## *Attachment 1: Description of Emission Reduction Measure Form*

*Please fill out one form for each emission reduction measure. See instructions in Attachment 2.*

**Title: Ammonia Fuel for California Highway Vehicles (Submitted 9/29/07)**

**Type of Measure (check all that apply):**

- ☐ Direct Regulation
- ☒ Market-Based Compliance
- ☒ Monetary Incentive
- ☐ Non-Monetary Incentive
- ☐ Voluntary
- ☐ Alternative Compliance Mechanism
- ☒ Other Describe: **Technology Improvement**

**Responsible Agency: ARB**

**Sector:**

- ☒ Transportation
- ☐ Electricity Generation
- ☐ Other Industrial
- ☐ Refineries
- ☐ Agriculture
- ☐ Cement
- ☐ Sequestration
- ☐ Other Describe:

**2020 Baseline Emissions Assumed (MMT CO2E): 170 MMT**

**Percent Reduction in 2020: ~100%**

**Cost-Effectiveness ($/metric ton CO2E) in 2020: $17.60/MT CO2E initially, then decreasing to zero.**

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**Description:** California uses ~15 billion gallons of gasoline and 1-2 billion gallons of diesel fuel annually for vehichle use. When burned in engines, each gallon of those fuels produces approximately 10 kg of CO2. Thus, the total annual contribution to worldwide GHGs by California from vehicles alone is approximately 170 million tons, roughly 2 percent of the annual worldwide CO2 emissions.

Because they contain no carbon, hydrogen (H2) and ammonia (NH3) are the only two fuels that deliver power to vehicles with zero greenhouse gas emissions. That is not true of any fossil fuels, and not true of biofuels. Compared to hydrogen, ammonia is by far the easier to store and deliver, and contains more than 50% more hydrogen energy per volume than liquid hydrogen itself. Ammonia has and will power internal combustion engines and fuel cells. Estimated cost to convert gas and diesel engines to operate on ammonia is $1500 per engine. Direct ammonia fuel cells, like hydrogen fuel cells, are still under development, and could become available in 5-7 years.

Ammonia fuel can be straightforwardly synthesized from water and air using renewable energy. That energy could come from wind, solar, various ocean energies, or offshore energy sources such as OTEC. It can also come from available nuclear energy, surplus hydroelectric power, or by adding additional power generating capacity to existing hydroelectric projects.

This author could find no information readily available on the number of vehicles on California highways. But, with a population of 35 - 40 million people, it can be assumed that there is approximately 15 - 20 million vehicles operating in California.

**Emission Reduction Calculations and Assumptions:** Each gallon of gasoliine or diesel fuel that is replaced by ammonia fuel saves 20-25 pounds (~10 kg) of CO2 from being emitted into the atmosphere. For the ~17 million gallons of gasoline and diesel consumed annually in California, that equates to ~170 million metric tons of CO2 annually.

**Cost-Effectiveness Calculation and Assumptions:** Each vehicle internal combustion engine should be able to be converted to operate on ammonia or ammonia-rich blend (for combustion-ignition diesel engines a small amount of clean high cetane additive may be required for efficient operation) for nominally $1500. Assuming a useful life of one of these engines/vehicles to be 10 years, the annualized conversion cost would be $150. Thus, for 20 million vehicles, the total annualized cost in California would be approximately $3 billion ($3B/170MMT = $17.6/MT). These costs would be expected to be borne by the vehicle owners, likely motivated by tax credits from the state of CA. Of course, in time these conversion costs go away, since new vehicles will be produced ammonia-ready and will need no conversion

There would also be a slight savings in fuel cost since ammonia fuel is approximately 2/3 the cost of gasoline or diesel on an equivalent energy basis. An additional cost, likely borne by the current gasoline/diesel providers or an emerging new ammonia fuel industry, would be the cost to install ammonia fueling capabilities at current fueling stations. This would simply require straightforward tank storage and pump/delivery system for fueling vehicles converted to run on ammonia. Again, these costs would be one time only, and would decrease to zero after the transition time.

**Implementation Barriers and Ways to Overcome Them:** The technology to operate internal combustion engines on ammonia is proven and available. Direct ammonia fuel cells are being commercialized. There appear to be no major obstacles to implementation.

**Potential Impact on Criteria and Toxic Pollutants:** In addition to emitting no CO2, combustion of NH3 in engines produces no CO, no SO2, and no particulates. Lab results have shown that NOx emissions are reduced by 75% over an equivalent gasoline engine. But the situation is actually better than that, because NH3 itself is the

active ingredient in NOx treatment, so NOx emissions can be effectively reduced to zero.

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