

Mic25-0108

USC ASTE 523, Spring 2025

Design of Low-Cost Space Missions

**Living on the
Moon and
Economic
Models**

***Selene: A Near-Term,
Income-Generating,
Lunar Settlement***

Part 5

***Living on the Moon
in the next decade***

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- **Living on the Moon**
 - **The Major Problem with Traditional Lunar and Space Architecture**
 - **What is there to do on the Moon?**
- **Lunar Economic Models**
 - **The Current Lunar Economic Climate**
 - **The Major Problem with Lunar Economics**
 - **Models for Specific Economic Areas**



Living on the Moon: The Major Problem with Traditional Lunar and Space Architecture

- Assume that a Moonie works 9 hrs/day, 6 days/week = 54 hrs/week
 - This leaves twice as much time (114 hrs/week) + any vacation days for sleeping and doing other things
 - These are ordinary people, not astronauts or selenauts, that are now living on the Moon

What do people do that are Living on the Moon?

- Most analysis is on what people do when they're working outside as construction workers or, less often, inside as diplomats or repairmen
 - In fact, people will do a great deal more than just their day job
- Most habitat analysis is based on minimizing the cost and, therefore, the size, and complexity (and funness) of the facility

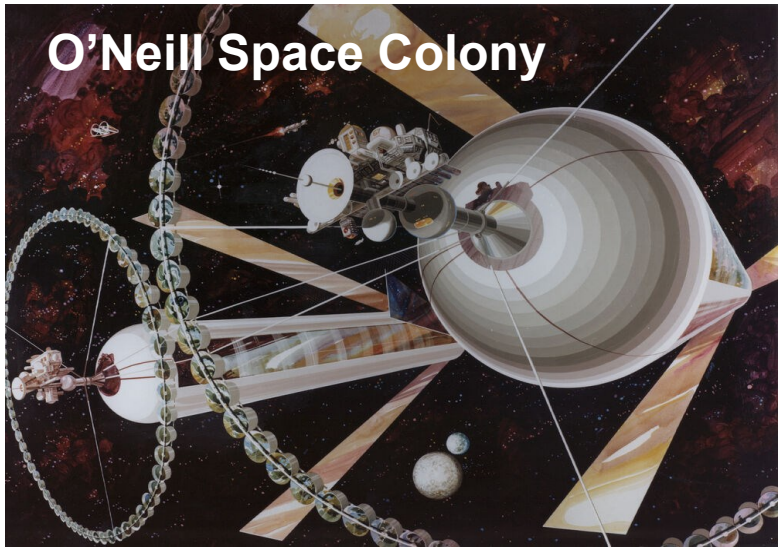
That isn't the right answer

- We need to design the settlement to meet the real day-to-day needs of the people who live there !!

We need to design the lunar settlement for ordinary people and how they live and behave when they're working and when they're not working.



O'Neill Space Colony vs. Selene Lunar Settlement Why was the O'Neill Colony so Popular?



