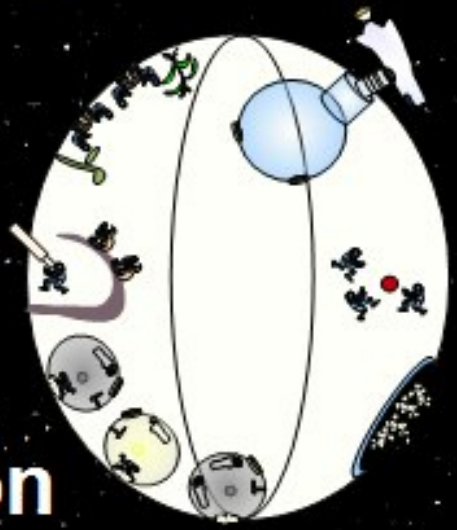
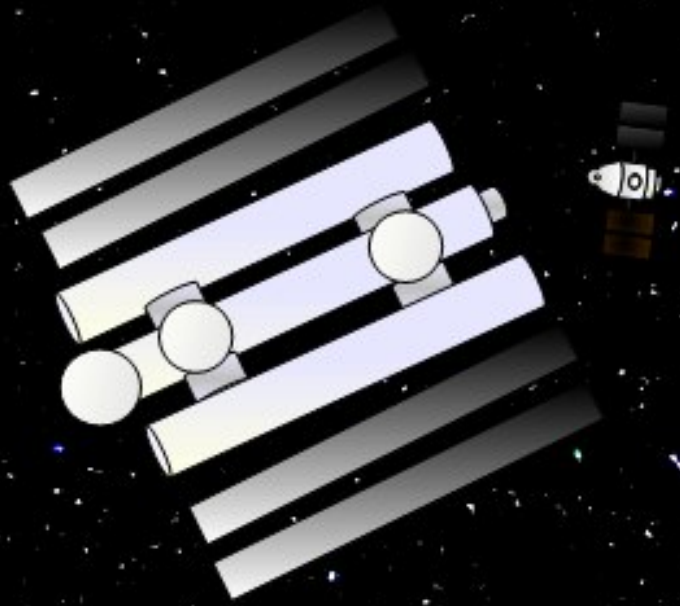


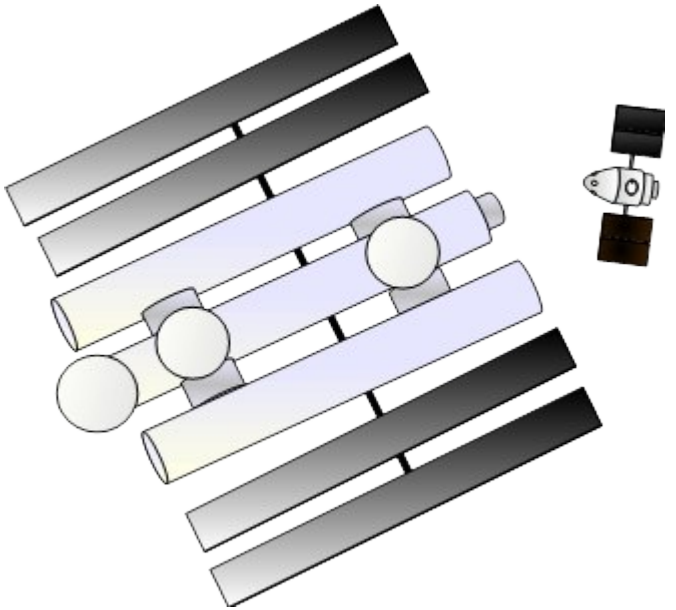
Economics and Food Provision Options for Luxury Food in an Orbiting Space Hotel AIAA SPACE 2016

Bryce L. Meyer



Overview

- Stages of Space Hotels
- Assumptions
- Dinner in Space
- Methods
  - Break out of costs
- Results
  - 180 day tour
  - 365 day tour
    - Unaccompanied
    - With Dependants
    - All recipes prepared at source (Earth).
    - All ingredients locally sourced



Future Space Tourists

- Like every mode of transport, and adventure destination, to date, early adopters pay heavily and surrender luxury.
- As launch costs drop, a wider range of tourists will expect more luxury for the high cost of travel. MREs will not be enough.
- As costs drop further, migration will result in colonies to support resorts, and ecosystems of suppliers nearer to resort.
  - My guess: once cost for 2 people is less then 10% of a combined household middle class income, the scale approaches a travel vacation to theme resorts at Orlando (or Anaheim).

Stage	Space Equiv	Earth Analog	Food Source	Staff	Cooking?
0	ISS as of 2016, All space outposts to 2016.	Everest Base Camp	All from Earth	Staff are not cooks	Prepackaged or simple recipies from canned/dehydrated Largely Guest cooked
1	Inflatable or Basic Orbital Unit/Hotel	Oil Rig, Antarctica Bases.	All from Earth	Cook as a secondary duty	Prepacked meals, some fresh foods, very simple recipies in bags
2	Beginning Space Resort	Bare bones Cruise Ship (i.e. Small boat).	Most from Earth, some local	Full-time Cook, a few servers	Some complex meals, more fresh foods
3	Next Level Space Resort	Major Hotel or Luxury Cruise Ship	Some from Earth, some orbital, some local	Full-time Cooks, many servers	Many complex dishes. Mostly fresh ingredients.
4	Full Space Resort as part of a small settlement.	All inclusive luxury resort as part of a community. Ex: Crocodile Bay, Costa Rica	Majority of foods either local or from orbital sources	Complete Full time, long term staff with layers	Many complex dishes. Mostly fresh ingredients.

