Defining Needs and Requirements for Sustainable Systems

Requirements Working Group

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- INCOSE SE HB v5
- INCOSE RWG Needs and Requirements Manual
- INCOSE RWG Guide to Needs and Requirements.

Webinar Goals / Objectives

- Defining Needs and Requirements for Sustainable Systems
  - Understand sustainability in terms of INCOSE Vision 2035
  - Understand what is meant by sustainability from an SE perspective
  - Understand why sustainability must be clearly defined in terms of the enterprise, specific SOIs, and their external environment.
  - Understand why sustainability must be addressed from the beginning of a project.
  - Learn what activities are needed that will result in the definition of lifecycle concepts to address the project goals and objectives concerning sustainability.
  - Understand the need to define the capabilities needed to achieve the organizational sustainability goals and objectives.
  - Understand the need to communicate those capabilities within a well-formed Integrated Set of Needs (ISON) that define the scope of the project in terms of sustainability and from which the Design Input Requirements (DIR) concerning sustainability will be transformed and against which the system will be validated.
  - Be aware of practical considerations considering sustainability

INCOSE Vision 2035 - Sustainability

- Value Statement
  - Architect balanced solutions that satisfy diverse stakeholder needs for capability, dependability, sustainability, social acceptability, and ease of use.
- Global Megatrends Shape the Systems of the Future
  - ……. advancement of technological capabilities and societal appetite for applying these technologies in a responsible, **sustainable** manner while transitioning away from fossil-fuel based energy.
- Sustainability Ethics
  - Sustainability will become a key attribute of the enterprise culture and products.
  - Enterprises will need to develop a positive ethical identity to attract and retain customers as well as employees.

https://www.incose.org/about-systems-engineering/se-vision-2035

INCOSE Vision 2035 - Sustainability

- The systems of the future will become smarter, self-organized, sustainable, resource-efficient, robust and safe, but trusted, in order to meet stakeholder demands and expectations.
  - Priority will be placed on systems that are **more efficient at resource utilization and responsible waste disposal**.
  - Though enterprises will continue to struggle with business and consumer pressures to increase consumption, versus environmental prerogatives to reduce waste.
  - Society will place great importance on **reuse**, giving rise to **Circular Economies**.
  - The global fossil-fuel based energy economy will be transformed to one based on clean and renewable sources.

https://www.incose.org/about-systems-engineering/se-vision-2035

INCOSE Vision 2035

- Growing Stakeholder Expectations
  - **Sustainable**
    - Stakeholders will demand that systems and services be **environmentally sustainable** – such as minimizing waste and undesirable impacts to climate change.
    - Sustainability as a system characteristic will be stressed as well as the **sustainability ethic** of the responsible enterprises.
    - More efficient resource utilization, recycling, reuse, and responsible waste disposal
  - **Socially Acceptable** – minimize impact on society and the environment; transition away from fossil-fuel based energy, minimize the carbon footprint, use clean and renewable sources, apply technologies in a responsible manner.
  - Maintainable/**Sustainable**
  - Affordable

https://www.incose.org/about-systems-engineering/se-vision-2035

What is Sustainability?

- “The ability to be maintained at a certain rate or level.”
- “The ability to maintain or support a process continuously over time.”
- “Sustainability is a societal goal that relates to the ability of people to safely co-exist on Earth over a long time.”
- “Sustainability is commonly described as having three dimensions (or pillars): environmental, economic, and social.”

Richard Beasley LinkedIn post 082025

What is Sustainability?

- The focus of INCOSE Vision 2035 is on environmental sustainability.
  - "Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment."
  - "To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations."
- "Sustainable development requires an integrated approach that takes into consideration environmental concerns along with economic development."

What is Sustainable Engineering?

- "Sustainability Engineering is an approach that supports the circular economy over its life."
- "The process of designing or operating systems **such that they use energy and resources sustainably,** in other words, at a rate that does not compromise the natural environment, or the ability of future generations to meet their own needs."
- "Reduce a product's environmental effects at **every stage of its lifecycle**–from conception, development, and prototyping to commercialization, recycling, and disposal."
- "The practice of designing products and processes that drive material and energy efficiencies to **minimize their environmental impact while cutting costs and improving the bottom line**."
- "Manufacturers can **minimize waste while maximizing the value** they deliver."
- "The process of using resources in a way that does not compromise the environment nor deplete the materials for future generations. Basically, it means finding ways to live more sustainably."

Product Sustainability/Disposability

- **Design for Sustainability**: consider environmental and social aspects as the key elements in product design to reduce the harmful impacts of the product throughout its lifecycle.
  - Promote product **recycling and materials reuse**.
  - Design components towards a **circular economy**.
    - Sharing, reusing, repairing, and recycling existing products and materials as much as possible, expanding the life of products, minimizing waste and pollution and creating a closed loop system.

  - Perform **environmental impact analysis across all lifecycle stages** to access potential harmful effects of the production, use, and disposal of the proposed system.
    - Considerations: Materials used and scrap waste from the production process, operation of the system, replacement parts, consumables, packaging, and disposal.
  - **Disposal analysis**
    - **Maximize the economic value** of residual system elements after useful life.
    - **Minimize the amount of waste** materials sent to landfills or incinerated.
    - **Design for disassembly** to avoid destructive separation of components such that the material can be reused in future generation of products, remanufacturing, refurbishment, or recycling processes.
    - Design for decomposing or biodegradation.

INCOSE SE HB v5, Section 3.1.10 Sustainability Engineering

Environmental Sustainability Measures

- Increased recycling
- Increased reuse
- Increased use of clean energy (vs fossil-fuel based energy)
- Increased use of renewable resources
- Increased product life
- Increased efficient use of resources (materials and energy)
- Reduction of the need for, and use of non-renewable resources
- Reduction of waste put in landfills
- Reduction of hazardous waste
- Reduction of harmful emissions/pollution
- Reduction of carbon footprint
- Reduction of costs associated with sustainability

Common Performance Metrics for buildings:

- Energy Use Intensity (EUI) – kBtu per square foot per year.
- Water Use Intensity (WUI) – Gallons per square foot per year.
- Carbon Intensity – kg CO_2e per square foot per year.
- Waste Diversion Rate – % of construction or operational waste diverted from landfill.

