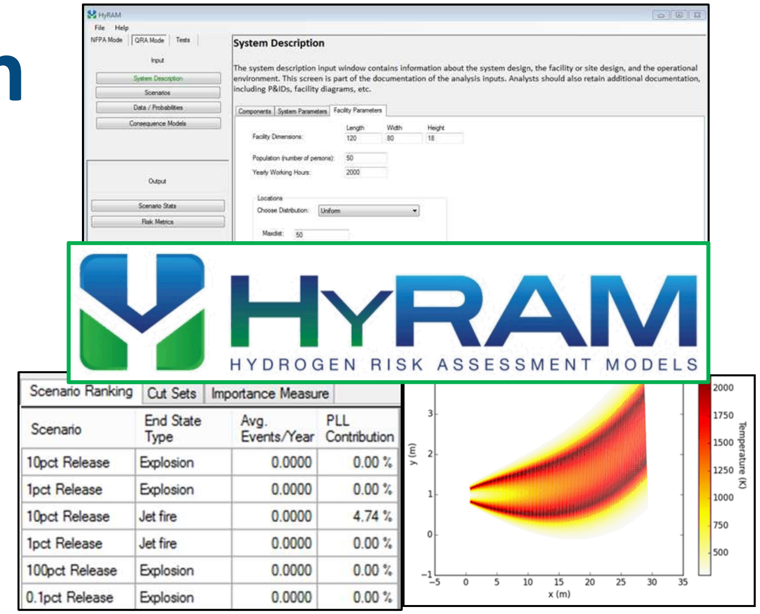
SAND2015-8873C

HyRAM: A methodology and toolkit for QRA of hydrogen systems



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Sandia National Laboratories

Albuquerque, NM and Livermore, CA

International Conference on Hydrogen Safety (ICHS 2015)

Yokohama, Japan

October 21, 2015

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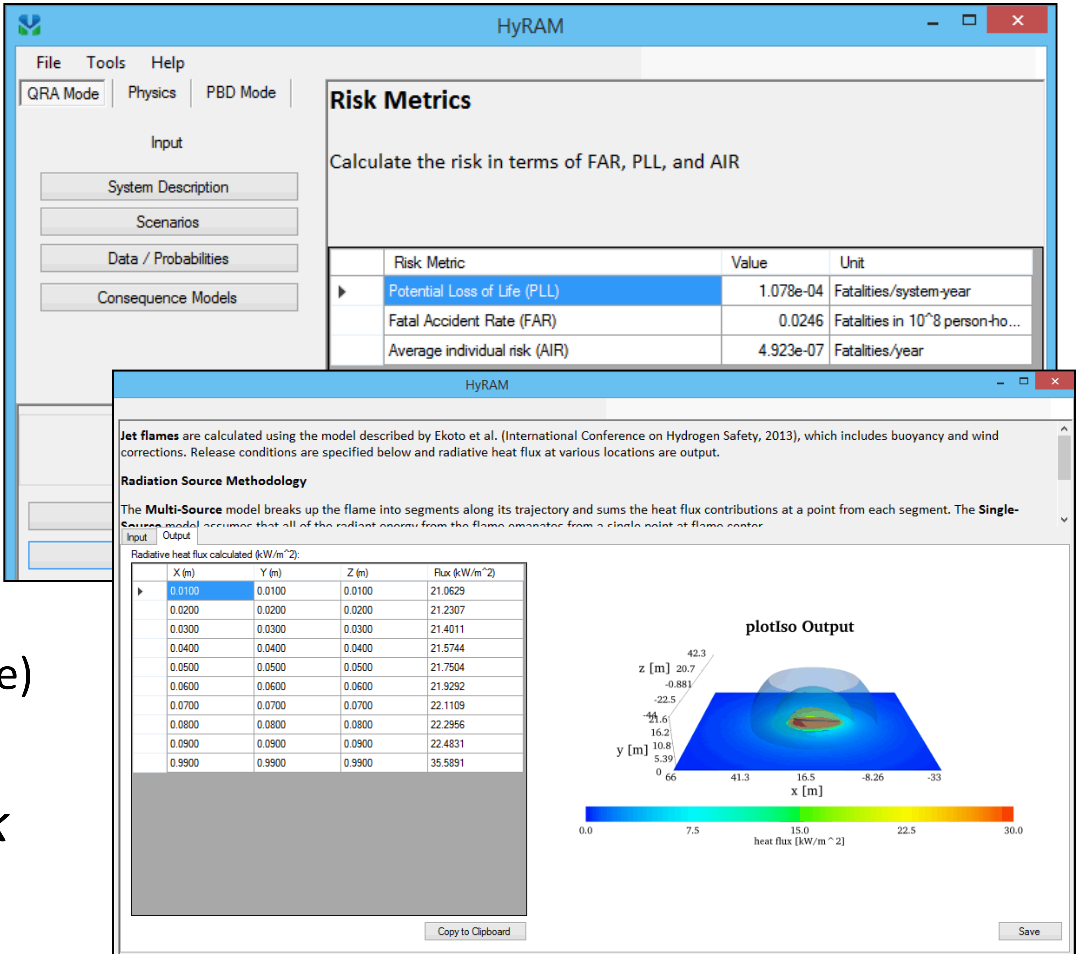
HyRAM in one slide