O'Neill Space Colony



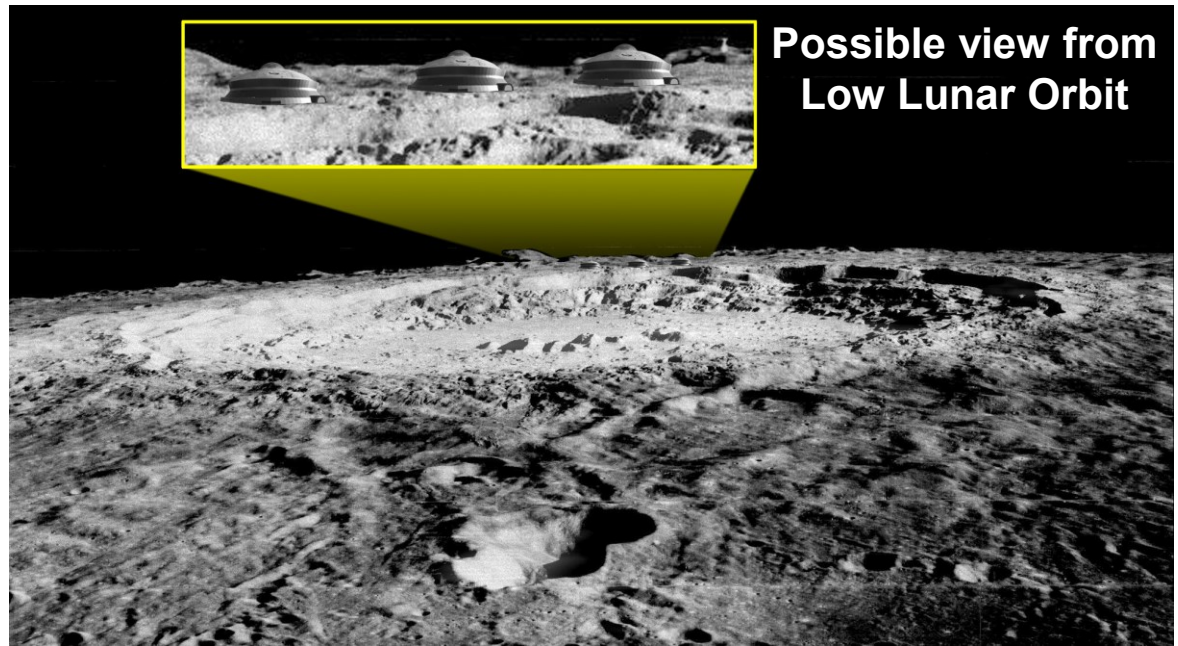
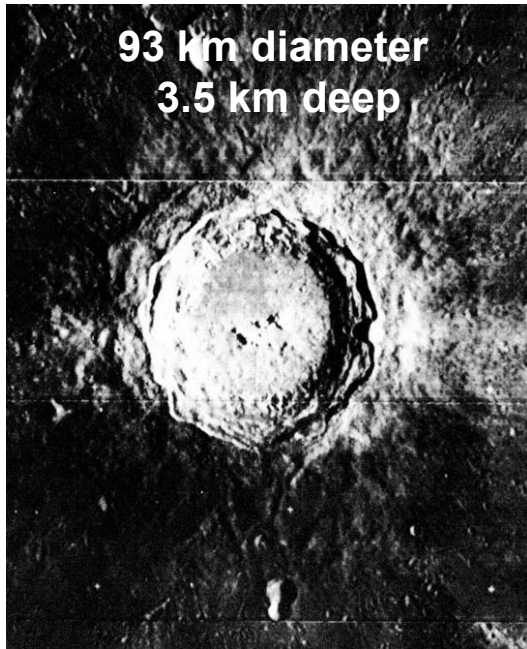
Both O'Neill Space Colony and Selene Lunar Settlement

- **O'Neill Space Colony**
 - Huge in size – 30 km long by 3 km in diameter – very expensive to build
 - **People oriented, but no substantial sources of external income**
- **Selene Lunar Settlement – largely patterned after the O'Neill Colony**
 - Dramatically smaller – 0.05 to 0.1 km high by 0.3 km in diameter
 - Dramatically cheaper – smaller in size and built where the material is
 - **People oriented, with many sources of large income**

Both approaches are strongly people oriented, but the Selene settlement has multiple sources of income to pay for the much smaller cost of creating it.