Assumptions

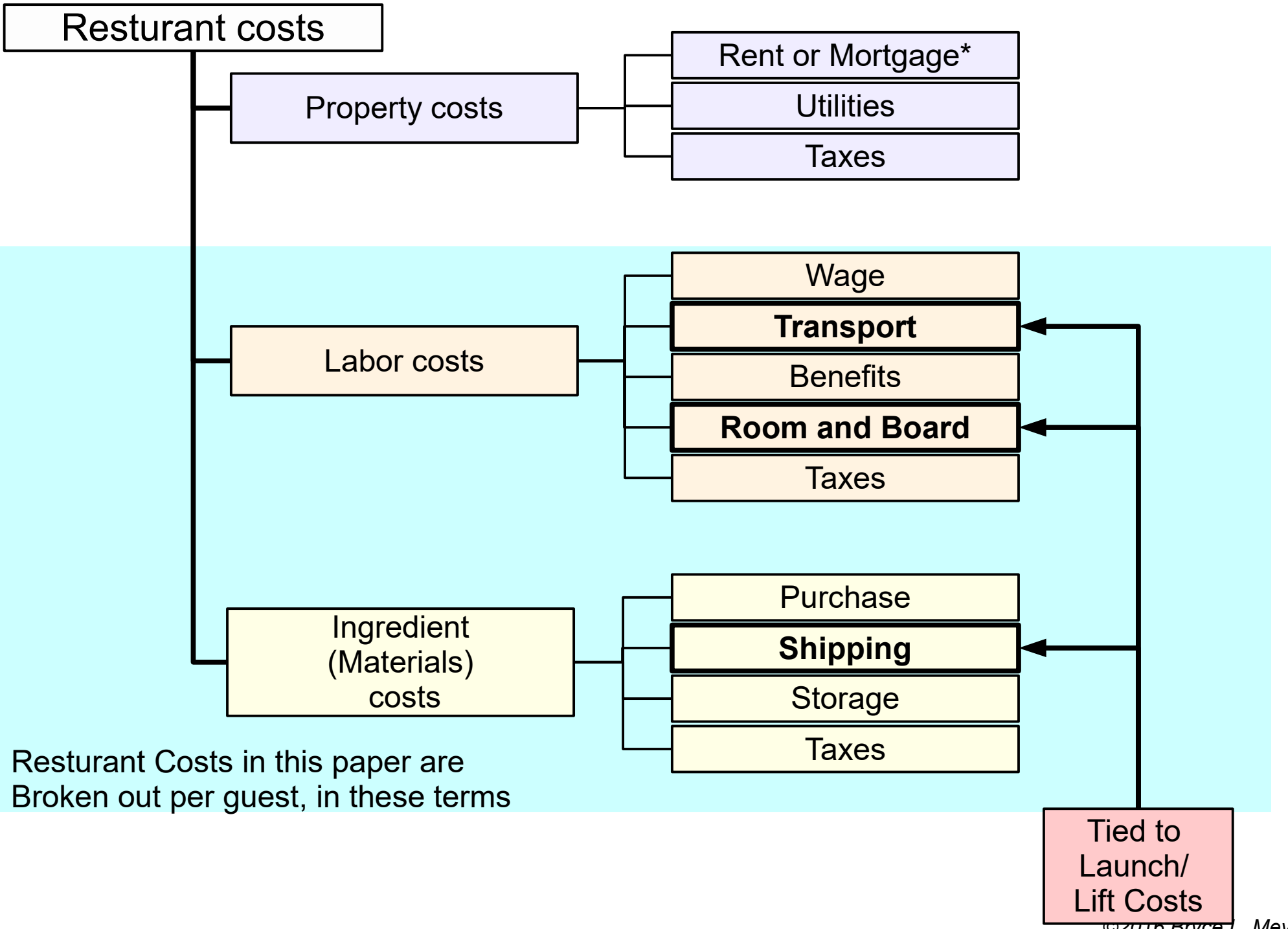
- Water is fully recycled, ditto for air.
- If waste biomass is recycled, it is not fed to guests unless grown into crops. Crew can eat recycled foods.
  - This includes 3D Printed foods
- Rent, while a significant cost, is a fixed amount.
  - This paper ignores real estate and utilities costs
- Stays over 365 days involve gravity
- Room and Board provided when working
- Transportation to and from resturant provided for labor, amortized into costs
- Guests want complex recipes and fresher food

Getting a Meal in Space: Options

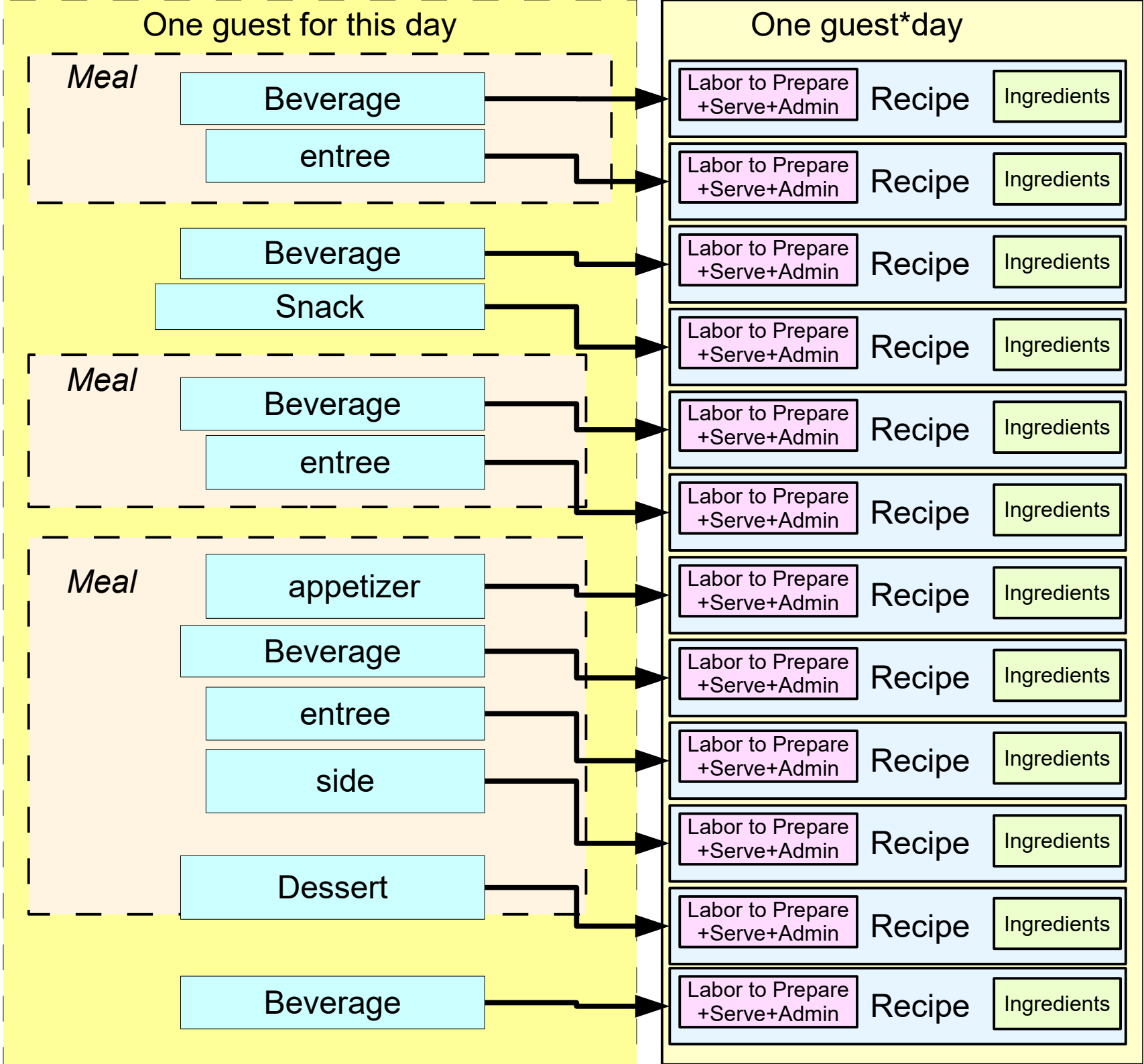
- Prepare each recipe on Earth, ship refrigerated or frozen, then warm up.
  - Advantage: Allows complex recipies, and minimizes in orbit labor.
  - Disadvantage: Food is not fresh, tastes mix together.
- Ship up ingredients from Earth, prepare in orbit
  - Advantage: Fresh Food.
  - Disadvantages: The more complex the recipe, the more labor in orbit is required, and the higher the level of expertise to assemble.
- Combine above.
- If food is grown in orbit, or at the resturant, ingredient shipment costs drop, reflected as a lower cost per unit mass.

