# Southwest Research Institute and Ammonia Research: Past, Present, and Future

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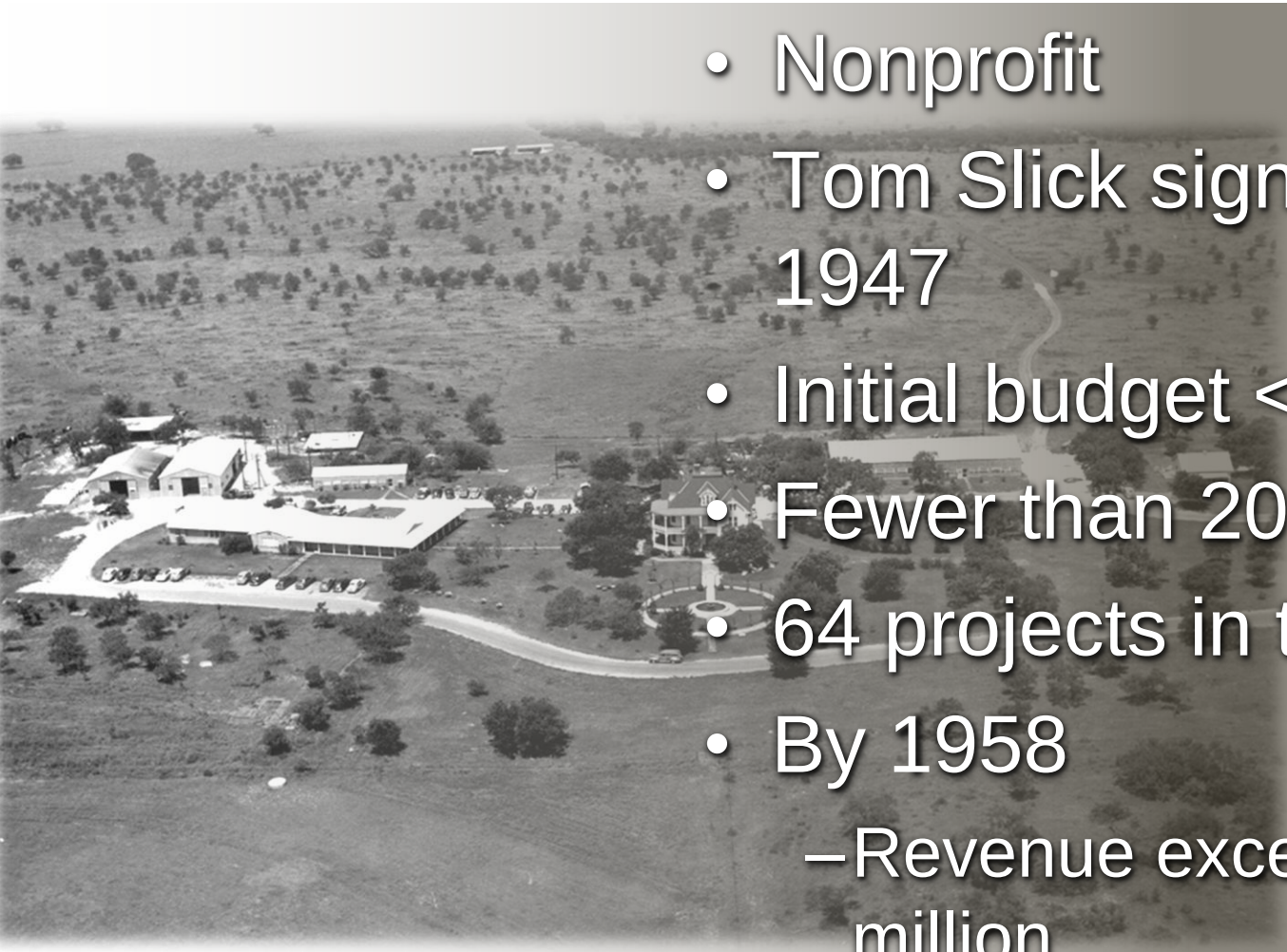
NH3 Fuel Conference
September, 2011


# SWRI BACKGROUND

# SwRI® in the 1950s



- Nonprofit
- Tom Slick signed charter in 1947
- Initial budget <$100,000
- Fewer than 20 employees
- 64 projects in the first year
- By 1958
  - –Revenue exceeding $4.5 million
  - –437 employees

