University of Udine
Department of Polytechnic Engineering and Architecture

MIFUS

MIFUS: Steel Decarbonization Policies around the World Mini Instant Fall University School

Lecture 4

Who is Running for Steel Decarbonization and Who for the Green Steel Race?

Professor Fabio Miani

University of Udine, Italy

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Contents

Executive Summary

This lecture addresses a fundamental question: Are steel decarbonization and green steel production the same objective, or are we witnessing two fundamentally different industrial races?

Key Thesis: Steel decarbonization and green steel represent different timelines, technologies, and strategic objectives—analogous to comparing 100-meter sprinters with marathon runners. Both are running, but not the same race.

Core Arguments

1. **The Emissions Reality:** Global steel production emits 3.7-4.1 $GtCO_2$/year, essentially equivalent to all passenger cars globally (3.3-3.6 $GtCO_2$/year), yet receives approximately 10% of the policy attention and investment.
2. **The Two Races:**
   - **100m Sprint (Decarbonization):** Rapid deployment of Electric Arc Furnace (EAF) technology achieving 60-70% emissions reduction by 2027-2030
   - **Marathon (Green Steel):** Development of Hydrogen Direct Reduced Iron (H-DRI) systems targeting 90-95% emissions reduction by 2030-2040
3. **The Runners:**
   - *Sprint leaders:* China, USA, Italy, Spain, Turkey
   - *Marathon leaders:* Germany, Sweden, Austria, Japan
4. **The Economic Reality:** Global conversion of all blast furnace-basic oxygen furnace (BF-BOF) capacity to EAF would require $285 billion (brownfield minimum) to $1.43 trillion (greenfield equivalent)—but only $30-50 billion is currently committed.
5. **The Technology Transfer Legacy:** A personal witness account of three decades of systematic knowledge transfer from European steel facilities and universities to emerging industrial competitors, with particular focus on the Danieli Metamorphosis Project.

Learning Objectives

By the end of this lecture, students will be able to:

- Distinguish between pragmatic decarbonization and aspirational green steel strategies
- Quantify and compare global emissions from steel versus transport sectors
- Calculate capital expenditure requirements for industrial-scale steelmaking transitions
- Analyze the role of technology transfer in reshaping global industrial competition
- Evaluate the thermodynamic, economic, and geopolitical constraints on steel decarbonization pathways

1 The Question: Two Races or One?

1.1 Opening Provocation

When asked *"Who is running for steel decarbonization and who for green steel?"* most people assume these are synonyms—different terms for the same objective.

They are not.

The Athletic Analogy: Asking who is winning steel decarbonization versus green steel is like asking who is winning the Olympics by comparing 100-meter sprint times with marathon times. They are different races, with different strategies, different timelines, and different winners.

Table 1: The Two Races: Sprint vs Marathon

Characteristic	100m Sprint (Decarbonization)	Marathon (Green Steel)
Technology	EAF + scrap	H-DRI + EAF
Emissions Reduction	60-70%	90-95%
Timeline	2024-2030	2030-2040
Technology Maturity	Proven, commercial	Pilot/demonstration scale
Cost Premium	Baseline	2-3× higher CAPEX
Leaders	China, USA, Italy	Germany, Sweden, Austria
CO Saved by 2030	600+ Mt (China alone)	20-40 Mt (Europe total)
Risk Level	Low (proven tech)	High (cost, H availability)

1.2 Why This Distinction Matters

1.2.1 The Climate Imperative

The atmosphere does not distinguish between "decarbonized" steel and "green" steel—it responds only to absolute emissions reduction.

- **China's pragmatic approach:** Converting 50-75 Mt/year to EAF (10% $\rightarrow$ 15% of production) will eliminate approximately 600 Mt CO by 2027
- **Europe's aspirational approach:** Multiple H-DRI projects totaling perhaps 40-50 Mt/year capacity will eliminate approximately 30-40 Mt CO by 2030-2035

Critical Question: If the climate emergency demands rapid emissions reduction, is a 600 Mt reduction by 2027 (China) preferable to a 40 Mt reduction by 2035 (Europe), even if the latter achieves deeper percentage reductions?

1.2.2 The Economic Sustainability

Steel companies must remain competitive while decarbonizing. The cost structure fundamentally differs:

Table 2: Economic Comparison: EAF vs H-DRI-EAF

Parameter	EAF (Scrap)	H-DRI-EAF
CAPEX (brownfield)	€200-300/tonne	€600-1,000/tonne
OPEX premium	Baseline	+$200-300/tonne steel
Technology risk	Minimal	Significant
Green H availability	Not required	Critical constraint
Commercial readiness	Full scale (2024)	Pilot/demo (2024)
Time to full production	2-3 years	5-10 years

2 The Invisible Twin: Steel and Automotive Emissions

2.1 The Comparison People Need to See

Public Perception vs Reality: Electric vehicle (EV) adoption dominates climate policy discourse. Steel decarbonization receives a fraction of the attention. Yet their emissions are nearly identical.

Table 3: Annual Global CO Emissions by Source (2024)

Source	Gt CO/year	% Global	Policy Attention*
Steel Industry	3.7-4.1	7-8%	Low ()
Passenger Cars & Vans	3.3-3.6	8-9%	Very High ()
Medium/Heavy Trucks	1.8-2.1	5-6%	Medium ()
Aviation	0.9-1.0	2.5%	High ()
Shipping	0.8-0.9	2%	Medium ()
Total Road Transport	5.6-6.1	17%	High ()
Total Transport (all modes)	8.0-8.7	24%	Very High ()

*Qualitative assessment based on policy investment, media coverage, consumer awareness

2.2 The Uncomfortable Questions

2.2.1 Question 1: Why the Attention Asymmetry?

If steel emissions approximately equal passenger car emissions, why does steel receive roughly 10% of the policy attention and investment?

Potential Explanations:

1. **Visibility:** Everyone drives a car; few people see steelmaking
2. **Consumer connection:** Cars are consumer products with vocal advocates; steel is an industrial input
3. **Narrative appeal:** EVs are "sexy" technology; steel is "boring" heavy industry
4. **Solution maturity:** EV technology is commercially proven (2024); steel decarbonization solutions are newer or less proven
5. **Political palatability:** Subsidizing car purchases is popular; subsidizing industrial facilities is not

2.2.2 Question 2: Which is Thermodynamically Harder?

Answer: Steel is significantly harder to decarbonize than automotive transport.

