Take Material to Space or Make It There?

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Most human missions in space have been brief, lasting only days or weeks, and they have taken all the materials they need. Using the alternate method, the International Space Station recycles water and oxygen, and it is often assumed that future Moon and Mars missions should also recycle their life support materials. The "take or make" decision is primarily based on cost, and making or recycling material on longer space missions can sometimes be less expensive than taking it. Longer missions favor recycling over resupply when the initial cost to provide recycling equipment is less than the cost to provide resupply. Recycling was clearly cheaper than taking material to the space station in the space shuttle era when launch costs were very high. Launch costs have decreased and the take or make decision point has changed. The recent reduction in launch cost by a factor of about twenty-five to fifty makes taking material cost less than making or recycling it for much longer missions. The cost breakeven point when making rather than taking material is less expensive is now much farther out in time than before. Material recycling or in situ production no longer saves cost except for very large or very long missions.

I. Introduction

Should we take materials such as oxygen and water into space, or should we make or recycle them there? The traditional assumption has been that recycling and in situ production will be necessary on long missions to minimize cost, and this assumption was justified by the very high space launch costs that prevailed throughout most of the space age. Since 2010 space launch costs have been reduced from the space shuttle's roughly seventy thousand dollars per kilogram to orbit to the Falcon Heavy's roughly one and a half thousand dollars, a reduction by a factor of more than forty. This requires a reassessment of the take or make decision, the choice between resupply and recycling or in situ production. It is now much less expensive to take materials into space. Recycling and planetary surface resource extraction systems must be less expensive than before to save cost.

This paper first develops simple cost models for taking material to space or making it there. Materials such as oxygen and water have negligible cost on Earth. Taking material into space requires providing containers and launching the filled containers to orbit. In the past the transportation cost to take materials to space greatly exceeded the container cost, but with the new lower launch costs, this is no longer true. Making material in space requires developing the material production equipment and launching it into space. The hardware development cost is usually much greater than its transportation cost. The material production systems also incur continuing costs for operations and maintenance.

This paper next describes the cost of launching material into space and estimates the cost of developing space hardware. As examples, the production of water and oxygen by recycling on the International Space Station (ISS) and from regolith on the Moon are considered.

II. The Take or Make, Resupply or Recycling Decision in Life Support

The choice between taking materials into space, resupply, or making them in space, by recycling, is fundamental in space life support. Recycling is strongly advocated for longer missions based on the launch mass it saves. Resupplying material, such as water for the crew, requires launching the required mass per crewmember per day. Launch mass can be reduced by providing a water recycling system. Recycling is considered advantageous if the total mass of resupply saved exceeds the mass of the recycling system and its spares and logistics. The date that resupply mass first exceeds the recycling system mass is the mass breakeven date, which is typically months or years. This long-accepted mass-breakeven reasoning has justified the development of recycling life support systems. Brief

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missions taking days to weeks, from Mercury in the 1960's to space shuttle in the 2010's, have all used resupply. The International Space Station (ISS), which has operated since 2000, uses extensive recycling.

The accepted conclusion that recycling is justified whenever it saves mass is based on an early key assumption that is no longer correct. This now invalid assumption is that launch mass is an adequate substitute metric for cost, meaning that mass can be used instead of dollar cost to compare resupply and recycling. The use of launch mass instead of cost assumed that launch cost is the major cost for both resupply and recycling. This ignores the cost of developing and operating the equipment, which may be minor compared to the transportation cost for filled resupply tanks but is significant for complex recycling equipment. Launch cost was very high for the space shuttle, which was used to build the ISS, but even with the high shuttle launch costs, the cost of developing recycling equipment was much higher than the cost of launching it. A better rough assessment would compare the development cost of recycling to the launch cost of resupply, temporarily setting aside the launch cost of recycling and the development cost of resupply. The cost breakeven date would be much further out than the mass breakeven date. Another reason to challenge the use of launch mass instead of cost is that the cost of launch has been greatly reduced since the space shuttle was used, by a factor of about forty. The cost breakeven date would be many times longer than the mass breakeven date, but the launch cost of resupply is now so low that the development cost of resupply cannot be ignored. If launch costs have another significant reduction, launch mass may not be important in the choice between resupply and recycling. Hardware development and operations costs will then determine the choice between take or make.