The Grand Copernican Rim Settlement and Downhill Ride

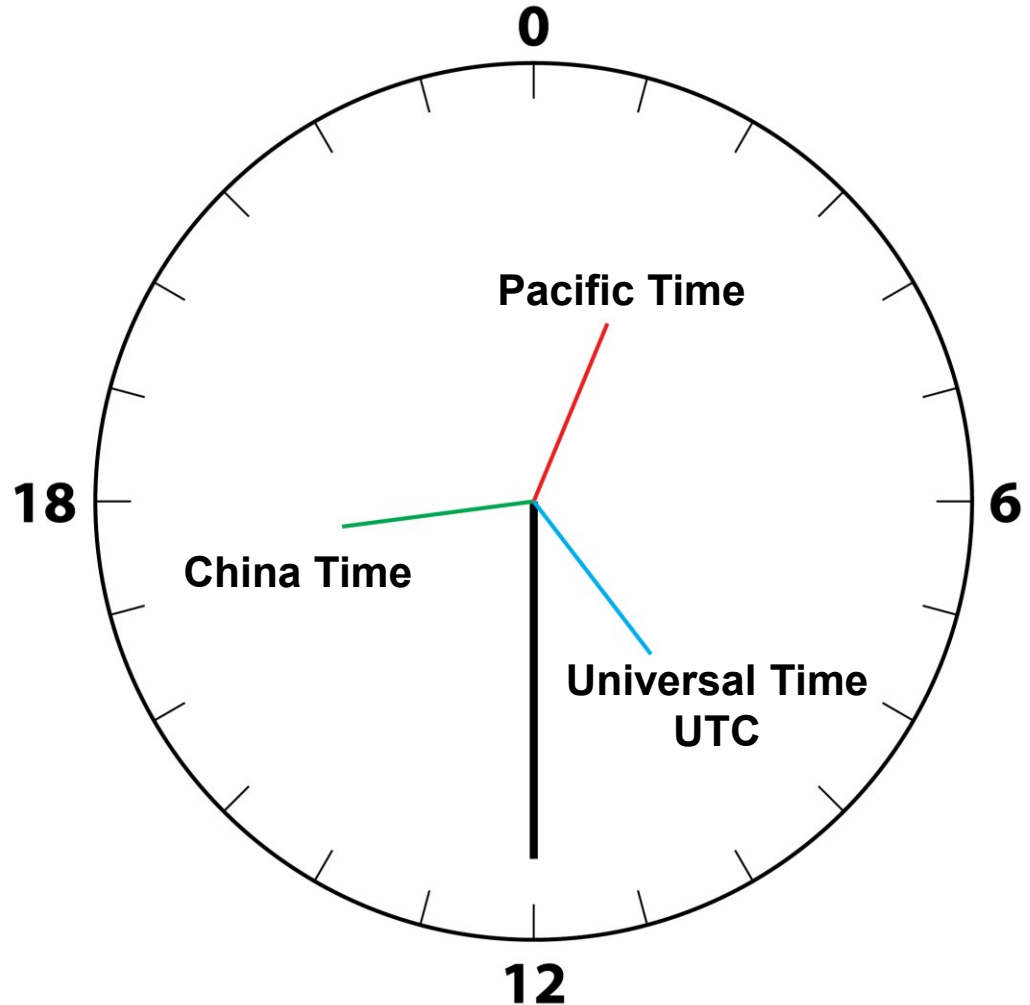


- **The “Grand Copernican Rim Settlement” is 3 large settlement enclosures in 3 time zones – 1 on Universal Time (UTC = London Time), 1 on Pacific Time (UTC – 8 hr) and 1 on China Standard Time (UTC + 8 hr)**
- **The “Grand Copernican Settlement” is 3.5 km above the crater floor and 93 km from the opposite rim—seen as sharp and crisp as if it’s right in front of you**
- **From the top of the rim to the crater floor the wall slopes downward, dropping 3.5 km (12,000 ft) over a distance of 19 km in a series of rolling terraces – the roller coaster ride of a lifetime in 1/6th g**



Copernican Rim Settlement Time Zones

- The “Grand Copernican Rim Settlement” is on 3 time zones:
 - 1 enclosure on Universal Time (UTC = GMT = London Time) [green = 9:30 am]
 - 1 enclosure on Pacific Standard Time (UTC – 8 hr) [red = 1:30 am]
 - 1 enclosure on China Standard Time (UTC + 8 hr) [blue = 5:30 pm]
- Each time zone is 8 hours from the other 2





What Can People Do on the Moon? Social Activities

- **Walk to Europe for dinner**
 - From the America enclosure to the European enclosure is a 10 min walk
 - To the China enclosure it's a 15 min ride in a golf cart
 - Note that the population is small -- there will likely be only 2 or 3 restaurants in each enclosure with open seating; others will have 1-2 tables and serve food only when pre-ordered
- **Have a party with friends**
 - Could invite people back on Earth to join via Zoom
- **Shop for clothes and products from around the world from previous tourists**
 - It's more cost-effective for them to sell stuff on the Moon and buy new items when they return to Earth
- **Go to a talk about Portugal from the Portuguese ambassador to the Moon**
- **Explore what's in the other two enclosures**
- **Serve as a tour guide, helper, or friend to people from your area of Earth**
- **Enjoy a romantic evening in your apartment in 1/6th g**

There are lots of things to do on the Moon to keep busy.



What Can People Do for Fun Inside the Settlement?

- **Fly**
 - May have human-powered flight on the Moon – don't know for sure
- **Trampoline**
 - Remember, you weigh 1/6th as much and fall 1/6th as fast
 - May not be able to find a roof high enough
- **Gymnastics**
 - High jump, long jump, diving, and balance beam
- **Running and swimming**
 - Not clear whether you will be faster or slower
- **Walk on your hands or ride a unicycle**
 - Slow fall rate gives you much better balance
- **Dancing or ballet**
 - Stay in the air forever
 - Throw your partner in the air

After an hour or so of exercise, you could lie in a beach recliner in 1/6th g and watch the Earth rotate overhead.



