ADVANCED SYSTEM CONCEPT FOR TOTAL ISRU-BASED PROPULSION AND POWER SYSTEMS FOR UNMANNED AND MANNED MARS EXPLORATION

Progress Briefing
Research Contract 07600-041
(under Prime Contract NAS5-98051)
OTC-G096-PB-00-1

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By

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INTRODUCTION

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- Advanced Concept Description
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- SCH_4/GOX Hybrid Testing
- Overall Study Approach
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- Fuels/Oxidizers/Sources Considered
- Propellant Processing Scenarios
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BACKGROUND AND ASSUMPTIONS

- Purpose: To Enable Cost-Effective, *In Situ* Production and Uses of Mars Atmospheric-Derived Oxidizers and Fuels and to Guide Technology Development and Unique Hardware Development, Advanced Concept Development and System Analysis Efforts

- Mars-produced Fuels and Oxidizers Will Enhance and/or Enable a Variety of Mars Exploration/Exploitation Missions by Providing a Very Cost-effective Supply of Propellants

- Most Cost-Effective Martian Resource Is the Atmosphere (95% CO_2), However, Mars Soil Can Also Provide other ISRU Species (Mg, Al, etc.) and Abundances (H_2O)

- Atmospheric CO_2 Can Be Easily Processed and Converted to CO, C and O_2

- Small Amount of H_2O Can Be Converted to H_2 and O_2, and N_2, and Ar Are Also Available from the Atmosphere -- with these Elements, There Are Many Propellant Combinations Possible

BACKGROUND AND ASSUMPTIONS (CONT.)

- Ground Transport Systems Include: Automated Unmanned Roving Vehicles, Personal Vehicles, Two-Person Unpressurized Rovers, Manned Pressurized Transport Rovers, and Larger Cargo Transports

- Flight Vehicles Include: Mars Sample Return Vehicles, Unmanned and Manned Surface-To-Surface “Ballistic Hoppers”, Surface-To-Orbit Vehicles, Interplanetary Transport Vehicles, Powered Balloons, Winged Aerocraft, Single-Person Rocket Backpacks, and Single-Person Rocket Platforms

- Auxiliary Power Systems Include: Brayton Cycle Turbines and Fuel Cells for Small Mars Outposts

- Implementation of this Architecture Will Also Greatly Support Logistics & Base Operations by Providing a Reliable and Simple Way to Store Solar or Nuclear Generated Energy

ADVANCED CONCEPT DESCRIPTION

- **It Is Believed That by Using the Baseline C/O System, in the Proper Fuel Form (CO Solid; C Solid) That Significant Economic Dividends Are Possible for Future Mars Base Activity**

- **The Production of O and CO through Solid State Electrolysis Appears to Be Well in Hand by Dr. Sridhar of the University of Arizona -- Hardware Is Now Being Prepared to Fly to Mars for an ISRU Demonstration**

- **ORBITEC Has Demonstrated Successful Hot Firings of Advanced Cryogenic Solid Hybrid Rocket Engines, Including: Solid CO, Solid H_2, Solid O_2, Solid CH_4, and Solid C_2H_2**

- **CO Gas Can Be Directly and Quickly Frozen to a Solid Hybrid Fuel Grain Below the Triple Point Temperature (68 K) by Using Cooled LOX (With the Low Pressure of the Mars Atmosphere (4.5 To 11.4 mm Hg, This Is Very Easy-@ 11.4 mm LOX Will Be at 63 K, and @6 mm LOX Will Be at 60 K) as the Freezing Fluid and Oxidizer in a Cryogenic Hybrid Engine**

- **Focusing on the Innovative and Revolutionary Use of <u>Solid</u> CO and C as Fuels with LOX in Hybrid Rockets and Power System Applications, but Have Broadened Scope to Include: SC/LOX, SCO/LOX, LCO/LOX, SCH_4/LOX, LCH_4/LOX, SC_2H_2/LOX, LH_2/SOX, LH_2/LOX, and other Secondary Derivative Propellants That May Have Significant Storability Advantages (e.g., H_2O_2/CH_3OH and H_2O_2)**

SCO/GOX HYBRID TESTING

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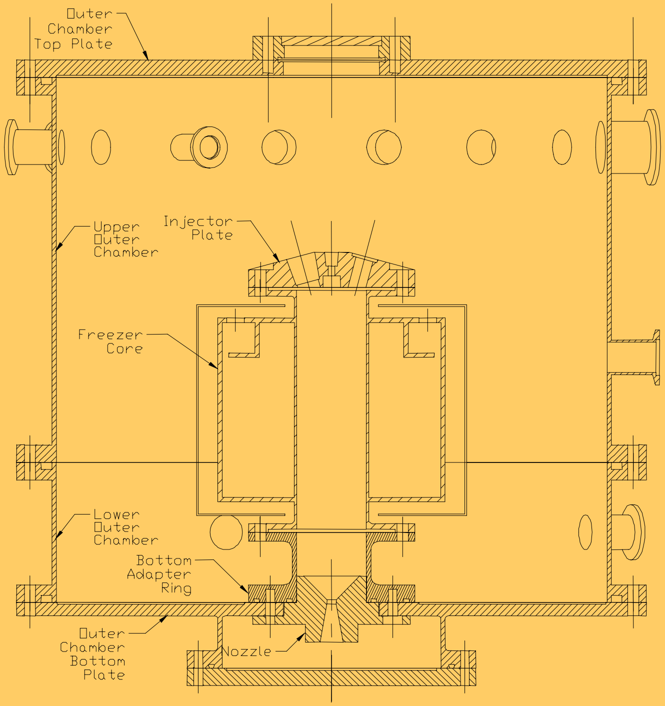
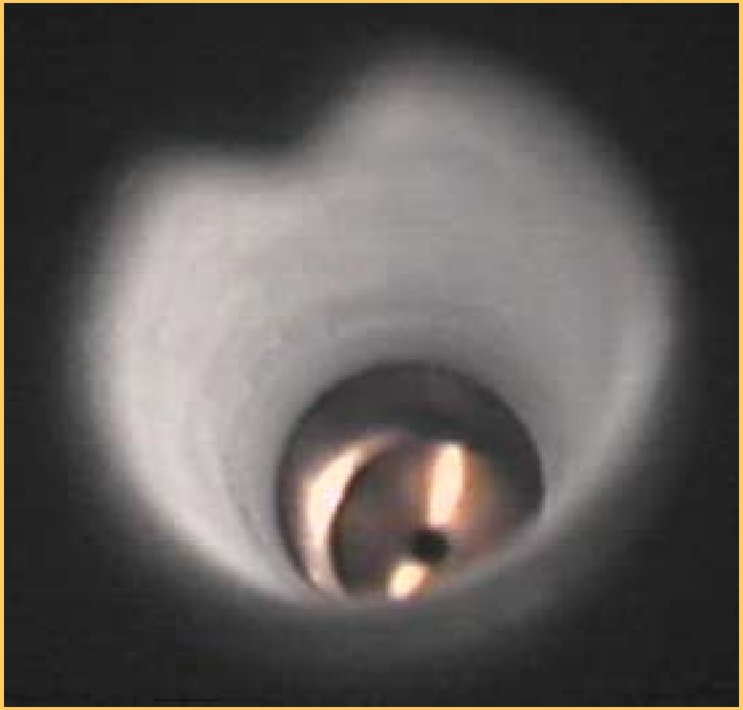
- **ORBITEC Has Been Very Active in Developing Advanced Cryogenic Hybrid Rocket Technology and Has Been the Only Organization in the World that Has Test Fired Solid CO Hybrid**
- **On January 29, 1998, ORBITEC Performed the First Ever Test Firing of a Solid CO/GOX Propellant Combination in the ORBITEC Mark-II Cryogenic Hybrid Rocket Engine**
- **100 Grams of Solid CO Was Frozen Onto the Inside of the Cylindrical Chamber of the Engine and LHe was Used to Freeze and Cool the CO for the Test**
- **The Freezing Pressure Was on the Order of 1 Torr and the Freezing Process Took 29 Minutes**
- **Based on Previous Experience, We Estimate that the CO Was Approximately 10 K Just Prior to the Test Firing**
- **Five Sucessful Tests Have Been Conducted to Date**
- **Patent is Pending**

ORBITEC's Mark II Cryogenic Hybrid Rocket Engine



VIDEO IMAGE OF A SOLID CO GRAIN FORMED IN THE MARK II ENGINE AND FIRING



PRESSURE-TIME AND O/F-TIME TRACES FOR SCO/GOX FIRINGS

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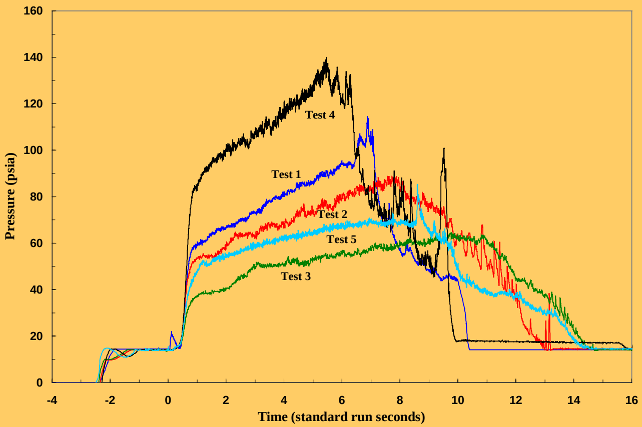

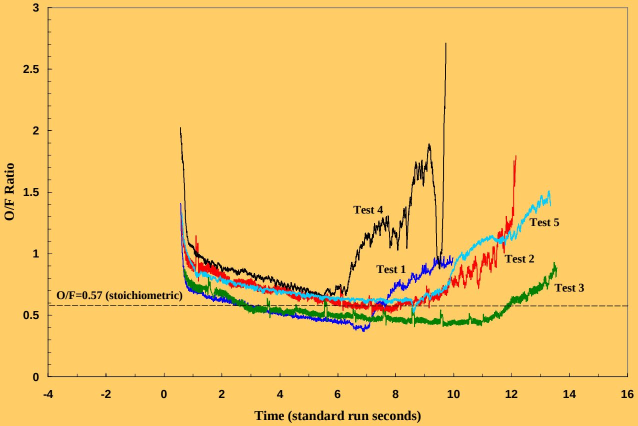

SCO/GOX HYBRID FIRING RESULTS

Variable	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**
Burn Time (s)	9.7	11.6	13.0	9.2	12.8
Initial SCO Temp. (K)	10-20	10-20	10-20	10-20	10-20
Main O_2 Flow (g/s)	6.0	6.0	4.0	10.0	6.0
Avg. Reg. Rate (cm/s)	0.058	0.048	0.043	0.061	0.044
Avg. p_c (psi)	71	67	52	95	55
Avg. O/F	0.57	0.70	0.51	0.92	0.76
C_{exp}* (m/s)	1117	1176	1127	1166	1019
C_{theo}^{*} (m/s)	1362	1352	1358	1325	1341
C_{eff}*	82%	87%	83%	88%	76%

Note: Each SCO fuel grain had an initial mass of 100 g.

