Krakatau Steel, Indonesia:
A Southeast Asian Exemplar in the Steel Decarbonization Trilemma

MIFUS Course: LLM-Assisted Journey through
Global Steel Decarbonization Worldwide

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Academic Year 2024-2025
Last Updated: December 2024

Abstract

This lecture note examines Krakatau Steel (PT Krakatau Steel Persero Tbk) as the exemplar case study for Southeast Asia in the global steel decarbonization landscape. As Indonesia's largest integrated steel producer and a state-owned enterprise, Krakatau Steel faces the critical trilemma of achieving greener steel production, maintaining workforce employment, and preserving industrial competitiveness. This study analyzes the current operational framework, environmental challenges, decarbonization pathways, and three-year future perspectives (2025-2028) within the context of Indonesia's developing economy, energy infrastructure constraints, and the ASEAN regional steel market dynamics. The case illuminates unique challenges faced by emerging market steel producers in balancing sustainability commitments with economic development imperatives.

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1 Introduction: Krakatau Steel in the Global Context

1.1 Strategic Importance for the MIFUS Course

Krakatau Steel represents a critical case study in our global steel decarbonization journey for several compelling reasons:

- **Emerging Market Dynamics**: Unlike the mature markets of Europe, Japan, or North America, Indonesia represents a rapidly industrializing economy where steel demand continues to grow, creating different decarbonization pressures and opportunities.
- **State-Owned Enterprise Model**: As a government-owned entity, Krakatau Steel operates under different governance structures and policy imperatives compared to privately-held steel producers in other regions.
- **Energy Infrastructure Constraints**: Indonesia's energy mix, heavily dependent on coal (approximately 65% of electricity generation), creates unique challenges and path dependencies for steel decarbonization.
- **ASEAN Regional Context**: The company operates within the complex ASEAN economic framework, facing competition from Chinese imports while serving growing regional markets.
- **Development vs. Environment Tensions**: The case exemplifies the acute tensions between economic development goals, employment generation, and environmental sustainability in emerging economies.

1.2 Company Overview and Production Capacity

PT Krakatau Steel (Persero) Tbk, established in 1970, is Indonesia's pioneering integrated steel producer, located in Cilegon, Banten Province. As of 2024, the company operates with the following key characteristics:

Table 1: Krakatau Steel Key Production Metrics (2024)

Parameter	**Value/Description**
Crude Steel Capacity	3.0 million tonnes/year
Hot Strip Mill Capacity	2.5 million tonnes/year
Cold Rolling Mill	1.2 million tonnes/year
Wire Rod Mill	480,000 tonnes/year
Primary Technology	Blast Furnace-Basic Oxygen Furnace (BF-BOF)
Employees (Direct)	Approximately 5,800 workers
Employees (Ecosystem)	Estimated 25,000+ indirect jobs
Energy Intensity	21 GJ/tonne crude steel
CO_2 Intensity	2.1-2.3 tonnes CO_2/tonne steel

1.3 Position in Regional and Global Steel Markets

Indonesia's steel consumption has grown significantly, reaching approximately 16-17 million tonnes in 2023, with domestic production meeting only about 40-45% of demand. Krakatau Steel accounts for roughly 20% of Indonesia's crude steel production, making it strategically important but insufficient to meet national needs.

The company competes in a challenging environment:

- Chinese steel imports dominate the Indonesian market (approximately 35-40% of total imports)
- Regional ASEAN producers (Thailand, Vietnam, Malaysia) offer competitive alternatives
- Domestic scrap-based mini-mills provide competition in long products
- Import dependency creates vulnerability to global price fluctuations and trade policies

2 The Trilemma Framework: Analytical Approach

2.1 Defining the Steel Decarbonization Trilemma

The steel decarbonization trilemma represents three interconnected but often conflicting objectives:

1. **Environmental Sustainability (Greener Steel)**
   - Reducing CO_2 emissions per tonne of steel
   - Minimizing air pollutants (SO_x, NO_x, particulates)
   - Achieving circular economy principles (waste reduction, recycling)
   - Meeting national and international climate commitments
2. **Employment and Social Welfare (Occupation)**
   - Maintaining direct employment in steel production
   - Preserving indirect jobs in the value chain
   - Managing just transition for affected workers
   - Developing new skills for green technologies
   - Regional economic development and community welfare
3. **Industrial Competitiveness**
   - Maintaining cost-competitive production
   - Achieving acceptable return on investment
   - Competing against imports and regional producers
   - Accessing capital for modernization and decarbonization
   - Meeting customer quality and delivery requirements

2.2 Why These Three Objectives Create Tensions

The trilemma exists because improvements in one dimension often create challenges in others:

Greener Steel ↔ Competitiveness: Low-carbon technologies (hydrogen DRI, electric arc furnaces with renewable energy, carbon capture) require substantial capital investment and often increase operational costs. Without carbon pricing mechanisms or green steel premiums, these investments erode competitiveness.

Greener Steel ↔ Employment: Automation often accompanies modernization for decarbonization. New technologies may require fewer but more highly skilled workers, creating transition challenges for existing workforce.

Competitiveness ↔ Employment: Cost-cutting measures to maintain competitiveness may pressure employment levels and wages, particularly when competing against lower-cost imports.

2.3 The Indonesian Context Amplifies These Tensions

Several factors make the trilemma particularly acute for Krakatau Steel:

- **Coal-Dependent Energy Grid**: Transitioning to low-carbon steel production is difficult when 65% of electricity comes from coal-fired generation
- **Limited Green Hydrogen Infrastructure**: No established hydrogen production, transportation, or storage infrastructure exists
- **Capital Constraints**: As a state-owned enterprise recovering from financial restructuring, accessing large-scale capital for green transitions is challenging
- **Import Competition**: Chinese steel often enters at prices below sustainable production costs, limiting ability to pass through green premiums
- **National Development Priorities**: Indonesia balances environmental goals with imperatives for job creation and industrial self-sufficiency

3 Current Situation Analysis (2024)

3.1 Production Technology and Environmental Performance

3.1.1 Blast Furnace-BOF Route Characteristics

Krakatau Steel operates the traditional integrated steelmaking route:

1. **Raw Material Preparation**
   - Iron ore sourcing: Primarily imported from Australia, Brazil, and increasingly from domestic sources
   - Coking coal: Imported from Australia and other sources
   - Limestone and other fluxes: Domestically sourced
   - Scrap integration: Limited use in BOF (typically 10-15%)

2. **Ironmaking (Blast Furnace)**
    - Two blast furnaces with combined capacity
    - Coke consumption: 450-480 kg/tonne hot metal
    - Pulverized coal injection (PCI): 120-140 kg/tonne hot metal
    - Energy efficiency: Moderate by global standards, improvement opportunities exist
3. **Steelmaking (Basic Oxygen Furnace)**
    - BOF process with continuous casting
    - Product mix: Flat products (hot rolled coils, cold rolled, coated products) and long products (wire rod)

3.1.2 Current Environmental Footprint

Table 2: Krakatau Steel Environmental Performance Indicators (2024 Estimates)

Indicator	Current Value	Industry Benchmark
CO_2 Intensity	2.1-2.3 t CO_2/t steel	EU: 1.85; China: 2.0; Global avg: 1.9
Energy Intensity	21 GJ/t steel	Best practice: 18-19 GJ/t
Coke Rate	450-480 kg/t HM	Best practice: 300-350 kg/t HM
Water Consumption	4-5 m^3/t steel	Best practice: 2-3 m^3/t
Solid Waste	400-450 kg/t steel	Typical for BF-BOF route

The data indicates that Krakatau Steel's environmental performance is within typical ranges for BF-BOF operations but lags best-practice facilities, suggesting significant room for improvement through efficiency measures before considering fundamental technology shifts.

3.2 Economic and Competitive Position

3.2.1 Financial Performance and Challenges

Krakatau Steel has faced significant financial challenges in recent years:

- **2020-2021 Restructuring**: The company underwent major financial restructuring with government support following years of losses
- **Debt Burden**: High debt levels have constrained operational flexibility and investment capacity
- **Utilization Rates**: Operating below optimal capacity utilization (typically 60-75%) due to market competition and maintenance requirements
- **Cost Structure**: Higher production costs compared to regional competitors, partly due to:
    - Imported raw materials (iron ore, coking coal)

  - Aging equipment requiring higher maintenance
  - Lower economies of scale compared to larger Asian producers
  - Energy costs in Indonesia's grid system

3.2.2 Competitive Pressures

Import Competition: Chinese steel products, often subsidized or dumped, create severe price pressure. Indonesia has imposed anti-dumping duties on some products, but enforcement challenges persist.

Regional ASEAN Competition: Thailand's integrated producers and Vietnam's growing steel sector offer alternatives for regional buyers.

Scrap-Based Domestic Competition: Indonesian mini-mills using electric arc furnaces and scrap can produce long products at lower costs, though quality differences exist.

