Safe and compact ammonia storage/delivery systems for SCR-DeNO$_X$ in automotive units

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Catalytic NO_X reduction

- Selective Catalytic Removal of NO_X:

$$4NO + 4NH_3 + O_2 \rightarrow 6N_2 + 6H_2O$$

- Needed for **diesel** and **lean-burn** engines (~~3-way catalyst~~)
- Main problem: Safe and compact
  NH_3-storage on-board for dynamic dosing into tail pipe.

Urea solves the safety issue…

but is not a simple
plug'n'play technology

Challenges of using urea

- Freezing
- Moderate storage capacity
- Complex system
- Droplet conversion and mixing in exhaust line
- Hydrolysis catalyst (?)
- No dosing at idle
- Solid deposits
  - undesired products of decomposition
  - droplet impaction
- Enforcing / OBD

Components in the urea system

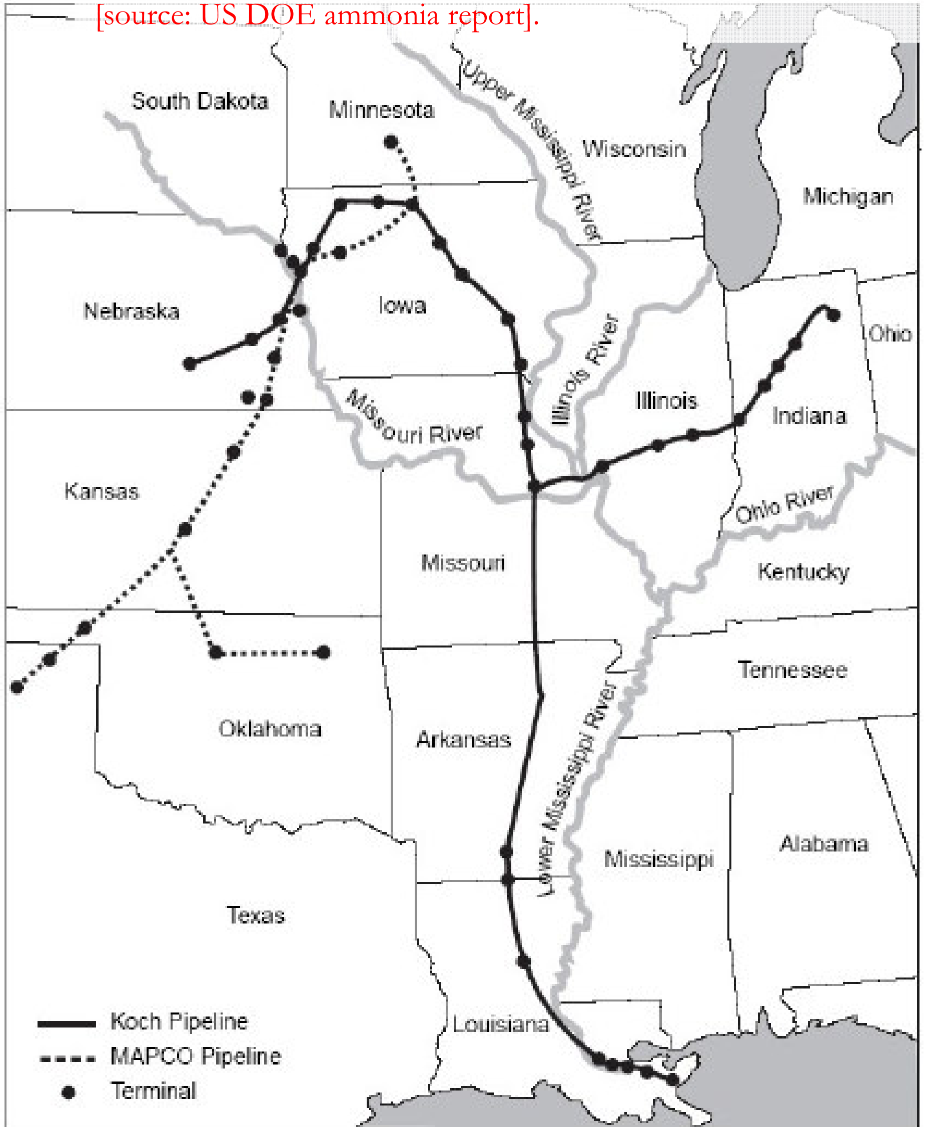
- Tank (incl. heater)
- Temperature sensor
- Level sensor
- Urea quality sensor
- Compressed air (some are airless)
- Heated urea transport flow tubes
- Supply module with filter
- Pump
- Supply line purging
- Spray nozzle
- Internal mixers in exhaust line

A couple of important questions:

- Is urea the only SCR enabler?
- Do OEMs have to wait for an AdBlue infrastructure?

Ammonia is there!

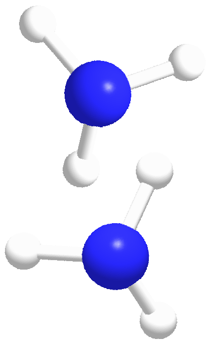
[source: US DOE ammonia report].

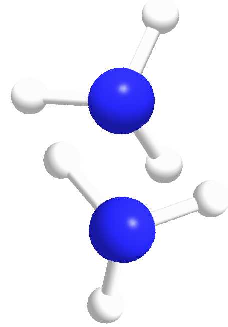


Dense and safe ammonia storage:

Controlled release from metal ammine complexes

The ammonia content	
$Mg(NH_3)_6Cl_2$:	38.1 mol NH_3/l
Liquid ammonia:	40.1 mol NH_3/l

