Hythane® -- Bringing Hydrogen to Zero Emissions Reality

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Overview of Presentation

- What is Hythane®?
- A Step Toward the Hydrogen Economy
- How can Hythane® help Implement CARB's ZBus bus strategy?
- Possible course of action
- Conclusions/Questions

The Hythane® Story

- Invented in 1989 by Frank Lynch and Roger Marmaro.
- Initial concept: extend range of a lean burn hydrogen vehicle by adding CNG.
- In 1990, HY-5 was designed to mimic the burn rate of Gasoline for duel fuel vehicles.
- In 1992-93, HY-7 was developed for larger Diesel derivative NG engines with oxidization catalysts.
- By 2002, extensive testing validated sweet spot for heavy-duty Hythane® engines at 7% H_2 by energy and 20% by volume.

Past and Current Hythane® Projects

- ‘89 tests of American Lung truck at CSU
- ‘90-91 CARB tests of the HY-5 prototype
- ‘92-93 NREL engine study at CSU
- ‘93 EPA tests of National Fuel Gas (Erie, PA) van
- ‘94-96 Montreal bus development, demo and testing by Environment Canada
- ‘99-00 Upgrade Montreal buses for SunLine Transit
- ‘03-04 Work with Cummins-Westport to develop engines for SunLine Transit (Thousand Palms, CA)
- Ongoing development of Yuchai engines for China

Hythane® Achievements

- 1st Hythane® Vehicle Burns "HY5", 1990
- 5% Hydrogen (by Energy Content), Balance CNG
- Tanks Under Truck Give 250 km Range
- CARB tests showed ULEV emissions

- 3-Vehicle Denver Hythane® Project, 1992
- Gasoline Truck, Compressed Natural Gas (CNG) Truck and "HY5" Truck (5 energy % H2 in CNG)
- CDH Tests show 50% NOx reduction

- Montreal Hythane® Bus Project (1995)
- Environment Canada test shows 45% NOx reduction

Hythane® Achievements (cont.)

SunLine's Second Hythane® Bus Project (2004)

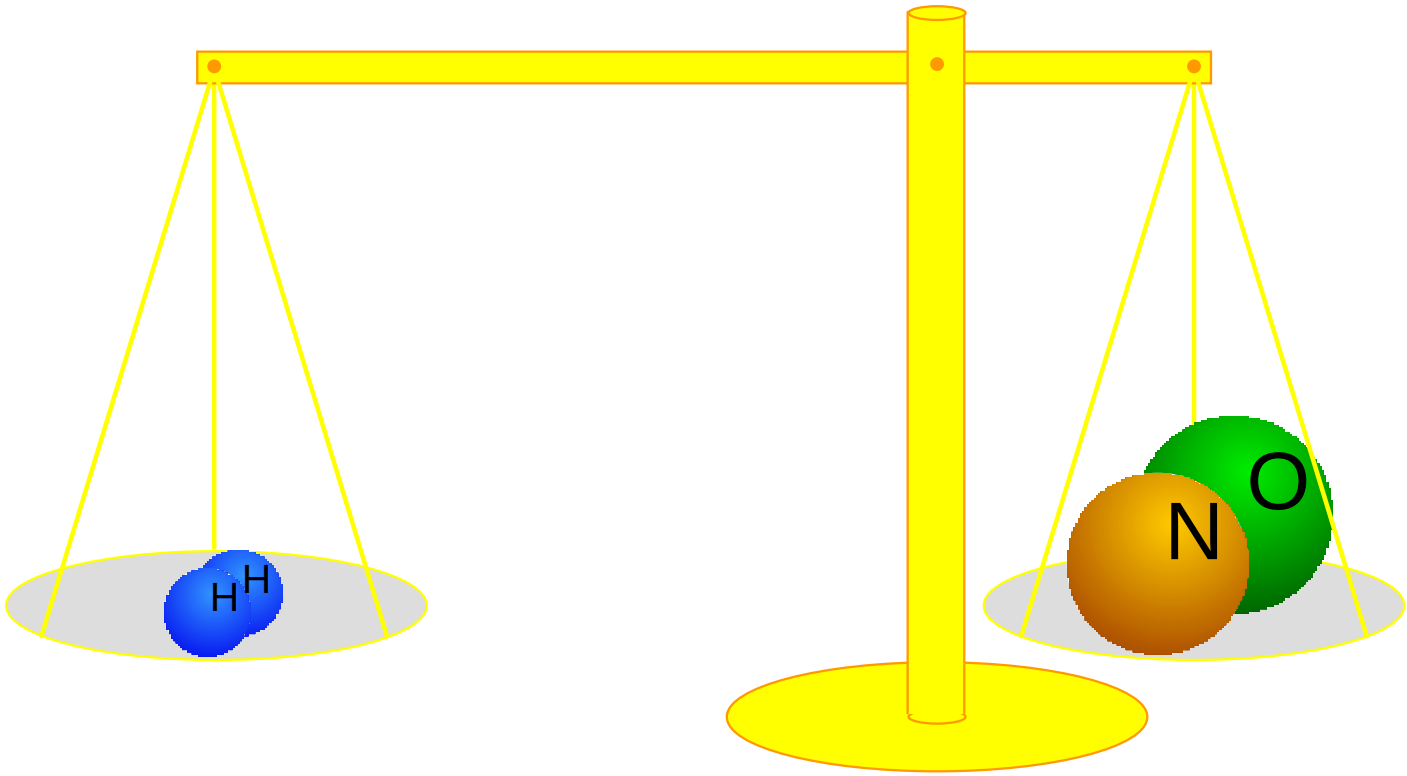
- First engine manufacturer involvement in Hythane®(Cummins-Westport)
- 20-32% hydrogen by volume
- Best emissions reduction to date (50% NOx decrease with 7% hydrogen energy [20% by volume])
- Some of SunLine's hydrogen is from renewable solar energy and NG reformation

