Maximizing Value in Energy Capital Projects
The Critical Role of Materials Engineering

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AGENDA

- Introduction
- Project Lifecycle and Material Decision Points
- Role of Innovative Materials in Energy Projects
- Tools for Value Optimization
- Examples
- Closing and Key Takeaways
- Q&A

Key Challenges in the Capital Project Space

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Why do we do projects

- **Energy Security & Supply**
- **Economic Growth & Job Creation**
- **Safety & Environment**
- **Profitability & Investment Returns**
- **Transition to Sustainability**
- **Technological Innovation & Advancement**
- **Geopolitical & Strategic Influence**

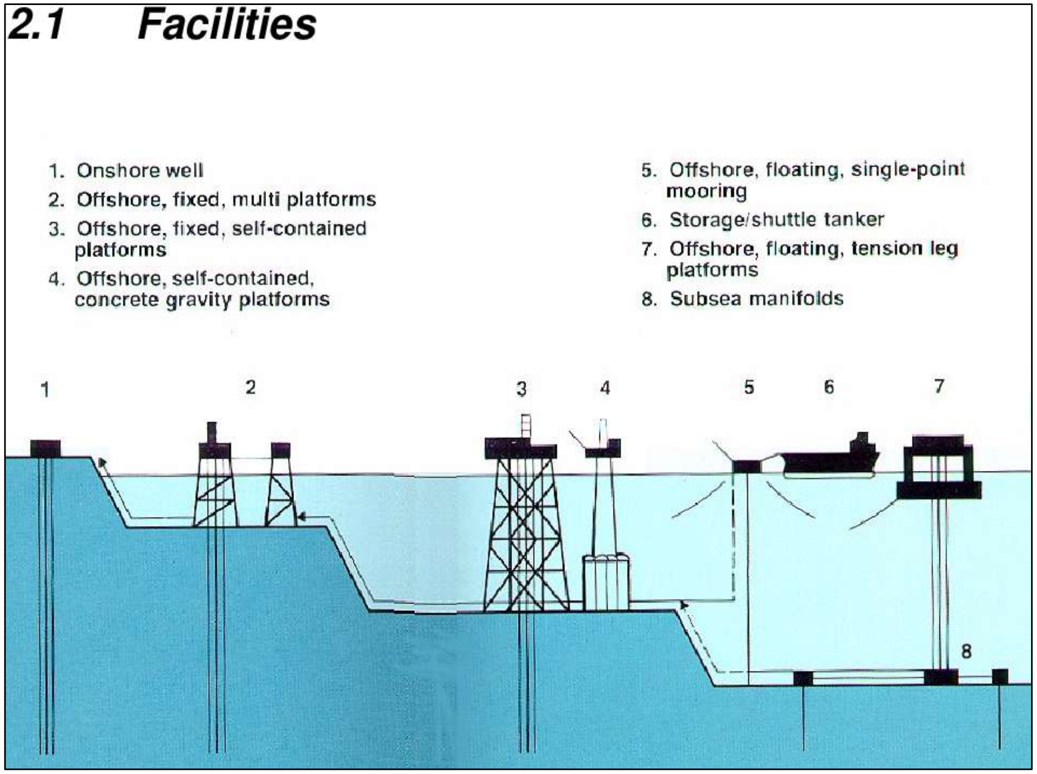
Project Challenges

Technical	**Complexity of Engineering & Design**
	Technology Integration & Reliability
Economic	**Scoping, Cost Overruns & Budget Blowouts**
	Uncertain Commodity Prices
Commercial	Long-Term Contractual Uncertainty
	Project Financing & ROI Risks
Organizational	Workforce Shortages & Skills
	Stakeholder & Partner Misalignment
Political/Regulatory	Evolving Environmental
	Geopolitical & Permitting Risks

Materials Challenges

Technical	Material Degradation & Corrosion
	Advanced Material Selection for Extreme
Economic	High Cost of Advanced Materials
	Supply Chain Disruptions for Critical Materials
Commercial	Long-Term Material Performance Uncertainty
	Material Qualification & Certification Complexity
Organizational	Limited Expertise in Advanced Materials
	Cross-Disciplinary Collaboration Gaps
Political/Regulatory	Environmental Restrictions on Certain Materials
	Geopolitical Risks in Raw Material Sourcing

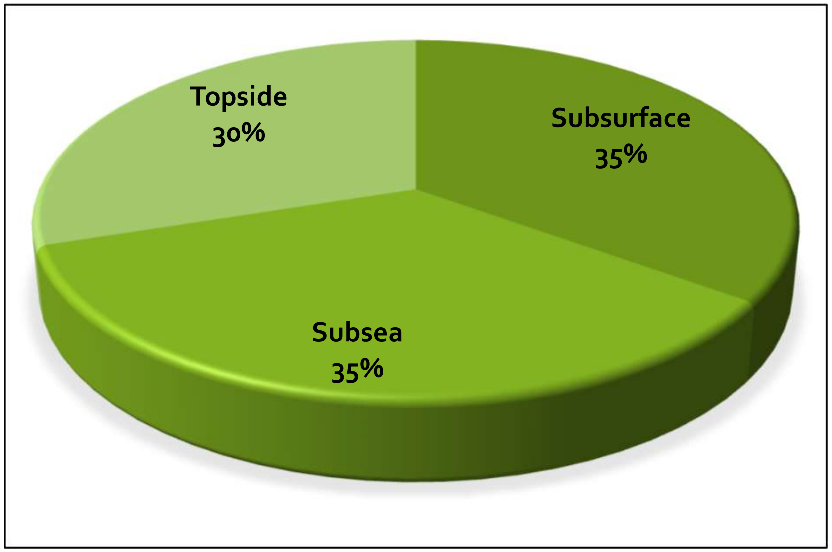
Schematic of an Offshore Development (Example)



