IN ANCIENT GREECE, PLUTARCH WROTE OF A WOODEN SHIP THAT THESEUS SAILED FROM CRETE TO ATHENS. AS THE WOOD PLANKS DECAYED, ATHENIANS WOULD REPLACE THEM WITH NEW WOOD. EVENTUALLY, ALL OF THE PLANKS WERE REPLACED. THE SHIP LOOKED THE SAME, BUT NONE OF THE PARTS WERE THE SAME.

**IS IT STILL THE SAME SHIP?**

AND WHAT IF YOU GATHERED ALL OF THE DECAYED PLANKS AND FASHIONED THEM INTO ANOTHER SHIP…?

**WOULD *THAT* BE THE SAME SHIP?**


1

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2

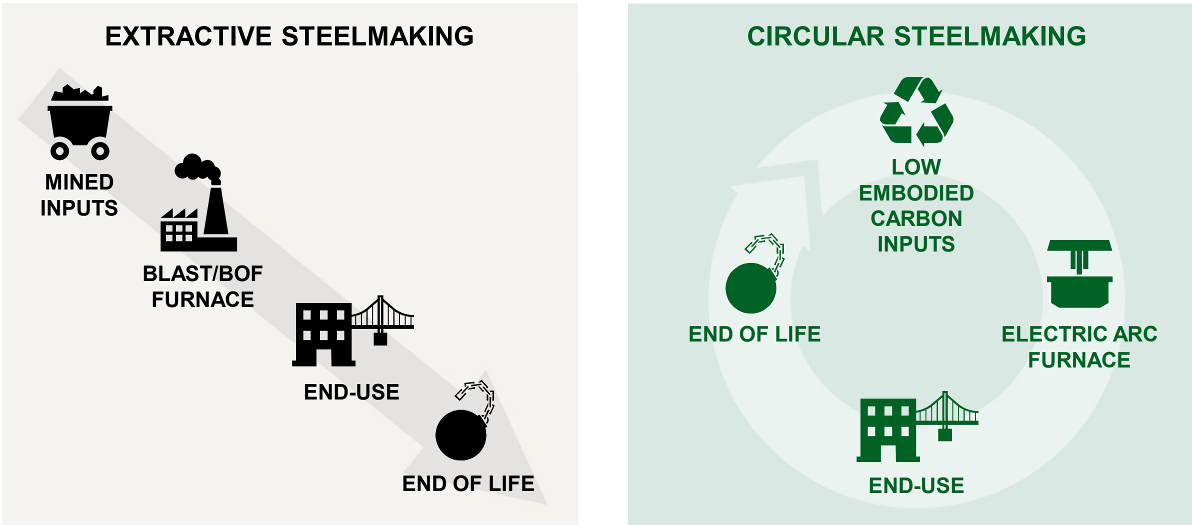

BOF & EAF PRODUCTION

3


BF-BOF
Basic Oxygen Furnace
CHINA, Present Day
Photo: Kevin Frayer, Getty Images
U.S. Steel, Gary Indiana
Photo: WBAA
EAF
Electric Arc Furnace

4

# EXTRACTIVE VS CIRCULAR STEELMAKING

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# EXTRACTIVE vs. CIRCULAR STATS

BOF EAF

| Extractive Steel | | Circular Steel |
|---|---|---|
| Coal, Iron Ore, Limestone | Primary Inputs | Recycled Steel, DRI |
| Up to 30% | Recycled Content Percentage | Up to 100% |
| 71% | Global Production Share | 29% |
| 31% | Domestic Production Share | 69% |
| 24.4 | Energy Required (GJ / tonne) | 10.0 |
| 3-4 | Man-hours worked ( /tonne) | 0.5 |
| **2.33 (2.37)** | **Carbon Intensity** (metric ton GHG /tonne) | **0.77** |

6

Data: World Steel Association, 2021.