CONCLUSIONS REACHED FROM SCO/GOX TESTS

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- SCO Can Be Easily Formed in a Solid Grain from the Gas Phase
- Grain Appears Structurally Sound
- No Indications of Grain Slipping During Burns Were Noticed
- SCO Burns Very Well with GOX – It Has Been One of the Smoothest Burning Cryogenic Solids That ORBITEC Has Tested
- Pressure Change with Time Was Primarily Due to the Increase in Area as the Grain Regressed; Some Contribution to the Increase in Grain Temperature Is Also Believed a Contributor
- Optimum O/F Ratio Was Easily Achieved the First Time Tried
- Tests Show Great Promise for the SCO/LOX Propellant Combination for Use as a Mars Sample Return and a Wide Variety of Mars Exploration Applications

SCH_4/GOX HYBRID PROPULSION TESTS

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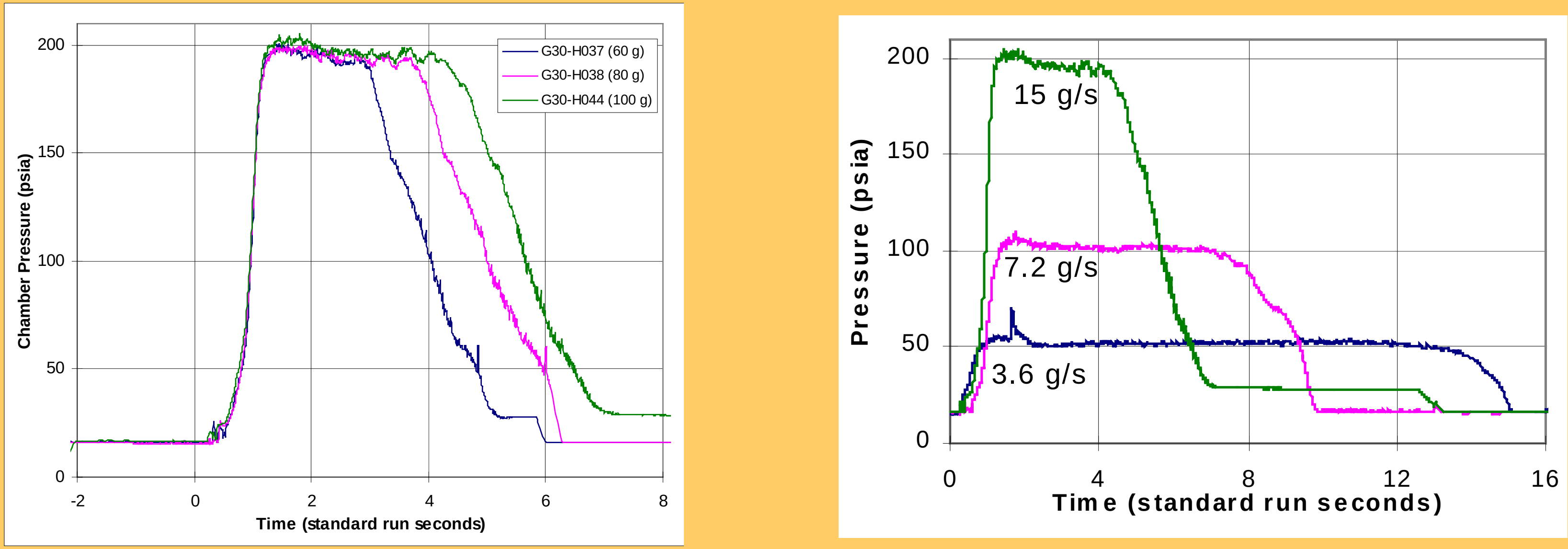
- **ORBITEC Has Also Completed Work to Design, Build, and Test a Solid Methane/GOX Hybrid Rocket Engine**
- **Total of 24 Successful Test Firings Were Performed**
- **Largest SCH_4 Grain Fired Had a Mass of 120 g**
- **Highest Steady Chamber Pressure Attained Was 240 Psia, and Highest Oxygen Mass Flow Rate Injected into the Engine Was 35 g/sec**



Pressure Curves for SCH_4/GOX Firings, Showing Effect of Grain Size and Varying Oxygen Flow Rate

SUMMARY OF ORBITEC CRYOGENIC HYBRID REGRESSION RATE DATA

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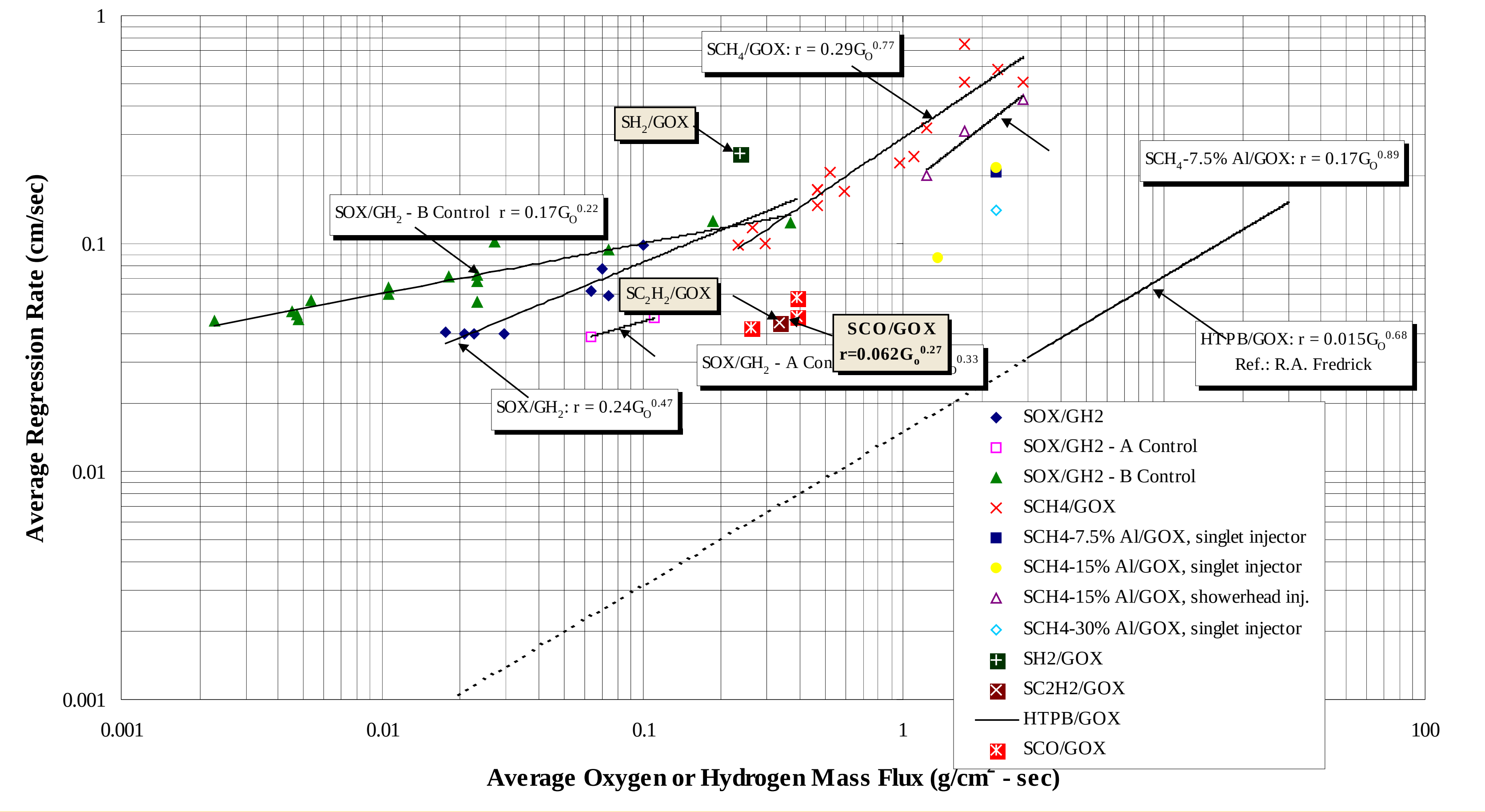
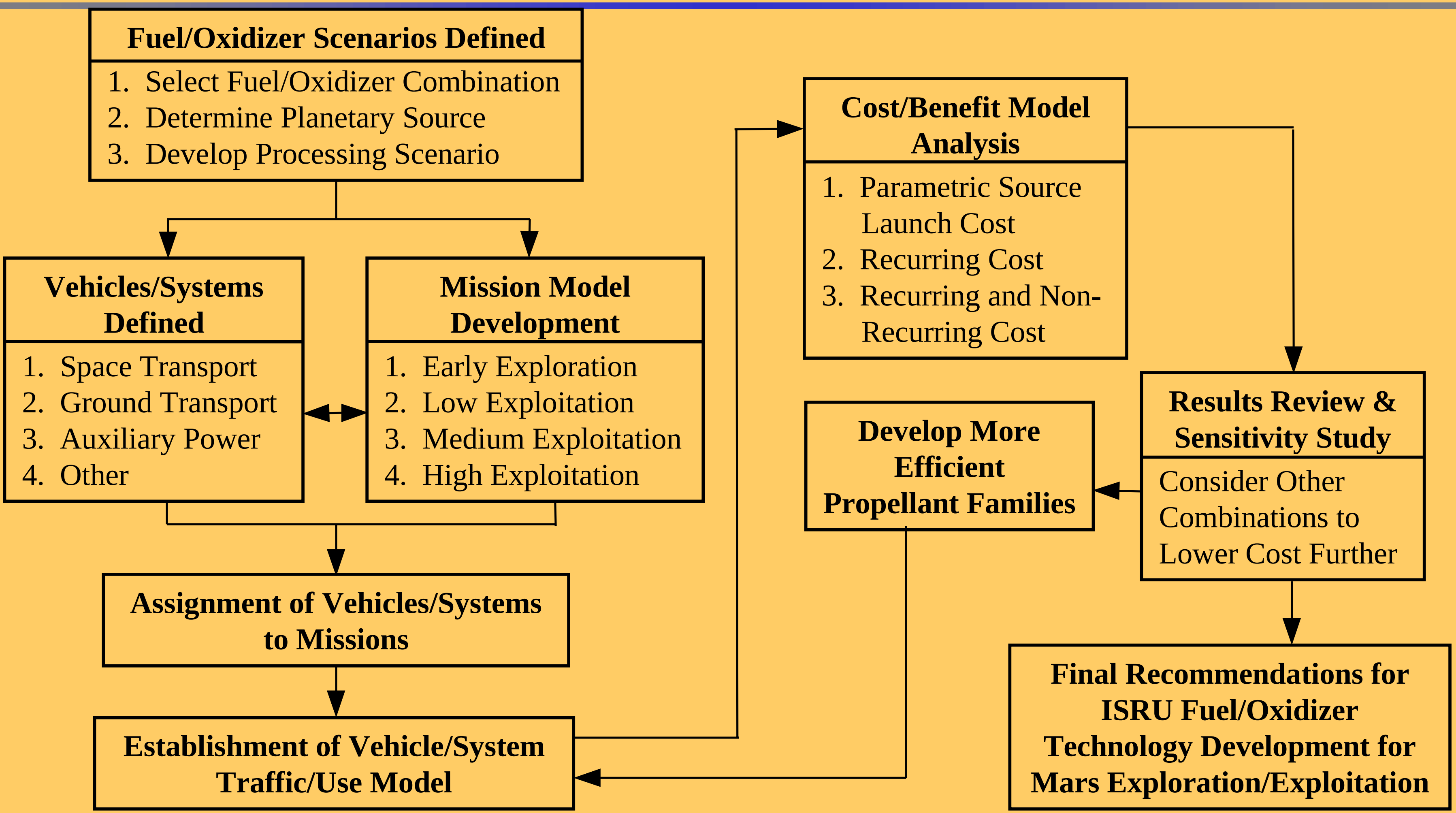


