

# LPG Fuel Blends Evaluation Project

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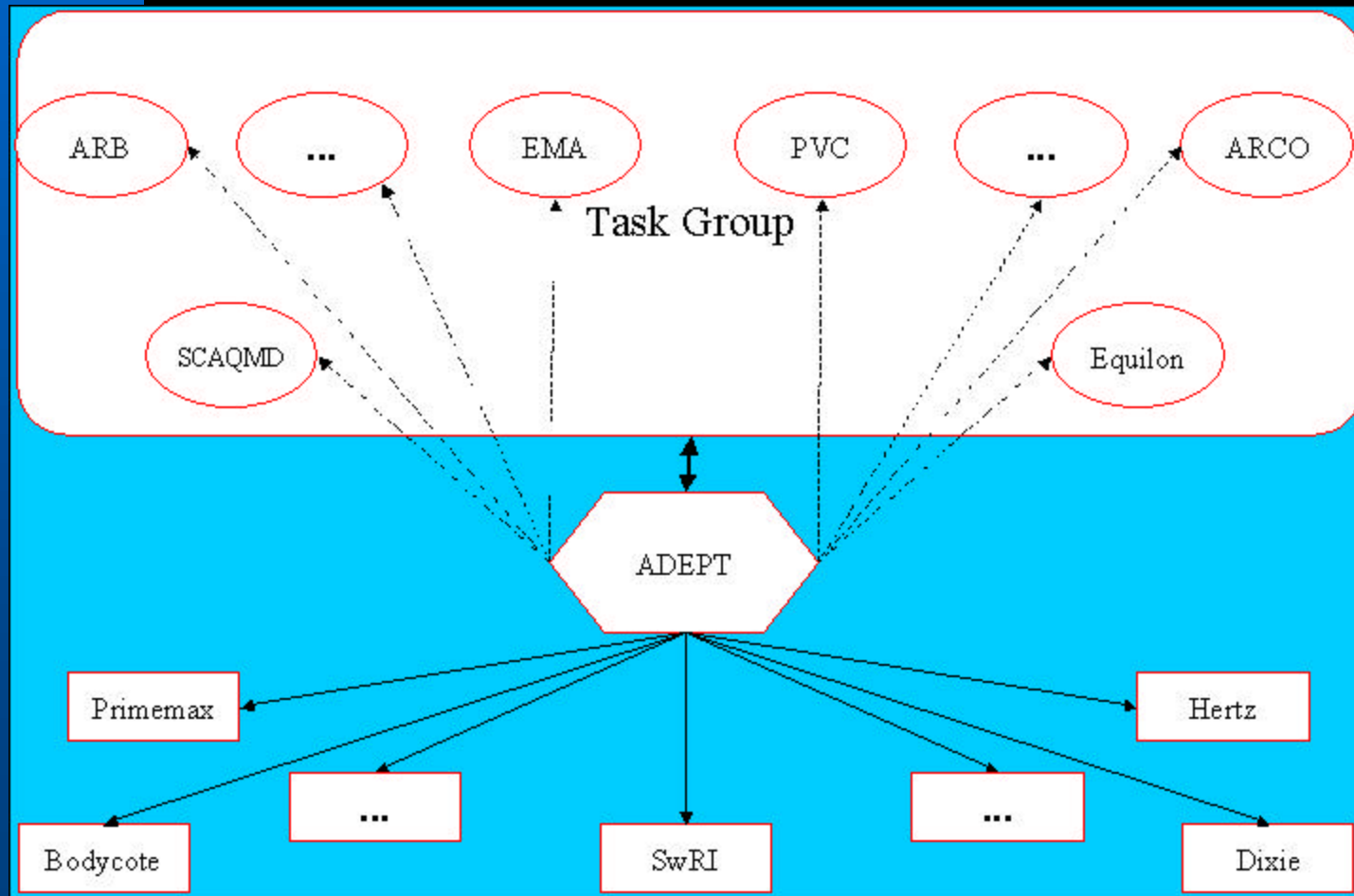
# Project Contributors/ Task Group

- ARCO Products Company
- California Air Resources Board
- Cummins Engine Company
- Engine Manufacturers Association
  - Equilon
  - Ford Motor Company
- National Propane Gas Association
- National Renewable Energy Laboratory
- **Natural Resources Canada**
- Propane Education and Research Council
  - Propane Vehicle Council
- Railroad Commission of Texas Alternative Fuels Research & Education Division
- South Coast Air Quality Management District
  - Tosco Refining Company
- Western Propane Gas Association

