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Sustainable Manufacturing – Technology

Opportunities, Trends, and Technoeconomic Analysis

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2019 PROGRAM PEER REVIEW
U.S. DEPARTMENT OF ENERGY ADVANCED MANUFACTURING OFFICE

AMO Strategic Analysis Team

The multi-laboratory **AMO Strategic Analysis Team** provides independent, objective, and credible information to inform decision-making.

This Poster provides example of the following Technology RD&D analysis topics:

1. **Technology Assessments:** Identify technical/economic/knowledge gaps, and deployment opportunities under current & prospective scenarios
2. **Long-Term Trend Analysis:** Domestic and international opportunities and risks facing manufacturers
3. **Analytical Tools and Data Development:** A broad foundation for credible analysis
4. **Collaborations:** Insights, information, topics and dissemination of StA analytical tools and data

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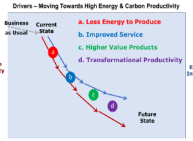

*AMO aims to improve the **energy productivity** of the U.S. manufacturing sector while reducing lifecycle energy and resource impacts of manufactured goods.*

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Analysis of Emerging Technologies

Technology Innovation is essential to manufacturing, yet undesirable impacts are difficult to change once a technology is extensively developed and widely used.
"The Collingridge Dilemma", 1980

Problem: The greatest opportunity to influence the design and ultimately environmental performance of a technology is during R&D; yet analysis has the least available data, greatest uncertainty, and a scarcity of tools and guidelines.

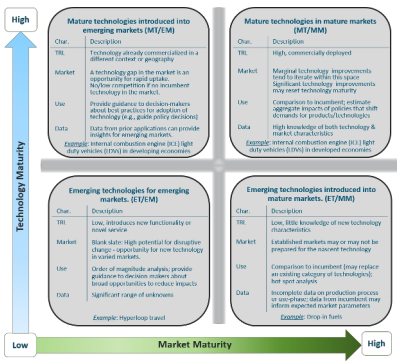
AMO StA Approach: Synthesize methods and develop appropriate new tools and guidelines.

Key Outcomes:

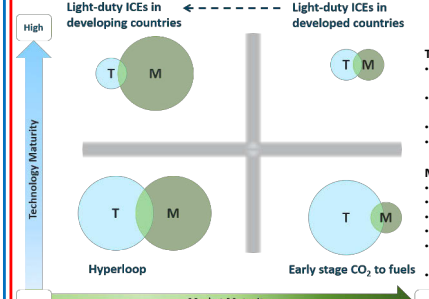
- **American Center for Life Cycle Assessment Conference Special Sessions on LCA of Emerging Technologies (2014-2018):** Round table audience input on LCA methods.
- **Publication: "***Life Cycle Assessment of Emerging Technologies: Evaluation Techniques at Different Stages of Market and Technical Maturity"* Special Issue on Life Cycle Analysis of Emerging Technologies, Journal of Industrial Ecology (in review)

Key Takeaway

Market and technology characteristics influence an analysis of emerging technologies.



Relative magnitudes of uncertainties associated with technology and market maturation and changes in uncertainty as technologies move between quadrants.



Emerging Technology Analysis Scoping Questions Outline:

Technology factors
- Interaction with technological system
- Functional materials (e.g., rare-earth metals for EV batteries)
- Commercialization pathway
- Production and use characteristics

Market Factor
- Service offered by the technology
- Background systems
- Consumer behavior
- Market dynamics
- Adoption patterns and characteristics of adoption regions
- Internal consistency

Industrial Sector Analysis: Global Industrial Decarbonization

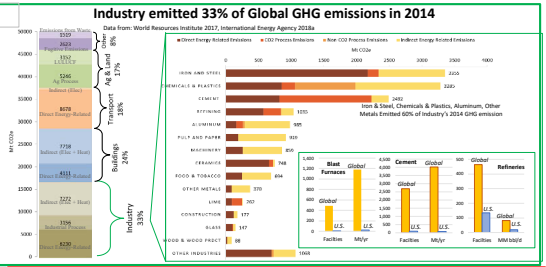
Motivation: Global Industrial Sector & Manufacturing Ecosystem

The Industrial Sector:
The historic trend toward specialization has lowered the total cost of producing manufactured products; manufacturing faculties are often interrelated by intermediate material inputs and outputs.