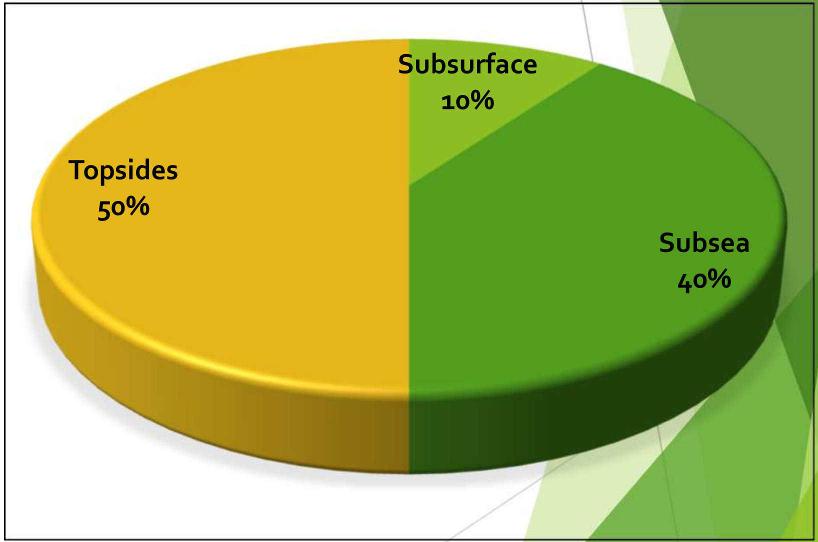
- Topsides
- Subsea
- Subsurface

CapEx in Offshore Projects

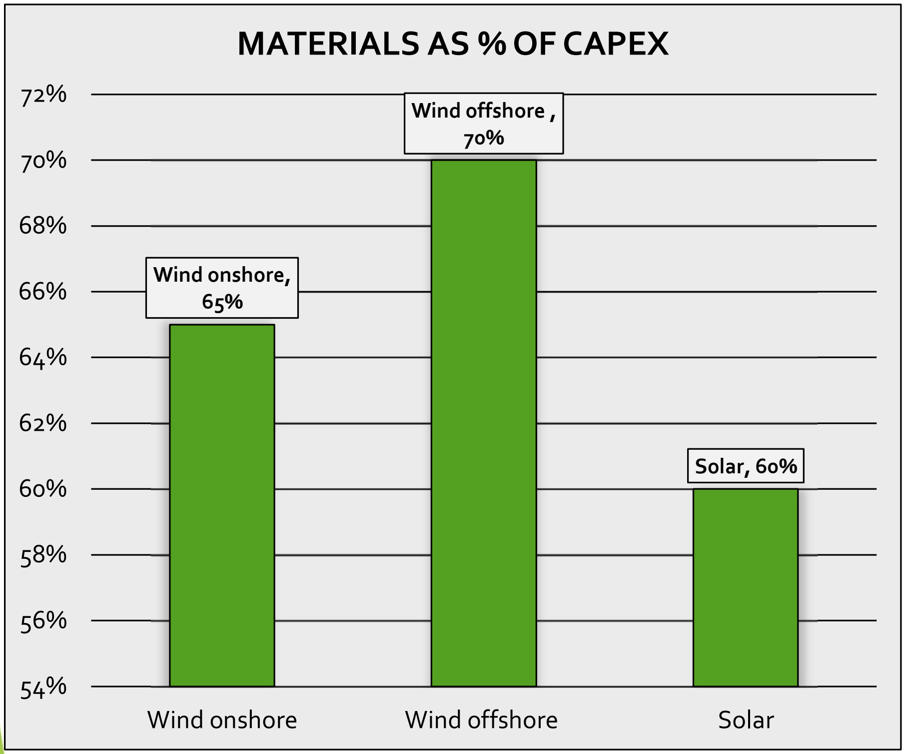
TYPICAL CAPEX DISTRIBUTION

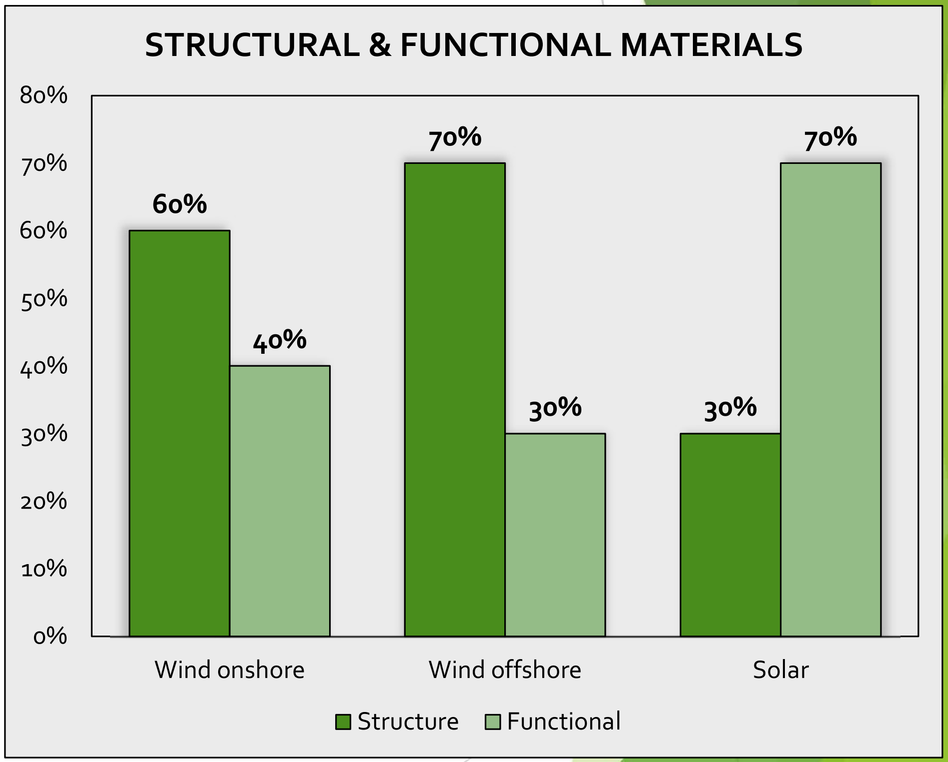


MATERIALS AS % OF CAPEX

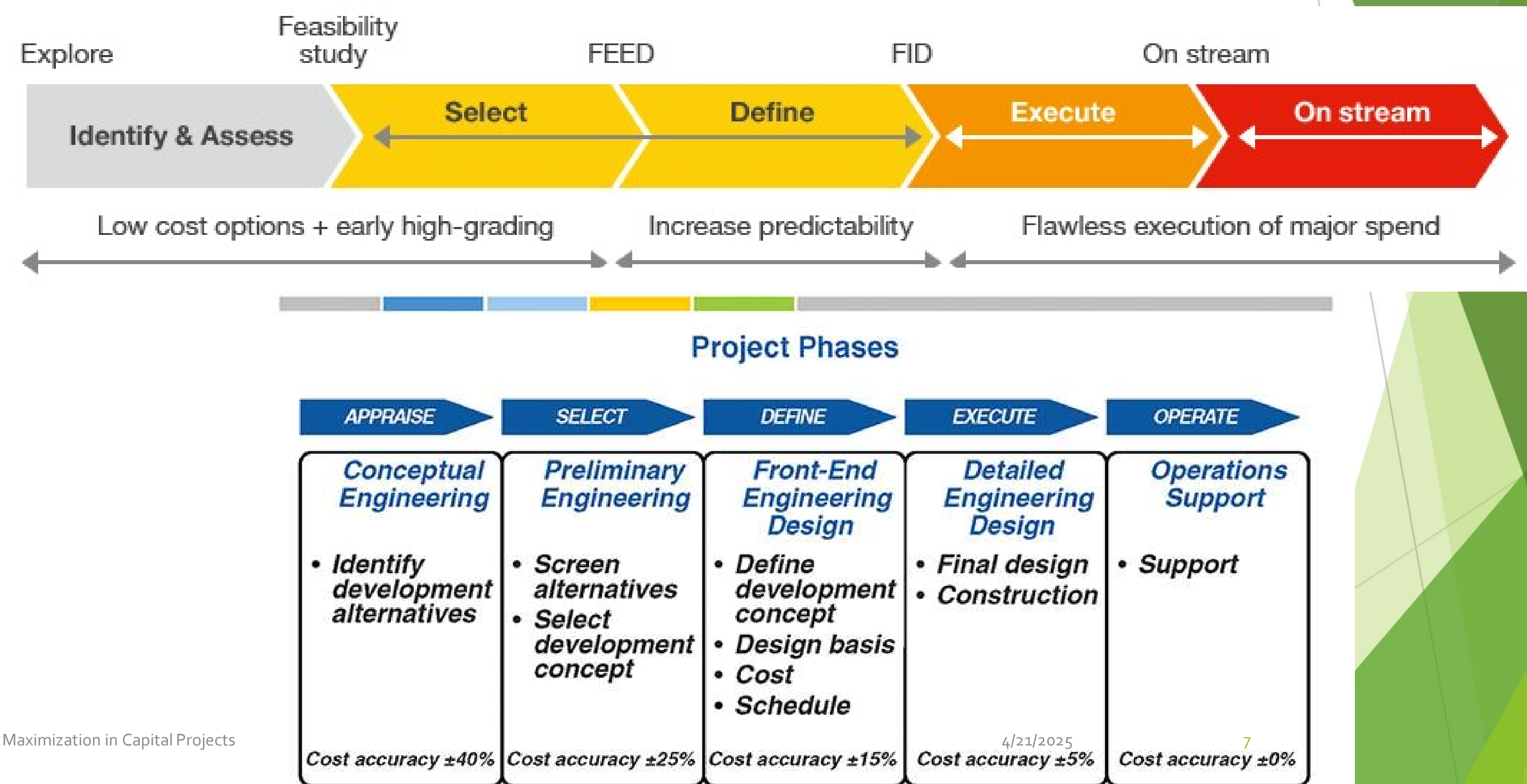


Renewables - Materials cost contribution

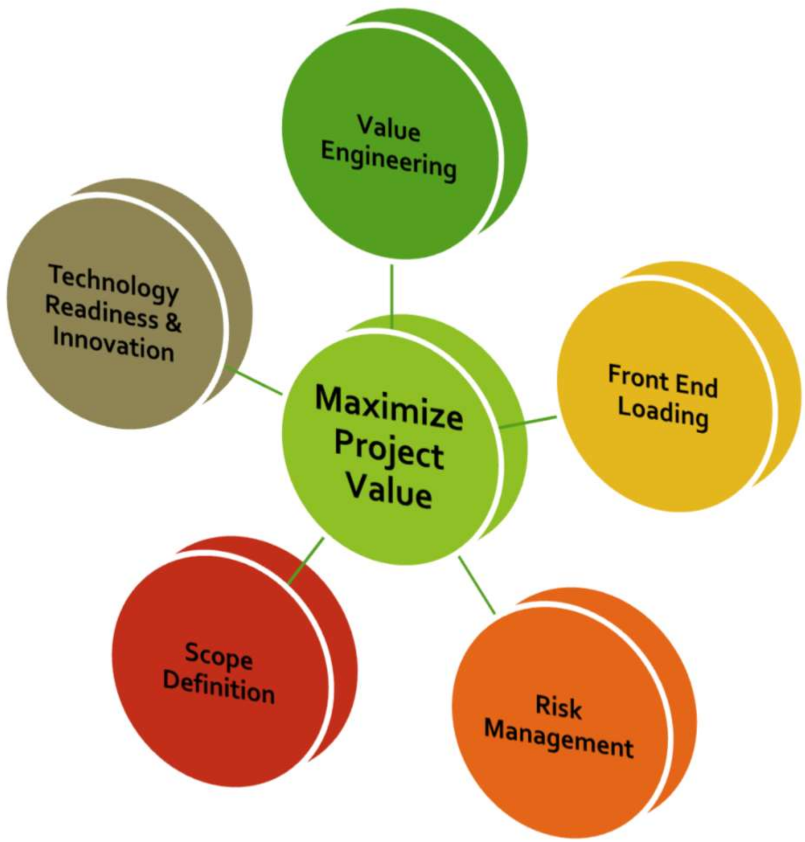




The Project Process



How can we maximize project value?



VALUE ENGINEERING
WHAT, WHY, WHEN - VALUE PROPOSITION

Value engineering is a systematic method to improve the value of a project by optimizing its design, materials, and processes.

Cost Reduction Without Sacrificing Quality & Safety:

Value engineering focuses on identifying and eliminating unnecessary costs while maintaining or improving the quality and functionality of the project.

Function-Oriented Approach:

It emphasizes understanding the essential functions of a project and finding alternative solutions to achieve those functions more efficiently.

Interdisciplinary Collaboration:

The process involves a multidisciplinary team, including engineers, designers, and stakeholders, to generate innovative ideas and solutions.