Other measures/metrics ????

Sustainability Considerations

- Sustainability can address:
  - Environment – sustain the health of the environment in which the enterprise and product depends and is a part.
  - Enterprise (organization, city, state, country, farm) – sustain the viability of the enterprise over time.
  - Engineered Systems – sustain system over its life (performance, maintenance, resources – supply chain).
  - **All three are interrelated and dependent on each other and must be considered as an integrated system**.
  - Systems thinking principles must be considered
    - The behavior of a system is a function of the interactions of its parts and interactions of the system with external systems and operating environment.

Sustainability Considerations - Examples

- Natural Systems – forests, oceans, rivers, lakes, deserts, mountains, atmosphere.
  - Ecosystems that are part of the environment, dependent on the environment, contributes to health of the environment, uses renewable natural resources, waste is biodegradable and is recycled.
  - Sustainable, climax state – inputs and outputs in balance
  - Resilient – ability to return to a climax state after acted upon by a natural disaster, human activities, engineered systems.
- Engineered Systems – operating within the Biosphere.
  - Part of the environment, dependent on the environment, uses both nonrenewable and renewable natural resources, creates waste, can impact the environment.
  - Sustainability must be managed.
    - Efficient, sustainable use of resources, minimize impacts to the natural environment (depletion of natural resources, pollution, waste management.)

Sustainability Considerations - Example

- Sustainable Cities (vision for the future)
  - A sustainable city is an urban center that makes rational use of natural and technological resources while ensuring adequate habitability without compromising future generations.
  - Sustainable cities prioritize the preservation of the natural world alongside the economic, social, and physical health and wellness of the city’s inhabitants.
  - Sustainable cities aim to change the way they operate for the benefit of future generations, ensuring that they do not put a strain on resources which will cause such resources to vanish before future generations have an opportunity to benefit from them.
  - Sustainable cities are designed with environmental concerns in mind and are committed to achieving green sustainability, social sustainability, and economic sustainability.
    - Reduce environmental impacts through its activities and promotes sustainable consumption and production patterns in accordance with its own territorial, geographical, social, economic and cultural conditions.
    - Resilient to the impacts of climate change reducing the vulnerabilities of its population.

Sustainability Considerations - Cities

Can a city be truly sustainable?

- **Dependence on external inputs: food, energy, resources, water, air, etc.**
- **Environmental impacts: amount of waste, pollution, impact on local climate**
- **Increasing threats from climate change (sea rise, flooding, hurricanes, tornadoes, drought, fires, depletion of aquifers and other sources of water),**
- **As well as:**
  - **Political will towards sustainability**
  - **In adequate building codes concerning sustainability**
  - **Aging infrastructure**
  - **Inadequate infrastructure**

“The population boom in Houston suburbs is straining water systems. Can they keep the taps running?”

“I have some very serious concerns about our water quantity,” said Chris Bogert, then Conroe's city engineer, during an otherwise standard council workshop. “Development has outpaced infrastructure… We are producing water and we are producing it fast. We just can’t keep up with development.”

Houston Chronical, 082025

Sustainability Considerations - Technology

- Environmental Footprint of AI & Data Centers
  - **High Energy Demand** – Training and running large AI models can consume 7–8× more energy than typical computing workloads. Global data center electricity use reached 460 TWh in 2022, with AI workloads driving rapid growth.
  - **Carbon Emissions** – If powered by fossil fuels, this energy use translates into significant CO_2 output, contributing to climate change.
  - **Water Consumption** – AI-focused data centers use vast amounts of water for cooling — in some cases, as much as a large neighborhood — straining local water supplies.
  - **Electronic Waste** – Frequent hardware upgrades for high-performance GPUs and servers generate e-waste containing hazardous materials like lead and mercury.
  - **Resource Extraction** – Manufacturing AI chips requires rare earth elements and critical minerals, often mined in environmentally damaging ways.

July 2025 U.S. federal rules — part of the **"Winning the Race: America's AI Action Plan"** waive or streamline environmental regulations for data centers, semiconductor plants, and related power infrastructure, deregulation under the Clean Water Act, fast-tracked siting and new rules centralize control over wind and solar projects on federal lands.

Sustainability Considerations - Example

- Space Station – Outside our Biosphere
  - Low Earth Orbit
  - Solar energy only natural resource
  - Dependent on resupply from Earth (fuel, crew, food, parts, water, air)
  - Can not sustain orbit without periodic reboost
  - Limited resource recycling (water, O2)
  - Waste disposal (special vehicles to return to Earth (burn up or return to surface).
  - Susceptible to poor waste management from other orbiting systems (orbital debris)
  - Susceptible to space environment (microgravity, micrometeorites, radiation.)

  - **Not sustainable by design**
    - **Can not sustain human life without frequent external support (resources, waste disposal, orbital maintenance).**

Sustainability Considerations - Example

- Moon Base
  - Further from Earth – increased time (days) and expense for construction, resupply
  - Combination of Solar and Nuclear energy
  - Dependent on resupply from Earth (fuel, crew, food, parts, water, air)
  - Has access to some in situ resources from lunar surface (water?, oxygen?, regolith)
  - Reuse – additive manufacturing possibilities
  - Waste disposal
    - Minimize waste
    - Recycling/Reuse must be maximized – additive manufacturing capabilities
    - Some recycling (water, oxygen, building materials)
  - No atmosphere, extreme temperature swings, extended day/night cycles
  - 1/6 Gravity, increased radiation shielding (cover with regolith, lava tubes) – environment harmful to humans
  - Major concern is sustainability of the engineered systems rather than natural environment.
  - **Sustainability must be the primary consideration of all architectures and design.**
  - **Can a Moon Base ever be truly sustainable given it dependence on resupply?**