# Project Participants

- Aeriform
- Air Liquide
- American Automobile Manufacturers Association
  - ARB Haagen Smit Laboratory (El Monte, CA)
    - Bell Hydrogas
    - **Bodycote Ortech Inc.**
    - Consulting Solutions
      - Cummins Ontario
      - Dixie Services Inc.
        - GFI
        - Hertz Engineering
          - IMPCO
          - Maxxam Analytics Inc.
  - Nova Chemicals Corporation
    - Phillips
    - Primemax Energy Inc.
  - Southwest Research Institute

# Organization Chart



# Background

- **Propane, or Liquefied Petroleum Gas (LPG) fuel quality issues**
- **Air Resources Board Ruling**

# ARB LPG Specification

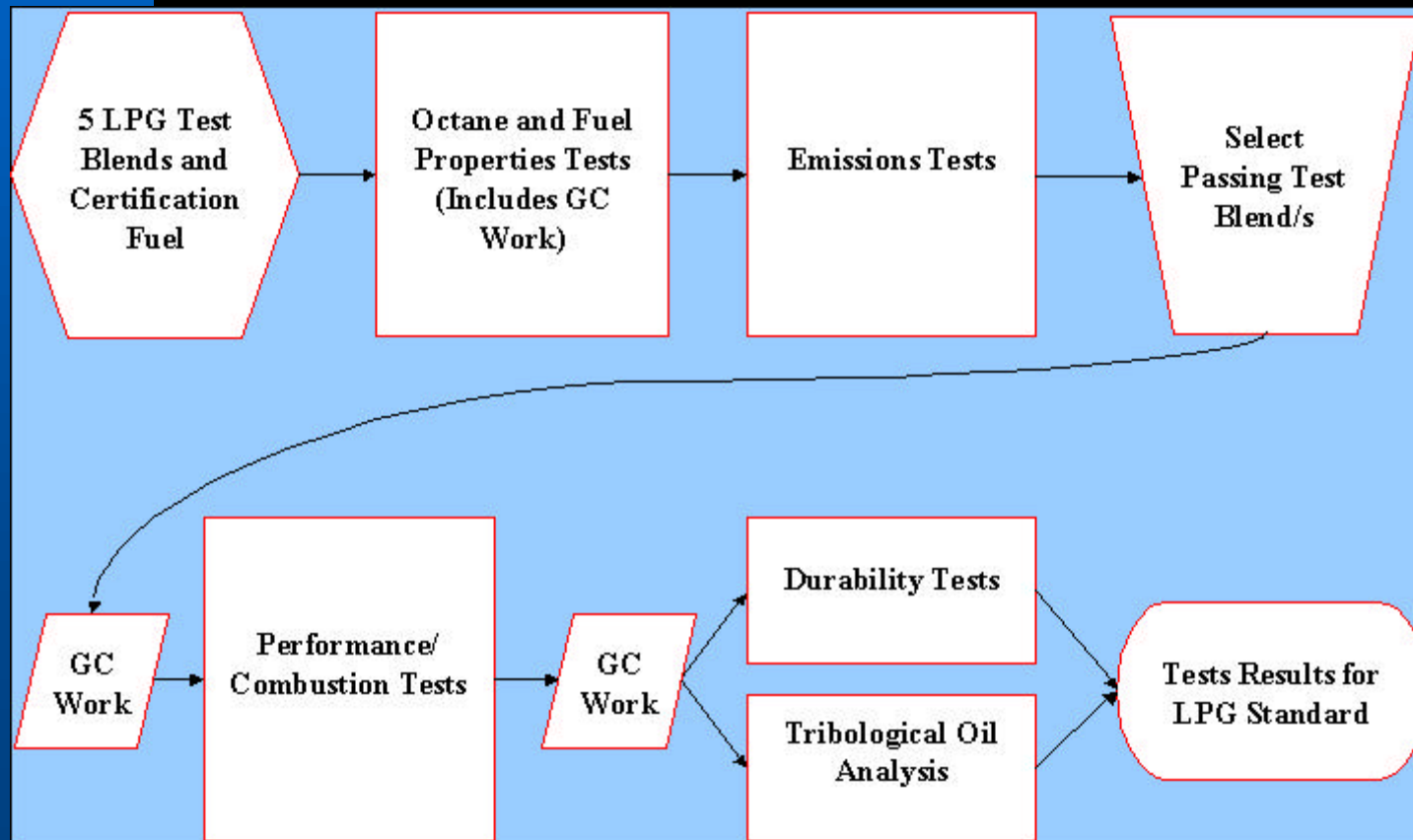
<b>ARB Ruling Specifications for LPG for Motor Vehicle Applications*</b>	
<b>Specification</b>	<b>Value</b>
Propane (C <sub>3</sub> H <sub>8</sub> )	85.0 vol.% (min.)
Propene or Propylene(C <sub>3</sub> H <sub>6</sub> )	10.0 vol.% (max.)
Butanes (C <sub>4</sub> H <sub>10</sub> ) or Volatility residue: evaporated temp., 95%	5.0 vol.% (max.) -37 °F (max.)
Butenes	2.0 vol.% (max.)
Pentenes and heavier	0.5 vol.% (max.)
Residual matter: residue on evap. of 100ml. Oil stain observed.	0.05 ml (max.) pass
Corrosion, copper strip	No. 1 (max.)
Sulfur	80 ppmw (max.)
Moisture Content	Pass
Vapor Pressure at 100°F	208 psig (max.)