Some general rules for the take or make decision are clear. For short missions, usually take. For longer missions, make when the mission duration is substantially longer than the cost breakeven date. Substantial cost saving is needed to justify "make" because making has much greater technical difficulty and risk than simply taking. The current much lower launch costs greatly reduce the cost saved by making, but making may still save cost. The take or make choice should be fully analyzed for longer missions, considering cost, performance, schedule, and risk.

III. A Parametric Take or Make Model

The key mission factors that determine when materials should be taken into space or made in space are the mass of material needed, the mission duration, and the mission location. Suppose that the material is needed at the rate of m kg/year and the mission duration is D years. The total mission mass is m* D, kg. The mission location affects the decision through the transportation cost to deliver the material, Transportation Cost, \$/kg. The cost to transport all the material is m * D * Transportation Cost, \$.

Taking the material requires placing it in a container and transporting the container filled with the material. The implementation factors that determine the cost of taking material are the cost of the material containers per kilogram of material contained, Container Cost, \$/kg, and the required additional container mass per kilogram of material contained, Container Mass, kg/kg. The cost to take the material is the container cost plus the transport cost of material and container and it increases over time t, years, with the mass of material.

$$\text{Cost to Take (t), \$} = m{*}t\text{, kg} * (\text{Container Cost, \$/kg} + (1+ \text{Container Mass, kg/kg}) * \text{Transportation Cost, \$/kg}) \quad (1)$$

The Container Mass, kg/kg, is typically 0.1 or 0.2 for water or gas tanks. In the past Transportation cost, \$/kg, has been much greater than Container Cost, \$/kg, but the recent large reductions in the cost of space launch make this no longer true.

Making material in space requires first providing the material production system and transporting it to space, and then continually providing and transporting parts and supplies to support operations. The initial production system factors that determine the cost of making the material are the cost of a production system that produces m kg/year, System Cost, \$, and the mass of the production system, System Mass, kg. The continuing factors that increase the cost of making the material are the yearly cost of operations, Operations Cost, \$/year and the yearly mass of the operating parts and supplies, Supplies Mass, kg/year. The cost to make the material is the fixed initial cost of providing and transporting the production system plus the time dependent cost of operating it and transporting its supplies.

$$\begin{gathered}\text{Cost to Make (t), \$} = \text{System Cost, \$} + \text{System Mass, kg} * \text{Transportation Cost, \$/kg} + \\ \text{t, years} * (\text{Operations Cost, \$/year} + \text{Supplies Mass, kg/year} * \text{Transportation Cost, \$/kg}) \qquad (2)\end{gathered}$$

The Operations Cost, \$/year, is typically ten percent of the System Cost, \$, per year. The System Cost, \$, and the Operations Cost, \$/year, * t, years, are usually much greater than the transportation cost for the system and supplies, even when the Transportation Cost, \$/kg, is large. If the cost equations are simplified by dropping the the

Transportation Cost from the Cost to Make and the Container Mass transportation cost from the Cost to Take, the Cost to Make is less when,

Cost to Make (t), $ < Cost to Take (t), $

System Cost, $ + t, years* Operations Cost, $/year < m*t, kg * (Container Cost, $/kg + Transportation cost, $/kg) (3)

The Cost to Make is less than the Cost to Take once the mission time is long enough that the accumulated cost of providing and transporting the filled containers is more than the cost of providing and operating the production system. This time is the Make Breakeven Time.

Make Breakeven Time (t) =

System Cost, $/[m, kg/year * (Container Cost + Transportation cost), $/kg - Operations Cost, $/year] (4)

The Make Breakeven Time is the cost of providing the production system divided by the rate it saves the cost of providing and transporting containers. The Make rate of saving is equal to the cost increase rate for providing and transporting containers minus the cost increase rate of operating the system. Including the dropped Container Mass * Transportation Cost in the Cost to Take could reduce the Make Breakeven Time by about ten percent.

The choice should be Take when the Make Breakeven Time is less than the mission duration, D. Nearly all past human missions have been brief and have taken all the needed materials. When the Transportation Cost is very large, as it was for the space shuttle, it dominates the Cost to Take and typically produces a short Make Breakeven Time, months rather than years. The high shuttle launch cost justified choosing Make for the ISS. The major effect of the recent greatly reduced Transportation cost is to significantly increase the Make Breakeven Time. And now that Transportation Cost is much less, the Container Cost to Take and the Operations Cost to Make must be considered. The Make option may still be best for long missions and permanent bases, but the cost saving is much less, which allows more consideration of other major system factors such as performance, safety, reliability, and risk.