OVERALL STUDY APPROACH



Fuel/Oxidizer Scenarios Defined

1. Select Fuel/Oxidizer Combination
2. Determine Planetary Source
3. Develop Processing Scenario

Vehicles/Systems Defined

1. Space Transport
2. Ground Transport
3. Auxiliary Power
4. Other

Mission Model Development

1. Early Exploration
2. Low Exploitation
3. Medium Exploitation
4. High Exploitation

Assignment of Vehicles/Systems to Missions

Establishment of Vehicle/System Traffic/Use Model

Cost/Benefit Model Analysis

1. Parametric Source Launch Cost
2. Recurring Cost
3. Recurring and Non-Recurring Cost

Results Review & Sensitivity Study

Consider Other Combinations to Lower Cost Further

Develop More Efficient Propellant Families

Final Recommendations for ISRU Fuel/Oxidizer Technology Development for Mars Exploration/Exploitation

MISSION IDENTIFICATION

- Scientific Exploration & Research
- Commercial Exploration
- Terraforming
- Infrastructure Construction
- Agriculture/Farming
- Manufacturing/Industrial Activities
- Resource Mining
- Weather/Environmental
- Communications Navigation Services
- Surveying/Mapping
- Personal Transportation
- Package/Mail Delivery/Package Delivery/Product Delivery/Food Delivery/Goods/Services/Cargo
- Government Activity/Law Enforcement/Emergency Rescue/Response
- Launch/Space Transport Satellite/Earth Cargo Launch/Space Transport
- Auxiliary Power/Emergency Power
- Live Support
- Waste/Trash Management
- Health Care/Maintenance
- Virtual Travel Market

EXAMPLE OF MISSION DEFINITION

Mission Category: Scientific Exploration and Research

Mission/Submission Scope?	# of Crew/ Robotic	Mission Duration	Distance from Base (km)	Travel Time	Payload Mass (kg)	Vehicle Type Required
Past/Current Life on Mars – search for evidence of past life, geology of the planet, ice at poles or permafrost (tools, sample boxes, life support, rover, sample rocks/dust, measure seismic activity)	2/Robotic 2/Robotic 2/Robotic Robotic	1-5 days 1 day 3-7 days Infinite	4000 km 500 km 10,000 km Infinite	Minutes Hours Minutes N/A	300 300 300 50	Ballistic Flight Ground Ballistic Flight Ground
Meteorology – study/characterize atmosphere, dust storms, other weather Phenomena (temperate, pressure, wind velocity, solar radiation, humidity) Delivery Vehicle Recovery Vehicle Sounding Rocket	Robotic Robotic Robotic	1 day 1 day < day	10,000 km 10,000 km ? altitude	Minutes Minutes Minutes	10 10 2	Ballistic Flight Ballistic Flight Ballistic Flight
Astronomy – any orbiting systems supplied from Earth - any ground-based systems located at base, so no requirement for transport						
Solar Monitoring – located at base, so no need for transport						
Other Science – study meteorites, characterize poles	2/Robotic 2/Robotic 2/Robotic	1-5 days 1 day 3-7 days	4000 km 500 km 10,000 km	Minutes Hours Minutes	200 50 200	Ballistic Flight Ground Ballistic Flight
Mars Moon Exploration (landing equipment, tools similar to the search for life/geology mission)	3/Robotic	1 week	Moon Orbits	Hours	100	Flight vehicle
Mission to Asteroid Belt	3/Robotic	Months	Asteroid Belt	Hours	100	Flight vehicle

FUELS/OXIDERS/SOURCES CONSIDERED

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Fuel / Oxidizer	Source			Space Transport		Ground Transport		Aerocraft		Powered Balloon	
	Earth	Mars	Moon	Solid Cryo - Hybrid	Liquid Bi - Prop	Brayton	Fuel Cell	Brayton	Fuel Cell	Brayton	Fuel Cell
CO / O_2		✓		✓	✓	✓	✓	✓	✓	✓	✓
C / O_2		✓		✓		✓		✓		✓	
CH_4 / O_2	✓H	✓	✓H	✓	✓	✓	✓	✓	✓	✓	✓
C_2H_2 /O_2	✓H	✓	✓H	✓		✓		✓		✓	
CH_3OH / H_2O_2	✓H	✓	✓H		✓	✓		✓		✓	✓
H_2/O_2	✓H	✓	✓HO	✓SOX	✓	✓	✓	✓	✓	✓	
CH_3OH /LOX	✓H	✓	✓H		✓	✓	✓	✓	✓	✓	✓

PROPELLANT PROCESSING SCENARIOS

1. All Earth-Supplied H_2 and O_2
2. Earth-Supplied H_2; O_2 from the Mars Atmosphere
3. Moon-Supplied H_2; O_2 from Lunar H_2O
4. All Mars-Supplied H_2; O_2 from H_2O in the Atmosphere
5. CO and O_2 Made from the Mars Atmosphere
6. C_2H_2 Made from Earth - Supplied H_2; Mars C and O_2 from Mars Atmosphere
7. C and O_2 Made from the Mars Atmosphere
8. CH_4 Made from Earth-Supplied H_2; C and O_2 from Mars Atmosphere
9. CH_4 Made from Mars-Supplied H_2 (Atmospheric Water); C and O_2 from Mars Atmosphere
10. CH_3OH Made from Earth H_2; C from Mars Atmosphere; H_2O_2 from Earth H_2 and Mars O_2
11. CH_3OH Made from Mars C, H_2, O_2
12. H_2O_2 From Mars H_2O, O_2

CO/O_2 PRODUCTION PLANT

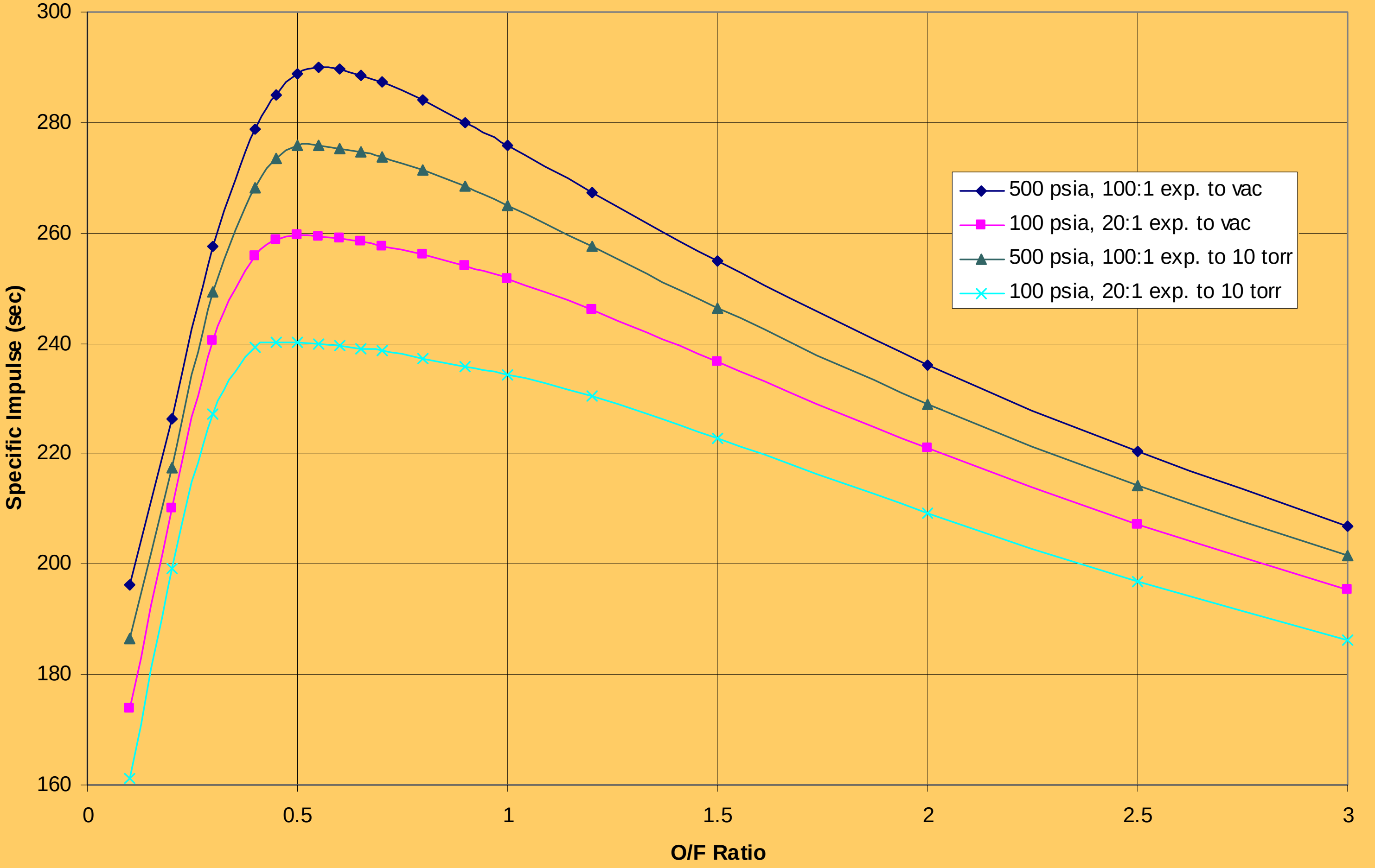
- Mass and Energy Requirements For Two Different Sizes of CO/O_2 Production Plants Were Developed
- Analysis for the Small Production Plant Assumes that the CO_2 Compressor and CO/CO_2 Separator Will Operate for One Cycle Per Day
- Analysis for the Large Plant Assume that the CO_2 Compressor and CO/CO_2 Separator Will Operate for 8 Cycles Per Day
- O_2 Generator in the Small Production Plant Would Operate for 7 Hours Each Day, While the Large Production Plant Would Operate 24 Hours Per Day