Customer Requirements: Automotive, construction, and manufacturing customers increasingly demand:

- Consistent quality and technical specifications
- Supply chain reliability
- Sustainability credentials (particularly for export-oriented manufacturers)
- Competitive pricing aligned with import alternatives

3.3 Employment and Social Dimensions

3.3.1 Direct Employment Structure

Krakatau Steel's workforce of approximately 5,800 direct employees represents a significant social asset:

Table 3: Estimated Workforce Distribution by Function

Function	**Approximate % of Workforce**
Production Operations	45%
Maintenance and Engineering	25%
Quality Control and R&D	8%
Logistics and Supply Chain	10%
Administration and Management	12%

3.3.2 Skill Profile and Training Needs

The current workforce is predominantly trained in conventional steelmaking:

- Strong experience in BF-BOF operations
- Limited exposure to emerging green technologies (hydrogen reduction, electrolysis, CCUS)

- Aging workforce demographics in some departments
- Growing need for digital skills as Industry 4.0 technologies are introduced

3.3.3 Indirect Employment and Regional Impact

The broader employment ecosystem includes:

- **Supply Chain**: Raw material handling, logistics providers, maintenance contractors
- **Downstream Users**: Fabricators, service centers, construction companies in the region
- **Community Services**: Schools, hospitals, retail serving the Cilegon industrial zone
- **Estimated Total**: 25,000-30,000 jobs depend directly or indirectly on Krakatau Steel operations

3.3.4 Social Welfare and Community Relations

As a state-owned enterprise, Krakatau Steel maintains significant social welfare commitments:

- Company housing and facilities for workers
- Educational institutions supported by the company
- Healthcare facilities for employees and families
- Community development programs in Cilegon and surrounding areas
- These commitments create social value but also represent fixed costs that must be maintained even during financial difficulties

4 Decarbonization Pathways and Technology Options

4.1 Short-Term Efficiency Improvements (2025-2027)

4.1.1 Blast Furnace Optimization

Without major capital expenditure, several efficiency measures can reduce emissions:

- **Increased Pulverized Coal Injection (PCI)**: Raising PCI rates from current 120-140 kg/tHM to 180-200 kg/tHM can reduce coke consumption and associated emissions by 8-10%
- **Oxygen Enrichment**: Enhancing oxygen injection can improve combustion efficiency and reduce fuel requirements
- **Blast Furnace Gas Recovery**: Better utilization of top gas for power generation through improved combined cycle systems

- **Potential CO_2 Reduction**: 5-8% through operational optimization
- **Investment Required**: $50-80 million
- **Payback Period**: 3-5 years through energy savings

4.1.2 Energy Management Systems

- Digital monitoring and control systems for energy flows
- Waste heat recovery enhancement (currently underutilized)
- Process integration for steam and electricity generation
- **Potential CO_2 Reduction**: 3-5%
- **Investment Required**: $20-40 million

4.1.3 Scrap Utilization Increase

- Upgrading BOF operations to handle 20-25% scrap charge (from current 10-15%)
- Developing domestic scrap collection and processing infrastructure
- Each 10% increase in scrap use reduces emissions by approximately 5-6%
- **Challenge**: Indonesia's scrap collection infrastructure is underdeveloped
- **Potential CO_2 Reduction**: 5-7%
- **Investment Required**: $30-50 million

Combined Short-Term Potential: 13-20% CO_2 reduction, bringing intensity to 1.7-1.9 tonnes CO_2/tonne steel by 2027-2028.

4.2 Medium-Term Transitional Technologies (2026-2030)

4.2.1 Natural Gas-Based Direct Reduced Iron (DRI)

Indonesia has significant natural gas reserves, making gas-based DRI a potential bridge technology:

- **Technology**: Midrex or HYL processes using natural gas as reductant
- **Emissions**: 50-60% lower than BF-BOF route (1.0-1.2 t CO_2/t steel)
- **Requirements**:
  - Reliable natural gas supply and pricing
  - EAF capacity for melting DRI
  - Investment: $500-700 million for 1.5 Mt/year DRI-EAF plant
- **Challenges**:
  - Indonesia prioritizes gas for power generation and LNG exports
  - Gas infrastructure to industrial zones needs development
  - Natural gas price volatility affects economics

4.2.2 Carbon Capture Utilization and Storage (CCUS)

- **Applicability**: Capturing CO_2 from blast furnace gas and BOF off-gas
- **Capture Potential**: 40-70% of total emissions, depending on technology
- **Indonesia Context**:
  - Geological storage potential exists in depleted oil/gas fields
  - CO_2-EOR (Enhanced Oil Recovery) could provide revenue offset
  - Limited existing CCUS infrastructure
- **Economics**:
  - Capture cost: $60-100 per tonne CO_2
  - Additional energy requirement: 10-20% increase
  - Total investment for Krakatau Steel scale: $400-600 million
- **Policy Requirement**: Carbon pricing or subsidies essential for viability

4.3 Long-Term Breakthrough Technologies (2030+)

4.3.1 Green Hydrogen-Based Direct Reduction

The ultimate low-carbon pathway for primary steelmaking:

- **Technology**: H2-DRI coupled with EAF (H2-DRI-EAF route)
- **Emissions**: Near-zero if using green hydrogen and renewable electricity (0.1-0.3 t CO_2/t steel)
- **Requirements**:
  - Green hydrogen production: 50-60 kg H_2 per tonne steel
  - Renewable electricity: 3.5 MWh per tonne steel (including hydrogen production)
  - For 3 Mt/year capacity: 160,000 tonnes H_2/year, requiring 5-6 GW electrolyzer capacity
- **Indonesia Context**:
  - **Renewable Potential**: Significant hydropower, geothermal, and solar resources
  - **Current Reality**: Limited renewable deployment in industrial regions
  - **Infrastructure Gap**: No hydrogen production, transport, or storage infrastructure
- **Economics**:
  - Current green hydrogen cost: $5-7/kg (Indonesia estimate)
  - Required for viability: <$2/kg
  - Total steel production cost increase: $200-300/tonne vs. conventional
  - Investment for full conversion: $2.5-3.5 billion

4.3.2 Electrolysis-Based Steelmaking

Emerging technologies like Boston Metal's molten oxide electrolysis:

- **Status**: Pilot/demonstration scale
- **Advantages**: Direct iron production from ore using electricity, zero carbon emissions with renewable power
- **Timeline**: Unlikely to be commercially viable before 2035-2040
- **Indonesia Relevance**: Long-term option pending technology maturation

5 Three-Year Outlook (2025-2028): Scenarios and Projections

5.1 Baseline Scenario: Incremental Improvement

Assumptions:

- Limited capital availability focuses on operational optimization
- No major policy interventions (carbon pricing, green steel mandates)
- Continued import competition constrains pricing power
- Gradual recovery of capacity utilization to 75-80%

Greener Steel Dimension:

- CO_2 intensity reduction: 8-12% (to 1.9-2.0 t CO_2/t steel)
- Implementation of PCI enhancement and energy management systems
- Limited CCUS pilot projects (if government support materializes)
- No fundamental technology shift

Employment Dimension:

- Workforce maintained at 5,500-6,000 (slight reduction through attrition)
- Moderate upskilling programs for digital technologies
- Continued social welfare commitments
- Regional employment ecosystem remains stable

Competitiveness Dimension:

- Cost reductions from efficiency improvements: 3-5%
- Market share maintained at 18-20% of domestic production
- Continued dependence on government support and trade protection

- Operating margins remain thin (3-5% EBITDA)
- Limited ability to invest in major modernization

Trilemma Assessment: This scenario maintains uncomfortable equilibrium but fails to position the company for long-term sustainability. Environmental progress is insufficient for 2050 net-zero commitments, competitiveness remains fragile, and employment is preserved but at risk if financial performance deteriorates.

5.2 Accelerated Transition Scenario: Strategic Restructuring

Assumptions:

- Government commits to substantial capital injection and policy support
- Indonesia implements carbon pricing or green steel incentives
- Strategic partnership with technology provider or foreign steel company
- ASEAN-level coordination on steel decarbonization creates regional market for green steel

Greener Steel Dimension:

- Commitment to 1.5 Mt/year gas-based DRI-EAF facility by 2027-2028
- CO_2 intensity reduction: 25-30% by 2028 (to 1.5-1.6 t CO_2/t steel)
- Pilot CCUS on remaining BF capacity
- Roadmap established for green hydrogen transition post-2030
- Increased scrap utilization in both BOF and new EAF

Employment Dimension:

- Short-term: Temporary construction employment surge (2,000-3,000 jobs)
- Medium-term: Net workforce reduction to 5,000 due to higher EAF efficiency
- Intensive retraining program: 1,500-2,000 workers transition to new technologies
- 500-700 workers face job displacement requiring social support
- New high-skill jobs in hydrogen/DRI operations: 300-400 positions
- Investment in local supplier ecosystem creates offsetting indirect employment

Competitiveness Dimension:

- Initial cost increase: $50-80/tonne due to capital costs
- Green steel premium capture: $30-50/tonne from export customers and domestic automotive/appliance sectors
- Improved energy efficiency reduces operating costs by 8-12%

- Access to green finance and concessional loans
- Strengthened market position with premium customers
- Potential for carbon border adjustment mechanism (CBAM) advantage in EU exports

Trilemma Assessment: This scenario makes real progress on decarbonization and positions the company for long-term competitiveness, but creates significant just transition challenges. Success requires:

1. Substantial government financial support ($800M-1.2B)
2. Active labor transition programs
3. Customer willingness to pay green premium
4. Regional policy coordination to prevent carbon leakage

5.3 Disruptive Scenario: Market Shock and Restructuring

Trigger Events (any combination):

- Severe tightening of Indonesian environmental regulations with short timelines
- Major Chinese overcapacity dump into ASEAN markets
- EU CBAM implementation without exemptions severely impacts exports
- Inability to service debt leads to bankruptcy and forced restructuring
- Climate-related physical risks (coastal flooding in Cilegon) require facility relocation

Greener Steel Dimension:

- Forced closure of highest-emission assets (older blast furnace)
- Capacity reduction to 1.5-2.0 Mt/year
- Rapid shift to scrap-EAF route for remaining capacity
- CO_2 intensity drops sharply (40-50%) but total production declines

Employment Dimension:

- Severe workforce reduction: 2,500-3,500 job losses (40-60% of workforce)
- Regional economic crisis in Cilegon industrial zone
- Indirect employment impacts: 10,000-15,000 jobs affected
- Potential social unrest and political backlash
- Government forced to provide extensive unemployment support and retraining

Competitiveness Dimension:

- Potential privatization or sale to regional/global steel company
- Shift to niche high-value products rather than commodity steel
- Increased import dependency for Indonesian market
- Loss of strategic industrial capability for Indonesia

Trilemma Assessment: This scenario achieves environmental objectives but at catastrophic employment and social cost. It represents the failure case of the trilemma, demonstrating why proactive management is essential. While not the most likely scenario, elements of this risk exist and underscore the urgency of strategic planning.