Table 4: Decarbonization Difficulty Comparison

Factor	Passenger Cars	Steel Production
Energy storage	Battery technology mature (Li-ion)	No battery can provide process heat
Temperature requirement	Ambient	800-1,000°C (DRI) or 1,500-2,000°C (BF)
Chemical reduction	Not required	Essential (FeO → Fe)
Alternative fuel	Electricity (infrastructure growing)	Green H (infrastructure nascent, expensive)
Asset lifetime	12-15 years (natural replacement)	30-40 years (capital lock-in)
Technology readiness	Commercial (2024)	Pilot (H-DRI) / Commercial (EAF)

The Thermodynamic Reality:

- **Cars:** Replace liquid fuel combustion with stored electricity → SOLVED (technologically, scaling economically)
- **Steel:** Need massive high-temperature heat + chemical reduction of iron oxide → PARTIALLY SOLVED (EAF for scrap, H-DRI still expensive/immature)

2.2.3 Question 3: Which Offers Better Climate Return on Investment?

This question has no simple answer, but consider:

- **EV Adoption:** Investment of $30,000-50,000 per vehicle saves approximately 4 tonnes CO/year during operation
- **EAF Conversion:** Investment of €200-300 per tonne capacity (brownfield) saves 1.2-1.4 tonnes CO per tonne steel produced annually for 30-40 years
- **H-DRI Systems:** Investment of €600-1,000 per tonne capacity saves 1.7-1.8 tonnes CO per tonne steel, but at 2-3× the capital cost and uncertain H supply

3 Who is Running, and In Which Race?

3.1 The 100-Meter Sprint: Pragmatic Decarbonization

3.1.1 China: The Late Entry, Rapid Acceleration

Strategic Context:

- **Production scale:** 1,015 Mt/year (53% of global production)
- **Traditional route:** 70% BF-BOF (700 Mt/year)
- **Current EAF share:** 10-15% (102-152 Mt/year)

October 2024 Policy Shift:

China's State Council announced aggressive EAF expansion, targeting shift from 10% to 15% EAF share within 18-24 months—a capacity increase of approximately 50 Mt/year.

Why This Matters:

- 50 Mt capacity shift = entire German steel production
- Investment: €15-25 billion over 3 years
- CO reduction: 60 Mt/year once operational
- Timeline: Faster than any European green steel program

The "Late Entry" Observation:

China was not historically an EAF leader:

- USA: 70% EAF since 1990s
- Italy/Spain: 70%+ EAF for decades
- Turkey: Regional EAF specialist
- China: Traditionally BF-BOF dominant

But when China enters a technology race at scale, they tend to win through sheer speed and volume of deployment.

3.1.2 United States: The Established Leader

Current Position:

- 70% EAF-based production (already achieved)
- 60 Mt/year total production
- 42 Mt/year through EAF route
- Nucor, Steel Dynamics Inc., Commercial Metals = major minimill operators

Historical Context:

The USA underwent its steel "disruption" in the 1970s-1990s:

- Integrated mills (US Steel, Bethlehem Steel) declined

- Minimills (Nucor model) rose
- Christensen's *The Innovator's Dilemma* literally studied this transition

Current Challenge:

Having already decarbonized 70%, the USA faces the harder remaining 30% (residual BF-BOF for premium grades). Limited momentum for further rapid change.

3.1.3 Italy, Spain, Turkey: The EAF Specialists

These nations achieved 60-70% emissions reductions decades ago through EAF dominance:

- **Italy:** 70% EAF (historically driven by scrap availability, no domestic iron ore)
- **Spain:** 75% EAF (similar drivers)
- **Turkey:** 70% EAF (regional scrap trading hub, low energy costs)

Key Insight: These countries "decarbonized" their steel sectors before climate policy even existed—driven by economic logic (scrap availability, energy costs), not environmental mandates.

3.2 The Marathon: Aspirational Green Steel

3.2.1 Germany: The €12.5 Billion H-DRI Bet

Strategic Vision:

Germany has committed approximately €12.5 billion in subsidies for steel decarbonization, with H-DRI as the primary technology pathway.

Major Projects:

- **ThyssenKrupp Duisburg:** 3 Mt/year H-DRI-EAF, €2-3 billion investment
- **Salzgitter SALCOS:** 2 Mt/year H-DRI-EAF, €1.5 billion investment
- **ArcelorMittal Hamburg:** Originally H-DRI planned, project under review/modification

The Challenge:

- Green hydrogen cost: Currently $9-10/kg, needs $4-5/kg for economic viability
- Electrolyzer capacity: Insufficient for steel sector demand
- Timeline risk: Full commercial operation unlikely before 2030
- Cost premium: 2-3× higher than EAF route

The ArcelorMittal Hamburg Lesson:

ArcelorMittal originally planned H-DRI for Hamburg but sought to use natural gas DRI as a bridge technology (achieving 60-70% reduction immediately). German policy required direct H-DRI commitment for subsidy eligibility. Result: Project delayed, cost escalation, potential withdrawal.

Policy Lesson: Perfect (H-DRI, 90%+ reduction, 2035) became the enemy of good (NG-DRI, 65% reduction, 2027).

3.2.2 Sweden: The Technology Showcase

HYBRIT Project (H2 Green Steel + SSAB + Vattenfall):

Sweden's approach combines favorable conditions with technology demonstration:

- Abundant hydroelectric power (low-cost green electricity)
- Strong policy support
- Premium market positioning (willing to pay for "green" certification)
- Initial scale: 1.3-2.5 Mt/year by 2030

Critical Caveat:

Sweden's conditions are nearly unique (hydropower abundance, small population, premium industrial customers). The HYBRIT model is technically impressive but may not scale globally.

3.2.3 Austria: voestalpine's Strategic Hedge

voestalpine Linz Project:

- 2.5 Mt/year capacity
- €1.5 billion investment
- H-DRI-EAF route
- Timeline: 2027-2030 for full operation

Strategic Positioning:

voestalpine serves high-value automotive and precision engineering markets. They can potentially pass through green steel cost premiums to customers (BMW, Mercedes, industrial applications requiring ESG compliance).

3.2.4 Japan: The Ultra-Premium, Long-Timeline Approach

Characteristics:

- Multiple pilot H-DRI projects
- Very high-quality steel focus (automotive, precision manufacturing)
- Patient capital, long-term strategic thinking
- Timeline: Full commercial deployment 2035-2040

Japanese Strategy:

Rather than rushing to deployment, Japan emphasizes perfecting the technology. This matches their industrial culture (precision, quality, long-term thinking) but results in slower absolute emissions reduction.

