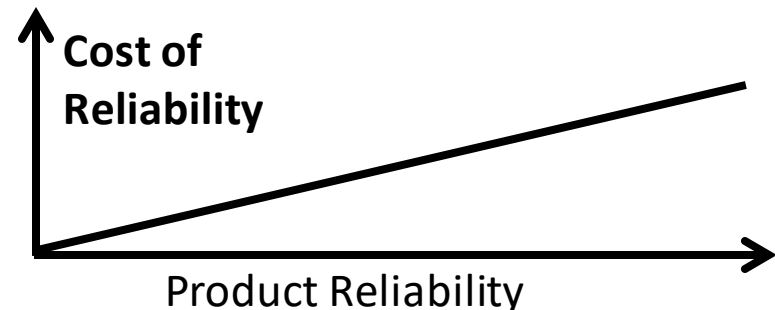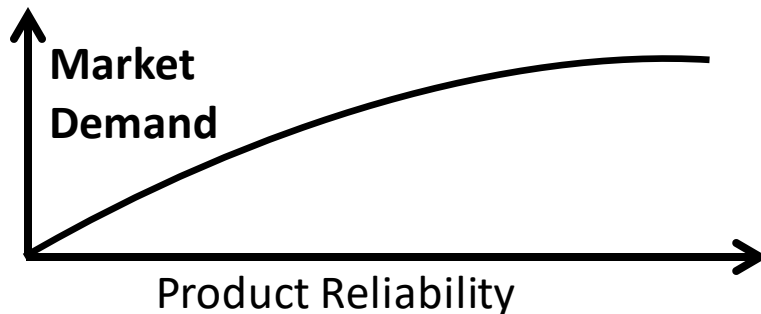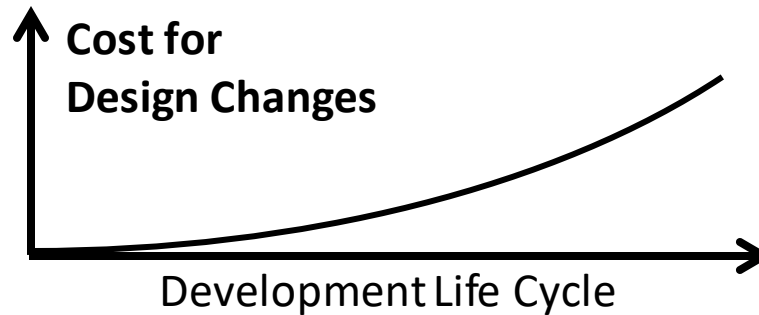# Design for Manufacturing, Assembly, and Reliability

Module 3E Design for Reliability

Motivation

Why is this module important?

☐ Product reliability problems are easier and cheaper to fix early in development lifecycle

Design for Reliability

Motivation

From the customer perspective

☐ Balance maintenance and reliability cost

☐ Balance procurement cost with downtime and replacement cost

Design for Reliability

3

U.S. DEPARTMENT OF ENERGY • OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY
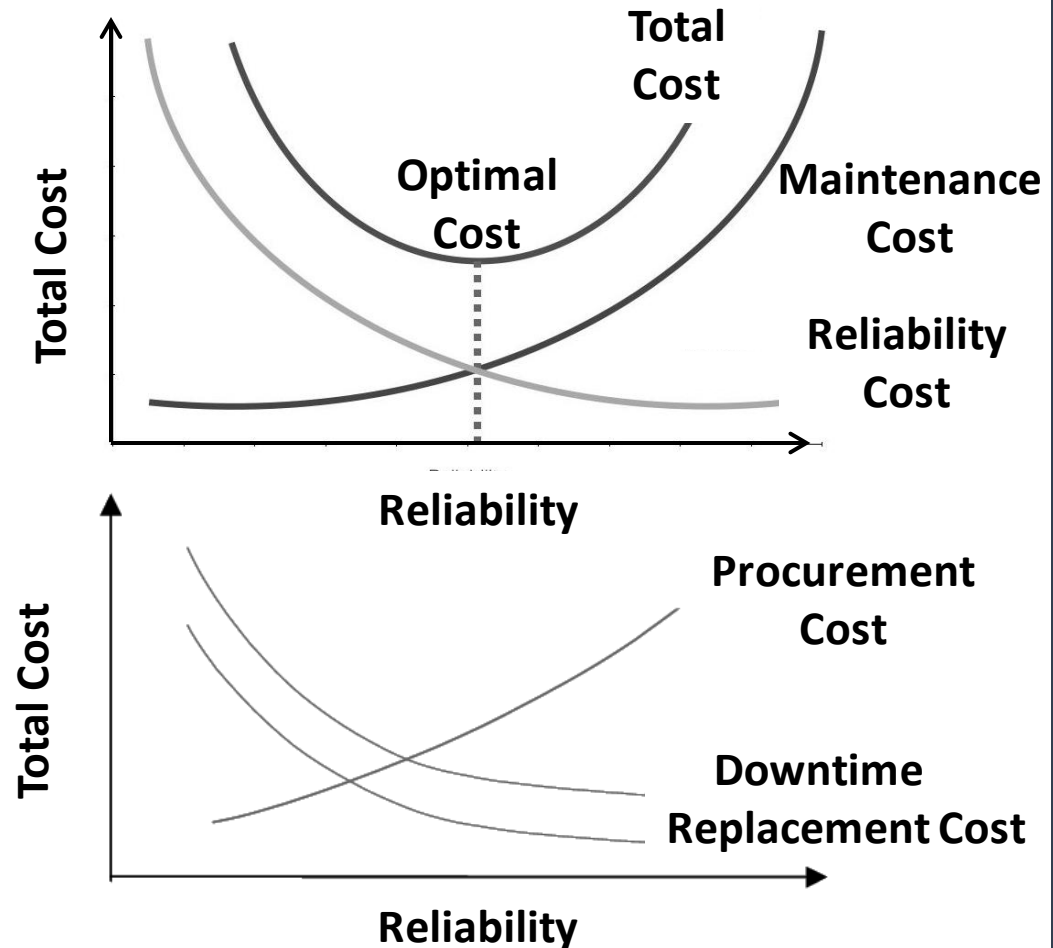
Motivation