- **Integration platform** for state-of-the-art hydrogen safety models & data
  - Generic reliability data for H2 systems
  - Standardized scenarios and models
  - H2 phenomena (gas release, ignition, heat flux, overpressure)
- Software built to enable **industry-led** *quantitative risk assessments* (QRAs)
  - Puts the R&D into the hands of H2 industry safety experts



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

Outline

- Research background & motivation
- HyRAM method overview - Quantitative Risk Assessment (QRA) and consequence models
- HyRAM Toolkit demo (interactive)

H2 codes and standards (C&S) are using QRA

- NFPA 2 and ISO TC197 want to use science and engineering basis to bring rigor into C&S requirements.

- **Ongoing activities** applying QRA & behavior models in NFPA 2 & ISO TC197
  - GH2 separation distances - NFPA2 Ch. 7 (SAND2014-3416)
  - Indoor fueling requirements - NFPA2 Ch. 10: (SAND2012-10150)
  - Performance-based compliance option - NFPA2 Ch. 5) (SAND2015-4500)
  - Generalized approach for defining country-specific mitigations – ISO TC197 WG24 (ISO TR-19980-1)
  - Revision of LH_2 separation distances – NFPA 2 (In progress)

- **Future possibilities**, including: Enclosures (NFPA2 Ch7 and ISO TC197); Evacuation zone analyses; Design insight…

What is Risk Assessment?

Risk = "the potential for loss" (more specifically, "uncertainty about the potential for and severity of loss(es)"

Risk Analysis

- A process used to identify and characterize risk in a system
  - What could go wrong?
  - How likely is it?
  - What are the consequences?

Risk Management

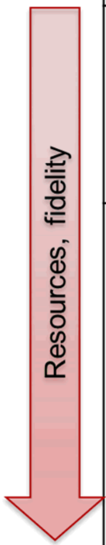
- Provide inputs to decision makers on:
  - Sources of risk
  - Strategies to reduce risk
  - Priorities

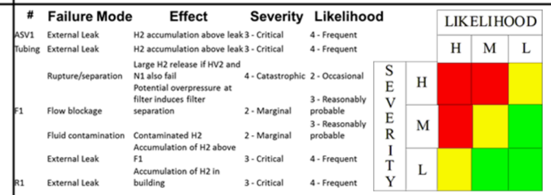
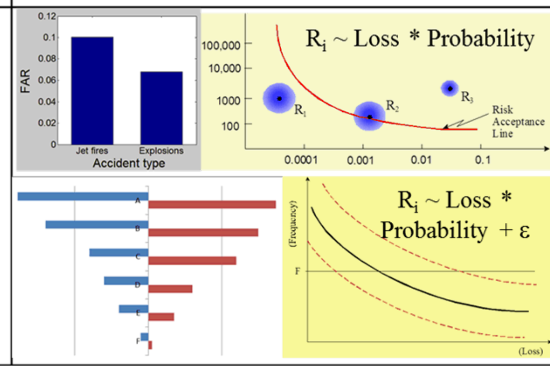
Can be <u>qualitative</u> or <u>quantitative.</u>

Quantitative form referred to as QRA (Quantitative Risk Assessment)

Risk Assessment

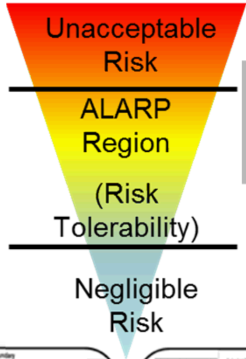
- **Caution:** One term, many methods!



