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The Elements with Total Material Requirements &Total CFP

TMR → Resource-view weight: tons of TMR for 1kg of metal production

TCFP → Total Carbon Footprint (from eco-sphere to a product)

- ● Magnet, motor
- ● Batteries
- ● IC tips and parts
- ● Electric wiring
- ● lightning
- ● Optical function
- ● Information media
- ● Thermoelectric,
- ● Catalyst, electrode
- ● Structural material
- ● Display & its porishing
- ● Fire retardant
- ● Solar cell

H TMR 7.05E2 TCFP 6.00E1																	
Li Li2CO3 1.87E2 1.75E1	Be 1.83E4 1.37E3											B B2O3 1.08E3 8.28E1	C 3.52E2 2.74E1	N 7.95E0 5.71E-1	O 9.99E0 6.38E-1	F 2.45E4 2.20E3	Ne 2.31E3 1.64E2
Na NaOH 1.59E2 1.89E1	Mg 1.75E3 1.61E2											Al 2.14E3 1.76E2	Si 8.12E2 7.25E1	P 1.44E3 1.06E2	S 6.86E1 6.06E0	Cl 1.76E2 2.08E1	Ar 1.37E4 2.20E1
K KCl 1.57E3 1.21E2	Ca CaO 1.03E2 8.72E0	Sc 2.25E5 1.66E4	Ti 4.64E3 4.15E2	V V2O5 1.89E3 1.30E2	Cr 2.15E3 1.47E2	Mn 5.40E2 5.30E1	Fe 6.55E1 1.06E1	Co 8.52E3 6.29E2	Ni 1.15E4 8.21E2	Cu 4.89E3 3.44E2	Zn 3.03E3 1.97E2	Ga 2.90E6 1.81E5	Ge 8.50E4 5.33E3	As 3.29E3 2.45E2	Se 2.26E5 1.57E4	Br 1.20E5 5.30E3	Kr 1.29E4 6.15E1
Rb RbCl 1.21E5 8.24E3	Sr SrCO3 7.29E2 5.79E1	Y Y2O3 5.12E4 3.88E3	Zr 1.98E3 1.72E2	Nb 4.05E3 3.01E2	Mo 2.68E3 2.41E2	Tc	Ru 6.92E7 4.70E6	Rh 2.19E8 1.49E7	Pd 1.44E6 1.03E5	Ag 3.99E7 2.71E8	Cd 8.32E5 5.16E4	In 8.37E5 5.21E4	Sn 5.81E4 3.94E3	Sb 9.20E2 7.42E1	Te 6.61E5 4.60E4	I 3.50E5 7.76E3	Xe 1.87E4 1.20E2
Cs CsCl 7.11E4 4.90E3	Ba BaSO4 2.42E2 2.27E1	(Ln) - -	Hf 1.76E4 1.67E3	Ta 8.73E3 6.86E2	W 1.39E3 1.18E2	Re 6.22E4 5.57E3	Os 2.77E8 1.88E7	Ir 2.99E8 1.88E7	Pt 2.19E8 1.49E7	Au 2.41E8 1.61E7	Hg 2.64E3 1.90E2	Tl 1.21E4 8.57E2	Pb 2.52E2 1.86E1	Bi 7.51E2 5.49E1	Po	At	Rn 9.86E6 6.73E5
Fr	Ra 4.29E6 3.01E5																

La La2O3 1.04E5 7.86E3	Ce CeO2 5.12E4 3.88E3	Pr 4.59E5 3.47E4	Nd 1.04E5 7.94E3	Pm	Sm 1.46E6 1.08E5	Eu Eu2O3 1.42E6 1.08E5	Gd Gd2O3 7.11E5 5.39E4	Tb 4.58E6 3.49E5	Dy 1.13E6 8.54E4	Ho Ho2O3 2.89E7 2.19E6	Er Er2O3 3.55E6 2.69E5	Tm Tm2O3 1.18E8 8.90E6	Yb Yb2O3 2.05E7 1.55E6	Lu Lu2O3 2.05E8 1.55E7