Global Manufacturing Ecosystem:
Inputs and outputs are increasingly subject to global supply and demand economics: either directly traded in global markets, or indirectly through supply chain materials traded in global markets.

U.S. Manufacturers:
Often have international markets and consumers, and technology development is increasingly influenced by international polices and regulations.

Industry emitted 33% of Global GHG emissions in 2014



Industrial Decarbonization Workshop; Aspen Global Change Institute, November 2018

Goal: Develop a blueprint for future action that addresses the inter-connected concerns of technical feasibility, cost-effectiveness, a supportive policy environment, and the need for social equity and global development associated with Global Industrial Decarbonization
Participants: 28 Experts in various industries, technology R&D, policy design, and sociological considerations of equity and global development.
International Represented: Australia, Canada, China, Germany, India, Norway, the United Kingdom, and the United States.

Workshop Report Highlights

"Technologies and Policies to Decarbonize the Industrial Sector"[†]

Key Findings
Industrial energy efficiency: *Near-term benefits*
Technology R&D *: Mid-term and long-term benefits*
Policies: *Accelerates/decelerates benefits*

Report Chapters:
Numerical Assessments, Technologies, Manufacturing Processes, and Research Directions, Policies. Business Cases, and Synergies, Draft version currently available. Final draft Summer 2019

Technologies, Manufacturing Processes, and Research Directions:

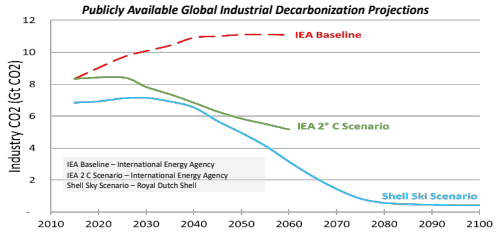
1) Materials and Carbon Capture
- Cement Production
- Iron and Steel Production
- Chemicals Production
- Chemical Separations
- Carbon Capture and Sequestration

2) Energy
- Energy Efficiency
- Electrification
- Hydrogen

3) Demand-Side
- Reduced Material Use: Longevity, Intensity, and Material Efficiency
- Additive Manufacturing (3D Printing)
- Material Substitution
- Circular Economy

Workshop Summary: Assessment of Abatement Potential

Publicly Available Global Industrial Decarbonization Projections

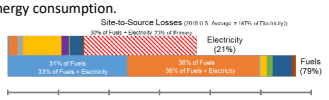


An Assessment of Abatement Potential in Global Industrial Decarbonization Projections

2020-2030	**Efficiency = 20% Emissions Reduction:** Incremental improvements in most industrial processes → Reductions taper after 2030 (diminishing returns). **Electrification:** Some processes shift towards electricity: light industry electricity use doubles from 2020 to 2040. **Total Emissions Reduction:** Largely offset by demand growth
2035-2060	**Structural Shifts Emerge = Further 30% Emissions Reduction:** emerging technologies nearing maturity for commercial deployment in the 2020-2035 timeframe. **Carbon Capture and Sequestration**: could deploy rapidly through this period → assuming a market pull or price push to incentivize it. **Total Emissions Reduction = 50%**
2060-2070	**Further Structural Shift Emerges = Further 30-50% reduction**: today's nascent process and energy. technologies develop rapidly: 2020-2050 pilot plant to demonstration plant → large-scale deployment beyond 2050. **Hydrogen:** scales rapidly in heavy industry. **Total Emissions Reduction < 100%** → A sufficient push could deliver net-zero emissions for industry.
2070-2120	**Fossil fuel use in industry shrinks** → with a long (and possibly fat) tail. **CCS:** little remaining use of CCS. **Total Emissions Reduction = 100%** → A zero-emission industrial sector eventually emerges.

Electrification: *Electrotechnology Assessments*

Motivation: A need to account for characteristics of electric heating processes, identify barriers to its implementation and determine its potential impact on US energy consumption.