6 Policy Framework and Recommendations

6.1 Current Indonesian Policy Landscape

6.1.1 National Climate Commitments

- **Updated NDC (2022)**: Indonesia commits to 31.89% emission reduction by 2030 (BAU), or 43.2% with international support
- **Net Zero Target**: 2060 or sooner with international support (announced at COP26)
- **Industrial Sector**: Relatively limited specific targets compared to energy and forestry sectors
- **Implementation Gap**: Significant gap between commitments and concrete policies/funding

6.1.2 Steel Sector Policies

- **National Steel Policy**: Focus on self-sufficiency and import substitution
- **Trade Protection**: Anti-dumping duties on specific products, import licensing
- **Local Content Requirements**: Mandates for infrastructure projects
- **Energy Subsidies**: Selective electricity subsidies for industry (being gradually reduced)
- **Green Industry**: Limited specific support for steel decarbonization (as of 2024)

6.1.3 Energy and Hydrogen Strategy

- **Renewable Energy Target**: 23% by 2025 (currently behind target)
- **Coal Phase-Out**: Gradual, no firm timeline for industrial applications
- **Hydrogen Roadmap**: Under development, focus initially on export markets (ammonia/hydrogen to Japan/S. Korea)
- **Gas Development**: PLN and Pertamina expanding gas infrastructure, but prioritizing power sector

6.2 Policy Recommendations for Indonesia

6.2.1 Carbon Pricing and Financial Mechanisms

Recommendation 1: Phased Carbon Pricing for Industry

- Implement carbon pricing starting at $5-10/tonne CO_2 (2025), rising to $30-40/tonne by 2030
- Revenue recycling: Use carbon revenues to fund decarbonization investments and just transition programs
- Border Carbon Adjustment: Coordinate with ASEAN partners to implement CBAM-equivalent for imports
- Free allocation for trade-exposed sectors initially, phasing out gradually

Recommendation 2: Green Steel Investment Fund

- Establish $2-3 billion fund for steel decarbonization over 10 years
- Combine government resources, multilateral development bank support, and climate finance
- Provide low-interest loans (2-3%) for verified decarbonization projects
- Grant support for pilot projects and R&D

Recommendation 3: Green Steel Procurement Mandates

- Government infrastructure projects must use steel meeting emissions intensity thresholds
- Phased implementation: 25% green steel by 2027, 50% by 2030, 100% by 2035
- Price premium support: Government absorbs differential cost during transition period
- Certification system: Establish Indonesian green steel standards aligned with international frameworks

6.2.2 Technology and Infrastructure Development

Recommendation 4: Hydrogen Infrastructure Roadmap

- Prioritize industrial clusters (Cilegon, Gresik) for hydrogen infrastructure development
- Target 200-300 MW electrolyzer capacity in Cilegon by 2028 (pilot scale for steel)
- Leverage renewable energy potential:
  - Offshore wind in Java Sea
  - Expanded geothermal in West Java
  - Large-scale solar farms with dedicated industrial connection

- Public-private partnership model with SOEs (PLN, Pertamina, Krakatau Steel)
- Investment required: $500-700 million for initial infrastructure

Recommendation 5: Scrap Metal Ecosystem Development

- Formalize and modernize scrap collection networks
- Tax incentives for scrap processing and upgrading facilities
- Quality standards for scrap metal categories
- Digital tracking system to prevent illegal exports and ensure domestic availability
- Target: Double domestic scrap availability to 4-5 Mt/year by 2030

Recommendation 6: CCUS Infrastructure Investment

- Map geological storage potential near industrial zones
- Pilot project: 500,000 tonnes CO_2/year capture at Krakatau Steel by 2028
- CO_2 pipeline infrastructure connecting Cilegon to offshore storage sites
- Partnership with oil & gas sector for EOR opportunities
- Investment: $300-400 million for pilot phase

6.2.3 Just Transition and Employment

Recommendation 7: National Steel Workforce Transition Program

- Establish dedicated training centers for green steel technologies
- Partnerships with universities and technical institutes:
  - Institut Teknologi Bandung (ITB)
  - Universitas Indonesia
  - Polytechnic institutes in Banten Province
- Curriculum development:
  - Hydrogen safety and handling
  - DRI-EAF operations
  - CCUS systems
  - Digital technologies and automation
  - Energy management systems
- Financial support:
  - Full salary maintenance during retraining (12-18 months)
  - Relocation assistance for workers moving to new facilities
  - Early retirement packages for workers unable to transition

- Budget: $50-80 million over 5 years

Recommendation 8: Regional Economic Diversification

- Cilegon industrial zone diversification strategy
- Attract downstream steel-using industries (automotive components, machinery)
- Green technology manufacturing (electrolyzer components, wind turbine parts)
- SME development programs for local suppliers
- Infrastructure improvements (port facilities, logistics parks)

6.2.4 Trade and Market Mechanisms

Recommendation 9: ASEAN Green Steel Alliance

- Regional cooperation framework for steel decarbonization
- Harmonized green steel standards and certification
- Joint R&D programs and technology sharing
- Coordinated border carbon adjustments to prevent leakage
- Green steel market creation within ASEAN (preferential treatment in public procurement)

Recommendation 10: Strategic Trade Policy Reform

- Shift from blanket protection to performance-based support
- Link trade protection to verified decarbonization progress
- Maintain anti-dumping enforcement but add carbon intensity criteria
- Differentiated tariffs: Higher tariffs on high-carbon imports, lower on green steel
- Export promotion for Indonesian green steel to premium markets

6.3 Company-Level Strategic Recommendations for Krakatau Steel

6.3.1 Immediate Actions (2025-2026)

1. Comprehensive Energy and Emissions Audit

- Engage international consultants (McKinsey, BCG, specialized steel consultants)
- Detailed assessment of all emission sources and reduction opportunities
- Benchmarking against global best practices
- Development of 2030 and 2040 decarbonization roadmaps
- Cost: $2-3 million; Timeline: 6-9 months

2. Quick-Win Efficiency Projects

- Pulverized coal injection enhancement: Target 180-200 kg/tHM
- Energy management system implementation
- Waste heat recovery upgrades
- Process control optimization using AI/ML
- Total investment: $60-90 million
- Expected CO_2 reduction: 10-15%
- IRR: 15-20% (based on energy savings)

3. Scrap Integration Expansion

- Upgrade BOF to handle 20-25% scrap charge
- Develop scrap procurement network and quality control
- Investment: $30-40 million
- CO_2 reduction: 5-7%

4. Strategic Partnership Development

- Explore partnerships with:
  - Japanese steel companies (JFE, Nippon Steel) for technology transfer
  - European companies (ArcelorMittal, SSAB) for decarbonization expertise
  - Korean companies (POSCO) for regional market integration
- Joint venture possibilities for new DRI-EAF capacity
- Technology licensing agreements
- Access to green steel markets and customers

5. Workforce Engagement and Planning

- Transparent communication about decarbonization plans
- Joint labor-management transition committee
- Skills assessment and training needs analysis
- Early voluntary retirement program for older workers
- Internal mobility opportunities identification

6.3.2 Medium-Term Transformation (2026-2028)

6. DRI-EAF Capacity Development

- Decision point: Natural gas-based DRI or wait for hydrogen
- Recommended approach: Gas-based DRI with hydrogen-ready design
- Capacity: 1.5 Mt/year DRI-EAF module
- Timeline: FID 2025, commissioning 2027-2028
- Investment: $600-800 million
- Financing structure:
  - Government equity: 40% ($240-320M)
  - Green bonds/concessional loans: 40% ($240-320M)
  - Strategic partner equity: 20% ($120-160M)

7. CCUS Pilot Implementation

- Blast furnace gas capture: 300,000-500,000 t CO_2/year
- Partnership with oil & gas companies for storage/EOR
- Government support essential (capital grant + carbon credit purchase)
- Investment: $150-200 million (pilot scale)
- Timeline: FID 2026, operation 2028

8. Product Portfolio Optimization

- Focus on higher value-added products:
  - Automotive-grade steel
  - High-strength construction steel
  - Coated and pre-painted products
- Develop green steel branding and certification
- Target premium customers willing to pay for sustainability
- Export market development (certified green steel to EU, Japan)

9. Digital Transformation

- Implementation of Industry 4.0 technologies:
  - IoT sensors throughout production chain
  - AI-powered predictive maintenance
  - Digital twin for process optimization
  - Real-time energy and emissions monitoring

  - Supply chain visibility and optimization
- Investment: $40-60 million over 3 years
- Benefits: 3-5% efficiency gain, reduced downtime, better quality control

10. Customer Engagement on Green Steel

- Direct engagement with major customers:
  - Automotive manufacturers (Toyota Astra, Honda Indonesia, etc.)
  - Appliance manufacturers
  - Construction and infrastructure developers
- Long-term offtake agreements for green steel at premium prices
- Joint development of product specifications
- Supply chain transparency initiatives

7 Comparative Regional Analysis

7.1 Learning from Other Emerging Market Steel Producers

7.1.1 India: Tata Steel and JSW Steel

Key Lessons:

