# Ammonia as a Key to Meeting the Fuel Demand of China

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on behalf of

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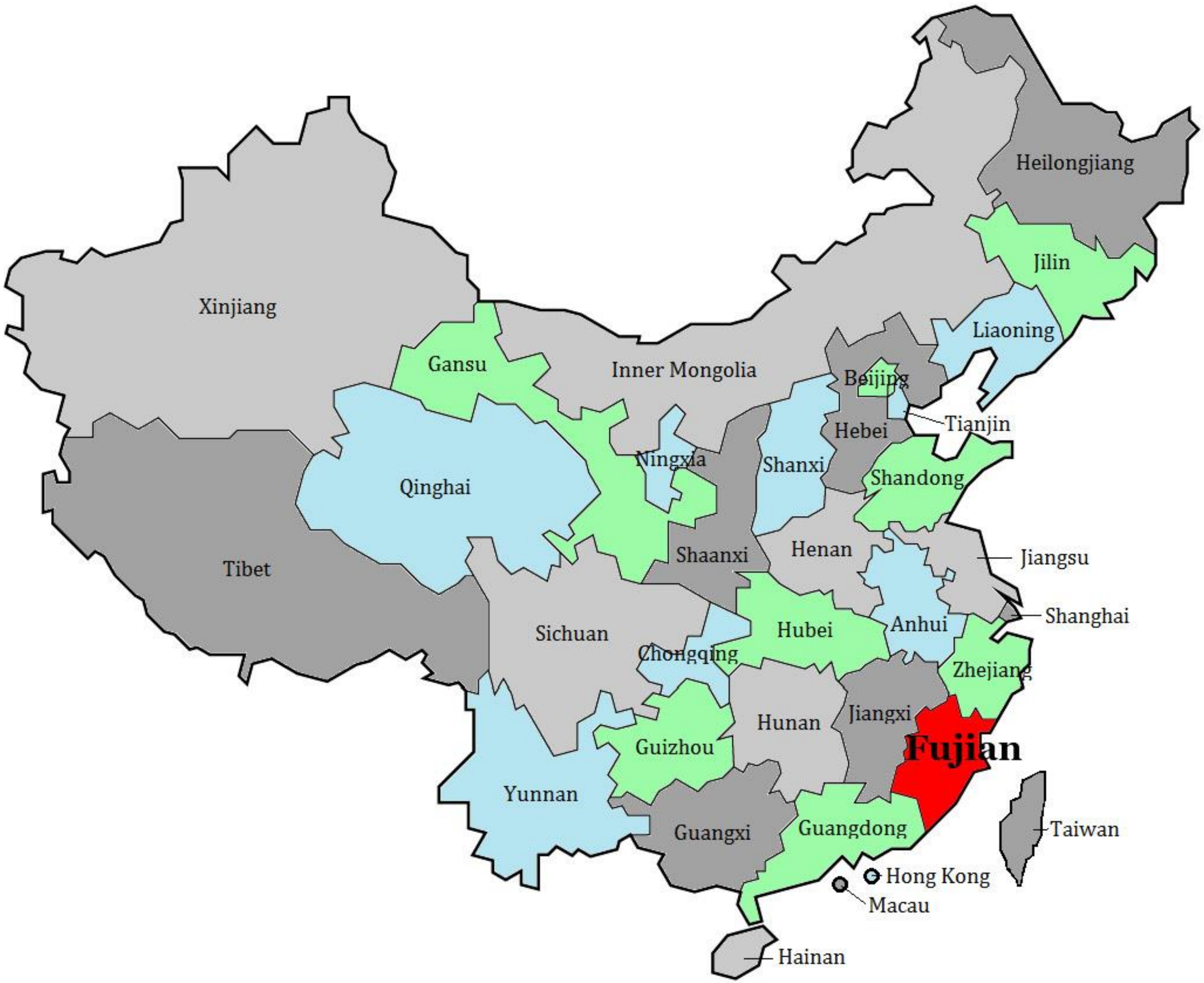
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# Outline

1. Fuel consumption and issues in China

2. Endeavours of Chinese government

3. Unique advantages of using $NH_3$ as a fuel in China

4. Roadmap of using ammonia as a fuel planned by Xiamen University for Fujian province, China.

5. Ammonia fuel research group of Xiamen University

6. Closing remarks

# 1. Fuel demand and issues in China

## 1.1 Sale statistics of vehicles

**2015 sale:**

China: 20 million (*limited* by lottery policy for environment )

vs. US: 17.5 million (*encouraged* for economy growth)