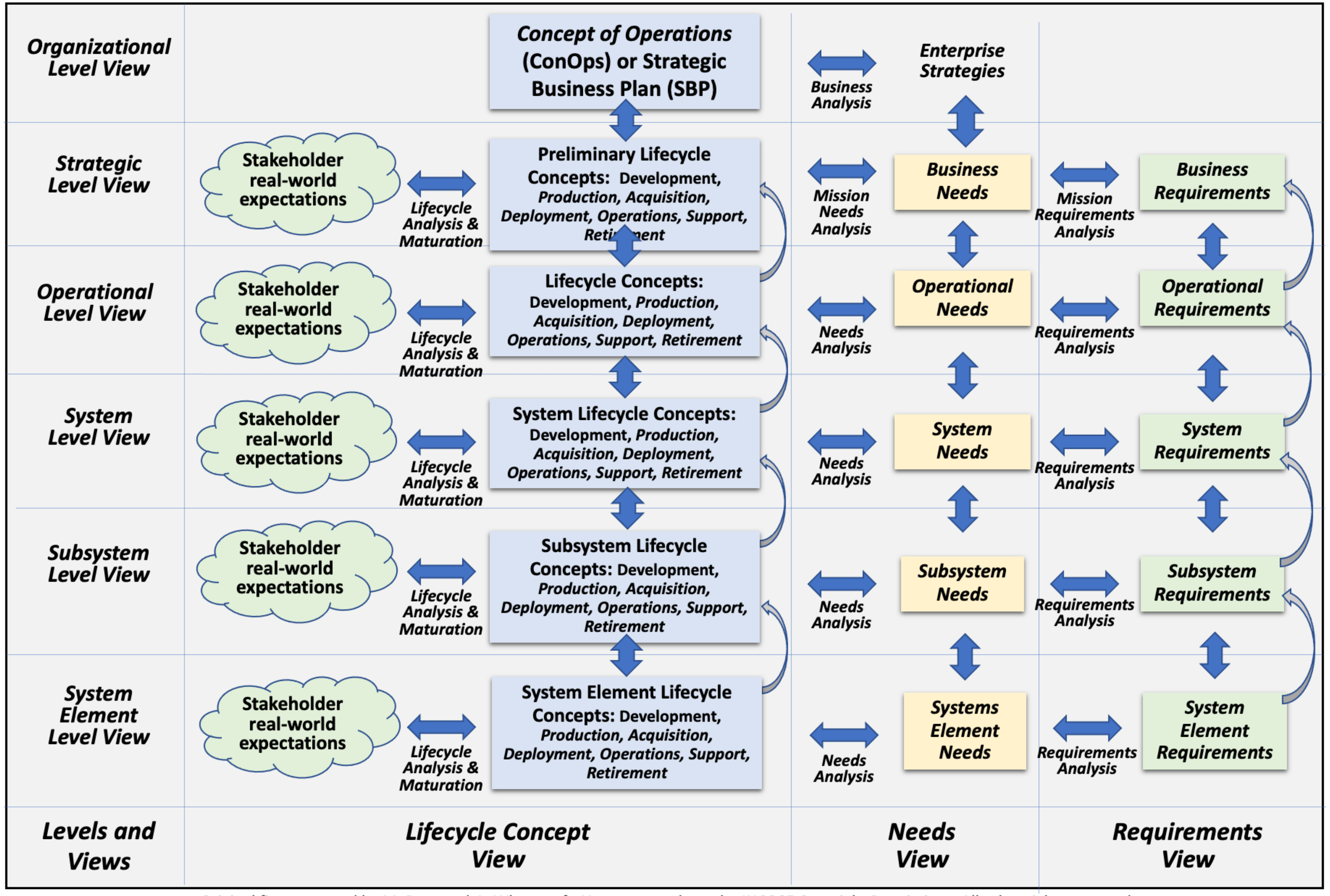
Sustainability Considerations - Example

- Mars Colony
  - Long distance from Earth – increased time (months) and expense for construction, resupply.
  - Combination of Solar and Nuclear energy
  - Dependent on resupply from Earth for foreseeable future
  - Has increased access to in situ resources from mars surface (water?, CO_2, soil, other possible natural resources.)
  - Atmosphere can be used to produce fuel (methane) when supplemented with a source of hydrogen.
  - Recycling/Reuse must be maximized, waste minimized – additive manufacturing capabilities
  - Requires a sustainable capability to produce food, air, water, and maintain systems
  - Limited atmosphere, extreme temperature swings, extended day/night cycles.
  - 1/3 Gravity, need for increased radiation shielding (cover with regolith, lava tubes) – environment harmful to humans
  - Questionable sustainability from a human reproductive perspective (low gravity and radiation impacts to reproductive systems and fetus development)
  - Major concern is sustainability of the engineered systems rather than natural environment, however planetary protection guidelines must be considered.
  - **Sustainability must be the primary consideration of all architectures and design**
  - **Can a Mars Colony ever be truly sustainable given existing constraints?**

Sustainability Considerations

- Your System!
  - What sustainability considerations can you define for your systems/products?
  - What sustainability measures can you define to assess your sustainability goal?
  - What processes/procedures/requirements can you define to help meet your sustainability goals for the systems/products you produce?
    - Organization/Design controls
    - Systems/products

Achieving Sustainability Goals Starts at the Top



Organizations must include the concept of sustainability in their set of core values and policies.

From a product perspective, the enterprise must define processes, procedures, and work instructions concerning sustainability across the lifecycle.

For individual products, sustainability must be included in the product mission statement, goals, objectives, lifecycle concepts, Integrated Set of Needs, and resulting Design Input Requirements.

Example: Apple announces massive battery sustainability upgrade for all its devices.

