REFRIGERATED LIQUID METHANE FUEL SUPPLY CONSIDERATIONS FOR HIGH SPEED CIVIL TRANSPORT

A PRESENTATION TO THE AD HOC REVIEW TEAM ON HIGH SPEED TRANSPORT AIRCRAFT

WASHINGTON, D.C.
NOVEMBER 19, 1987

L. S. GAUMER AIR PRODUCTS
ALLENTOWN, PA
REFRIGERATED LIQUID METHANE (RLM)

- CHARACTERIZATION
- DEMAND
- SUPPLY
- PRICING
- FACILITY
- SAFETY / REGULATIONS
- CONCLUSIONS
- CRITICAL ISSUES FOR FURTHER STUDY
# RLM Characterization

## Typical Methane Purity Levels

<table>
<thead>
<tr>
<th>Product</th>
<th>% by Volume Methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquefied Natural Gas (LNG)</td>
<td>85 - 98</td>
</tr>
<tr>
<td>Propellant, Methane Type II (2)</td>
<td>99.93</td>
</tr>
<tr>
<td>Commercial Gaseous, Cylinders</td>
<td>93 - 99.99</td>
</tr>
</tbody>
</table>

1) Impurities vary with feed source and are typically ethane, propane and inerts such as nitrogen.

2) U.S. Air Force Purchase Description Refrigerated Liquid Methane.
RLM DEMAND

- HIGH-SPEED CIVIL TRANSPORT
- GROUND TRANSPORTATION SYSTEMS
- U.S. SPACE LAUNCH PROGRAMS
THOUSANDS OF TONS/DAY

HIGH-SPEED CIVIL TRANSPORT YEAR 2000 ESTIMATES

EUROPE

NORTH AMERICA

PACIFIC RIM*

*INCLUDES ASIA

GEOGRAPHIC AREA

SOURCE: HIGH-SPEED CIVIL TRANSPORT STUDIES, PHASE I REPORTS NASI-18377 AND NASI-18378
RLM DEMAND
GROUND TRANSPORTATION SYSTEMS
(NORTH AMERICA)

• TRAINS
• MOTOR VEHICLES

TOTAL POTENTIAL YEAR 2000 - 5-10 THOUSAND TONS/DAY

SOURCE: AIR PRODUCTS ESTIMATES
RLM DEMAND
U.S. SPACE LAUNCH PROGRAMS

TOTAL POTENTIAL YEAR 2000 - <1 THOUSAND TONS/DAY

SOURCE: NASA MSFC ESTIMATE
WORLD NATURAL GAS DEMAND

THOUSANDS OF TONS/DAY

85  2000
EUROPE

85  2000
UNITED STATES

85  2000
PACIFIC RIM

GEOGRAPHIC REGION

RLM DEMAND SUPPLIED BY IMPORTED LIQUID
NON RLM DEMAND SUPPLIED BY IMPORTED LIQUID
RLM DEMAND SUPPLIED BY NATURAL GAS
NON RLM DEMAND SUPPLIED BY INDIGINEOUS OR PIPELINE NATURAL GAS

SOURCE: CHEVRON, EEC, NPC 1986-87
# WORLD PROVEN RESERVE RATIOS

<table>
<thead>
<tr>
<th></th>
<th>RESERVES / PROD</th>
<th></th>
<th>RESERVES / CONSUMPTION</th>
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<tbody>
<tr>
<td></td>
<td>CRUDE OIL</td>
<td>NATURAL GAS</td>
<td>CRUDE OIL</td>
<td>NATURAL GAS</td>
</tr>
<tr>
<td>NORTH AMERICA</td>
<td>9</td>
<td>15</td>
<td>7</td>
<td>15</td>
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<tr>
<td>EUROPE</td>
<td>12</td>
<td>35</td>
<td>4</td>
<td>28</td>
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<tr>
<td>PACIFIC RIM</td>
<td>14</td>
<td>51</td>
<td>6</td>
<td>49</td>
</tr>
<tr>
<td>OTHER</td>
<td>49</td>
<td>88</td>
<td>80</td>
<td>98</td>
</tr>
<tr>
<td>TOTAL</td>
<td>34</td>
<td>58</td>
<td>34</td>
<td>58</td>
</tr>
</tbody>
</table>