The Space Cook

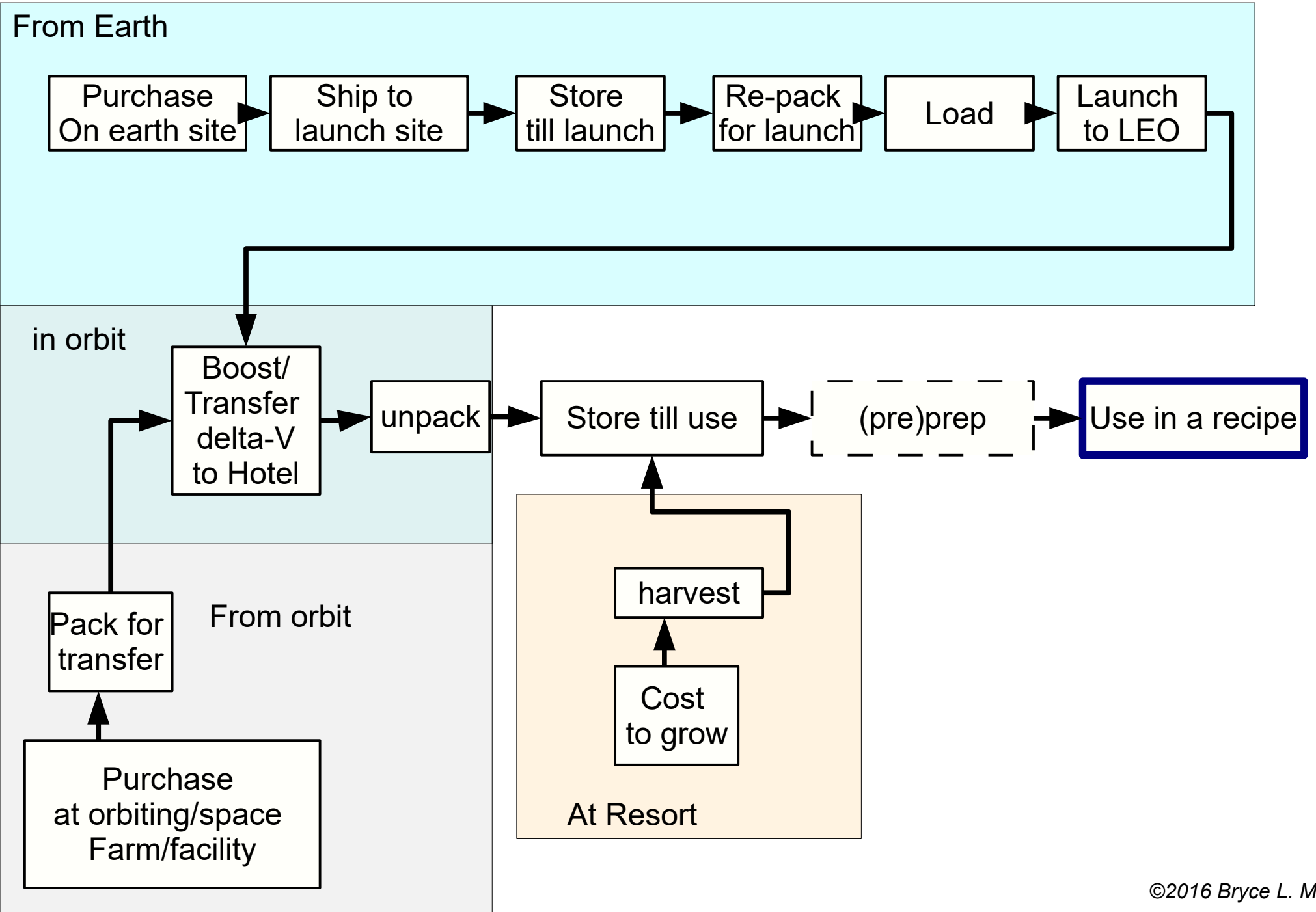
- All the skills of an Earth Cook plus:
  - Some Astronaut Skills
    - Live in tight quarters
    - Physically fit
    - Knows space safety.
  - Ability to cook in zero-g or limited-g:
    - Knows how to take advantage of equipment and physics of cooking without gravity, in limited space, with limited ingredients.
    - Cook Pot Problem: how to make rues and sauces using reduction and boiling
      - Ring shaped cook pot. Toroid shape, centrifugal force, gas extraction at center, heating at periphery. Stirers.
      - Round bread rolls on cross shaped racks. Radiative ovens.

