Ammonia Fuel Risk Levels

"Similar, if not Lower than"
Gasoline, LPG, Methanol, Natural Gas, and Hydrogen

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NH3 Fuel Conference
Argonne National Laboratory, Chicago, IL
September 22, 2015

A summary of the two existing studies of Ammonia Fuel Safety

Comparative Quantitative Risk Analysis of Motor Gasoline, LPG, and Anhydrous Ammonia as an Automotive Fuel

Quest Consultants Inc
USA, 2009

Prepared for Iowa State University

LINK:
http://nh3fuel.files.wordpress.com/2013/01/nh3_riskanalysis_final.pdf

Safety assessment of ammonia as a transport fuel

Risø National Laboratory
Denmark, 2005

Part of the EU supported project "Ammonia Cracking for Clean Electric Power Technology"

LINK:
http://nh3fuel.files.wordpress.com/2013/05/riso-ammonia-transport-safety-report.pdf

Ammonia Fuel Risk Levels
– Conclusions –

Quest:

"In summary, the hazards and risks associated with the truck transport, storage, and dispensing of refrigerated anhydrous ammonia are **similar to those of gasoline and LPG** ...

The risks associated with all three fuels would fall into the **acceptable** category for all referenced risk criteria."

Quest: p. 53 of 59 (6-13)

Risø:

"An overall conclusion is that the hazards in relation to ammonia need to be (and probably can be) controlled by technical and regulatory options ...

When these safety systems are implemented, the risks of using ammonia is **similar, if not lower than** for the other fuels."

NOTE: compares anhydrous ammonia to gasoline, LPG, CNG, methanol, and hydrogen – in internal combustion engines or fuel cells.

Risø: pp. 39-40 of 160

Ammonia Fuel Risk is “acceptable” – What Does That Mean? –

- Based on the data, **Ammonia Safety shouldn’t be an obstacle to funding**, development, or deployment of ammonia fuel applications.

- Note, moreover, that this “acceptable” risk profile was achieved under the **highest possible risk scenario**: Passenger cars in public.

- Therefore, in most realistic ammonia fuel applications, Ammonia Safety is even MORE acceptable. Because, compared to passenger vehicle fuel use:
  - Stationary power is inherently safer
  - Off-road / Industrial power is inherently safer
  - Remote power is inherently safer

- Simple conclusion: “Ammonia belongs in the R&D portfolio.”
  David Garman, ”The Curse of Shiny Objects,” Keynote Speech NH3 Fuel Conference, 9/21/2015

Ammonia Fuel Risk Levels
– How similar is “similar”? –

Truck Transport Safety

“Hazard Corridors” & “Vulnerability Zones”