IV. Transportation Cost

Commercial rockets have greatly reduced the cost to launch mass to orbit. The space shuttle payload was 27,500 kg to LEO but only 2,270 kg to Geosynchronous Earth Orbit (GEO) using the Inertial Upper Stage. [1] The initially planned space shuttle budget was 4 billion dollars per year for 10 launches, 400 million dollars per launch. Actual costs were higher due to a lower than planned launch rate of about four per year. [2] The real incremental cost per launch was 1.44 billion in 2010 dollars, which is 1.99 billion in 2023 dollars. [3] [4] The cost per kilogram for shuttle launch to LEO was $1,990 million/27,500 kg = $72.3 k/kg in current dollars.

The Falcon 9 launches 22,800 kg to Low Earth Orbit (LEO) at a cost of 67 million dollars, for a launch cost is 2.94 $k/kg. [5] The Falcon Heavy launches 63,800 kg to LEO at a cost of 97 million dollars, for a launch cost of $1.52 $k/kg. [6] [7] The space shuttle cost to LEO was roughly 25 to 50 times higher in current dollars. The new low launch cost makes resupply and storage life support very much cheaper than before, which favors making material over taking or recycling it.

SpaceX projects a further remarkable decrease in launch cost for Starship. Elon Musk has repeatedly estimated "Insanely Low Starship Launch Costs Of $10/kg." [8] The latest estimates are the same [9], but the $10/kg to LEO is only the marginal cost for an additional flight without paying back any of the development cost.

To breakeven and then begin to make a profit, the development cost must be recovered. Usually some of the development cost is charged to each flight. However, once the development cost is covered, all revenue above the continuing operational cost is profit. In a competitive market, price usually drops down toward marginal cost. Elon Musk said, "Yeah, looks like marginal cost [EMPHASIS ADDED] of launch will be less than $1M for more than 100 tons to orbit, so it's mostly about fixed costs divided by launches per year." [8] Musk has quoted the cost of a Starship launch as $2 million [10], which would make the total cost to LEO equal to $20/kg. Dropping launch cost from $1.52 k/kg for Falcon Heavy to $10-20/kg for Starship would be a further two orders of magnitude decrease.

V. Hardware Development Cost

The hardware development cost is more difficult to determine than the transportation cost. Hardware development cost includes DDT&E (Design, Development, Test, and Engineering) and hardware production.

Development cost can be estimated using the Advanced Missions Cost Model (AMCM). This cost relationship model is a single equation using mass, quantity, mission type, number of design generations, and technical difficulty to estimate the total cost for DDT&E and production. [11] Cost is scaled by quantity and mass. The AMCM is based on 260 government aerospace including ships, aircraft, missiles, and planetary and manned spacecraft. [11] [12]

The AMCM formula for the cost of DDT&E and production in millions of 1999 dollars is:

$$\text{Cost} = 5.65 * 10^{-4}\, Q^{0.59}\, M^{0.66}\, 80.6^{S}\, (3.81 * 10^{-55})^{(1/(IOC-1900))}\, B^{-0.36}\, 1.57^{D} \tag{5}$$

Q is the total quantity of development and production units, M is the system dry mass in pounds, S is the specification according to the type of mission (2.13 for human habitat, 2.39 for planetary base, 2.46 for crewed planetary lander), IOC is the year of initial operation capability, B is the block or hardware design generation (1 for new design, 2 for second generation), and D is the estimated difficulty (0 for average, 2.5 for extremely difficult, and -2.5 for extremely easy). [11] According to the Bureau of Labor Statistics CPI Inflation Calculator, $1 in 1999 has the same buying power as $1.82 in 2023. [4]

VI. Operations Cost

Operations costs can be estimated as a percentage of the system development cost per year. For the space shuttle, the ten-year operations costs were 58% of the total cost, so that the yearly operations cost was (0.58/10)/0.42 = 0.138 or 13.8% of the development cost per year. For ISS, the ten-year operations costs were 51% of the total cost, so that the yearly operations cost was (0.51/10)/0.49 = 0.104 or 10.4% of the development cost per year. [11] The JSC Mission Operations Cost Model (MOCM) estimated the operations cost per year as 10.9% of the total development and production cost. [13] The operations cost can be roughly estimated at 10% of the development cost per year.

VII. Take or Recycle Water and Oxygen for the Space Station?

Water and oxygen are currently recycled on the International Space Station (ISS), but they are also supplied using tanks. The ISS was built using the space shuttle and its high launch cost made recycling much less expensive than resupply. Do the current much lower launch costs now cause “take” to cost less than “make?”