Key drivers

Reliability goals and plans drive:

Design prioritizations:

☐ Avoid under-reliability and customer dissatisfaction costs

☐ Avoid over-reliability costs without increase to market demand (i.e., reliability that is higher than the customer is willing to pay for)
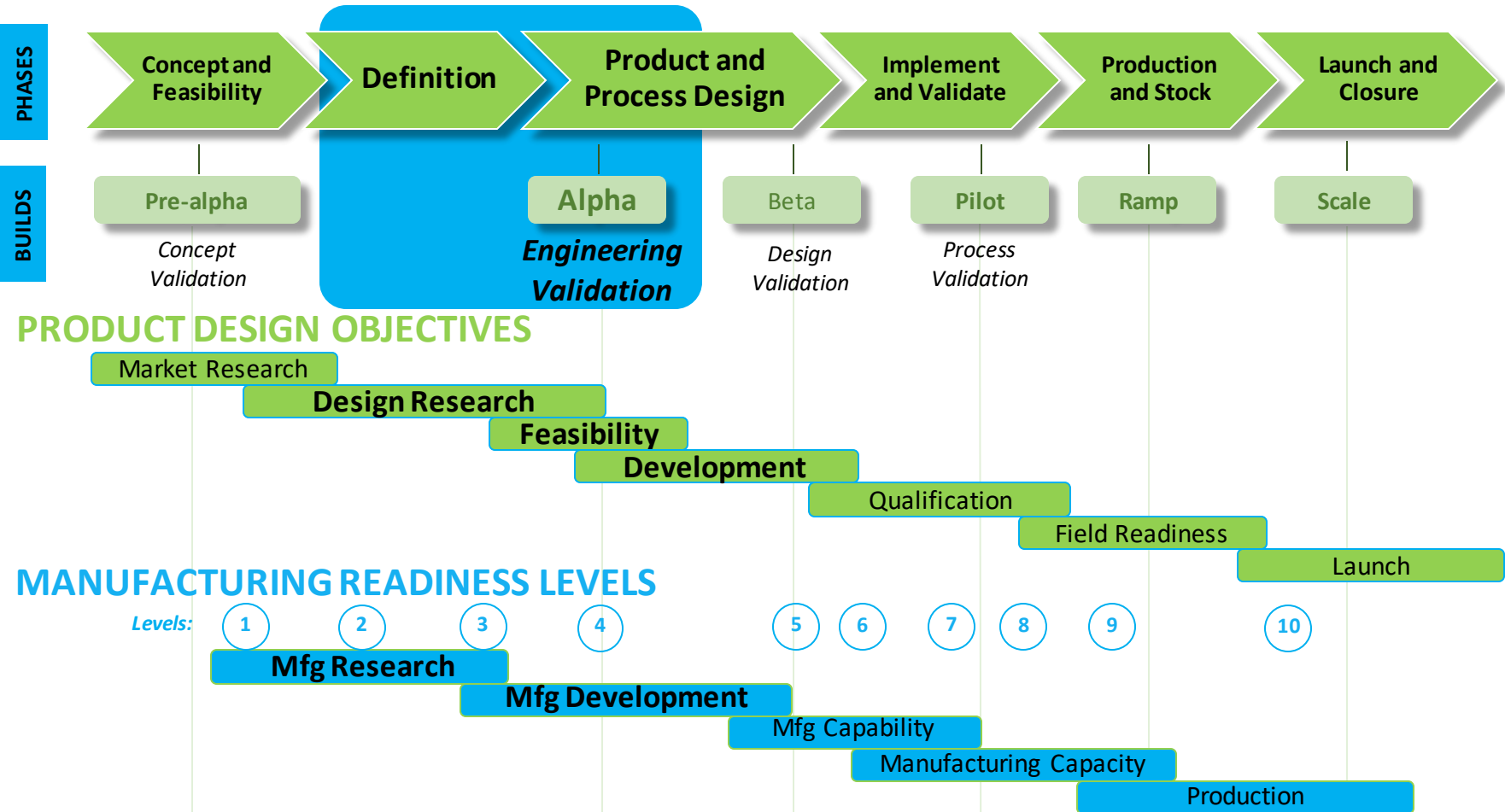
Schedule predictability:

☐ Avoid time-to-market delays and cost implications

Failure-rate predictability:

☐ Warranty burden and service costs

Design For Reliability

Where does this fit into the development cycle?