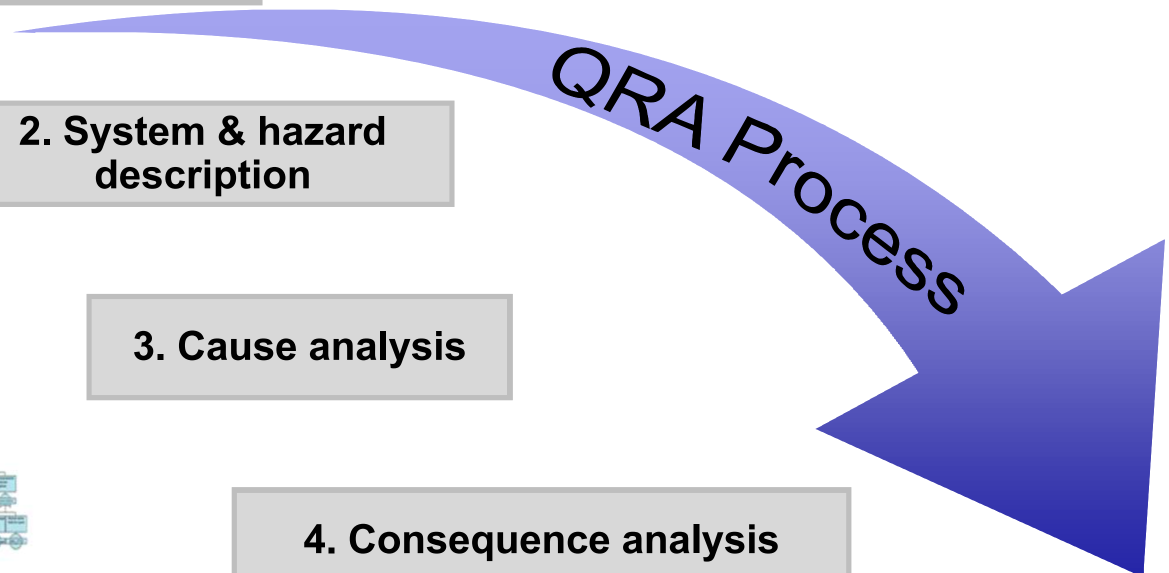
Type	Example methods	Example outputs
Qualitative to semi-quantitative	• FMEA • HAZOP • PHA	
Quantitative	**QRA [Quantitative Risk Assessment]** • Fault Trees • Event Trees • Bayesian Networks • Simulations	

- Rigorous QRA methods involve a wide range of models, data
- Relatively new concept for C&S development
  - SFPE guidance issued in **2006;** NFPA in **2007**: *Does not require a particular analysis method, goal, criteria, etc.*

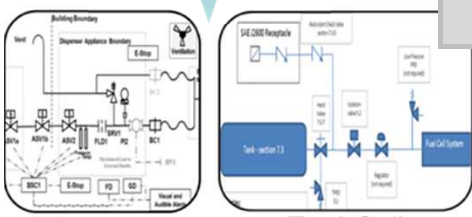
Generic QRA Method



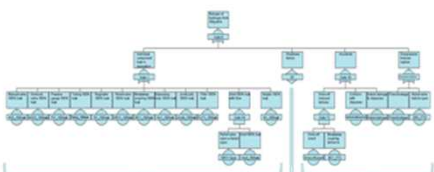
1. Set analysis goals



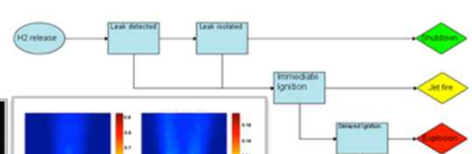
2. System & hazard description

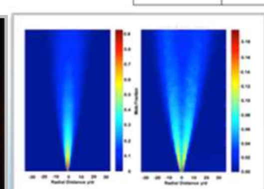


3. Cause analysis

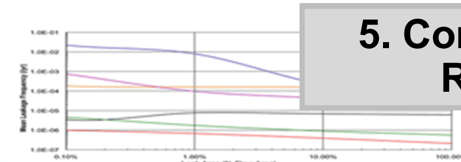


4. Consequence analysis





5. Communicate Results

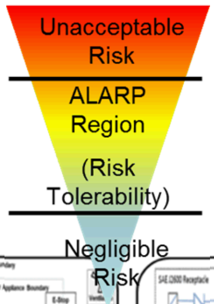


Occupation	FAR
U.S. Workforce total	1.8
Construction and extraction occupations	5.9
Industrial machinery, installation, repair, and maintenance workers	10.4
Industrial truck and tractor operators	3.0
Laborers and freight, stock, and material movers, hand	3.1
Farming, fishing, and forestry occupations	13.5

HyRAM Motivation

- The general QRA method is robust – but…quality varies based on the models and tools used
- Quality methods & strong technical basis are extremely important for developing consensus for RCS
- Comprehensive QRA uses a range of models, techniques, experts & disciplines – putting the pieces together is non-trivial.