Component	Small Mass (kg)	Plant 10 kg/day Energy (kW-hr)	Large Mass (kg)	Plant 1,000 kg/day Energy (kW-hr)
CO2 Compressor	120	24	1,500	2,400
Oxygen Generator	15	15	437	1,500
CO/CO2 Separator	120	24	1,500	2,400
Support Equipment	75	-	950	-
TOTAL	330	63	4,387	6,300

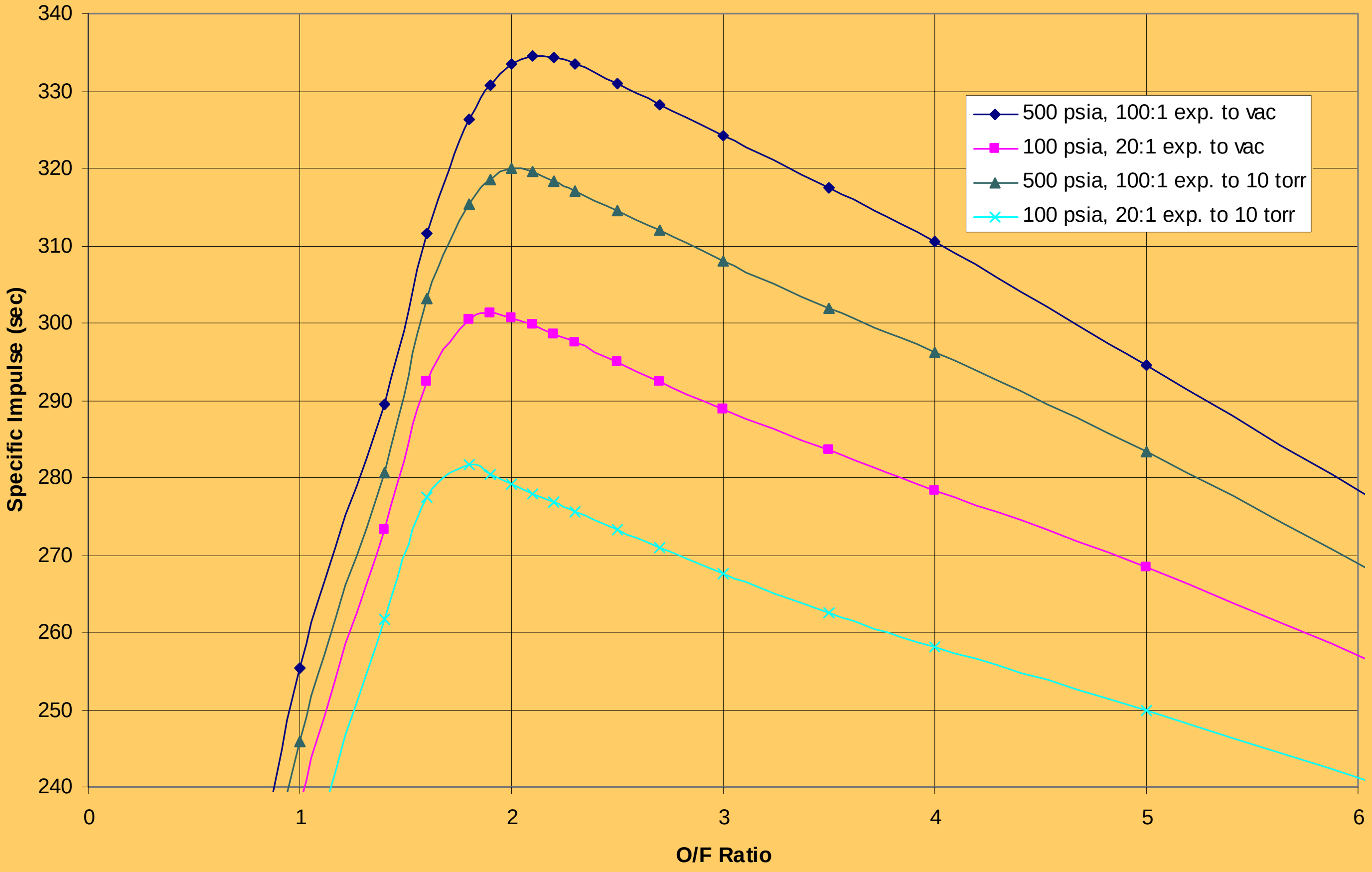
PERFORMANCE CALCULATIONS FOR SELECTED PROPELLANTS

- CEA Code Used to Calculate the Propellant Performances
- Combinations Include:
  - SCO/LOX
  - C/LOX
  - SCH_4/LOX
  - SC_2H_2/LOX
  - LH_2/LOX
  - CH_3OH/H_2O_2

SCO/LOX


Specific Impulse (sec)
300
280
260
240
220
200
180
160
0
0.5
1
1.5
2
2.5
3
O/F Ratio
◆ 500 psia, 100:1 exp. to vac
■ 100 psia, 20:1 exp. to vac
▲ 500 psia, 100:1 exp. to 10 torr
× 100 psia, 20:1 exp. to 10 torr

CARBON/LOX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Specific Impulse (sec)
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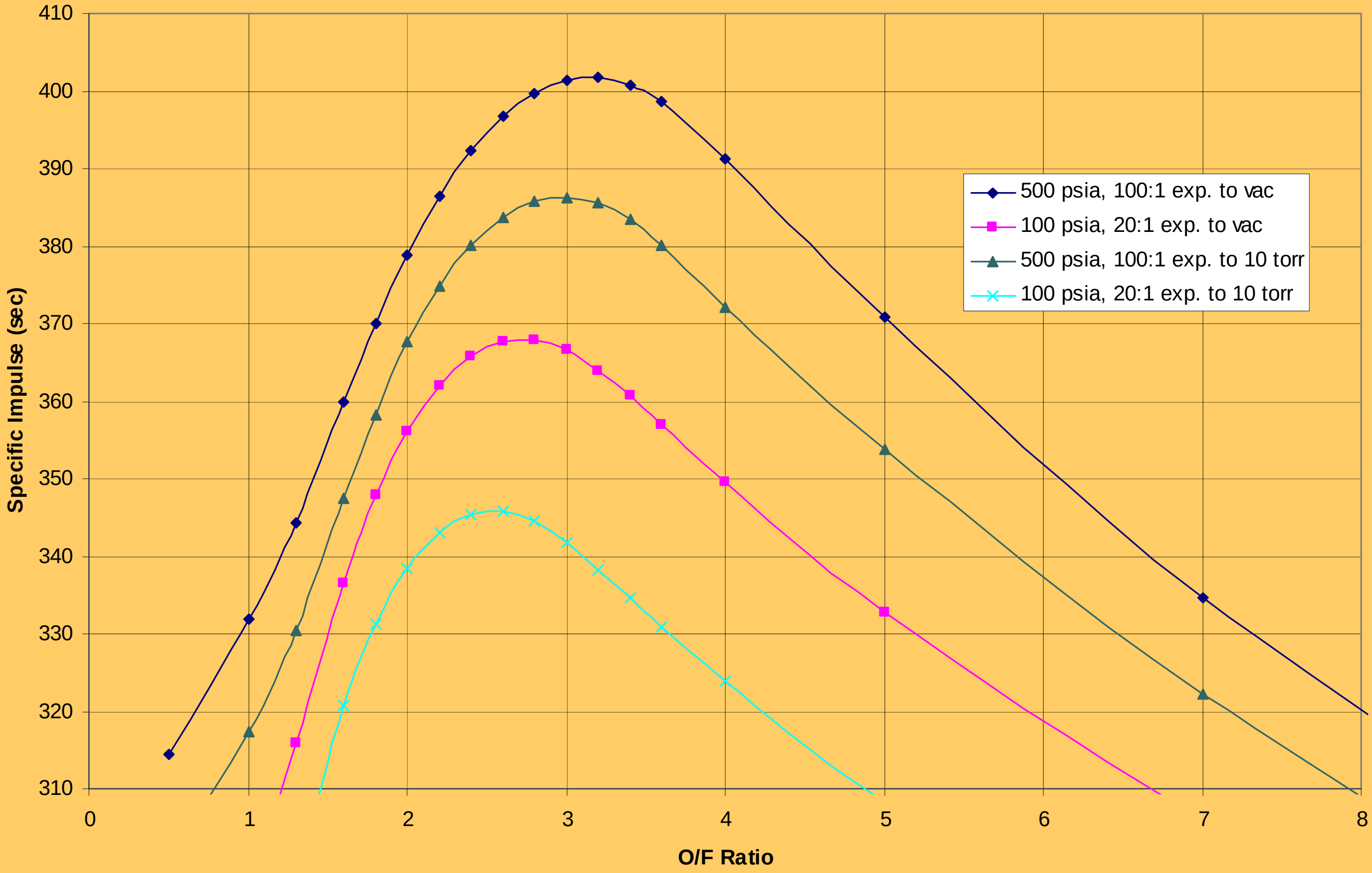
O/F Ratio
◆ 500 psia, 100:1 exp. to vac
■ 100 psia, 20:1 exp. to vac
▲ 500 psia, 100:1 exp. to 10 torr
× 100 psia, 20:1 exp. to 10 torr

SCH$_4$/LOX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O/F Ratio
500 psia, 100:1 exp. to vac
100 psia, 20:1 exp. to vac
500 psia, 100:1 exp. to 10 torr
100 psia, 20:1 exp. to 10 torr