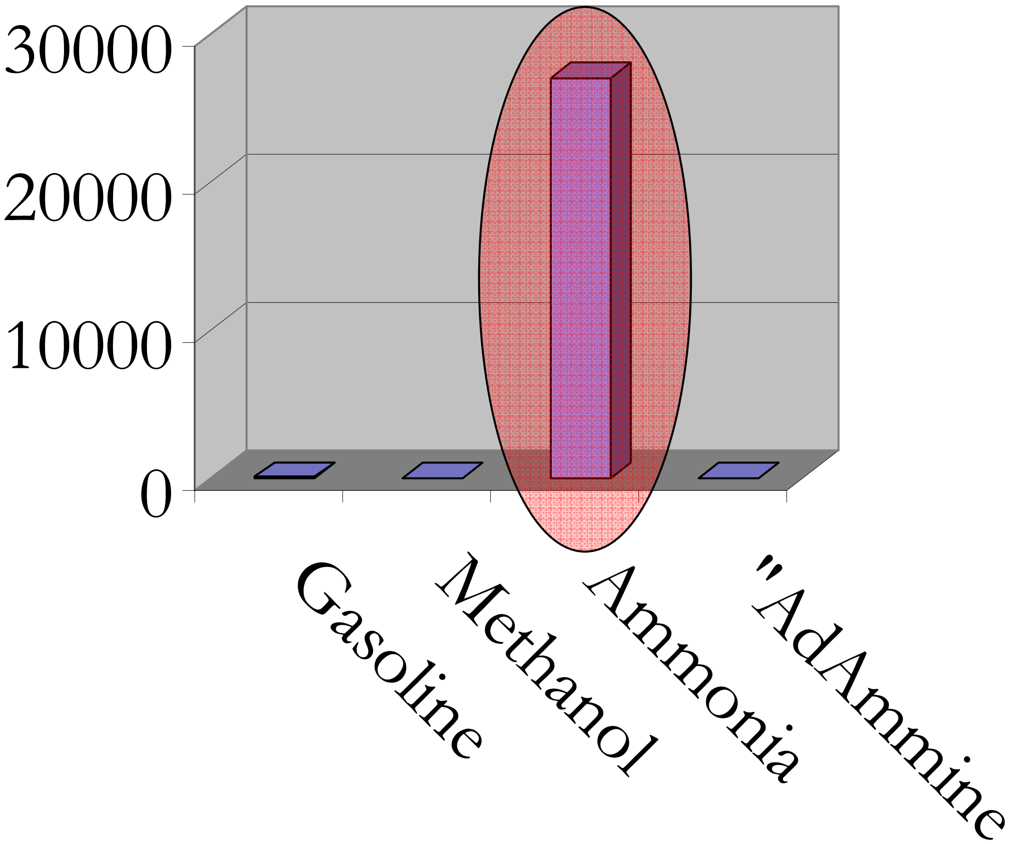




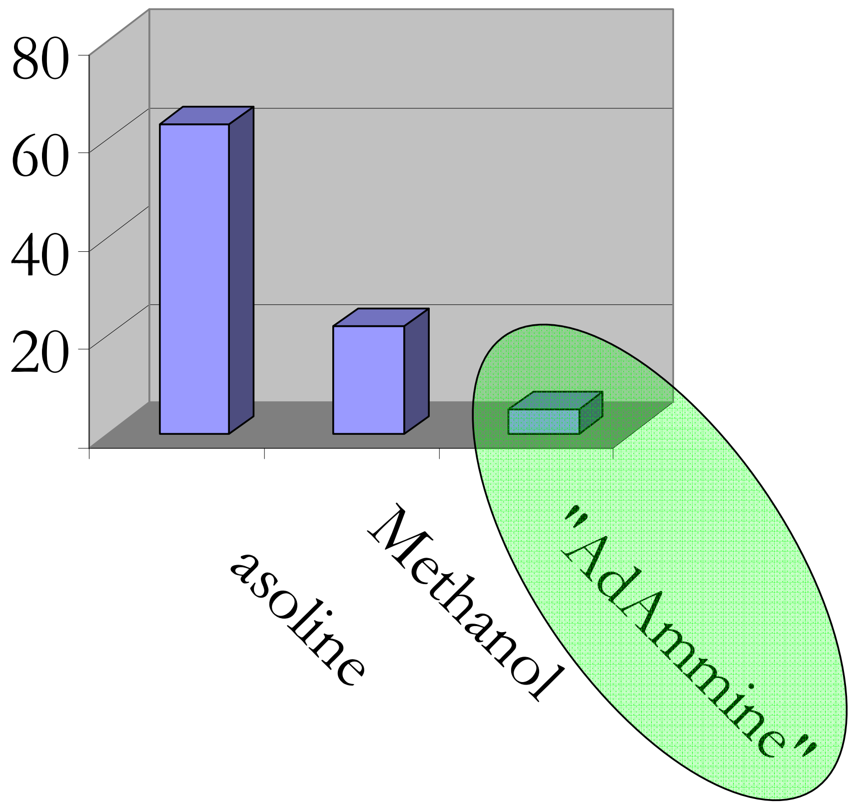
Reversible ammonia storage:

$$MgCl_2 + 6NH_3 \rightleftharpoons Mg(NH_3)_6Cl_2$$

Volatility-to-toxicity ratio*

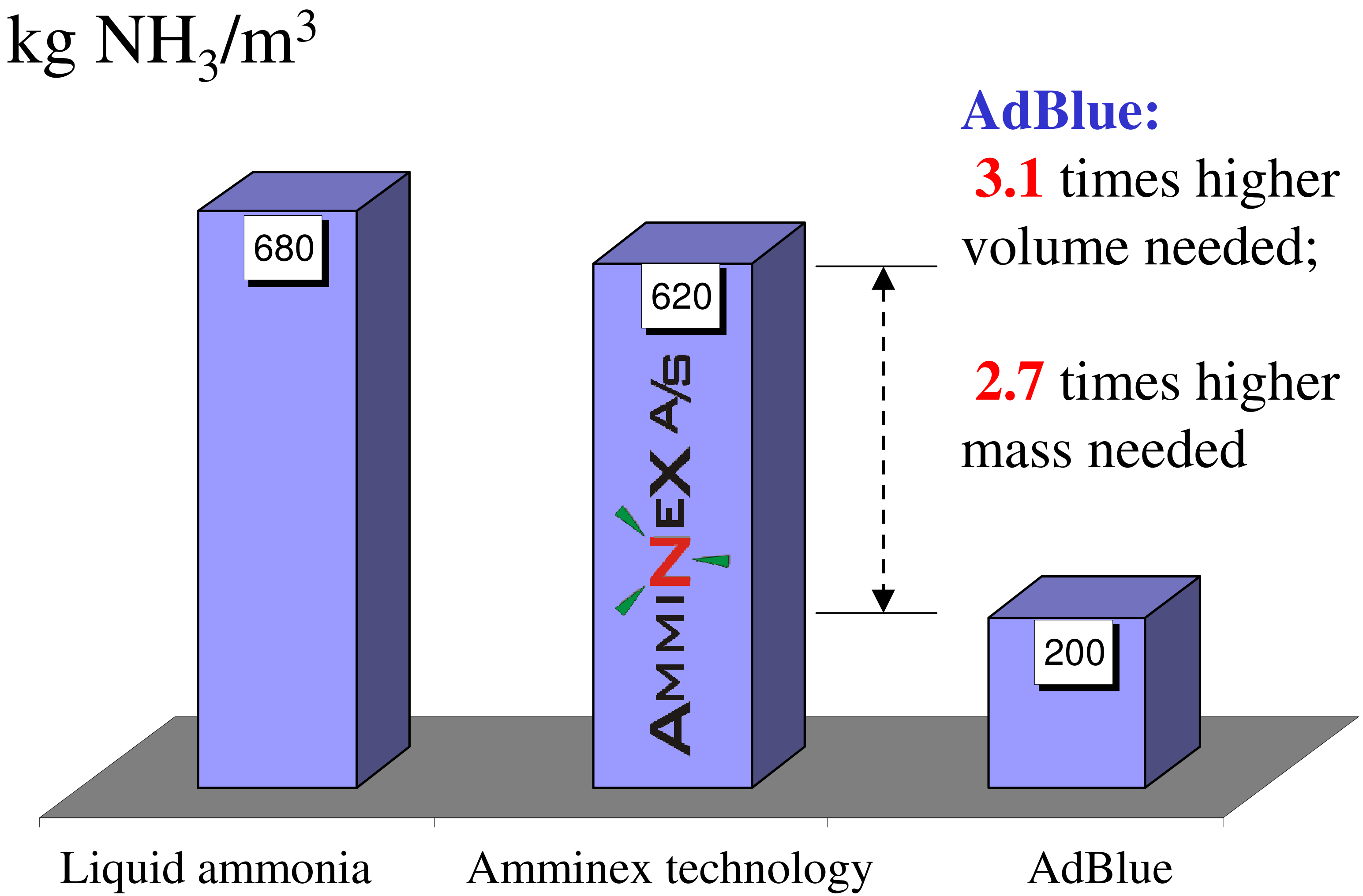


1 liter liquid ammonia
=> 1.1 liter storage material
=> 1.3 kg storage material
=> 4000 times lower volatility



* Vapor pressure divided by IDLH (NIOSH) partial pressure

Details on the ammonia capacity

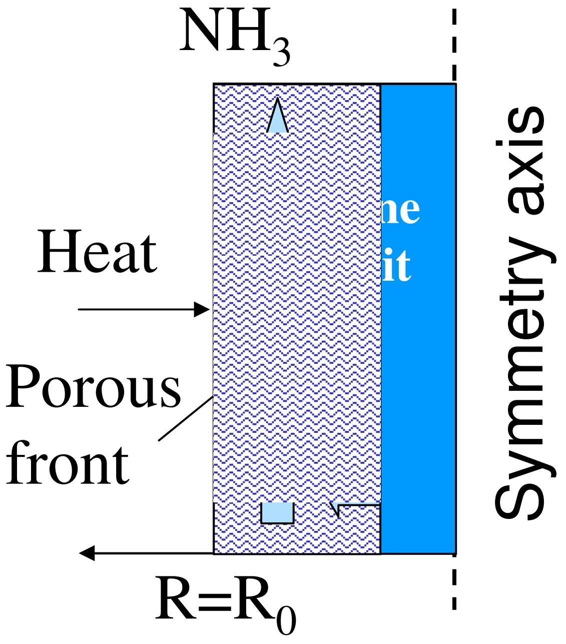


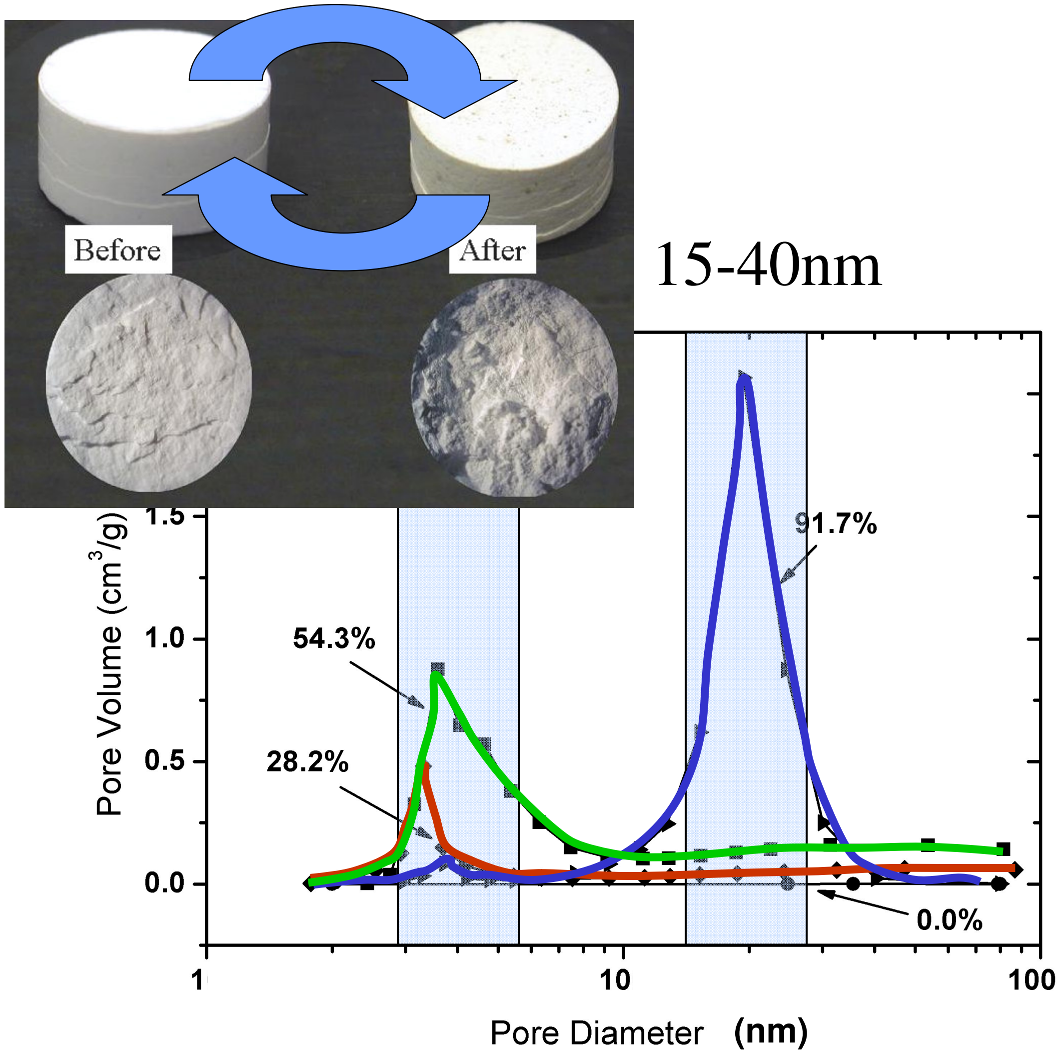
AdBlue:

3.1 times higher volume needed;

2.7 times higher mass needed

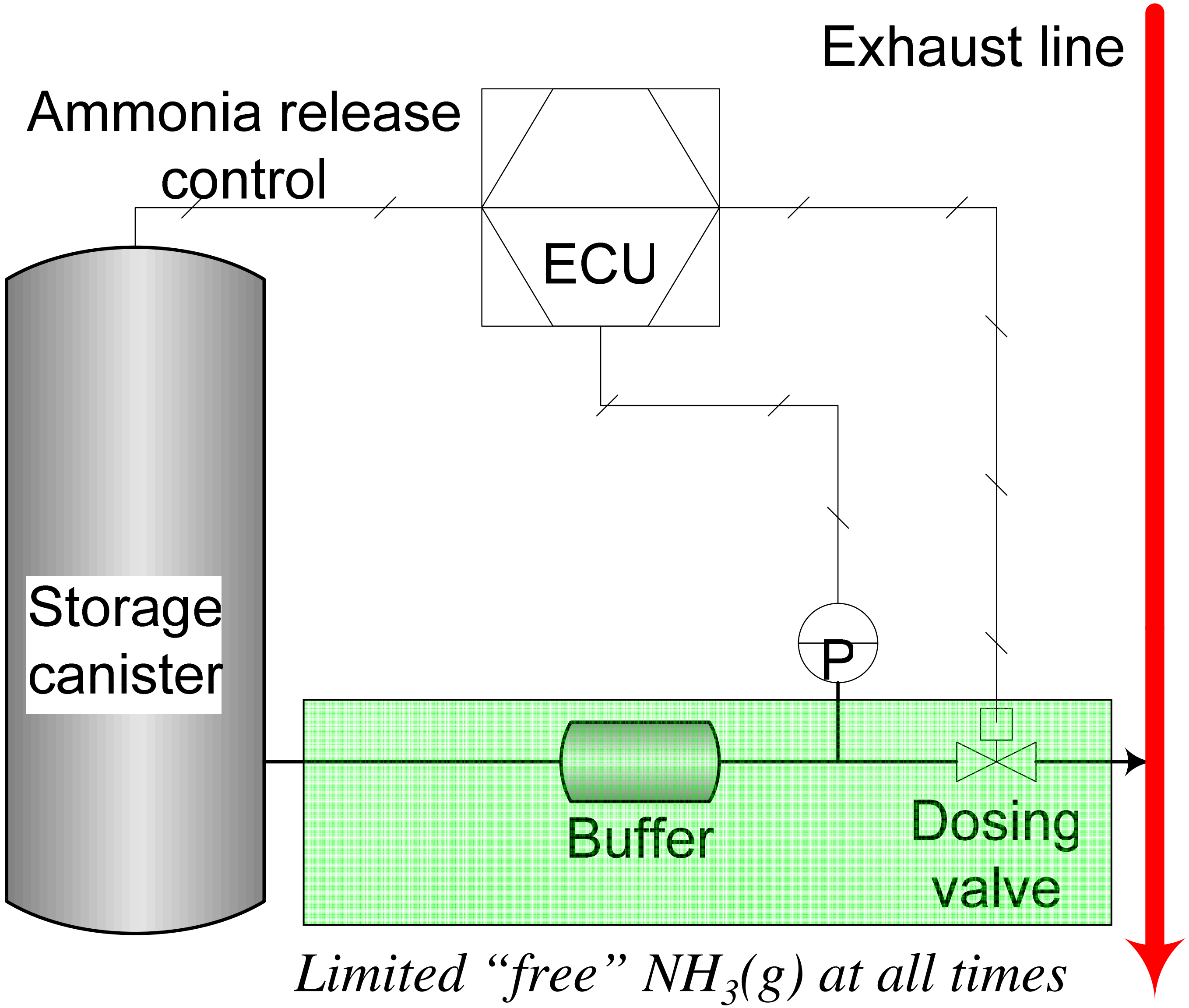
Getting NH_3/H_2 out of dense rods: a self-generated nanoporosity





Tue Johannessen (tj@amminex.com)