Generic QRA Process & HyRAM philosophy



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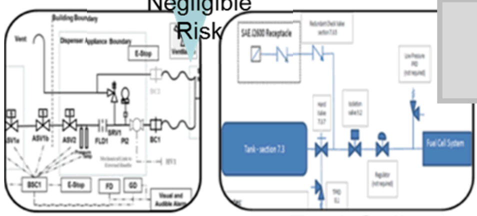

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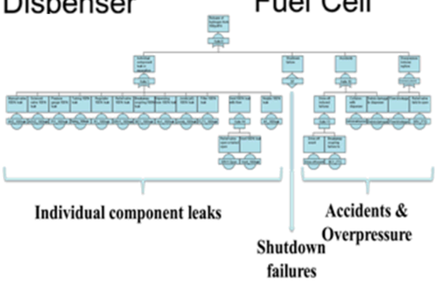

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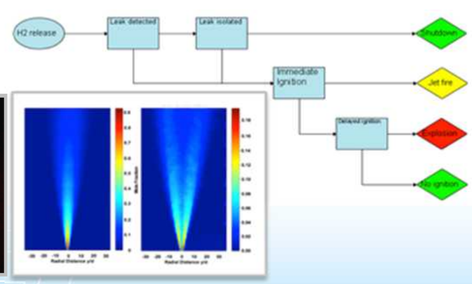

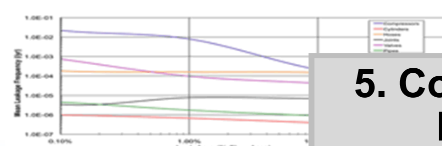

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5. Communicate Results

User-specific – Each analyst can establish own analysis goals, defines own system

User-neutral – All analysts apply established science & engineering basis (encoded in HyRAM)

Elements of QRA quality

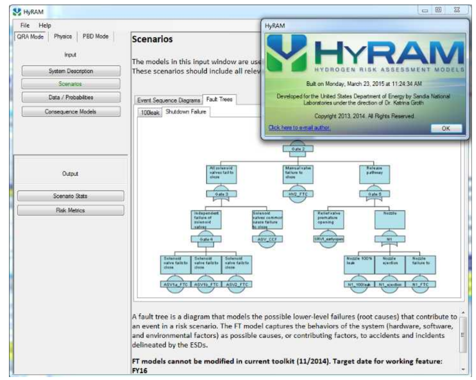
- **Repeatability**
  - Defined objectives and scope;
  - Clear definitions of failure modes, consequences, criteria, models, and data
  - Document the system, assumptions,
- **Validity & Verifiability**
  - Data, models, system, and analysis must be sufficiently documented for a peer reviewer to evaluate assumptions, completeness, etc.
  - Use experimentally validated models (as available) and published models and data.
- **Comparability**
  - Necessitates flexible modeling tools, documentation of methodology
- **Completeness**
  - Ability to update models as knowledge improves
  - Ensure that analyzed system matches the system as built and operated

Project Approach: Three coordinated activities

Apply R&D in RCS

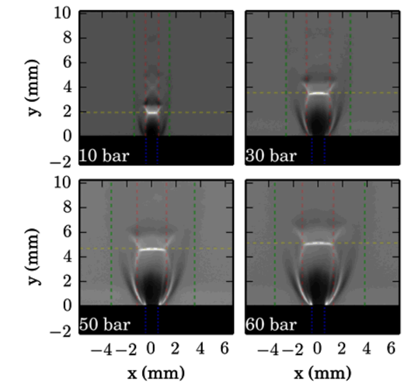
Apply risk assessment techniques in step-out hydrogen technologies

QRA methods, tools R&D



Develop integrated algorithms for conducting QRA (Quantitative Risk Assessment) for H_2 facilities and vehicles

H2 behavior R&D



Develop and validate scientific models to accurately predict hazards and harm from liquid releases, flames, etc.

