41th SENAFOR

TOOLS FOR THE DEVELOPMENT OF ALLOY DESIGNS FOR HOT ROLLED FLAT STEEL PRODUCTS

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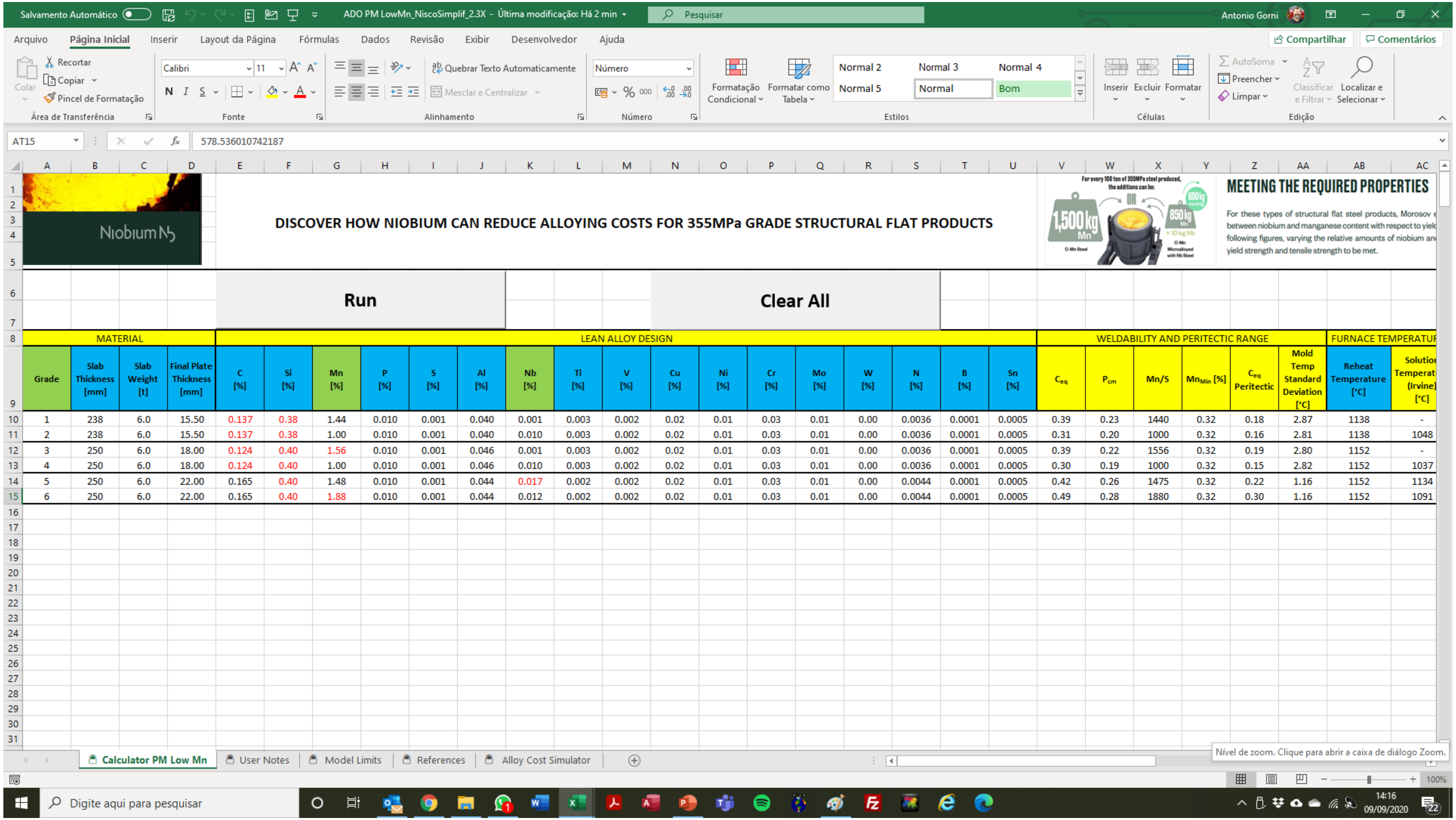
Description of ADO

- **Alloy Design Optimizer** (a.k.a. **ADO**) is an Excel application developed by CBMM that allows the comparison between real and proposed alloy designs of Nb microalloyed steels.