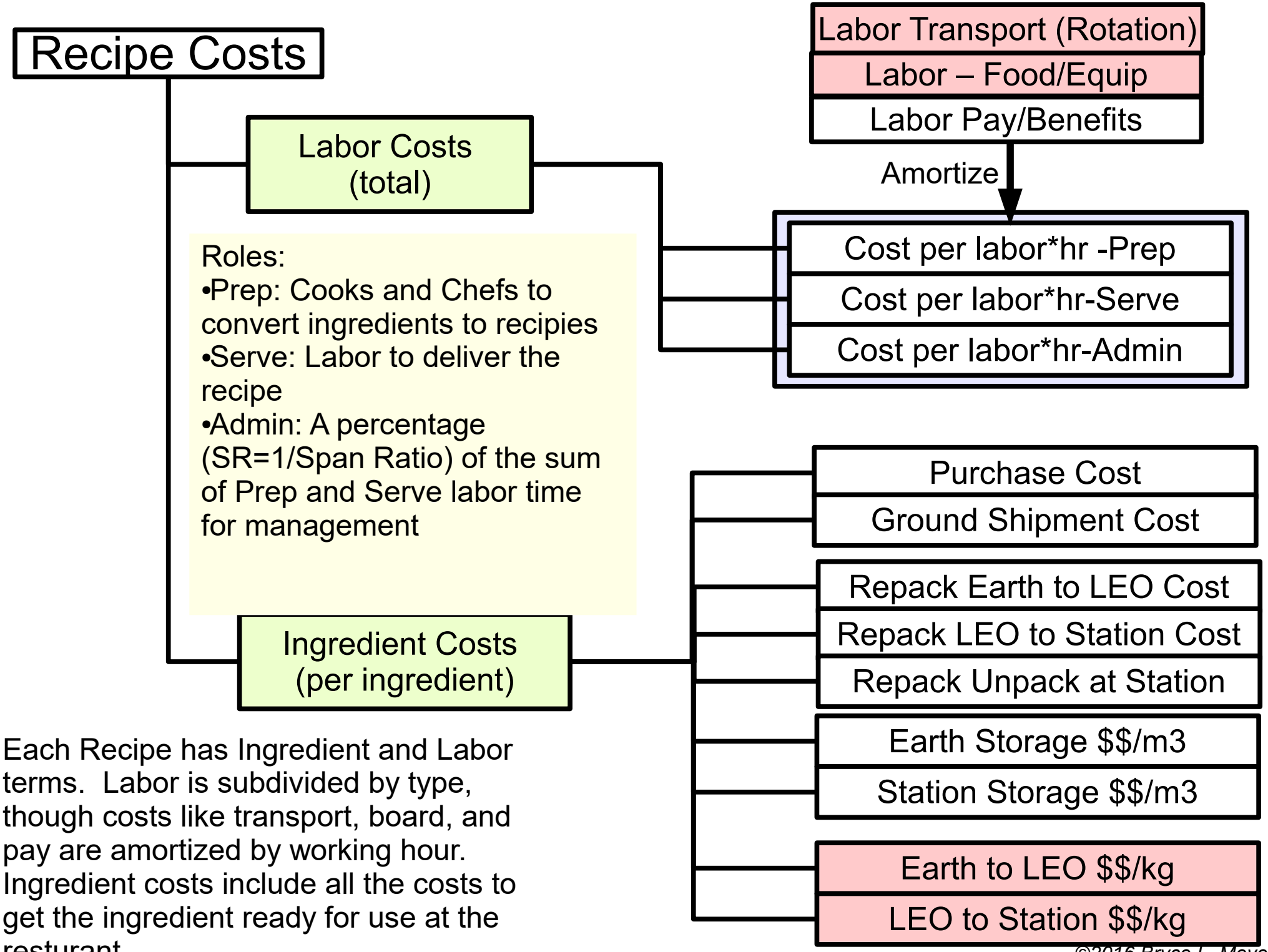


Each Guest's food and drink (beyond water) Can be broken into Recipes



Getting an Ingredient to the Resturant





Each Recipe has Ingredient and Labor terms. Labor is subdivided by type, though costs like transport, board, and pay are amortized by working hour. Ingredient costs include all the costs to get the ingredient ready for use at the resturant.

Getting to an Estimate: Cost Per Recipe

Cost per guest per day (C_d): The costs of the sum of the recipes consumed per 24 day per guest:

$$C_d = \sum_{r=1}^{\#\ recipes} C_r$$

In turn, the cost of each recipe is the sum of the labor and ingredients to make and serve the recipe:

$$C_r = [T_{L,prep} * C_{L,prep} + T_{L,serve} * C_{L,serve} + SR * (T_{L,serve} + T_{L,prep}) * C_{L,adm}] + [\sum_{i=1}^{\#\ ingredients} C_i * (m_{i,r}/m_{i,unit})]$$

Labor Term:
Time for each labor type multiplied by cost per hour, all in, for that labor type. Administration time is SR * (serve + prep time)

Ingredient Term:
Sum of the all-in costs for each ingredient * portion of the purchased unit used

All-in Per Hour Labor Costs

All in cost per labor hour (any type):

Travel cost is tied to Launch and Lift cost too... mass multiplier for person to cargo equivelent * Launch and Lift Costs

$$C_{L,travel} = m_{TtoC} * [\, C_{EtoL} + C_{LtoS} \,]$$

Term to iterate: Cost to launch from Earth to LEO + Cost to boost from LEO to the Resturant

$$C_L = (C_{L,travel} / (WR * RR)) + m_{pea} * [C_{EtoL} + C_{LtoS}] / WR + C_{L,w} * (1 + P_B)$$

Cost per person to travel to and from the resturant (for each work interval/tour).
WR=% of time worked of total time in a tour, averaged
RR = Rotation Rate = Tour length in days

Mass for food and personal allowance per person per tour * Launch and Lift Cost per kg Divided by % of time worked for total time in a tour

Per hour effort cost * a multiplier for benefits, taxes, etc.

All in Ingredient Costs

Each Ingredient has a series of costs accumulated in its journey to be used in a recipe

Mass per unit * Launch and Lift Costs * Overhead for packing etc.

Volume per unit * Storage costs on Earth and at the Resturant * Overhead (volume) for packing etc.