Ac	Th 4.83E2 2.92E2	Pa	U U2O3 2.34E2 2.17E1

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All data and calculations are available from
https://lca.sdgoods.net/tmr-tcfp/

chemicals	TCFP	TMR
1,4-Butanediol	7.87E+01	8.93E+02
2-Ethylene hexanol	8.71E+03	1.28E+05
acetone	2.38E+01	3.29E+02
acetylene	6.22E+01	7.03E+02
activated charcoal	5.62E+00	4.10E+01
agrochemical	1.75E+01	5.18E+02
air	0.00E+00	1.00E+00
alcohol	4.22E+00	1.72E+03
allylbenzene	5.17E+00	5.60E+01
alumina	5.14E+00	1.64E+02
aluminium fluoride	1.09E+03	1.21E+04
aluminum (Al)	1.76E+02	2.14E+03
aluminum chloride	2.35E+01	2.54E+02
ammonia	1.16E+01	1.41E+02
ammonium oxide	1.22E+01	1.36E+02
ammonium sulfate	8.63E+00	8.51E+01
antimony (Sb)	7.42E+01	9.20E+02
antimony concentrate	2.15E+01	2.90E+02
aqua regia	8.50E+00	7.74E+01
argon (Ar)	2.20E+01	1.37E+04
arsenic (As)	2.45E+02	3.29E+03
arsenic concentrates	5.58E+01	7.61E+02
barite concentrate	1.30E+01	1.37E+02
barium sulfate (BaSO4) (sulphat	2.27E+01	2.42E+02
bastne site	1.16E+02	1.58E+03
bauxite	3.49E-01	7.73E+00
benzene	2.63E+01	4.27E+02
beryl concentrate	6.86E+01	1.04E+03
beryllium (Be)	1.37E+03	1.83E+04
bismuth (Bi)	5.49E+01	7.51E+02
Bismuth concentrate	1.44E+01	2.03E+02
borax	3.51E+01	4.89E+02
boric acid	8.28E+01	1.08E+03
bromine (Br)	5.30E+03	1.20E+05
butanol	6.46E+03	9.49E+04
butyl alcohol	3.55E+01	3.99E+02
butyraldehyde	6.48E+03	9.51E+04
cadmium (Cd)	5.16E+04	8.32E+05
calcium carbide (CaC2)	1.83E+01	2.08E+02
calcium chloride	1.57E+01	1.84E+02
calcium hydroxide (Ca(OH)2)	7.31E+00	8.10E+01
calcium metal	8.04E+01	8.81E+02
calcium sulfate (CaSO4) (sulpha	8.14E+00	9.92E+01
carbon dioxide	4.15E+00	3.39E+01
carbon disulfide	1.08E+01	9.90E+01
carbon electrode	2.06E+01	2.60E+02
carbon monoxide	1.14E+01	1.53E+02
Celia.	3.88E+03	5.12E+04
cement	4.27E+00	2.72E+01
Ceres concentrates	1.81E+01	2.65E+02
cesium chloride	4.90E+03	7.11E+04
Cesium-containing concentrates	1.98E+02	2.89E+03