3.3 The Linguistic Bloc Analysis

Original Insight by Professor Miani:

There appears to be a correlation between linguistic/cultural blocs and steel decarbonization strategies:

Table 5: Linguistic Bloc Patterns in Steel Strategy

Linguistic/Cultural Bloc	Steel Strategy	Potential Explanatory Factors
German-speaking (Germany, Austria)	H-DRI marathon runners	Gründlichkeit (thoroughness), engineering perfectionism, hydropower potential
Nordic (Sweden, Finland)	H-DRI marathon runners	Abundant hydropower, environmental leadership identity
Romance/Mediterranean (Italy, Spain, France*)	EAF sprint runners (historically)	Pragmatic, scrap-based economics, no domestic iron ore
Sinosphere (China)	Rapid EAF expansion (recent)	(speed), centralized execution, industrial policy control
Anglosphere (USA, UK)	EAF-based (achieved earlier)	Market-driven disruption (Nucor model), early minimill adoption

*France is more complex, with both large integrated mills and EAF presence

Interpretation Caution:

This analysis is provocative and potentially insightful, but must be handled carefully:

- Correlation $\neq$ causation
- Geography (hydropower, scrap availability) may be more explanatory than culture
- Industrial path dependencies matter (existing infrastructure)
- Could be seen as deterministic or stereotyping if not nuanced

Suggested Framing: "Industrial cultures and geographic advantages interact to create distinct strategic approaches, rather than determining outcomes mechanistically."

4 The Capital Requirement: Why "Just Switch to EAF" Isn't Simple

4.1 The Question: What Would Global Conversion Cost?

Scenario: Forget the scrap shortage constraint for the moment. If we had unlimited scrap availability, how much capital would be required to convert all remaining BF-BOF capacity (approximately 1,330 Mt/year globally) to EAF?

4.2 The Real-World Data Point: ABS Acciai

Disclosure: Professor Miani was Chief Metallurgist at ABS Acciai SpA in the 1990s. ABS Acciai is Danieli's demonstration/prototype plant for premium special steelmaking.

Recent Project:

- Danieli Q-One furnace installation
- Capacity: 600,000-700,000 tonnes/year
- Investment: Approximately €600 million
- Cost per tonne capacity: €857-1,000/tonne
- **Product:** Special/alloy steels (NOT commodity carbon steel)
- **Quality level:** Automotive-grade, precision engineering applications

Critical Distinction:

ABS Acciai represents *greenfield premium minimill* investment. This is the high end of the cost spectrum—the technology China is now buying to move upmarket from commodity steel.

4.3 The Cost Spectrum: Three Scenarios

4.3.1 Scenario A: Brownfield Optimization (€200-300/tonne)

Assumption: Convert existing BF-BOF facilities to EAF while retaining downstream infrastructure:

- **Keep:** Continuous casting machines, ladle furnaces, degassing stations, rolling mills, utilities, site logistics
- **Replace:** Blast furnaces, coke ovens, BOF, sintering plants
- **Add:** EAF, electrical infrastructure upgrades

Real-World Examples:

- Algoma Steel (Canada): 3.7 Mt/year, CAD $700M (€480M) = €130/tonne
- ArcelorMittal Hamburg: 3 Mt/year, €500M planned = €167/tonne
- Average: €200/tonne for brownfield conversion

Global Calculation: Cost = 1,330 Mt $\times 200/tonne$
$= 266billion$

$\approx \$285 billion$
$Over 5 years = \$57 billion/year$

4.3.2 Scenario B: Mixed Reality (€400-500/tonne)

Assumption:

- 50% brownfield conversions (€200/tonne)
- 50% require substantial new infrastructure (€600/tonne)
- Average: €400/tonne

Global Calculation: Cost = 1,330 Mt $\times 400/tonne$
$= 532 billion$
$\approx \$570 billion$
$Over 5 years = \$114 billion/year$

4.3.3 Scenario C: Premium Quality Everywhere (€857-1,000/tonne)

Assumption: ABS Acciai-level quality (Professor Miani's direct experience):

- Greenfield premium minimills
- Danieli/SMS/Primetals technology
- Automotive-grade quality capability
- Complete infrastructure (as if building new facilities)

Global Calculation: Cost = 1,330 Mt $\times 1,000/tonne$
$= 1.33 trillion$
$\approx \$1.43 trillion$
$Over 5 years = \$286 billion/year$

4.4 Context: How Large Are These Numbers?

Table 6: Capital Requirement Context

Investment Program	Amount (USD)	Timeframe
BF→EAF (Scenario A)	$285 billion	5 years
BF→EAF (Scenario B)	$570 billion	5 years
BF→EAF (Scenario C)	$1,430 billion	5 years
US Infrastructure Bill	$1,200 billion	10 years
EU Green Deal Investment	€1,000 billion	10 years
China Belt & Road Initiative	$1,000 billion	10 years (est.)
Global renewable energy (annual)	$500 billion	Per year
Global military spending (annual)	$2,240 billion	Per year
Global steel industry revenue	**$1,900 billion**	**Annual**
Global steel industry profit (good year)	**$100-150 billion**	**Annual**

4.5 The Brutal Economic Reality

Even the "optimistic" brownfield scenario ($285 billion) would require:

- 60% of annual global steel industry profits for 5 consecutive years
- Or: 15% of global steel revenue for 5 years
- Or: Debt financing requiring investment-grade credit (not available to all producers)
- Or: Government subsidies at unprecedented scale

Current Reality (2024-2025):

Announced global investment in EAF and green steel projects: approximately $30-50 billion over the next 5-10 years.

The Gap: Even for the cheapest brownfield scenario, current commitments are 5-6× insufficient.

4.6 The Scrap Constraint We Ignored

Earlier, we assumed "unlimited scrap availability." This was deliberate oversimplification. Now address the reality:

Global Scrap Economics (2024):

- Total scrap collected: 750 Mt/year
- Current EAF consumption: 570 Mt/year
- Available surplus: 180 Mt/year

If We Tried Full EAF Conversion: Scrap needed = 1,330 Mt $\times 80\% scrap ratio$
$= 1,064 Mt/year$
$Current surplus = 180 Mt/year$
$SHORTFALL = 884 Mt/year$

Conclusion: Even with unlimited capital, full EAF conversion is physically impossible without:

1. Decades for scrap accumulation (as infrastructure ages and becomes available)
2. OR massive DRI production (defeating the purpose of "cheap" EAF path)
3. OR radical material efficiency / circular economy transformation

4.7 Why China's Strategy Makes Sense

China's Pragmatic Approach:

- **NOT attempting:** Full conversion to EAF (impossible due to scrap)
- **ACTUALLY doing:** Partial conversion (10% $\rightarrow$ 15% = 50 Mt capacity)
- **Investment:** €15-25 billion (achievable)
- **Scrap requirement:** 40 Mt/year additional (within available surplus)
- **CO reduction:** 60 Mt/year (massive absolute impact)

This is why pragmatism beats perfectionism in climate impact.