Cost and time to prep the ingredient so it can be used in various reciepes

$$C_i = m_{i,unit} * [C_{EtoL} + C_{LtoS}] * O_{i,m} + v_{i,unit} * [C_{store,Earth} + C_{store,Rest}] * O_{i,v} + T_{prep,i} * C_{L,prep}$$
$$+ C_{buy} + C_{gndshp} + C_{repack,E} + C_{repack,LEO} + C_{unpack,Rest} + C_{hvst}$$

Costs to purchase the ingredient, ship it on the ground to the launch site, costs to repack for various transport legs, unpack, and in the case of a crop from the resturant, harvest the ingredient

Labor creeping into my ingredient... Nutmeg for example may be brought in whole then ground.

Example Cases: Assumptions

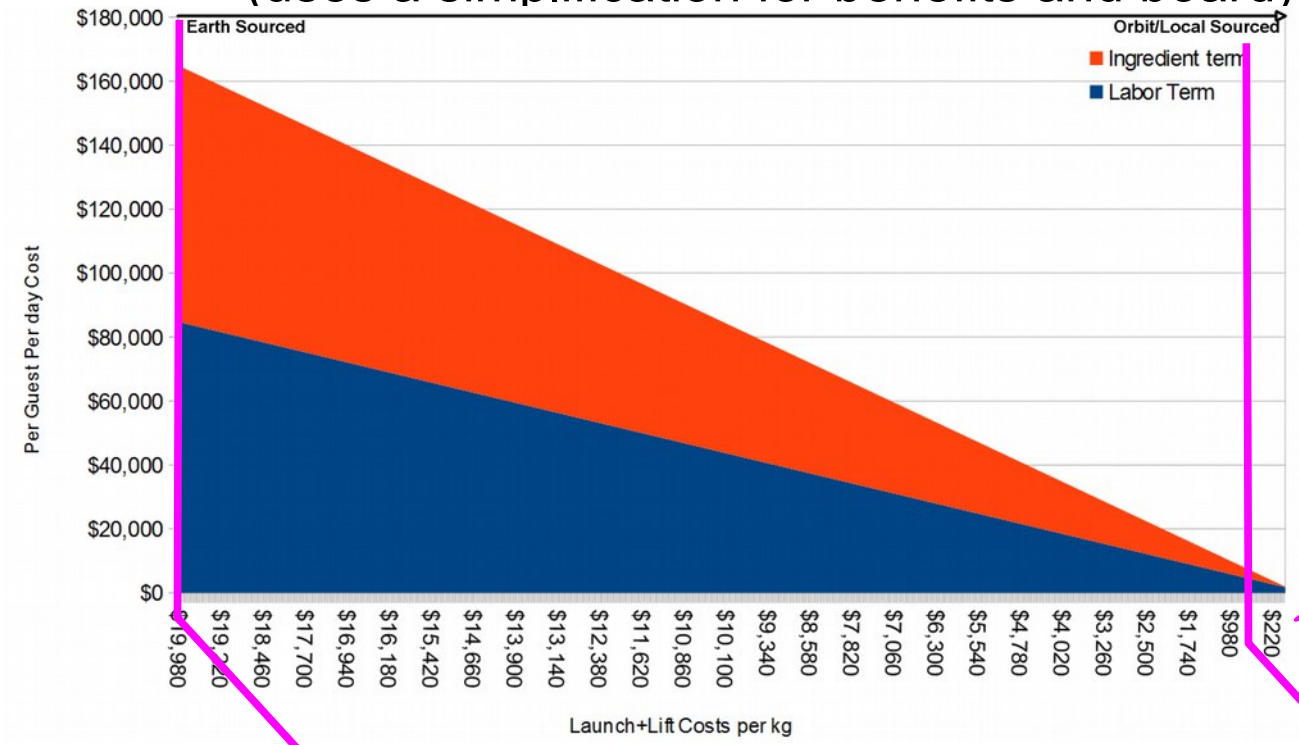
- Hourly wage ($C_{L,w}$) for all labor types is $150/hr.
- Mass to person equivelent for travel to the resturant for labor (m_{TtoC}) = 600 kg/person
  - Based very loosely on projected SpaceX costs.
- Benefits (P_B) add 50% to the hourly wage.
- 8 recipes per guest, 4 person*hrs to prep, serve all 8 recipes (i.e. 30 mins per recipe avg.)
- Assume an average of ~8 hrs/day, all days (i.e. WR=30%).
- Each Recipe uses 0.5kg of ingredients, which cost $40/kg to buy at source (roughly the cost of high end coffee, spices).
- For Scenarios 2-5: Assume crew bring up 0.1kg/tour hr (with them on in later deliveries).

Why Iterate for Launch and Lift?

- [C_{EtoL} + C_{LtoS}] = Launch and Lift Costs averaged for all masses.
- In early stages of resturant/resort development all items come from Earth, C_{EtoL} is the primary driver in the term. Represented in higher launch and lift values.
- In later stages, more ingredients come from in orbit or locally, C_{LtoS} is the driver. Represented in lower launch and lift values.
- In the latest stages, fewer ingredients come from outside from the resort, and crew supplies are sourced locally. Represented in lowest launch and lift values.
- Affects labor if boost costs drop, or labor becomes more local.