- It was developed to **optimize** both **chemical composition**, as well as the corresponding **process parameters**, in order to **minimize alloy costs** while keeping or even upgrading **product performance**.

Description of ADO



MATERIAL				LEAN ALLOY DESIGN																		WELDABILITY AND PERITECTIC RANGE						FURNACE TEMPERATUR	
Grade	Slab Thickness [mm]	Slab Weight [t]	Final Plate Thickness [mm]	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Al [%]	Nb [%]	Ti [%]	V [%]	Cu [%]	Ni [%]	Cr [%]	Mo [%]	W [%]	N [%]	B [%]	Sn [%]	C_{eq}	P_{cm}	Mn/S	Mn_{Min} [%]	C_{eq} Peritectic	Mold Temp Standard Deviation [°C]	Reheat Temperature [°C]	Solutio Temperat (Irvine) [°C]
1	238	6.0	15.50	0.137	0.38	1.44	0.010	0.001	0.040	0.001	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005	0.39	0.23	1440	0.32	0.18	2.87	1138	-
2	238	6.0	15.50	0.137	0.38	1.00	0.010	0.001	0.040	0.010	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005	0.31	0.20	1000	0.32	0.16	2.81	1138	1048
3	250	6.0	18.00	0.124	0.40	1.56	0.010	0.001	0.046	0.001	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005	0.39	0.22	1556	0.32	0.19	2.80	1152	-
4	250	6.0	18.00	0.124	0.40	1.00	0.010	0.001	0.046	0.010	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005	0.30	0.19	1000	0.32	0.15	2.82	1152	1037
5	250	6.0	22.00	0.165	0.40	1.48	0.010	0.001	0.044	0.017	0.002	0.002	0.02	0.01	0.03	0.01	0.00	0.0044	0.0001	0.0005	0.42	0.26	1475	0.32	0.22	1.16	1152	1134
6	250	6.0	22.00	0.165	0.40	1.88	0.010	0.001	0.044	0.012	0.002	0.002	0.02	0.01	0.03	0.01	0.00	0.0044	0.0001	0.0005	0.49	0.28	1880	0.32	0.30	1.16	1152	1091

Description of ADO

- **ADO** has an internal mathematical model for the **prediction of mechanical properties** of microalloyed steels.

- To obtain the best results, this mathematical model must be developed for **each hot flat rolling line under analysis**.

- Its development is relatively easy, through **statistical analysis of massive sets** of **chemical composition** and **process data** of the line being analysed, together with the respective results of **mechanical properties**.

Description of ADO

- An **example of such model** was developed by former British Steel:

$$UYS = 73 + 166\sqrt{C} + 40Si + 38Mn + 1547Nb + 357\sqrt{V} + 12.35d^{-1/2} + UYS_{FRT} + UYS_{P}$$

where:

$$UYS_{FRT} = 0.446\Delta T_{FRT}$$

$$UYS_{P} = 254\sqrt{V} - 9395Ti$$

$$\Delta T_{FRT} = Ae_3 - FRT + 100$$

$$UTS = 84 + 627\sqrt{C} + 71Si + 76Mn + 1004Nb + 320\sqrt{V} + 4.40d^{-1/2} + UTS_{FRT} + UTS_{P}$$

where:

$$UTS_{FRT} = 0.256\Delta T_{FRT}$$

$$UTS_{P} = 318\sqrt{V} - 10676Ti$$

BEAVERSTOCK, R.C. et al. International Rolling Conference, Paris, 2006.