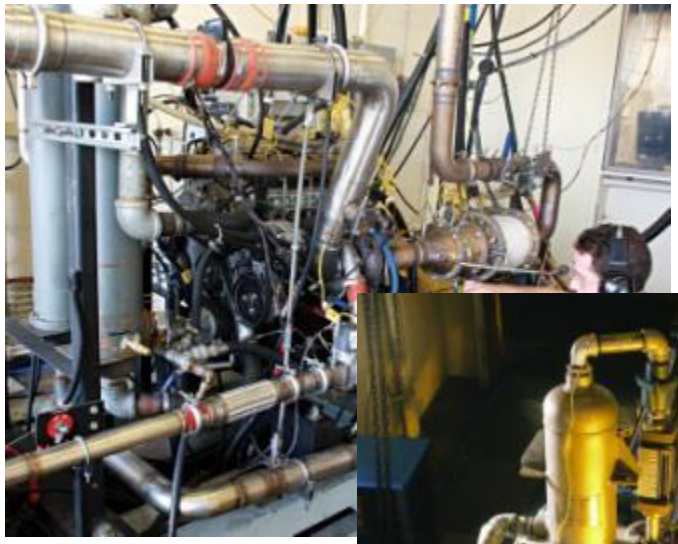
# SwRI® Today

- Over 3,200 employees
- Over 1,200 acres / 4.86 $km^2$ facility in San Antonio, Texas
- 2.2 million $ft^2$ / 204,387 $m^2$ of laboratories & offices
- Over 940 patents
- 34 *R&D 100* awards

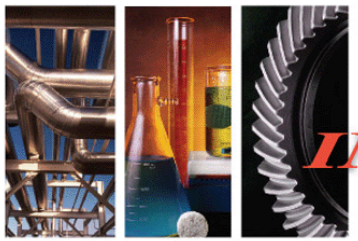
# SwRI Technical Divisions

- Aerospace Electronics, Systems Engineering and Training
- Applied Physics
- Applied Power
- Automation and Data Systems
- Chemistry and Chemical Engineering
- **Office of Automotive Engineering**
  - **Engine, Emissions and Vehicle Research**
  - **Fuels and Lubricants Research**
- Geosciences and Engineering
- Mechanical Engineering
- Signal Exploitation and Geolocation
- Space Science and Engineering

# Office of Automotive Engineering




- Over 200 engine test cells from 1 to 4,000 kW
  - Including emissions certification
- Accelerated exhaust aftertreatment testing
- Vehicle testing
  - Light Duty and Heavy Duty chassis dynamometers
- Combustion test benches
  - Single cylinder engines
  - Combustion bomb
- Engine and CFD Simulation