- Gasoline
- LPG
- Ammonia

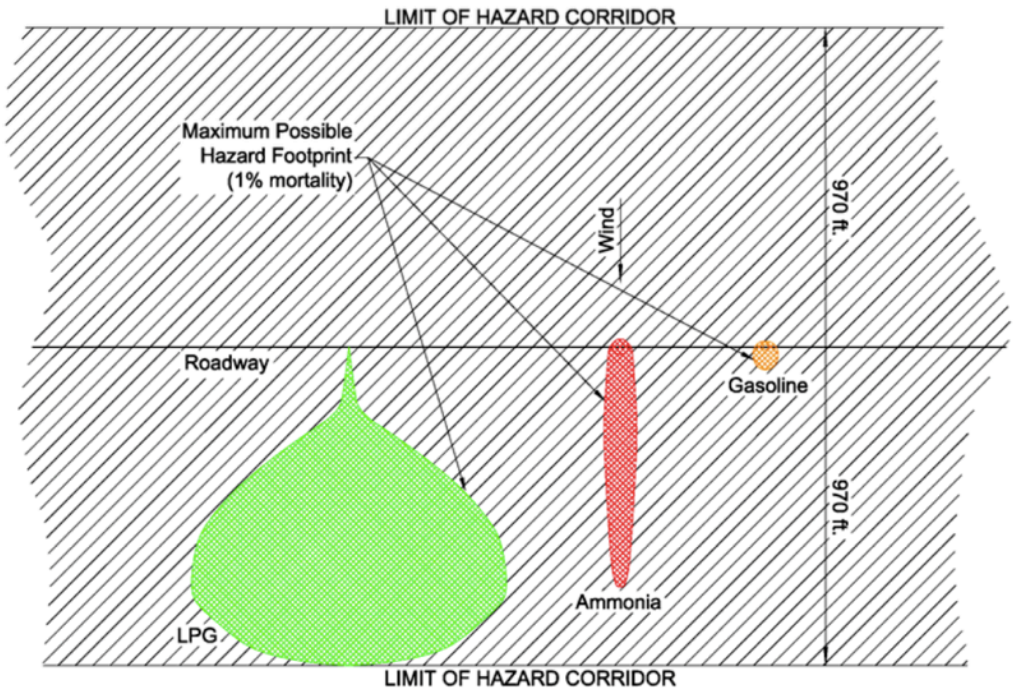


Figure 6-2
Vulnerability Corridors and Zones for the Truck Transport of Gasoline, LPG, and Refrigerated Ammonia

Quest: p43 (6-3)

“An Engineering Problem, with Engineering Solutions”

Truck Transport safety

Gasoline: 1.75 x (10)-7 releases/mile/truck

LPG: 5.84 x (10)-8 releases/mile/truck

Ammonia: 1.9 x (10)-8 releases/mile/truck

Quest, p33 (4-4)

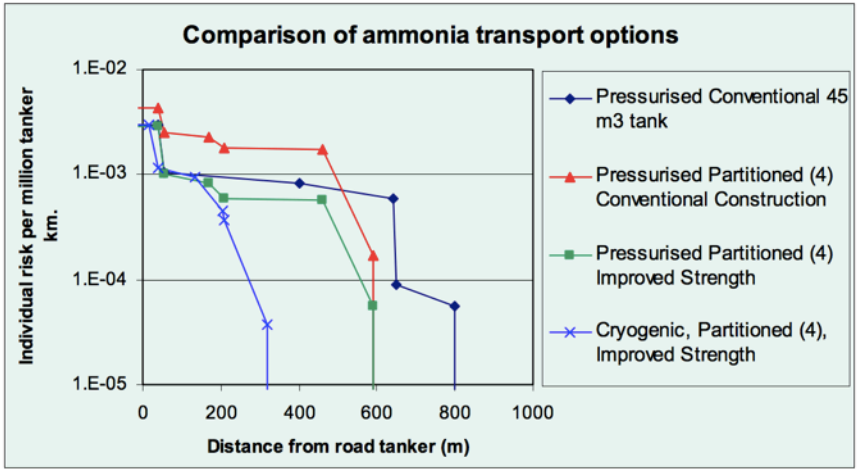


Figure 14 Individual risk of different technological solutions for the transportation of ammonia by road tankers.

Ammonia has the lowest probability of an accidental release in truck transport, but …

“Nevertheless, risk-reducing options are strongly needed.

A solution that causes the risk levels to drop below the risks for LPG requires that ammonia be transported

- in refrigerated form,
- in road tankers carrying typically four separated (pressure) tanks of about 11 m3 each,
- which are as resilient against impact and abrasion as conventional (large) pressure tanks.”

Risø: p39

Ammonia Fuel Risk Levels
– How similar is “similar”? –

Service Stations

“Risk Contours”