- ”Significantly expand" the use of recycled materials across all Apple products,
  - Use 100 percent recycled cobalt1 in all Apple-designed batteries by 2025.
  - Use entirely recycled rare earth elements by 2025,
  - All Apple-designed printed circuit boards will use 100 percent recycled tin soldering and gold plating.
  - Sourcing over two-thirds of all aluminum, nearly three-quarters of all rare earths, and more than 95 percent of all tungsten in Apple products from 100 percent recycled material.
- Make every Apple product carbon neutral by 2030.
- Apple is also tackling plastic and only has 4 percent plastic remaining in its packaging footprint, with labels and lamination key areas addressed.
  - New printing methods to print more information directly onto the product boxes
  - New overprint varnish reduces the plastic lamination found on those boxes.
- Apple also has a robust product trade in and refurbishment program.
- With the future of the planet more in the public conscience than ever before, Apple products of the future could be a great solution to put consumers' minds at ease about their own impact on the environment.
- 250 of Apple's suppliers have committed to transitioning to 100% renewable electricity for Apple production. (What about other sustainability measures by suppliers?)

Focus is on environment, supply chain, reuse, and waste minimization.

https://www.imore.com/apple/apple-announces-massive-battery-sustainability-upgrade-for-all-of-its-devices

Example: Axiom Space Station (post on LinkedIn 081925)

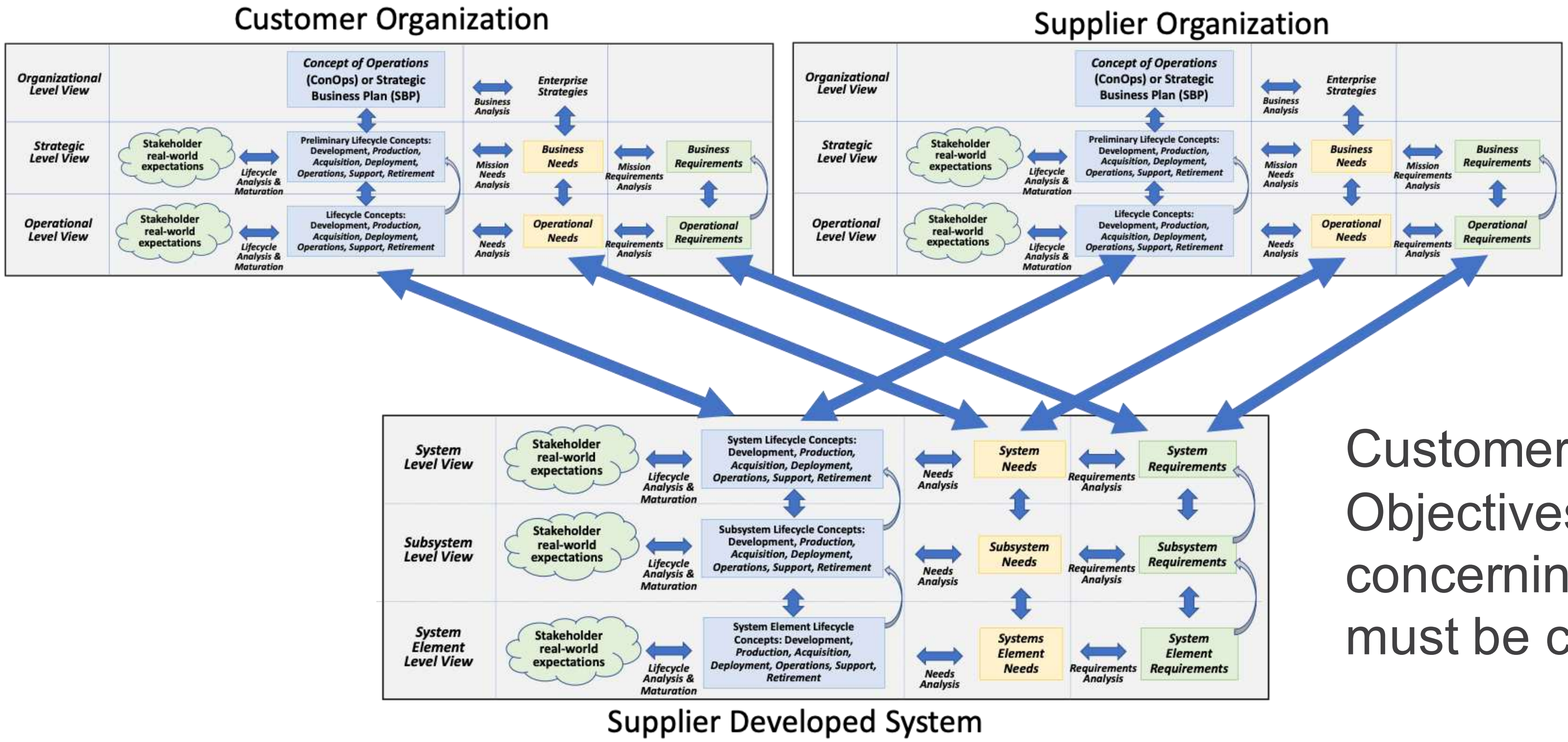
- Incorporating lessons learned from ISS equipment failures/malfunctions has pointed our focus towards ease of maintenance and future upgrades.
- With Axiom Space's vertical integration and in-house design and manufacturing, we have optimum control over our space station hardware.
- We are designing systems to be maintainable, upgradable and repairable on orbit with *as little need for ground resupply as possible*.

While they didn't use the word "sustainability", sustainability will be aided by decreasing the need for ground resupply.

While a good step towards sustainability, they need to make "sustainability" a key goal for not only resupply, but orbital maintenance, reuse, and waste minimalization as well.