**2010-2022 sale increase:**

China: 15$^+$% per year

vs. US: 0% until 2022

## 1.2 Ownership statistics of vehicles

**2015 ownership:**

Family based:

China: 34 vehicles/100 families (30% families own 1, and 70% own 0)

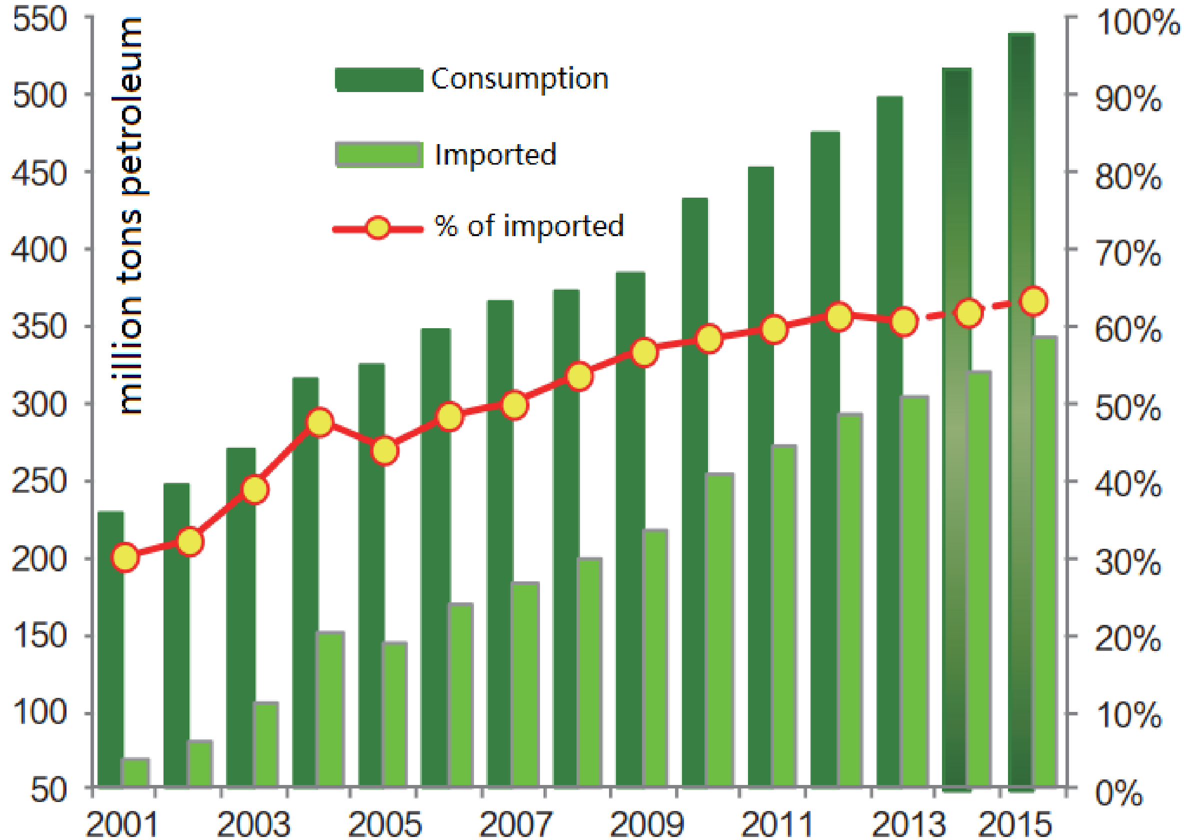
vs.US: 110 vehicles/100 families (34% own 1, 37% own 2, 20% own 3, and 9% own 0 )

Passenger cars per capita:

China: 0.05 (1 per 20 persons), half of world average.

vs.US: 0.5 (1 per 2 persons)

# 1.3 Petroleum consumption statistics in China




Redrawn from International Petroleum Economics,pp 44-53, Vol. 24, 2016, in Chinese

All imported petrol goes to cars;

However, the upper limit of ownership is 150 million cars if using fossil fuels in China!

## 1.4 Related issues

Photochemical smog: $CO_2$ is not the only issue in China.

# 1.5 Formation and constituents of photochemical smog

Fine particles + Ground Level Ozone


NOx + VOC 

Surplus $O_2$ + Hi T (>1200$^{o}$C)

NOx : Nitrogen Oxides, e.g., NO, $NO_2$

VOC: Volatile Organic Compounds (VOC), e.g., emitted hydrocarbons.