PHASES

| Concept and Feasibility | Definition | Product and Process Design | Implement and Validate | Production and Stock | Launch and Closure |

BUILDS

| Pre-alpha | | Alpha | Beta | Pilot | Ramp | Scale |

Concept Validation — *Engineering Validation* — *Design Validation* — *Process Validation*

PRODUCT DESIGN OBJECTIVES

- Market Research
- **Design Research**
- **Feasibility**
- **Development**
- Qualification
- Field Readiness
- Launch

MANUFACTURING READINESS LEVELS

Levels: 1 2 3 4   5 6 7 8 9   10

- **Mfg Research**
- **Mfg Development**
- Mfg Capability
- Manufacturing Capacity
- Production

Design for Reliability

Module Outline

☐ Learning objectives

☐ Reliability process overview

☐ Establishing reliability goals

☐ Reliability driven product design

☐ Available tools and partners

☐ Links to other relevant modules
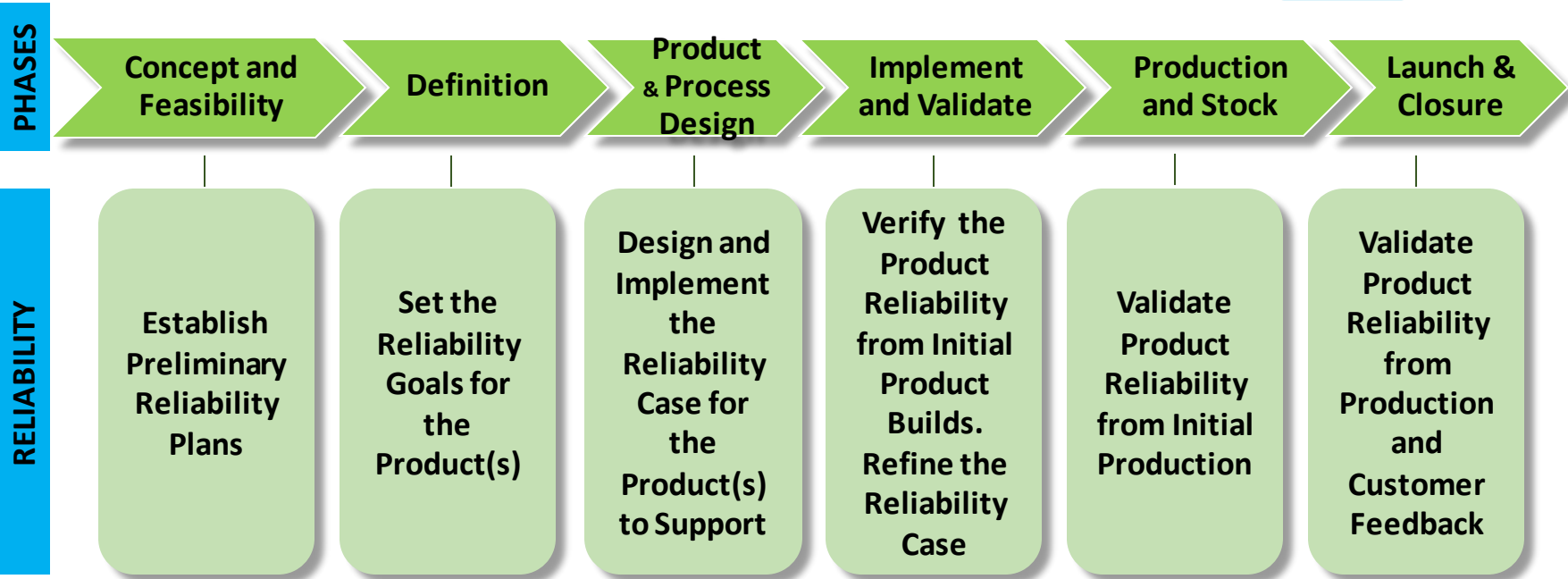
www.build4scale.org

Learning Objectives

☐ LO1. Understand importance of reliability goals and how to set them

☐ LO2. Understand strategies for managing reliability goals throughout product lifecycle

☐ LO3. Understand available tools and partners to assist "Design for reliability"

Reliability Process Overview

Key drivers and lifecycle review

PHASES	Concept and Feasibility	Definition	Product & Process Design	Implement and Validate	Production and Stock	Launch & Closure
RELIABILITY	Establish Preliminary Reliability Plans	Set the Reliability Goals for the Product(s)	Design and Implement the Reliability Case for the Product(s) to Support	Verify the Product Reliability from Initial Product Builds. Refine the Reliability Case	Validate Product Reliability from Initial Production	Validate Product Reliability from Production and Customer Feedback

- ☐ Converting market/customer requirements into consistent (i.e., reliable) product realization

- ☐ Reliability involves activities throughout the product lifecycle

Reliability Process Overview

Objectives

Reliability testing objectives by build version:

☐ **Pre-alpha testing**: establish reliability goals

☐ **Alpha testing**: test and refinement of the product design

☐ **Beta testing**: test and refinement of manufacturing processes

☐ **Pilot**: validate design and manufacturing before production

☐ **Production ramp**: validate warranty and service impacts

Tip: Product reliability and warranty burden implications are realized after launch, but proper design for reliability enables accurate predictions to be made and corrective actions to be implemented much earlier in the production process