What Else Can People Do? Communications

- **Outside the enclosure**
 - The goal is to have continuous communications with all individuals and groups outside the enclosure
 - Want continuous monitoring of their safety
 - Should be straightforward to implement with current technology
- **Inside the enclosure**
 - Want large number of internet/Zoom channels available continuously
 - Lots of languages
 - Diplomats and teachers training 8.2 billion people on Earth
 - Individuals talking to family and friends on Earth (and on the Moon)
 - International Lunar University running both classes and data
- **Multiple TV channels (not as many as in major US cities)**
 - Several channels in multiple languages from Earth
 - News broadcasts to Earth of activities on the Moon
- **Continuous mobile phone coverage equivalent to Earth**
- **Need both 1-way and 2-way communications**

Communications is both much easier because of modern technology and also much harder because of the huge potential demand and the large number of languages and cultures involved.



What Else Can People Do? Outside the Settlement

- **The more than 50 km back and forth downhill ride from the rim to the floor of Copernicus**
 - This one is unique to Copernicus, but there are similar slopes on all major craters over the entire Moon
 - May want to do this multiple times
- **Rover tours of nearby areas**
 - Maria, mountains, rills, and other craters
 - See known areas of interest or explore areas no one has ever seen before
- **Multi-day exploration missions**
- **Places to visit**
 - Tycho cemetery
 - Far Side Observatory
 - These may need to be multi-day trips due to the transportation problem
- **Walking tours**
 - Walk in areas no one has ever been
 - Pick up samples or find the first Moon diamond

Recall that the Moon is huge (North America + South America) and you have a jeep. Exploring it will not be a fast or simple process.

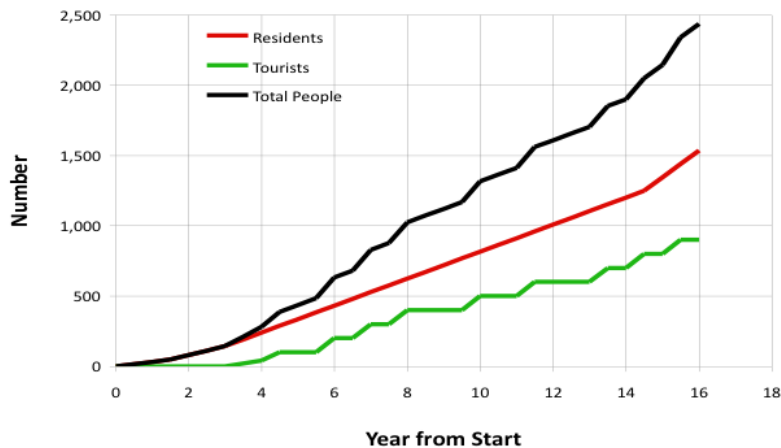


- **Lunar population growth with time**
- **Current Lunar Economic Climate**
- **Lunar Burial**
- **Unmanned Mini-Rover**
- **Lunar Tourism**
- **“Lunar Ranch**
- **Weddings and Ceremonies**
- **Ambassadors to the Moon**
- **He³**
- **Marketing, Advertising, and co-Branding**
- **Revised Income Estimate**
- **Summary of Lunar Economics**

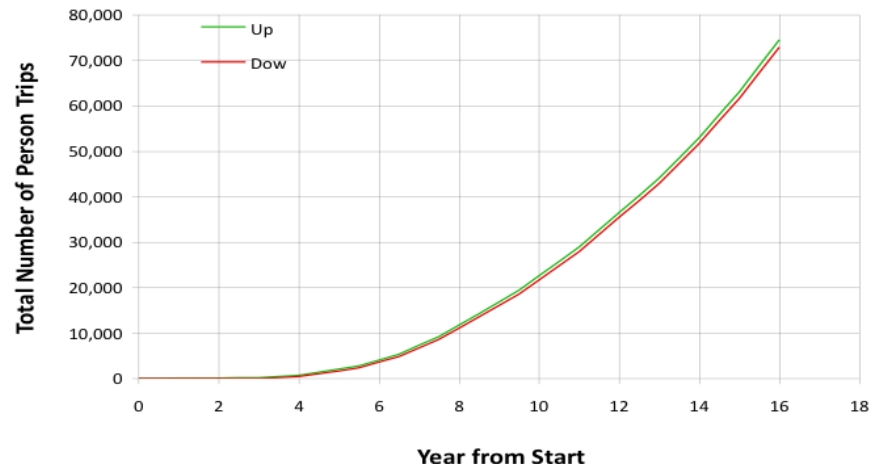


How Does the Lunar Settlement Population Grow with Time?