chemicals	TCFP	TMR
chilesin	1.19E+01	1.54E+02
chlorine (Cl)	2.08E+01	1.76E+02
chromium (Cr)	1.47E+02	2.15E+03
chromium concentrates	1.91E+01	4.31E+02
chromium nitrate	8.43E+01	1.69E+03
Cinnabar concentrates	2.55E+01	3.64E+02
coagulant	1.31E+01	1.11E+02
coal	3.72E-01	9.59E+00
cobalt (Co)	6.29E+02	8.52E+03
cobalt concentrate	4.52E+01	6.38E+02
Coconut Fruit	2.58E+00	9.19E+02
coconut oil	1.57E+01	4.52E+03
coke (carbon fuel)	2.51E+00	2.46E+01
copper	3.44E+02	4.89E+03
Copper anode mud	2.66E+03	3.82E+04
Copper catalyst	3.98E+02	5.72E+03
copper concentrate	9.68E+01	1.39E+03
copper nitrate	3.50E+02	4.98E+03
copper sulfate	2.74E+01	3.07E+02
Copper-Chromium Catalysts	4.28E+02	6.22E+03
cyanide disposal	5.93E+02	4.77E+03
D2EHPA	1.07E+04	1.57E+05
defoamer	9.68E+02	1.42E+04
deionized water	5.04E-01	4.16E+00
dichloromethylsilane	9.88E+00	1.06E+02
diethyl ether	1.29E+01	1.40E+02
dilute sulfuric acid	2.68E+00	2.76E+01
dust treatment	5.29E+00	5.44E+01
dysprosium (Dy)	8.54E+04	1.13E+06
erbium oxide (Erbium oxide)	2.69E+05	3.55E+06
ethanol	5.77E+00	3.21E+03
ethylene oxide	5.17E+00	3.75E+01
ethylenediamine	7.25E+00	7.77E+01
ethylenediaminetetraacetic acid	7.25E+00	7.77E+01
europium oxide (EuO)	1.08E+05	1.42E+06
Exhaust gas treatment	7.14E-01	3.40E+00
Fe2O3	2.34E+01	3.43E+02
fertilizer	7.90E+00	7.60E+01
flotation agent	4.69E+00	9.30E+02
fluorine (F)	2.20E+03	2.45E+04
Fluorine-containing liquid treatm	4.66E+00	1.33E+02
foaming agent	4.14E+01	4.46E+02
formaldehyde	6.58E+00	1.03E+02
gadolinium oxide	5.39E+04	7.11E+05
gallium (Ga)	1.30E+03	1.39E+04
germanium (Ge)	5.33E+03	8.50E+04
Glass matrix material	3.91E+01	4.76E+02
glucose	1.88E+00	1.38E+03
gold concentrate	6.07E+03	9.10E+04
hafnium (Hf)	1.47E+03	1.76E+04
HCN	6.73E+00	7.42E+01
He	2.41E+03	4.18E+04

chemicals	TCFP	TMR
hexane	4.75E+00	5.05E+01
High Purity Quartz	1.20E+02	1.35E+03
High-purity silicon	4.09E+01	4.05E+02
holmium oxide (HoO)	2.19E+06	2.89E+07
hydrochloric acid	1.01E+01	9.01E+01
hydrogen	6.00E+01	7.05E+02
hydrogen fluoride	6.13E+02	6.79E+03
hydrogen peroxide	2.56E+00	2.25E+01
ilmenite concentrate	1.93E+01	2.55E+02
indium (In)	5.21E+04	8.37E+05
Industrial Carbon	2.74E+01	3.52E+02
Industrial silicon	7.25E+01	8.12E+02
iodine (I)	7.76E+03	3.50E+05
iridium (Ir)	2.03E+07	2.99E+08
iron	1.06E+01	6.55E+01
iron ore	1.01E+01	1.60E+02
iron powder	2.66E+00	1.06E+01
iron sulfate	4.14E+00	3.13E+01
isopropanol	5.65E+00	6.18E+01
Itria.	1.09E+04	1.43E+05
kerosene	3.38E+01	3.92E+02
krypton (Kr)	6.15E+01	1.29E+04
lauryl alcohol	3.57E+01	6.23E+03
lead (the metal)	1.86E+01	2.52E+02
lead concentrate	8.69E+00	1.32E+02
limestone	4.64E+00	7.06E+01
liquid nitrogen	2.62E+00	8.61E+02
lithium carbonate (Li2CO3)	1.75E+01	1.87E+02
lithium chloride	2.57E+02	3.07E+03
Lithium concentrate	3.48E+01	4.20E+02
lutetium oxide	1.55E+07	2.05E+08
Magnesite concentrate	1.12E+01	1.40E+02
magnesium (Mg)	1.61E+02	1.75E+03
magnesium chloride	3.86E+01	4.41E+02
manganese (Mn)	5.30E+01	5.40E+02
manganese concentrate	1.27E+01	1.68E+02
Membrane Cleaner	2.29E+01	2.16E+03
mercury	1.90E+02	2.64E+03
methane	9.23E+00	1.41E+02
methanol	2.52E+00	4.91E+01
methyl isobutyl ketone	6.75E+01	8.70E+02
molybdenum (Mo)	5.25E+02	5.83E+03
molybdenum concentrate	2.41E+02	2.68E+03
money (written before an amou	1.61E+07	2.41E+08
natural gas	8.58E+00	1.35E+02
Ne	1.64E+02	2.31E+03
neodymium (Nd)	7.94E+03	1.04E+05
nickel (Ni)	8.21E+02	1.15E+04
Nickel concentrate	8.75E+01	1.25E+03
niobium (Nb)	3.01E+02	4.05E+03
niobium concentrate	5.06E+01	6.37E+02
nitric acid	3.61E+00	3.92E+01