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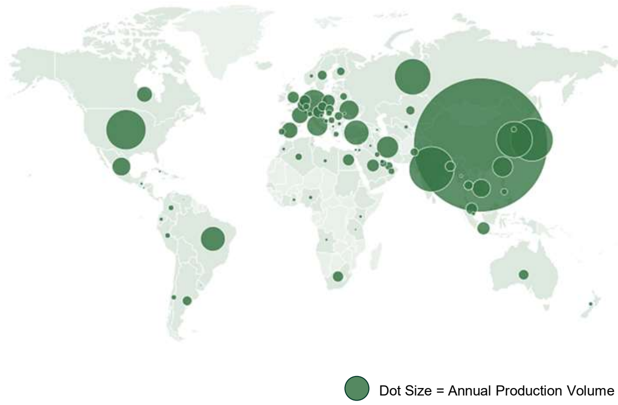
## GLOBAL STEEL PRODUCTION

Top 10 Countries By Tons Produced (2019)
- 84% of Total Global Production

| Rk | Country | Global Share | BOF | EAF |
|---|---|---|---|---|
| 1 | China | 53.3 % | 90 % | 10 % |
| 2 | India | 6.0 % | 44 % | 56 % |
| 3 | Japan | 5.3 % | 75 % | 25 % |
| **4** | **United States** | **4.7 %** | **30 %** | **70 %** |
| 5 | South Korea | 3.8 % | 68 % | 32 % |
| 6 | Russia | 3.8 % | 66 % | 34 % |
| 7 | Germany | 2.1 % | 70 % | 30 % |
| 8 | Turkey | 1.8 % | 32 % | 68 % |
| 9 | Brazil | 1.7 % | 78 % | 22 % |
| 10 | Iran | 1.4 % | 10 % | 90 % |




7 Data: World Steel Association, 2019.

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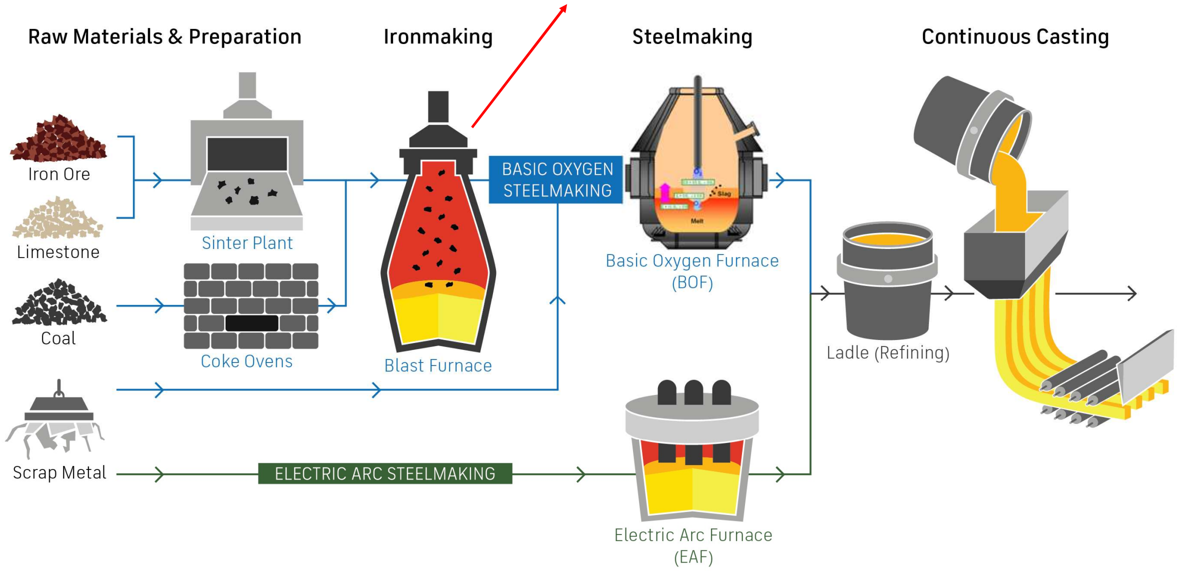
## PROCESS OVERVIEW