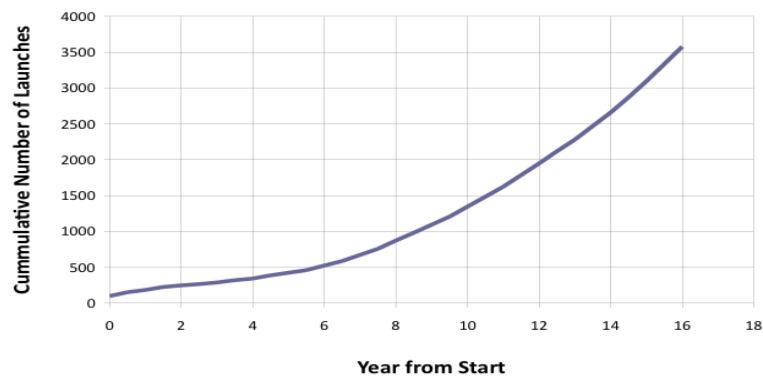
Lunar Population



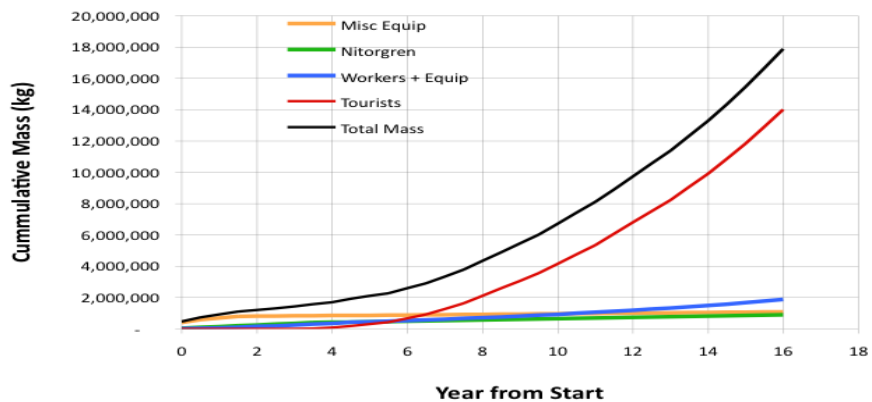
Person Trips to the Moon



Cummulative Launches (At 5,000 kg/launch)



Cummulative Mass to the Moon



The Lunar Settlement(s) reach 1,000 people about 12 years after building begins. We may be able to do it sooner.



Lunar Economics in the Current US Economic Climate

- **Advantages**

- **Changing lunar settlement and long-term lunar development from a government program to a much lower cost commercial activity can reduce the potential cost to the government by 10's of billions of dollars**
- **This is consistent with the current government goal of shifting work to the commercial sector and reducing government cost**

- **Disadvantages**

- **Lunar exploration or settlement will not reduce the cost of eggs or in any way realistically impact the lives of individuals in the US or around the world**
- **It isn't clear whether the US government can or would economically support commercialization of lunar settlements**
 - **If all of the background work were done commercially, that would probably be supported, but that isn't likely to happen**



Lunar Burial Economics

Per person recurring cost and income

- **Burial in space has been ongoing since 1997**
 - 1 person (astrogeologist Eugene Shoemaker) is buried on the Moon
- Estimated recurring cost of a single lunar burial
 - Note that nearly all burial activities on the Moon can be automated
 - Taking cremated sample to the Moon (crater Tycho) \$100
 - Administrative and management costs \$500
 - Create and inscribe metal plaque (headstone equivalent) \$100
 - Place plaque and take photos of plaque and Earth \$300
 - Electronic memory unit of experiences and photos \$200
 - **Total per person cost** **\$1,200**
 - Special services (varies with user) \$10,000
- Income (single burial)
 - **Normal burial income** **\$20,000**
 - Special services \$500,000
- **50,000 to 500,000 lunar burials/year (0.05% to 0.5% of all burials)**
 - **Likely to be different for different regions and cultures on Earth**
- **Bottom line –good profit margin, income of ~\$1B to \$10B+ per year**
- Large number of secondary markets (next chart)
 - Won't know real market size until it is done