Hythane® – Facilitating the Transition to Hydrogen

- ✓ Proven technology
- ✓ 5 - 7 % by Energy of H_2/Natural gas blend (20% by volume)
- ✓ Up to 50% NOx emission reductions
- ✓ Piggybacks on existing CNG/NG infrastructure
- ✓ Provides tremendous strategic flexibility: Can be calibrated to reduce NOx by up to 30% without decrease in range or increase range up to 10% with no decrease in NOx
- ✓ Reduces emissions of greenhouse gases by 7%
- ✓ Roll out of Hythane® infrastructure (NG reformation & blending) most cost effective 1st step toward Hydrogen infrastructure development.
- ✓ Clean H_2 Enriched NG Fuel is available **TODAY!**

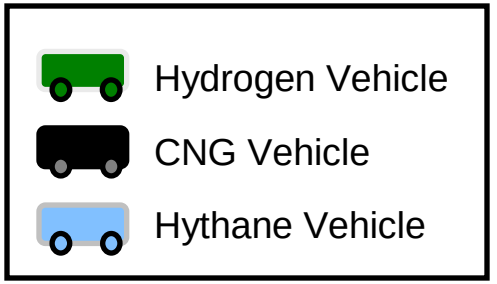
HYTHANE®

Hythane® Leverage

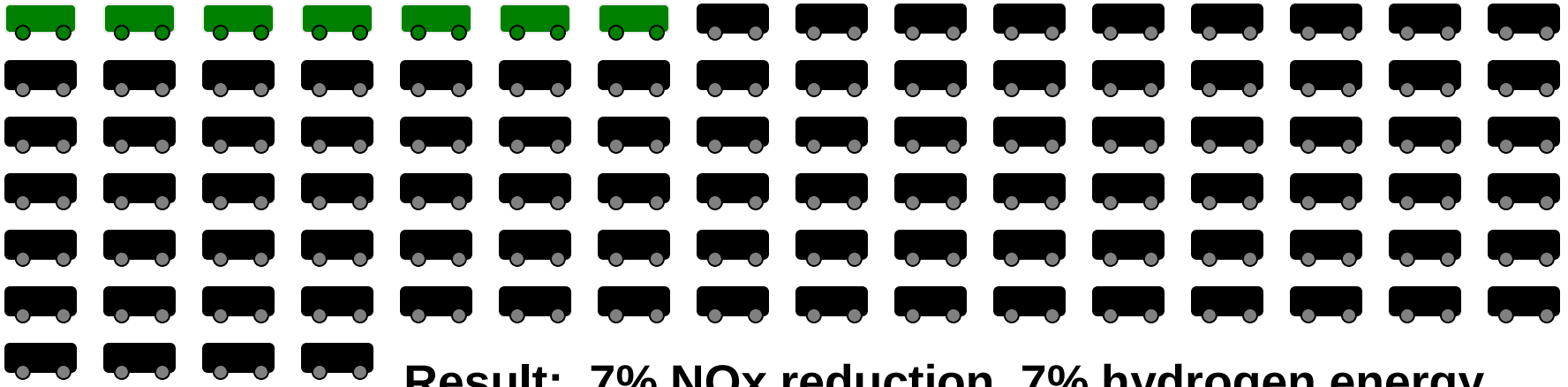


Most Cost-effective Use of H_2

What is the best use of 7% Hydrogen Energy?