Continuous Improvement:

Value engineering is not a one-time activity but an ongoing process that can be applied throughout the project lifecycle to enhance value at each stage.

Risk Management:

By exploring different design and process options, value engineering helps identify and mitigate risks early, leading to more resilient and successful project outcomes.

Value Engineering-Benefits

Cost Efficiency - Rising Costs: Budget Adherence:

Innovation and Technology Integration - Rapid Technological Change: Optimized Design

Sustainability and Environmental Impact - Environmental Regulations, Minimized Footprint:

Risk Management - Complexity and Uncertainty, Resilience

Stakeholder Alignment and Satisfaction - Diverse Stakeholder Needs, Enhanced Communication

Lifecycle Cost Optimization - Long-Term Viability, Improved ROI

Adaptability to Future Changes - Scalability and Flexibility, Future-Proofing:

8. Competitive Advantage - Market Differentiation, Faster Time to Market

The Project Stages & Front-End Loading (FEL)

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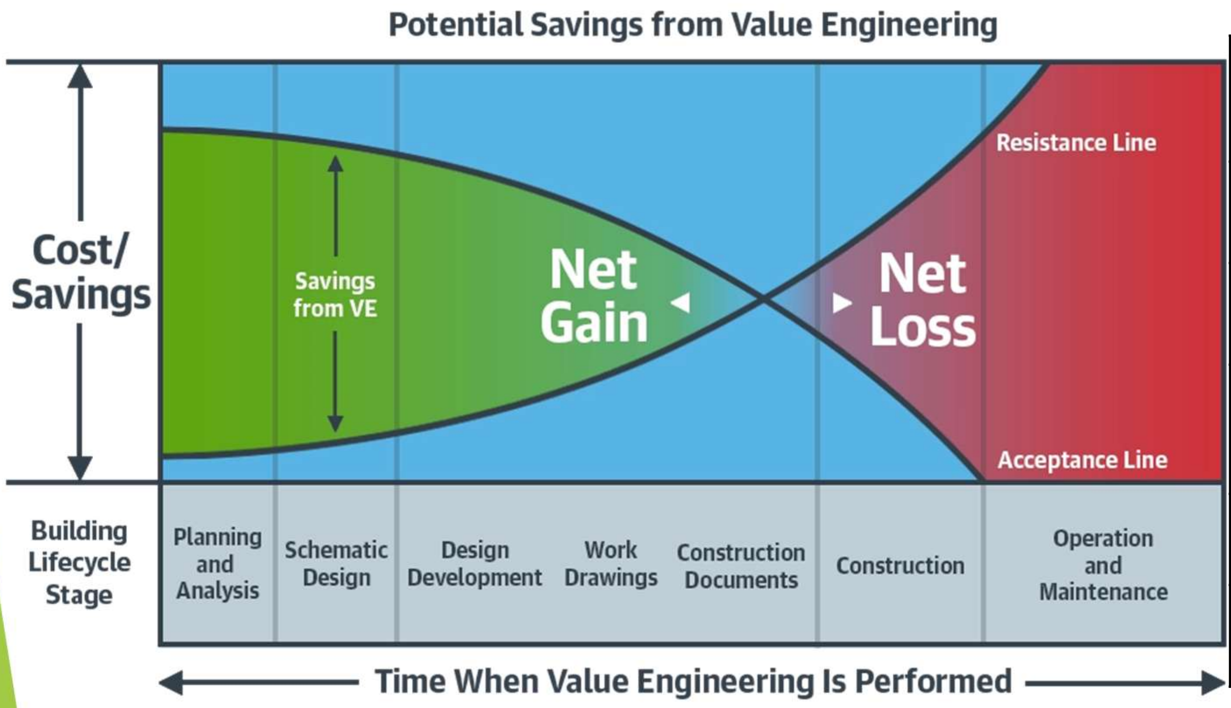