SC_2H_2/LOX

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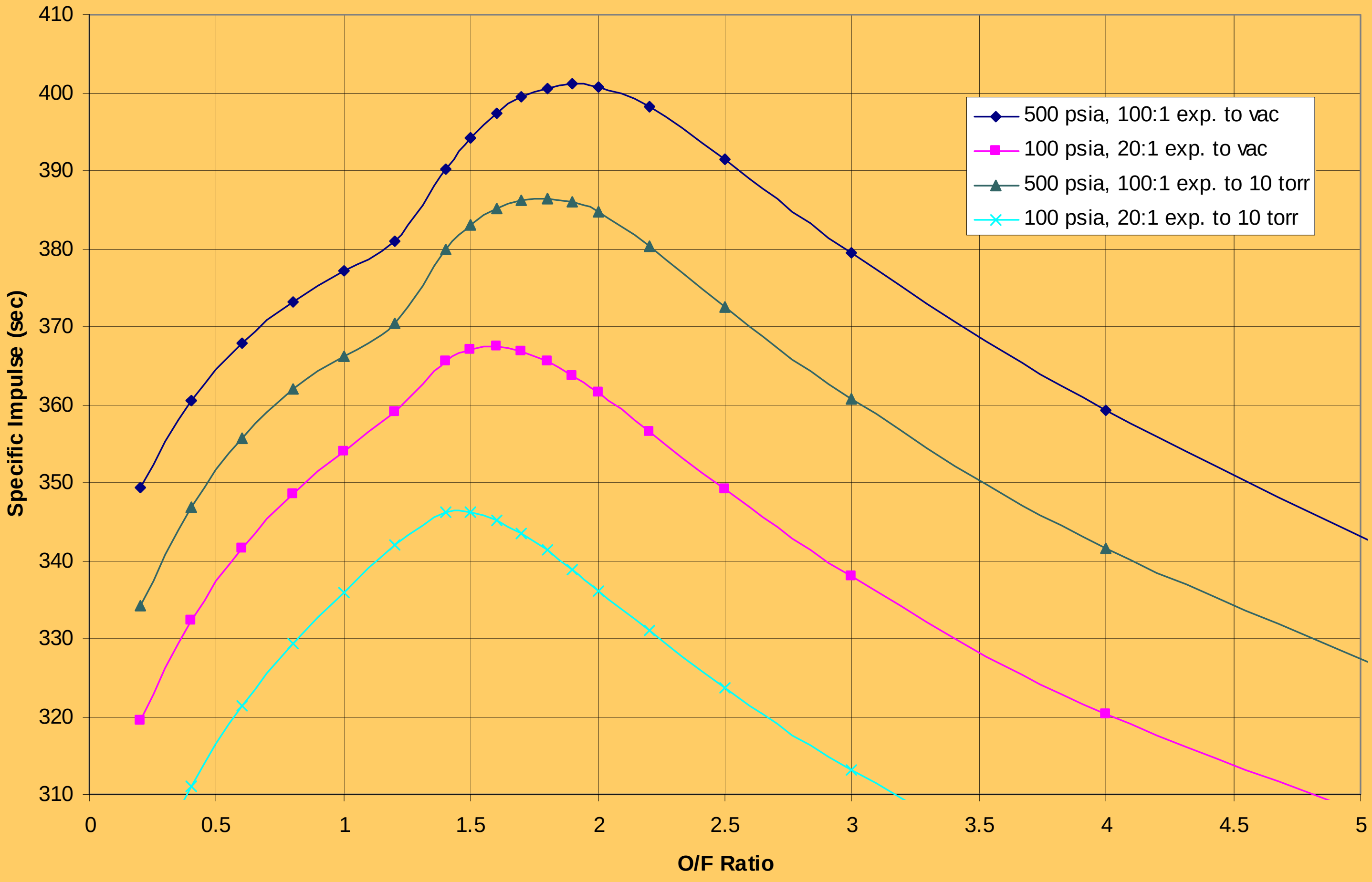
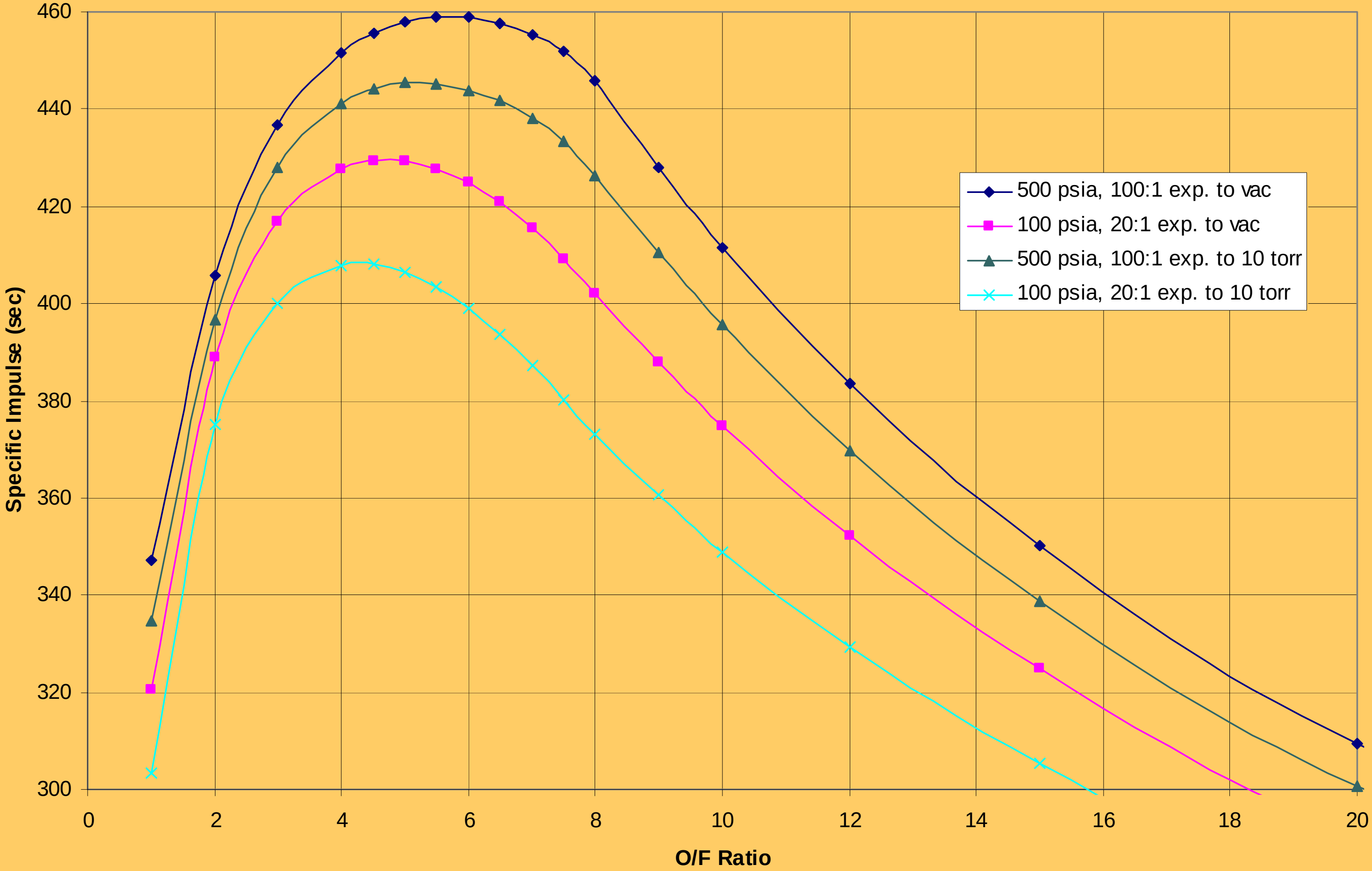


LH_2/LOX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Specific Impulse (sec)
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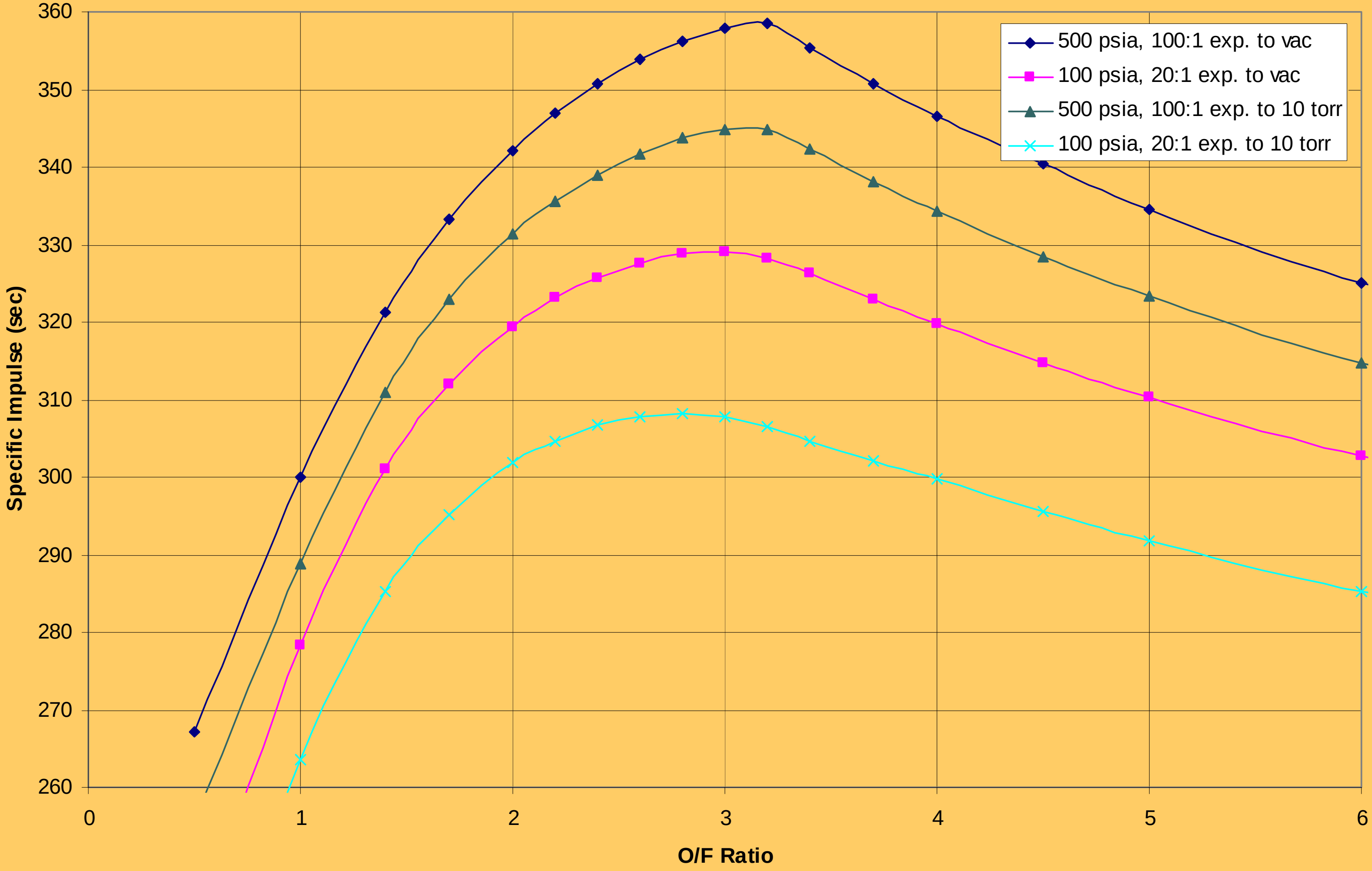
O/F Ratio
◆ 500 psia, 100:1 exp. to vac
■ 100 psia, 20:1 exp. to vac
▲ 500 psia, 100:1 exp. to 10 torr
× 100 psia, 20:1 exp. to 10 torr

CH_3OH/H_2O_2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Specific Impulse (sec)
O/F Ratio
500 psia, 100:1 exp. to vac
100 psia, 20:1 exp. to vac
500 psia, 100:1 exp. to 10 torr
100 psia, 20:1 exp. to 10 torr

TRAFFIC MODEL DATA SHEET EXAMPLE

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[Note: each period represents 5 years]