ADO Components

- **Calculator:** this is the main spreadsheet, where data about steel chemical composition and rolling process is input; results are output here as well.
- **User Notes:** brief information about **ADO** functions.
- **Model Limits:** show the validity ranges of the alloy contents and hot rolling process parameters which are specific for the specific model included at an **ADO** version.
- **References:** public literature used in the development of **ADO**.
- **Alloy Cost Simulator**: info about ferroalloys (price, recovery, and so on) must be input here, as they will be used to calculate the total alloy costs. Generally common users do not need to deal with this info.

Preparing ADO for Use

- The mathematical model used by **ADO** to calculate the mechanical properties is **interchangeable** and programmed in Visual Basic Application language.

- To achieve **maximum precision** and **relevance**, it is strongly recommended that, before using ADO to analyze the performance of the products of a given rolling line, a **specific mathematical model** is developed to calculate mechanical properties for that line and the type of products considered – that is, **structural**.

Data Input/Output

- This is usually done through statistical analysis of **huge and detailed data sets** including **chemical composition**, **process parameters** and the corresponding **mechanical properties** from the same line being analyzed.

- The use of models available from **literature** is also possible, but generally **they not perform so well as customized models** specially developed for the line being analysed.

- Information about **characteristics and prices of ferroalloys** must be previously input in the corresponding spreadsheet. This data is incorporated to **ADO** and must supplied again only if there is any change in this information.

Data Input/Output

- ADO **requires** the following data:
  - **Thickness** of slab and final plate;
  - **Chemical composition** of steel;
  - **Hot rolling process** parameters (in function of the model being used);
  - **Ferro-alloy** costs (optional).

- ADO **generates** the following information:
  - Relevant **metallurgical process** parameters;
  - **Mechanical properties** of the finished plate (generally yield/tensile strength);
  - **Alloy costs**, according to the chemical composition being used.

- Color of the spreadsheet cells indicates data priority:
  - **Green**: mandatory input data;
  - **Blue**: optional input data;
  - **Yellow**: output of the results calculated by ADO.

Data Input

- The **Calculator Low Mn** spreadsheet of ADO has the following sections:
  - **Material:** input of slab/plate thicknesses;
  - **Alloy Design:** input of steel chemical composition;
  - **Weldability and Perictetic Range**: output of relevant parameters for slab casting and plate application, calculated from its chemical composition;
  - **Furnace Temperatures**: input of slab reheating temperature and output of Nb dissolution temperature.
  - **Rolling Process Temperatures**: input of hot rolling process temperatures and output of austenite critical temperatures;
  - **Cooling Temperatures**: input of accelerated cooling data (if used);
  - **Comparable Properties with Reduced Costs**: input of actual plate mechanical properties (if available), output of their predicted values according to the current model and output of the calculated costs.

A Detailed View of ADO Features

- The **Material** Section - Input of slab/plate geometric data
  - In this specific case, **three pairs of options** are being evaluated.
  - Note that, in this specific case, data about slab/final plate thicknesses is not required and their cells are blue. But this depends on the model currently being used by ADO. Generally such information is mandatory.

MATERIAL			
Grade	Slab Thickness [mm]	Slab Weight [t]	Final Plate Thickness [mm]
1	238	6.0	15.50
2	238	6.0	15.50
3	250	6.0	18.00
4	250	6.0	18.00
5	250	6.0	22.00
6	250	6.0	22.00

A Detailed View of ADO Features

- The **Alloy Design** Section - Input of chemical composition
  - In this specific case only the input of Mn and Nb contents is mandatory (green cells), as the model currently used by this **ADO** version does not require further data.
  - Some numbers are in red color. This is a warning, because **ADO** has already run and identified that these values extrapolated the valid range of the current model, according to data in the **Model Limits** spreadsheet.