chemicals	TCFP	TMR
nitrogen (N)	5.71E-01	7.95E+00
o Tetrahydrofuran	4.97E+01	5.53E+02
ocean water	0.00E+00	1.00E+00
ore dressing	1.57E+01	3.47E+03
Ore Mining	2.71E+00	3.99E+01
Organic liquid waste treatment	1.21E+00	1.05E+01
osmium (Os)	1.88E+07	2.77E+08
oxidized lantern	7.86E+03	1.04E+05
oxygen	6.38E-01	9.99E+00
palladium (Pd)	1.03E+05	1.44E+06
petroleum coke	7.32E+00	9.91E+01
PGM concentrate	3.84E+04	5.65E+05
phosphate ore	1.23E+01	1.77E+02
phosphoric acid (H3PO4)	7.30E+00	7.54E+01
phosphorus	1.06E+02	1.44E+03
PHS	9.27E+00	1.32E+02
platinum (Pt)	1.49E+07	2.19E+08
Pollack concentrate	2.03E+01	2.73E+02
polyaluminum chloride	6.73E+00	5.72E+01
Polyether compounds	3.33E+03	4.90E+04
potassium chloride	1.21E+02	1.57E+03
potassium hydroxide (KOH)	2.13E+02	2.75E+03
praseodymium (Pr)	3.47E+04	4.59E+05
propylene	2.08E+00	1.67E+01
propylene oxide	1.92E+04	2.82E+05
quicklime	8.72E+00	1.03E+02
Radioactive sludge treatment	3.89E+01	3.97E+02
Radioactive tailings processing	1.24E+02	1.64E+03
radium (Ra)	3.01E+05	4.29E+06
radon (Rn)	6.73E+05	9.86E+06
Rare earth concentrates	1.55E+03	2.05E+04
red-light district	1.38E+00	9.44E+01
rhenium (Re)	5.57E+03	6.22E+04
rhodium (Rh)	1.49E+07	2.19E+08
rhodium catalyst	2.71E+07	3.99E+08
rubidium chloride	8.24E+03	1.21E+05
Rubidium-bearing concentrates	4.72E+02	6.93E+03
ruthenium (Ru)	4.70E+06	6.92E+07
Salt Wastewater Treatment	3.27E+00	3.26E+01
salt water	4.00E-01	1.81E+01
saltwater	3.05E-01	6.89E+00
samarium (Sm)	1.10E+05	1.46E+06
scandium (Sc)	1.66E+04	2.25E+05
selenium (Se)	1.57E+04	2.26E+05
Silica concentrate	1.16E+01	1.51E+02
silica sand	9.74E+00	1.41E+02
Silicone oil	3.56E+01	3.85E+02
silver	2.71E+06	3.99E+07
silver concentrate	3.83E+04	5.64E+05
Sludge treatment	9.29E-01	5.23E+00
sodium (Na)	7.24E+01	7.58E+02
sodium carbonate (Na2CO3)	2.28E+01	2.00E+02