5 A Personal Witness Account: The Metamorphosis Project

5.1 Disclosure and Credibility

Professor's Background:

- Chief Metallurgist, ABS Acciai SpA (1990s)
- Instructor, Danieli Metamorphosis Project, University of Udine (2006-2008)
- 30+ years observing steel industry technology transfer

This section presents a first-hand account of systematic technology transfer from European steel facilities and universities to emerging industrial nations, with focus on implications for current decarbonization competition.

5.2 The 1990s: Shop Floor Training at ABS Acciai

5.2.1 The Ladle Furnace Station

What is the Ladle Furnace (LF)?

After steel leaves the EAF or BOF, it enters the Ladle Furnace for secondary metallurgy. This is where premium steel quality is actually achieved:

- **Desulfurization:** Reduce sulfur to <20 ppm (automotive requirement)
- **Inclusion control:** Float out oxides (bearing steel cannot tolerate inclusions)
- **Alloy additions:** Precise composition control (±0.01% tolerance for aerospace)
- **Temperature control:** Exact temperature for continuous casting quality
- **Degassing:** Vacuum treatment for ultra-clean steel

Why LF Knowledge Matters:

The difference between commodity steel ($220/tonne) and premium automotive-grade steel ($650/tonne) is largely determined by LF operations. This is *craft knowledge*—you cannot learn it from textbooks alone.

5.2.2 The Observation: "Full of Chinese Guys in Training"

Professor's Direct Account:

"In the 1990s at ABS Acciai, our Ladle Furnace stations were full of Chinese engineers in training. Good people. Smart. Asking excellent questions. Taking detailed notes."

What We Thought Then:

- Standard customer training practice
- Good business for ABS Acciai / Danieli
- Technology export benefiting Italian economy
- Building international relationships

What We Didn't Realize:

- We were training future competitors
- Transferring 50+ years of European metallurgical knowledge in 6-12 month training programs
- Those trainees would return to build China's premium steel capacity
- The knowledge transfer was irreversible

5.3 The 2000s: Formal Academic Training (University of Udine)

5.3.1 The Danieli Metamorphosis Project

Official Description (from Danieli website):

"At the forefront of research and training of talents... Accelerated ramp-up of the factories in India and Russia."

What This Actually Was:

A systematic, university-level training program for engineers from China, Russia, Ukraine, and India—already employed by Danieli—to acquire theoretical foundations to complement shop floor training.

5.3.2 Professor Miani's Direct Involvement (2006-2008)

Courses Taught:

- Advanced metallurgy theory
- Secondary steelmaking processes
- Quality control systems
- Process optimization
- Clean steel production
- Special steel alloy design

Student Composition:

- **Chinese engineers:** Largest group, returning to build China's premium steel capacity
- **Russian engineers:** Building Russia's modern steel sector
- **Ukrainian engineers:** Developing Ukraine's steel industry (then 4th largest in Europe)
- **Indian engineers:** Expanding India's growing steel sector

Critical Detail: Professor wrote in his notes: "Russian and Ukrainian (then friends)"—because in 2006-2008, they were classmates learning together. Within 15 years, some would be on opposite sides of a war.

5.3.3 The Industry-Wide Pattern

Not Just Danieli:

Professor's observation: "SMS and Primetals I believe were running something the like"

All three major equipment vendors (Danieli, SMS Group, Primetals Technologies) have branches in the Udine region. Industry-wide technology transfer through parallel training programs was likely occurring.

Estimated Scale:

- 3 major vendors running parallel programs
- 10+ years duration (mid-2000s to mid-2010s)
- Dozens to hundreds of engineers trained per vendor
- Total: 1,000-3,000+ metallurgists/engineers from BRIC countries

5.4 The 2010s-2020s: Deployment and Competition

5.4.1 Where Did Those Students Go?

China:

- Building premium minimills using Danieli/SMS/Primetals technology
- Installing ABS Acciai-type facilities (€800-1,000/tonne investments)
- Moving upmarket: from $220/tonne commodity $\rightarrow$ $500-800/tonne premium
- Targeting automotive, aerospace, precision engineering markets

India:

- Rapidly expanding capacity (now 140 Mt/year, 2nd globally)
- Using knowledge from Metamorphosis-trained engineers
- Increasingly competitive in export markets

Russia:

- Modernized steel industry using European technology
- Post-2022 sanctions: Now isolated, but retains transferred knowledge
- Cannot get new Western equipment, but can operate what they have

Ukraine:

- Tragic footnote: Much steel capacity destroyed in 2022 war
- Some trained engineers now refugees, possibly in European industry

5.5 The Strategic Questions This Raises

5.5.1 For Universities

Question: Should universities participate in corporate training programs that transfer strategic industrial technology to potential competitors?

Arguments FOR:

- Knowledge should be shared globally

- Steel technology aids economic development
- Academic mission includes international education
- Universities need industry funding

Arguments AGAINST:

- Undermines home nation's industrial competitiveness
- Transfers strategic capabilities
- May have unintended geopolitical consequences (Russia-Ukraine example)
- Benefits may be captured by companies, costs borne by society

5.5.2 For Equipment Vendors

Question: Did Danieli, SMS Group, and Primetals Technologies make rational business decisions that were collectively strategically harmful to European steelmaking?

Vendor Logic (Short-term):

- BRIC countries represent huge markets
- "If we don't sell/train, our competitors will"
- Revenue funds European RD and employment
- Training programs justify premium pricing
- University partnerships add credibility

Long-term Consequences:

- Created competitors to their traditional customers (European steelmakers)
- Transferred strategic knowledge irreversibly
- Enabled BRIC industrial rise
- European steelmakers complain: "You armed our competitors!"

Classic Tragedy of the Commons: Each vendor acts rationally individually, but collectively they transform global competition permanently—potentially against their traditional customer base's interests.

5.5.3 For National Industrial Policy

Question: Should European governments have regulated this technology transfer?