**iron ore + coal = iron + $CO_2$**

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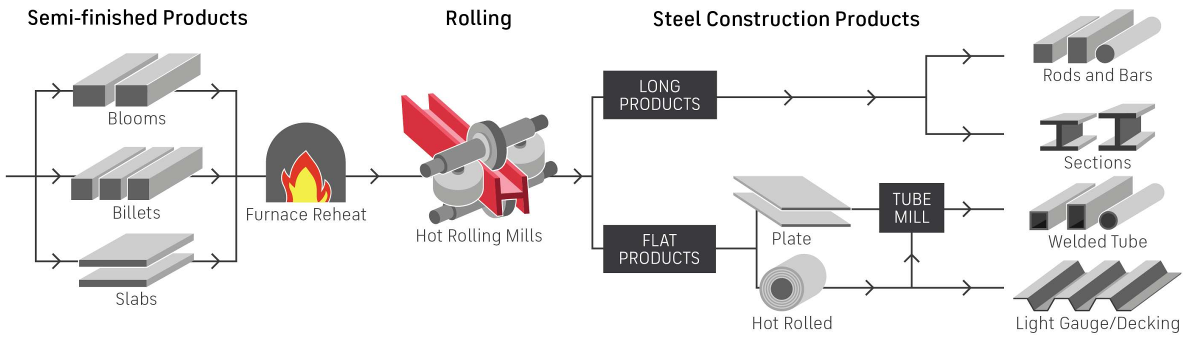
## PROCESS OVERVIEW: ROLLING MILL




9

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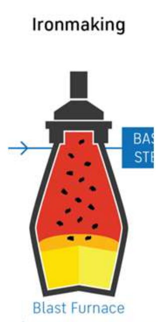
## IRON MAKING: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

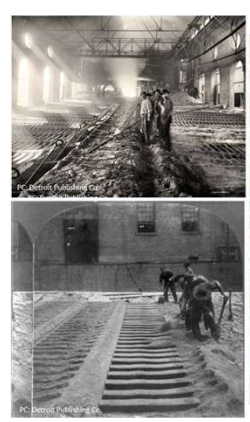



**Smelting:**
- Combine coke & sinter (limestone & iron ore) into Blast Furnace under high heat (2200-2900°F)
- Carbon monoxide "reduces" iron oxide (ore), transfers an electron from molecule, leaving nearly pure iron
- Lime helps remove impurities (sulfur, minerals, etc.)
- CO becomes $CO_2$

**"Pig Iron"**

**Direct Reduction:**
- Solid state = less energy (1500-1900°F)
- Carbon monoxide "reduces" iron oxide (ore), transfers an electron from molecule, leaving nearly pure iron
- Natural gas is common source ($CH_4$)
- C strips O from iron ore, becomes $CO_2$ (then can be captured)
- Hydrogen can also be used (electrolysis is cost-prohibitive)

**"Sponge Iron"**



10

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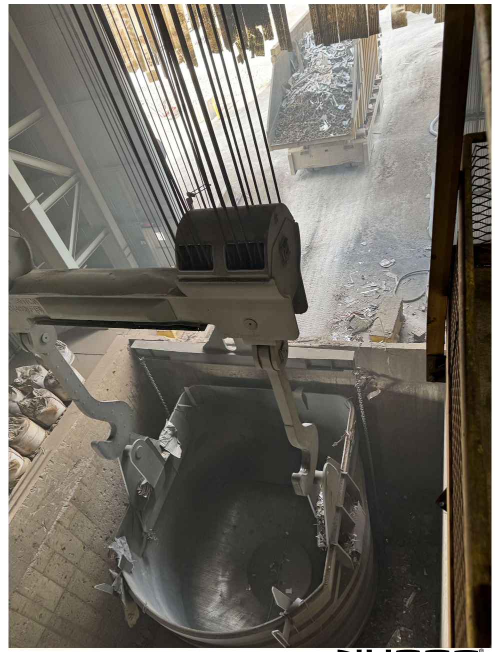
## “CHARGING” THE EAF