chemicals	TCFP	TMR
sodium chloride	1.04E+01	9.20E+01
sodium cyanide	7.25E+00	7.77E+01
sodium fluoride (NaF)	5.62E+02	6.21E+03
sodium hydroxide	1.89E+01	1.59E+02
sodium hypochlorite	2.46E+01	2.05E+02
sodium lauryl sulfate (sodium la	4.00E+01	5.39E+03
sorbitan	4.62E+01	2.19E+03
sorbitol (artificial sweetener)	3.45E+01	1.90E+03
stearic acid	2.44E+01	2.75E+02
strontium carbonate (SrCO3)	5.79E+01	7.29E+02
sulfur (S)	6.06E+00	6.86E+01
sulfuric acid	2.57E+00	2.51E+01
Sulfurous acid gas treatment	8.84E+00	9.84E+01
surfactant	1.22E+01	1.23E+02
tantalum (Ta)	6.86E+02	8.73E+03
Tantalum concentrate	4.82E+01	6.66E+02
tellurium (Te)	4.60E+04	6.61E+05
terbium (Tb)	3.47E+05	4.58E+06
tetrahydrofuran	1.19E+02	1.34E+03
thallium (Tl)	8.57E+02	1.21E+04
thorium (Th)	2.92E+02	4.38E+03
thorium concentrate	1.63E+00	3.14E+01
thulium oxide (TlO)	8.90E+06	1.18E+08
tin	3.94E+03	5.81E+04
tinstone concentrate	2.78E+02	4.10E+03
titanium (Ti)	4.15E+02	4.64E+03
toluene	2.63E+00	1.70E+01
tributyl phosphorus	9.82E+00	1.07E+02
tributylamine	6.07E+01	6.83E+02
tributylphosphate	5.16E+03	7.59E+04
Trioxide sulfate	5.99E+00	6.79E+01
tungsten (W)	1.18E+02	1.39E+03
Tungsten concentrate	1.80E+01	2.73E+02
uranium ore	3.88E+02	5.69E+03
Uranium ore concentrate	4.23E+02	6.04E+03
uranium oxide	1.77E+01	2.34E+02
V2O5	1.30E+02	1.89E+03
Vanadium concentrates	7.29E+01	1.07E+03
VOC Treatment	5.24E+00	7.44E+01
waste acid treatment	9.54E-01	5.88E+00
Waste Alkali Treatment	2.96E+00	3.10E+01
Wastewater Treatment	3.27E-01	1.33E+00
water (esp. cool, fresh water, e.	0.00E+00	1.00E+00
xanthate	4.15E+01	6.58E+02
xenon (Xe)	1.20E+02	1.87E+04
ytterbium oxide (YbO)	1.55E+06	2.05E+07
zinc (Zn)	1.97E+02	3.03E+03
zinc concentrate	7.28E+01	1.17E+03
zircon sand	4.18E+01	5.96E+02
zirconium (Zr)	1.72E+02	1.98E+03

