conceptual power-added ammonia-fueled internal combustion engines

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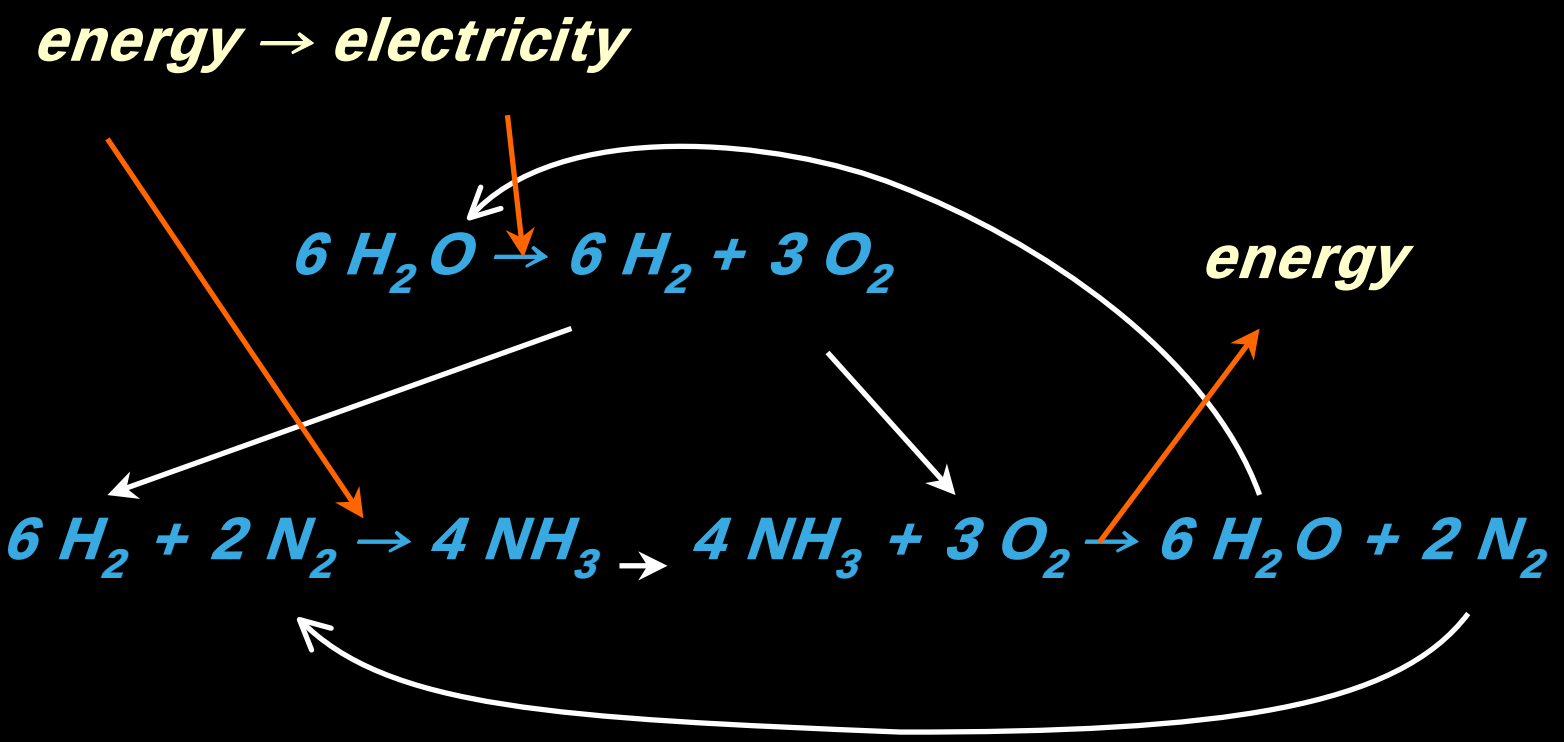
ammonia fuel

ammonia, NH_3, as energy carrier

- energy content: 5.17 MWh/t or 0.444 toe/t
- liquid density: 600kg/m^3 @300K
- liquid/vapor boundary: 239K/1bar, 294K/9bar
- critical point: 405K/112 bar
- current way of synthesis: H.B. process

ammonia fuel life cycle



why ammonia

ammonia—the one and only liquid fuel satisfies all the following:

- ***carbon free***
- ***completely renewable***
- ***reasonablely high energy density***
- ***life cycle inherently pollution free***
- ***practical to handle, store and transport***

ammonia as combustion fuel

comparing to hydrocarbon fuels:

- ***low heating value***
- ***low flame speed***
- ***narrow flammable range***
- ***high octane number***

ammonia-fueled internal combustion engine

goal: higher fuel/cost efficiency

↑ fuel efficiency ⇦ ↑ thermal efficiency ⇨ ? side-effects:

- ↑ compression ratio ⇨ engine cost ↑ weight ↑
- flame-speed enhancer ⇨ engine cost ↑ weight ↑
- turbocharger ⇨ engine cost ↑ weight ↑
- multi-spark-plug ignition ⇨ engine cost ↹ weight ↹
- electronic valve control ⇨ engine cost ↓ weight ↓
- ↑ power-stroke/cycle ⇨ engine cost ↓ weight ↓
- ↓ or ✂ cooling system ⇨ engine cost ↓ weight ↓

ammonia-fueled internal combustion engine (I.C.E.)

↑ power-stroke/cycle + ✂ cooling system ?

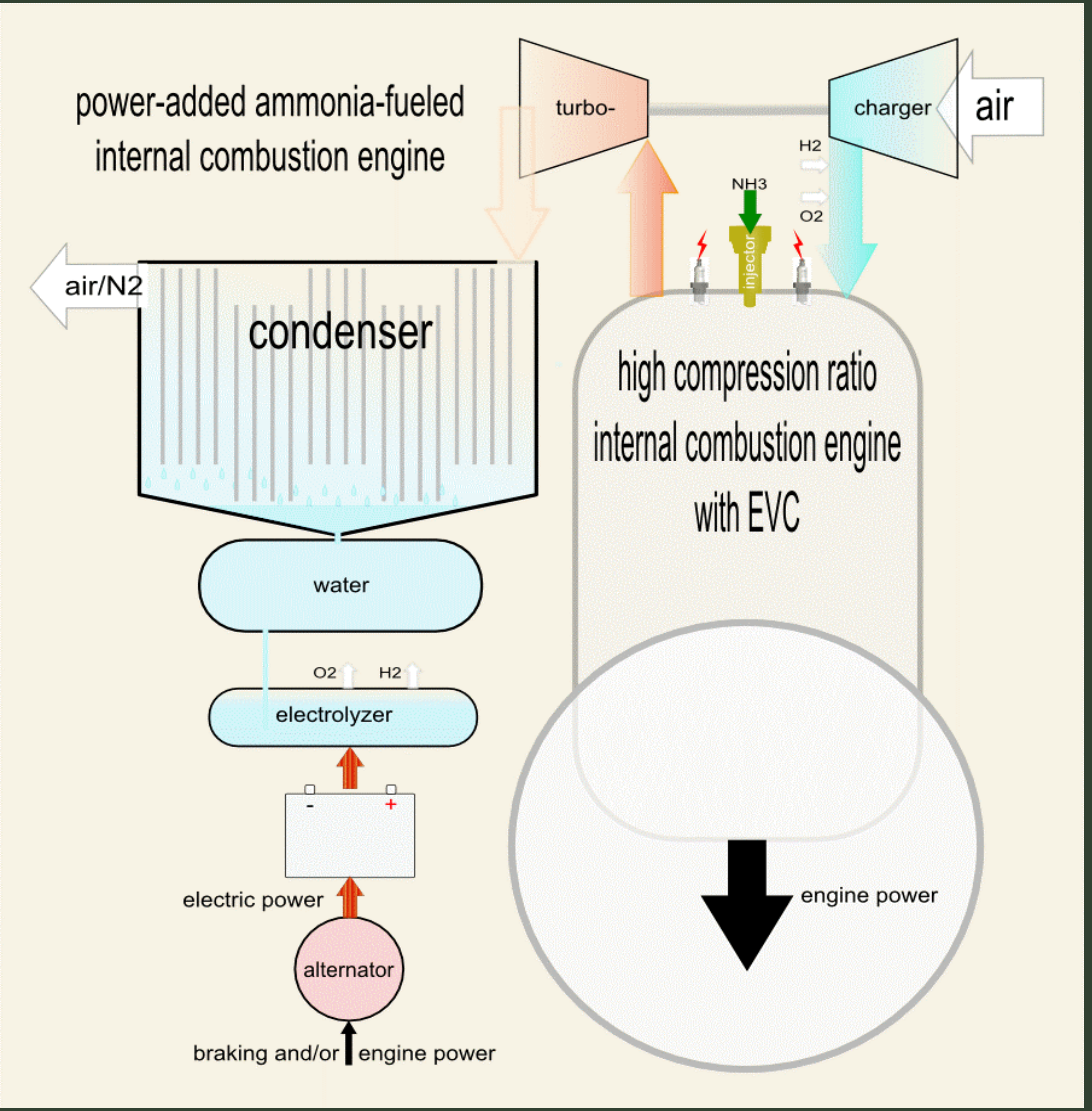
2nd 👓 at ammonia:

- ↓ flammability ⇨ ↓ auto-ignite
- ↗ latent heat of vaporization ⇨ ↗ cooling effect
- ↗ vapor pressure ⇨ ↗ driving power
- combustion exhaust ⇨ $H_2O + N_2$

power-added ammonia-fueled I.C.E.

scenario 1: *double-punch*—vapor+combustion power

- ✓ high compression ratio
- ✓ turbocharger
- ✓ multi-spark ignition
- ✓ electronic valve control (EVC)
- ✓ combustion enhancer (H_2, O_2)
  - ⇦ onboard electrolysis
  - ⇦ braking power generation
  - ⇦ onboard water production
- ✦ direct liquid ammonia injection
  - ⇨ produce vapor power
  - ⇨ cool engine within

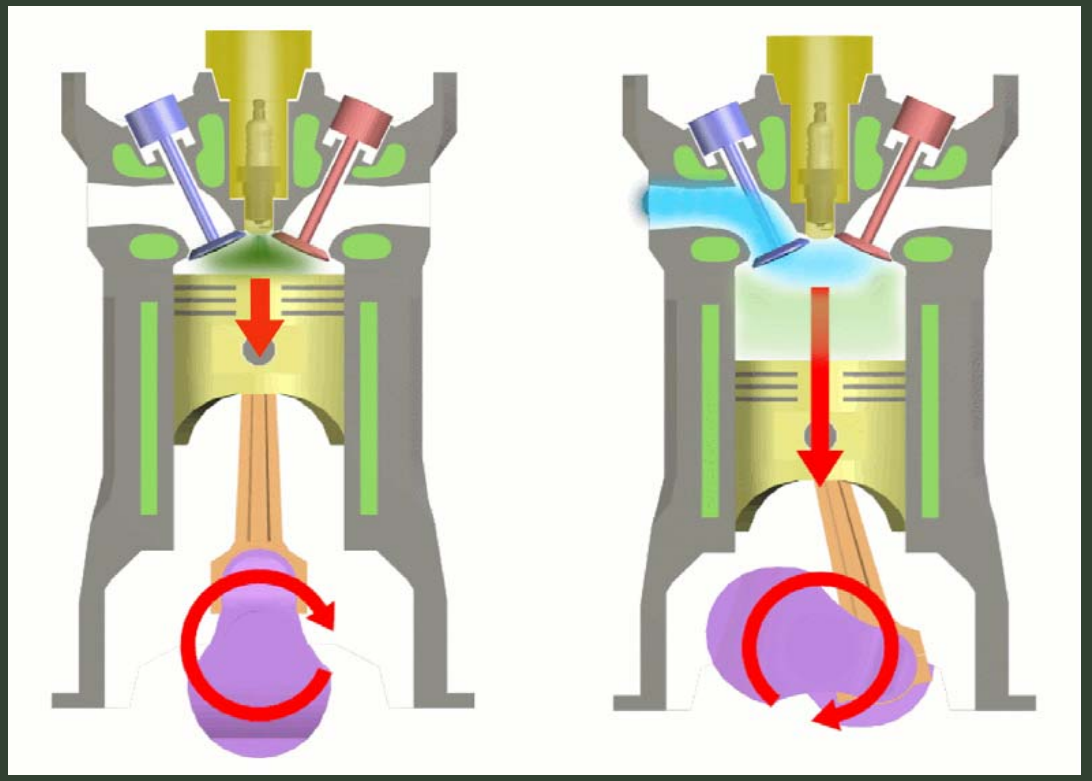


power-added ammonia-fueled I.C.E.