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# SWRI & NH3

# Past SwRI NH3 Research

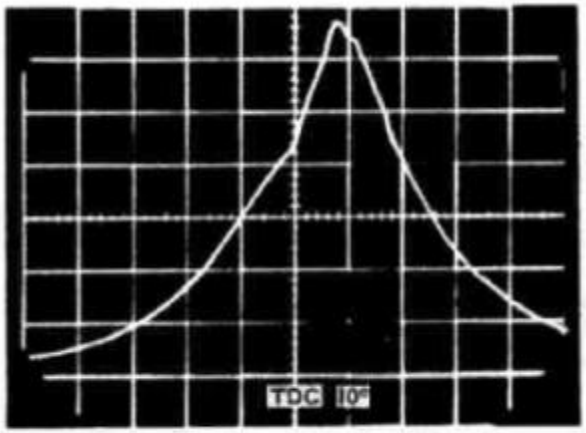



Fig. 8 - Ammonia pressure time diagram

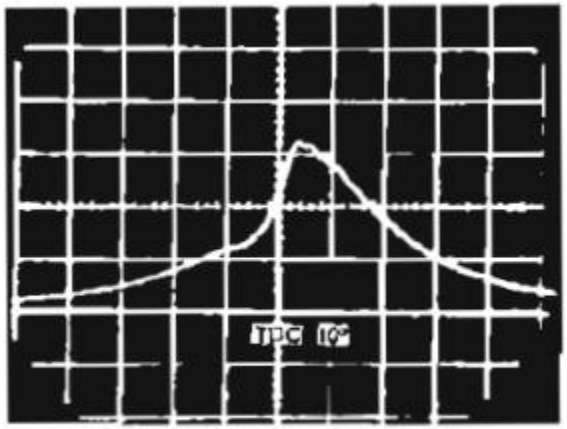



Fig. 12 - Ammonia plus 10% hydrogen

Army "Energy Depot" in the 1960s

SAE Paper 660156

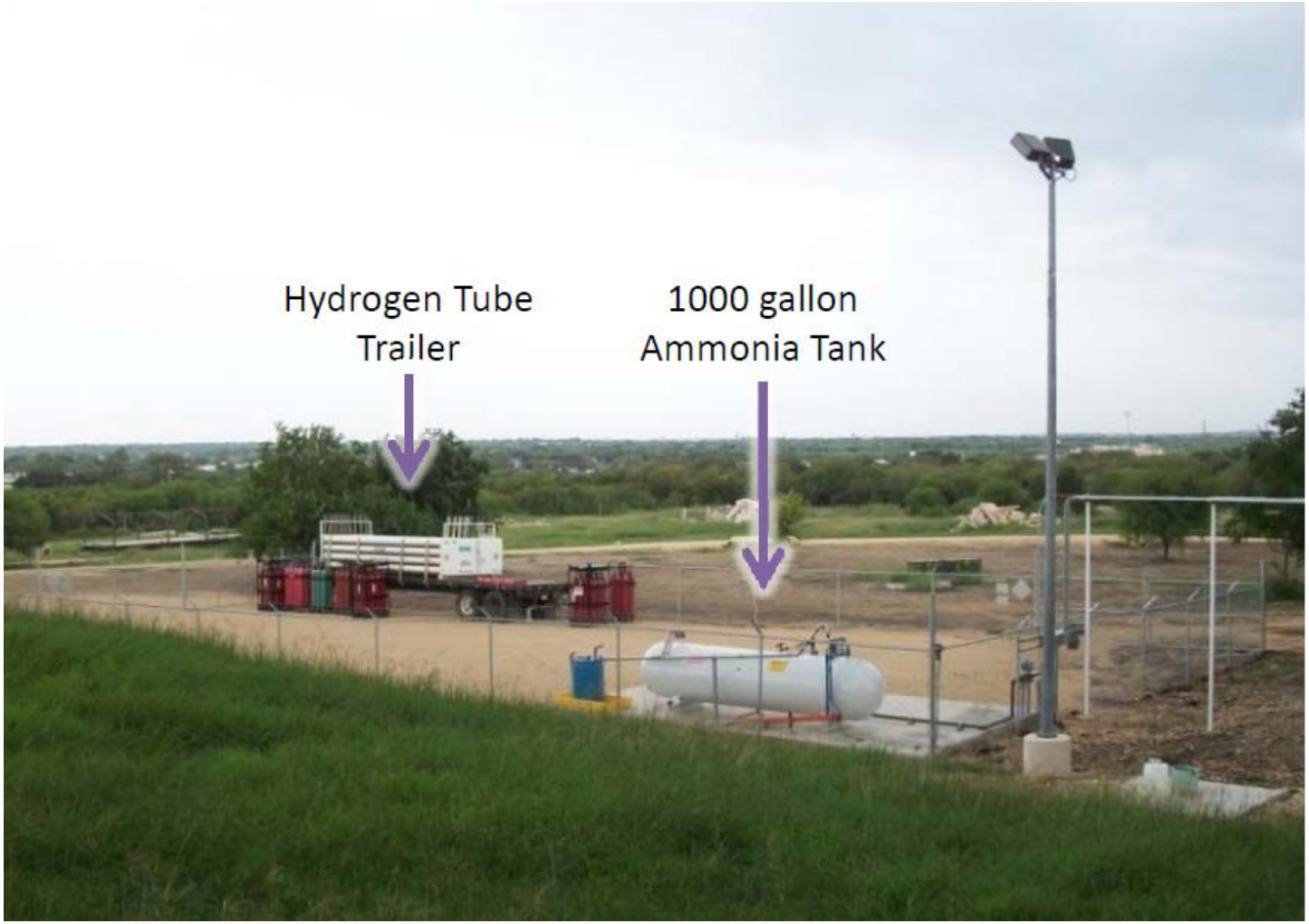
- Compression Ignited NH3
- No ignition enhancement at CR 35:1
- Investigated diesel, hydrogen, and acetylene as combustion promoters

NH3 combustion research portion of "Energy Depot" was promising, but nuclear research was deemed infeasible