**If carbon is present, then particulates are always present too.**

# 2. Endeavours of Chinese Government

**Electricity-based high speed train:**
energy efficient; decentralized emissions are centralized and hence significantly reduced.

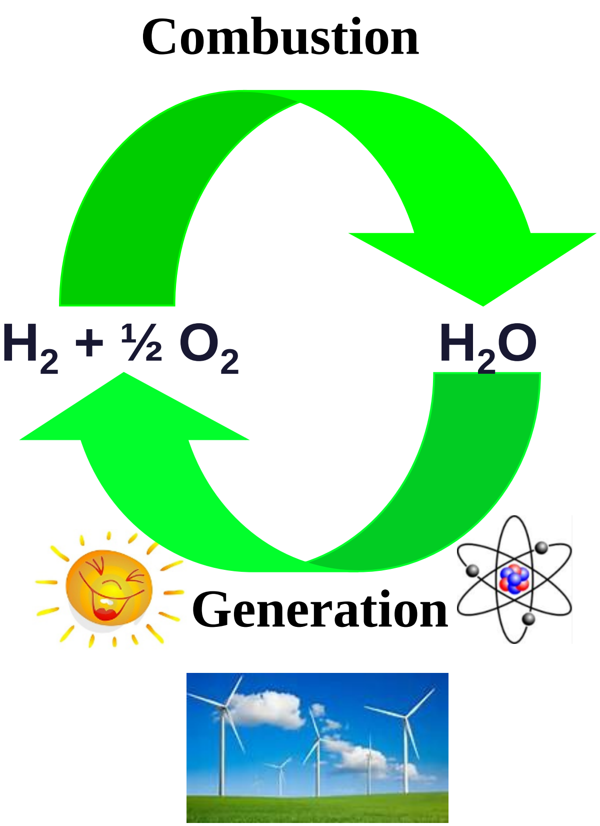
**Electric car:**
A govermental promotion focus in the 13th 5-year plan (2013-2017).

However, clean battery production is a bottleneck in addition to the unsatisfactory pricing and performance.

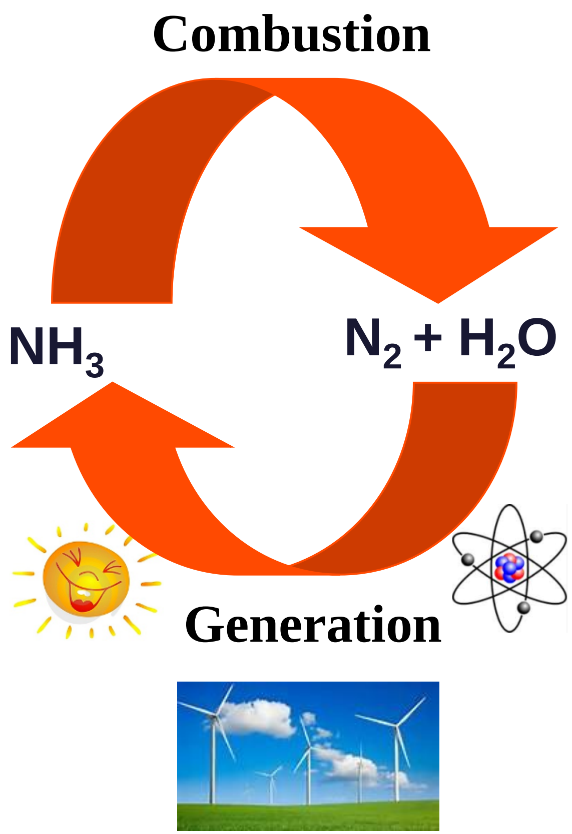
So what and how ?