A simple, low-cost ammonia delivery system

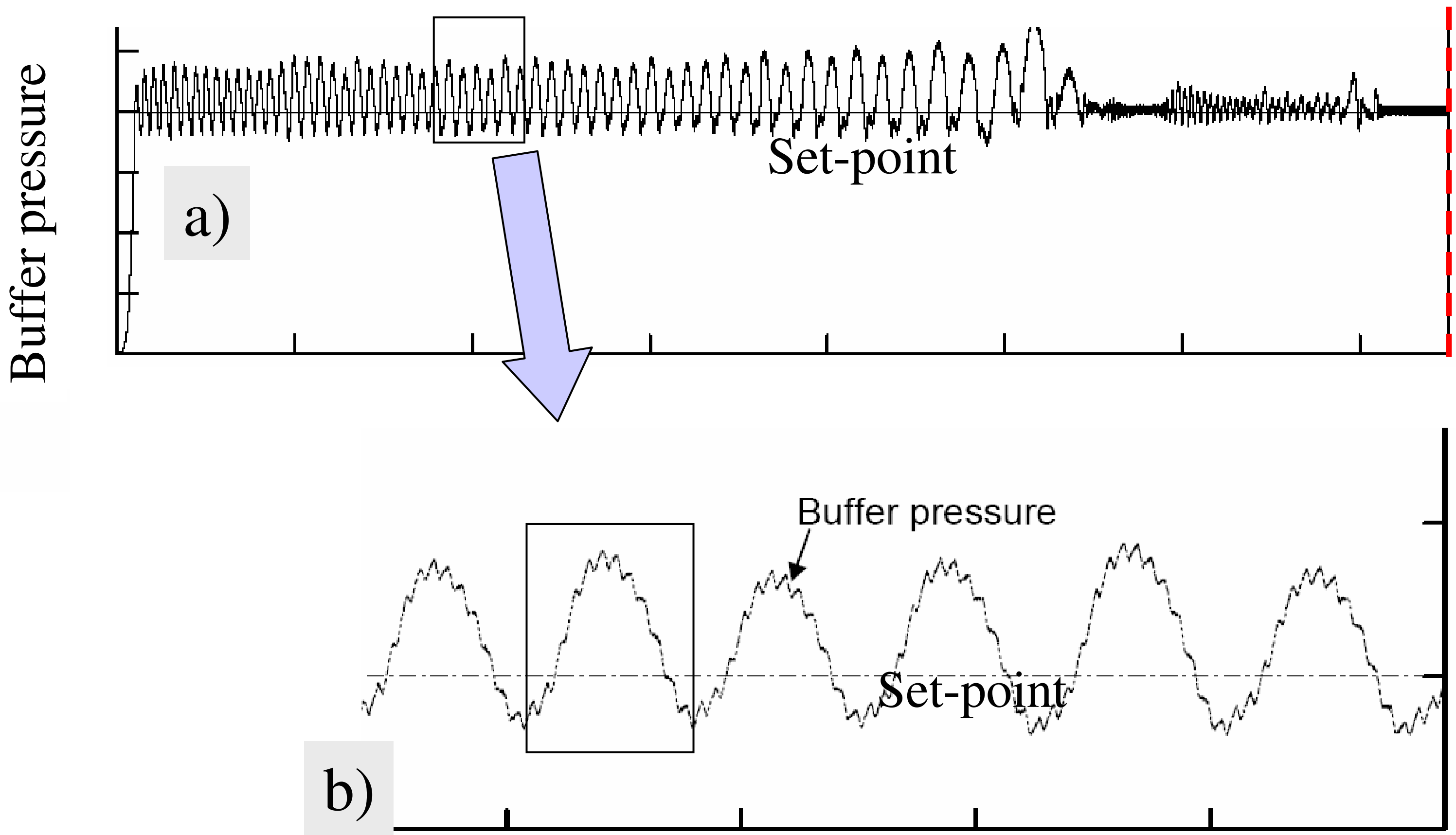


Limited "free" $NH_3(g)$ at all times

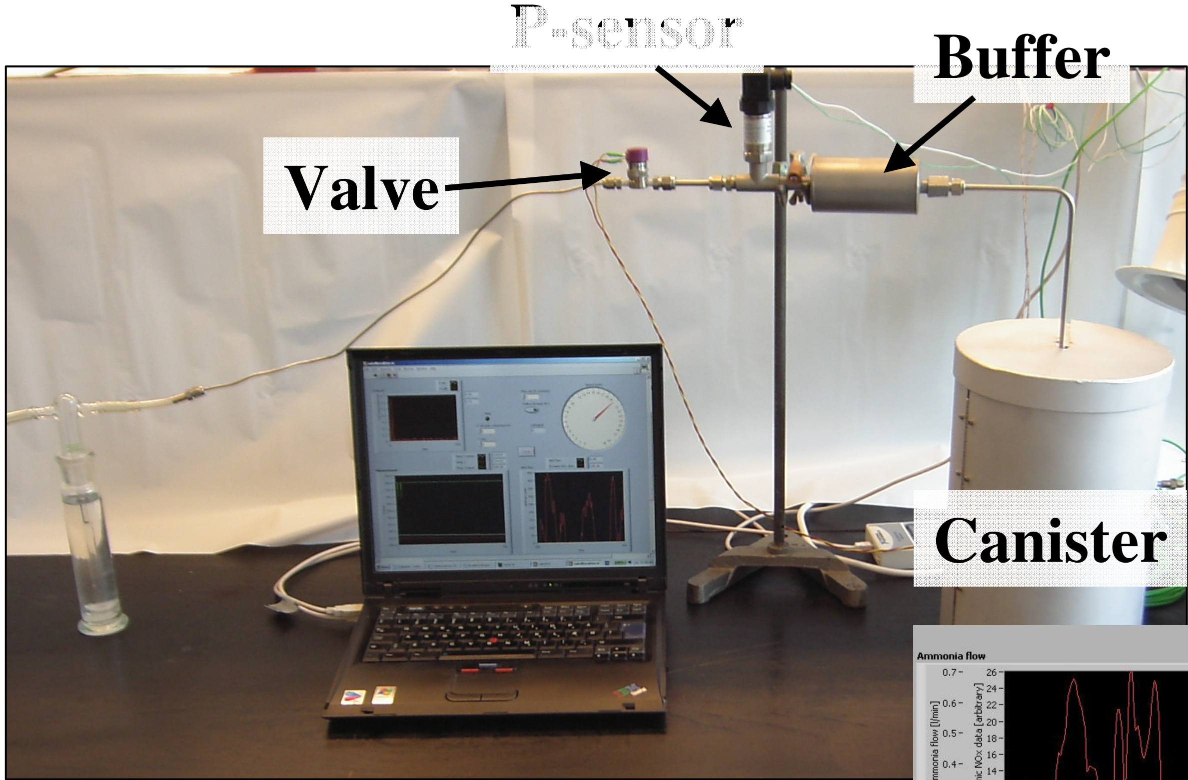
Example of system dynamics

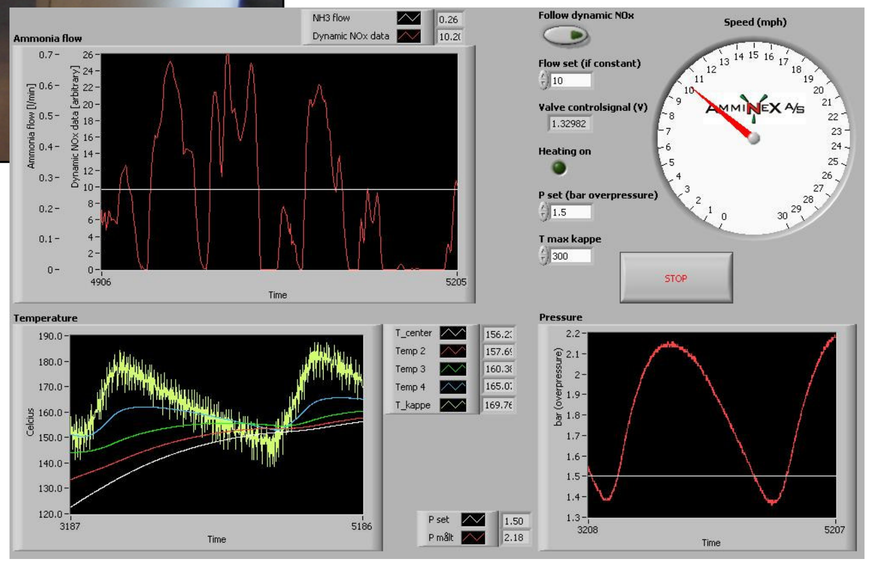
46 hrs

>99% NH_3-release

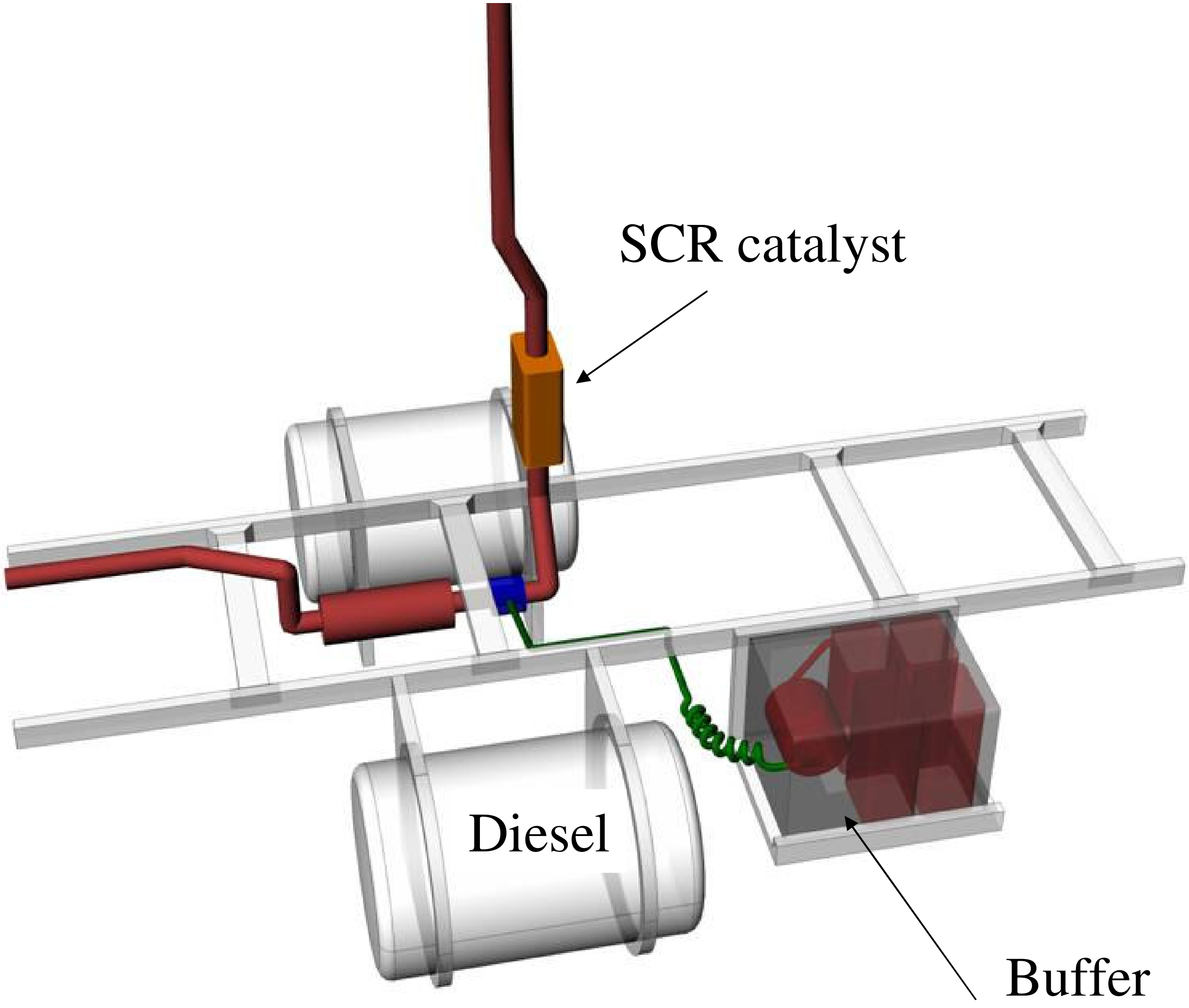


