



A Proposed Methodology for Quantitative Lunar Resource Assessments (QLRA)

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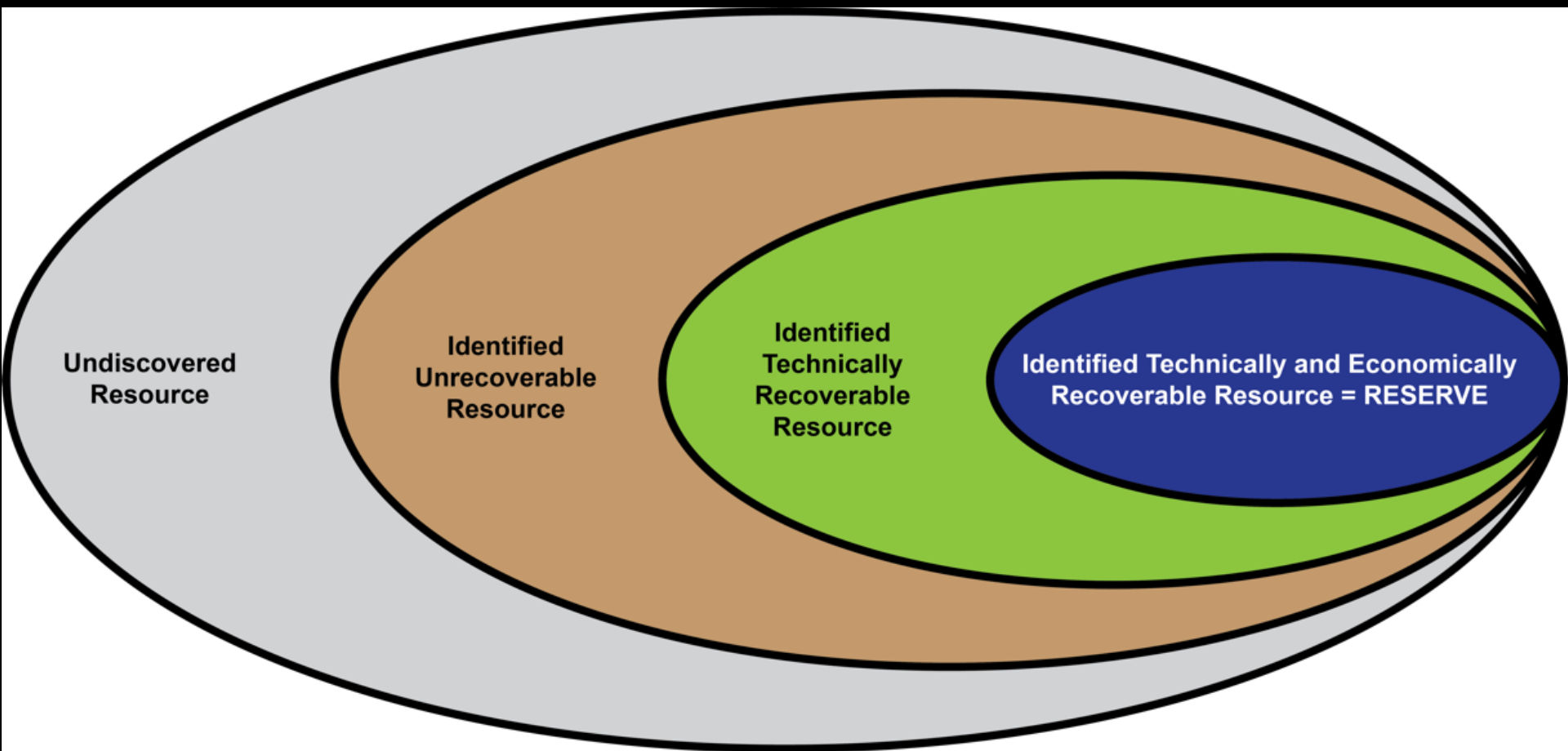
Outline

- **Some definitions**
- **Quantitative resource assessments?**
- **A proposed methodology**
- **Feasibility for diverse resources**
- **Next steps**

Some Definitions (in a lunar context)

- **Resource**: something on the Moon that can be converted into a *commodity*.
- **Commodity**: something that can be used to further space exploration.
- **Deposit**: a concentration of a resource; called a *continuous deposit* if widely distributed.
- **Reserve**: a resource that can be converted into a commodity within your budgets (cost, mass, power, volume, schedule, risk, etc.).