# 3. Unique advantages of using $NH_3$ as a fuel in China

## 3.1 Clean nature of $NH_3$



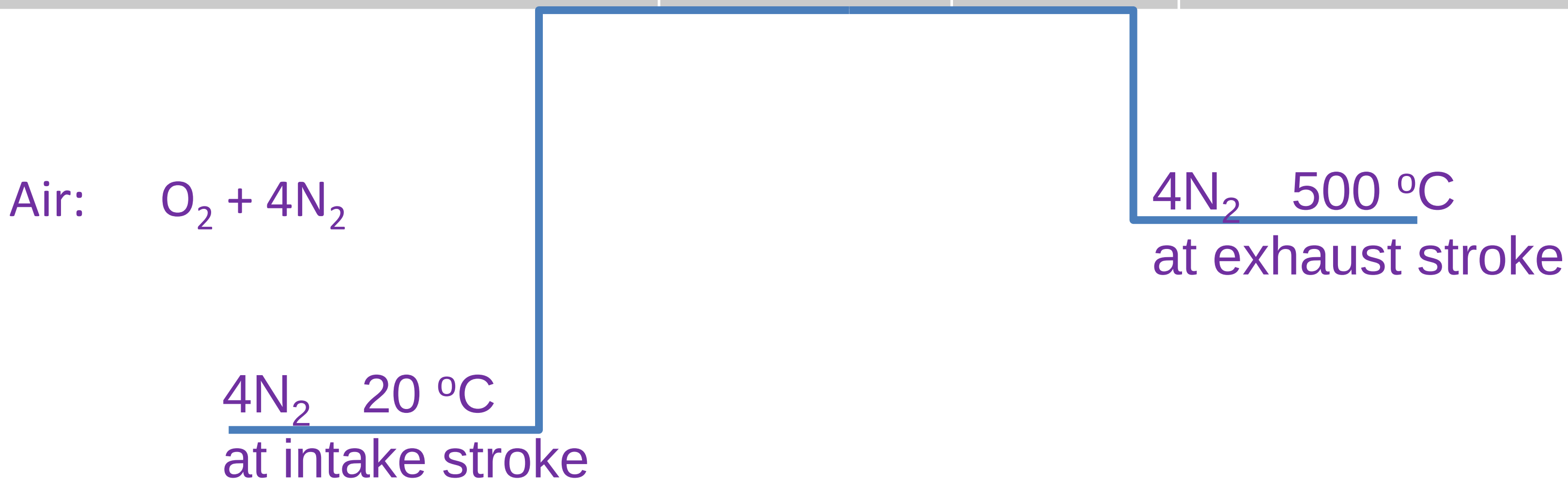

$H_2$: More challenges than $NH_3$.




**$NH_3$: the other and better hydrogen.**

A unique advantage of $NH_3$ on air-fuel ratio

| Fuel | Molecular mass | HHV MJ/kg | Air Fuel ratio (AF) Φ =1, mass |
|---|---|---|---|
| Gasoline, $C_8H_{15}$ | 111 | 47.30 | 14.6 |
| Ammonia, $NH_3$ | 17 | 22.50 | 6.1 |
| Hydrogen, $H_2$ | 2 | 141.90 | 34.0 |




-- AF for ammonia is only 40% of gasoline, thus approximately 40% less nitrogen is heated and goes to exhaust gases.

-- Energy gain from combustion: 1 kg $NH_3$ ≈ 0.8 kg gasoline.

# 3.2 Production scale and infrastructure

**2014 anhydrous $NH_3$ production:**

China: 48 million tons (58 in 2015)
US: 9.2 million tons
World: 144 million tons

**-- China is producing 33% of the world ammonia (vs. US 6.4%);**

**-- Infrastructure for fertilizer is existing.**

# 3.3 Energy economics

**Price:**

Anhydrous $NH_3$ 2015 average: CN￥2,100/ton ≈ US$315/ton)

Gasoline 2015 average: CN￥8,000/ton ≈ US $1200/ton)

Energy gain from combustion: 1 kg $NH_3$ ≈ 0.8 kg gasoline

The cost of $NH_3$ as a fuel is only 1/3 of gasoline in China!

**Potential of future lower pricing:**

Off-peak and intermittent power account for 1/3 of the total generation, which can be stored and managed with $NH_3$ conversion.

## 3.4 Equivalent market scale

2015 gasoline consumption in China: 110 million tons

2015 $NH_3$ production in China: 58 million tons

Current production of $NH_3$ can equivalently juice 50% of existing cars!

# 4. Roadmap of using ammonia as a fuel planned by Xiamen University for Fujian Province

## 4.1 Dual fuel of “ammonia + natural gas”

Justifications:

1. “Gasoline + Natural gas” dual fueled taxis are widely used in China.
2. Ignition timing, electronic control and fuel injection are similar for natural gas and ammonia.
3. Overcome the slow flame speed issue of ammonia.
4. Increase the acceleration of natural gas fueled taxis.

Taxi: “Gasoline + Natural gas”

Timeline:
A demo (passenger car) is ready in 2 years at Xiamen University.

# 4.2: Dual fuel of "ammonia + methanol"

Justifications:

1. Methanol fueled taxis are being used in China;
2. Similar air/fuel ratio: air intake control is simplified;
3. Similar HHV: thermal design is simplified;
4. Miscible: single phase processing and direct injection;
5. Cogeneration from coal.