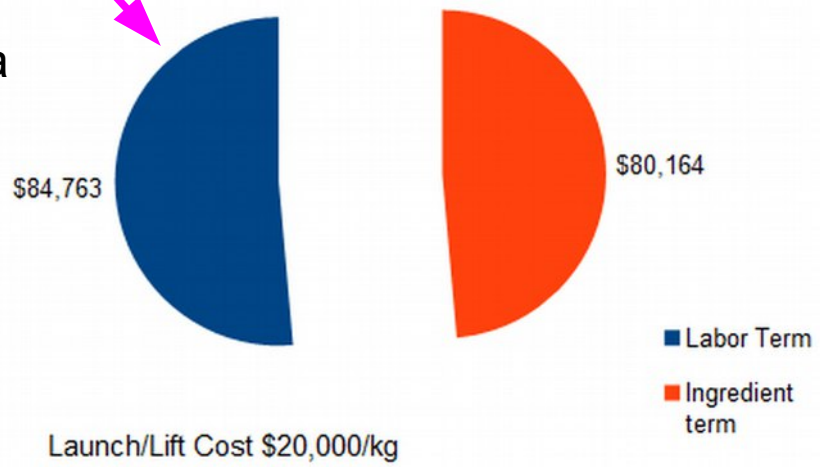
Scenario 1: Tour length=180 days

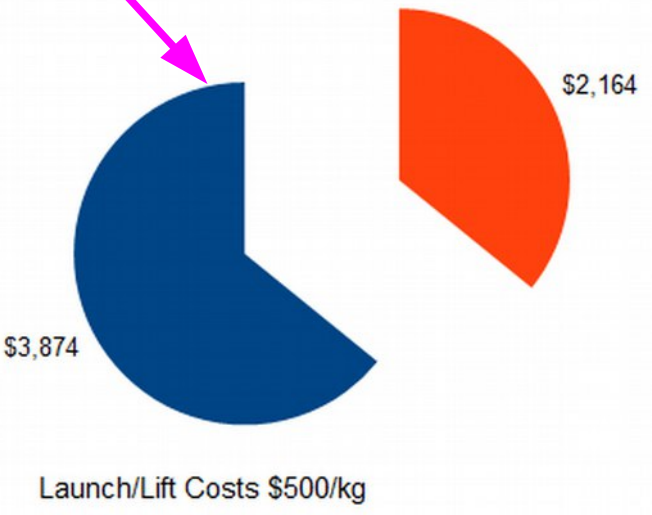
(uses a simplification for benefits and board) (less accurate)



Represents either lower costs to orbit and boost, or a shift in mass to closer sources

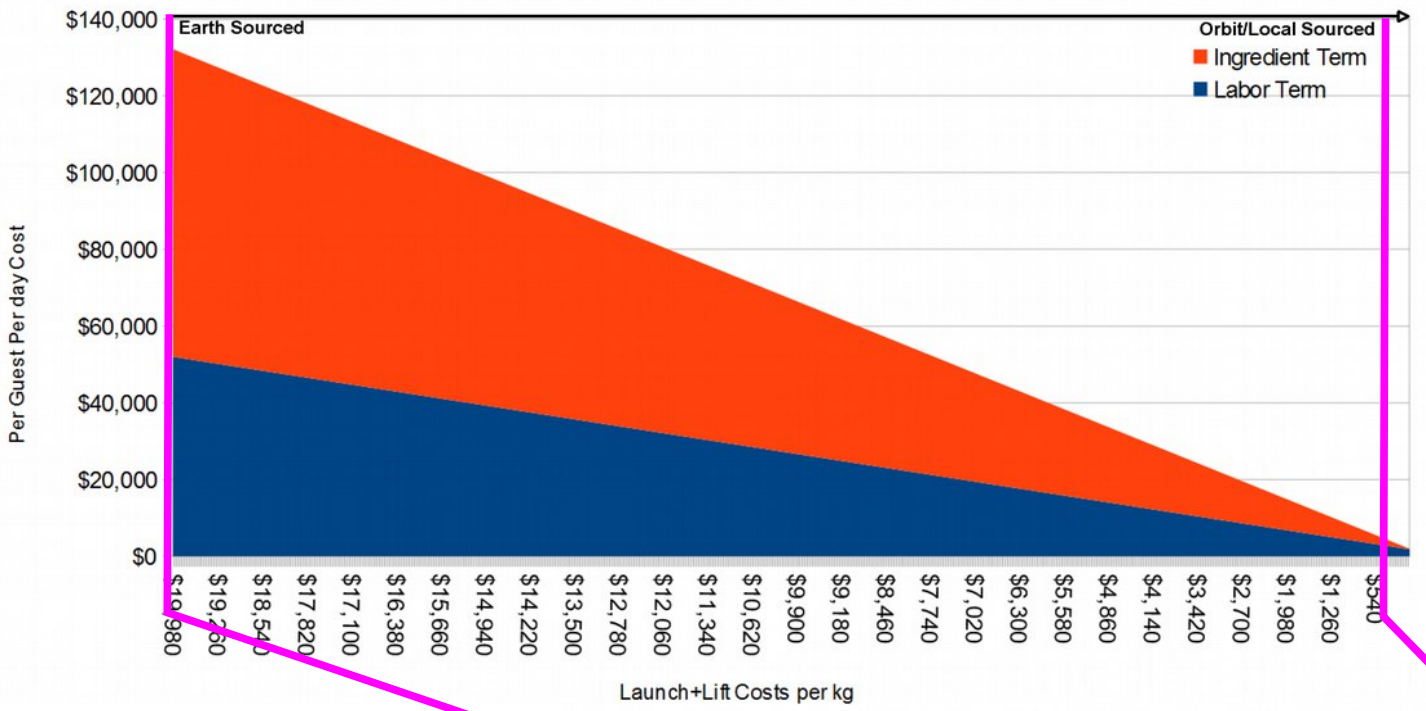
~$165,000 for a day's food per guest
(for 3 meals, about $52,000 per meal)



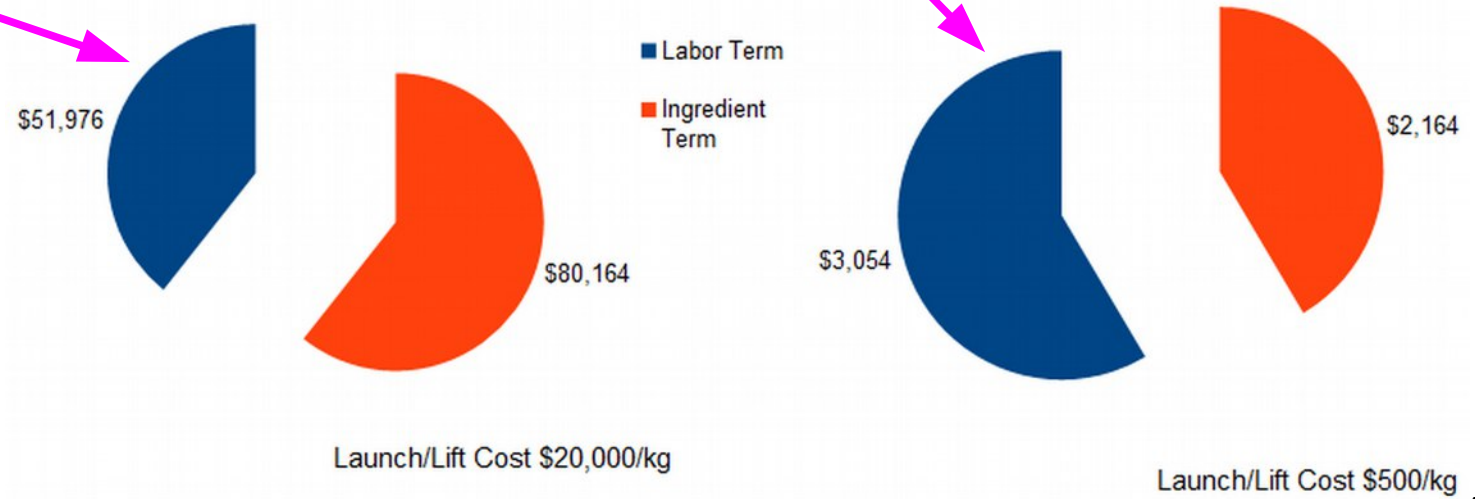


Scenario 2:Tour Length=365 days

(using full equations on prior slides) (more accurate)