- Gasoline
- LPG
- Ammonia

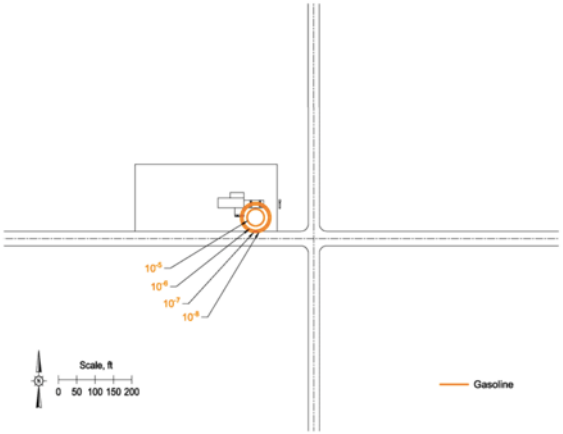


Figure 6-4
Risk Contours for a Service Station Storing and Dispensing Gasoline

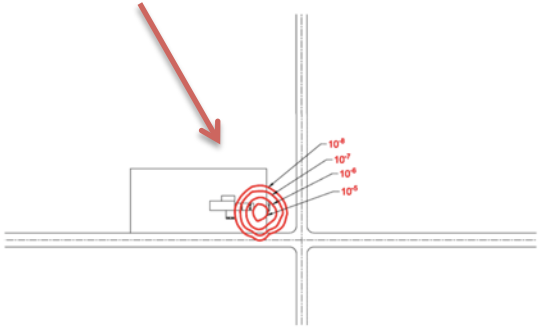


Figure 6-6
Risk Contours for a Service Station Storing and Dispensing Anhydrous Ammonia

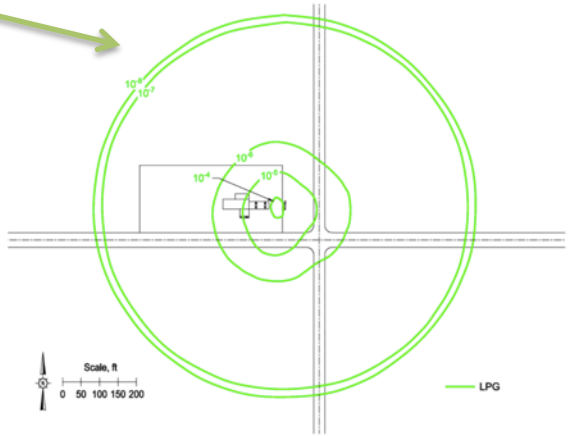


Figure 6-5
Risk Contours for a Service Station Storing and Dispensing LPG

Quest: pp45-46 (6-5, 6-6)

"An Engineering Problem, with Engineering Solutions"

Service Stations

"Small, but long-lasting releases of ammonia due to e.g. leaks and ruptures of hoses, cause serious dangers at distances up to 150 m distance …

This requires additional technical safeguards to reduce the likelihood of these releases (It is especially important to stop the release as soon as possible to interrupt exposure).

But also in case these safeguards are in place, **safety distances around these ammonia-refuelling stations should be no less than 70 m**."

Risø: pp39-40

"The refrigerated ammonia storage system is designed such that if a small or significant release of ammonia were to occur in the storage, heating, or pumping systems, the released ammonia liquid and vapor would be **contained in a vault and vented through a vertical stack** extending upward. As the ammonia vapors warm and disperse from the elevated stack, the ammonia/air plume will be positively buoyant and will have no ability to slump back to grade. **This storage method essentially eliminates the grade-level risk associated with the storage of refrigerated ammonia**."

Quest: p50 (6-10)

Ammonia Fuel Risk Levels
– How similar is "similar"? –

Driving a Car

"**The fuel used to power a motor vehicle does not contribute significantly to the fatality rate of motor-vehicle accidents** …

This conclusion is based on a simple review of the available NSC data and would be expected to be true if anhydrous ammonia were the automotive fuel since **anhydrous ammonia would be carried in a pressure vessel similar to LPG**."

Quest: pp9-10 (1-3 – 1-4)

"It should be emphasised, that this study does not exclude any accidents where the release of ammonia from a car will kill a driver, passenger or other individuals …

This will happen **no more often**, than that people are killed by burning gasoline or LPG."