Resource Classification (too simple)



Resource Classification

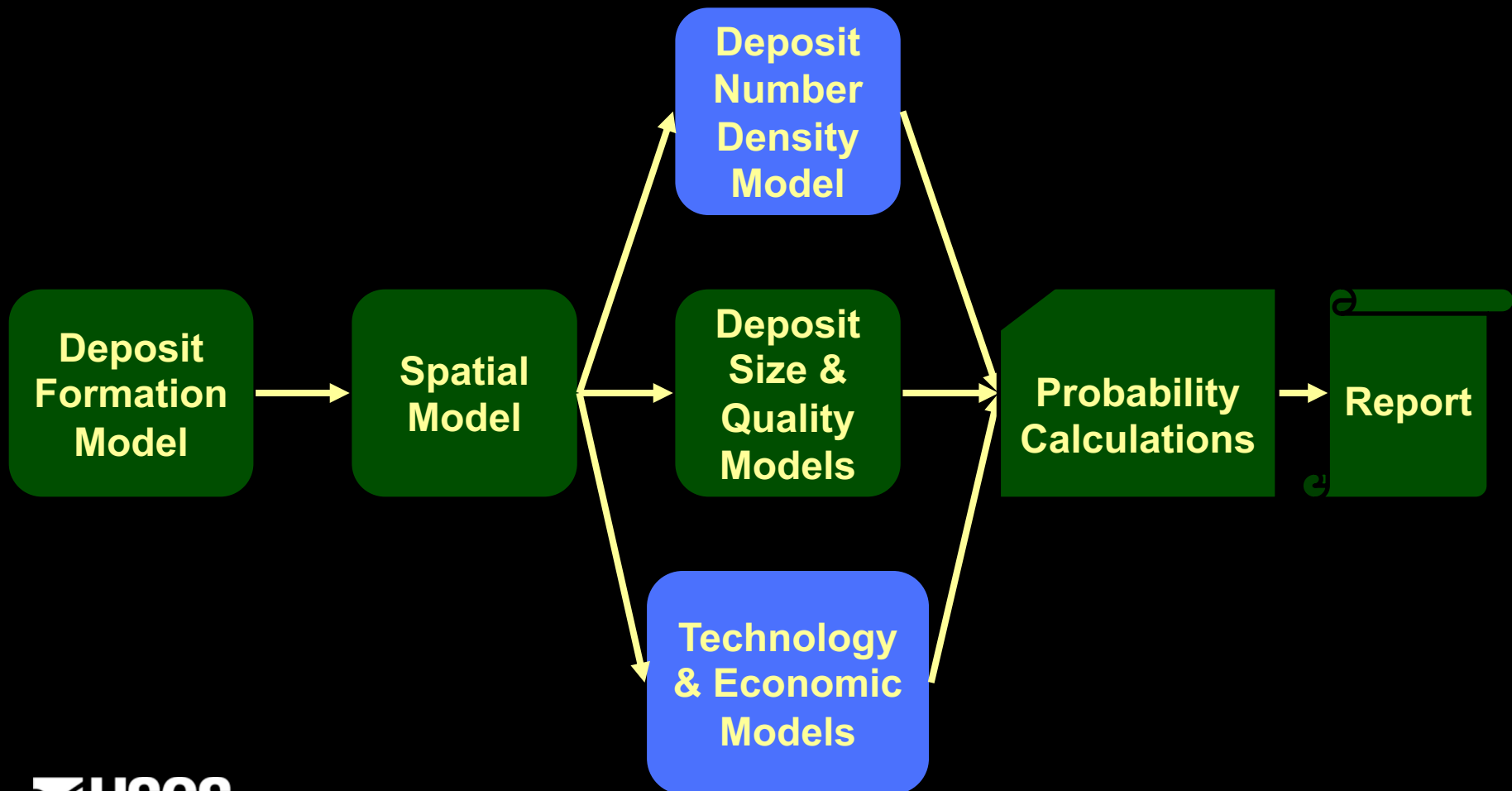
	Unrecoverable	Technically Recoverable	Recoverable within Budget(s)
Speculative	Resource	Resource	Reserve
Inferred	Resource	Resource	Reserve
Measured	Resource	Resource	Reserve