- **Scale Advantages**: Larger integrated producers (Tata Steel Jamshedpur 10+ Mt/year) achieve better economies of scale for decarbonization investments
- **Hydrogen Strategy**: Tata Steel piloting hydrogen injection in blast furnaces, targeting 10% hydrogen in reducing gas by 2025
- **Scrap-EAF Growth**: JSW Steel expanding EAF capacity rapidly, targeting 50% EAF in product mix by 2030
- **Renewable Energy**: Both companies investing heavily in captive renewable power (solar, wind) to reduce costs and emissions
- **Government Support**: Production-Linked Incentive (PLI) schemes supporting specialty steel and green steel development

Relevance to Krakatau Steel:

- Scale disadvantage suggests focus on niche/premium products rather than competing on volume
- Hydrogen injection pilots could be tested at lower cost before full DRI-EAF investment
- Captive renewable energy should be part of strategy (Indonesia has good solar potential in Java)

7.1.2 Vietnam: Hoa Phat Group

Key Characteristics:

- Rapid growth: 0 to 8+ Mt/year crude steel capacity in 15 years
- Fully integrated BF-BOF operation at Dung Quat (started 2019)
- Lower cost structure due to newer, more efficient equipment
- Aggressive domestic market capture (50%+ of Vietnamese market)
- Limited focus on decarbonization to date (priority on growth and market share)

Competitive Threat to Krakatau Steel:

- Hoa Phat's cost advantage creates pricing pressure in ASEAN markets
- Modern equipment means lower baseline emissions even without green technology
- If Vietnam implements decarbonization policies later, newer assets face less stranding risk

Strategic Implications:

- Krakatau Steel cannot compete on cost with newer, larger facilities
- Must differentiate through green credentials and product quality
- Regional coordination on environmental standards essential to level playing field

7.1.3 Thailand: G Steel and Sahaviriya Steel Industries

Key Characteristics:

- Mix of integrated and EAF production
- Financial difficulties and restructuring (similar to Krakatau Steel experience)
- Moderate progress on efficiency but limited breakthrough investments
- Strong position in ASEAN long products market

Relevance:

- Similar challenges with aging assets and capital constraints
- Demonstrates difficulty of financing major transitions without government support
- EAF expansion path (using scrap and DRI) proving successful for some Thai producers

7.2 Lessons from Developed Market Transitions

7.2.1 European Experience: H2 Green Steel (Sweden)

Model:

- Greenfield hydrogen-based DRI-EAF plant (5 Mt/year planned)
- Fully integrated with renewable energy (hydropower, wind)
- Premium pricing model targeting automotive and engineering customers
- Strong government support and green financing access

Key Insights:

- **Greenfield Advantage**: Starting fresh avoids brownfield constraints and stranded asset risks
- **Customer Pre-commitment**: Secured offtake agreements with Mercedes-Benz, BMW, Volvo before construction
- **Premium Pricing**: Targets $100-150/tonne premium for near-zero-carbon steel
- **Policy Support**: Benefits from EU carbon pricing, green finance taxonomies, and potential CBAM advantages

Applicability to Krakatau Steel:

- Limited direct applicability due to Indonesia's different energy context
- Customer pre-commitment model is relevant and should be pursued
- Demonstrates that premium market exists for truly green steel
- Highlights need for supportive policy framework

7.2.2 Japan and South Korea: Incumbent Strategies

Nippon Steel and POSCO Approaches:

- **Phase 1 (current)**: Blast furnace optimization, increased scrap use, CCUS pilots
- **Phase 2 (2030s)**: Hydrogen injection in blast furnaces (up to 30% hydrogen in reducing gas)
- **Phase 3 (2040s)**: Full hydrogen-based DRI-EAF for some capacity
- **Parallel track**: Maintaining some BF-BOF capacity with CCUS for specific product grades

Key Features:

- Multi-decadal transition roadmaps with clear phase gates
- Massive R&D investments ($1-2 billion each)

- Government-industry partnerships (NEDO in Japan, POSCO with Korean government)
- Gradual approach maintains competitiveness during transition
- Recognition that some products (ultra-high-strength steel for automotive) may require blast furnace route even with CCUS

Relevance to Krakatau Steel:

- Phased approach most realistic given capital constraints
- Cannot match R&D spending, but can benefit from technology transfer
- Need to identify which products truly require integrated route vs. EAF-suitable products
- CCUS + hydrogen injection could be bridge strategy for Indonesia

8 Economic Analysis: Costs and Financing

8.1 Decarbonization Cost Estimates

Table 4: Cost Comparison of Decarbonization Pathways for Krakatau Steel

Pathway	**CAPEX ($M)**	**OPEX Change**	**CO_2 Int. (t/t steel)**	**Cost/t ($/t)**
Current BF-BOF	Baseline	Baseline	2.1-2.3	550-600
Optimized BF-BOF	60-90	-3 to -5%	1.8-1.9	530-570
BF-BOF + CCUS	400-600	+8 to +12%	0.8-1.2	650-750
Gas DRI-EAF	600-800	+5 to +8%	1.0-1.2	620-700
H_2 DRI-EAF	1,200-1,500	+25 to +35%	0.1-0.3	800-950
Scrap EAF	300-400	-10 to -15%	0.4-0.6	500-550

Note: Costs assume Indonesian context including energy prices, financing costs, and construction costs. H_2 DRI-EAF assumes green hydrogen at $3-4/kg (future projection).

8.2 Financing Structure Analysis

8.2.1 Traditional Financing Challenges

Krakatau Steel faces significant barriers to conventional project financing:

- **Balance Sheet Constraints**: Recent restructuring limits debt capacity
- **Return on Investment**: Green steel projects show 8-12% IRR vs. 15%+ required by commercial lenders
- **Technology Risk**: New technologies (especially hydrogen-based) carry execution and performance risks
- **Market Risk**: Uncertainty about green steel premium realization
- **Currency Risk**: $-denominated equipment vs. Rupiah revenues

8.2.2 Blended Finance Approach

Recommended Financing Structure for 1.5 Mt Gas DRI-EAF Project ($700M total):

Table 5: Proposed Financing Structure

Source	Amount ($M)	% of Total	Terms
Government Equity	210	30%	Subordinated, patient capital
Climate Finance (GCF, CTF)	140	20%	2% interest, 15-year tenor
MDB Loans (ADB, WB)	175	25%	4% interest, 20-year tenor
Green Bonds	105	15%	5-6% yield, 10-year maturity
Strategic Partner Equity	70	10%	Commercial terms, tech transfer
Total	**700**	**100%**	**Blended cost: 3.5-4%**

Blended Finance Benefits:

- Reduces financing cost from 8-10% (commercial) to 3.5-4% (blended)
- Improves project economics: IRR increases from 9% to 13-14%
- Shares technology and market risk with experienced partners
- Demonstrates government commitment, attracting other investors

8.2.3 Carbon Finance and Revenue Enhancement

Potential Revenue Streams:

1. **Voluntary Carbon Credits**:
   - Emission reduction: 1.0-1.2 Mt CO_2/year (vs. BF-BOF baseline)
   - Credit price: $15-25/t CO_2 (current voluntary market)
   - Annual revenue: $15-30 million
   - Challenge: Additionality and permanence demonstration
2. **Green Steel Premium**:
   - Target premium: $50-80/t steel for <1.0 t CO_2/t steel
   - Realistic capture: $30-50/t (Indonesian market conditions)
   - For 1.5 Mt production: $45-75 million/year additional revenue
   - Requires certification and customer contracts
3. **CBAM Advantage** (if maintained):
   - EU exports: Potential 200-300 kt/year
   - CBAM avoidance value: $50-80/t (EU carbon price projection)
   - Additional margin: $10-24 million/year
   - Requires compliance with EU verification systems

4. **Energy Savings**:
   - DRI-EAF typically 10-15% more energy efficient than BF-BOF
   - Annual energy cost reduction: $15-25 million
   - Immediate benefit, not dependent on carbon markets

Total Annual Revenue Enhancement: $85-150 million, significantly improving project economics.

8.3 Sensitivity Analysis

Key variables affecting project viability:

Table 6: Sensitivity Analysis for Gas DRI-EAF Project

Variable	Base Case	Downside	Upside
Natural Gas Price ($/MMBtu)	8-10	12-14	6-7
Green Steel Premium ($/t)	40	20	70
Capacity Utilization (%)	85	70	95
Project IRR (%)	13.5	8.2	18.7
NPV ($M, 8% discount)	185	-45	420

Critical Success Factors:

1. Gas price stability (largest operating cost variable)
2. Green premium realization (market acceptance crucial)
3. Capacity utilization (avoiding expensive stranded assets)

Risk Mitigation Strategies:

- Long-term gas supply contract with price collar (floor and ceiling)
- Off-take agreements with anchor customers guaranteeing premium
- Government price support mechanism during initial 5-year period
- Flexible design allowing hydrogen blending as costs decline

9 Workforce Transition: Detailed Planning

9.1 Current Workforce Analysis

9.1.1 Demographics and Skill Composition

9.1.2 Skills Gap Analysis

Current Skills (Strong):

- Blast furnace operations and maintenance

Table 7: Krakatau Steel Workforce Demographics (2024 Est.)