Phase	Scoping / Conceptual Design	Feasibility/ Preliminary Engineering	Definition FEED or Basic Engineering	Engineering, Procurement & Construction	Startup & Operations
	FEL-1	FEL-2	FEL-3		
Client Goals	• Develop concepts • Evaluate alternatives • Quantify risks	• Select best identified project approaches • Quantify economics • Project definition	• Finalize Scope & Execution Plan • Capital appropriation • Contracting	• Maintain budget and schedule • Achieve mechanical completion and handover	• Operation to achieve design performance
Deliverables	• Preliminary design basis • Block Flow Diagrams • Equipment list • Plot plan	• Design basis • PFDs • Material balance • Process data sheets • Preliminary equipment layout	• Update FEL-2 deliverables • P&IDs • Equipment specifications • 3D model	• Engineering • Procurement • Construction, or • Construction Management • Commissioning	• Training/startup assistance • Performance test
Cost Estimate	Class 5 Order-of Magnitude +50% / - 30%	Class 4 Preliminary +30% / -20%	Class 3 Budget +20% / -15%	Class 2 Control +15% / -10%	Class 1 Definitive +10% / - 5%
Feasibility study	Scoping	Feasibility	Bankable		
Test work	Bench-scale testing	Pilot plant testing	Optimization / variability testing		