# Current SwRI NH3 Research

- Significant NH3 engine experience
  - Combustion
  - Safety and Security
- Alternative fuels storage facility
  - 2000 gal. Anhydrous Ammonia
  - 3000 gal. Compressed Hydrogen
  - Meets all local, state, and federal safety and security regulations
    - Leak detectors, security fence, pressure relief devices, etc.
- SwRI is unable to publish NH3 data as it is client sensitive

# Alternative Fuel Storage Facility



# Other Alternative Fuels

- Hydrogen
- Compressed and Liquefied Natural Gas
- Liquefied Petroleum Gas
- Ethanol
- Methanol
- Coal and water slurries
- Biodiesel and Vegetable Oils
- Dimethyl Ether
- Fischer-Tropsch liquids

# Other SwRI NH3 Capabilities

Mechanical Engineering Division

- CFD modeling of ammonia safety
  - Concentration, distribution, toxicity

Fire Technology Department

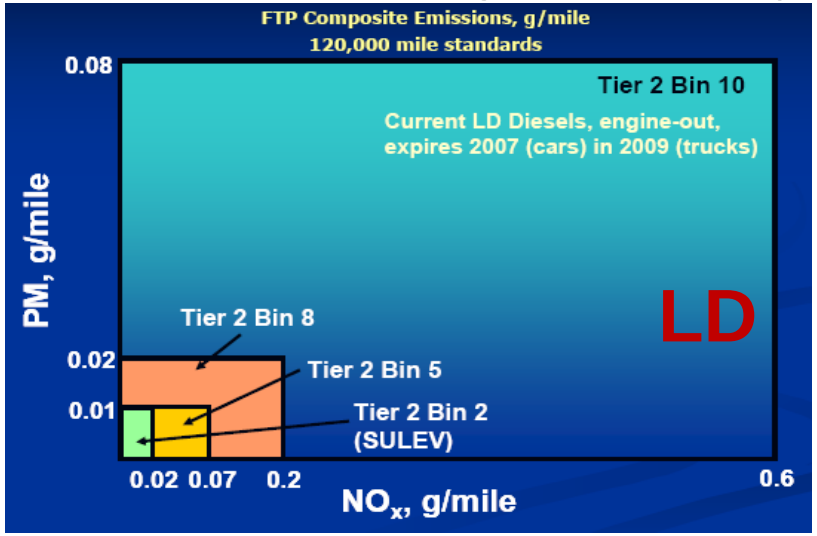
- Simulation and measurement of small to large scale fires, blasts, and explosions

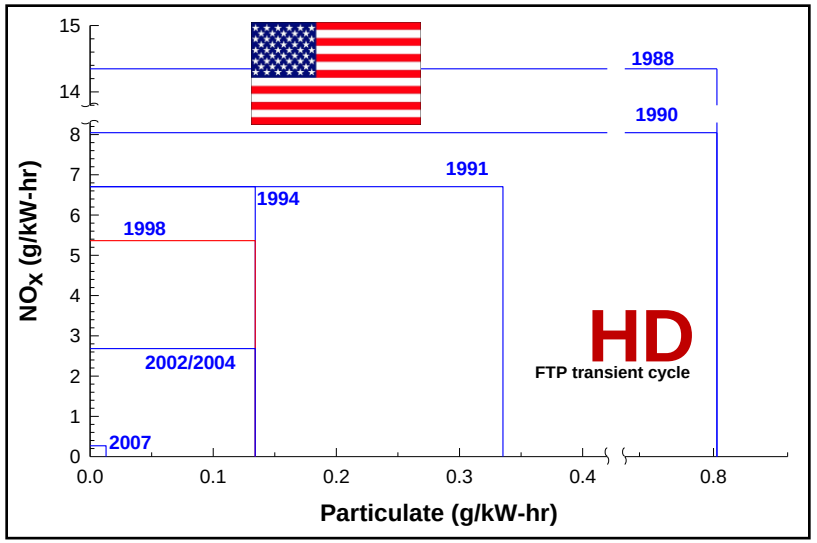
Ignition of engine compartment hydrogen release

Ruptured **hydrogen** cylinder in car

# Future NH3 Research

- Government regulations have forced research to focus on emissions (NOx, HC, CO, PM) over the last several decades
  - Industry has met the very aggressive emissions reductions
  - Emissions regulations likely to be stable for some time