Category	Number	Percentage
Age Distribution		
Under 30 years	870	15%
30-40 years	1,740	30%
40-50 years	2,030	35%
Over 50 years	1,160	20%
Education Level		
High School/Vocational	3,480	60%
Diploma/Associate	1,160	20%
Bachelor's Degree	870	15%
Graduate Degree	290	5%
Employment Type		
Permanent	5,220	90%
Contract	580	10%

- BOF steelmaking
- Rolling mill operations
- Traditional quality control
- Mechanical and electrical maintenance

Skills Needed for Green Transition (Gaps):

- Hydrogen handling and safety protocols
- DRI plant operations (shaft furnace technology)
- EAF operations and optimization
- Advanced process control and automation
- Data analytics and AI/ML applications
- CCUS systems operation and maintenance
- Renewable energy integration
- Carbon accounting and environmental management systems

9.2 Transition Scenarios and Employment Impacts

9.2.1 Scenario 1: Baseline (Incremental Improvement)

Employment Impact (2025-2028):

- Net change: -5% (-300 positions) through natural attrition
- Minimal displacement or forced redundancies

- Modest upskilling for digital technologies
- Workforce composition remains largely stable

9.2.2 Scenario 2: Accelerated Transition (DRI-EAF Investment)

Employment Impact Analysis:

Phase 1 - Construction (2025-2027):

- Construction employment: +2,000-2,500 temporary jobs
- Engineering and project management: +150-200 positions
- Opportunity for internal workforce participation in construction support roles

Phase 2 - Commissioning and Ramp-up (2027-2028):

- New technology training: 1,500 workers
- Parallel running of old and new assets: Temporary workforce expansion
- Gradual shift of personnel from BF-BOF to DRI-EAF operations

Phase 3 - Steady State (2028+):

- DRI-EAF operations require 20-25% fewer workers than equivalent BF-BOF capacity
- For 1.5 Mt DRI-EAF vs. 1.5 Mt BF-BOF replacement:
  - BF-BOF employment: 1,800 direct workers
  - DRI-EAF employment: 1,350-1,400 direct workers
  - Net reduction: 400-450 positions
- However, higher skill levels and wages for DRI-EAF workers
- New positions created: Quality control, environmental monitoring, hydrogen safety specialists (100-150 jobs)
- Net employment impact: -300 to -350 positions (5-6% of total workforce)

Affected Worker Categories:

- Blast furnace operators and support staff: 600-700 workers
- Coking operations: 150-200 workers (if coke plant closed)
- BOF operations: 300-400 workers (partially)
- Some maintenance roles (DRI-EAF requires less intensive maintenance)

9.3 Just Transition Program Design

9.3.1 Comprehensive Retraining Program

Program Structure:

Track 1: Direct Technology Transition (Target: 1,200 workers)

- Duration: 12-18 months
- Combines classroom instruction and hands-on training
- Modules:
  1. DRI fundamentals and shaft furnace technology (3 months)
  2. EAF operations and advanced steelmaking (3 months)
  3. Hydrogen safety and handling (2 months)
  4. Process control and automation (2 months)
  5. Environmental monitoring and reporting (1 month)
  6. On-the-job training at partner facilities (6 months)
- Training locations:
  - Domestic: ITB, UI, Krakatau Steel training center
  - International: Placements at Midrex/HYL facilities (India, Middle East) for select personnel
- Financial support: Full salary + training stipend

Track 2: Adjacent Industry Transition (Target: 300 workers)

- For workers unable or unwilling to transition to new technologies
- Duration: 6-12 months
- Target sectors:
  - Petrochemical industry (similar process industry skills)
  - Power generation (increasingly renewable energy sector)
  - Manufacturing and fabrication
  - Quality control and testing services
- Job placement assistance and wage subsidy (2 years, declining)

Track 3: Entrepreneurship and SME Development (Target: 100-150 workers)

- Support for workers wanting to start businesses
- Focus areas:
  - Steel trading and service centers
  - Maintenance services

  - Logistics and transportation
  - Scrap collection and processing

- Support package:
  - Business training and mentorship
  - Seed capital and guaranteed contracts from Krakatau Steel
  - Preferential procurement for 3 years

Track 4: Early Retirement (Target: 200-250 workers)

- Voluntary program for workers aged 55+
- Enhanced pension benefits
- Healthcare coverage maintained until age 65
- Bridge payment until pension eligibility
- Consultation and financial planning services

9.3.2 Social Safety Net and Community Support

Income Support During Transition:

- Full salary maintenance during retraining (12-18 months)
- Transition allowance: 3-6 months salary upon completion of training
- Wage insurance: If new job pays less, 50% of difference covered for 2 years
- Housing assistance if relocation required

Family Support Services:

- Spouse employment assistance
- Educational support for children (scholarships, tutoring)
- Mental health and counseling services
- Financial advisory services

Community Development Initiatives:

- Cilegon economic diversification fund: $50 million over 5 years
- Infrastructure improvements (schools, healthcare, transportation)
- Support for local businesses and service providers
- Youth training and apprenticeship programs

Table 8: Just Transition Program Budget (5-year period)

Program Component	Cost ($ millions)
Direct retraining programs	35-45
Salary and income support	80-100
Early retirement packages	40-50
Job placement and entrepreneurship	15-20
Community development	50
Program administration	10-15
Total	**230-280**

9.3.3 Program Costs and Funding

Funding Sources:

- Government budget allocation: 60% ($140-170M)
- Krakatau Steel corporate contribution: 20% ($45-55M)
- International climate finance (Just Transition Fund): 20% ($45-55M)

9.4 Success Metrics and Monitoring

Key Performance Indicators:

- **Reemployment Rate**: Target 85% within 24 months of displacement
- **Income Maintenance**: Average post-transition income ≥ 90% of pre-transition
- **Training Completion**: 80% of enrolled workers complete retraining programs
- **Worker Satisfaction**: Survey-based assessment, target 70% positive
- **Community Well-being**: Unemployment rate, household income, social services usage in Cilegon

Monitoring and Governance:

- Tripartite monitoring committee (government, company, labor unions)
- Quarterly progress reports and public disclosure
- Annual independent evaluation
- Adaptive management: Program adjustments based on outcomes
- Worker voice: Regular consultation and feedback mechanisms

10 Environmental Performance and Sustainability

10.1 Current Environmental Challenges

10.1.1 Air Quality Impacts

Krakatau Steel's operations contribute to regional air quality challenges:

- **Particulate Matter (PM10, PM2.5)**:
  - Source: Coke ovens, blast furnace charging, BOF off-gas, material handling
  - Estimated emissions: 2,000-2,500 tonnes/year
  - Impact on Cilegon air quality index
- **Sulfur Dioxide (SO_2)**:
  - Source: Coke making, blast furnace operations
  - Estimated emissions: 3,500-4,000 tonnes/year
  - Acid rain concerns for regional agriculture
- **Nitrogen Oxides (NO_x)**:
  - Source: High-temperature combustion processes
  - Estimated emissions: 1,500-1,800 tonnes/year

Regulatory Compliance:

- Indonesian environmental standards (PROPER rating system)
- Current rating: Green (compliance) but not Blue (best practice)
- Areas of concern: Episodic exceedances during upset conditions
- Upgrading required: Baghouse filters, electrostatic precipitators, gas cleaning systems

10.1.2 Water Usage and Discharge

- **Water Consumption**: 12-15 million m^3/year (4-5 m^3/tonne steel)
- **Source**: Coastal seawater intake + freshwater from local watershed
- **Cooling Water**: 80% of usage (once-through and recirculating systems)
- **Process Water**: 20% (quenching, dust suppression, descaling)
- **Wastewater Treatment**:
  - Treatment capacity: Adequate for normal operations
  - Discharge standards: Generally compliant with effluent limits
  - Concerns: Heavy metals (zinc, chromium) in specific waste streams
  - Opportunity: Increased water recycling (current rate 70%, best practice 95%)

Table 9: Solid Waste Generation (Annual Estimates)

Waste Type	Quantity (kt/yr)	Current Utilization
Blast Furnace Slag	600-700	85% (cement, construction)
BOF Slag	250-300	60% (road base, fertilizer)
Mill Scale	80-100	30% (recycled to sinter)
Dust and Sludge	120-150	20% (zinc recovery, disposal)
Refractory Waste	15-20	10% (mostly landfilled)
Total	**1,065-1,270**	**65-70% average**

10.1.3 Solid Waste and By-Products

Circular Economy Opportunities:

- Increase slag utilization to 95% through better marketing and processing
- Dust and sludge processing for zinc recovery (economic viability needs assessment)
- BOF slag stabilization for higher-value applications
- Collaboration with cement industry for slag activation techniques

10.2 Environmental Benefits of Decarbonization Pathways

10.2.1 Co-benefits of DRI-EAF Transition

Beyond CO_2 reduction, DRI-EAF offers multiple environmental advantages:

Table 10: Environmental Performance: BF-BOF vs. DRI-EAF

Pollutant	BF-BOF (kg/tonne steel)	Gas DRI-EAF (kg/tonne steel)
CO_2	2,100-2,300	1,000-1,200
SO_2	1.2-1.5	0.1-0.2
NO_x	0.5-0.7	0.2-0.3
Particulates	0.7-0.9	0.1-0.2
Water consumption (m^3)	4-5	2-3

Key Improvements:

- **Air Quality**: 80-90% reduction in SO_2 (no coke ovens), 60% reduction in particulates
- **Water Use**: 40-50% reduction (EAF closed-loop cooling more efficient)
- **Waste Generation**: 30-40% reduction in total solid waste
- **Land Use**: Smaller footprint (no coke ovens, smaller facilities overall)

Community Health Benefits:

- Reduced respiratory illness incidence in Cilegon region
- Lower environmental justice concerns
- Improved quality of life and property values
- Quantifiable health cost savings: $5-10 million/year (estimate)

10.2.2 Life Cycle Assessment Considerations

Comprehensive Environmental Footprint:
While DRI-EAF reduces direct emissions, full life cycle assessment must consider:

- **Upstream Emissions**:
  - Natural gas production and transport (for gas-based DRI)
  - Electricity generation mix (for EAF and future hydrogen)
  - Iron ore mining and pelletization
- **Indonesia-Specific Factors**:
  - Current grid emissions factor: 0.85 kg CO_2/kWh (coal-heavy)
  - DRI-EAF using current grid: Limited environmental benefit
  - Requires parallel grid decarbonization or dedicated renewable power
  - Natural gas leakage rates in Indonesian infrastructure (methane emissions concern)
- **Downstream Considerations**:
  - DRI-EAF steel properties suitable for most but not all applications
  - Some ultra-high-strength grades may require integrated route
  - Scrap quality and tramp elements (copper, tin) can limit recycling in EAF

Recommendation: Life cycle assessment (LCA) should be conducted for each decarbonization pathway in Indonesian context, including:

- Baseline LCA for current operations
- Scenario LCAs for each major technology option
- Sensitivity analysis for grid decarbonization scenarios
- Comparison with imported steel (including transport emissions)

10.3 Environmental Governance and Reporting

10.3.1 Current Practices

- **Environmental Management System**: ISO 14001 certified
- **PROPER Rating**: Indonesian government environmental performance program, currently Green level
- **Disclosure**: Annual sustainability report (following GRI standards partially)
- **Community Engagement**: Regular dialogue with Cilegon communities, complaint mechanism

10.3.2 Enhanced Governance for Decarbonization Era

Recommendations:

1. **Board-Level Sustainability Committee**
   - Dedicated committee overseeing decarbonization strategy
   - Quarterly review of environmental KPIs
   - Executive compensation linked to emissions reduction targets
2. **Science-Based Targets**
   - Commit to Science Based Targets initiative (SBTi) for steel sector
   - Set 1.5°C-aligned pathway targets
   - Interim targets: 2028, 2032, 2040 milestones
   - Public disclosure and annual progress reporting
3. **Enhanced Disclosure**
   - Adopt TCFD (Task Force on Climate-related Financial Disclosures) framework
   - Scope 1, 2, and 3 emissions reporting
   - Climate risk assessment (physical and transition risks)
   - Scenario analysis for different decarbonization pathways
4. **Third-Party Verification**
   - Annual emissions audit by accredited verifier
   - Product-level carbon footprint certification (e.g., ResponsibleSteel, EPD)
   - Participation in customer supply chain disclosure (CDP Supply Chain)
5. **Stakeholder Engagement**
   - Multi-stakeholder advisory panel (NGOs, community, workers, customers)
   - Annual public forum on decarbonization progress
   - Transparent grievance mechanism for environmental concerns
   - Partnership with environmental research institutions

11 Strategic Recommendations Summary

11.1 Priority Actions Matrix

Table 11: Prioritized Action Plan (2025-2028)

Action	Timeline	Investment	Impact
Immediate Priority (2025)			
1. Energy audit & efficiency plan	Q1-Q2 2025	$2-3M	Foundation
2. PCI enhancement project	Q2-Q4 2025	$40-50M	8% CO_2 reduction
3. Workforce skills assessment	Q1 2025	$0.5M	Planning basis
4. Strategic partnership search	Q1-Q3 2025	$1M	Access to tech/capital
5. Green steel market study	Q2 2025	$0.3M	Revenue strategy
Near-Term (2025-2026)			
6. Scrap utilization expansion	2025-2026	$30-40M	5% CO_2 reduction
7. Energy management systems	2025-2026	$20-30M	3% CO_2 reduction
8. DRI-EAF feasibility & FID	2025-2026	$5-10M (study)	Major pathway decision
9. Just transition plan development	2025-2026	$2M	Social sustainability
10. Green finance structuring	2026	$3M	Enable investment
Medium-Term (2026-2028)			
11. DRI-EAF construction	2026-2028	$600-800M	30% capacity greening
12. CCUS pilot project	2026-2028	$150-200M	15-20% CO_2 capture
13. Workforce retraining programs	2026-2028	$35-45M	Enable transition
14. Digital transformation	2026-2028	$40-60M	Efficiency gains
15. Customer offtake agreements	2026-2027	Minimal	Secure premium market

11.2 Success Factors and Risks

11.2.1 Critical Success Factors

1. **Government Commitment**
   - Financial support: $400-500M over 5 years
   - Policy framework: Carbon pricing, green procurement mandates
   - Energy infrastructure: Natural gas availability, grid decarbonization

- Trade protection: Maintain anti-dumping enforcement while promoting green steel

2. **Strategic Partnership**
   - Technology transfer from established DRI-EAF operators
   - Risk sharing for major investments
   - Access to global green steel markets and customers
   - Knowledge transfer for operations and optimization

3. **Market Development**
   - Customer willingness to pay green premium
   - Long-term offtake agreements providing revenue certainty
   - Export market access (EU, Japan, Australia)
   - Domestic regulation driving green steel demand

4. **Social License**
   - Worker buy-in through transparent communication and fair transition
   - Community support through economic diversification
   - Civil society recognition of environmental benefits
   - Union partnership in managing change

5. **Financial Viability**
   - Access to blended finance at affordable rates
   - Operational efficiency improvements delivering cost savings
   - Green steel premium realization
   - Capacity utilization achievement (>80%)

11.2.2 Major Risks and Mitigation

12 Comparative Conclusions and Global Insights

12.1 Krakatau Steel in Global Decarbonization Context

12.1.1 How Indonesia/Southeast Asia Differs from Other Regions

Versus China:

- **Scale**: Krakatau Steel 3 Mt/year vs. Chinese facilities often 10-20 Mt/year
- **State Capacity**: China's centralized planning vs. Indonesia's more market-oriented but resource-constrained approach
- **Technology Access**: China developing indigenous technology; Indonesia must rely on imports

Table 12: Risk Assessment and Mitigation Strategies

Risk	Impact	Mitigation Strategy
Chinese steel dumping intensifies	Loss of market share, price pressure	Enhanced trade enforcement, product differentiation, ASEAN coordination
Gas supply constrained/expensive	DRI-EAF economics unviable	Hydrogen-ready design, long-term gas contracts, CCUS alternative
Green premium fails to materialize	Insufficient project returns	Government price support, mandatory green procurement, CBAM advantages
Technology performance issues	Cost overruns, delays	Proven technology selection, experienced EPC contractor, performance guarantees
Workforce resistance to change	Labor disruption, social conflict	Early engagement, generous transition packages, transparent communication
Capital markets inaccessible	Investment delayed/cancelled	Government guarantees, multilateral development bank involvement, phased approach
Grid decarbonization too slow	Limited emissions reduction	Captive renewable power, hydrogen from renewables, focus on gas-DRI initially
Stranded asset risk (BF-BOF)	Financial write-downs	Gradual transition, maintain BF-BOF for specific products, CCUS retrofit option

- **Environmental Pressure**: Chinese cities facing acute air quality crisis driving faster action; Indonesia's environmental pressure more moderate
- **Financial Resources**: China can mobilize massive capital; Indonesia requires external support

Versus Europe:

- **Policy Framework**: EU has carbon pricing, CBAM, extensive green finance; Indonesia lacks comprehensive framework
- **Energy Infrastructure**: Europe has renewable energy and emerging hydrogen infrastructure; Indonesia starting from coal-dependent baseline
- **Customer Demand**: European customers willing to pay green premiums; Asian price-sensitive markets
- **Social Safety Net**: European welfare systems can support workers; Indonesia requires building transition programs from scratch

Versus India:

- **Domestic Market**: India's larger, growing market supports multiple large producers; Indonesia remains import-dependent

- **Scrap Availability**: India has larger scrap market; Indonesia's scrap ecosystem underdeveloped
- **Conglomerate Structure**: Indian steel companies (Tata, JSW) have diversified portfolios providing cross-subsidy; Krakatau Steel more dependent on steel operations
- **Private Capital**: India's steel sector increasingly private with access to capital markets; Krakatau Steel's SOE status creates different dynamics

Versus Japan/South Korea:

- **Technology Leadership**: Japan/Korea developing frontier technologies; Indonesia adapting/importing
- **Product Sophistication**: Northeast Asian focus on ultra-high-quality steels; Indonesia primarily commodity products
- **Export Orientation**: Japan/Korea significant exporters; Indonesia primarily domestic market focused
- **R&D Capacity**: POSCO/Nippon Steel invest \$1B+/year in R&D; Krakatau Steel minimal R&D budget

12.1.2 Universal vs. Context-Specific Challenges

Universal Challenges (faced by all regions):

- High capital cost of low-carbon technologies
- Long asset lifetimes creating stranded asset risks
- Need for coordinated policy (carbon pricing, trade protection, R&D support)
- Workforce transition and just transition imperatives
- Customer willingness to pay green premiums
- Competition from regions with slower decarbonization

Context-Specific to Indonesia/Emerging Markets:

- Development imperatives competing with environmental goals
- Limited financial resources and high cost of capital
- Energy infrastructure constraints (coal-dependent grid)
- Weaker environmental governance and enforcement
- Technology dependence on foreign suppliers
- Competing with established low-cost producers (China, Vietnam)
- Building transition programs and social safety nets from limited base

12.2 Lessons for Other Emerging Market Steel Producers

12.2.1 What Other Countries Can Learn from Indonesia's Situation

For Southeast Asian Neighbors (Thailand, Vietnam, Philippines, Malaysia):

1. **First-Mover Advantage**: Indonesia's challenges show importance of regional coordination on standards and trade policy
2. **Energy Infrastructure**: Decarbonizing steel requires parallel grid decarbonization or dedicated renewable power
3. **Finance Mobilization**: Blended finance essential; cannot wait for purely commercial viability
4. **Scrap Ecosystems**: Developing domestic scrap collection is critical enabler for EAF routes
5. **Just Transition**: Planning for workforce impacts from the beginning, not as afterthought

For Other Emerging Economies (Latin America, Africa, Middle East):