Challenges:

- How do you regulate "training services"?
- WTO commitments limit technology export restrictions
- China was a "responsible stakeholder" in early 2000s (pre-Xi assertiveness)
- Difficult to predict 20-year consequences

- Export controls exist for military technology, but steel seemed "peaceful"

Comparison:

- USA now restricts semiconductor equipment sales to China
- Netherlands restricts ASML lithography equipment exports
- But in 2000s, steel technology seemed less strategically sensitive

5.6 The Metamorphosis: What Actually Transformed

What Danieli Called "Metamorphosis": Traditional steel → Modern efficient steel production

What Actually Transformed:

1. **Europe:** Technology leader → Declining producer (in relative terms)
2. **BRIC:** Emerging markets → Industrial competitors
3. **Knowledge:** European monopoly → Globalized commodity
4. **Competitive advantage:** Eroded irreversibly

5.7 The Irreversibility

Professor's Key Insight:

"Once knowledge transfers, it's gone forever. You can sanction Russia, but you can't un-teach what Russian engineers learned. You can compete with China, but you can't un-train Chinese metallurgists. The butterfly emerged from its chrysalis. And it flew away. That's metamorphosis."

6 Who's Winning? Depends on Which Race You're Watching

6.1 The Sprint: Absolute Emissions Reduction by 2030

Metric: Total CO reduction achieved by 2030

Clear Leader: China

- 50-75 Mt capacity conversion (10% $\rightarrow$ 15% EAF)
- 600 Mt CO reduction by 2027-2030
- Investment: €15-25 billion (achievable, committed)
- Technology: Proven EAF (low risk)

Established Position: USA

- Already 70% EAF (420 Mt CO reduction vs hypothetical BF-BOF baseline)
- Limited further rapid progress (harder residual 30%)
- Not "winning" now, but won their race in the 1980s-1990s

European Marathon Runners:

- Germany, Sweden, Austria: Perhaps 40-50 Mt total capacity in H-DRI projects
- 30-40 Mt CO reduction by 2030-2035
- High investment per tonne, high technology risk
- Much smaller absolute impact by 2030

If Climate Impact by 2030 is the Metric: China wins decisively.

6.2 The Marathon: Ultimate Emissions Intensity

Metric: Lowest possible CO per tonne steel, regardless of timeline

Technology Leaders: Germany, Sweden, Austria

- H-DRI-EAF: 90-95% emissions reduction potential
- Full commercial deployment: 2030-2040
- If successful, lowest carbon intensity globally
- Premium market positioning ("green steel" certification)

EAF Pragmatists: China, USA, Italy, Spain

- EAF + scrap: 60-70% emissions reduction
- Reaching diminishing returns (scrap constraint)
- Would need DRI for remaining 20-30% reduction
- Economic logic favors natural gas DRI over H-DRI (2-3× cheaper)

If Ultimate Technical Achievement is the Metric: Germany/Sweden's H-DRI approach wins—if it achieves commercial viability at scale.

6.3 The Geopolitical Race: Industrial Competitiveness

Metric: Who controls future steel production and strategic industrial capacity?

China's Strategic Position:

- 53% global production (1,015 Mt/year)
- Rapidly adding EAF capacity (pragmatic decarbonization)
- Buying European premium technology (Danieli, SMS, Primetals)
- Moving upmarket: \$220/t $\rightarrow$ \$500-800/t premium steel
- Training was completed decades ago (1990s-2000s)
- Can now compete in premium markets with European-equivalent technology at Chinese cost structure

Europe's Strategic Position:

- Technology leadership in H-DRI (potentially)
- But: Equipment vendors already transferred much knowledge to China
- Declining production share (overcapacity, Chinese competition)
- High energy costs, regulatory burden
- Betting on green steel certification as remaining advantage

Potential Scenario (2035):

- China produces premium steel at \$400-500/tonne using Danieli-equivalent technology
- Germany produces "green steel" at \$650-800/tonne with H-DRI
- Question: Will customers pay \$150-300/tonne premium for "green" certification?
- Answer depends on CBAM (Carbon Border Adjustment Mechanism) and ESG requirements

If Industrial Competitiveness is the Metric: China is winning through scale, cost structure, and acquired European technology.

6.4 The Thermodynamic Reality Check

All strategies face fundamental physical constraints:

6.4.1 The Scrap Ceiling

Reality: Global scrap generation is limited by existing steel stock aging and becoming available.

- Current: 750 Mt/year available
- Maximum potential (2040): Perhaps 900-1,000 Mt/year
- Insufficient for full EAF conversion globally

Implication: World needs 400-500 Mt/year DRI capacity (either H-DRI or NG-DRI) regardless of strategy choices.

6.4.2 The Hydrogen Challenge

Green H Requirements for Steel:

If 400 Mt/year DRI using hydrogen:

- H consumption: 50 kg H/tonne DRI
- Total H needed: 20 million tonnes/year
- Electrolyzer capacity: 200-250 GW (at high utilization)
- Electricity required: 800-1,000 TWh/year of additional renewable electricity

Context:

- Current global electrolyzer capacity: <10 GW
- Current green H production: <1 million tonnes/year
- Need 20-25× scale-up just for steel sector

The hydrogen needed for steel decarbonization alone is a massive infrastructure challenge, roughly equivalent to adding 10-15% to global renewable electricity generation.

6.5 The Policy Implications

6.5.1 For Climate Policy

The Uncomfortable Trade-off:

- **Fast + Good:** China's EAF expansion achieves 60-70% reduction by 2030 (600 Mt CO saved)
- **Slow + Perfect:** Europe's H-DRI achieves 90-95% reduction by 2035 (40 Mt CO saved)

Question for policymakers: Does the climate emergency allow us the luxury of waiting for perfect solutions, or should we deploy good solutions immediately?

Alternative Policy Approach:

1. **Phase 1 (2024-2030):** Maximize EAF deployment where scrap available (60-70% reduction)
2. **Phase 2 (2027-2035):** Deploy natural gas DRI as bridge (65-75% reduction, available now)
3. **Phase 3 (2030-2040):** Transition NG-DRI to H-DRI as green hydrogen becomes economically viable (90-95% reduction)

This sequential approach maximizes near-term emissions reduction while maintaining pathway to ultimate deep decarbonization.

6.5.2 For Industrial Policy

European Strategic Dilemma:

- Past: Transferred technology advantage to emerging competitors (Metamorphosis Project)
- Present: Betting on H-DRI technology leadership as remaining differentiation
- Future: Will green steel certification be valuable enough to sustain European industry?