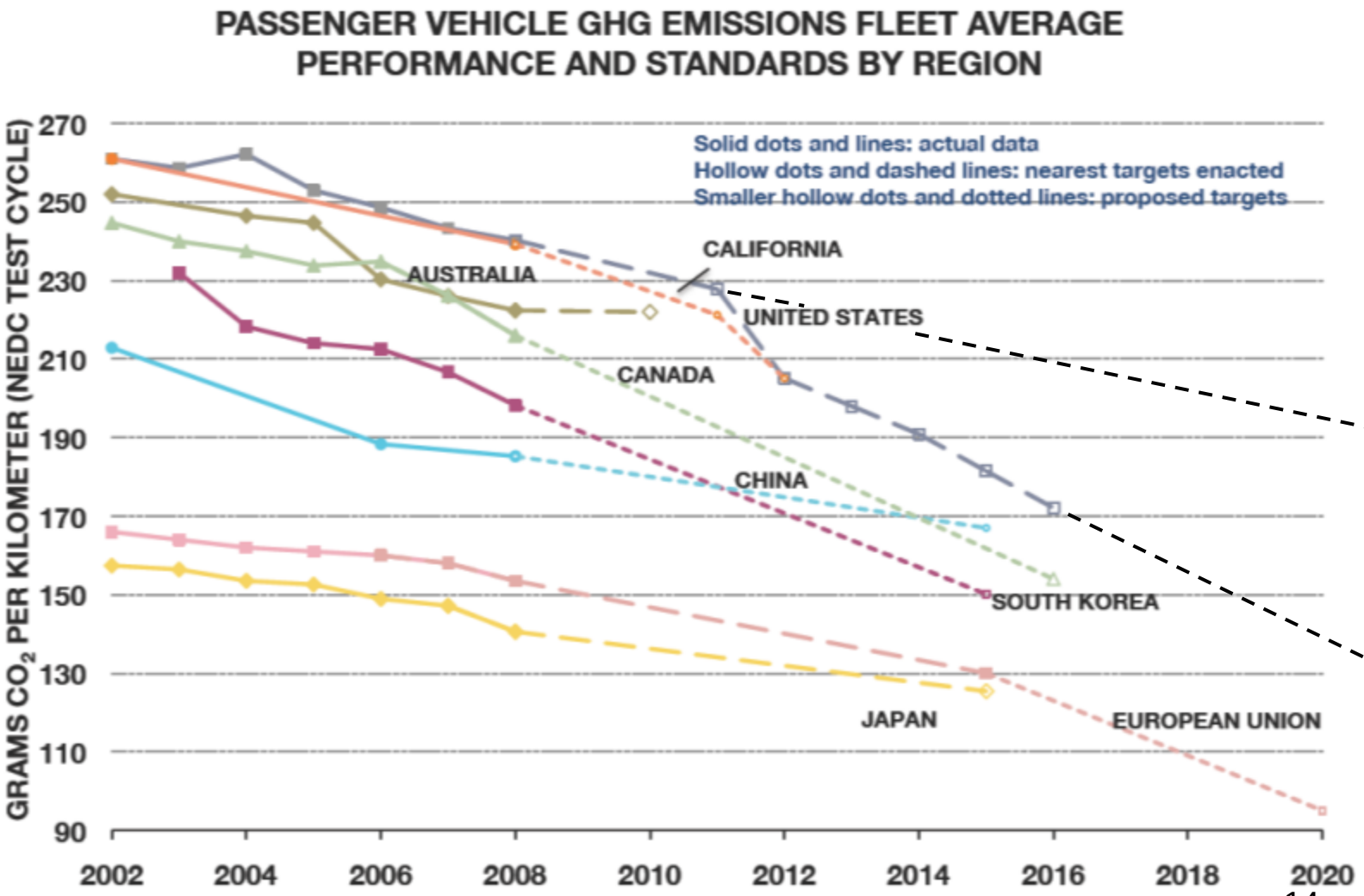



- Efficiency/Fuel Economy/CO2 Emissions is the government's next focus
  - EPA heavy-duty ruling last month details CH4 and N2O regulation
  - There are provisions (credits) for alternative fuel vehicles