11

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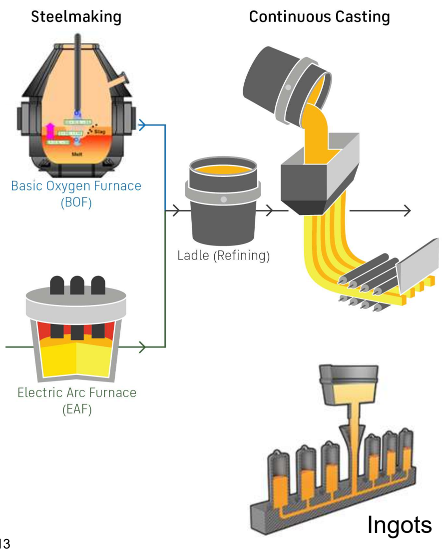
12

## PROCESS OVERVIEW: MELT SHOP

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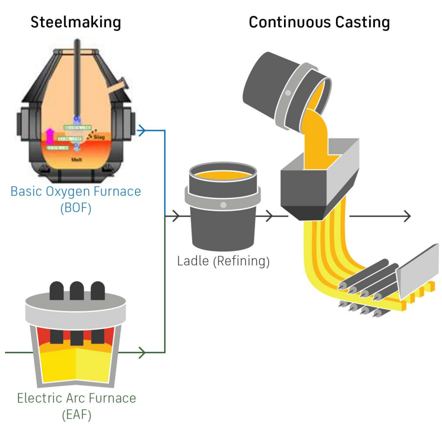
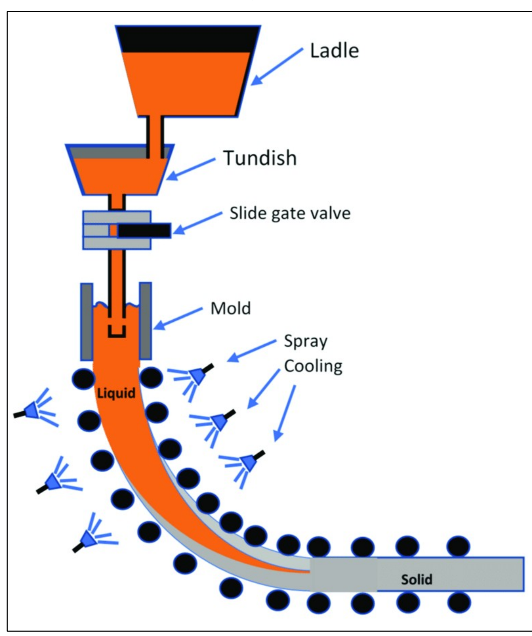
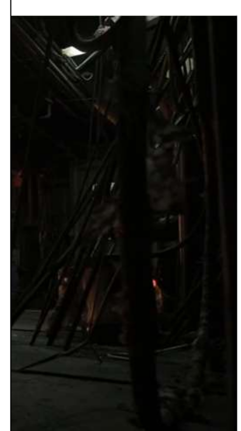
13

## PROCESS OVERVIEW: MELT SHOP & CASTER



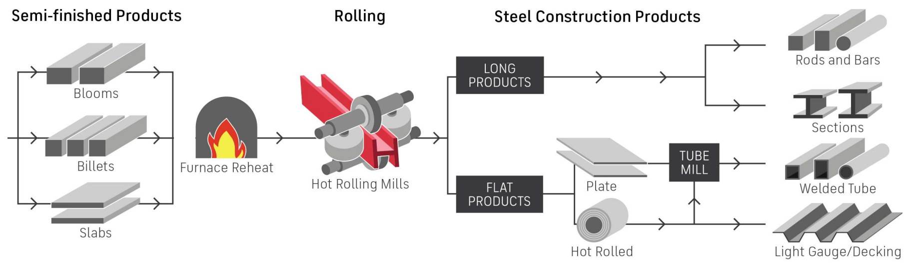



14

14

## PROCESS OVERVIEW:  ROLLING MILL






15

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## PROCESS OVERVIEW:  ROLLING MILL (W/ HEAT TREATMENTS)