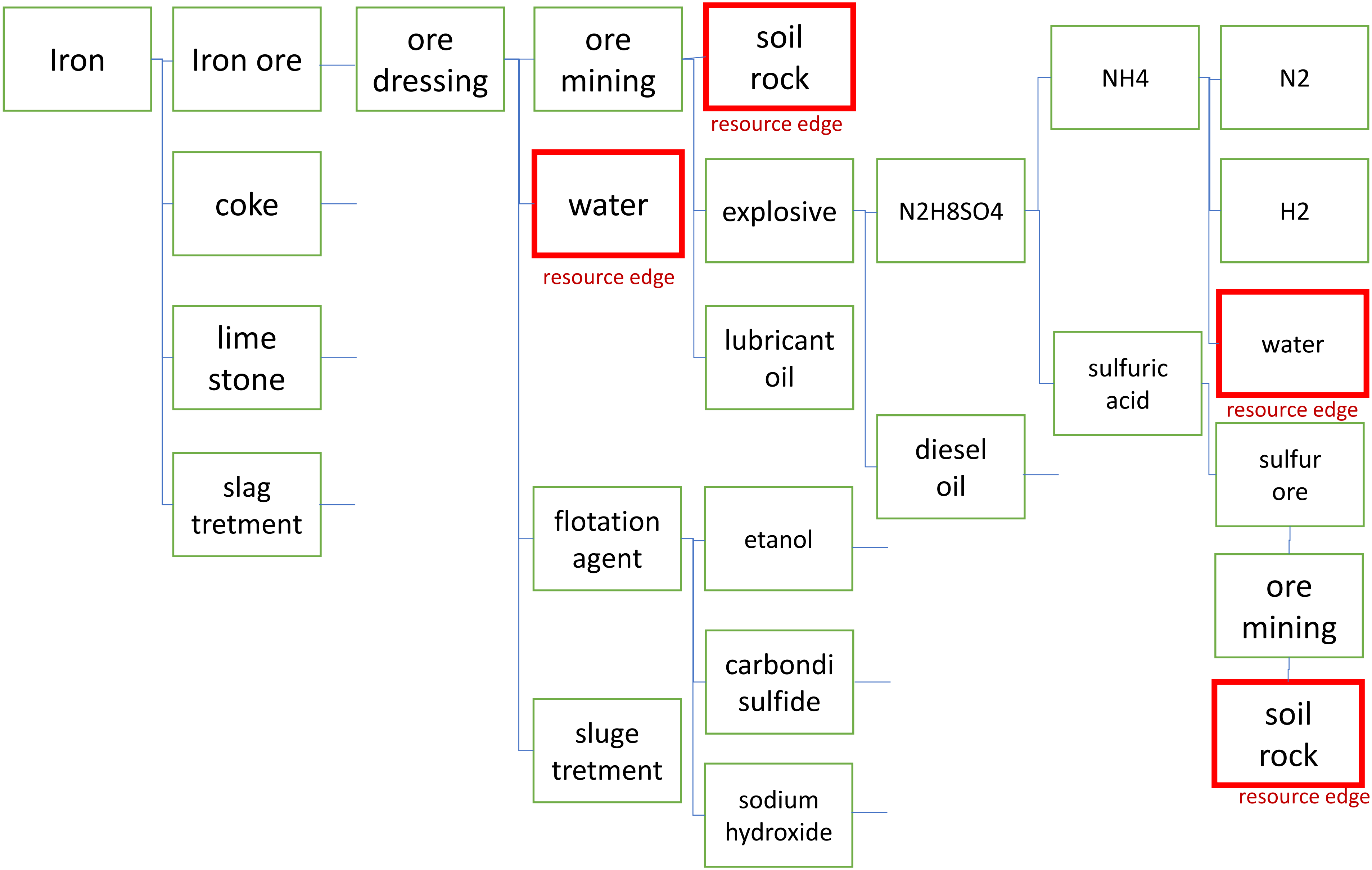
Total Material Requirement (TMR)

- **Definition**: TMR quantifies the total amount of materials extracted from nature to support an economy, including "hidden" material flows.
- **Purpose**: Developed to measure human reliance on natural resources and assess sustainability.

•**Developed in the 1990s**: Introduced as the “ecological rucksack” to represent the hidden environmental impacts of material extraction.

•**Goal**: Highlight the “invisible” resource usage and raise awareness of total environmental load.

•**Pioneer of Footprint Concepts**: Set the stage for various “footprint” metrics, focusing on resource dependency rather than direct environmental impact.



Iron

Iron ore

coke

lime stone

slag tretment

ore dressing

ore mining

water

resource edge

flotation agent

sluge tretment

soil rock

resource edge

explosive

lubricant oil

etanol

carbondi sulfide

sodium hydroxide

N2H8SO4

diesel oil

NH4

sulfuric acid

N2

H2

water

resource edge

sulfur ore

ore mining

soil rock

resource edge

Evolution and Current Relevance of Total Material Requirement (TMR)

- **Legacy of the TMR Concept**
    - Originated at Germany's Wuppertal Institute and further developed by researchers like Halada from NIMS.
    - TMR values were quantified and included as a supplementary indicator in Japan's Basic Environmental Plan.
- **Shift in Focus from Environmental to Economic Factors**
    - Discussions on resource use and recycling moved towards availability and efficient use within the human economy.
    - TMR became seen as one environmental factor among others, not directly linked to toxicological impacts, which led to reduced emphasis on it in policy and academic debates.
- **Reduced Attention in the Era of Circular Economy**
    - Despite the rising importance of material intensity in circular economy discussions, the TMR concept has largely faded from focus, except among a few dedicated researchers.

TMR remains a valuable concept for understanding resource impact, though it has been overshadowed by broader circular economy perspectives as the resource edge point.