Propellant: Solid CO/LOX

Mission Area	Time Period (low model)											Time Period (medium model)											Time Period (high model)											Total Period Summary	
	1	2	3	4	5	6	7	8	9	10	Totals	1	2	3	4	5	6	7	8	9	10	Totals	1	2	3	4	5	6	7	8	9	10	Totals	Low	Medium
1 Scientific Exploration &Res																																			
FV1											0											0											0	0	0
FV2											0											0											0	0	0
FV3											0											0											0	0	0
FV4											0											0											0	0	0
FV5											0											0											0	0	0
Totals:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GS1											0											0											0	0	0
GS2											0											0											0	0	0
GS3											0											0											0	0	0
GS4											0											0											0	0	0
GS5											0											0											0	0	0
Totals:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PHASE I
ANALYSIS SENARIOS
TO ASSESS COST/BENEFIT

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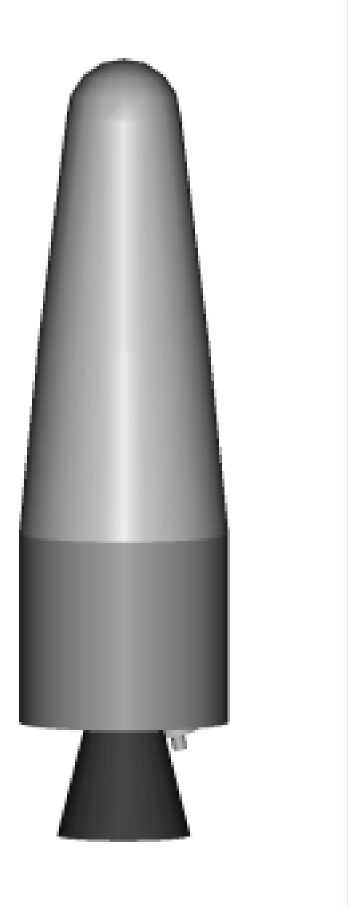
- MAV Replacement for Mars Sample Return Mission
- Ballistic Surface Hopper, Assuming H_2/O_2, CO/O_2, CH_4/O_2, C/O_2 and Single Stage, 1000 Kg Payload, Fly to 500, 1000 Km Distances
- Rover/Transporter to 300 Km Distance Once Per Day, Using Fuel Cell or Brayton Cycle
- Outpost Chemical Power Using Fuel Cell or Brayton Cycle and H_2/O_2, CO/O_2, CH_4/O_2, CH_3OH/O_2

MISSION CHARACTERISTICS AND ASSUMPTIONS

Orbit:	600 km
Orbit Type:	Circular
Payload Mass:	3.6 kg
Stage 1 Subsystem Mass:	16.9 kg
Stage 2 Subsystem Mass:	1.7 kg
Initial Launch Velocity:	241 m/s
First Stage Delta-V:	2382 m/s
Second Stage Delta-V:	1514 m/s
Total Delta-V:	4137 m/s

TSTO
MAV REPLACEMENT FOR MARS SAMPLE RETURN MISSION



TWO-STAGE TO ORBIT MARS ASCENT VEHICLE

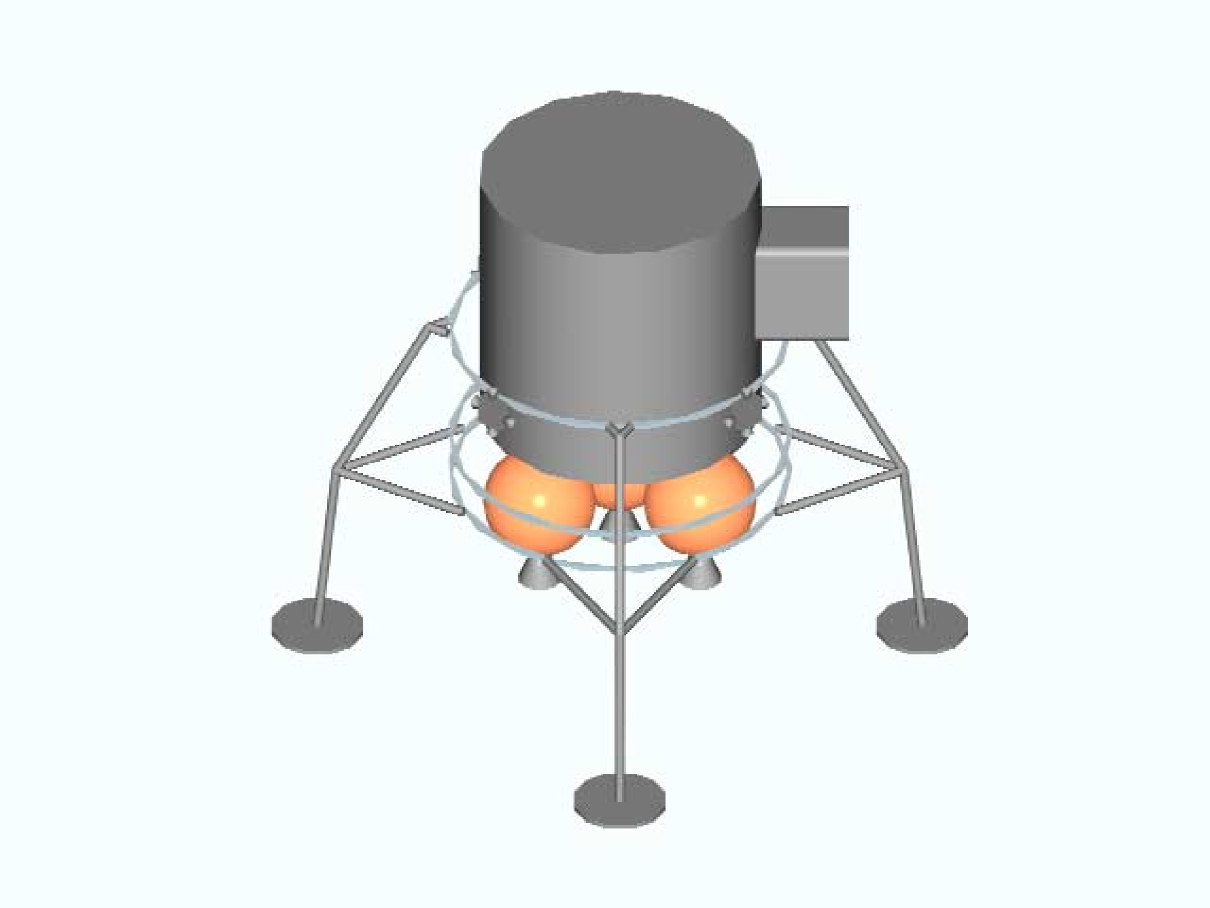
Propellant Combination	Propulsion System	Terrestrial Propellants	Propellant Mass (kg)	Dry Mass[*] (kg)	GLOW (kg)	ELM (kg)
SCO/LOX	Hybrid	-	107.2	50.9	161.7	50.9
SC/LOX	Hybrid	-	65.9	38.7	108.2	38.7
SC-H_2/LOX[**]	Hybrid	C, H_2	56.3	36.0	95.9	53.3
SC_2H_2/LOX	Hybrid	H_2	40.4	31.0	75.0	32.1
HTPB/LOX	Hybrid	HTPB	48.2	33.5	85.3	47.3
LCH_4/LOX	Bi-Propellant	H_2	37.5	30.2	71.3	32.4
CTPB binder	Solid	Solid	81.3	40.7	125.6	122.0

Orbit: 600 km circular orbit, Payload: 3.6 kg

[*] Dry mass does not include 3.6 kg payload

[**] SC with 5% H_2 additive by mass

ISRU-BASED ONE-WAY BALLISTIC SURFACE HOPPER



CHARACTERISTICS OF ONE-WAY HOPPER MISSIONS WITH POWERED LANDINGS

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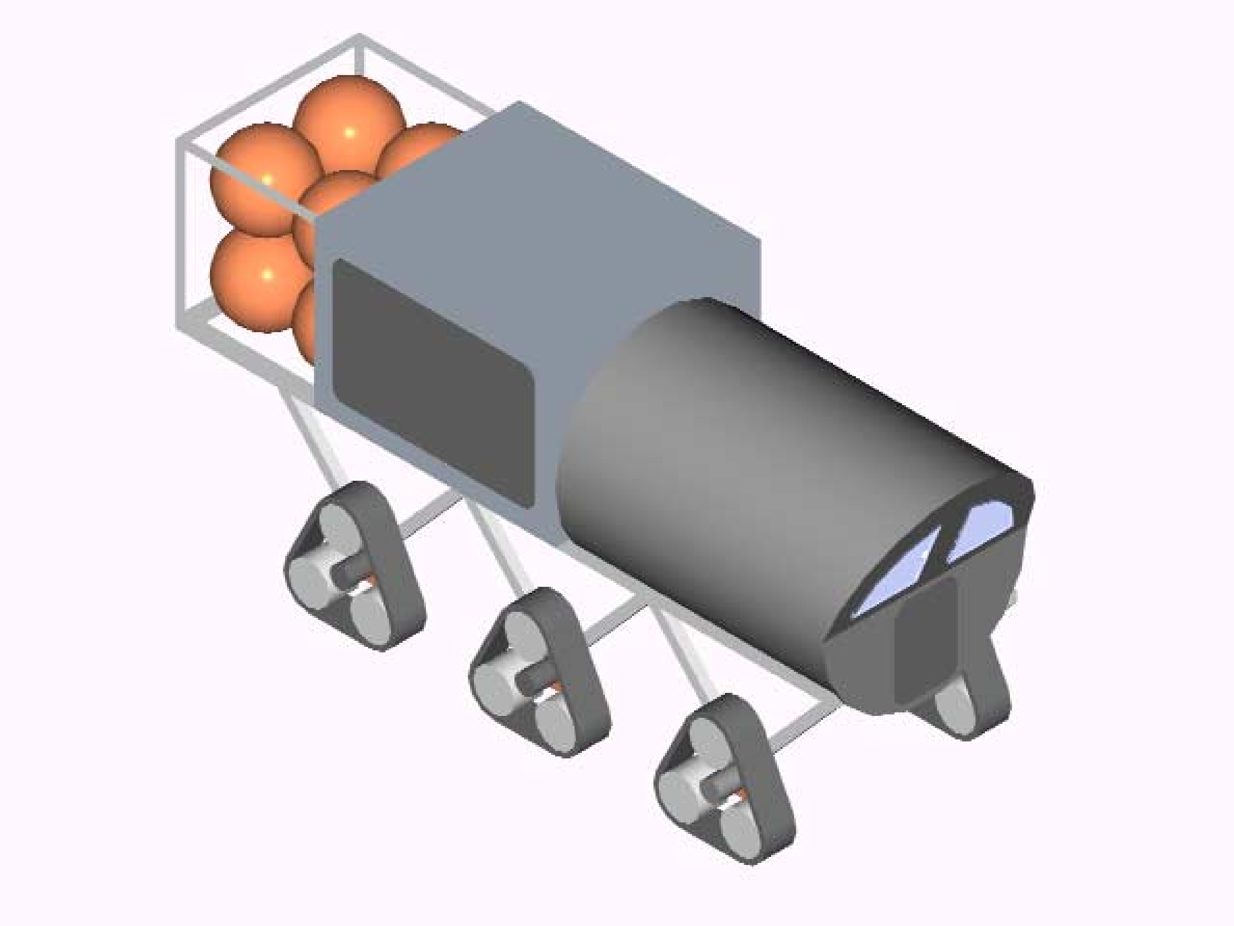
Propellant Combination	Propulsion System	Terrestrial Propellants	Distance (km)	Propellant Mass (kg)	Dry Mass (kg)	GLOW (kg)	ELM (kg)
SCO/LOX	**Hybrid**	**-**	**500**	**4040**	**2320**	**6360**	**0**
SC/LOX	**Hybrid**	**-**	**500**	**3090**	**2220**	**5310**	**0**
LCH_4/LOX	**Bi-Propellant**	**H_2**	**500**	**2160**	**2110**	**4270**	**129**
LH_2/LOX	**Bi-Propellant**	**H_2, O_2**	**500**	**1760**	**2070**	**3830**	**1760**
SCO/LOX	**Hybrid**	**-**	**1000**	**8250**	**2790**	**11,040**	**0**
SC/LOX	**Hybrid**	**-**	**1000**	**5770**	**2520**	**8290**	**0**
LCH_4/LOX	**Bi-Propellant**	**H_2**	**1000**	**3690**	**2280**	**5970**	**220**
LH_2/LOX	**Bi-Propellant**	**H_2, O_2**	**1000**	**2900**	**2190**	**5090**	**2900**