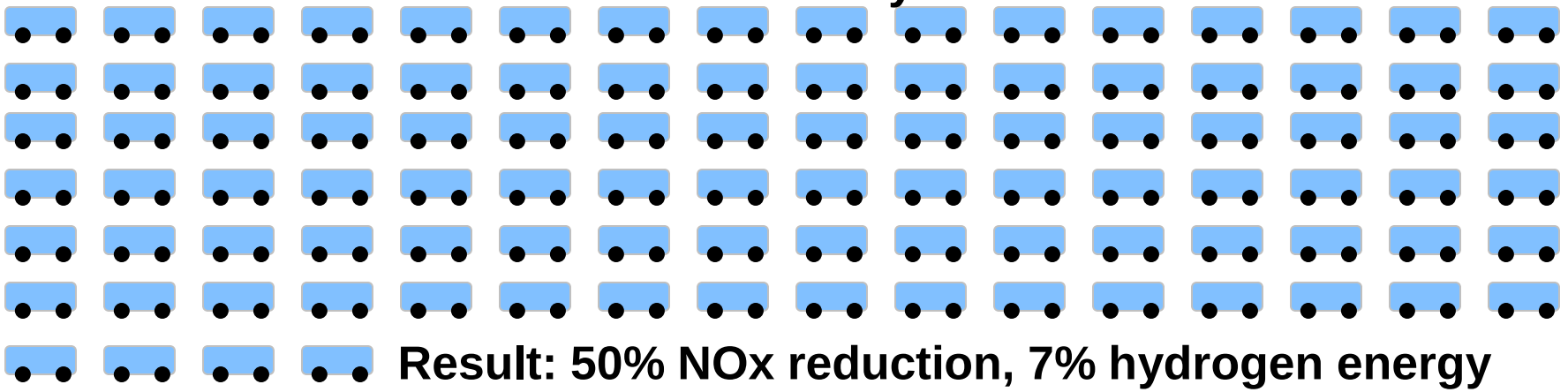


Case 1: Convert 7 CNG Vehicles to Hydrogen



Result: 7% NOx reduction, 7% hydrogen energy

Case 2: Convert 100 CNG Vehicles to Hythane®



Result: 50% NOx reduction, 7% hydrogen energy

ZBus Regulation

- What is the intention of ZBus requirement?
  - Accelerate the introduction of Hydrogen into transit fleet use
  - Reduce transit fleet emissions by 15%
  - Reduce transit riders exposure to toxic air contaminants
  - Stimulate the commercialization of fuel cell bus technology
  - Create a demand for large numbers of units, thereby driving down the price
  - Stimulate the development of hydrogen production capacity as well as fueling infrastructure

Barriers to ZBus Implementation

- FC Bus Technology not ready for widespread commercialization
- FC Buses currently 10X price of diesel or natural gas models
- Hydrogen expensive – 4X cost of diesel and 5X cost of natural gas
- Production and dispensing infrastructure not in place and expensive to build

How to Reduce NG Bus Fleet Emissions by 15% by 2010

- Convert 15% of fleet to Pure Hydrogen
- Convert 15% of fleet to Electric
- Take 15% of fleet out of service
- Convert 30% of existing Natural Gas Bus fleet to Hythane®

Evaluating Options that Ease ZBus Implementation

- Look for a bridge technology that meets the goals while:
  - ✓ Utilizing technology that is ready today
  - ✓ Minimizing the impact on vehicle range
  - ✓ Gives the largest emissions benefit for resources used
  - ✓ Requires least impact to existing vehicles and infrastructure
  - ✓ Lays groundwork for the hydrogen production & dispensing infrastructure needed for ZBus mandate