Lunar Burial and Ancillary Markets

- **Market size**
 - **Largest market is probably for individual burial at time of death:**
 - **Approximately 100,000,000 people die annually**
 - **Assume 50,000 to 500,000 customers (0.05% to 0.5%)**
 - **Market of ~\$1B to \$10B per year, with large profit margins**
- **Other related markets:**
 - **Husband and wife buried “together forever in heaven”**
 - **Family buried after being killed in car accident**
- **Lunar burial does not have to happen at time of death**
 - **Bodies of previously deceased could be briefly recovered to obtain small sample for lunar burial**
 - **Could provide only a plaque and electronic memory unit for burial**
- **Lunar cemetery tourism**
 - **People could visit the lunar cemetery to see the remarkably peaceful location and view of Earth that will last literally millions of years**
- **Ideal location is the mountains in the center of the crater Tycho**
 - **85 km diameter, 4.7 km deep and about 100 million years old**
 - **Tycho is the center (and origin) of lunar rays that make it the most identifiable location in the visible Universe at full Moon**

Lunar burial appears to be an excellent business, but is entirely new.



Is the Lunar Burial Market Real?

- There appears to be a very large market both for lunar burial and ancillary services
 - Burials of pairs, e.g. husband and wife together forever in heaven
 - Burials of people who have died unexpectedly, a child who died and is now in heaven
 - Memorials to people that died previously
 - Tourists visiting the lunar cemetery
- Historically, only 1 person has ever been buried on the Moon
- **We really don't know whether the \$1B to \$10B annual market is real**
- There are probably 4 determining issues, maybe more
 - Does some organization pay the NRE to make it low cost
 - Does an event (killing of a group of school children) or a famous person (death of well-known actor) make it well known and liked
 - What is the religious response to being “buried in heaven”
 - What is the response of any particular nationality or culture

The bottom line is that the response will likely be different in different countries and cultures. China, India, Kenya, Brazil, and the United States will likely respond differently. We simply don't know what's real and it will likely be different in different countries and cultures.



Economics of Unmanned Mini-Rover

- **Basic goal is to have 500 small rovers that can be driven by students around the world during daylight hours on the Moon and for the student**
 - **First unit cost of \$100,000 with 90% learning curve**
 - **Total cost of 500 units = \$19.4M**
 - **Average cost of 500 units = \$38.9K, 500th unit = \$33.0K**
- **Assume 5 year lifespan = 60 lunar “days”**
 - **Each day is 2 weeks long, about 340 hours**
 - **Days near the poles will be both longer and shorter at times**
 - **Split the the operation of each rover into 3 segments with 8 hours in Europe, 8 hours in N America, and 8 hours in Asia so that students in each area can work in normal daylight hours for them**
 - **Assume income of \$200/hr and 80% efficiency = \$55K/lunar day = \$3.2M/rover lifetime**
 - **Assume operational/administrative costs of \$100/hr sold = \$1.6M over the lifetime of the rover**
- **With these assumptions, each Unmanned Mini-Rover could generate a net profit of over \$1.5M over 5 years = total profit of \$750M for 500 units**
 - **Allows room for failure of some rovers and creation of a new generation of rovers**



Lunar Tourism Economics

Per person recurring cost

- **Estimated transportation cost to the Moon = \$1,600/kg = \$725/lb = \$45/oz = \$1.6 million/metric ton and \$2,000/kg round trip fare**
 - This should remain an independent variable in our analysis
- **Round-Trip Rocket Fare by personnel class**
 - Economy class = 150 kg on the Moon = \$300K
 - First class = 250 kg on the Moon = \$500K
- **Typical stay time = 16 days (full daylight plus sunrise and sunset)**
- **Estimated hotel and meal cost**
 - Economy class (electronic window) = \$3K/day = \$50K
 - First class (real window) = \$15K/day = \$240K
- **Touring cost**
 - Most inside activity (swimming, running, gymnastics, Earth viewing) is free
 - Economy class (Rover tours) = \$20K
 - First class (Rover and spacesuit tours) = \$150K
- **Total cost**
 - Economy class = \$370K/person
 - First class = \$890K/person



