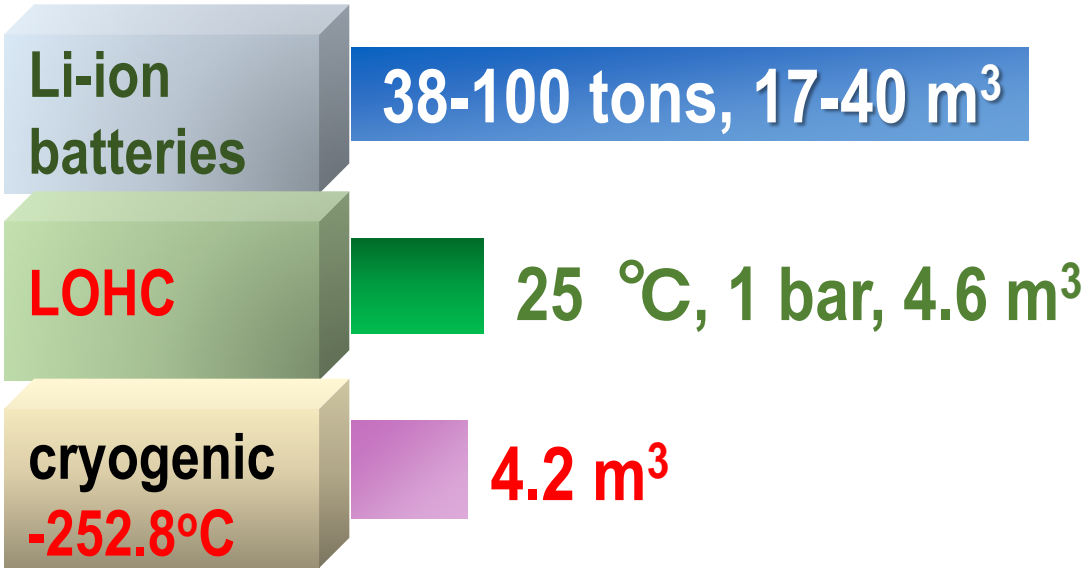
Estimated Cost of Fueling Station

Country	cost	number of gas station	number of fueling station	number of fueling station in need
US	$1.5 - $2 MM	114,000	<100	72,960
Japan	~$3-5 MM	40,357	93	25,828
Germany	~$3 MM	14,300	15	9,152
China	~$1.2 MM	97,000	<15	62,080

It is extremely challenging to meet the infrastructural need for technologies based on compressed gas!

Energy Storage for 10 MWh: Comparison

LOHC technologies are well suited for large scale energy storage !