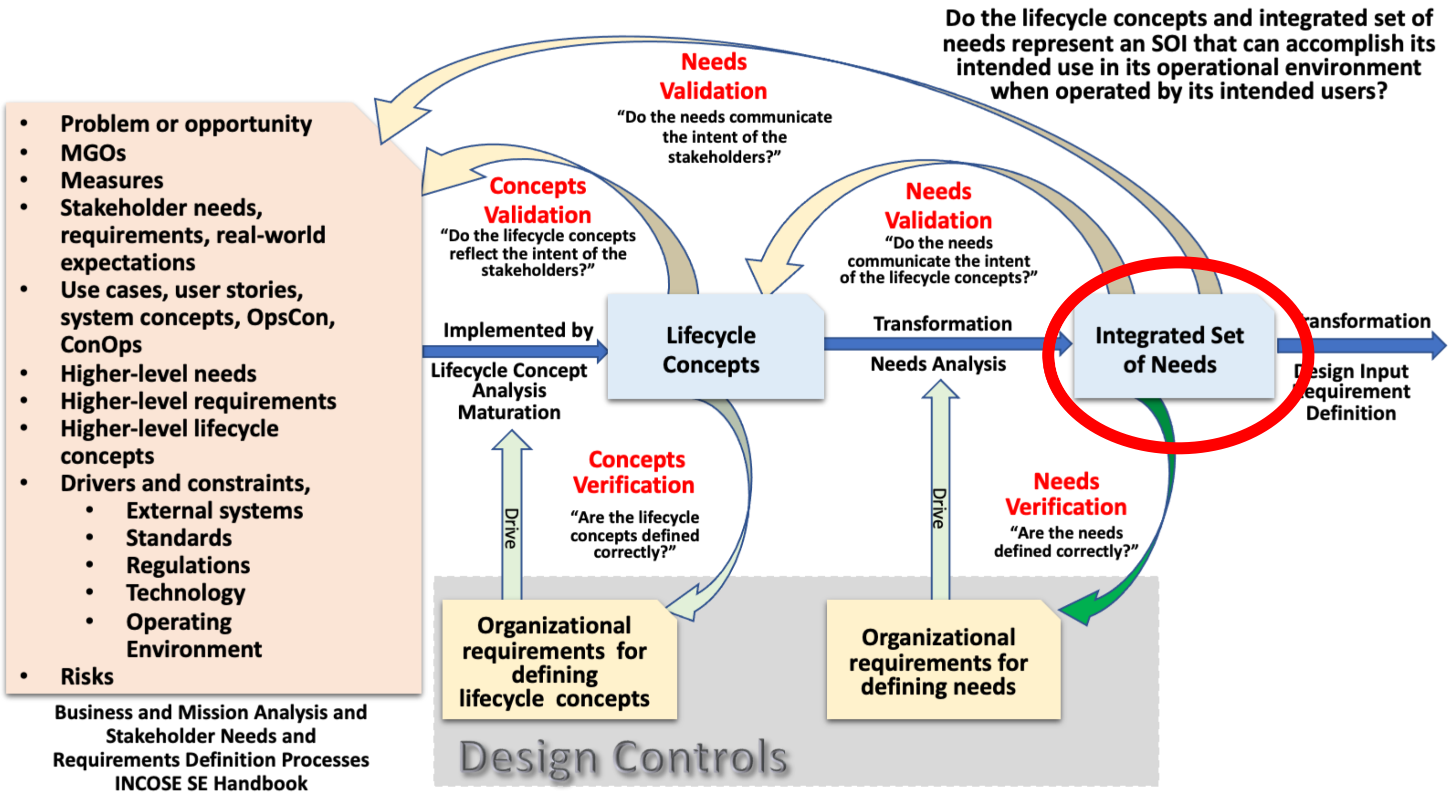
In this context the focus of "sustainability" is the ability to "sustain" on orbit operations.

Customer/Supplier Common Goals



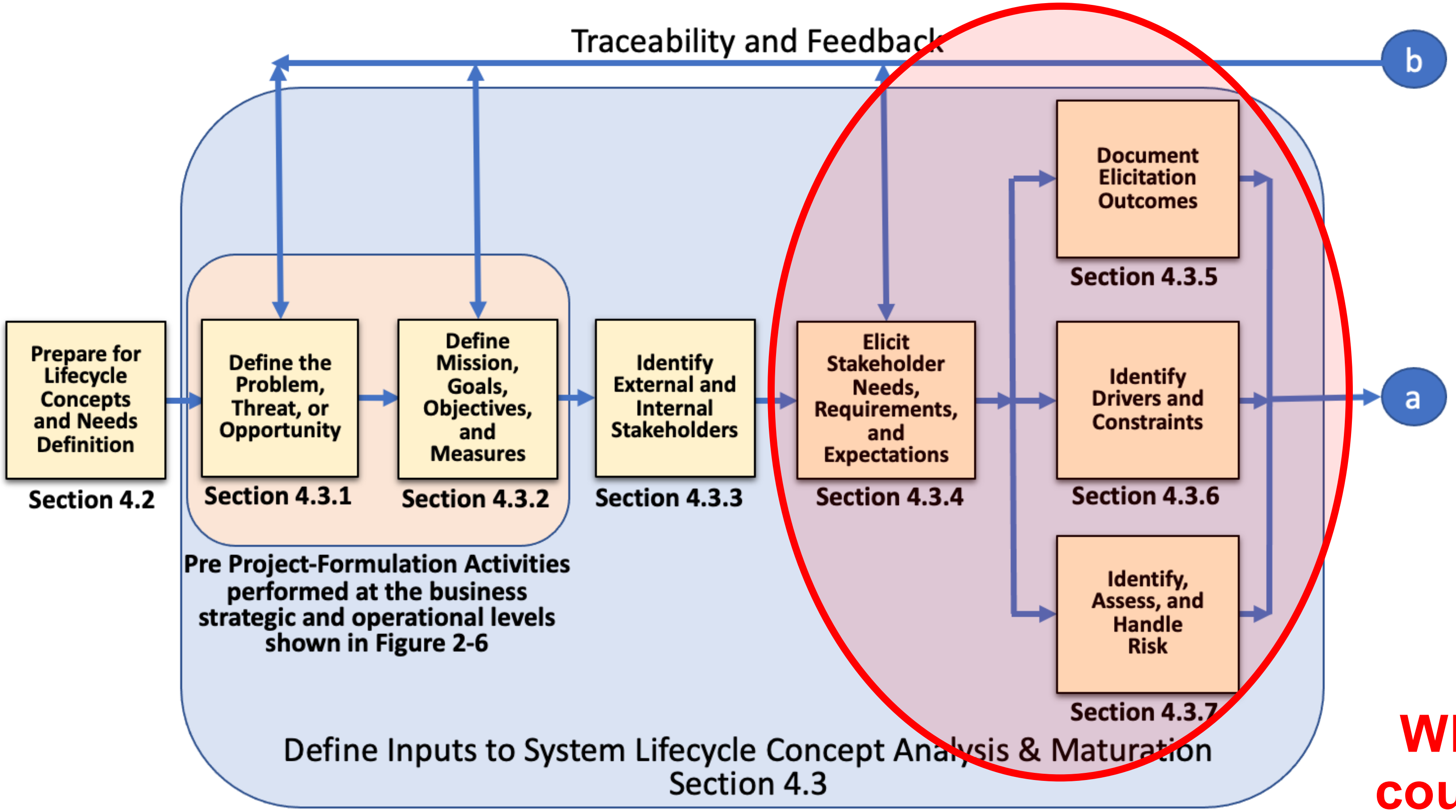
Customer/Supplier Goals, Objectives, and Measures concerning sustainability must be consistent.