Value Engineering
Too late is too expensive !



FEL Stage	Value Engineering Impact	Areas
FEL 0	Moderate value	early concept selection and feasibility assessment.
FEL 1	High value	preliminary design optimization and cost-saving identification.
FEL 2	Very high value	comprehensive design optimization, cost reduction, and risk management.
FEL 3	High value	final validation and fine-tuning before FID.
FEL 4	Moderate to low value	execution phase optimization and troubleshooting.

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Role of a materials engineer

(When decisions are taken is as important as what and how they are taken)

	Concept	Select	Define	Execute	Run & Maintain
Project Objectives	❑ Identifying needs and objectives ❑ feasibility analysis ❑ market research concept development ❑ risk assessment ❑ resource planning ❑ stakeholder engagement preliminary project plan ❑ key decisions	❑ Project approval ❑ project charter ❑ project team vendor selection ❑ detailed planning ❑ finalize project approach ❑ risk management ❑ procurement planning	❑ Requirements gathering ❑ scope definition ❑ stakeholder analysis ❑ project objectives ❑ project Management plan ❑ risk identification ❑ constraints and assumptions ❑ Requirements communication plan ❑ baseline definition ❑ approval & sign off	❑ Detailed design ❑ permitting and approvals ❑ supply chain management ❑ mobilization and site construction execution ❑ quality and technical assurance ❑ progress monitoring and reporting ❑ Cost management ❑ safety management ❑ Communication ❑ commissioning and handover ❑ Documentation ❑ look back	
Materials & Metallurgical Engineer	❑ Materials feasibility ❑ Constructability ❑ Fabricability ❑ Cost	❑ Materials related risk ❑ Adequate materials selection ❑ Can it be procured/built?	❑ Finetune risk analysis ❑ Look at costs ❑ Look at tradeoffs ❑ Fit for purpose engineering ❑ Functional analysis ❑ Risk and materials	❑ Quality assurance ❑ Technical assurance ❑ Materials & corrosion selection/control ❑ Design reviews/comments ❑ Inspection plans & implementation ❑ Troubleshooting ❑ Deviations	❑ Materials selection ❑ Risk management ❑ Corrosion control ❑ Failure analysis ❑ Specialized testing ❑ Advisory ❑ Cost management

Most value added

Innovation

Final Investment Decision

Va

Risk-is never Zero
It's managed to be ALARP

- Risk includes – TECOP
  - Tech/Econ/Commercial/Ops /Org/Political/Social reasons
- Materials and metallurgy is the foundation of any design
- What you do in a project has significant ramifications
- Typically, materials decisions account for 25-35% of the project cost

Likelihood ↑ / Impact →	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Risk mitigation using material will include materials substitution, design barriers, coatings, inhibitors, novel inspection and monitoring and sensing…and analytics

Technology Readiness

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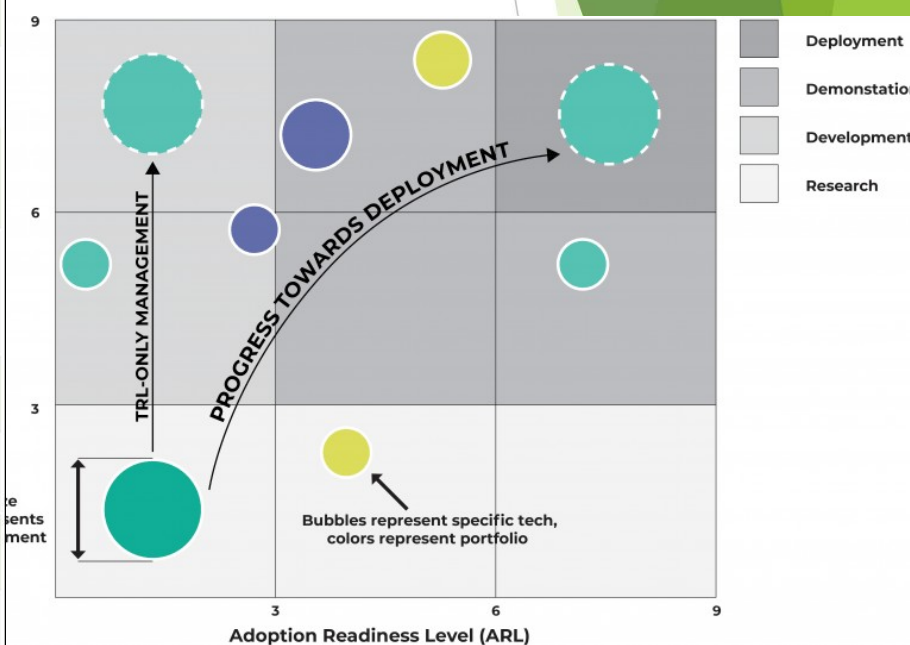
Technology Readiness Level (TRL) is a systematic scale from 1 to 9 used to assess the maturity of a technology, from initial concept (TRL 1) to full commercial deployment (TRL 9).