Methanol fueled taxis

Timeline:
Demo ready in 4 years at Xiamen University.

| Fuel | Molecular mass | HHV MJ/kg | Air Fuel ratio (AF) Φ =1, mass |
|---|---|---|---|
| Gasoline, $C_8H_{15}$ | 111 | 47.30 | 14.6 |
| Light diesel, $C_{12.3}H_{22.2}$ | 170 | 44.80 | 14.5 |
| Heavy diesel, $C_{14.6}H_{24.8}$ | 200 | 43.80 | 14.5 |
| IsoOctane, $C_8H_{18}$ | 114 | 47.80 | 15.1 |
| Ethanol, $C_2H_5OH$ | 46 | 29.70 | 9.0 |
| Methanol, $CH_3OH$ | 32 | 22.70 | 6.5 |
| Ammonia, $NH_3$ | 17 | 22.50 | 6.1 |
| Hydrogen, $H_2$ | 2 | 141.90 | 34.0 |
| Propane, $C_3H_8$ | 44 | 49.90 | 15.7 |
| Heptane, $C_7H_{16}$ | 100 | 48.07 | 15.2 |
| Cetane, $C_{16}H_{34}$ | 226 | 47.28 | 15.0 |
| Coal, C | 12 | 33.8 | 11.5 |
| Toluen, $C_7H_8$ | 92 | 42.5 | 13.5 |

| Fuel | Formula | Miscibility with $NH_3$ |
| --- | --- | --- |
| *Hydrocarbons* | $CH_3CH_2CH_3$ | Insoluble |
| | $CH_3(CH_2)_4CH_3$ | Insoluble |
| | $C_6H_6$ | Moderately soluble |
| | $C_6H_5CH{=}CH_2$ | Soluble |
| *Substituted hydrocarbons* | $CHBr_3$ | Miscible |
| | $C_2H_5I$ | Soluble |
| | $BrCH_2CH_2Br$ | Soluble |
| | $Cl_2C{=}CH_2$ | Miscible |
| | $CH_3NO_2$ | Miscible |
| | $C_6H_5NO_2$ | Solubility, 24% |
| *Carbonyl derivatives* | $(CH_3)_2CO$ | Miscible |
| | $CH_3CHO$ | Miscible |
| | $CH_3(CH_2)_3CHO$ | Easily soluble |
| | $CH_3CO{-}NH_2$ | Very easily soluble |
| | $CH_3CS{-}NH_2$ | Easily soluble |
| | $(H_2N)_2CS$ | Solubility, 37% |
| | $CH_3CH_2CO_2CH_3$ | Miscible |
| | $C_6H_5CH_2CO_2CH_3$ | Miscible |
| *Alcohols* | $CH_3OH$ | Miscible |
| | $CH_3(CH_2)_6OH$ | Miscible |
| | $C_6H_5CH_2OH$ | Miscible |
| | $1,2{-}C_6H_4(OH)_2$ | Very easily soluble |
| *Amines* | $CH_3NH_2$ | Miscible |
| | $(CH_3)_3N$ | Miscible |
| | $CH_3(CH_2)_4NH_2$ | Miscible |
| | $C_6H_5N$ | Miscible |
| *Ethers* | $(C_2H_5)_2O$ | Miscible |
| | $[CH_3(CH_2)_3]_2O$ | Soluble |
| | $C_6H_5OCH_3$ | Miscible |

# 5. Ammonia research group of Xiamen University

| Research topic | Assistant/associate/full Professors and engineers |
|---|---|
| Combustion kinetics and engine prototype | Zhaolin Wang |
| Engine efficiency and energy optimization | Yingru Zhao |
| Reduction of emissions (NOx, SOx, etc) | Shuirong Li |
| Combustion thermodynamics and fluid mechanics | Yaoli Zhang |
| Electronic control (fuel injection, ignition timing, etc) | Duo Wang |
| Fuel properties | Yueyuan Ye |
| Ammonia as A/C refrigerant an fuel line arrangement | Shan Xie |
| High performance materials | Yannan Xie |
| Solar to $NH_3$ fuel | Songsheng Zheng |
| Nuclear to $NH_3$ fuel | Guang Ran |
| $H_2$, $CH_3OH$ and $NH_3$ fueling station and infrastructure | Yunquan Liu |
| $NH_3$ fuel economics and commercialization pathway | Guangxiao Huang |
| Innovation assessment and intellectual property | Binbin Zhang |

# 6. Closing remarks

1. China is probably the most prospective candidate that utilizes ammonia as a clean fuel;

2. China is joining the ammonia fuel club;

3. Welcome to share the ammonia opportunities of China and be ambitious to initiate a fuel revolution.