scenario 1: *double-punch*—vapor+combustion power

2-stage intake stroke:

- ⇨ liquid ammonia injection right after exhaust valve is closed and piston is at top while intake valve remains closed, vaporization of ammonia absorbs engine heat while producing vapor pressure up to 112 bar
- ⇨ intake valve opens only after vapor pressure drops below that of turbocharged air mixture

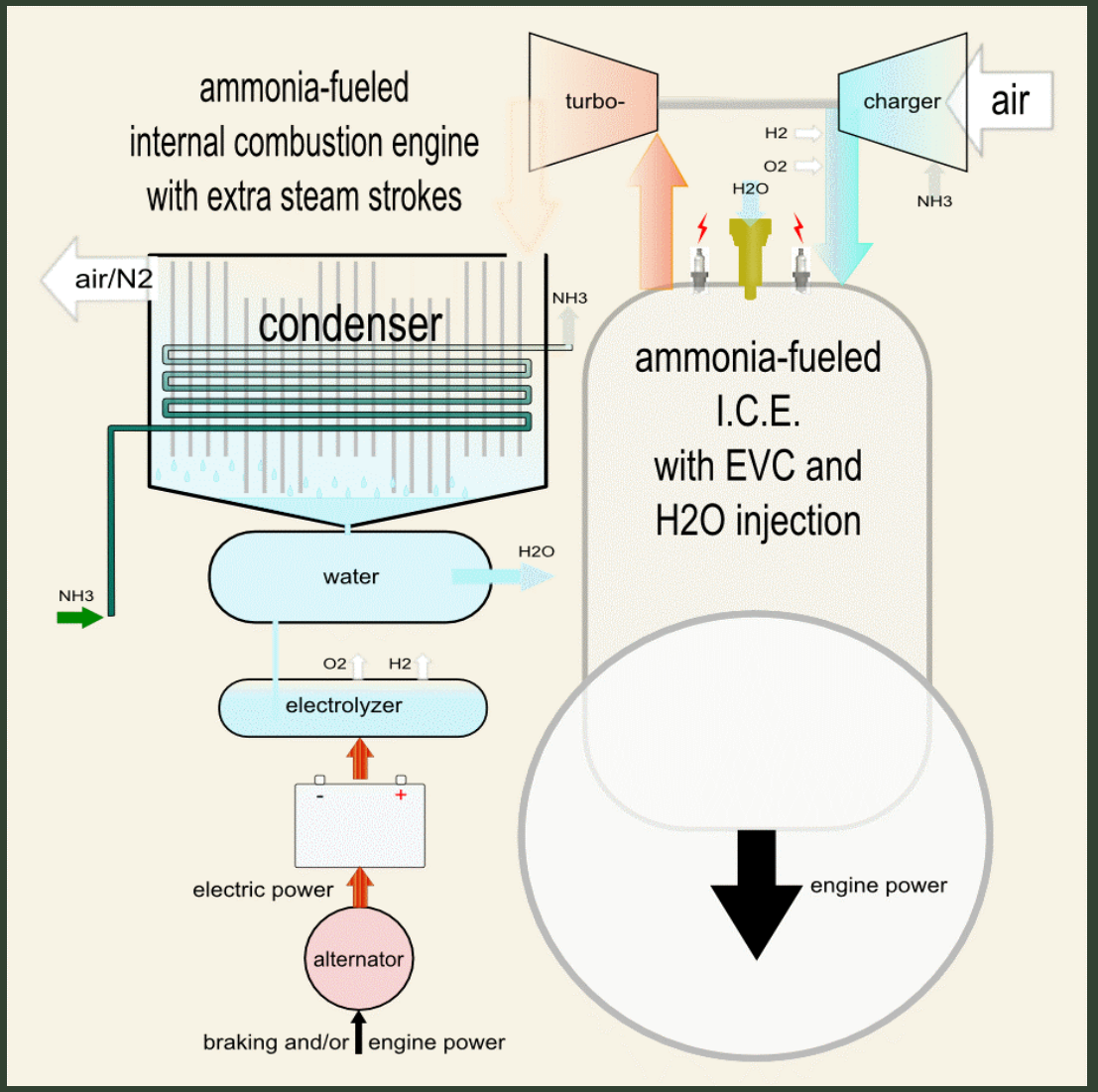


limitation: metered fuel injection may yield too little steam-power/cooling

power-added ammonia-fueled I.C.E.

scenario 2: *steam recycle*—steam + combustion power

- ✓ high compression ratio
- ✓ turbocharger
- ✓ multi-spark ignition
- ✓ electronic valve control (EVC)
- ✓ combustion enhancer (H_2, O_2)
  - ⇦ onboard electrolysis
  - ⇦ braking power generation
  - ⇦ onboard water production
- ✦ ammonia vaporization cooling enhanced condenser
- ✦ extra *on-demand* H_2O steam strokes (*not* a fixed 6-stroke cycle engine!)