**Rolling Processes:**
- As-rolled
- Control-rolled
- Thermo-mechanical Control Process (TMCP) with or without accelerated cooling

**Heat Treatments:**
- Normalized (~1600°F, ambient cooling)
- Annealed (rate-controlled cooling)
- Quenched & Tempered (temper ~ 1100-1200 °F, rate-controlled cooling)

16

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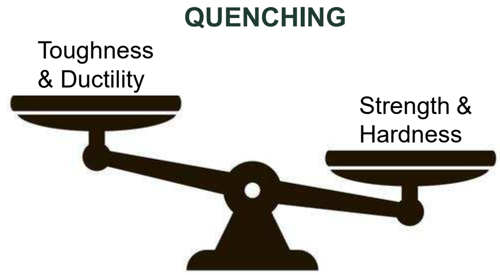
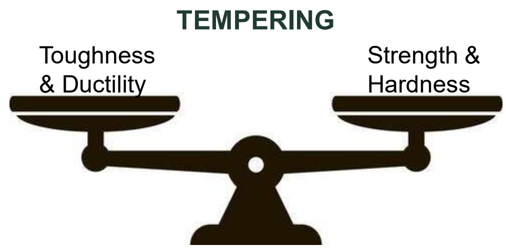
# QUENCHED & TEMPERED

**Quenching** (from 1500-1700°F): Confines carbon atoms (and other hardening elements) within crystal lattice. Traps elastic strain. Maximizes strength and hardness.




**Tempering** (to 300-1200°F): Allows some trapped carbon to precipitate out, partially relieving elastic strain (at molecular level). Generates balance of properties.




17

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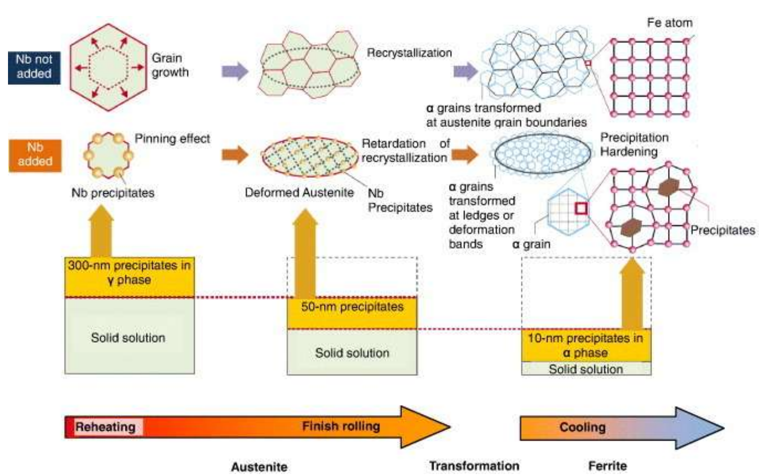
17

# GRAIN REFINEMENT

**ASTM A709 –** "the steel shall be made to fine grain practice."

**ASTM A6 –** fine grain practice involves the addition of one or more austenitic grain refining elements:

- Aluminum
- Niobium (AKA Columbium)
- Vanadium
- Titanium




**Can you guess what bridge steel grade <u>DOES NOT</u> have a "grain refining practice"?**

18

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## CAN YOU MURDER STEEL?
NO, BUT YOU CAN KILL IT!

ASTM A709 – "For all grades, the steel shall be killed."