- **Speculative**: *We have reason to expect it*
- **Inferred**: *Extrapolate from data in hand*
- **Measured**: *Interpolate from data in hand*

Quantitative Resource Assessments

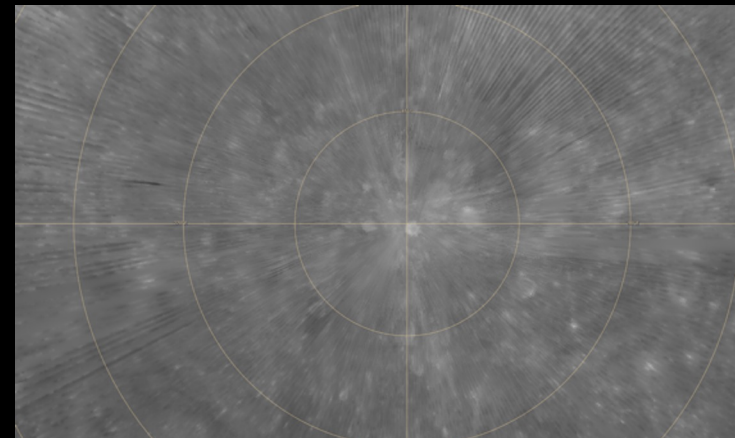
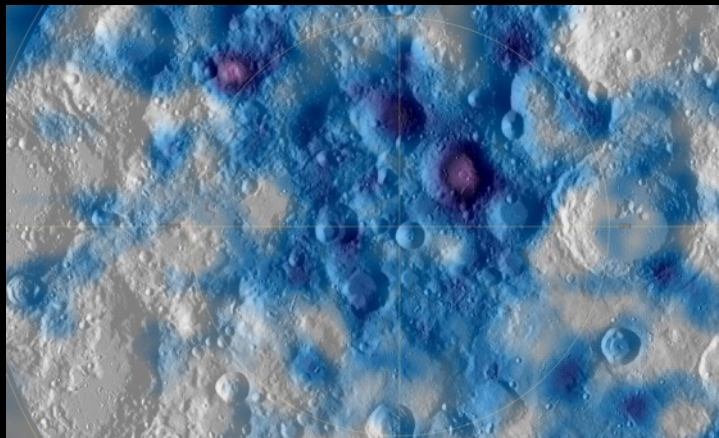
- What makes it quantitative?
 - Rigorous statistics that allow decisionmakers to assess risks, which requires...
 - ...information on the variability of the resource, not just isolated discoveries, which requires...
 - ...statistically meaningful amounts of data along with detailed information on the uncertainties in the data and their interpretation.