Lunar Tourism Economics

Per Person and Total Annual Cost and income

- **Estimated per person price = per visit income**
 - Economy class = \$1,500K
 - First class = \$10,000K
- **Estimated tourist population for Year 6**
 - Economy class = 400/lunar day = 4,800/year
 - First class = 50/lunar day = 600/year
- **Estimated annual income for Year 6**
 - Economy class = \$7.2B/yr
 - First class = \$6.0B/yr
- **Estimated total cost and income, Year 6**
 - Cost = \$2.3B/yr
 - Income = \$13.2B/yr
- **Estimated tourist population for Year 12**
 - Economy class = 900/lunar day = 10,800/year
 - First class = 100/lunar day = 1,200/year
- **Estimated annual income for Year 12**
 - Economy class = \$16.2B/yr
 - First class = \$12.0B/yr
- **Estimated total cost and income, Year 12**
 - Cost = \$5.1B/yr
 - Income = \$28.2B/yr



Is the Number of Lunar Tourists Reasonable?

- **Approximate number of people worldwide in various wealth ranges**

— \$1M to \$5M	49.0M people
— \$5M to \$10M	4.5M people
— \$10M to \$50M	2.3M people
— \$50M to \$100M	100K people
— \$100M to \$500M	60K people
— Over \$500M	5K people
- 1 person may bring multiple tourists, such as family and colleagues
- 1 person may visit the Moon multiple times
- Economy class at year 12
 - **10,000 visits/year**
 - **7,000,000 people have the money to visit**
- First class at year 12
 - **1,200 visits/year**
 - **165,000 people have the money to visit multiple times and bring others**
- Numbers are acceptable, but it might be worth reducing price to increase the potential market
 - **Additional analysis is needed -- HOW MANY PEOPLE WOULD COME??**



“Lunar Ranch” Economics

- Our definition of a “lunar ranch”
 - A lunar ranch is a private enclosure near, but not connected to, a large lunar settlement
 - Built by a wealthy individual or business entirely for their own use
 - Use a lunar rover to go back and forth to a settlement as desired
- Why build a lunar ranch?
 - Prestige is the primary reason
 - “I own a ranch on the Moon”
 - Is a good location for vacations, entertainment, business meetings
 - Can have meals there (cooked or catered) or “go into town” for dinner
- Cost and income
 - Initial cost could range from \$100M to \$1B
 - I have seen homes in LA on the market for \$175M
 - No significant income and the owner doesn’t care

The lunar ranch is the equivalent of a luxury yacht, castle, or expensive home – the main value is the prestige of owning and using it.



Weddings and Ceremonies

- **For activities in which you want family, friends, or many guests present then a ceremony on the Moon is not appropriate**
 - Typically, a wedding wants to be a celebration to bring two families together and celebrate with friends
 - This doesn't work for a wedding on the Moon
- **Alternatively, when the purpose is to show off the importance of the event or the importance of the event sponsors, then a Lunar ceremony could work very well**
 - The very first wedding on the Moon will likely be a worldwide event
 - Ceremonies that could occur on the Moon
 - Weddings
 - Change of government
 - Funerals
 - Worldwide agreement
- **Exceptionally difficult to estimate price or frequency**
 - As an estimate, use 26/year at \$50M to \$150M each, average of \$100M
 - **Gives estimated annual income of \$2.5B**

It will be extremely difficult to estimate the income from weddings or ceremonies. It will likely depend strongly on the country or culture.



Ambassadors to the Moon

- Role of the Ambassador is discussed elsewhere
- **Assume ambassadors from 200 countries**
 - Estimated number of personnel as follows

—1 person	40 embassies
—2 people	100 embassies
—3 people	25 embassies
—5 people	25 embassies
—8 people	10 embassies
 - **Estimated total population of 520 people working primarily in accommodating needs of visitors and educating people on Earth**
- Assume average stay of 3 years and cost of \$1M/year, including First Class round trip fare
 - \$500M/year of additional fees (rovers, trips, conferences, parties)
- **Total cost for all diplomats of \$1B/year**

It is likely that diplomats and ambassadors will contribute strongly to the population and the culture, but will not be a major income source.