A. Costs to Take Water and Oxygen

A space station water tank weighs 21.2 kg and holds 103 kg of water, 0.21 kg tank mass per kg of water. [14] The AMCM formula (5) is used to compute the tank cost per kilogram of water delivered. Assuming one hundred units will be built, Q = 100, a human habitat, S = 2.13, initial operation in 2020, IOC = 2020, a second-generation design based on the space station tank, B = 2, and extremely easy difficulty, D = -3, cost is 164.2 million current dollars to deliver 100 tanks each holding 103 kg of water. The tank cost is 15.94 $k/kg of water provided.

A space qualified oxygen tank weighs 12.7 kg and contains 35.4 kg of oxygen, 0.36 kg tank mass per kg of oxygen. [15] Using the AMCM and assuming one hundred units will be built, Q = 100, a human habitat, S = 2.13, initial operation in 2020, IOC = 2020, a tenth-generation design based on many previous space oxygen tanks, B = 10, and extremely easy difficulty, D = -3, cost is 66.1 million current dollars to deliver 100 tanks each with 34.5 kg of oxygen. This is 18.7 $k per kg of oxygen. The water and oxygen tank costs per kilogram of water delivered are much lower than shuttle launch costs but much higher than current Falcon 9 and Falcon Heavy launch costs. Since the launch cost is significantly below the tank cost, further reductions in launch cost will have little effect on the take or make decision. Table 1 shows the Cost to Take Water and Oxygen.

Table 1. Total cost to Take water and oxygen to the space station.

	Falcon launch cost		Shuttle launch cost	
	Water	Oxygen	Water	Oxygen
Material mass per container, kg	103.00	35.40	103.00	35.40
Container Mass, kg	21.20	12.70	21.20	12.70
Container Cost, $k each	1,642	661	1,642	661
Container Cost, $/kg material	15.94	18.67	15.94	18.67
Transportation Cost, $k/kg	1.52	1.52	72.30	72.30
Transportation Cost, $k/kg material	1.83	2.07	87.18	98.24
Total cost to Take, $k/kg	17.78	20.74	103.13	116.91

The current transportation cost is the Falcon Heavy rate of 1.52 $k/kg to LEO. Since the containers add mass, the transportation cost per kg of supplied material is slightly higher. At the Falcon Heavy rate, the container cost is much larger than the transportation cost. At the shuttle launch cost of 72.3 $k/kg, the transportation cost is much larger than the container cost.

B. Costs to Recycle Water and Oxygen

The ISS Water Processor Assembly (WPA) has a mass of 476 kg and its yearly resupply mass is 478 kg/year. It can recycle about 50 kg/day of water. [14] Using the AMCM, one unit was built, Q = 1, a human habitat, S = 2.13, initial operation in 2020, IOC = 2020, a first-generation design, B = 1, and average difficulty, D = 0. The system cost is 411 million current dollars. Since the system is essentially replaced every year, this is also the yearly operations cost. If the WPS provides 50 kg of water per day, it produces 18,250 kg per year and the cost per kilogram is 22.50 $k/kg. This is a little higher than the cost of taking water to the space station at the Falcon Heavy launch cost. Taking water to ISS now seems slightly cheaper than recycling it.

The ISS Oxygen Generator System (OGS) has a mass of 113 kg and can supply 5.9 kg of oxygen per day. One unit was built, Q = 1, a human habitat, S = 2.13, initial operation in 2020, IOC = 2020, a first-generation design, B = 1, and average difficulty, D = 0. The system cost is 70.1 million current dollars. Assuming a typical operations cost of ten percent of the original cost per year, the yearly cost is $7,010 k and the cost per kilogram is 3.26 $k/kg. This is much less than the cost of taking oxygen to the space station, even at the lower Falcon Heavy launch cost. Table 2 shows the Cost to Make water and oxygen.

Table 2. Total cost to Make (recycle) water and oxygen.