Reliability Process Overview

Accountability
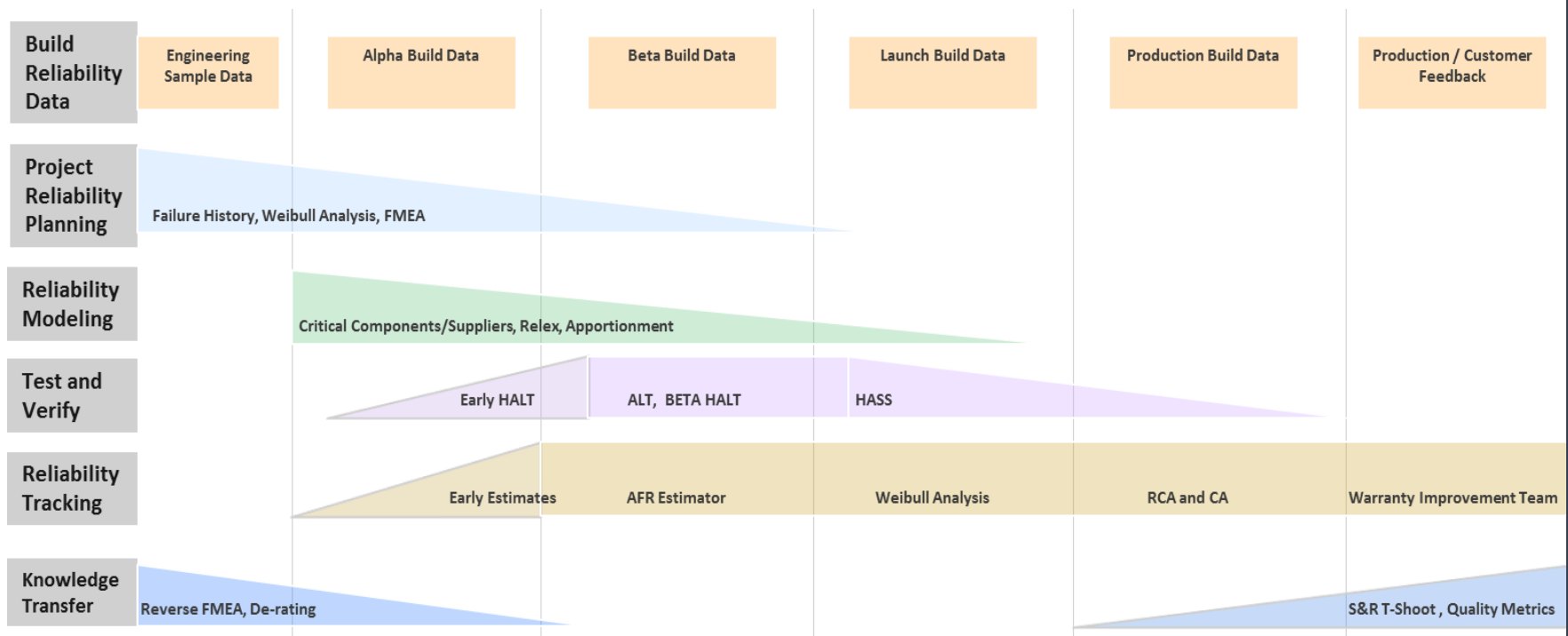
Broad engineering roles/teams/responsibilities:

☐ **Design (Research and development [R&D])**: functionality, usability, reliability, performance, serviceability, and manufacturability

☐ **Manufacturing**: design specification conformance at production capacity

☐ **New product introduction (NPI) process**: translate design into processes for production ramp (can be owned by design team, manufacturing team, or some combination of teams)

☐ **Other teams**: marketing, quality, technical publications, service and repair, finance, etc.

Tip: For proper accountability, the design team needs to remain involved after NPI handoff in order to prove that reliability goals are being met