Critical Dependency: CBAM (Carbon Border Adjustment Mechanism) must work effectively, or European high-cost green steel cannot compete with Chinese lower-cost decarbonized steel.

Alternative Consideration:

Should Europe pursue Chinese-style pragmatic decarbonization (EAF expansion) rather than betting entire strategy on H-DRI? This would achieve faster emissions reduction with lower cost and risk, albeit giving up on "first mover" advantage in H-DRI.

6.5.3 For Technology Transfer Governance

Lessons from the Metamorphosis Project:

1. Knowledge transfer through "training programs" can circumvent export controls
2. University participation provides credibility and accelerates transfer
3. Individual company decisions (rational) can have collective strategic costs
4. Effects manifest over decades, making contemporary assessment difficult
5. Once transferred, knowledge cannot be "taken back" through sanctions or policy

Current Analogies:

- Semiconductor manufacturing equipment (USA/Netherlands restricting to China)
- AI model training and deployment (export control debates)
- Battery technology (Chinese dominance partly through technology absorption)

Question: Are we repeating the pattern in new technology domains, or have lessons been learned?

7 Conclusion: Multiple Races, Multiple Winners

7.1 The Core Insight

Steel decarbonization and green steel are not synonyms. They represent different objectives with different timelines, technologies, costs, and strategic implications.

The Athletic Analogy Revisited:

- **100m Sprint:** China is winning decisively through rapid EAF deployment
- **Marathon:** Germany/Sweden lead technologically in H-DRI, but commercial success unproven
- **Athlon (already completed):** USA, Italy, Spain won decades ago through early EAF adoption

Asking "who is winning?" requires first asking "which race are we measuring?"

7.2 The Climate Perspective

From an atmospheric CO perspective:

By 2030:

- China's pragmatic approach will have eliminated 600 Mt CO/year
- Europe's aspirational approach will have eliminated 40 Mt CO/year
- USA maintains 420 Mt CO reduction achieved in prior decades

Critical Question: Does the climate care whether reduction is achieved through "decarbonization" (EAF, 65%) or "green steel" (H-DRI, 95%), or does it only respond to absolute tonnes CO not emitted?

If climate urgency is genuine, perhaps perfect should not be the enemy of good.

7.3 The Industrial Perspective

From a competitiveness standpoint:

Technology Transfer Consequences:

- 1990s-2000s: European companies and universities transferred decades of metallurgical knowledge to BRIC engineers
- 2010s-2020s: Those engineers built competing steel industries using European technology
- 2030s projection: China competes in premium markets with European-equivalent technology at lower cost structure

Remaining European Advantages:

- H-DRI technology leadership (if successful)
- Green steel certification (if CBAM creates value)
- Brand/quality reputation (diminishing as Chinese quality improves)

- Proximity to premium customers (valuable but not decisive)

Industrial competitiveness increasingly depends on policy-created advantages (CBAM, subsidies) rather than technological superiority alone.

7.4 The Personal Reflection

Professor Miani's 30-year witness account provides unique perspective:

1990s: Training Chinese metallurgists at ABS Acciai Ladle Furnaces—"seemed like good business"

2000s: Teaching Danieli Metamorphosis courses at University of Udine—"standard academic practice"

2020s: Watching those trained engineers build competing industries—"irreversible transformation"

The Question: Was this avoidable, or was it inevitable consequence of globalization and WTO integration?

Professor's Conclusion: "Once knowledge transfers, it's gone forever. The butterfly emerged from its chrysalis. That's metamorphosis. We can't un-train the metallurgists I taught in the 1990s and 2000s. We can only decide what we do next."

7.5 Final Synthesis: What Should We Do?

7.5.1 For Climate Policy

Recommendation: Deploy available technologies immediately (EAF, NG-DRI) while developing ultimate solutions (H-DRI).

Rationale: The atmosphere doesn't distinguish between 65% reduction now and 95% reduction in 2040. Cumulative emissions matter. Fast partial reduction beats slow perfect reduction for climate impact.

7.5.2 For Industrial Strategy

Recommendation: European steel should pursue both pragmatic decarbonization AND green steel differentiation.

Rationale:

- Can't compete with China on cost in commodity grades (that ship sailed with technology transfer)
- Can potentially compete on green certification if CBAM works
- Must maintain production base for strategic industries (automotive, aerospace, defense)
- Should not put all eggs in H-DRI basket (too risky, too expensive)

7.5.3 For Technology Governance

Recommendation: More careful consideration of strategic technology transfer, especially through "training" channels.

Rationale:

- Export controls exist for equipment, but training programs circumvent them
- University participation accelerates transfer and provides credibility
- Individual company rationality can create collective strategic costs
- Should apply lessons from steel to emerging technology domains (AI, quantum, synthetic biology)

7.6 The Provocative Closing Question

For Student Debate:

Debate Question:
Professor Miani trained Chinese, Russian, Ukrainian, and Indian metallurgists in the 1990s (shop floor) and 2000s (university courses). Those engineers now run steel facilities competing with European producers.
Was this:

- An ethical choice? (knowledge sharing benefits humanity)
- A strategic mistake? (armed competitors)
- An inevitable consequence? (globalization makes knowledge transfer unstoppable)
- All of the above?

And the follow-up question: **What would YOU have done differently in 1990 or 2006, knowing what we know in 2025?**

A Data Tables and References

A.1 Global Steel Production by Route (2024)

Table 7: Global Steel Production Routes

Production Route	Capacity (Mt/year)	% of Total	CO Intensity (kg/tonne)
BF-BOF (integrated)	1,330	70%	1,800-2,200
EAF (scrap-based)	570	30%	400-600
Total	**1,900**	**100%**	**Average: 1,950**

A.2 Regional EAF Penetration

Table 8: EAF Share by Major Steel-Producing Regions

Region/Country	Total Production (Mt)	EAF Share (%)	EAF Capacity (Mt)
China	1,015	10-15%	102-152
India	140	55-60%	77-84
Japan	87	25%	22
USA	81	70%	57
Russia	76	30%	23
South Korea	67	30%	20
Germany	36	30%	11
Turkey	33	70%	23
Brazil	31	35%	11
Italy	21	70%	15
Spain	11	75%	8
World Total	**1,900**	**30%**	**570**

A.3 Major H-DRI Projects (Europe)