	Falcon launch cost		Shuttle launch cost	
	Water	Oxygen	Water	Oxygen
Material per year, kg	18,250	2,154	18,250	2,154
System Mass, kg	476	113	476	113
System Cost, $k	410,711	70,113	410,711	70,113
Operations Cost, $/year	410,711	7,011	410,711	7,011
Operations Cost, $/kg	22.50	3.26	22.50	3.26
System Mass per year, kg/year	476	11.3	476	11.3
Transportation Cost, $k/kg	1.52	1.52	72.30	72.30
Transportation Cost, $k/year	724	17	34,415	817
Transportation Cost, $k/kg material	0.04	0.01	1.89	0.38
Total cost to Make, $k/kg	22.54	3.26	24.39	3.64

The current transportation cost is the Falcon Heavy rate of 1.52 $k/kg to LEO and the earlier shuttle launch cost rate was 72.3 $k/kg. Even for the very much higher shuttle cost, the recycling system hardware cost is much larger than its transportation cost. It is incorrect to neglect the recycling system hardware cost under the assumption that the recycling system launch cost is greater, even for the historically high shuttle launch cost.

C. Which is Better, to Take or Recycle Water and Oxygen?

Even with the new much lower launch cost, taking water is not significantly cheaper than recycling it. Recycling costs 22.54 $k/kg of water recycled, and the launch cost of that hardware is only 1.89 $k/kg of water recycled, even at shuttle launch costs. The water tanks cost 15.94 $k/kg of water taken, and the mass of the water and tank, 1.2 kg per kg of water taken, adds only another 1.83 $k/kg launch cost at the current Falcon Heavy rate of $1.52 k/kg. Taking or recycling water for the space station costs about the same at current launch costs. At the shuttle launch cost of 72.3 $k/kg, the launch cost of the 1.2 kg water and tank is 87.18 $k/kg of water supplied, for a total of 103.13 $k/kg. Recycling water was strongly favored at shuttle launch costs.

Recycling oxygen is still cheaper than taking it in tanks, even at the Falcon Heavy launch cost. The oxygen recycling cost is 3.26 $k/kg, while the oxygen tank cost alone is 18.67 $k/kg of oxygen provided. The launch cost of the 1.36 kg of water and tank is 2.07 $k/kg at the Falcon Heavy rate, for a total cost of 20.74 $k/kg to take oxygen. Recycling oxygen still provides a saving, but less than at shuttle costs.

VIII. Take or Recycle Water and Oxygen on a Moon Mission?

The space station has operated for decades and will continue to be used, so the take or recycle decision depends largely on the continuing operational costs. The mission duration is long enough that the initial hardware costs for recycling equipment are small compared to the accumulated operational costs. If the next Moon mission does not establish a permanently inhabited base, the crew size and mission duration will affect the take or recycle decision. For recycling to save cost, the total masses of water and oxygen required over time must be large enough that the cost of taking them is greater than the cost of providing recycling equipment. The recycling cost breakeven date decreases directly with the crew size, so that doubling crew size cuts the breakeven date in half. The breakeven date to take or recycle water and oxygen on a Moon mission will be computed.

A. Crewmember Water and Oxygen Requirements

The crewmember oxygen requirement is 0.84 kg/CM-d. [16] Table 3 shows the life support water requirement for a single crew member in kilograms per crewmember-day (kg/CM-d).

Table 3. Life support water requirements, kg/CM-d.

Food preparation water	0.75
Drinking water	1.62
Wash water	4.09
Shower water	2.73
Urine flush water	0.49
Total water	9.68

The water requirements are based on early space station planning, except that large clothes and dish washing requirements have been eliminated. [16]

B. Moon Transportation Cost

The cost per kg of payload for a Moon mission is much higher than for LEO. The mass that must be placed in LEO includes the rockets and propulsion mass needed to take the payload to the Moon and land it on the surface. A rocket's stack-to-payload mass ratio is the total mass needed in LEO (payload mass plus rocket mass plus propulsion mass) divided by the payload mass. This mass ratio is sometimes called the gear ratio or the location factor. To send hardware from LEO to lunar orbit and then land it on the surface has a gear ratio of about 7.2. [17] The launch cost for a Moon base would be 10.8 $k/kg, based on the Falcon Heavy cost of 1.52 $/kg and a Moon base gear ratio of 7.2.

C. Costs to Take Water and Oxygen

The water and oxygen tanks assumed for the Moon base are the same as above for the space station. Table 4 shows the Cost to Take Water and Oxygen.

Table 4. Cost to Take water and oxygen to a Moon base.