Enabling methods, data, tools for H_2 safety & RCS community

Recent Sandia R&D enabling QRA

- Design brief template to facilitate documentation & transparency
  - AC LaFleur, AB Muna & KM Groth. *Fire Protection Engineering Design Brief Template: Hydrogen Refueling Station* SAND2015-4500, Sandia National Laboratories, Albuquerque, NM, June, 2015.
- HyRAM software & technical basis (documented QRA approach, models, data; synthesized from 40+ sources -- see next slide)
  - KM Groth, ES Hecht & JT Reynolds. *Methodology for assessing the safety of Hydrogen Systems: HyRAM 1.0 technical reference manual* SAND2015-DRAFT, ~Nov 2015.)
  - Ongoing development with state-of-the-art from R&D community (HySafe, IEA HIA Task 37)
- Experimental work to validate models *Turbulent Combustion Lab.*
  - **Cold Hydrogen**:
    - E. S. Hecht, M. D. Zimmerman, A. C. LaFleur & M. Ciotti. Design of the Cryogenic Hydrogen Release Laboratory. SAND2015-7521, Sept **2015**
    - I. W. Ekoto et al. Liquid Hydrogen Release and Behavior Modeling: State-of-the-Art Knowledge Gaps and Research Needs for Refueling Infrastructure Safety SAND2014-18776, October, 2014.
  - **GH2 releases, jet flame models, overpressure experiments –** see next slide.

Sources of models & data in HyRAM 1.0

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Major elements of HyRAM software

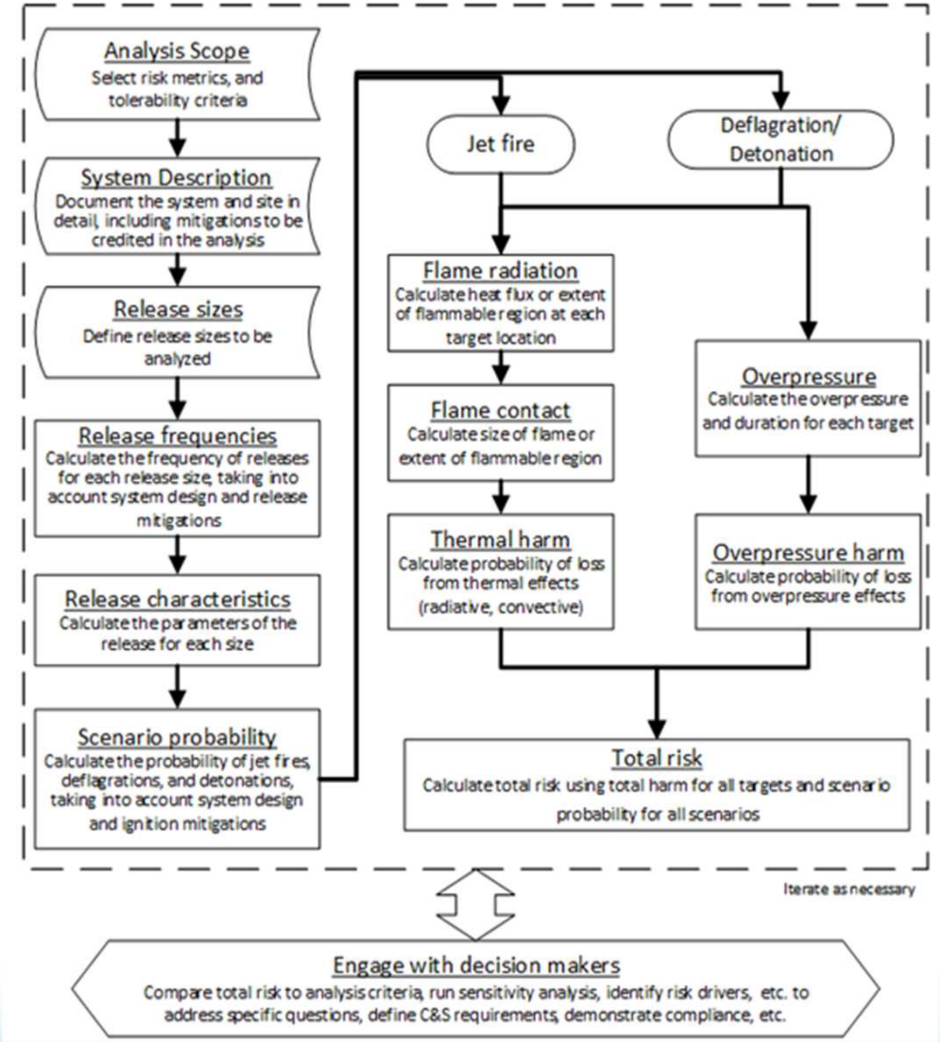
QRA Methodology
- Risk metrics calculations: FAR, PLL, AIR
- Scenario models & frequency
- Release frequency
- Harm models