1. **Resource Endowments Matter**: Countries with natural gas or renewable energy potential have more pathway options
2. **Scale Economics**: Smaller producers face tougher economics; regional cooperation or niche strategies necessary
3. **Technology Selection**: Avoid bleeding-edge technology risk; proven DRI-EAF route more suitable than experimental approaches
4. **Policy Sequencing**: Carbon pricing alone insufficient; requires comprehensive package of finance, trade policy, and transition support
5. **SOE Governance**: State ownership creates opportunities (patient capital, social missions) and challenges (political interference, soft budget constraints)

12.2.2 What Makes a Steel Decarbonization Strategy Successful?

Based on global analysis including Krakatau Steel case:

1. **Clear Long-Term Vision with Flexible Pathways**
   - Commitment to net-zero by 2050 or earlier
   - Multiple technology pathways kept open given uncertainties
   - Phase-gates for major investment decisions
   - Adaptive management as technologies and markets evolve
2. **Comprehensive Policy Package**
   - Carbon pricing or equivalent (regulations, standards)
   - Financial support (grants, loans, guarantees)

- Trade policy (border adjustments, anti-dumping aligned with carbon)
- Procurement mandates creating demand signals
- R&D and demonstration project funding
- Just transition programs with adequate resources

3. **Whole-System Approach**
   - Steel sector cannot decarbonize in isolation
   - Requires parallel decarbonization of electricity grid
   - Development of hydrogen or alternative energy infrastructure
   - Coordination with downstream users (automotive, construction)
   - Scrap collection and circular economy development
4. **Stakeholder Alignment**
   - Government, industry, labor, communities pulling in same direction
   - Transparent dialogue on trade-offs and distribution of costs/benefits
   - Mechanisms for those bearing costs to be compensated
   - Regional/international cooperation to prevent carbon leakage
5. **Adequate Timelines**
   - Recognition that steel industry transitions take decades
   - Interim targets (2030, 2040) to track progress
   - Avoid both complacency and unrealistic expectations
   - Balance urgency of climate crisis with practical realities

13 Conclusion: Navigating the Trilemma

13.1 The Fundamental Trade-offs

The Krakatau Steel case illuminates the steel decarbonization trilemma with particular clarity. Unlike mature economies where existing wealth and institutions can buffer transition costs, emerging markets face starker choices:

Can Indonesia achieve all three goals simultaneously?

The analysis suggests: *Not in the short term, but possibly over a 10-15 year horizon with the right strategies and support.*

Short Term (2025-2028): Trade-offs are acute

- Aggressive decarbonization (DRI-EAF investment) threatens competitiveness without policy support and creates workforce displacement
- Prioritizing competitiveness (cost reduction focus) delivers minimal environmental progress
- Protecting employment (avoiding technology changes) fails both environmental and long-term competitiveness goals

Medium Term (2028-2035): Trade-offs can be managed

- Green steel premiums begin to materialize, improving project economics
- Workforce transition programs complete, new skills embedded
- Indonesian grid decarbonizes, reducing DRI-EAF emissions further
- ASEAN regional coordination reduces competitive distortions
- Technology costs decline (hydrogen, CCUS, renewable energy)

Long Term (2035-2050): Synergies emerge

- Low-carbon steel becomes competitive advantage in global markets
- High-skill green steel workforce supports productivity and wages
- Indonesia develops domestic green technology and expertise
- Environmental improvements deliver health and quality-of-life benefits
- Steel industry remains viable contributor to Indonesian economy

13.2 The Imperative for Proactive Management

The Krakatau Steel case demonstrates that *inaction is the worst strategy*:

- **Environmental Pressures Will Intensify**: Indonesian regulations will tighten, export markets will demand green credentials, physical climate risks will grow
- **Competitive Position Will Erode**: Failure to modernize leaves facilities increasingly uncompetitive as competitors invest in more efficient technologies
- **Stranded Assets**: Delayed action means more BF-BOF capacity becomes stranded, creating larger write-offs and disruptions
- **Workforce Impacts Worsen**: Gradual managed transition is more humane and effective than sudden crisis-driven restructuring
- **Loss of Agency**: Proactive strategy allows Indonesia to shape its transition; reactive approach means accepting solutions imposed by external pressures

13.3 Recommendations for Course Participants and Policy Makers

13.3.1 For Students and Researchers

1. **Context Matters Enormously**: Technology and economic assessments from Europe or Northeast Asia cannot be directly applied to emerging markets. Always consider:
    - Local energy infrastructure and costs
    - Available financial resources and cost of capital

- Institutional capacity for policy implementation
- Social and labor market conditions
- Position in global value chains

2. **Systems Thinking Required**: Steel decarbonization cannot be analyzed in isolation. Must consider:
   - Upstream (iron ore, energy, equipment supply)
   - Downstream (steel-using industries, scrap recovery)
   - Parallel sectors (power, chemicals, cement)
   - Social systems (labor markets, communities)
   - Political economy (state-business-labor relations, trade policy)
3. **Quantitative and Qualitative**: Both rigorous modeling (techno-economic, emissions) and qualitative understanding (political feasibility, social acceptability) are essential
4. **Comparative Analysis**: Learn from other regions but recognize limits of transferability
5. **Uncertainty and Optionality**: Acknowledge uncertainty in technology costs, policy evolution, market development; value flexible strategies that preserve options

13.3.2 For Policy Makers

1. **Act Now with Long-Term Vision**: Begin implementing policy frameworks even as technologies mature
2. **Comprehensive Packages**: Carbon pricing alone is insufficient; requires finance, trade policy, transition support, infrastructure investment
3. **Regional Coordination**: ASEAN-level cooperation essential to prevent carbon leakage and race-to-bottom dynamics
4. **Just Transition as Priority**: Workforce and community impacts must be addressed proactively, not as afterthought
5. **Public Investment**: Market failures in low-carbon transitions require substantial public finance
6. **Transparency and Accountability**: Clear targets, regular monitoring, public disclosure build credibility and social license

13.3.3 For Industry Leaders

1. **Strategic Planning**: Develop decarbonization roadmaps now, even with uncertainties
2. **Partnerships**: Seek technology partners, financial partners, customer partnerships

3. **Quick Wins**: Implement efficiency improvements that deliver CO_2 reductions and cost savings
4. **Workforce Engagement**: Bring workers into transition planning early
5. **Market Development**: Work with customers to develop green steel markets and premiums
6. **Policy Advocacy**: Engage constructively with government on supportive frameworks

13.4 Final Reflections

The Krakatau Steel case is more than a technical challenge of replacing one production technology with another. It is fundamentally about:

- **Development Pathways**: Can emerging economies industrialize sustainably, or must they follow the high-carbon path of predecessors?
- **Global Equity**: How are costs and benefits of climate action distributed between developed and developing nations?
- **Industrial Strategy**: What does comparative advantage mean in a carbon-constrained world?
- **Social Contract**: How do societies manage structural economic transitions while maintaining social cohesion?
- **Time Horizons**: How do we balance urgent climate imperatives with realistic institutional and technological timelines?

The trilemma of greener steel, employment, and competitiveness is not unique to Krakatau Steel or Indonesia. It is emblematic of the broader sustainability transition facing the global economy. The choices made—by companies, governments, workers, and civil society—will determine not only the future of the steel industry but the viability of broader climate goals and the prosperity of industrial communities worldwide.

The challenge is immense. The stakes are high. But with comprehensive strategies, adequate resources, and collective commitment, the trilemma can be navigated toward outcomes that advance all three goals over time.

Discussion Questions for Students

1. Compare the decarbonization challenges facing Krakatau Steel with those of steel producers in Europe, China, and India. What factors account for the differences?
2. If you were advising the Indonesian government, how would you prioritize policy interventions? What should be the first three actions?
3. Evaluate the three scenarios presented (baseline, accelerated transition, disruptive). Which do you consider most likely? What factors would tip outcomes toward one scenario or another?

4. Design a just transition program for Krakatau Steel workers. What are the key elements? How would you measure success?
5. Should Indonesia prioritize domestic steel production (supporting Krakatau Steel) or allow more imports if they have lower carbon footprints? What are the trade-offs?
6. How should the costs of steel decarbonization be distributed among: (a) steel companies, (b) steel-using customers, (c) government/taxpayers, (d) workers, (e) international climate finance? Justify your allocation.
7. Assess the viability of hydrogen-based steelmaking in Indonesia by 2035. What would need to happen for this to become reality?
8. Compare state-owned enterprise (SOE) vs. private ownership models for managing steel industry transitions. What are advantages and disadvantages of each?
9. How should ASEAN countries coordinate on steel decarbonization? What mechanisms would be most effective?
10. If you were CEO of Krakatau Steel, what would be your strategy for the next five years? Present your plan with key decisions, timelines, and resource requirements.

Suggested Further Reading

Steel Industry and Decarbonization

- International Energy Agency (IEA), *Iron and Steel Technology Roadmap*, 2020
- Material Economics, *Industrial Transformation 2050: Pathways to Net-Zero Emissions from EU Heavy Industry*, 2019
- Agora Energiewende & Wuppertal Institut, *Climate-Neutral Industry: Key Technologies and Policy Options for Steel, Chemicals and Cement*, 2019
- OECD, *Measuring and Managing CO_2 Emissions in the Steel Industry*, 2020
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Just Transition

- International Labour Organization (ILO), *Guidelines for a Just Transition Towards Environmentally Sustainable Economies and Societies for All*, 2015
- Mertins-Kirkwood, H. and Deshpande, Z., *Who is Included in a Just Transition? Considering Social Equity in Canada's Shift to a Zero-Carbon Economy*, Canadian Centre for Policy Alternatives, 2019
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- Indonesia Ministry of Energy and Mineral Resources, *Indonesia Energy Outlook 2023*
- Ministry of Industry, *Making Indonesia 4.0 Roadmap*, 2018
- Asian Development Bank, *Indonesia Energy Transition Outlook 2023*
- Purnomo, H. et al., "Indonesia's Steel Industry Development Strategy in the Era of Industrial Revolution 4.0," *IOP Conference Series: Materials Science and Engineering*, 2020

Emerging Markets and Development

- Rodrik, D., "Green Industrial Policy," *Oxford Review of Economic Policy*, 2014
- Newell, P. and Mulvaney, D., "The Political Economy of the 'Just Transition'," *The Geographical Journal*, 2013
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Regional Steel Studies

- Hasanbeigi, A. and Springer, C., *Deep Decarbonization Roadmap for the Indian Steel Industry*, Global Efficiency Intelligence, 2019
- Fischedick, M. et al., "Techno-economic Evaluation of Innovative Steel Production Technologies," *Journal of Cleaner Production*, 2014
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Appendix A: Key Technical Terms and Definitions

Blast Furnace (BF) A shaft furnace that reduces iron ore using coke as fuel and reducing agent, producing liquid iron (hot metal) at approximately 1,500°C.