	Water	Oxygen
Material mass per container, kg	103.00	35.40
Container Mass, kg	21.20	12.70
Container Cost, $k each	1,642	661
Container Cost, $/kg material	15.94	18.67
Transportation Cost, $k/kg	10.80	10.80
Transportation Cost, $k/kg material	13.02	14.67
Cost to Take, $k/kg	28.97	33.34
Mass use rate, kg/CM-d	9.68	0.84
Cost to Take, $k/CM-d	280.40	28.01

The Cost to Take, $k/kg, is multiplied by the crewmember daily mass use rate, kg/CM-d, to get the Cost to Take, $k/CM-d. The changes from the space station case are the much higher transportation cost to the Moon and measuring cost in $k/CM-d rather than $k/kg.

D. Costs to Recycle Water and Oxygen

The water recycling and oxygen regeneration systems assumed for the Moon base are the same ISS systems as for the space station calculation. The initial development cost of the system is a major factor in determining the cost breakeven date. Table 5 shows the initial system and the incremental daily cost to make water and oxygen. It also includes the breakeven date computation.

Table 5. Make breakeven date for water and oxygen on a Moon base.

	Water	Oxygen
Initial cost		
System Cost, $k	410,711	70,113
System Mass, kg	476	113
Transportation Cost, $k/kg	10.8	10.8
Transportation Cost, $k	5,141	1,220
Initial System Cost to Make, $k	415,851	71,333
System production rate, kg/d	50	5.9
Crewmember use requirement, kg/CM-d	9.68	0.84
Crewmembers supported, CM	5.17	7.02
Initial system cost per crewmember, $k/CM	80,509	10,156
Daily cost		
Yearly cost fraction	1.00	0.10
Daily cost, $k	1,125	19.21
Daily product, kg	50.00	5.90
Operating cost per kg, $k/kg	22.50	3.26
Crewmember use requirement, kg/CM-d	9.68	0.84
Daily Cost to Make, $k/CM-d	217.85	2.73
Breakeven calculation		
Daily Cost to Take, $k/CM-d	280.40	28.01
Daily Saving to Make, $k/CM-d	62.56	25.27
Cost breakeven date, d	1,287	402

The initial cost to deploy the recycling systems is computed first. The System Cost and System Mass are as in Table 2. Even with the higher Transportation Cost to the Moon's surface, the system development cost dominates the Initial System Cost to Make. The number of crewmembers supported by each system is computed using the system daily production rate and the crewmember daily use requirement.

The operating cost per day is recomputed, but it is nearly identical to the continuing operations cost, Total cost to Make, $k/kg, in Table 2. This occurs despite the different LEO and Moon transportation costs because even the higher Moon transportation cost is negligible compared to the system development cost for recycling equipment.

The operating cost per kilogram, \$k/kg, is multiplied by the Crewmember use requirement, kg/CM-d, to give the Daily Cost to Make, \$k/CM-d, for water and oxygen.

For "make" to save cost, the initial system cost per crew member must be more than paid back by the daily cost savings of "make" over "take." The Daily Cost to Make, \$k/CM-d, is subtracted from the Daily Cost to Take, \$k/CM-d, to give the Daily Saving to Make, \$k/CM-d. The Cost breakeven date, d, is found by dividing the Initial system cost per crewmember, \$k/CM, by the Daily Saving to Make, \$k/CM-d. The breakeven date for water recycling is quite long, 1, 287 days, about 3.5 years, and the breakeven date for generating oxygen from water is 402 days, a little more than one year. The ISS recycling water and oxygen generation systems saved significant cost for the multi-decade ISS mission at high space shuttle transportation costs, but a Moon mission at current transportation costs would have to continue for many years for recycling to save significant cost.

IX. Conclusion

This paper described the "take or make" decision analysis using a general parametric model. The major decision drivers are the make system's initial cost, its continuing operational cost, the take system's continuing operational cost, and the mission duration. The lowest cost is often determined by one driving parameter.

Example calculations were made for water recycling and oxygen generation for the space station and a future Moon base. The original "make" decision saved substantial cost for space station because of its long duration and the high shuttle transportation costs but "make" would save little for a future space station at current much lower transportation costs. The "take" decision would be best for a future Moon mission unless the mission established a permanent base or continued for many years.

Transportation cost is now so low that launch mass and cost is not usually a decision factor. The general "take or make" rules depend on mission duration.

1. For a short duration mission, less than a few years, probably "take."
2. For a very long duration mission, many years or a permanent base, usually "make."
3. For an intermediate duration mission, several years, "make" only if the mission duration is several times the cost breakeven date.

These rules provide a rough cost decision guide, but a systems analysis of the "take or make" tradeoff should consider the performance, reliability, safety, and risk of each system for the specific mission.

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