Sustainability must be Addressed From the Beginning of the Project



From the product perspective, sustainability stakeholder real-word expectations must be understood, lifecycle concepts defined, sustainability capabilities identified and communicated within the Integrated Set of Needs.

Lifecycle Concepts and Needs Definition

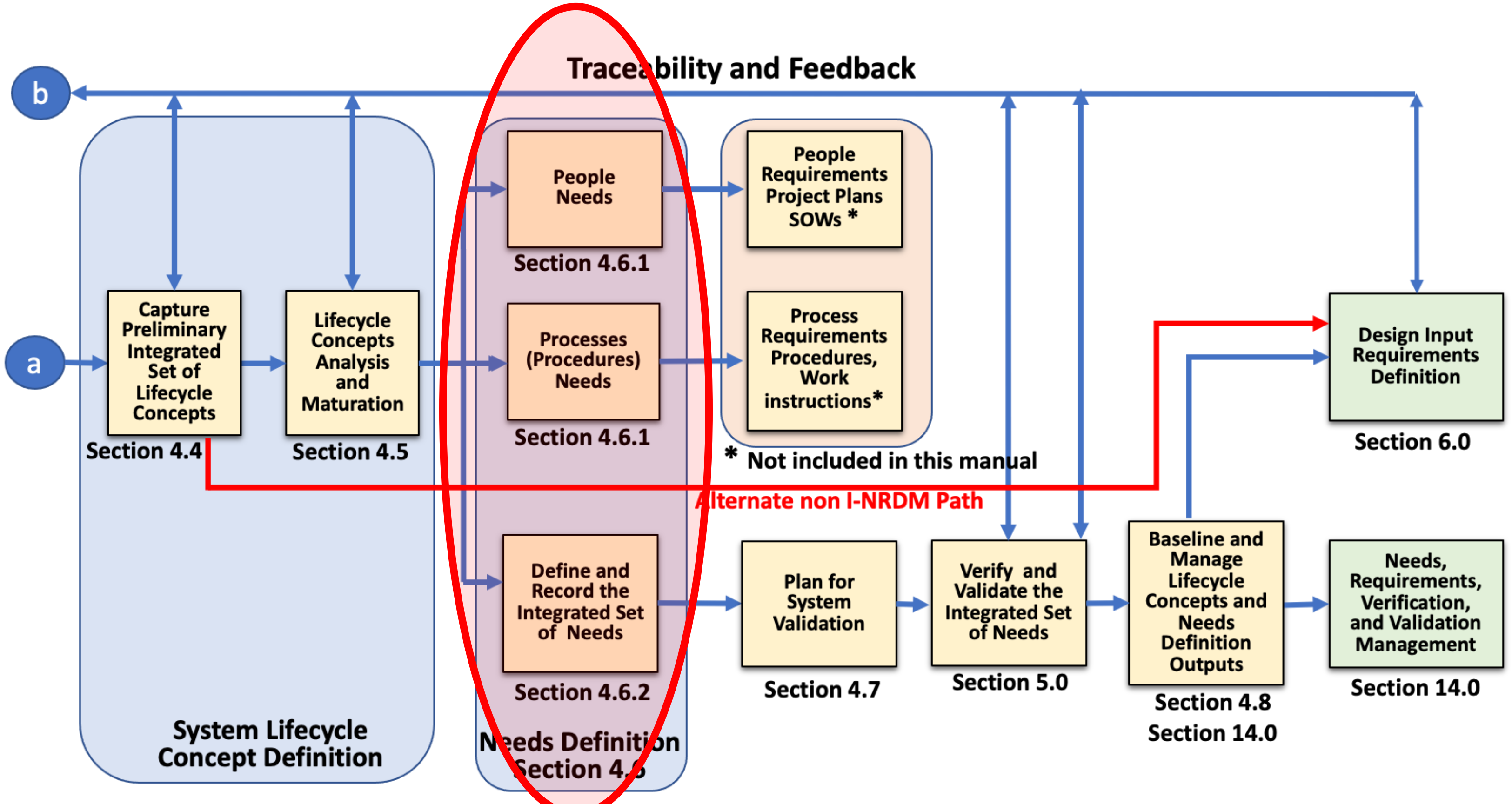


As part of elicitation, in addition to use cases and user stories, define mis-use cases and loss scenarios from the perspective of sustainability.