# Overview of LD Transportation CO2 Regulations

April 2010 Update

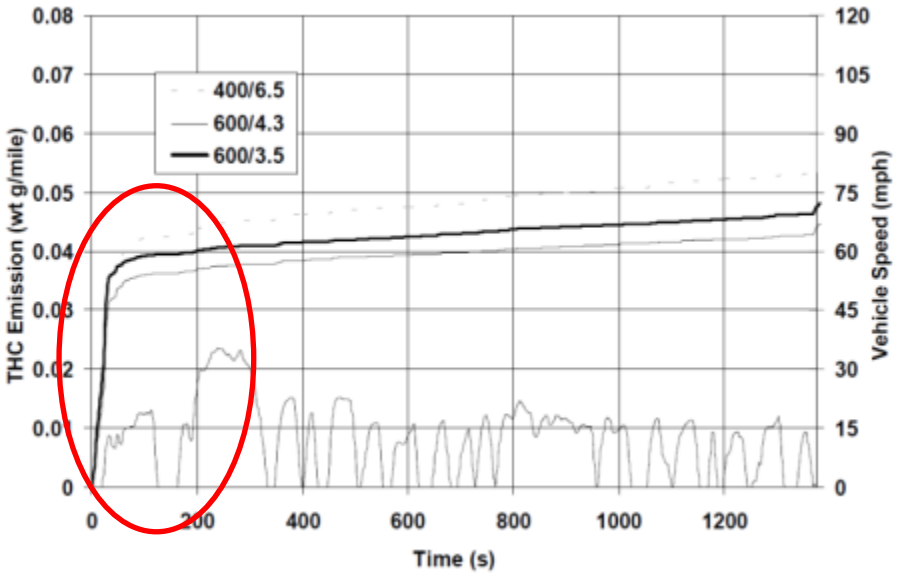


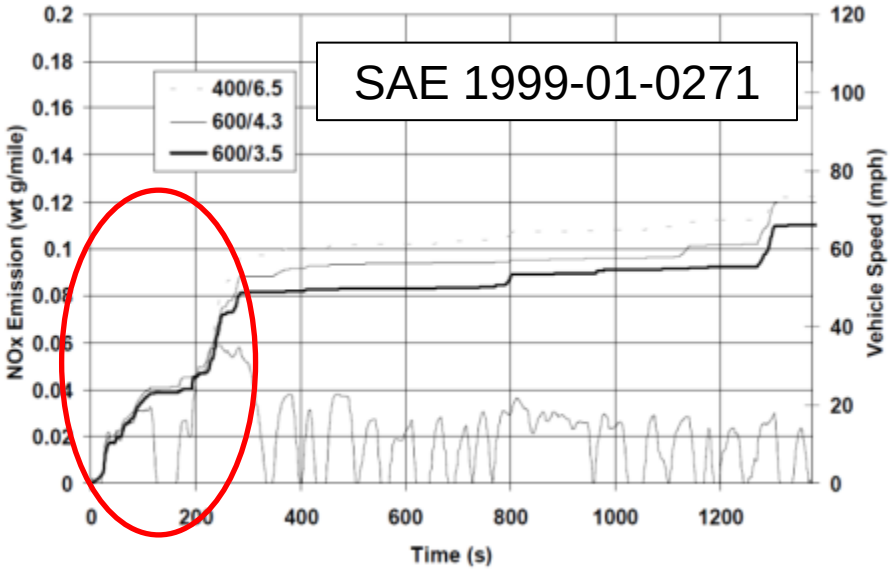
# CO2 Emissions Regulations

- Opportunities for NH3:
  - Zero CO2 with NH3 combustion
  - Reduced CO2 with Dual Fuel combustion
- But must meet continuing stringent emissions regulations
  - Including NH3 emissions regulations
    - EU – maximum of 25ppm NH3 over cycle
    - Real world public perception also an issue
- Regulations based on driving cycles (transient)
  - Steady state experiments only first approximation
  - Usually 20-50% emissions penalty for hot transient
    - Not an issue for gensets as emissions are steady state based
  - Further emissions increases with cold start

# Cold Start with NH3 Only

- For engines using aftertreatment
  - Majority of emissions come from cold start
    - Poor combustion because of cold engine
    - No catalyst activity because of low temperatures
- <u>May be significant challenge for on-road NH3</u>