- What does that mean?
- Oxygen dissolves into molten steel:
  - Solubility decreases as steel cools
  - Excess oxygen causes precipitates → porosity, etc.
- Deoxidation is used to remove excess oxygen:
  - Aluminum, Silicon, or Manganese
- Form oxides and collect into the slag
- Called "killed" steel because the deoxidized steel doesn't bubble in a mold, as if "lifeless"

- Continuously cast steels must be killed, otherwise porosity would create weak points in slab that could break

19

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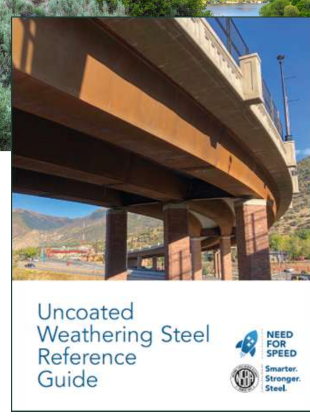
## WEATHERING GRADES

- Ancient metallurgical practice –
  - Au & Cu
  - Black patina on bronze art and artifacts
- What's the difference between A709-50 and A709-50W?
  - Addition of Cu, Ni & Cr
- These elements react with oxygen and form a patina, and adhere tightly to base metal
- Patina is stable and provides protective barrier ("fighting fire with fire")
- Cr & Ni combine with Cu to reduce porosity of patina, helping prevent oxygen from reaching with iron




20

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20

## LOW-HYDROGEN PRACTICE

- HPS grades require "low-hydrogen practice"
- One such practice is a Vacuum Tank Degasser (VTD)
  - Vacuums help bring dissolved gases out of solution
- LMF is placed inside VTD, atmospheric pressure is removed – hydrogen, oxygen, nitrogen float out
- Bottom layers less affected by vacuum due to downward ferrostatic pressure: argon bubbles!

- Argon not very soluble in steel, stays a bubble:
  - Stirs the liquid steel
  - Lifts unwanted gases (e.g., hydrogen) to the surface to be sucked up by the vacuum

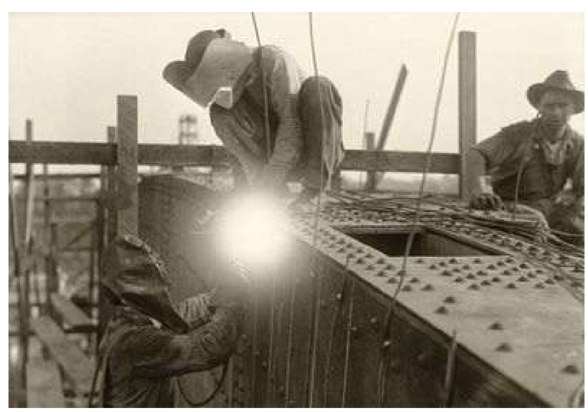
21

21

## **WELDABILITY:** (EASE OF WELDING WITHOUT PROBLEMS)

- ↑ Carbon: ↑ Hardenability, ↑ Strength
- ↑ Hardenability: ↓ Ductility, ↓ Weldability
  - Why? Becomes more susceptible to hydrogen embrittlement (AKA, cold cracking)
- Other "hardening agents": Molybdenum, Vanadium, Copper, Nickel:
  - Contribute to "Carbon Equivalency"
  - Combined effects of hardening elements:

$$CE = C + {}^{Mn}/_{6} + {}^{(Cr + Mo + V)}/_{5} + {}^{(Cu + Ni)}/_{15}$$



- Most bridge steels between 0.45 & 0.65 → low to mid-0.3's is very weldable likely **no heat treatment!**