- What mis-use cases could impact your sustainability goals and objectives?
- What events (internal or external) could result in your sustainability goals and objectives not being met?

What drivers, constraints, risks could impact your efforts to meet your sustainability goals and objectives?

Lifecycle Concepts and Needs Definition



As part of lifecycle concepts analysis and maturation, address needed capabilities to achieve your sustainability goals and objectives within the identified drivers, constraints, and risks.

These capabilities are realized by addressing needs concerning the organization (people), processes, and the engineered system (product).

Significance of the Integrated Set of Needs

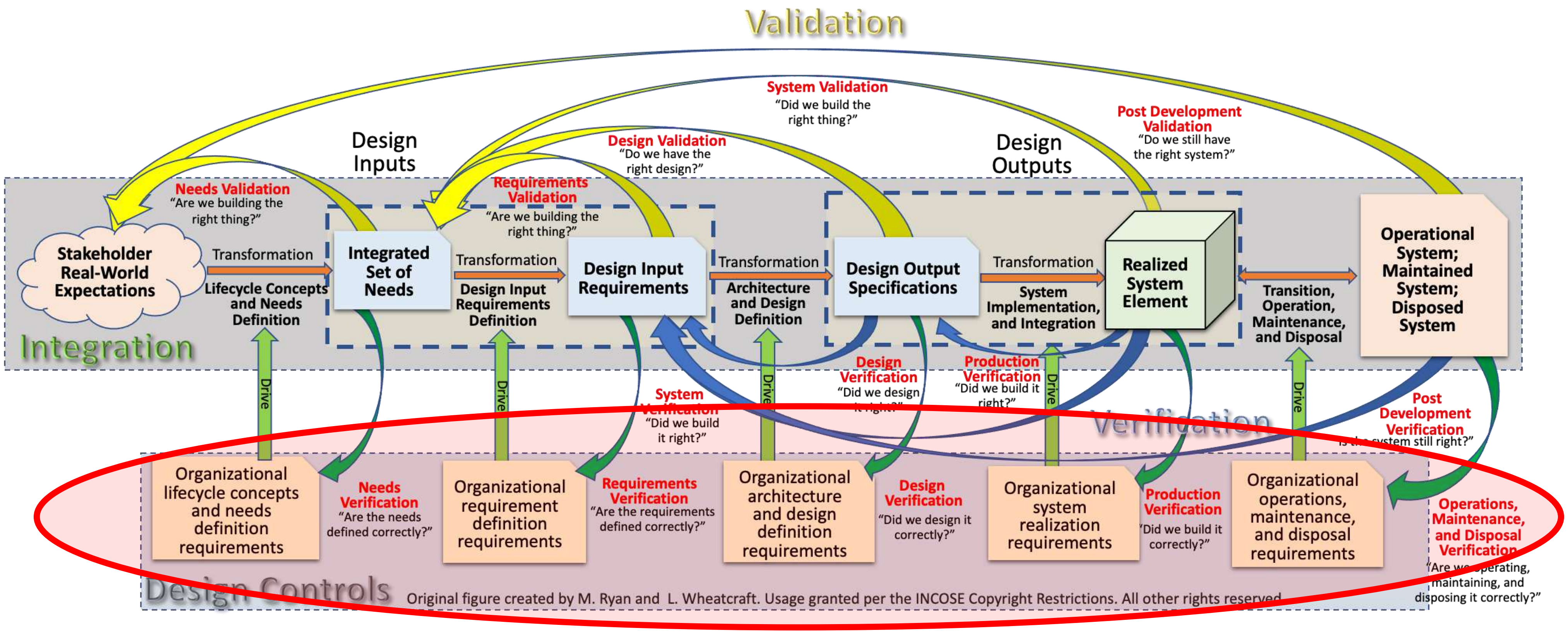
- The Integrated Set of Needs (ISON) represents the agree-to and baselined scope of the project.
- This means that the customer has **agreed with the needs dealing with sustainability** and has **agreed to provide the funding and resources** necessary to realize those needs.
- Customer acceptance of the realized system will be based on successful system validation that the needs have been realized.
- Requirements will be transformed from the needs via Requirements Analysis
  - Sustainability requirements must be defined for the people, process, and product.
  - Each requirement will address the question: “What must the people, process, and/or product do to meet the intent of the needs from which they are transformed.”
  - The result will be one or more well-formed requirements that have the characteristics defined in the INCOSE RWG Guide to Writing Requirements (GtWR).
  - People and process sustainability requirements will be documented within the design controls.
  - Product sustainability requirements will be documented with the product DIR.

Example Need Statements for the Project Team

- The stakeholders need the **project team** to maximize the ability to recycle parts and materials.
- The stakeholders need the **project team** to maximize the ability to reuse parts.
- The stakeholders need the **project team** to use clean energy sources (vs fossil-fuel based energy) whenever practicable.
- The stakeholders need the **project team** to be designed to maximize the use of renewable resources.
- The stakeholders need the **project team** to use resources (materials and energy) efficiently.
- The stakeholders need the **project team** to avoid the use of non-renewable resources within the design.
- The stakeholders need the **project team** to minimize waste put in landfills.
- The stakeholders need the **project team** to not design a system that will result in hazardous waste.
- The stakeholders need the **project team** to prevent harmful emissions/pollution to be released in the environment during manufacturing, operations, maintenance, or disposal.
- The stakeholders need the **project team** to reduce the carbon footprint of the organization.
- The stakeholders need the **project team** to ensure the costs associated with achieving the organization's sustainability goals and objectives do not add to the production cost of the product.