Hythane® and ZBus Mandate

- Hythane® - only technology that can deliver on most of CARB's ZBus goals today
  - Proven technology is ready for implementation today
  - Hythane® reduces NOx emissions by 50% over NG baseline
  - Reduce fleet emissions by NOx 50% upon implementation
  - Utilizes existing NG infrastructure and adds hydrogen with minimum impact
  - Best known available leverage of hydrogen
  - Yields the most Bang for the Buck (Best use of Funds)

Existing Natural Gas Infrastructure Eases Transition

- Via Time to Market
  - No longer experimental - over 3 million NGVs on the globe now
- Easy Transition
  - Near-term Objective
    - Existing CNG vehicles can easily be converted to operate on Hythane®
    - Hythane® can be deployed at existing CNG & LCNG stations
    - Customer base already accustomed to using a gaseous fuel
  - Medium-term Objective
    - Hythane Company is currently developing LNG/Cryogenic Hythane®
    - LNG/Cryogenic Hythane® to be deployed at existing LNG stations

Proposal

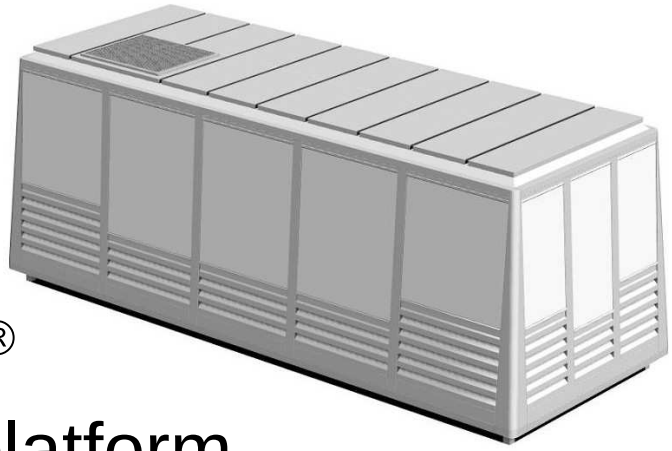
- Make Hythane® an option to achieve the interim emission reduction equivalency of Zbus

- CARB help fund the verification of Hythane® on the 3 of the 4 primary natural gas engines in use
  - ✓ B Gas Plus – 52
  - ✓ C Gas Plus – 487
  - ✓ DDC – 1964
  - ☐ There are 887 Cummins L10s in use, but 95% are MY 1998 and older

Hythane® Conversion of Existing Natural Gas Buses

- Cost $187,500 to calibrate and verify that Hythane® will yield 50% NOx reduction per engine
- Once calibration is performed, will cost about $3000 per bus to manufacture and install conversion kit.
- Chance that for some buses NOx reduction will significantly exceed 50%

HYTHANE® Maker



- Co-manufactured with HyRadix® using the Adeo™ Reformation platform
- 500 Nm^3/hr of Hythane® (~ 275 Scfm) @ 100psi
- One Hythane® Blending unit that will fuel 40 buses per day cost $800,000
- Assume the installation of 1 Hythane® maker for every 40 buses or fraction thereof – therefore excess capacity is likely
- Can produce100 Nm^3/hr Hydrogen for H2 applications

Assumptions

- 2.5 miles per GGE
- 43,000 miles/yr (LAMTA average)
- 2 g/bhp-hr NOx emissions level
- Each bus will operate on Hythane® for seven years
- Existing compression and storage can be used for Hythane®

Hythane® – Helping to Realize the ZEV Bus Future

- Cost of two fuel cell bus demonstrations in Bay Area for **six buses** and **two fueling facilities**
  - $33.5 million
  - NOx reduction ~ 17.2 tons (0.41 tons/bus X seven years operation)
- Cost to convert 30% of existing natural gas buses to Hythane® (**1,407**) and build **40 hydrogen production & dispensing facilities**
  - $37 million
  - NOx reduction = 1,970 tons (0.2 tons/bus X seven years operation)

Hythane® can Accelerate the Introduction of Hydrogen into Fleet Use

- Most cost effective use of Hydrogen that is available today
- Infrastructure that builds on and co-exists with Natural Gas stations
- Infrastructure that will continue to be useful into the Hydrogen economy
- Pre-Approval of “Hythane®” as means to fulfill the ZBus requirements

HYTHANE®

Thank you from Hythane Company!

Questions?

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