Basic Oxygen Furnace (BOF) A steelmaking vessel where hot metal from the blast furnace is refined into steel by blowing oxygen through the melt, reducing carbon content.

Direct Reduced Iron (DRI) Iron ore reduced to metallic iron at temperatures below the melting point, using reducing gases (typically natural gas or hydrogen), producing solid sponge iron.

Electric Arc Furnace (EAF) A furnace that melts scrap steel or DRI using electric arcs, typically more flexible and lower emissions than BF-BOF route.

Carbon Capture, Utilization and Storage (CCUS) Technologies to capture CO_2 from industrial sources, either use it in other processes or store it permanently underground.

Green Hydrogen Hydrogen produced by electrolysis of water using renewable electricity, resulting in zero carbon emissions.

Carbon Intensity Tonnes of CO_2 emitted per tonne of steel produced; key metric for comparing environmental performance.

Pulverized Coal Injection (PCI) Technology to inject pulverized coal directly into blast furnace, partially replacing coke and reducing costs and emissions.

Scope 1 Emissions Direct emissions from owned or controlled sources (e.g., blast furnace, power generation).

Scope 2 Emissions Indirect emissions from purchased electricity, steam, heating, or cooling.

Scope 3 Emissions All other indirect emissions in the value chain, both upstream (raw materials) and downstream (product use).

Carbon Border Adjustment Mechanism (CBAM) Policy instrument (notably EU's) that applies carbon cost to imports based on their embedded emissions, leveling the playing field with domestic producers facing carbon pricing.

Just Transition Framework ensuring that the shift to low-carbon economy creates decent work opportunities and leaves no one behind, particularly workers and communities dependent on fossil fuels.

Stranded Asset An asset that suffers from unanticipated write-downs, devaluations, or conversion to liabilities, often due to regulatory changes (e.g., carbon pricing making high-emission assets uneconomic).

Appendix B: Calculation Examples

B.1: CO_2 Emissions Calculation for BF-BOF Route

Typical emissions sources and magnitudes per tonne of crude steel:

$$\begin{aligned}
\text{Coke consumption} &: 450 \text{ kg/t} \times 3.1 \text{ kg CO}_2\text{/kg coke} = 1,395 \text{ kg CO}_2 \\
\text{PCI coal} &: 130 \text{ kg/t} \times 2.9 \text{ kg CO}_2\text{/kg coal} = 377 \text{ kg CO}_2 \\
\text{Limestone flux} &: 50 \text{ kg/t} \times 0.44 \text{ kg CO}_2\text{/kg limestone} = 22 \text{ kg CO}_2 \\
\text{Electricity} &: 500 \text{ kWh/t} \times 0.85 \text{ kg CO}_2\text{/kWh} = 425 \text{ kg CO}_2 \\
\text{Other fuels} &: \hfill 100 \text{ kg CO}_2 \\
\hline
\text{Total} &: \hfill \mathbf{2,319} \text{ kg } \mathbf{CO_2}\text{/tonne steel}
\end{aligned}$$

Note: This represents a typical Indonesian BF-BOF operation with coal-heavy electricity grid.

B.2: CO_2 Emissions Calculation for Gas-Based DRI-EAF Route

Emissions for natural gas-based DRI-EAF per tonne of crude steel:

$$\begin{aligned} \text{Natural gas (DRI)} &: 11 \text{ GJ/t} \times 56 \text{ kg CO}_2\text{/GJ} = 616 \text{ kg CO}_2 \\ \text{Electricity (DRI + EAF)} &: 600 \text{ kWh/t} \times 0.85 \text{ kg CO}_2\text{/kWh} = 510 \text{ kg CO}_2 \\ \text{Electrode consumption} &: 20 \text{ kg CO}_2 \\ \text{Minor inputs} &: 10 \text{ kg CO}_2 \\ \hline \text{Total} &: \mathbf{1,156} \text{ kg CO}_\mathbf{2}\text{/tonne steel} \end{aligned}$$

Emissions reduction: $(2,319 - 1,156)/2,319 = 50.2\%$

Note: If electricity from renewable sources, reduction increases to 73% (616 kg CO_2/tonne).

B.3: Green Steel Premium Required for Project Viability

Cost increase for DRI-EAF vs. BF-BOF:

- BF-BOF production cost: \$570/tonne
- Gas DRI-EAF production cost: \$650/tonne
- Cost differential: \$80/tonne

Revenue from carbon credits:

- Emissions reduction: 1.16 tonnes CO_2/tonne steel
- Carbon credit price: \$20/tonne CO_2
- Revenue: \$23/tonne steel

Required green premium:

$$\begin{aligned} \text{Green premium needed} &= \text{Cost differential} - \text{Carbon credit revenue} \\ &= \$80 - \$23 \\ &= \$\mathbf{57}\text{/tonne steel} \end{aligned}$$

This represents the minimum premium customers must pay for the project to break even operationally (not including return on capital).

B.4: Hydrogen Requirement for H_2-DRI Route

Stoichiometric hydrogen requirement:

Iron ore (Fe_2O_3) reduction:

$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$

Practical requirements per tonne of steel:

- Iron ore (as Fe_2O_3): 1.6 tonnes

- Theoretical H_2: 40 kg
- Practical H_2 (including inefficiencies): 50-60 kg
- For 3 Mt/year capacity: 150,000-180,000 tonnes H_2/year

Electrolyzer capacity required:

- Electrolyzer efficiency: 60-70 kWh/kg H_2 (current)
- Annual electricity requirement: 9-12 TWh/year
- Average power requirement: 1.0-1.4 GW
- Electrolyzer capacity (85% capacity factor): 1.2-1.6 GW

Cost implications at current green hydrogen prices ($5/kg):

$$\text{Hydrogen cost per tonne steel} = 55 \text{ kg} \times \$5/\text{kg} = \$275/\text{tonne}$$
$$\text{Additional cost vs. gas-DRI} \approx \$200 - 250/\text{tonne}$$

This illustrates why hydrogen-based steel requires significant cost reductions or substantial green premiums.

Appendix C: Financing Case Study Example

1.5 Mt/year Gas-Based DRI-EAF Project Financial Model

Project Parameters:

- Total CAPEX: $700 million
- Construction period: 30 months (2026-2028)
- Operating life: 30 years
- Capacity: 1.5 million tonnes/year crude steel
- Capacity utilization: 85% (Year 1-3), 90% (Year 4+)

Operating Economics (per tonne of steel):
Annual Cash Flows (steady state, Year 4+):

- Production: 1.35 million tonnes (90% utilization)
- Revenue: $931 million
- Operating costs: $756 million
- EBITDA: $175 million
- Depreciation: $23 million (30-year straight line)
- Interest expense: $25 million (blended rate 3.6%)

Revenue & Costs	**$/tonne**
Revenue	
Base steel price	650
Green steel premium	40
Total Revenue	**690**
Operating Costs	
Iron ore pellets	180
Natural gas	140
Electricity	90
Electrodes and consumables	35
Labor	45
Maintenance	40
Other operating costs	30
Total Operating Costs	**560**
EBITDA per tonne	**130**

- Tax: $32 million (25% rate)
- Net income: $95 million
- Operating cash flow: $118 million

Project Returns:

- Project IRR (unlevered): 13.2%
- NPV at 8% discount rate: $185 million
- Payback period: 8.5 years
- Debt service coverage ratio (DSCR): 2.1x

Sensitivity Analysis - Impact on IRR:

Variable	**-10%**	**Base**	**+10%**
Steel price	9.8%	13.2%	16.5%
Green premium	11.7%	13.2%	14.6%
Gas price	15.1%	13.2%	11.4%
Capital cost	14.8%	13.2%	11.9%
Capacity utilization	10.2%	13.2%	15.8%

Key Observations:

- Project is viable with blended finance structure (3.6% weighted cost)
- Most sensitive to base steel price and capacity utilization
- Green premium provides important revenue cushion
- Gas price risk is material; long-term supply contract essential
- Without blended finance (at 8-10% commercial rate), IRR drops to 8-9% (sub-commercial)

Acknowledgments

This lecture note was developed for the MIFUS course on Global Steel Decarbonization at the University of Udine. The analysis draws on publicly available data from industry sources, government reports, international organizations (IEA, OECD, World Steel Association), and academic research. All financial projections and scenario analyses represent estimates for educational purposes and should not be considered investment advice or definitive forecasts.

Special acknowledgment to the global steel industry practitioners, policy makers, and researchers whose work has informed this analysis, and to the students whose questions and discussions have shaped the development of this material.

This document represents a snapshot of analysis as of December 2024.
The steel industry transition is rapidly evolving; students are encouraged to seek out current data and developments in their independent research.