Payload = 1000 kg and is included in GLOW; 873 other non-propulsion mass included; vehicle structural mass fraction = 0.1

ISRU-POWERED ROVER/ TRANSPORTER



FUEL NEEDS FOR A 300 KM, TEN-HOUR TURBINE-POWERED, ROVER MISSION

- **Rover Mass Kept Constant for all Fuels**
- **Turbine Efficiency of 65% for all Fuels**
- **100 kg Mass Penalty Assessed for Exhaust Recovery System**
- **Payload of 1000 kg**

Fuel Type	H_2/O_2	CH_4/O_2	CO/O_2
Fuel Use, Exhaust Recovered (kg)	113*	154 (13*)	249
Fuel Use, Exhaust Not Recovered (kg)	104*	142 (12*)	223

*Mass Supplied from Earth or Moon as Hydrogen

FUEL REQUIREMENTS FOR POWER ASSUMING 70% OVERALL EFFICIENCY

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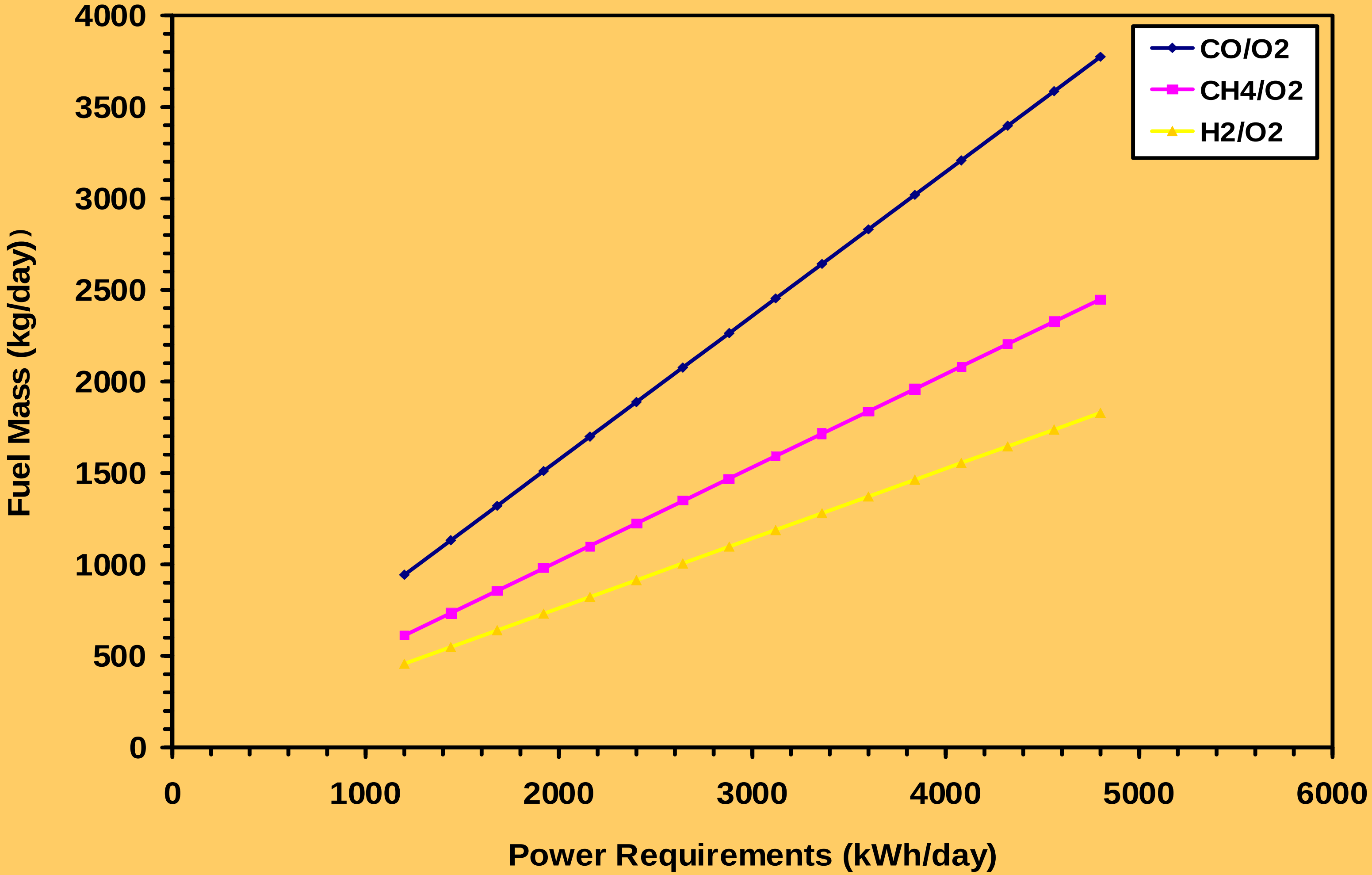

PRELIMINARY COST-BENEFIT COMPARISON OF ISRU PROPELLANTS

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Mission	ELM per Mission (kg)	ELM Cost ($M)	ISRU Savings per Mission ($M)	Missions per Year	ISRU Savings per Year ($M)
MAV Sample Return					
Baseline Solid	122	1.22	----	1	----
SC_2H_2/LOX Hybrid	32.1	0.32	0.90	1	0.90
LCH_4/LOX Bi-Prop	32.4	0.32	0.90	1	0.90
SC/LOX Hybrid	38.7	0.39	0.83	1	0.83
HTPB/LOX Hybrid	47.3	0.47	0.75	1	0.75
SCO/LOX Hybrid	50.9	0.51	0.71	1	0.71
$SC\text{-}H_2$/LOX Hybrid	53.3	0.53	0.69	1	0.69
One Way Hopper (1000 km)					
LH_2/LOX Bi-Prop Baseline	2,900	29.0	----	10	----
LCH_4/LOX Bi-Prop	220	2.20	26.8	10	268
SC/LOX Hybrid	0	0	29.0	10	290
SCO/LOX Hybrid	0	0	29.0	10	290
Turbine Powered Rover (300km)					
LH_2/LOX Turbine Baseline	113	1.13	----	100	----
LCH_4/LOX Turbine	7.7	0.08	1.05	100	105
SCO/LOX Turbine	0	0	1.13	100	113
Outpost Auxiliary Power					
LH_2/LOX Turbine Baseline	1400	14.00	----	50	----
LCH_4/LOX Turbine	100	1.00	13.00	50	650
LCO/LOX Turbine	0	0	14.00	50	700

Note: Processing equipment not amortized over ISRU derived propellant ELM, ELM ~ $10,000/kg, C and O_2 from Mars, H_2 from Earth

PHASE I CONCLUSIONS

- ISRU Will be a Significant Benefit to the Mars Program
- SCO/LOX Propellant System is likely good for Short Ballistic Hops and Wide Use in Ground Systems; Will Require Staging or Other Propellant Saving Measures for Large Orbital Operations
- Improving Mass Fraction Helps Lower Performance Systems
- Cryogenic Solid Grains Can Be Made and Stored in Mars Propellant Facilities
- CH_4/LOX Propellants Are Excellent for Large Orbital Operations
- Carbon/LOX and Acetylene/LOX Hybrids Also Are Excellent for More Demanding Missions
- H_2/O_2 Systems would be Best Suited for High-Performance Missions, If Mars Can Supply Water
- Large Cargo Transport Best Accommodated by Ground Transport Vehicles; Ballistic Rocket Flight Makes Sense for High Priority Missions
- O/F Choice Can Make a Significant Cost-Benefit Difference
- For Ground-based Systems, Hydrogen in the Exhaust Can and Should Be Recovered; CO_2 Can Be Released
- Consider Savings Attributed to Wings, Aeroshells, Parachutes, etc.
- Likely Need Nuclear Power Systems in Many Sizes
- The ISRU Analysis Approach is a Complex Problem
- Need to Do a Reasonable Concept Design on Vehicles and Process Equipment to Arrive at Correct Answer