	Technology Readiness Level Definition
TRL 1	**Basic Research:** Initial scientific research has been conducted. Principles are qualitatively postulated and observed. Focus is on new discovery rather than applications.
TRL 2	**Applied Research:** Initial practical applications are identified. Potential of material or process to solve a problem, satisfy a need, or find application is confirmed.
TRL 3	**Critical Function or Proof of Concept Established:** Applied research advances and early stage development begins. Studies and laboratory measurements validate analytical predictions of separate elements of the technology.
TRL 4	**Lab Testing/Validation of Alpha Prototype Component/Process:** Design, development and lab testing of components/processes. Results provide evidence that performance targets may be attainable based on projected or modeled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated System:** System Component and/or process validation is achieved in a relevant environment.
TRL 6	**Prototype System Verified:** System/process prototype demonstration in an operational environment (beta prototype system level).
TRL 7	**Integrated Pilot System Demonstrated:** System/process prototype demonstration in an operational environment (integrated pilot system level).
TRL 8	**System Incorporated in Commercial Design:** Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration).
TRL 9	**System Proven and Ready for Full Commercial Deployment:** Actual system proven through successful operations in operating environment, and ready for full commercial deployment.



TRL and ARL together ensure technology success

TRL, Value Engineering & Risk Management are aligned

Stage	TRL Role	Value Engineering Role	Risk Management Role
Concept & R&D (TRL 1-3)	Identify & evaluate emerging materials (e.g., perovskites for solar cells).	Evaluate cost vs. performance trade-offs for novel materials.	Identify early-stage risks (e.g., degradation, manufacturability).
Prototyping & Validation (TRL 4-6)	Test material performance under simulated conditions (e.g., corrosion, fatigue, thermal cycles).	Optimize material composition, coatings, and processing techniques.	Conduct failure mode analysis (FMEA) to predict risks.
Pre-Commercialization (TRL 7-8)	Conduct pilot-scale deployment to validate field performance.	Identify supply chain bottlenecks and cost-reduction opportunities.	Implement safety & regulatory compliance measures.
Commercialization & Scaling (TRL 9)	Full-scale deployment of optimized materials.	Ensure cost-efficient procurement & manufacturing.	Implement real-time monitoring & predictive maintenance.

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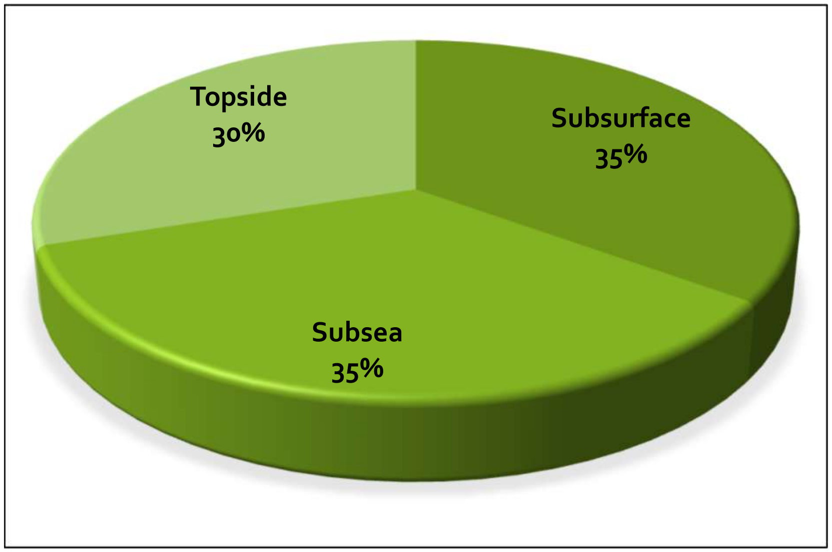

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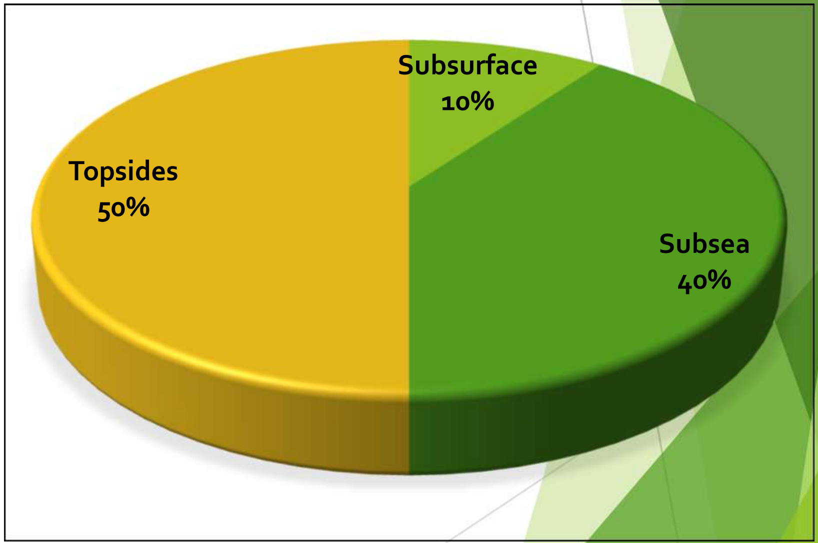