# Meeting Emissions Regulations

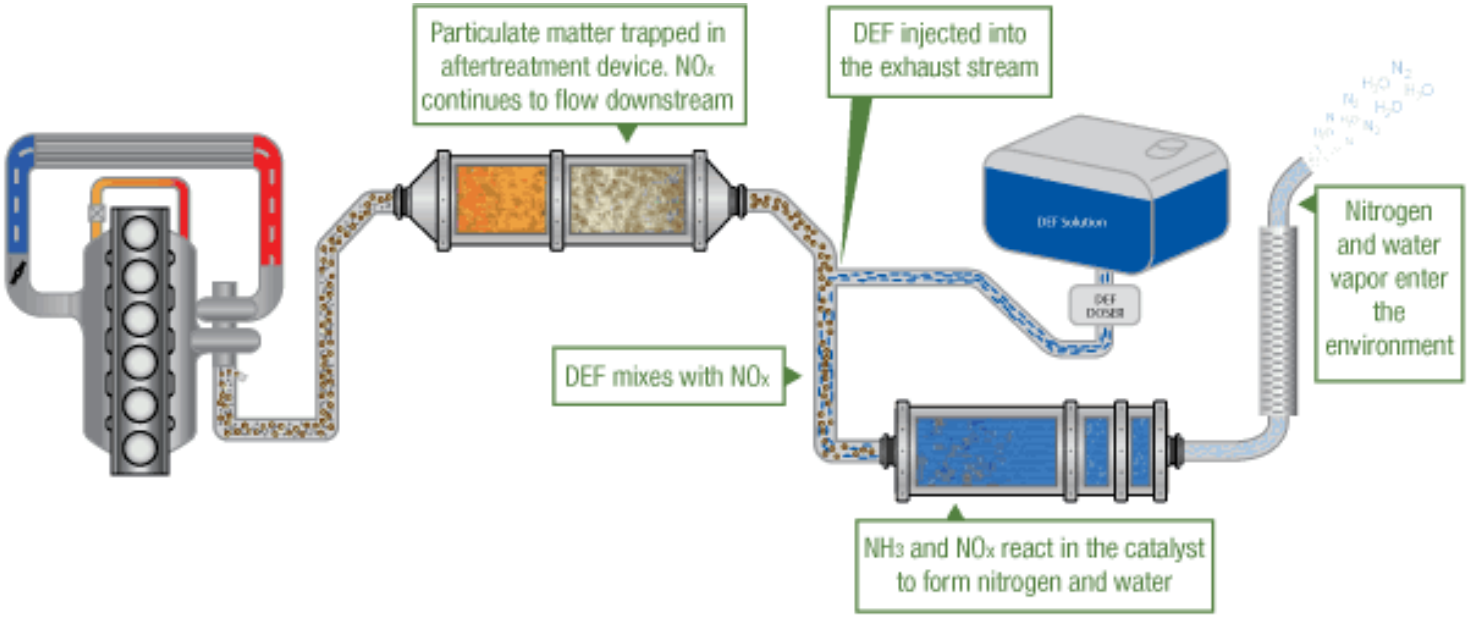
- SwRI Invention Disclosure:

  Selective Catalytic Reduction (SCR) Catalyst

  – Diesel operation with NH3 as CO2 reducer and source of ammonia for SCR NOx control

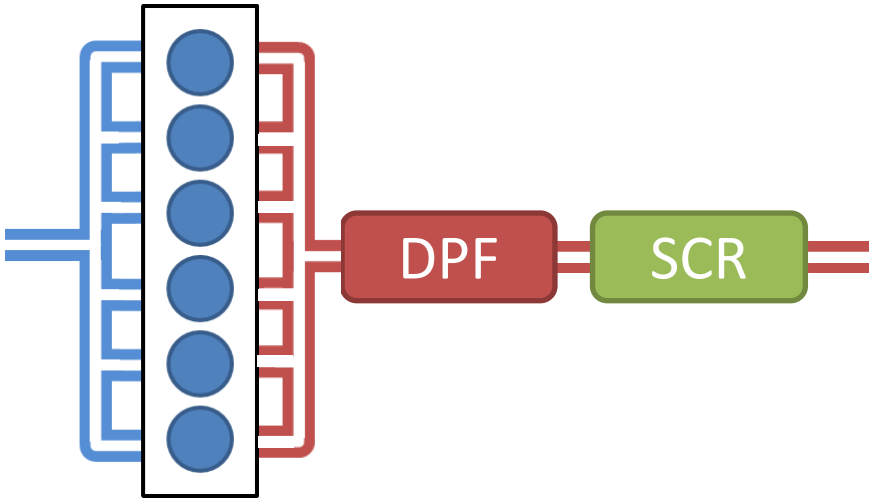
  – NH3 as only fuel with SCR for NOx control and cold start NH3 trap