Driving cycle dynamics demonstrated





Retrofit or new vehicles – both possible



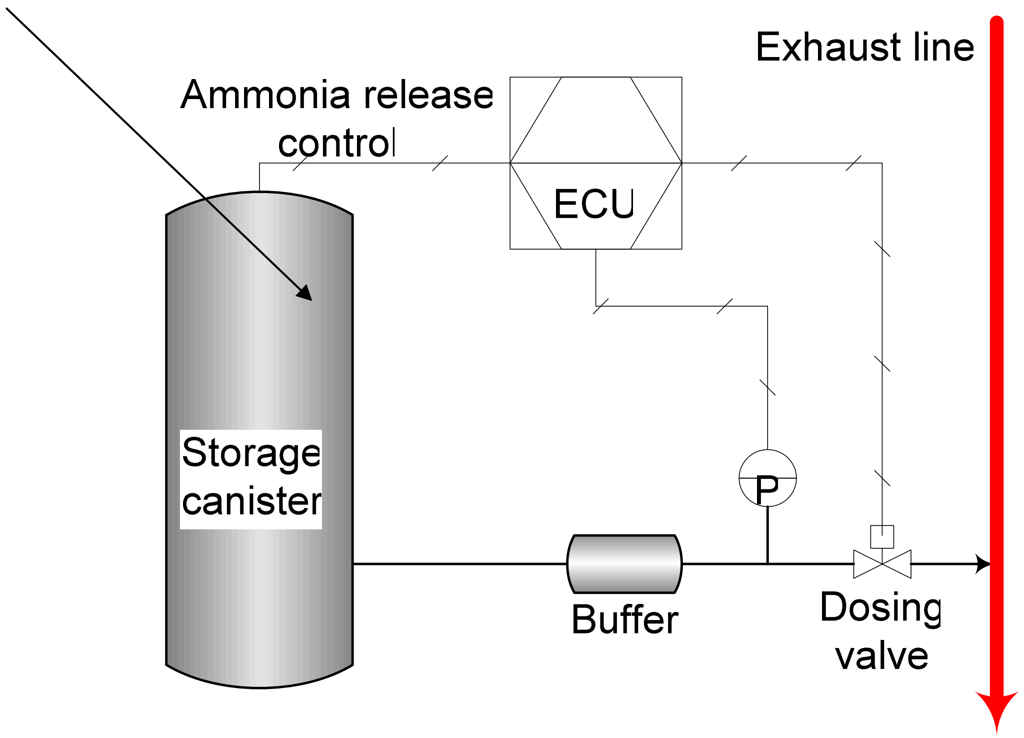
Also very suitable for light duty

- 6-8 liters ammine-canisters equals 18-24 liters of AdBlue
- No extensive infrastructure and end-user intervention

1 kg NO_X removed <=> 1 kg “AdAmmine” (0.9 liter)