LEAN ALLOY DESIGN																	
C [%]	Si [%]	Mn [%]	P [%]	S [%]	Al [%]	Nb [%]	Ti [%]	V [%]	Cu [%]	Ni [%]	Cr [%]	Mo [%]	W [%]	N [%]	B [%]	Sn [%]
0.137	0.38	1.44	0.010	0.001	0.040	0.001	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005
0.137	0.38	1.00	0.010	0.001	0.040	0.010	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005
0.124	0.40	1.56	0.010	0.001	0.046	0.001	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005
0.124	0.40	1.00	0.010	0.001	0.046	0.010	0.003	0.002	0.02	0.01	0.03	0.01	0.00	0.0036	0.0001	0.0005
0.165	0.40	1.48	0.010	0.001	0.044	0.017	0.002	0.002	0.02	0.01	0.03	0.01	0.00	0.0044	0.0001	0.0005
0.165	0.40	1.88	0.010	0.001	0.044	0.012	0.002	0.002	0.02	0.01	0.03	0.01	0.00	0.0044	0.0001	0.0005

A Detailed View of ADO Features

- The **Weldability and Peritectic Range** Section – Output of quality parameters
  - Parameters calculated by **ADO** (yellow cells).
  - **Weldability Evaluation** using Carbon Equivalent formulas: $\mathbf{C_{eq}}$ and $\mathbf{P_{cm}}$;
  - **Hot Ductility**: Mn/S ratio, minimum Mn amount in steel to avoid plate cracking during hot rolling;
  - **Peritectic Criticality**: the mold temperature standard deviation must be as low as possible in order to minimize slab cracking due to peritectic transformation.

WELDABILITY AND PERITECTIC RANGE					
C_{eq}	P_{cm}	Mn/S	Mn_{Min} [%]	C_{eq} Peritectic	Mold Temp Standard Deviation [°C]
0.39	0.23	1440	0.32	0.18	2.87
0.31	0.20	1000	0.32	0.16	2.81
0.39	0.22	1556	0.32	0.19	2.80
0.30	0.19	1000	0.32	0.15	2.82
0.42	0.26	1475	0.32	0.22	1.16
0.49	0.28	1880	0.32	0.30	1.16

A Detailed View of ADO Features

- The **Furnace Temperatures** Section – Slab reheating data
  - Input of **slab discharge temperature** (not mandatory in this specific case).
  - Output of **Nb full dissolution temperature** calculated by Irvine equation.

FURNACE TEMPERATURES	
Reheat Temperature [°C]	Solution Temperature (Irvine) [°C]
1138	-
1138	1048
1152	-
1152	1037
1152	1134
1152	1091

A Detailed View of ADO Features

- The **Rolling Process Temperatures** Section
  - Input and output of selected rolling parameters.
  - Data input not mandatory in this case, as current model is excessively simplified.
  - Output of maximum temperature for holding phase start of TMCP (**RLT**).
  - Output of maximum temperature for finishing phase start of TMCP (**RST**).
  - Output of minimum temperature for austenitic rolling (**Ar_3**).

ROLLING PROCESS TEMPERATURES								
Start Roughing Temperature [°C]	Finish Roughing Temperature [°C]	RLT (Bai 2011) [°C]	Holding Thickness [mm]	Holding Time [s]	Start Finishing Temperature [°C]	RST (Bai 2011) [°C]	Finish Rolling Temperature [°C]	Ar3 (Ouchi) [°C]
		-				-	906	750
		946				871	906	785
		-				-	946	745
		938				863	946	789
		1000				925		739
		974				899		706

A Detailed View of ADO Features

- The **Cooling Temperatures** Section – Accelerated Cooling
  - No data input is required here in this specific version, as the current **ADO** version does not consider the effect of accelerated cooling after rolling.