SOURCE: BP REVIEW 1986
LIQUEFIED NATURAL GAS PRODUCTION

THOUSANDS OF TONS/DAY

SOURCE: ADVANCES IN CRYOGENIC ENGINEERING, VOLUME 31, 1985
ENERGY PRICES - UNITED STATES

*REFINERY GATE PRICING PLUS 5¢/GAL. TRANSPORTATION COSTS.

$ / EGJA

JET A*

RLM

REFRIGERATED LIQUID METHANE DELIVERED TO AIRPORT

NATURAL GAS

NATURAL GAS PRICE FOR ELECTRIC UTILITIES

EGJA: EQUIVALENT GALLON OF JET A 125,000 BTU/GALLON
ENERGY PRICES - WESTERN EUROPE

*REFINERY GATE PRICING PLUS 5¢/GAL. TRANSPORTATION COSTS.

- JET A*
- RLM
- REFRIGERATED LIQUID METHANE DELIVERED TO AIRPORT
- NATURAL GAS
  - NATURAL GAS IN WESTERN EUROPE

$ / EGJA

EGJA: EQUIVALENT GALLON OF JET A 125,000 BTU/GALLON

AIR PRODUCTS
ENERGY PRICES - JAPAN

*REFINERY GATE PRICING PLUS 5¢/GAL. TRANSPORTATION COSTS.

RLM
REFRIGERATED LIQUID METHANE DELIVERED TO AIRPORT

JET A*

LNG
LNG INTO JAPAN

$ / EGJA

76 77 78 79 80 81 82 83 84 85 86 87

7 76 77 78 79 80 81 82 83 84 85 86 87

EGJA: EQUIVALENT GALLON OF JET A 125,000 BTU/GALLON
RLM PRICING

ASSUMPTIONS

- 3000 TONS PER STREAM DAY
- 91% ON-STREAM FACTOR
- GAS TURBINE DRIVE
- NATURAL GAS FEED
- STORAGE AND TRANSPORTATION TO AIRPORT BOUNDARY INCLUDED
- NO AIRPORT FACILITIES INCLUDED
- CAPITAL CHARGES AT 28% OF INVESTMENT
- 1986 DOLLARS
RLM PRICING

CURRENT AIRPORT DELIV.
PRICE OF JET A
$.63/EGJA

$ / MMBTU NATURAL GAS
LOWER HEATING VALUE BASIS

EGJA: EQUIVALENT GALLON OF JET A 125,000 BTU/GALLON
RLM
SAFETY / REGULATIONS

- LOCKHEED-ADL-NASA LEWIS STUDY, 1981
  - FUSELAGE CONFIGURATION
  - DISSIPATION RATE
  - FIRE IMPACTS
  - HAZARDS ANALYSIS AND EXPERIMENTATION NECESSARY

- NBS TECHNICAL NOTE 690, 1976
  - QUANTITY-DISTANCE STANDARDS
  - RLM VS. GASOLINE
  - SAFE STORAGE AND USE

- DOT FEDERAL SAFETY STANDARD 193 FOR LNG FACILITIES
RLM CONCLUSIONS

- HSCT demand small fraction of total natural gas demand
- Adequate proven natural gas reserves
- RLM price less than Jet A at airport boundary
- Consistent performance and non-degrading
- Known material compatibility
- Safe, reliable, and proven production, storage and distribution
- Airport facilities, operations, and safety requirements undefined
RLM CRITICAL ISSUES FOR FURTHER STUDY

- Review Air Force propellant specification applicability
- Develop more detailed supply/demand analysis for specific airport locations
- Detailed engineering analysis, design and cost estimate of airport storage and servicing facilities
- Analyze environmental/regulatory/safety implications of production/storage facilities for specific airport locations