Light-duty test system

0.5-1 gall. sized prototypes

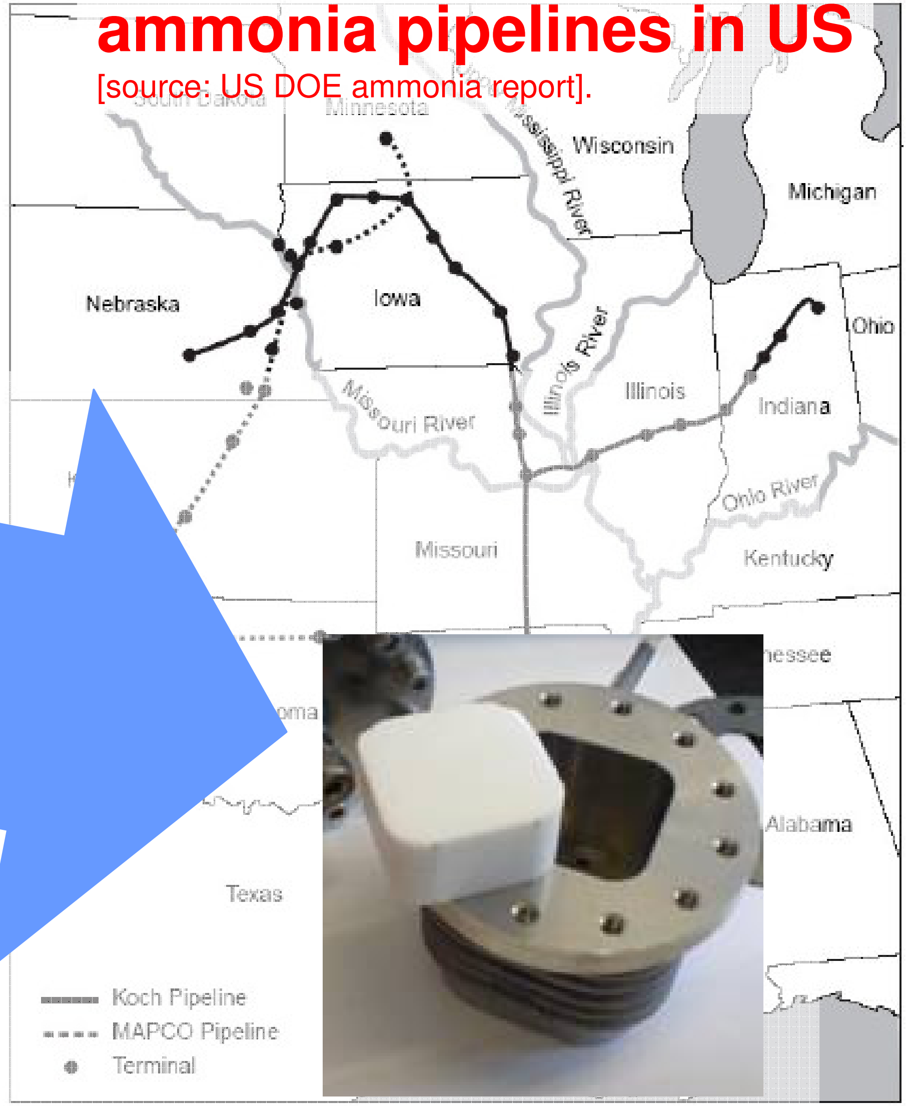


Recharging of canisters: Demonstrated

- Existing infrastructure for ammonia distribution
- Canisters can be recharged with storage material inside

Example of some of the ammonia pipelines in US

[source: US DOE ammonia report].



Enforcing / compliance

- No end-user intervention → less risk of neglecting
  - No end-user handling; no false urea refill
  - Easy to detect empty ”AdAmmine” system
  - Simpler OBD

Urea infrastructure

An example urea production and distribution pathway

Slide from DEER proceedings (available on-line)