Risø: p.45

“An Engineering Problem, with Engineering Solutions”

Driving a Car

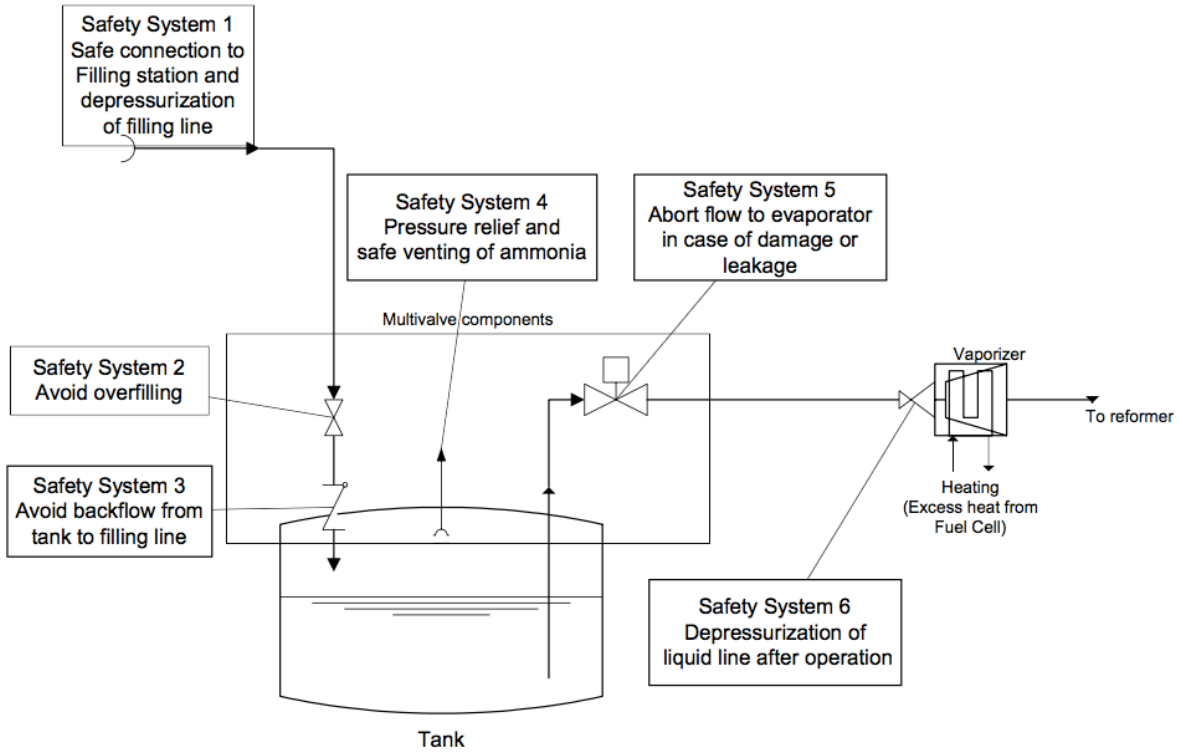


Figure 2. Principle of the ammonia tank system design.

Risø: p11

Marangoni Eco Explorer, 100% ammonia fuel, contained in adapted LPG fuel tank
Bigas design & build, Italy 2012

Ammonia Fuel: stored in LPG tanks
So, how safe are LPG Fuel Tanks?

"There are **no recorded injuries or fatalities in Australia that have resulted from ruptures and/or BLEVE's of vehicle LPG containers**.

It is the view of Energy*Safety* that **this good fortune should not become a pretext for failure to take action** on what is clearly a potential hazard."

Effect of Vehicle Fires on LP Gas Containers Installed to AS/NZS 1425:2007 **Energy*Safety***

Test 11 (4-11-09)

A Manchester container with no protection was tested in a vehicle fire (Ford Escort, centre in the left side photograph below). The container BLEVE'd with sufficient force to destroy the vehicle beyond recognition, as shown in the right side photograph.

Photographs A.11-Vehicles delivered for test and the remains of the Ford Escort.

Investigation into the Effect of Vehicle Fires on the Integrity of LP Gas Containers Installed to AS/NZS 1426:2007, Government of Western Australia, Department of Commerce, EnergySafety, 2010
http://contegointernational.com/wp-content/uploads/2013/11/AustraliaPropane_Test.pdf

Ammonia Fuel: Non-flammable, Not Explosive

"The RF index is based on the upper and lower flammability levels as an indicator for the ignition probability and the heat of combustion of the flammable compound:

According to it **ammonia is by far the less hazardous compound due to ignition probability and hazard**.

Hydrogen is by far the most hazardous substance."