Design for Reliability
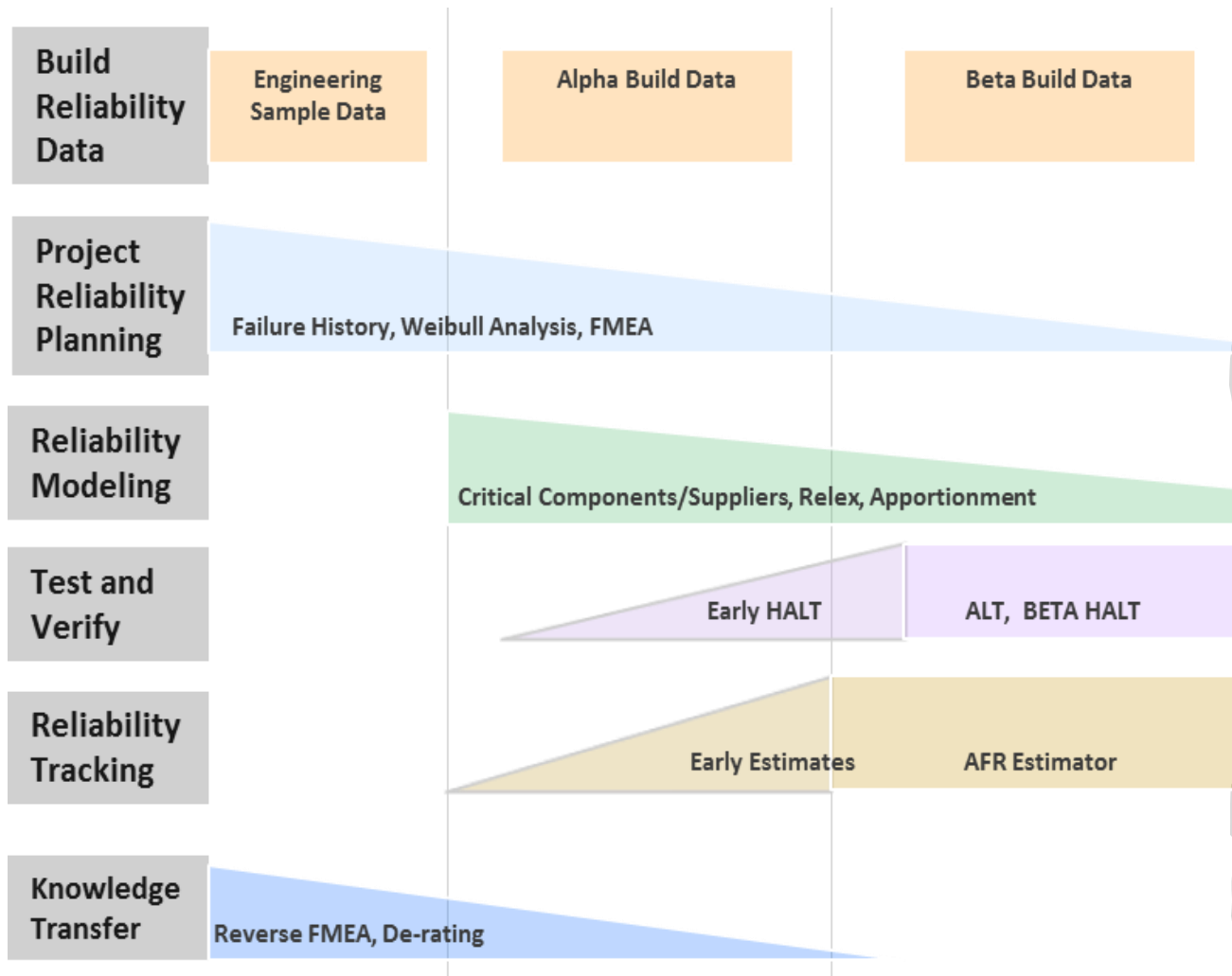
Reliability Program Plan

Example – A good plan

Build Reliability Data	Engineering Sample Data	Alpha Build Data	Beta Build Data	Launch Build Data	Production Build Data	Production / Customer Feedback

Project Reliability Planning
Failure History, Weibull Analysis, FMEA

Reliability Modeling
Critical Components/Suppliers, Relex, Apportionment

Test and Verify
Early HALT — ALT, BETA HALT — HASS

Reliability Tracking
Early Estimates — AFR Estimator — Weibull Analysis — RCA and CA — Warranty Improvement Team

Knowledge Transfer
Reverse FMEA, De-rating — S&R T-Shoot , Quality Metrics

Image enlarged on next two slides

Design for Reliability

Reliability Program Plan

Example – *A good plan (cont.)*

| Build Reliability Data | Engineering Sample Data | Alpha Build Data | Beta Build Data |

Project Reliability Planning — Failure History, Weibull Analysis, FMEA

Reliability Modeling — Critical Components/Suppliers, Relex, Apportionment

Test and Verify — Early HALT; ALT, BETA HALT

Reliability Tracking — Early Estimates; AFR Estimator

Knowledge Transfer — Reverse FMEA, De-rating

Continued on next slide

Reliability Program Plan

Example – *A good plan (cont.)*

Build Reliability Data		Launch Build Data	Production Build Data	Production / Customer Feedback
Project Reliability Planning				
Reliability Modeling				
Test and Verify		HASS		
Reliability Tracking		Weibull Analysis	RCA and CA	Warranty Improvement Team
Knowledge Transfer				S&R T-Shoot , Quality Metrics

Design for Reliability

13

www.build4scale.org

U.S. DEPARTMENT OF ENERGY • OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY

Reliability Planning

Example – A poor plan

Background:

☐ Jane Doe Solar Panel company did not understand market requirements for long-term usability versus the less important need for consistent energy conversion over life. In addition, they had no strategy in place to manage their design for reliability (including early reliability testing).
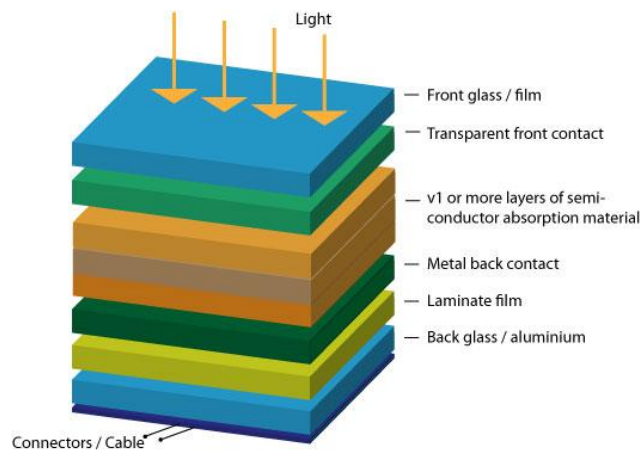