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1601 S. De Anza Blvd, Suite 100
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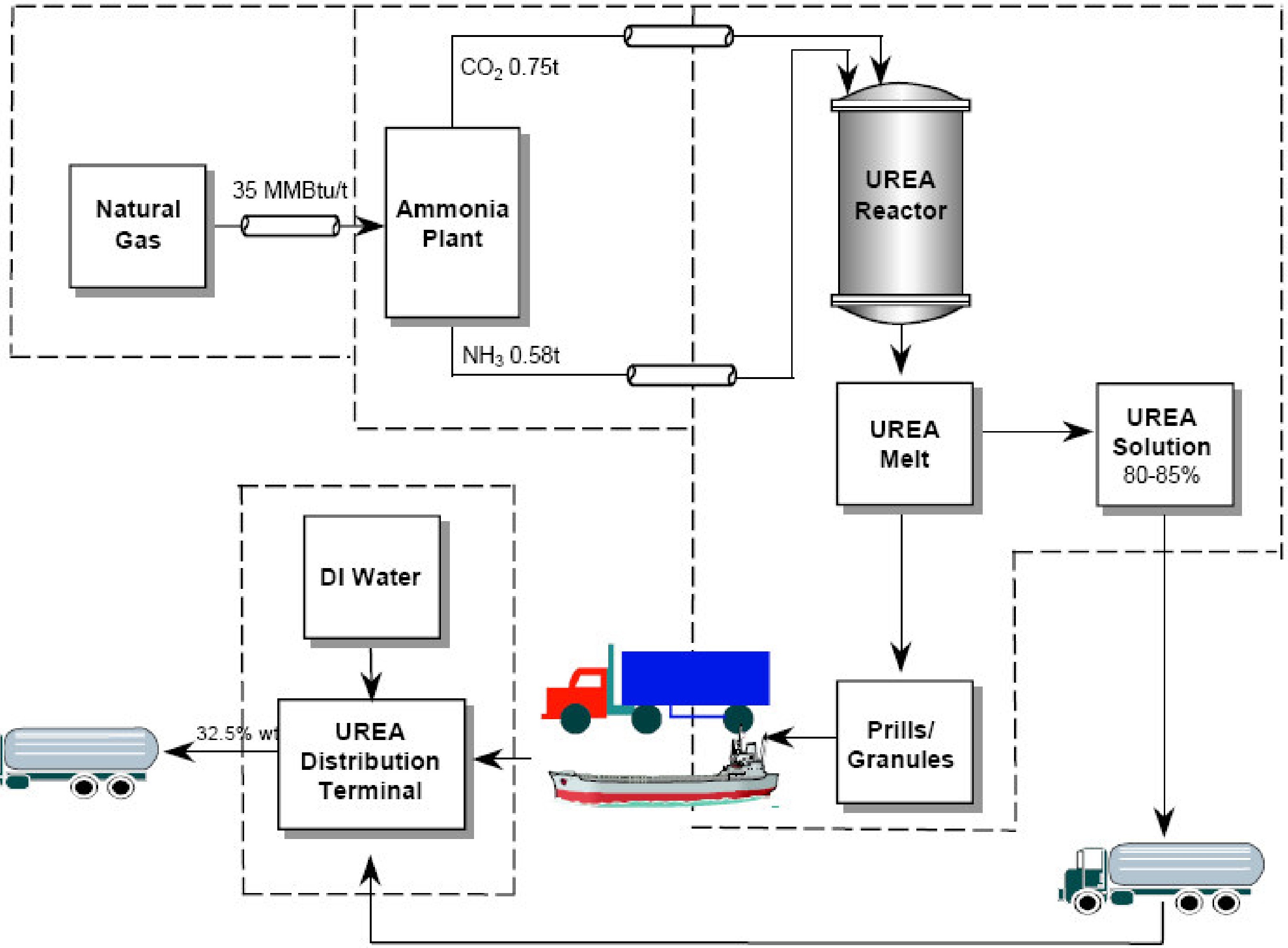
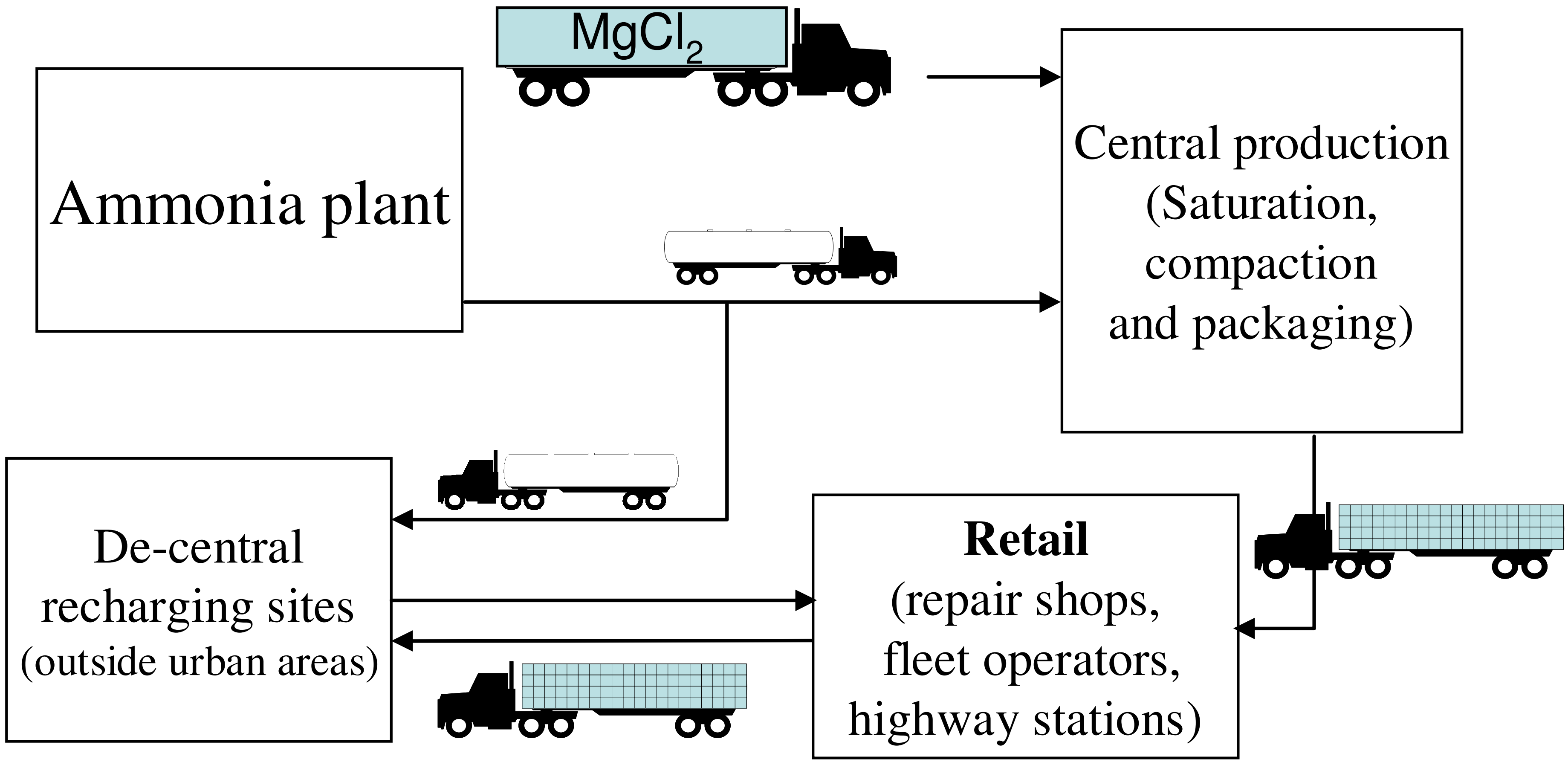
Reference: 72457 NREL SCR



“AdAmmine” Infrastructure



The storage capacity of “AdAmmine” is as high as solid urea.
AdBlue is urea and approx. 70% water. The transported volume (in retail) of AdBlue is three times higher than “AdAmmine”

Prices and production: bulk chemicals

- Ammonia: 300-350$/ton
- $MgCl_2$: 250$/ton in bulk quality
- Solid ammonia storage material:
  - Combination of existing bulk production technology.
- No tank station infrastructure
- Canister re-saturation: Anhydrous ammonia

- Will always be competitive with the price of distributed AdBlue.

Value propositions – both soft and hard

- **Car/truck:** Low cost of storage/dosing system (low impact on vehicle cost)
- **Car/truck:** High capacity (lower impact on design)
- **Driver/user:** No end-user intervention (user-friendly)
- **Driver/user:** Low raw-material cost (inexpensive for end-users)
- Authorities: Easier to enforce!

Summary

- Higher capacity than *AdBlue* (factor 3 by volume; 2.7 by mass)
- Fewer moving parts in the Amminex dosing system
- No complex urea chemistry
  - Long-term storage possible (no decomposition in tank)
- No issues of freezing
- Flexibility in dosing point; fast mixing with exhaust gas
- No drop in exhaust temperature due to water evap.
- A simpler infrastructure: “car dealers, repair shops and fleet-operators”.
  - Storage canisters replaced at service intervals. No end-user intervention. Avoiding the need for *AdBlue* at every gas station
- Lower price of raw materials (lower than *AdBlue*).
  - *OEM canister*: salt ($MgCl_2$) + ammonia + steel
  - *recharging:* anhydrous ammonia
- Ammonia is available world wide. $MgCl_2$ is 10% of sea salt.

AMMINEX A/S

Ammonia-enabling technology