\*Effective: December 8, 1999

# Project Objectives

- **Provide ARB with test data to help develop and support the current LPG fuel quality standard**
- **Identify which LPG blend could provide equal or better emissions than Certification LPG**
- **With blend/s that pass the initial emissions tests:**
  - (1) Conduct appropriate performance and combustion tests**
  - (2) Conduct appropriate durability tests**

# Test Program: Flow Chart





# Fuels Tested

<b>Tested LPG Fuel Blends Composition (% Vol.)</b>			
<b>Fuel</b>	<b>Propane</b>	<b>Propene</b>	<b>n-Butane</b>
<b>Cert. Fuel</b>	93.5 ± 1%	3.5 ± .5%	1.9 ± .5%
<b>Test Fuel # 1</b>	85.0 ± 1%	10.0 ± .5%	5.0 ± .5%
<b>Test Fuel # 2</b>	80.0 ± 1%	15.0 ± .5%	5.0 ± .5%
<b>Test Fuel # 3</b>	80.0 ± 1%	10.0 ± .5%	10.0 ± .5%
<b>Test Fuel # 4</b>	76.0 ± 1%	3.8 ± .5%	20.0 ± .5%
<b>Test Fuel # 5</b>	77.0 ± 1%	21.0 ± .5%	2.0 ± .5%

# Octane Tests

Octane Rating Tests			
LPG Fuel Blend Name	Research Octane #	Motor Octane #	Anti-Knock Index*
Certification Fuel	108.4	96.1	102.3
Fuel #1	107.7	94.6	101.2
Fuel #2	106.6	93.7	100.2
Fuel #3	107.0	94.1	100.6
Fuel #4	106.8	94.4	100.6

\*Anti-knock Index is the average of Research and Motor Octane numbers

# Emissions Tests

- **Light-Duty Emissions**
  - F150 Bi-Fuel Engine
  - ARB Haagen Smit Laboratory
  - *Passing Fuel: Fuel #1*
- **Medium-Duty Emissions**
  - Cummins B5.9 LPG Engine
  - Bodycote Ortech Laboratory
  - *Passing Fuel: Fuel #1*

# Performance/Combustion Tests

- **Southwest Research Institute**
- **Test Protocol: Cert. Fuel, Fuel #1**
  - **Performance Mapping at:**
    - 2800, 2600, 1640, and 1460 RPM
    - Each at 100%, 75%, 50%, and 25% load
  - **Measured Parameters:**

torque, power, brake thermal efficiency, average peak in-cylinder pressure, average peak pressure location, indicated mean effective pressure (IMEP), coefficient of variation of IMEP, ten percent burn angle, combustion duration, maximum rate of pressure rise, and cumulative heat release
- ***Fuel #1 Passed***

# Durability Tests

- **Bodycote Ortech Inc.**
- **Fuel #1**
- **Cummins B5.9 LPG engine**
- **500 hours at 100% load**
- **Tribological oil analysis**

# Durability Tests Conditions

- Constant 100% peak power;
- Water out temperature @  $225^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ;
- Intake manifold temperature @  $155^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ;
- Air inlet restriction at 20" H<sub>2</sub>O;
- At rated RPM speed;
- Measure blow by over time (measure oil losses);
- Record any drop in power;
- Monitor wear metals in oils samples at 50 hr intervals.
- Measure and note valve lash. May periodically adjust valve lash as needed to continue tests;
- Change lubrication oil at 250-hour point.
- *Fuel #1 Passed*

# Project Conclusion

- **Fuel #1 passed all Task Group Established Criteria**

# Suggested Next Steps

- **Review Existing ARB Standard in 2004**
- **Harmonize Standard with European and other key markets (i.e. Australia, Japan)**
- **Design instruments to rapidly detect key LPG fuel quality parameters at key distribution points: at refinery rack, at bulk and transport tanks, at the pump, and on-board**