Light
— Front glass / film
— Transparent front contact
— v1 or more layers of semi-conductor absorption material
— Metal back contact
— Laminate film
— Back glass / aluminium

Connectors / Cable
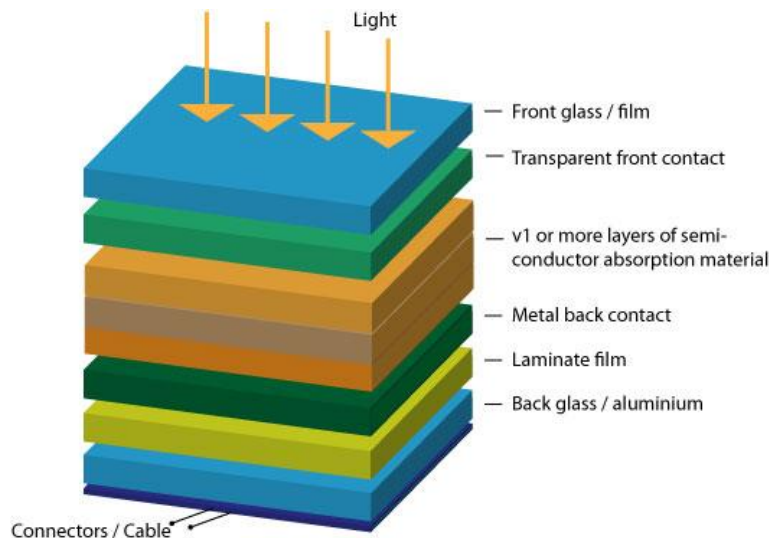
Reliability Planning

Example – A poor plan (cont.)

Result:

☐ They over-invested time and money in coatings and materials development to maximize energy conversion stability. The resulting schedule slips motivated them to under-invest in reliability and deliver products that often failed after a few years. A design correction was possible, but the problem was not identified until well after many products had been in service.

Light
- Front glass / film
- Transparent front contact
- v1 or more layers of semi-conductor absorption material
- Metal back contact
- Laminate film
- Back glass / aluminium

Connectors / Cable

Establishing Reliability Goals

Primary considerations

☐ **Market differentiation:** will customers pay for higher reliability, and how will the marketing/ sales group define "higher reliability" to customers?

☐ **Total cost (TC):** what are the cost implications of high reliability?

☐ **Brand power:** what are the positive and negative effects on overall product brand?

☐ **Consequence of failure:** are there safety or other property damage concerns to consider?

Tip: Start with preliminary reliability goals up front and gather information throughout product development to refine the goals appropriately. Use reliability knowledge from past products to improve future products.

Reliability Bathtub Curves

Overview

☐ The bathtub curve is generated by mapping (1) the rate of early "infant mortality" failures when first introduced, (2) the constant rate of "random" failures during its useful life, and (3) the rate of "wear out" failures as the product exceeds its design lifetime
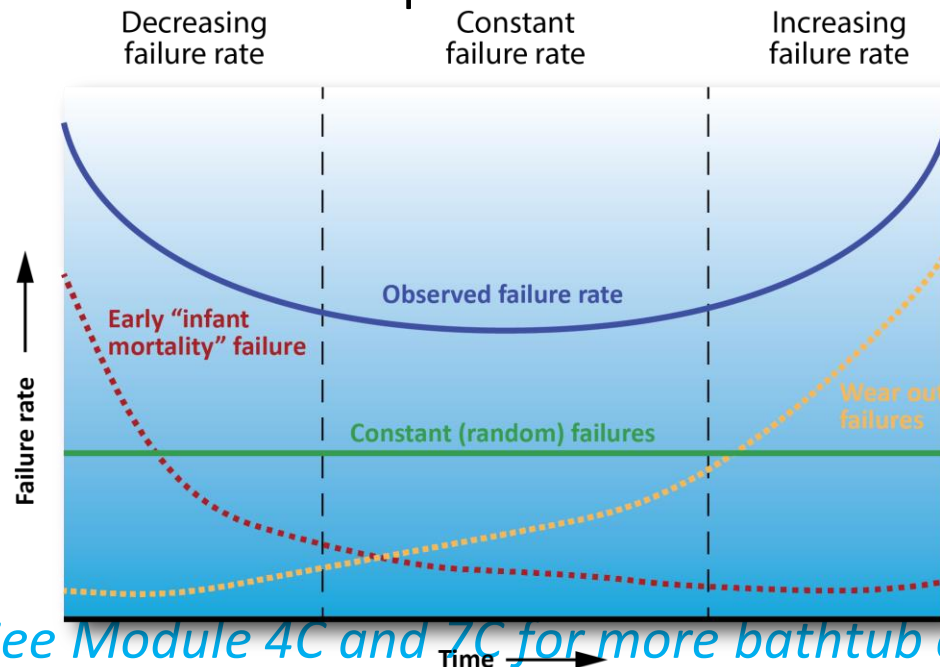
See Module 4C and 7C for more bathtub curves

U.S. DEPARTMENT OF ENERGY • OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY

Quality Goals

Establish these prior to product design

☐ **Early failure rate (infant mortality)**: typically caused by manufacturing, assembly, shipping issues

Example: less than one percent in first 90 days

☐ **Design reliability goal (constant rate failures)**: typically drives the component selection and design strategy

Example: 90 percent system survivability at year five at 25°C (or other environment/use parameters)

☐ **Design life goal (wear out)**: this is the point where the components selected will start to wear out

Example: seven years at 25°C (or other environment/use parameters)

Reliability-Driven Design

Decision tradeoffs

☐ Reliability-driven design facilitates intelligent design-tradeoff decisions

☐ Cost/benefit analysis used for selecting best approach
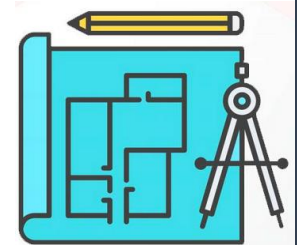
Example design and decision alternatives:

☐ Overdesign versus replacement or repair strategy for unreliable component/subsystem

☐ High factor of safety conservative design versus plan for 100% inspection on critical components

☐ Computer simulation of performance versus functional physical testing

☐ Product screening tests with high rejection rates versus higher quality manufacturing or design without screening test

Design Considerations

Reliability, test, inspection, and repair

☐ **System complexity**: number of subsystems, interdependence between subsystems

☐ **Modular design**: easier to troubleshoot and repair

☐ **"Smart" design**: embedded sensors or firmware/software indicators to reveal when and where failures occur (consider whether this can be part of an "Internet of Things (IoT)" strategy for pre-emptive failure intervention)
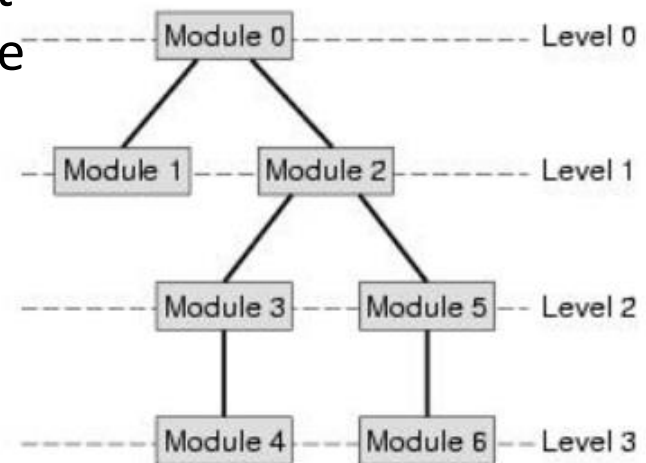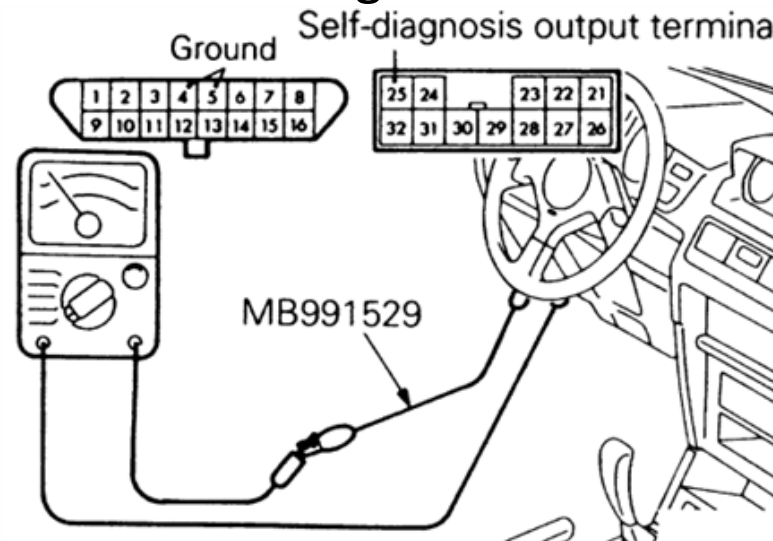
Design Considerations

Reliability, test, inspection, and repair (cont.)

☐ **Packaging and shipping**: ease of packaging, durability through shipping, durability through unpacking and set-up

☐ Design for self-diagnosis and repair

☐ Design for part replacement
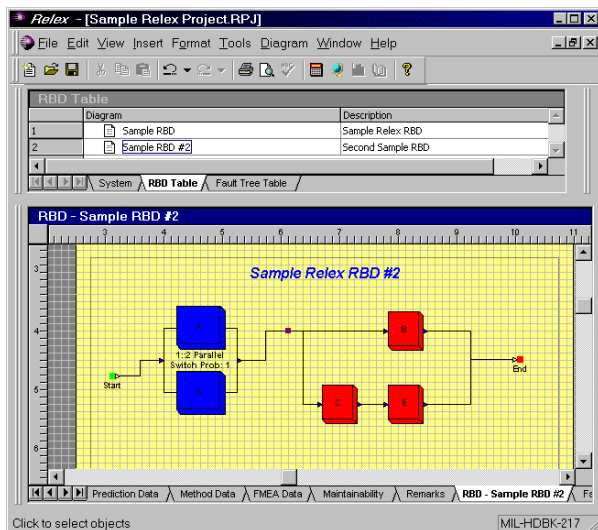
☐ Design for redundancy or overdesign