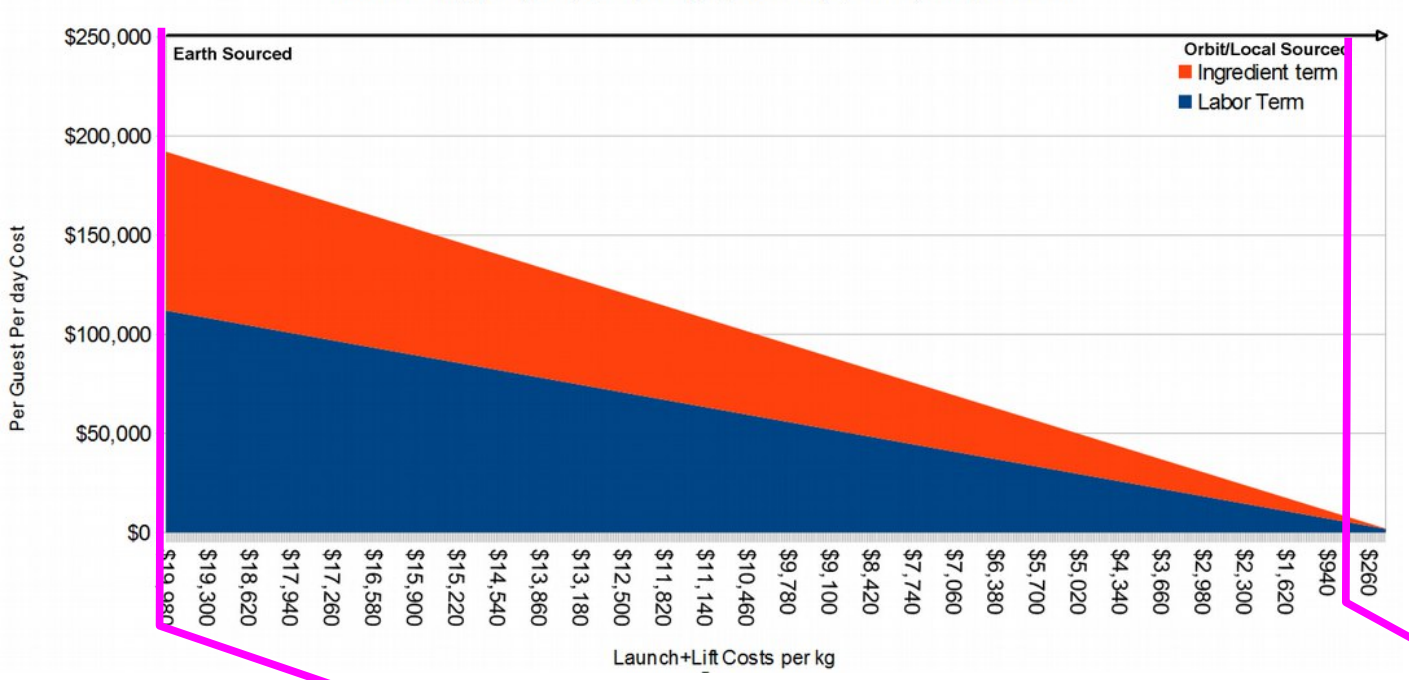


~$132,000 for a day's food per guest (for 3 meals, about $44,000 per meal)



Scneario 3: 1 Year Tour with 2 Dependants.

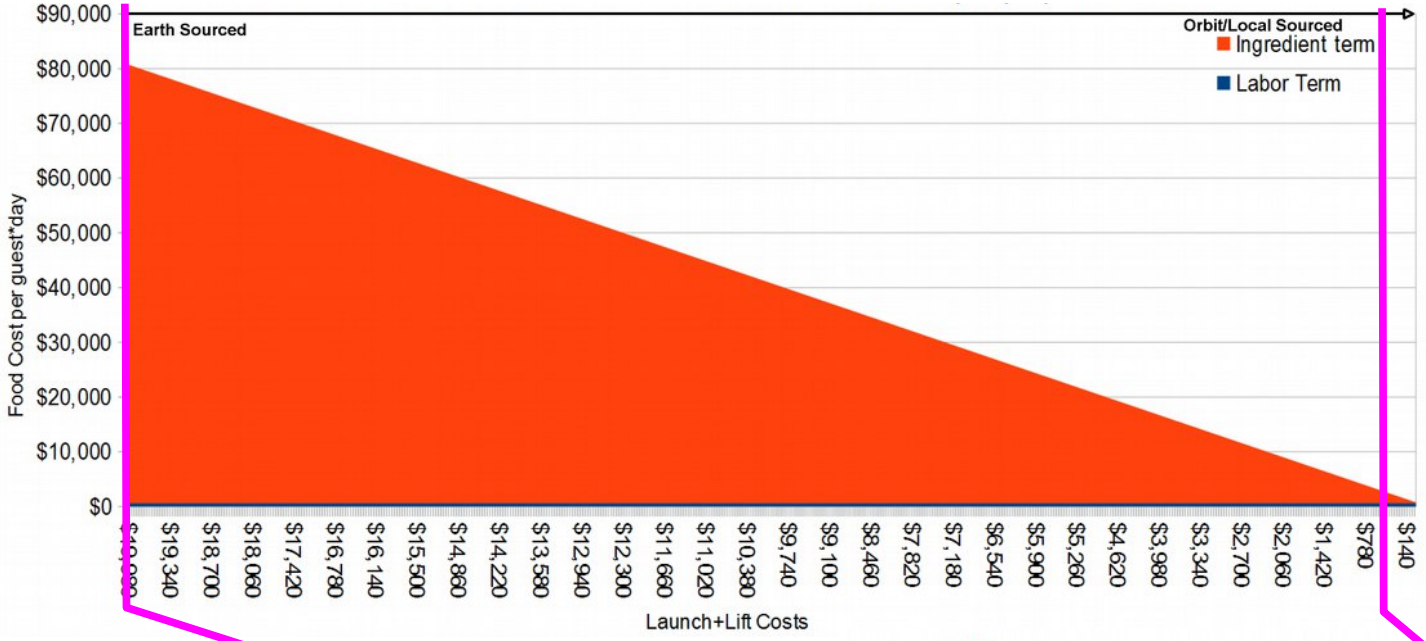
Dependants and long tours will likely require gravity, either using a spinning station, or locating on the Moon. However, having family along will make for happier crew (maybe :0).