Hydrogen Storage

Storage at ambient conditions

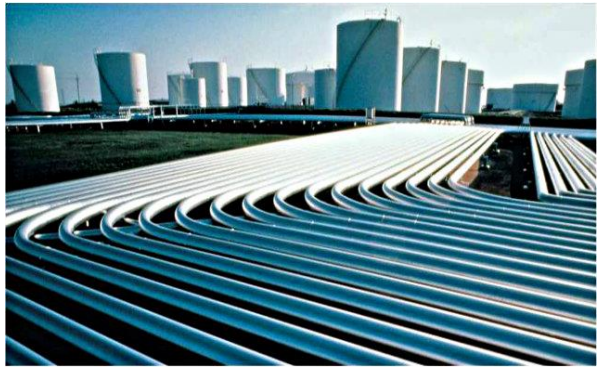
Hydrogen Delivery

Usable hydrogen： 1.7 MT

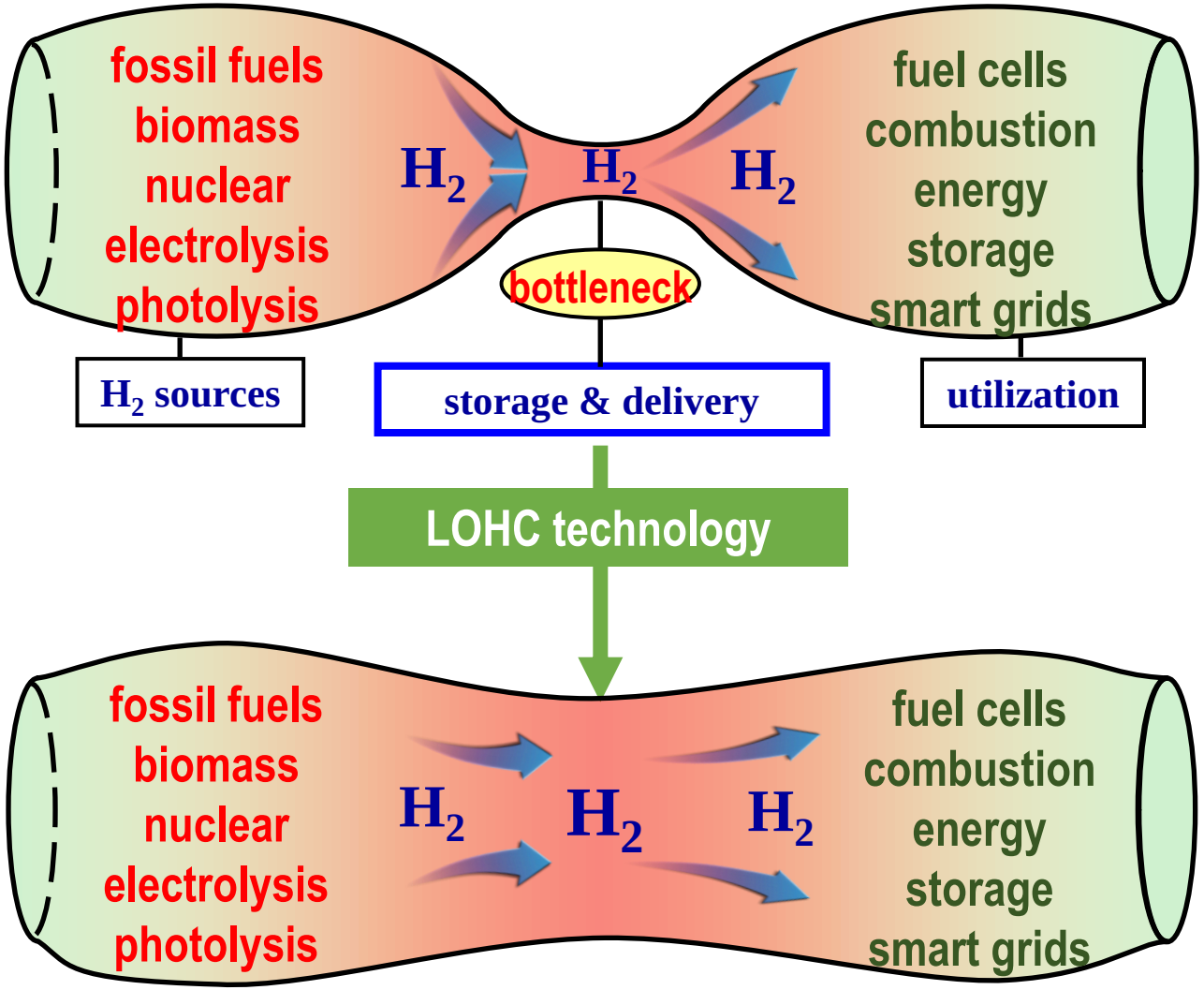
30T tanker truck

> 4 ×

trailer (11 tubes) at 20 MPa



Grand Challenge of Hydrogen Economy



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- **Applications**
- Outlook

Demo Project: Energy Storage

- Electrolysis using hydroelectric power
- Hydrogen storage with LOHC to produce “hydrogen oil”
- Providing a hydrogen supply system for a 30 kW fuel cell for EV
- Providing a hydrogen supply system for a 50 kW internal combustion system for co-gen of heat & electricity
- Completion date: November 30, 2017
- Scale-up to MW-GW level of energy storage

Hydrogen Fueling Station

600 kg of usable H_2 in a 10m^3 tank

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Current Status of LOHC Technology

pros

- safe
- low cost
- efficient
- scalable
- ready to implement

cons

- need heat to release H_2
- currently only usable for large mobile devices, e.g. buses or trucks