Materials Strategies to Maximize Project Value

Category	Strategy
Maximizing Value	Lifecycle Cost Analysis (NPV)
	FFP Performance-Based Selection
	Multi-Functional Materials
	Supply Chain Optimization
	Sustainability & Circular Economy
Reducing Cost	Material Substitution
	Process Optimization
	Lightweighting
	Design for Manufacturing (DFM)
	Local Sourcing
	Waste Reduction
Maximizing Functionality	Material-Performance Matching
	Advanced Materials Integration
	Chemical, Coatings & Surface Treatments
	Customization & Hybrid Materials
	Design and Structural Optimization
Risk Management	Failure Mode & Effects Analysis (FMEA)
	Redundancy & Safety Factors
	Monitoring, Sensing, Material Testing & Validation
	Supplier & Quality Control
	Environmental & Regulatory Compliance
	Scenario Analysis & Contingency Planning

How does materials engineering connect with Value Creation

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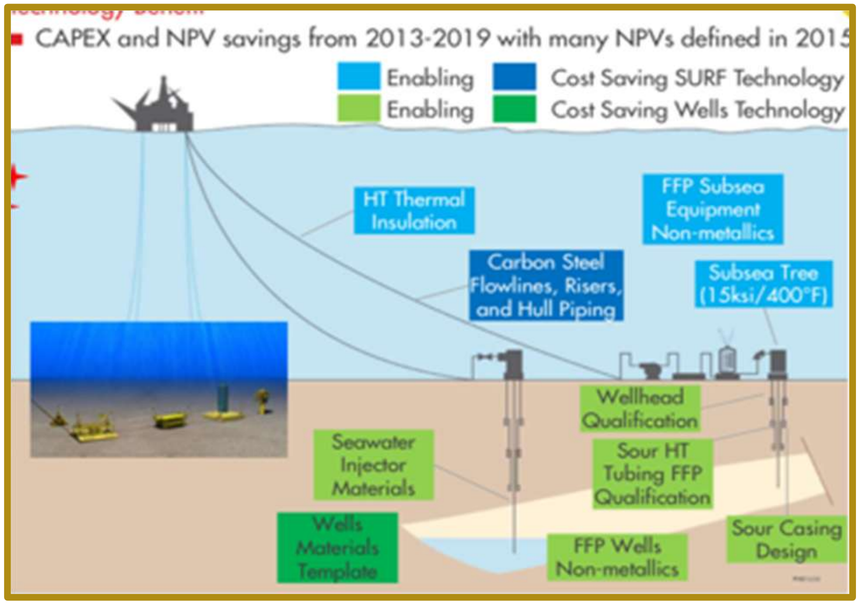
Application	Maximizing Value	Reducing Cost	Maximizing Functionality	Risk Management
Wind Turbines	- Use composite materials (carbon fiber, fiberglass) for blades to enhance efficiency and durability.	- Replace expensive carbon fiber with glass fiber composites where feasible.	- Use advanced coatings for erosion and UV protection.	- Perform fatigue and failure analysis for extreme wind conditions.
	- Use recyclable thermoplastic composites for sustainability.	- Optimize blade aerodynamics to reduce material usage.	- Employ smart sensors for real-time structural health monitoring.	- Develop circular economy strategies for blade disposal.
Offshore & Onshore Oil & Gas Pipelines	- Use high-strength, corrosion-resistant alloys (e.g., duplex stainless steel, Inconel) for critical pipelines.	- Use polyethylene-lined pipes to reduce corrosion-related expenses.	- Apply coatings and cathodic protection to extend pipeline life.	- Conduct real-time corrosion monitoring and inline inspections.
	- Implement smart pigging technology for predictive maintenance.	- Optimize steel grades to balance cost and durability.	- Use composite repair wraps to reinforce aging pipelines.	- Ensure compliance with API 5L, NACE MR0175.
Subsea Oil & Gas Equipment	- Use titanium and super-duplex stainless steel for deep-sea applications.	- Utilize non-metallic flexible risers instead of rigid steel.	- Deploy autonomous robotic inspection for subsea infrastructure.	- Perform stress and fatigue analysis for deep-sea environments.
	- Implement cladding techniques to enhance corrosion resistance.	- Replace some metal parts with high-performance polymers.	- Use high-pressure-resistant elastomers for better performance.	- Use real-time leak detection sensors.
Liquefied Natural Gas (LNG) Storage & Transport	- Use cryogenic materials (9% nickel steel, aluminum, or stainless steel) for LNG tanks.	- Develop new insulation materials (aerogels) to reduce boil-off gas losses.	- Implement vacuum-insulated pipelines to minimize heat transfer.	- Conduct thermal stress analysis to prevent failure in extreme temperatures.
Hydrogen Production (Electrolysis - Green Hydrogen)	- Use proton exchange membrane (PEM) electrolyzers for high efficiency.	- Develop nickel-based catalysts as an alternative to platinum-group metals.	- Use ionomer membranes with improved proton conductivity for better efficiency.	- Test for hydrogen embrittlement resistance in materials.
	- Implement high-performance iridium-platinum catalysts.	- Use low-cost stainless steel instead of titanium for balance-of-plant components.	- Implement ceramic-coated electrodes for durability.	- Ensure compliance with ISO 22734 for electrolyzers.
Hydrogen Storage & Transport	- Use lightweight composite tanks to improve storage efficiency.	- Replace expensive carbon-fiber tanks with aluminum-lined composites.	- Use high-strength steel alloys for pipelines.	- Perform fracture mechanics analysis to prevent hydrogen embrittlement.
	- Implement metal-organic frameworks (MOFs) for better hydrogen adsorption.	- Develop membrane-based hydrogen separation to reduce purification costs.	- Implement solid-state hydrogen storage for enhanced safety.	- Use real-time leak detection systems.