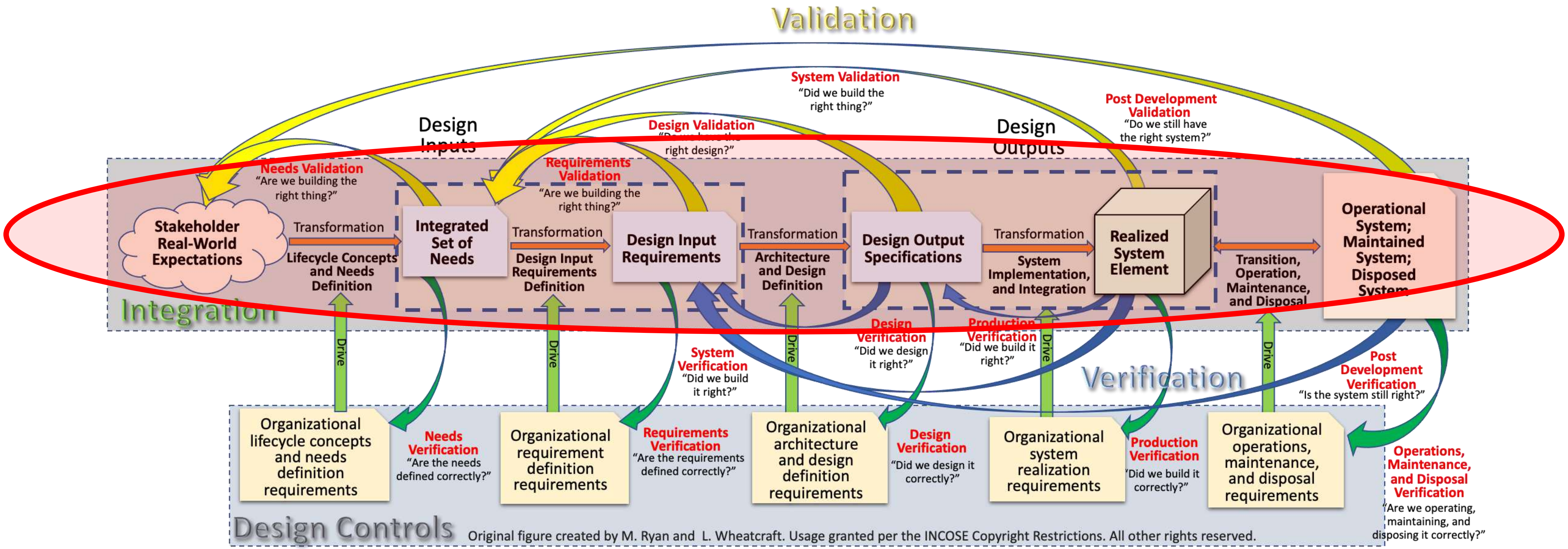
While valid stakeholder expectations, there is a lot of work that must be done to define well-formed sets of needs and requirements for both the SOI and organization producing that SOI!

Sustainability must be Addressed in Processes, Procedures, and Work Instructions



The organization sustainability needs and requirements concerning people and processes must address their sustainability goals, objectives, and measures within their sets of Design Controls.

Sustainability must be Addressed Across the Lifecycle



The organizational sustainability needs for the product will be communicated within the Integrated Set of Needs and implemented within the sets of Design Input Requirements.

Making Sustainability Happen – a Challenge!

- For both your organization and individual products
  - Define a mission statement, goals, objectives from a sustainability perspective.
    - Environmental sustainability
    - Sustainability of the enterprise
    - Sustainability of the product through its life.
  - List the sustainability measures you will use to measure progress toward your sustainability goals.
  - List drivers, constraints, and risks that may limit the ability to achieve the sustainability goals and objectives.
  - Update your enterprise business and business operations requirements for sustainability.
    - Develop a sustainability standard for your organization
  - Develop lifecycle concepts, needs, and design input requirements addressing sustainability for both your infrastructure as well as your products.
  - Update your design controls to address sustainability across the lifecycle.

Practical Considerations: ASARP

- While the ideal sustainability goals and objectives for a system may be aspirational, the ISON must strike a balance between the ideal and what is ”As Sustainable As Reasonably Practicable (ASARP)".
- The needs validation process must ensure that the collection of needs statements are feasible and align with the ASARP principle, particularly in critical areas such as:
  - **Budget:** Can the sustainability needs be met within the available budget?
    - Can the organization realize cost savings by adopting sustainability principles?
  - **Supply Chain:** Will the materials and parts that support sustainability be available when needed and at an affordable cost?
  - **System Cost**: How will meeting the sustainability goals and objectives drive the selling price of the system.
    - Will the resulting system be affordable for the consumer?
    - Will consumers be willing to pay extra for the sustainability features of the product (versus similar products that are not as sustainable)?
  - **Regulatory Compliance:** Is the developing organization and resulting product satisfying legal and sustainability standards defined by agencies like the EPA or OSHA, or equivalent regulatory agencies?

Questions and Discussion

Lou Wheatcraft

- **Lou Wheatcraft** is a senior consultant and managing member of Wheatland Consulting, LLC. Lou is an international expert in systems engineering with a focus on needs and requirements development, management, verification, and validation across the system lifecycle.
- Lou's goal is to help systems engineers practice better systems engineering from a needs and requirements perspective across all lifecycle stages of system/product development. Getting the needs and requirements right upfront is key to a successful project.
- Lou has over 50 years' experience in systems engineering, including 22 years in the United States Air Force. Lou has taught over 200 requirement seminars over the last 25 years. Lou supports clients from government and industries involved in developing and managing systems and products including aerospace, defense, medical devices, consumer goods, transportation, and energy.
- Lou is very active in the INCOSE and is the current co-chair of the RWG. Lou is a principal author of several RWG manuals and guides including the Needs and Requirements Manual (NRM), Guide to Needs and Requirements GtNR), Guide to Verification and Validation (GtVV), and newly released version 4 of the Guide to Writing Requirements (GtWR).
- Lou has a BS degree in Electrical Engineering from Oklahoma State University; an MA degree in Computer Information Systems; an MS degree in Environmental Management; and has completed the course work for an MS degree in Studies of the Future from the University of Houston – Clear Lake.