Economics of Lunar He³

- **Nuclear fusion using He³ is a potential source of global electric power with no radioactive waste**
 - Has not yet been proven in power plants
 - Several companies are now working to do that
 - Positive assessment based in part on work by former geologist, Apollo 17 astronaut, and US Senator Harrison Schmitt
- **Isn't sufficient He³ on Earth to make it efficient for energy generation**
 - He³ is available in the lunar regolith in small quantity, but sufficient to be worthwhile mining
- Demand is ~29 tons/year to replace current Uranium-based power generation
 - Price will be \$100 to \$200 per liter = \$750M to \$1.5B per ton
- **Total income to replace current worldwide Uranium power generation is \$21.5B to \$43B per year**
 - 95% profit margin allows room to reduce price or increase use
 - Can also be used on the Moon, of course, to generate power during the day and the long lunar night



Marketing, Advertising, and co-Branding

- The market for advertising from the Moon is huge, but dramatically diverse
 - **The same marketing approach is unlikely to work in the US, Kenya, and central China**
- Best approach may be to split the market into regions, such as

— North America	-- South America
— India and southern Asia	-- China and western Asia
— Australia and southeast Asia	-- Europe
— Middle East	-- Russia and eastern Asia
- Could, for example, sell the marketing opportunities for each region to separate companies that know that region
- **The Moon gives us a different view of some products and of our collective place in the Universe, but it doesn't make life better or easier on a day-to-day basis**
- **A realistic assessment of the market is extremely hard, if not impossible**

The biggest problem is that we simply don't know how these distinctly different markets will respond to different products (i.e., lunar tourism, Moon bikes, or lunar burial) and different advertising.



Revised Income Estimate

<u>Source</u>	<u>Basis (per year)</u>	<u>Annual Income</u>
Tourism	600 tourists/month = 7,000/yr@ \$1M–\$2M each	\$13B–\$28B
Space Burial	100,000 to 500,000@\$5K–\$20K each	\$1B–\$10B
Helium-3	30 tons/yr at \$750M to \$1.5B/ton	21.5B - \$43B
Diplomats/National Representatives	400 people \$1.0M/person	\$1B
Sports, entertainment and the Arts	???	\$2B–\$10B
Mining/Minerals (except ³ He)	???	\$2B–\$10B
Science	Astronomy, Geology, Biology, Physics, Chemistry	\$2B–\$5B
The Moon Wheel for low-g biology	??? Basic science needed for solar sys exploration	\$1B
Weddings and Ceremonies	26/year @ \$50M - \$150M each	\$2.5B
Solar System Exploration	20% of NASA budget + commercial	\$5B
Solar Power Satellites	2–10 @\$8.5B each	\$17B–\$85B
Knowledge Preservation	???	\$0.5B–\$1B
Manufacturing	Low & 0-g manufacturing, spce use components	\$2B–\$5B
Marketing/Co-Branding	(Separate estimate available)	\$35B–\$200B
Lunar mini-rovers	500 units with 5 year life; \$1.6M per rover	\$0.8B
Total Annual External Income		\$106B–\$406B



Lunar Village Population Estimate

Group	Start-Up	Mature	Where
ILU			
Students	2	40	In+Out
Staff		10	Inside
Medical/science	3	20	Inside
Tourism center			
Tourists	3	100	Inside
Staff	1	50	Inside
Outside Tours	1	30	Outside
Religious center		10	Inside
Embassies		400	Inside
LUNYWOOD: Marketing/Advertising	2	20	In+Out
Construction	12	100	In+Out
Repair and trade	2	12	Inside

Farm and food chain			
Farmers	1	15	Inside
Food chain		3	Inside
Cooks/delivery	2	30	Inside
Memorial park		5	In+Out
Library		5	In+Out
Far side observatory		8	Outside
Mining	4	30	Outside
Administration			
Air, power, water	4	15	In+Out
Police		3	Inside
Administration	1	8	Inside
Miscellaneous	2	25	In+Out
Inside Total	24	766	Inside
Outside Total	16	173	Outside
Total	<u>40</u>	<u>939</u>	



Summary of Lunar Economics

- For lunar economics to be successful, we must
 - Reduce the schedule
 - Dramatically reduce cost
 - Increase income
- **The most important step in all of these is to work inside a lunar enclosure**
 - **This lets us use ordinary commercial equipment on the Moon**
 - Don't want to reinvent all of the equipment that we use
 - Also gives us the opportunity for a wide variety of “social” jobs that aren't possible in the traditional NASA/DoD model
 - **Lunar tourism**
 - **Public education**
 - **Sports and entertainment**
 - **Lunar burial**
 - **International Lunar University**
 - **Advertising and marketing**
 - **Projected total income in the broad range of \$100B to \$400B annually**

The Moon offers more ways to become a billionaire than any location on Earth. It can also be lots of fun. Seems like a good deal. Unfortunately, nearly all of the areas are new and, therefore, uncertain.