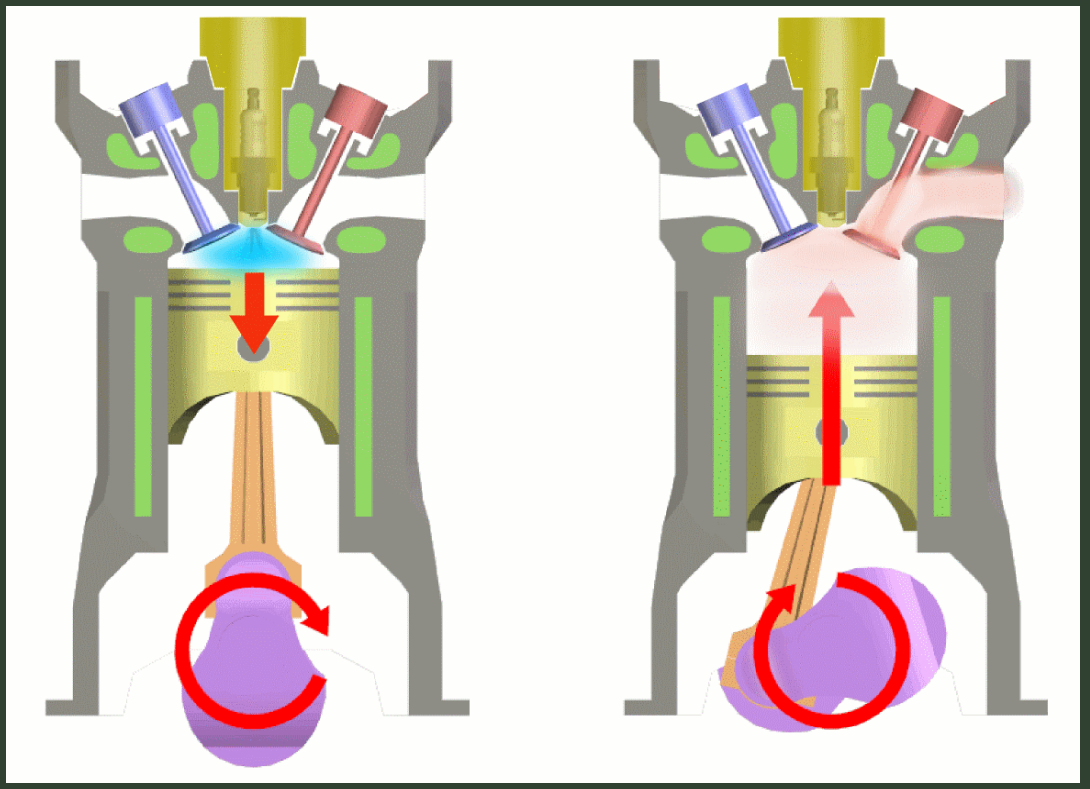


power-added ammonia-fueled I.C.E.

scenario 2: *steam recycle*—steam + combustion power

2-steam-stroke inserted in between the normal 4-stroke cycle *on-demand*:

- ⇨ steam power/cooling stroke: H_2O injection right after exhaust valve is closed and piston is at top while intake valve remains closed, vaporization of H_2O absorbs engine heat while producing vapor pressure up to 220 bar
- ⇨ steam exhaust stroke: exhaust valve opens to let out water vapor



- ✦ recycle unlimited:
  - ✓ so long as enough steam is condensed back to water and engine is hot

intelligent power-added ammonia-fueled I.C.E.

cheap, flexible electronics vs. expensive, rigid mechanics

maximize fuel/cost efficiency ⇦ more sophisticated and flexible system of electronic sensor/control

- valve control
- timing control
- alternator control
- electrolysis control
- fuel metering control
- steam strokes control, etc.