Risø: Annex A, p.4

	RF number [kJ/g]	Explosive Limits % lower – upper
Ammonia	7	15 – 28
Methane	40	5.5 – 44
Hydrogen	402	4 – 75
LPG, propane	52	2.1 – 9.5
LPG, butane	59	2.1 – 9.5
Methanol	29-41	5.5 – 44
Ethanol	39	
Natural Gas		4.4 – 17
Gasoline		0.6 – 8

Explosive, at 1204° F

Risø: Annex A, pp. 4 – 18

Note: OSHA gives ammonia lower-upper limits as 16 – 25%

Ammonia Fuel: Similar Risk Level, Different Risks

"**All materials have a rating of 3 or 4 and thus may cause large difficulties in emergency situations**.

For ammonia it is due to the health while the others are very flammable.

The rating of 3 for **ammonia** indicates that emergency situations **may be handled by professionals having the right protection** available. Most of **the others** have a rating of 4 for flammability that **may be too dangerous to handle**."

Risø: p.45

	Health	Flammability
Ammonia	3	1
Natural Gas	1	4
Methane	1	4
Hydrogen	0	4
LPG	1	4
Methanol	1	3
Gasoline	1	3

"The NFPA rating for ammonia is 3 taking into account the physical stress of emergency people … thus the NFPA rating "overpredicts" the toxicity."

Risø: p.45

National Fire Prevention Association:
http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=704

Ammonia Fuel:
Similar Risk Level, Different Risks

Real Dangers of Ammonia:

- "The odor threshold for ammonia is between 5-50 ppm of air ... It is recommended that **if an employee can smell it they ought to back off** and determine if they need to be using respiratory protection."
- "Ammonia is not, strictly speaking, a poison and repeated exposure to it produces **no additive (chronic) effects** on the human body."
- Note: ammonia is not "toxic" unless you're a fish or suffer metabolic illness.
- "In the lungs, liquid anhydrous **ammonia causes destruction** of delicate respiratory tissue. Exposure to ammonia vapor may cause: Convulsive coughing, Difficult or painful breathing, Pulmonary congestion, Death."
- "Because liquid ammonia boils at -28°F, the expanding gas has **the potential to freeze anything in its path** of release, including human flesh and organs."
- Alkalis affect tissue differently than acids, which tend to burn and seal off a wound. Alkalis, such as **ammonia cause liquidization of tissue** and turn tissue into a sticky "goo" and mix with this tissue, causing further damage. As a result, anhydrous ammonia burns keep spreading until the chemical is diluted.

OSHA: https://www.osha.gov/SLTC/etools/ammonia_refrigeration/ammonia/

The Smell Test
… for an Inherently Safer Fuel

"NH3 is detectable by odor at concentrations much less than those necessary to cause harm. This allows persons who smell the gas to escape."

PPM	Duration	Effect
25	≤ 1 hour	"A clearly defined objectionable odor," and no more than "mild transient adverse health effects."
150	≤ 1 hour	No "irreversible or other serious health effects," and won't "impair their abilities to take protective action."
400		"Severe irritation of throat, nasal passages."
700		"Severe eye irritation."
750	≤ 1 hour	No "life-threatening health effects."
1,883	≥ 30 mins	"Onset of lethality" … "fatal to 1% of exposed population."
4,005	≥ 30 mins	"Fatal to 50% of exposed population."
8,519	≥ 30 mins	"Fatal to 99% of exposed population."

Quest: pp23-24 (3-6 – 3-7)

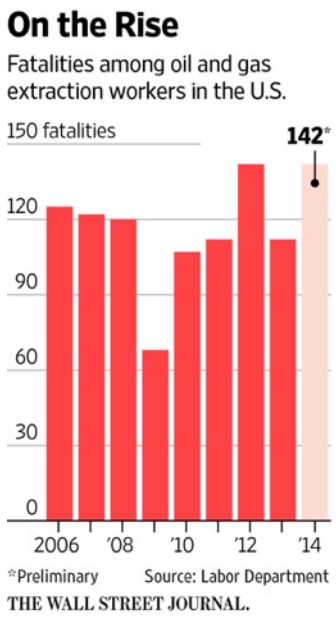
Could run
(everyone to hospital)