A.4 Capital Expenditure Estimates by Technology

A.5 Key Cost Parameters for H-DRI Economics

Table 9: Announced H-DRI Steel Projects

Project	Country	Capacity (Mt/y)	Investment (€B)	Target Date
ThyssenKrupp Duisburg	Germany	3.0	2.0-3.0	2026-2030
Salzgitter SALCOS	Germany	2.0	1.5	2026-2033
ArcelorMittal Hamburg	Germany	3.0	0.5-1.0	Under review
HYBRIT (SSAB + partners)	Sweden	1.3-2.5	1.5-2.0	2026-2030
H2 Green Steel	Sweden	5.0	2.5-3.0	2025-2030
voestalpine Linz	Austria	2.5	1.5	2027-2030
Total (Selected)		**17-19**	**9.5-13.0**	**2025-2033**

Table 10: CAPEX per Tonne Annual Capacity (2024 Estimates)

Technology/Configuration	€/tonne	Notes
EAF brownfield conversion	130-300	Reuses existing downstream (CCM, rolling)
EAF greenfield commodity	300-500	Basic minimill, construction-grade steel
EAF greenfield premium	800-1,000	Danieli Q-One type, automotive-grade
H-DRI-EAF greenfield	600-1,000	Includes DRI plant + EAF + infrastructure
BF-BOF greenfield	1,200-1,500	Full integrated mill (rarely built now)

B Suggested Student Exercises

B.1 Exercise 1: The Sprinter vs Marathon Calculation

Objective: Quantify absolute emissions impact of different strategies.

Scenario A (China Sprint):

- Convert 50 Mt/year capacity from BF-BOF to EAF
- BF-BOF emissions: 2.0 tonnes CO/tonne steel
- EAF emissions: 0.5 tonnes CO/tonne steel
- Timeline: 3 years (2025-2027)

Scenario B (Germany Marathon):

- Build 5 Mt/year H-DRI-EAF capacity
- BF-BOF emissions: 2.0 tonnes CO/tonne steel
- H-DRI-EAF emissions: 0.1 tonnes CO/tonne steel
- Timeline: 8 years (2025-2032)

Table 11: Hydrogen DRI Cost Sensitivities

Parameter	**Current (2024)**	**Target**	**Impact on Steel Cost**
Green H price	$9-10/kg	$4-5/kg	$200-250/tonne steel
Electricity price	$60-80/MWh	$30-40/MWh	$100-150/tonne steel
DRI CAPEX	€600-800/t	€400-500/t	$50-100/tonne steel
Capacity factor	60-70%	85-90%	$80-120/tonne steel
Total cost premium vs BF-BOF: Currently $400-600/tonne, Target $100-200/tonne			

Questions:

1. Calculate annual CO reduction for each scenario once fully operational.
2. Calculate cumulative CO reduction 2025-2035 accounting for different timelines.
3. Which approach eliminates more CO by 2030? By 2035? By 2040?
4. What discount rate (if any) should we apply to future emissions reductions for climate impact?

B.2 Exercise 2: The Economics of Technology Choice

Scenario: A European steelmaker operates a 2 Mt/year BF-BOF plant and must choose decarbonization pathway.

Option A: EAF Brownfield Conversion

- CAPEX: €250/tonne = €500 million
- OPEX: Scrap cost $350/t, electricity $60/MWh
- Emissions reduction: 65%
- Timeline: 3 years to full operation
- Risk: Medium (scrap price volatility)

Option B: H-DRI-EAF

- CAPEX: €750/tonne = €1,500 million
- OPEX: Green H $8/kg, electricity $70/MWh
- Emissions reduction: 92%
- Timeline: 7 years to full operation
- Risk: High (H supply, technology, cost)

Additional Information:

- Current steel price: €650/tonne
- EU ETS carbon price: €80/tonne CO (projected €120/t by 2030)
- Available subsidy: 40% of CAPEX for Option B only

- Debt financing: 5% interest, 15-year term

Questions:

1. Calculate levelized cost of steel for each option.
2. Calculate NPV over 20 years with 7% discount rate.
3. At what carbon price does Option B become economically competitive with Option A?
4. How does CBAM (Carbon Border Adjustment) affect the competitive position?
5. What would you recommend and why?

B.3 Exercise 3: The Scrap Constraint

Objective: Understand physical limits on EAF expansion.

Given Data:

- Global steel stock: 60 billion tonnes (in infrastructure, buildings, vehicles)
- Average steel product lifetime: 40 years
- Collection efficiency: 85%
- EAF scrap charge: 80% scrap, 20% DRI/pig iron

Questions:

1. Calculate theoretical maximum annual scrap generation.
2. If global steel production is 1,900 Mt/year, what is maximum possible EAF share with current scrap availability?
3. How much DRI capacity would be needed to achieve 50% global EAF share? 70% share?
4. Estimate when scrap availability would support 70% global EAF share based on steel stock growth.
5. What policies could accelerate scrap availability?

B.4 Exercise 4: The Technology Transfer Debate

Objective: Analyze ethical and strategic dimensions of industrial knowledge transfer.

Scenario: You are a professor at a European university in 2006. A major equipment manufacturer (similar to Danieli) offers funding for a training program:

- €500,000 annual funding for 5 years
- Support for 3 PhD students and 2 postdocs
- You will teach advanced metallurgy to international engineers (employed by the company)
- Students will be from China, India, Russia, Ukraine
- Company will build demonstration facilities at your university

Assignment:

Prepare a 5-page memo to your university administration addressing:

1. **Benefits:** Research funding, international collaboration, industrial relevance, student opportunities
2. **Risks:** Technology transfer to potential competitors, strategic implications, long-term consequences
3. **Alternatives:** Different program structures, geographical restrictions, retention strategies
4. **Governance:** What oversight mechanisms would you recommend?
5. **Recommendation:** Accept, accept with modifications, or decline? Justify your position.

Discussion Questions:

- Should universities prioritize national industrial interests or global knowledge sharing?
- Can you effectively restrict knowledge transfer once training occurs?
- What is the university's responsibility for downstream consequences 20 years later?
- Compare to current debates: AI technology transfer, semiconductor manufacturing, biotechnology

B.5 Exercise 5: Regional Strategy Analysis

Objective: Develop decarbonization strategy appropriate to regional characteristics.