Generalized Methodology



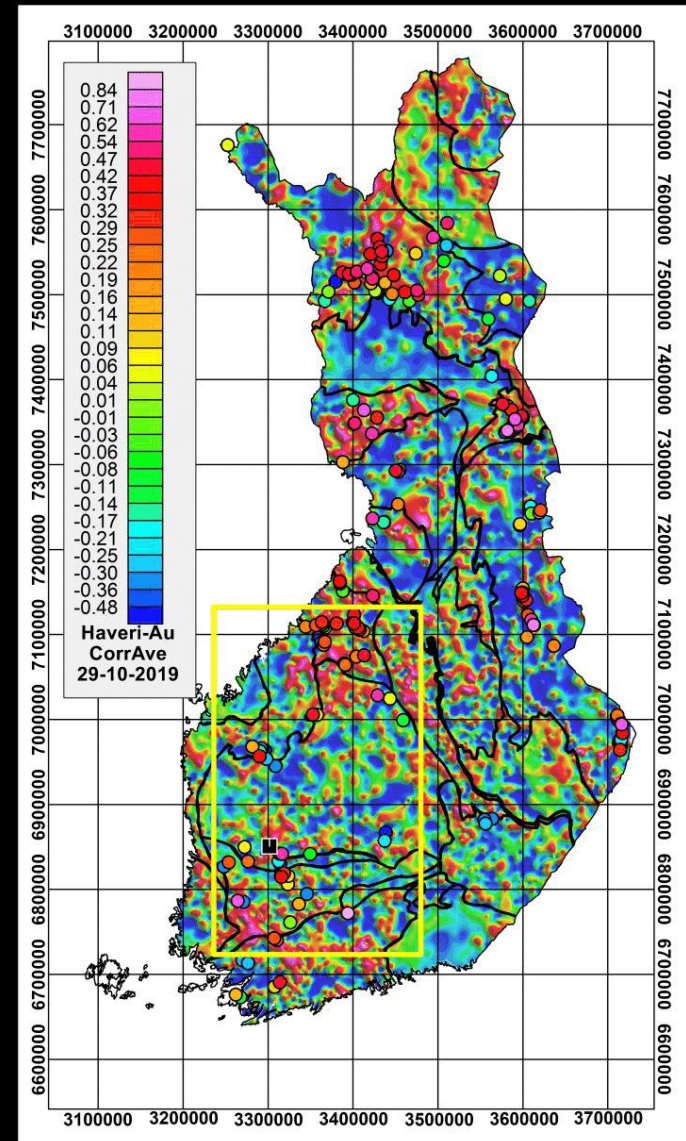
Deposit Formation Model

- **Qualitative description of how deposits of the resource are formed**
 - Should be systematic, laying the groundwork for comparing disparate resources
 - Essential to avoid statistical mess by mixing data from different types of deposits of the same resource



Spatial Model

- **Defines study area**
 - Traditionally a large region (state or country)
 - Ideal for large geopolitical decisions
 - Modern GIS tools can allow analysis to be done on a higher resolution grid
 - Especially useful for continuous deposits
 - Best in a “data-rich” case



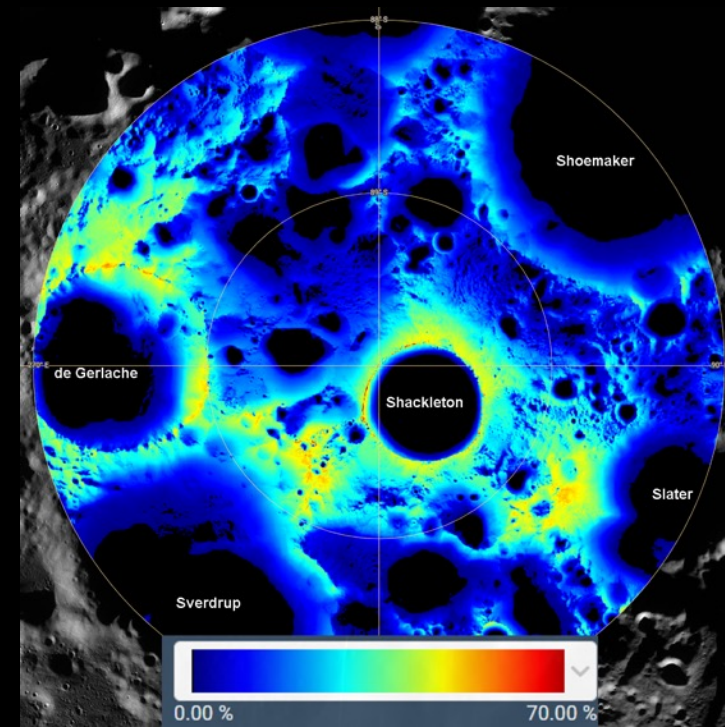
Deposit Number Density Model

- **Probability distribution for unresolved deposits**
 - Not relevant for “continuous” deposits
 - Micro PSRs [Hayne et al. 2021] could be an example