COOLING TEMPERATURES		
Start Cooling Temperature [°C]	Cooling Rate [°C/s]	Finish Cooling Temperature [°C]

A Detailed View of ADO Features

- The **Comparable Properties with Reduced Costs** Section – Final Results
  - Input of **real** plate mechanical properties (only for comparison).
  - Output the **predicted** mechanical properties calculated by **ADO**.
  - Output of **alloy costs**, allowing a comparison between the two proposals.
  - Mechanical properties calculations are halted if Nb amount is **beyond model validity range**; a special warning (**Nb High!**) is issued in red, as seen below.

COMPARABLE PROPERTIES WITH REDUCED COSTS											
YS [MPa]	TS [MPa]	Elong [%]	YS_{calc} [MPa]	TS_{calc} [MPa]	$Elong_{calc}$ [%]	Cost Mn [US$/t]	Cost Nb [US$/t]	Cost V [US$/t]	Cost Si [US$/t]	Alloy Total Cost [US$/t]	Delta Cost Alloy [US$/t]
412	547	26	402	545		22.59	0.36	0.65	7.97	35.24	
			406	529		15.69	3.61	0.65	8.06	31.68	3.57
374	526	23	406	551		24.41	0.36	0.65	8.57	37.66	
			406	529		15.69	3.61	0.65	8.57	32.18	5.47
			Nb High!	Nb High!		23.14	6.14	0.65	8.57	42.16	
			442	579		29.49	4.33	0.65	8.57	46.71	-4.55

Eco ULNb

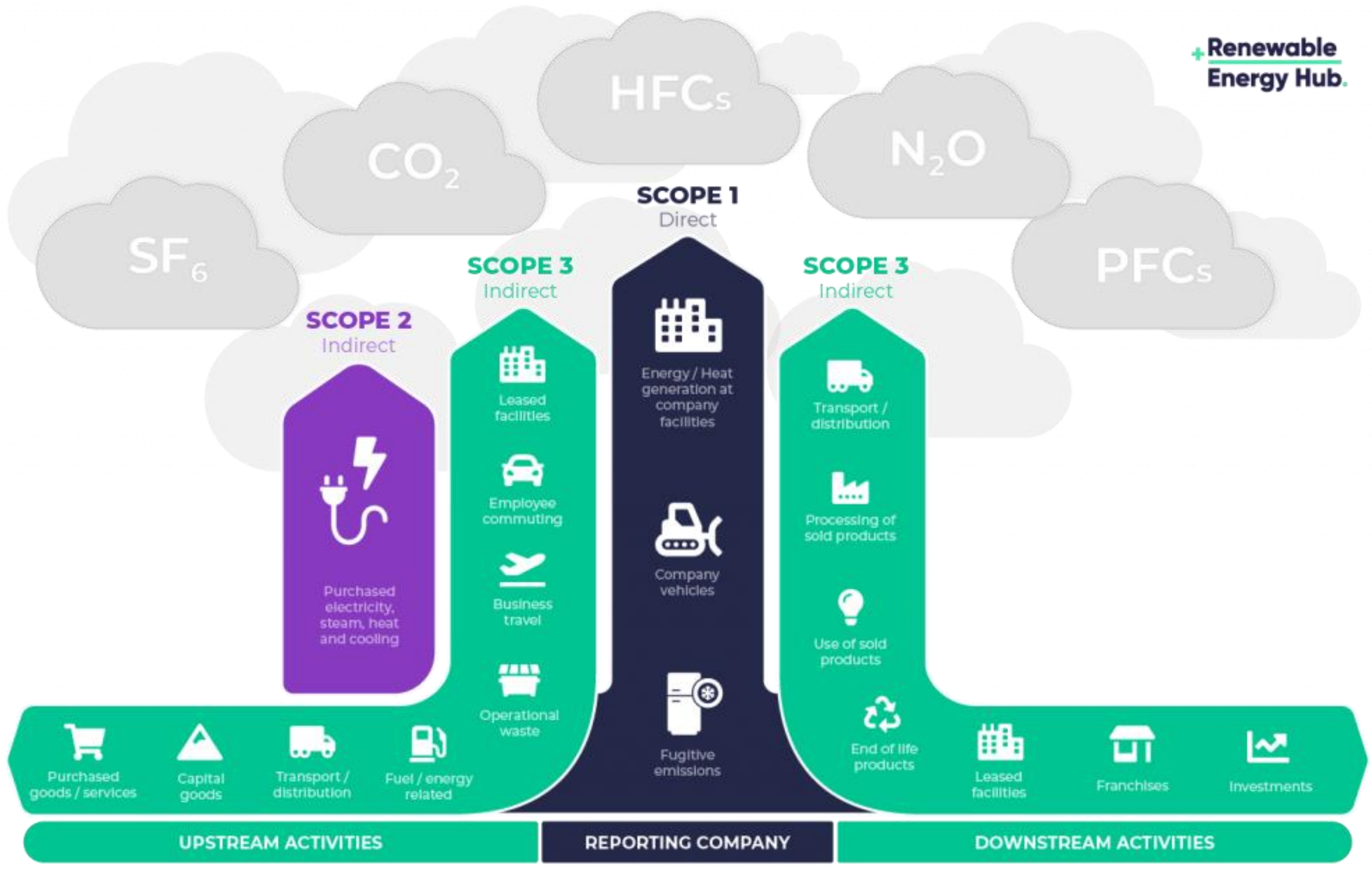
- This application calculates the impact of alloy design on **secondary refining operations**, as well in the **Global Warming Potential (GWP).**