22

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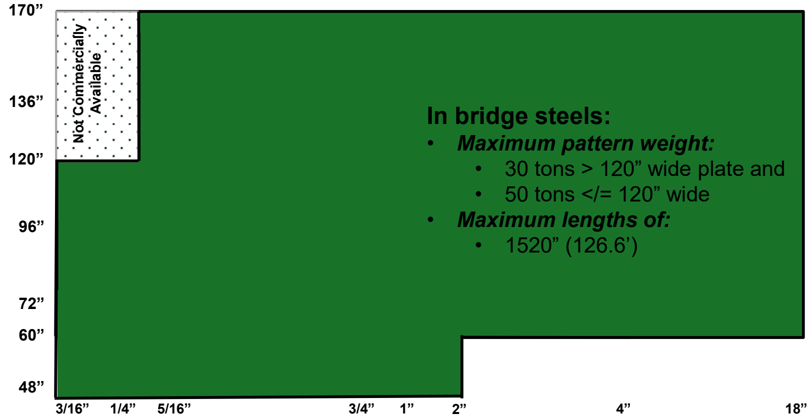
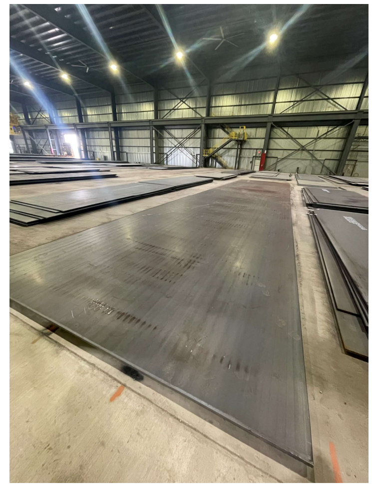
22

## PLATE SIZE AVAILABILITY




**In bridge steels:**

- ***Maximum pattern weight:***
  - 30 tons > 120” wide plate and
  - 50 tons </= 120” wide
- ***Maximum lengths of:***
  - 1520” (126.6’)



***1.125” X 162” X 728” A709-50T2***

23

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## LARGE BRIDGE PLATES = FABRICATION SAVINGS

***Bridge:*** *Bridge in Wisconsin*
***Plate size:*** *1” x 147” x 1,412” (117’-8”)*

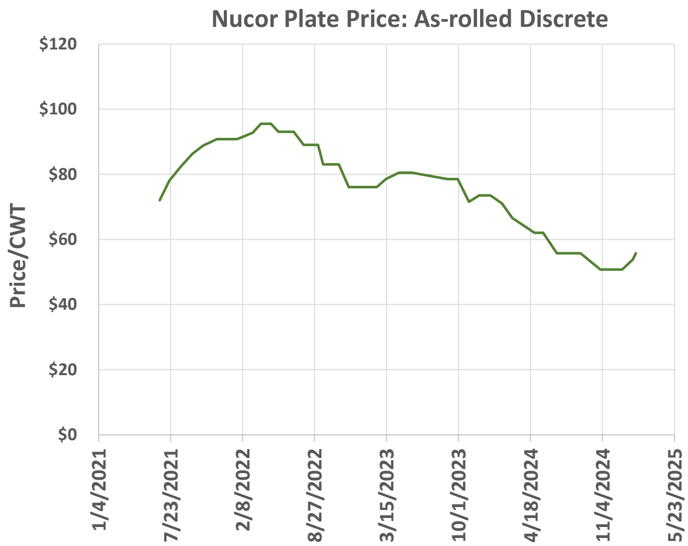
Fabricated Girder in the shop

Install at jobsite

- *We believe this is largest plate shipped in North America*
- *Shipped on double idler set, three 89’ flatcars*

24

24




**Lead Time:**
**6 – 8 weeks**

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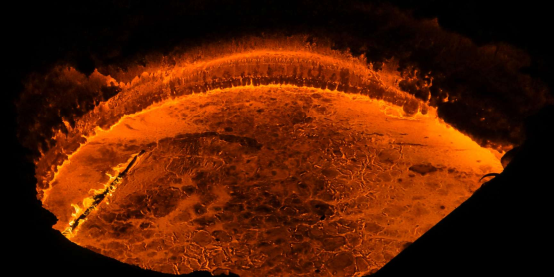
# THANK YOU



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26