Select a Region:

1. China (1,015 Mt/year, 10-15% EAF, growing scrap)
2. India (140 Mt/year, 55% EAF, rapid growth)
3. USA (81 Mt/year, 70% EAF, mature market)
4. Germany (36 Mt/year, 30% EAF, high energy costs)
5. Japan (87 Mt/year, 25% EAF, premium quality focus)

Analysis Requirements:

For your chosen region, develop a 10-page strategy document addressing:

1. **Current State:** Production volume, technology mix, emissions intensity, cost structure
2. **Constraints:** Scrap availability, energy costs, hydrogen infrastructure, capital availability
3. **Opportunities:** Existing infrastructure, policy support, market positioning
4. **Technology Roadmap:** Phased approach 2025-2040 with specific projects and timelines
5. **Economics:** Investment requirements, funding sources, expected cost per tonne
6. **Emissions Impact:** Annual and cumulative CO reduction by decade
7. **Competitiveness:** How does strategy affect global market position?
8. **Risks:** Technology, economic, geopolitical risks and mitigation strategies

Presentation: Defend your strategy to the class, addressing questions about trade-offs and alternatives.

C Recommended Further Reading

C.1 Core Technical References

1. **International Energy Agency (IEA)** - *Iron and Steel Technology Roadmap* (2020, updated 2023)
   - Comprehensive technology assessment
   - Scenario analysis for decarbonization pathways
   - Available: www.iea.org
2. **Vaclav Smil** - *Still the Iron Age: Iron and Steel in the Modern World* (2016)
   - Historical perspective on steel technology
   - Thermodynamic and material constraints
   - Economic and social dimensions
3. **World Steel Association** - *Steel Statistical Yearbook* (Annual)
   - Production data by country and technology
   - Trade flows and consumption patterns
   - Available: www.worldsteel.org
4. **HYBRIT** - *Fossil-Free Steel: Technical Project Reports*
   - Detailed H-DRI technical documentation
   - Pilot plant operational data
   - Available: www.hybritdevelopment.se

C.2 Strategic and Economic Analysis

1. **Clayton Christensen** - *The Innovator's Dilemma* (1997)
   - Minimill disruption of integrated steel
   - Technology adoption and market dynamics
   - Relevant to understanding EAF vs BF-BOF transition
2. **Michael Porter** - *The Competitive Advantage of Nations* (1990)
   - Diamond framework for industrial competitiveness
   - Cluster effects and geographical advantages
   - Applicable to regional steel strategies
3. **Agora Industry** - *Climate-Neutral Steel: European Green Deal Industrial Strategy*
   - Policy analysis of European approach
   - Cost modeling and subsidy requirements
   - Available: www.agora-industry.org

C.3 Technology Transfer and Geopolitics

1. **Dan Breznitz & John Zysman** - *Run of the Red Queen: Government, Innovation, Globalization, and Economic Growth in China* (2013)
   - Technology absorption strategies
   - Industrial policy and innovation
2. **Chris Miller** - *Chip War: The Fight for the World's Most Critical Technology* (2022)
   - Contemporary technology competition
   - Parallels to steel technology transfer
   - Export controls and strategic technology

C.4 Primary Sources: Company and Policy Documents

1. **Danieli & C. Officine Meccaniche SpA**
   - Corporate history: www.danieli.com/en/about-us/history
   - Technology documentation for Q-One and QLP systems
   - Training center information
2. **European Commission** - *Carbon Border Adjustment Mechanism (CBAM) Documentation*
   - Regulatory framework for green steel certification
   - Implementation timeline and scope
3. **China State Council** - *Steel Industry Development Policies*
   - Capacity control and restructuring plans
   - Environmental and quality standards
   - Note: Official documents available in Chinese

D Glossary of Key Terms

BF-BOF Blast Furnace - Basic Oxygen Furnace: Integrated steelmaking route using iron ore and coal/coke. Emissions: 1.8-2.2 tonnes CO per tonne steel.

CBAM Carbon Border Adjustment Mechanism: EU policy to impose tariffs on imported goods based on embedded carbon emissions, creating market value for low-carbon production.

CCM Continuous Casting Machine: Equipment converting liquid steel into semi-finished products (slabs, blooms, billets). Can be retained during BF-BOF to EAF conversion.

DRI Direct Reduced Iron: Iron ore reduced using gas (natural gas or hydrogen) rather than coke, producing solid "sponge iron" for EAF feedstock. Lower emissions than blast furnace.

EAF Electric Arc Furnace: Steelmaking using electricity to melt scrap or DRI. Emissions: 0.4-0.6 tonnes CO per tonne steel (scrap-based).

Green Steel Steel produced with minimal CO emissions (typically >90% reduction), usually via H-DRI-EAF route with renewable electricity and green hydrogen.

H-DRI Hydrogen Direct Reduced Iron: DRI process using hydrogen instead of natural gas. Emissions: near-zero if green hydrogen used. Currently pilot/demonstration scale.

Ladle Furnace (LF) Secondary metallurgy station where steel chemistry is refined after initial melting. Critical for premium steel quality (desulfurization, degassing, precise alloying).

Minimill Steel plant based on EAF technology, typically smaller scale than integrated BF-BOF plants. Historically produced lower-quality products but technology now enables premium grades.

NG-DRI Natural Gas Direct Reduced Iron: DRI using natural gas (CH). Emissions: 1.2 tonnes CO per tonne steel (35-40% reduction vs BF-BOF). Commercially proven technology.

Scrap Recycled steel from end-of-life products, manufacturing waste, or demolition. Primary feedstock for EAF steelmaking. Availability limited by existing steel stock aging.

Steel Decarbonization Broad term for reducing CO emissions from steel production through any technology pathway. May achieve 60-70% reduction (EAF) or 90

Acknowledgments

This lecture synthesizes insights from:

- 30+ years of professional experience in steel metallurgy
- Direct participation in international technology transfer programs
- Analysis of contemporary decarbonization strategies globally
- Integration of frameworks from Smil, Christensen, Porter, and others

Special acknowledgment to the engineers I trained over decades—Chinese, Russian, Ukrainian, Indian, and others—whose dedication to learning and professional excellence was always impressive, regardless of subsequent geopolitical developments.

Disclaimer

Views expressed in this lecture are those of Professor Miani based on personal experience and professional analysis. They do not represent official positions of:

- University of Udine
- ABS Acciai SpA
- Danieli & C. Officine Meccaniche SpA
- Any government or international organization

Historical accounts of technology transfer programs are based on personal participation and observation. Students are encouraged to conduct independent research and form their own conclusions about strategic and ethical dimensions.

Contact Information

Professor Fabio Miani
Department of Polytechnic Engineering and Architecture
University of Udine
Via delle Scienze, 206
33100 Udine, Italy

Email: fabio.miani@uniud.it

As I am working chiefly in the very early morning, not precise office hours but always available for discussion and interactions, and for an office or online appointment. Most of materials here are as pdfs available at https://www.gotrawama.eu/estep25udine/pdf/.

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