- The table at right shows the consequences from the **partial substitution of 0.5% Mn by 0.010% Nb**:

ECONOMY				
Slag Splashing (0)	Gunning (1)	1		
Energy Savings: Tapping Temperature (°C)		16		
Addition Savings: FeSiMn (Kg/t LOW Mn)		8.651	US$/t	5.30
Addition Savings: Al Deoxidation (Kg/t LOW Mn)		0.141	US$/t	0.39
SAVING BOF LINING REFRACTORY (Kg/t LOW Mn)	GUNNING	0.116	US$/t	0.23
	SLAG SPLASHING		US$/t	
SAVING STEEL LADLE LINING REFRACTORY (Kg/t LOW Mn)		0.050	US$/t	0.04
INCREASE METALLIC YIELD (%)		0.66	US$/t	0.81
Ladle Furnace Savings (ONLY IF TAPPING TEMPERATURE: ALLOWED < NEEDED)	Electrical Energy (KWH/t LOW Mn)	123	US$/t	0.03
	Electrode (Kg/t LOW Mn)	0.100	US$/t	0.19
TOTAL SAVING		US$/t LOW Mn		6.99
DECREASE "P" CONTENT at TAPPING		ppm		34.5
DECREASE "H" CONTENT in STEEL LADLE		ppm		1.7
DECREASE "N" CONTENT in STEEL LADLE		ppm		6.7
DECREASE "S" CONTENT in STEEL LADLE		ppm		2.0
Reduction of Manganese Centerline Segregation		%		67
Saving in Global Warming Potential (GWP)		Kg CO_{2e} / tonne		62

Eco ULNb

This **GWP reduction** can be included in the **Scope 3** of the figure below.



Conclusions

- The digital tools developed by CBMM, ***Alloy Design Optimization (ADO)*** and ***ecoULNb***, are helping to **accelerate** e make the process of developing structural steel alloys **more accurate**.

- In this specific opportunity, these tools are supporting the effort of creating more refined products with **lower cost** and **carbon footprint** through the **partial exchange of manganese for micro additions of niobium**.

- **These applications are continuously being improved** in order to cover, with greater precision, a wider range of structural products.

CBMM
Niobium Nb

Niobium | High Strength Steel | Light Weight & Weldable | Lean & Competitive Design | Environmentally Sustainable Structure

THANK YOU FOR YOUR ATTENTION! QUESTIONS?

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