Generic freq. & prob. data
- Ignition probabilities
- Component leak frequencies (9 types)

Physics models
- Properties of Hydrogen
- Unignited releases: Orifice flow; Notional nozzles; Gas jet/plume; Accumulation in enclosures
- Ignited releases: Jet flames w/ and w/o buoyancy; overpressures in enclosures

Mathematics Middleware
- Unit Conversion System
- Math.NET Numerics

Documentation
- Algorithm report (DRAFT ~Nov 2015)
- User guide (SAND2015-7380 R)



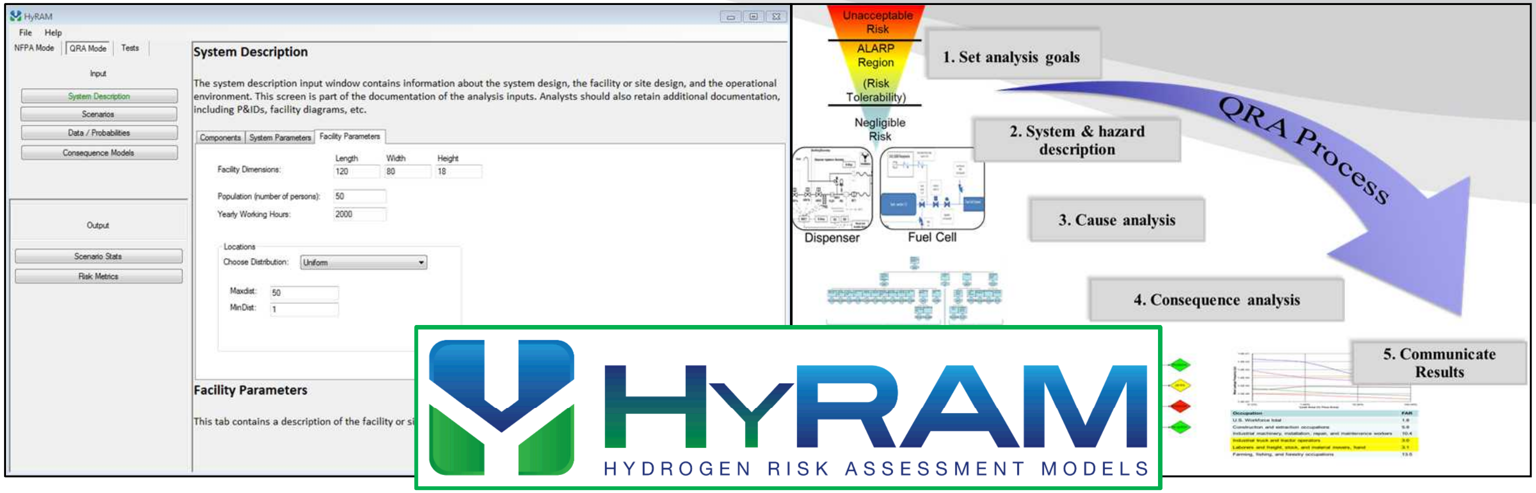
+ Free download via web (~early 2016)

HyRAM Toolkit demo

Next steps

- **Long-term vision** Fully configurable, tested software product available for users to calculate hydrogen risk values and independent consequence models to design, develop and adapt system designs globally.

- Plans to release HyRAM 1.0 in early 2016 via web download
- Upcoming extensions:
  - Integration of overpressure model into QRA mode (undergoing internal testing)
  - Add risk-features for modeling root causes, ranking risk contributors, adding mitigations (Fault Trees, Event Sequence Diagrams, Importance Measures)
  - Add validated model for liquid/cryogenic H_2 release (experimental work ongoing)



Thank you!

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Research supported by DOE Fuel Cell Technologies Office (EERE/FCTO)