# Current Diesels



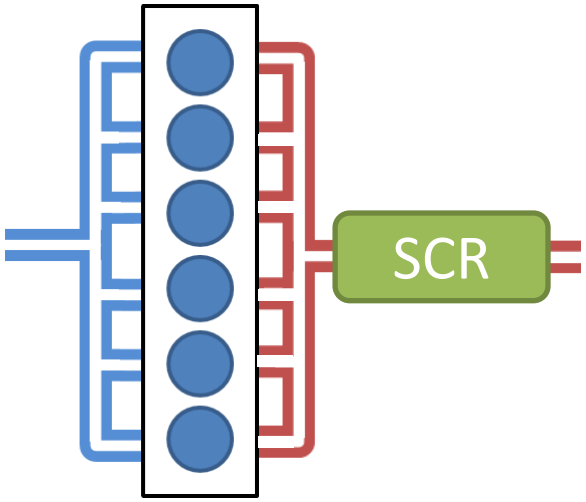

- Urea injected upstream of SCR and converted into NH3 to reduce NOx
  - Requires secondary tank
  - Urea injector often suffers from coking
  - Urea contains carbon → $(NH_2)_2CO$

# Diesel + NH3




- Use NH3 as supplemental fuel (port or direct injection)
- NH3 only used after catalyst warm-up
- Unburned NH3 from combustion used to reduce NOx in SCR
- Reduced CO2 emissions
- May reduce PM emissions → reduced DPF (Diesel Particulate Filter) regenerations → reduced fuel consumption

# NH3 Only



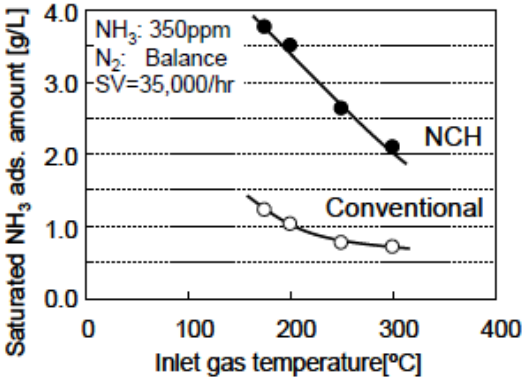



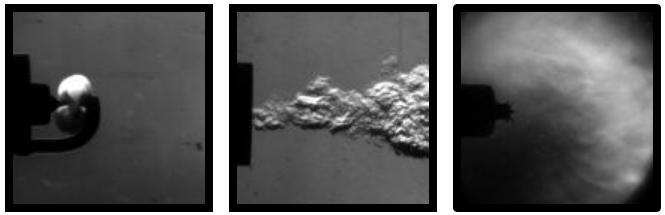

Figure 6. Temp.-dependence of Saturated $NH_3$ adsorption

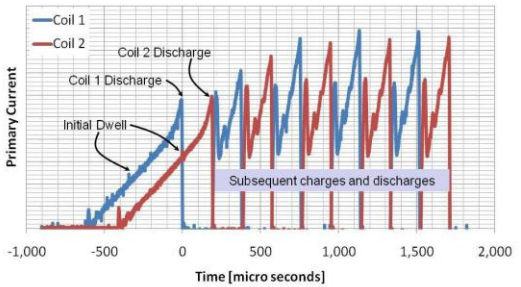
*SAE 2009-01-0906*

- NH3 only fuel with possible on-board reforming
- SCR traps unburned NH3 during cold start
- Unburned NH3 from combustion used to reduce NOx in SCR
- Zero CO2, HC, PM emissions
  - No need for DPF

# Other Future Considerations

- NOx and NH3 exhaust sensors will likely be important for catalyst function and diagnostics
  - Effect of malfunctions on emissions will be regulator concern
- Advanced ignition systems could aid with poor NH3 ignitability
  - SwRI has vast experience through EGR engine research which has similar challenges
  - SwRI recently received R&D 100 Award for DCO™ Ignition System (Dual Coil Offset)






# Summary

SwRI's expertise in automotive technology and fuels and lubricants combined with its new alternative fuels storage facility make it uniquely positioned to partner with the ammonia community to make ammonia an environmentally friendly, efficient, and safe fuel of the future

# Thank You

For more information

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