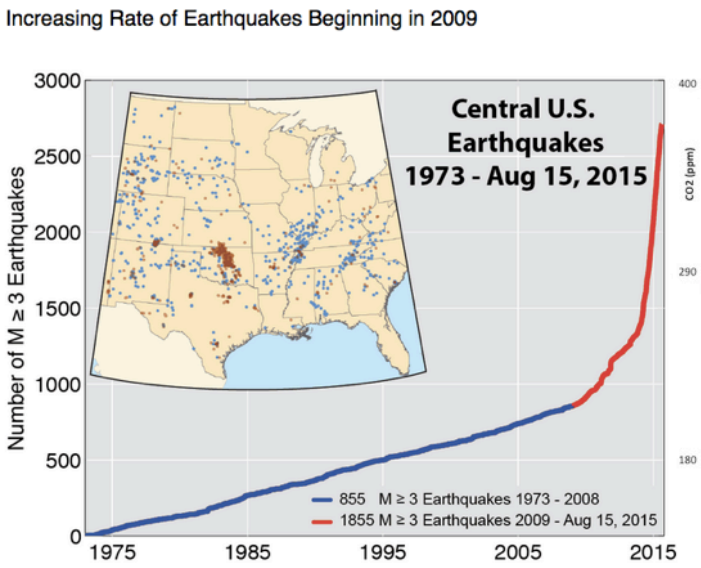
Couldn't run
(chained dog)

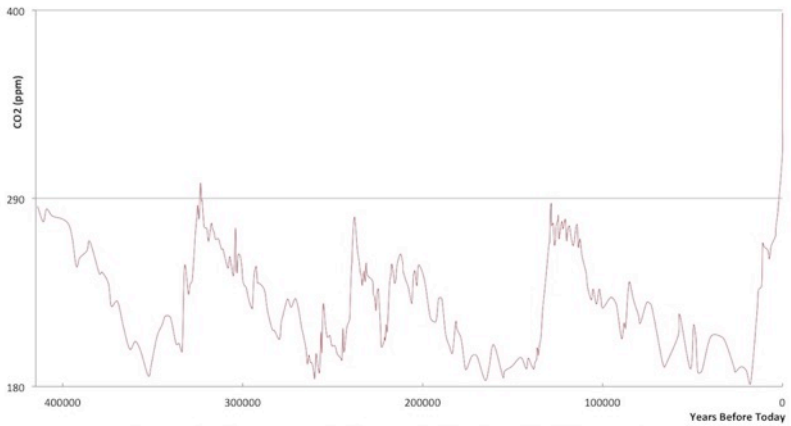
September 18, 2015
Henan Province, China
300kg ammonia released
1 fatality, 20 injured (reported)

South China Morning Post, 09/18/2015,
http://www.scmp.com/news/china/society/article/1859615/children-cough-blood-and-animals-die-chinese-factory-leaks

Context for “Acceptable Risks,” aka Cost of Business (as usual)







Context for "Acceptable Risks," aka Cost of Business (as usual)

Volkswagen, this morning:

- "So let's be clear about this, our company was dishonest – with the EPA, and the California Air Resources Board, and with all of you.