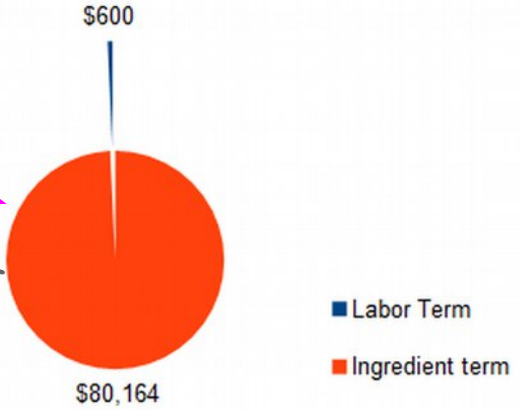
~$192,000 for a day's food per guest (for 3 meals, about $64,000 per meal)

Scenario 4: All Food is Pre-Packed, Guest (or other) Cooks/Serves.

This is what has happend before in space travel



Total is almost the same as Scenario #2's Ingredient cost i.e. ~$81,000/day, $27,000/meal

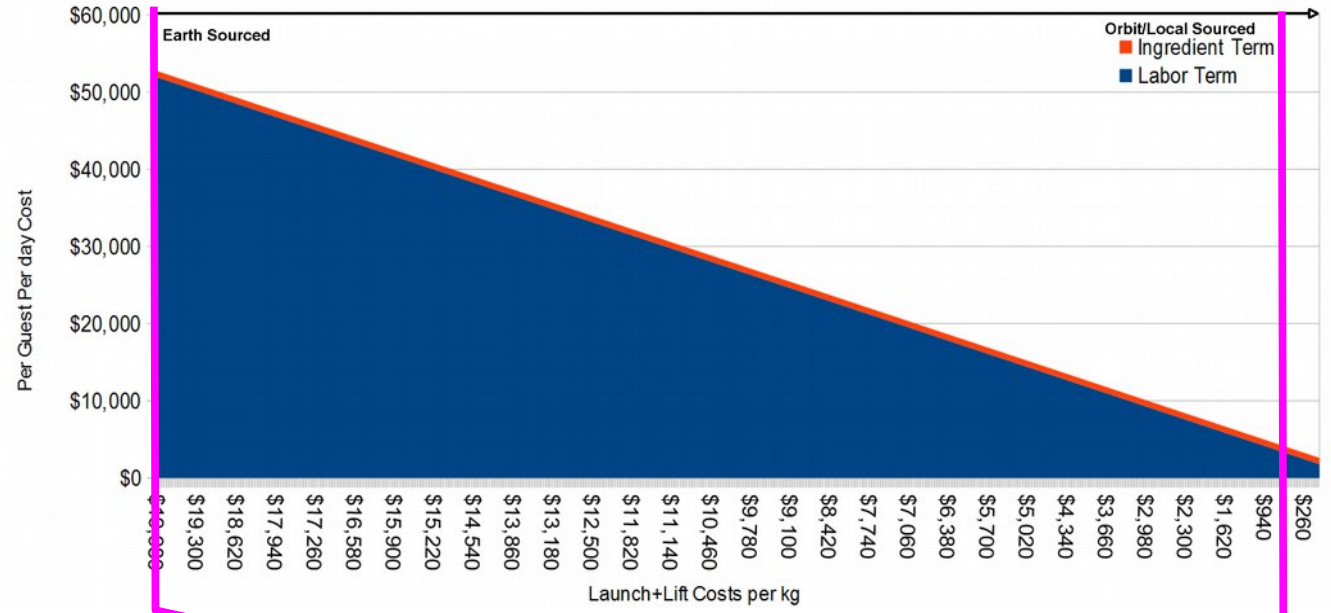


Launch/Lift Costs $20,000/kg

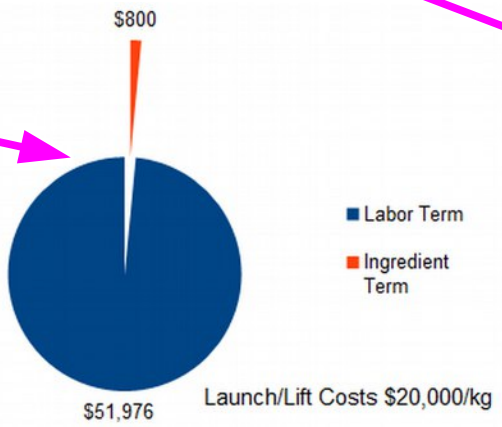
Launch/Lift costs $500/kg

Scenario 5: All Ingredients local to Resturant, all the Labor Lifted In

The resturant is tied to a space farm...crew is rotated in on 365 day tours



$52K/Day
$17K/Meal



Results

- Longer Tour Lengths and Sourcing Food closer to the Resturant reduce costs

Scenario	Tour Length	Ingredient Source	Labor Source	Recipe Cost Per Day ($K)
1	180 days	variable	Away from resturant	165
2	365 days	variable	Away from resturant	132
3	365 days, 2 dependants	variable	Away from resturant	192
4	365 days	Earth or sim, all meals prepacked	Source of Ingredients	81
5	365 days	Local to Resturant	Away from resturant	52

Conclusions/Future Work

- This is VERY coarse analysis.
  - Need to simulate with guest menus, labor sources.
  - Need to add in room costs for crew.
- For a guest paying $20M to get to a space hotel, and paying $10M/night, $200K for food per day is not significant.
- Gravity = Longer Tours, Dependants = may reduce costs.
- Space Farms, near or at the resturant may be a must.

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