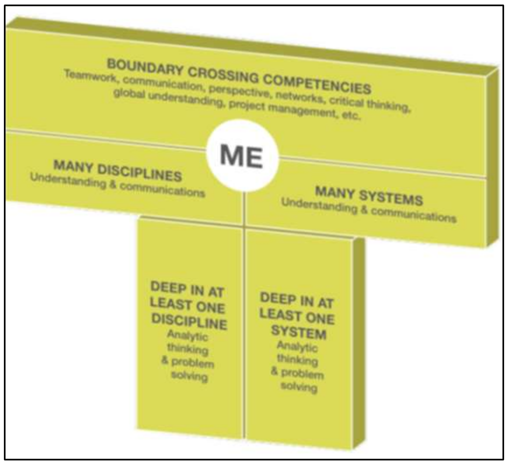
Materials Engineering in Projects-Value Creation

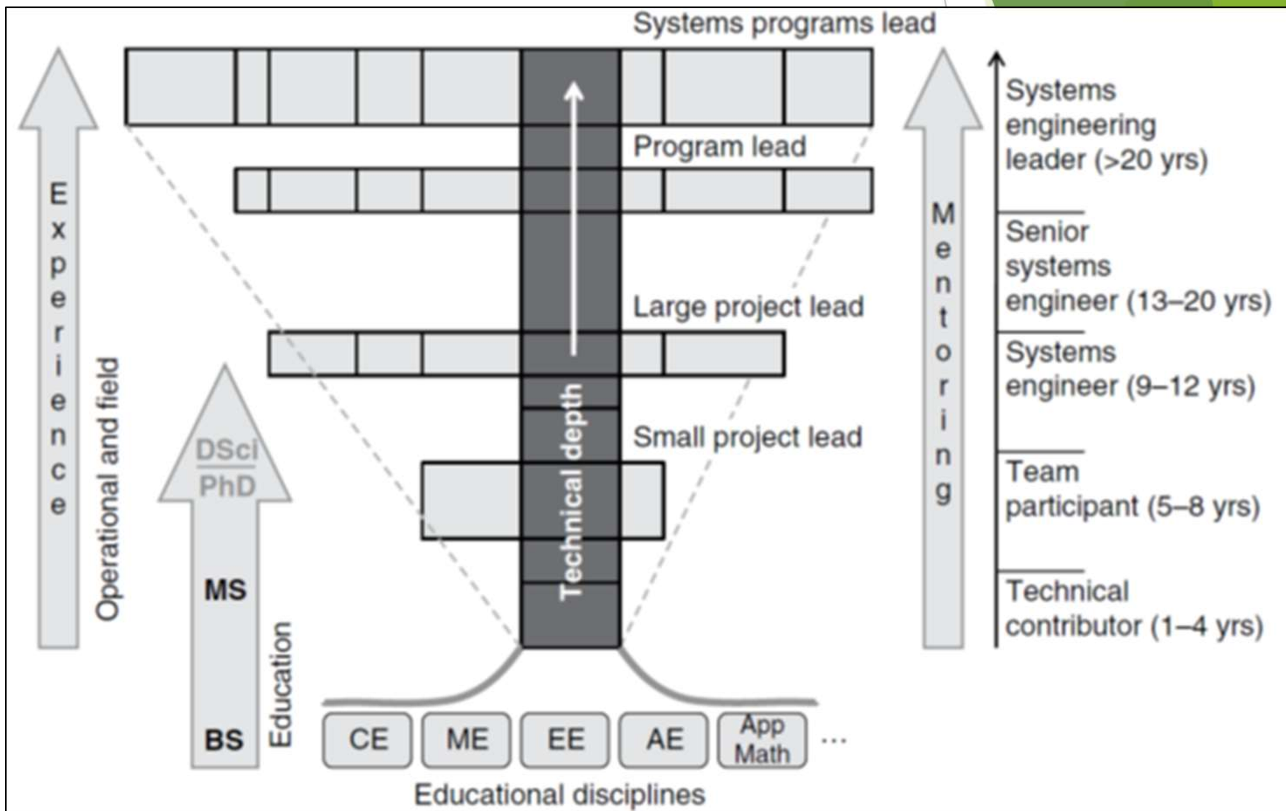


Key Technologies Developed & Deployed

- ❑ Novel, corrosion prediction models – precursor to ML
- ❑ Qualification of large forgings using novel fracture mechanics design and NDE techniques (FFS)
- ❑ Fracture mechanics design for sub-sea equipment
- ❑ High temperature corrosion inhibitors
- ❑ High temperature flexible submerged insulation
- ❑ Elastomers and seals resistant to high temperature and H_2S

T-Engineer Concept





Key Takeaways

- **Understanding Value Maximization in Capital Projects**
  - Importance of optimizing project design, materials, and processes.
  - Effective material selection significantly impacts project costs (25-35%).
- **Challenges in Renewable Energy Projects**
  - Technical, economic, and operational risks (TECOP framework).
  - High capital expenditure (CapEx) and material cost contributions.
- **Role of Materials Engineering in Project Success**
  - Early-stage material decisions drive innovation and cost efficiency.
  - Material substitution, coatings, inhibitors, and advanced sensing technologies for risk mitigation.

- **Value Engineering for Project Optimization**
  - Systematic approach to improving value throughout project stages.
  - Value engineering must be integrated early—delayed decisions increase costs.
- **Technology Readiness & Risk Management**
  - Technology Readiness Level (TRL) ensures structured innovation deployment.
  - Alignment of TRL with value engineering and risk management.
- **Strategic Material Decisions for Maximizing Value**
  - Innovative materials enhance project durability and reduce failure risks.
  - Examples include corrosion prediction models, novel fracture mechanics, and high-temperature resistant materials.
- **Digitalization & Emerging Energy Technologies**

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SINCE 2022

Driving Transformative Change in the Energy Sector
Hydrogen, CCUS, e-Fuels, e-NH3, Renewables

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