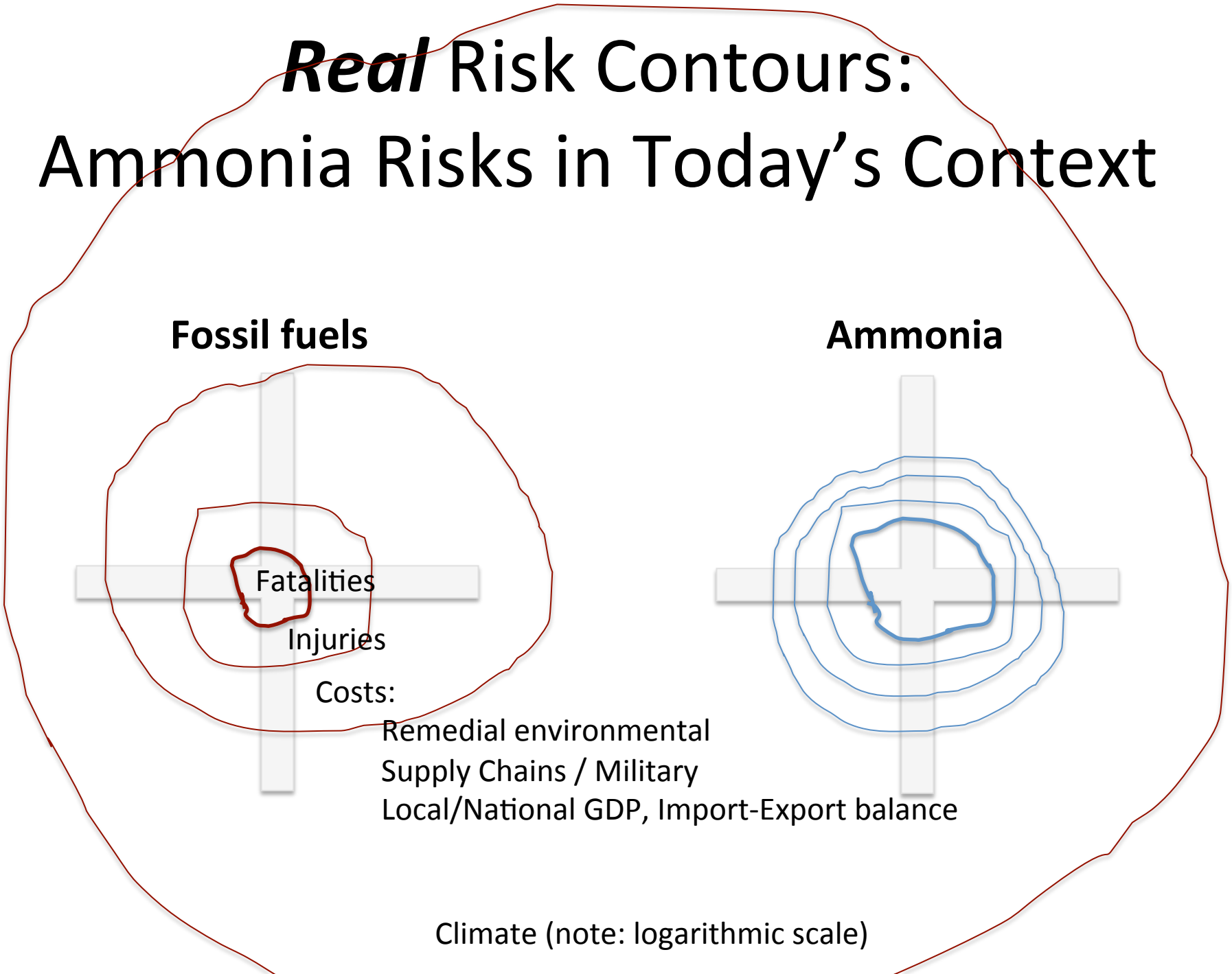
  And, in my German words, we have totally screwed up."
  Michael Horn, President and CEO, Volkswagen Group of America, 9/22/2015

- "Using a defeat device in cars to evade clean air standards is illegal and a threat to public health."
  Cynthia Giles, Environmental Protection Agency

Quantifying these risks:

- 11 million cars
- $7.3 billion set aside (potentially $18 billion in fines)
- $31 billion wiped off market capitalization
  http://www.nbcnews.com/business/autos/volkswagen-11-million-vehicles-could-have-suspect-software-emissions-scandal-n431456

Real Risk Contours: Ammonia Risks in Today's Context



Ammonia Fuel Risk Levels
– CONCLUSION –

- "The acceptance of ammonia will not be based on the results of numerical risk analysis, but will also be influenced by the public's perception of the threats of ammonia."
  Risø: p. 40

  But …

- Ammonia safety should not a barrier to the commercial development of ammonia fuel technologies.

- "Ammonia isn't sexy. It just works."
  David Garman, The Curse of Shiny Objects, NH3 Fuel Conference, 9/21/2015

- Thank you.