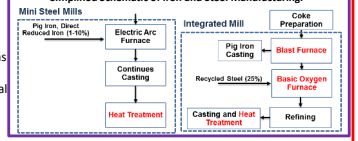
Overview
Industry Focused Analysis: Identify electrification opportunities in major industries process heating applications
Technology Focused Analysis: Specific electrotechnology capability, barriers, and traditional processes retrofit potential
- Fundamental energy-material interaction of the electrotechnology in processing different materials.
- LIGHTEnUp prospective scenario electrotechnology deployment.

The two approaches are co-dependent and together help achieve the study's goal

Methodology: Industry Based Analysis:

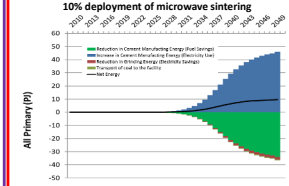
Step 1 - Identify major manufacturing steps or processes.
Step 2 - Collect energy use data for the selected processes
Step 3 - Identify applicable ETs which meet the process requirements
Step 4 - Find impact to energy consumption assuming large scale electrification based on considerations for thermal efficiency and other factors. (Technical Potential)

Simplified Schematic of Iron and Steel Manufacturing.



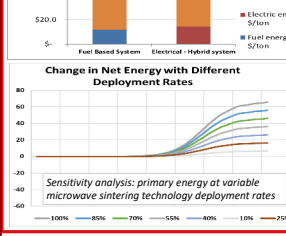
Technology Based Analysis - LIGHTEnUp Results

10% deployment of microwave sintering



Deployment Rates reflect Incremental Cost of microwave sintering vs traditional sintering

Change in Net Energy with Different Deployment Rates



Key Findings: Industry Based Analysis

Iron and Steel Sector - Process Heating: Energy Intensity & Alternatives

Process	Energy Intensity (MMBtu/ton)	Process Requirement	Electrotechnology Options
Ironmaking			
Blast Furnace	11.72	Reduction of iron ore into iron using coke and hot air blast. Sometime supplemented by gaseous fuel.	Option is to eliminate use of coke through use of plasma smelting process.
Direct Reduction – current in USA	9.17	Reduction of iron ore by solid reducing gases or other materials at 650 deg. C. There is very little external energy used other than the hot reducing gases/agents as reducing agent.	No good available option to produce reducing agent.
Steelmaking			
Basic Oxygen Furnace	0.68	Minimum external fuel used. The feed material is pig iron and other material added in BOF.	Electric heating in EAF to substitute BOF steel production.
Electric Arc Furnaces	1.66	Use of electricity and fuel. Electricity 1.42 MMBtu/ton. fuel 0.64 MM Btu/ton.	Plasma technology to replace fuel firing and achieve charge preheating
Rolling (Integrated and Mini Mills)			
Hot	2.58	Heating of steel slabes to up to 2300 deg. F mostly by using natural gas fuel.	Induction heating for continuous systems and resistance or some batch systems.

Process Heating Energy Results

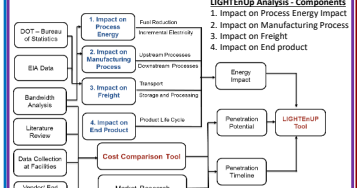
Case 1: All integrated steel mill operations are converted to mini mills + direct reduced iron.

Case 2: Traditional steel making processes converted electrowinning

Case	Description	Total On-site (TBtu/ year)	Total Primary (TBtu/ year)	Incremental Electricity On-site (TBtu/year)	Incremental Energy use at generation (TBtu/year)
	Baseline – Current Usage	880	1,174	-	-
1	Convert to Direct Reduced Iron (DRI) based EAF steel making process	1,028	1,750	277	899
2	Convert to Electrowinning iron production with EAF steel making	945	2,836	847	3,567

Methodology: Technology Based Analysis

Step 1 - Study microwave heating mechanisms
Step 2 - Review applications in industry
Step 3 - Develop case studies for specific applications using LIGHTEnUp tool
Step 4 - Expand the model to determine the application in a subsectors



LIGHTEnUp Analysis - Components
1. Impact on Process Energy Impact
2. Impact on Manufacturing Process
3. Impact on Freight
4. Impact on End product

Figure 2: Process Flow of LIGHTEnUp modelling Framework

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