Reliability Tools

Risk analysis, priorities, and initial predictions

☐ **Failure Mode Effect Analysis**: Predicting potential failures and comparing overall impacts for prioritizing risks and mitigation options

☐ Historical data (i.e., service, repair, field failure rates, warranty data) useful starting point for reliability predictions and decisions

Reliability Block Diagram

$T_u = 10°C$

$\mu = 1.7 \times 10^5 \ h$

$\sigma = 0.99$

(b) Failure rate vs. time (years)
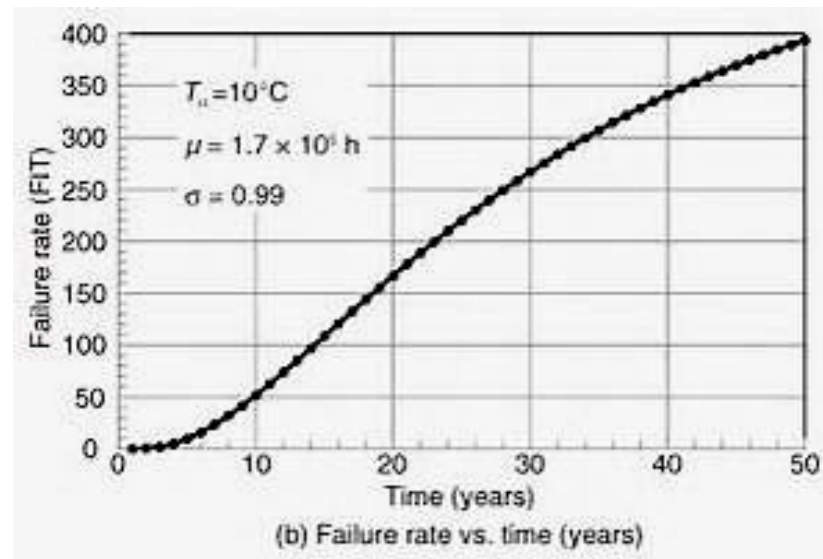
Design for Reliability

Reliability Tools

Data collection

☐ Reliability databases (i.e., in Relex software)

☐ Online and catalog information (i.e., component specifications can provide lifetime and use case data)

Specifications

Component	Parameter	Design Specification
Battery	Charge time	6 hours
Battery	Discharge time	2 hours
Mobile wireless link	Minimum range	3 meters
GPS receiver	Accuracy	10 meters
Compass	Accuracy	One cardinal direction
Speed	Accuracy	2 miles per hour
GPS (Android)	Accuracy	30 feet
GPS (Android)	Update time	5 seconds

Reliability Tools

Software and statistics

- ☐ Weibull analysis and life probability statistics for warranty forecasting and test planning

- ☐ Commercial off-the-shelf reliability software (i.e., Reliasoft, Relex, Windchill)

- ☐ Closed loop software link between computer-aided engineering (CAE) tools and reliability data/calculations
  - Easier design changes and optimization
  - Automatic updates to documentation, process, design package, etc.

Computer modeling and simulation of performance:

- ☐ **Mechanical loads**: structural, fluid flow, thermal, etc.

- ☐ **Environment loads**: temperature, pressure, and humidity

- ☐ **Cyclic fatigue analysis**: electrical, thermal, and mechanical

Design for Reliability   24

Reliability Tools

Assessment methods and examples

Destructive evaluation method:

☐ Accelerated and highly accelerated life tests (HALT)

☐ "Tear-down" and "Break-open" product or components

Non-destructive evaluation methods:

☐ Highly Accelerated Stress Screen (HASS) or proof testing

☐ Burn-in or stabilization testing

☐ Out of box audit (OBA)

☐ On-going reliability testing (ORT)

☐ X-ray, ultrasound, or thermal imaging

☐ Manual or automated versions for testing

See Modules 4C and 7B for more details

Design for Reliability

25

Reliability Partners

Potential partner demographics

☐ Reliability organizations and consultants

☐ Test & inspection development and service professionals

☐ Software/hardware vendors

U.S. DEPARTMENT OF ENERGY • OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY

Reliability Partners

Examples

☐ Reliability organizations and consultants

https://accendoreliability.com/

http://www.sre.org/

http://rs.ieee.org/

https://asq.org/

https://accendoreliability.com/

☐ Test and inspection development and service professionals

https://ewi.org/

http://reliantlabs.com/

http://www.intertek.com/

https://www.nts.com/

http://www.sgs.com/

Design for Reliability   27

Reliability Partners

Examples (cont.)

☐ Software/hardware vendors

http://www.reliasoft.com/index.html

https://www.ptc.com/en/product-lifecycle-managementwindchill/quality

https://www.isograph.com/

http://keysight.com/

Other Relevant Modules

Further details

☐ Module 2B Product Lifecycle Management Tools

☐ Module 2C and 4A – PFMEA and DFMEA details

☐ Module 4C Beta Prototype and Test Plan: Simulating Product Use Conditions

☐ Module 7B – Sustaining Quality and Warranty: Pilot and Scaling for the Production Ramp

☐ Module 7C – Sustaining Quality and Warranty: Field Product Quality, Service, and Repair