Deposit Quality and Quantity

- **Probability distribution for key deposit characteristics**
 - For terrestrial minerals = grade and tonnage
 - Will vary between resources
 - For solar energy, could be
 - (a) % of time illuminated and
 - (b) maximum duration in darkness



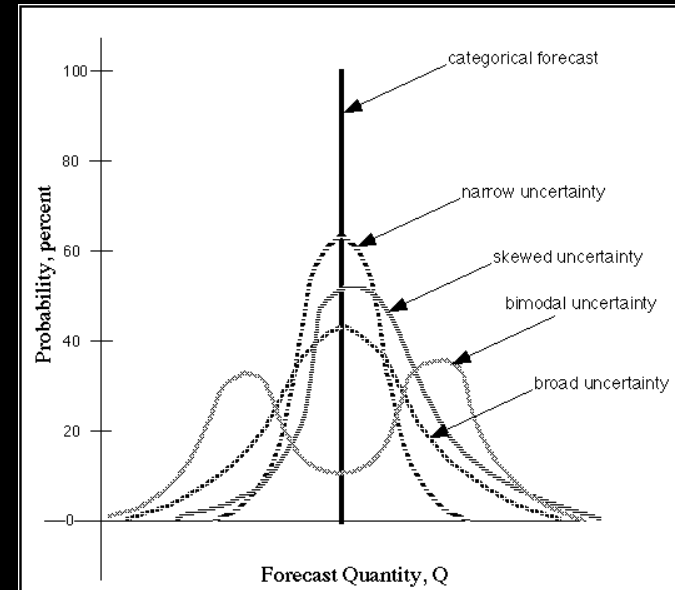
Technology and Economic Models

- Logical and/or mathematical expressions to describe characteristics that make a resource recoverable within available budget(s)
 - Optional for *resource* assessment, necessary for assessing *reserves*.
 - Should consider “Social License to Operate”
 - Can be contentious...



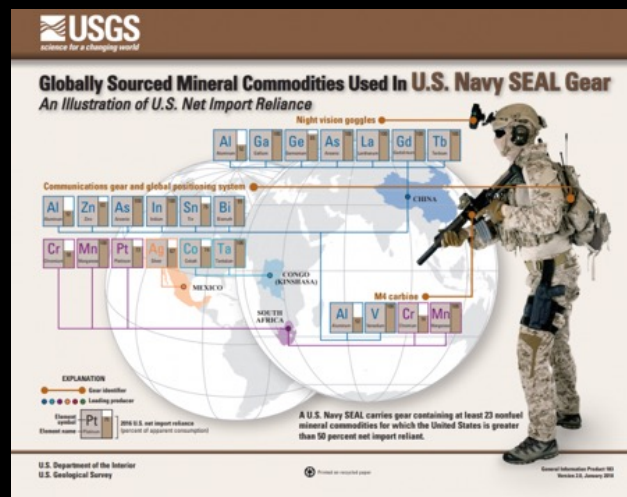
Probability Calculations

- Use numerical statistical methods (e.g., Monte Carlo) augmented with techniques such as fuzzy logic
- Output the probability distribution (as a few values or a mathematical function)



Publish Report

- **Summary must be readily intelligible to non-expert decision makers**
- **To be trusted, body of the report should make data and methods transparent for critique by experts**
 - *Required of US taxpayer funded work*



Data for QLRA: Six Examples

■ Energy

- ✓ Solar (ready to assess, recoverable today)
- ^3He (not a commodity until we have fusion power)

■ Minerals

- ✓ Regolith for aggregate (ready to assess)
- ✓ Regolith for oxygen (ready to assess)

■ Water

- ? Regolith bound water (need to understand mobility)
- X Ice (need in situ data)

Future

- More data is coming!
 - Go VIPER!
- USGS will be more active in working with NASA to conduct formal lunar resource assessments instead of just researching their feasibility



CLPS Deliveries 2021-2024