PHASE II PROGRAM

- **Schedule**
- **Study Ground Rules**
- **Tasks**
- **Progress**

PHASE II SCHEDULE

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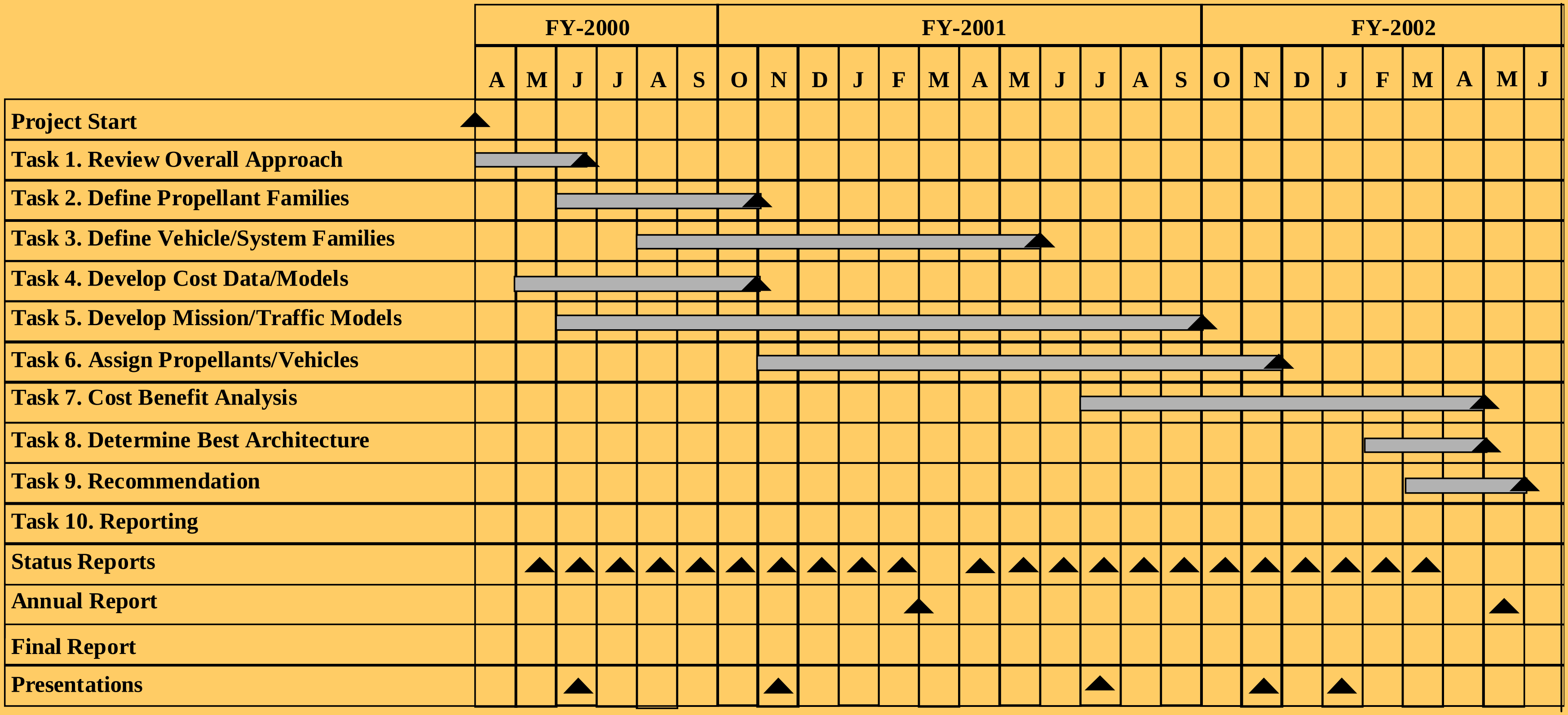

Project Start

Task 1. Review Overall Approach

Task 2. Define Propellant Families

Task 3. Define Vehicle/System Families

Task 4. Develop Cost Data/Models

Task 5. Develop Mission/Traffic Models

Task 6. Assign Propellants/Vehicles

Task 7. Cost Benefit Analysis

Task 8. Determine Best Architecture

Task 9. Recommendation

Task 10. Reporting

Status Reports

Annual Report

Final Report

Presentations

CURRENT REQUIREMENT /GROUND RULES

- **Purpose of the Study Is to Assess Cost-Effective, In-situ Production and Use of Mars-Derived Oxidizers and Fuels to Guide Advanced Concept Development, System Analysis Efforts, and Technology and Unique Hardware Developments**
- **The Study Timeframe Includes the Early Manned Exploration Period and Extends 50 Years from the “End” of the Initial Human Mars Exploration Activity**
- **Missions to Be Used Are Those Defined by the Project Team**
- **Earth Launch Mass (ELM) Costs Will Be Parametrically Assessed at $10,000/kg, $1,000/kg, and $400/kg**
- **Human Activity Models Assumed for the 50-year Period of Assessment to Be 10,000 Humans for High, 1000 Humans for Medium and 100 Humans for Low**
- **Mission Vehicle Assignment and Mission Frequency Will Be Determined by Consensus of the Workshop Participants and the Project Team and Based Upon the Other Requirements and Guidelines**
- **All Cost Estimates Will Be in Year 2000 Dollars**
- **Ground Vehicles Are to Include: Automated Unmanned Roving Vehicles, Personal Vehicles, Two-Person Unpressurized Rovers, Manned Pressurized Transport Rovers, and Larger Cargo Transports**
- **Flight Vehicles Are to Include: Mars Sample Return Vehicles, Unmanned and Manned Surface-to-Surface “Ballistic Hoppers”, Surface-to-Orbit Vehicles, Interplanetary Transport Vehicles, Powered Balloons, Winged Aerocraft, Single Person Rocket Backpacks, and Single Person Rocket Platforms**
- **Auxiliary Power Systems Are to Include: Brayton Turbines and Fuel Cells for Small Mars Outposts**
- **Only Propellants to Be Considered Are Those Derivable from Earth (Earth Deliveries), the Mars Atmosphere, or Water/Hydrogen Resources from the Moon**
- **Potential Propellant Candidates to Be Considered Include: CH_4/O_2, C/O_2, C_2H_2/O_2, CO/O_2, H_2O_2/CH_3OH, CH_3OH/LOX and H_2/O_2.**

TASK 1. REVIEW OVERALL STUDY APPROACH

- Plan to Hold Approach Review through Workshop in Madison, June 21 - 22, 2000
- Invited Participants Include:
  - OSEAC Members - Eric Rice, Robert Gustafson, Mike Duke, Jerry Hanley, Doug O'Handley, Pete Priest
  - NIAC - Bob Cassanova
  - NASA - Bob Cataldo, Bill Larson, Diane Linne, Chris McKay, Dave McKay, Mike O'Neal, Bryan Palaszewski, Jerry Sanders, Tom Sullivan
  - Universities - George Miley, Leslie Gertsch, Richard Gertsch, KR Sridhar
  - Industry - Niklas Jarvstrat, Bill Siegfried
  - Others -

•1.5 Day Agenda includes:
  - Phase I Review
  - Phase II Approach Review
  - Technical Discussions

TASK 2. DEFINE PROPELLANT FAMILY SCENARIOS

1. All Earth-Supplied H_2 and O_2
2. Earth-Supplied H_2; O_2 from the Mars Atmosphere
3. Moon-Supplied H_2; O_2 from Lunar H_2O
4. All Mars-Supplied H_2; O_2 from H_2O in the Atmosphere
5. CO and O_2 Made from the Mars Atmosphere
6. C_2H_2 Made from Earth-Supplied H_2; Mars C and O_2 from Mars Atmosphere
7. C and O_2 Made from the Mars Atmosphere
8. CH_4 Made from Earth-Supplied H_2; C and O_2 from Mars Atmosphere
9. CH_4 Made from Mars-Supplied H_2 (atmospheric water); C and O_2 from Mars Atmosphere
10. CH_3OH Made from Earth H_2; C from Mars; H_2O_2 from Earth H_2 and Mars O_2
11. CH_3OH Made from Mars C, H_2, O_2
12. H_2O_2 Made from Mars H_2O, O_2

TASK 3. DEFINE VEHICLE/ SYSTEM FAMILY SCENARIOS

Flight Vehicles	Ground Vehicles	Power Systems
MAV's for Sample Return	Automated Rovers	Turbine
Ballistic Hoppers	Personal Closed Rovers	Fuel Cell
Surface to Orbit	2 - Person Open Rovers	
Interplanetary	Multi-Person Closed Rovers	
Powered Balloons	Large Cargo Transports	
Winged Aerocraft		
Single Rocket Backpacks		
Single Rocket Platforms		

TASK 4. DEVELOP COST DATA/MODELS

- The Predicted Cost-Benefit of ISRU Propellants and Their Associated Production and Use Is Greatly Affected by the Earth Launch Mass (ELM) Cost or the Earth to Mars Surface Transport Cost
- The Latter is Much More Difficult to Estimate in the Future
- For ELM to Use Values of $10,000, $1,000 and $400 per kg
- As Part of the Cost-Benefit Analysis, Need to Understand Each Mission Scenario and How Much Mass is Required From Earth -- This Depends on the Missions that Are Defined, Their Frequency and Their Propellant Option
- Must Include Not Only ELM Propellant for Mars Delivery, But All of the Masses Associated with Storage, Processing, Upgrading/Refurbishment, Resupply, etc. of both Earth-Supplied and Mars-Supplied Propellants
- Must Also Consider the Different Recurring and Non-Recurring Costs of the Flight and Ground Systems that Are Designed for Each Propellant Use
- Will Estimate These Costs Using Aerospace CER’s or Other Software Models

TASK 5. DEVELOP MISSION AND TRAFFIC MODELS

- **Traffic/Use Model Outlines How Often These Activities Take Place**
- **Four Different Levels of Human Presence on Mars Were Defined:**
  - **(1) Early Exploration (10 to 20 years),**
  - **(2) Low Presence (100 Permanent Inhabitants After 50 Years)**
  - **(3) Medium Presence (1,000 Permanent Inhabitants after 50 Years)**
  - **(4) High Presence (10,000 Permanent Inhabitant after 50 Years)**
- **50-Year Clock Begins after the Initial Exploration Period is Over**
- **Once Defined Vehicles Are Assigned to the Given Missions, the Next Task is to Identify How Often the Mission Needs to Be Accomplished**
- **Data Needs for the Worksheet Include: Number of Crew, Robotic or Manned Mission, Distance from Base, Travel Time, Payload and Vehicle Type Required**

TASK 6. ASSIGN PROPELLANTS/ VEHICLES/SYSTEMS TO MISSIONS

- **Once the Mission Data Are Developed, then Can Assign a Ground, Flight Vehicle or Power System that Can Satisfy the Specific Mission Need**
- **The Goal Would Be to Develop Only a Few Sets of Ground and Flight Vehicles that Can Satisfy all the Missions**

TASK 7. COST/BENEFIT MODEL ANALYSIS/TRADES/SENSITIVITIES

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- Once Cost-benefit Model Is Developed, Costs for Each Single Propellant Option Will Be Developed
- Groups or Families of Propellant Options Would Then Be Developed and Analyzed
- Expect that There May Be Significant Benefit in Selecting Both High and Low Performance Propellants for the Various Vehicles Considered
- Goal Is to Determine the Best Propellant Families to Satisfy the Lowest Cost for Exploration/Colonization Scenarios on Mars

TASK 8. DEVELOP THE MOST COST EFFECTIVE ARCHITECTURE

- **As a Result of Conducting the Architecture Study and Looking at All the Predicted Costs, Issues and Sensitivities, We Will Recommend the Most Cost Effective Architecture**
- **A Separate System Definition Document Will Be Prepared for NIAC/NASA Use**

TASK 9. PREPARE FINAL RECOMMENDATIONS

- **ORBITEC Will Prepare Its Final Recommendations on The Results of the Study to NASA/NIAC**

PHASE II PROGRESS

- **Made All Arrangements for June 21-22, 2000 Workshop in Madison**
- **Sent Out Invitations to Prospective Participants**
- **Evaluating Cost Model Approaches**
- **Working on Propellant Family Definitions**
- **Prepared for the Annual Review**
- **Submitted 1st Progress Report**