Positioning TMR in a Nature-Positive World

- **Growing Importance of Nature-Positive Goals**: As nature-positive approaches gain prominence, it’s essential to assess and manage our true impact on natural resources, namely **resource edge** approach..

- **TMR as a Comprehensive Metric**: TMR captures the total material dependency, including hidden flows, providing a fuller picture of resource use beyond direct emissions or waste.

- **Aligning TMR with Nature-Positive Actions**: By reducing TMR, we directly support biodiversity, reduce habitat destruction, and promote sustainable resource management.

- **Guiding Policy and Industry**: TMR offers data for policies and business practices that align with nature-positive strategies, ensuring resources are used responsibly for a balanced, sustainable future.

Reasons Why TMR has been underutilized

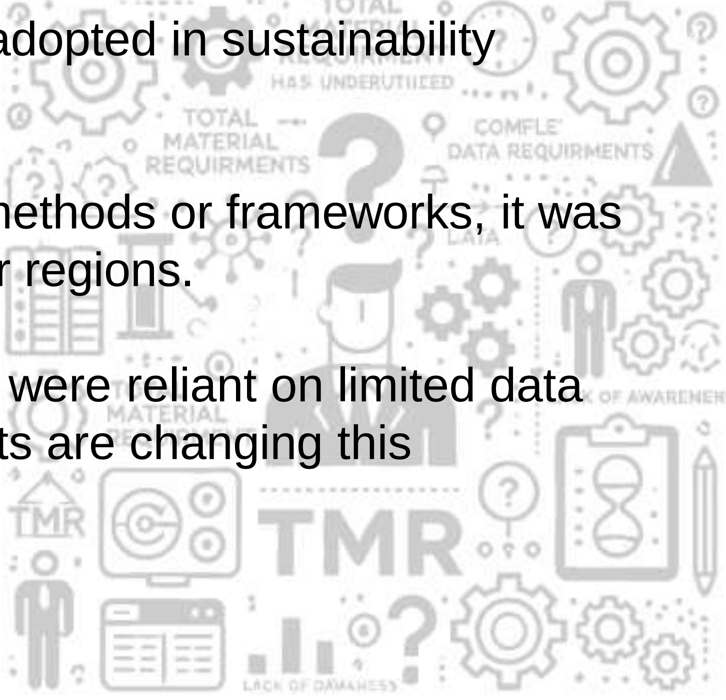
- **Ambiguity as an Environmental Indicator**: TMR's role as an environmental load factor has been unclear, making it challenging to integrate into standard environmental impact assessments.

- **Complex Data Requirements**: Calculating TMR requires extensive data on hidden material flows, which was difficult to obtain and often incomplete.

- **Limited Awareness and Focus**: With more attention on metrics like carbon footprint, TMR was overshadowed and not widely adopted in sustainability practices.

- **Lack of Standardization**: Without standardized methods or frameworks, it was hard to apply TMR consistently across industries or regions.

- **Data Accessibility**: In the past, TMR calculations were reliant on limited data sources, but recent open data and AI advancements are changing this



Challenges in TMR Data Collection and the Role of Generative AI

- **Challenges in Widespread Adoption of TMR**
  - **Data Complexity**:.
  - **Boundary Data Limitations**:
- **The Game Changer: Emergence of Generative AI (Large Language Models)**
  - While often referred to as "generative," these AI systems fundamentally perform large-scale language processing grounded in extensive data mining.
  - Through careful prompting, these AI models can be guided to conduct targeted data mining, enabling access to previously inaccessible data, such as specific mining and waste management information on each specific site..
- **New Potential with Data Mining AI**
  - By leveraging data mining capabilities in generative AI, we can obtain essential data for TMR calculations that was previously out of reach.
  - This approach, termed **Data Mining AI**, represents a powerful tool for advancing TMR research and improving resource efficiency assessments.

Benefits of Using Generative AI for Data Mining in TMR

- **Main Advantages of Generative AI in Data Mining**
  - **Pattern and Trend Discovery**: Identifies hidden patterns and trends from large amounts of unstructured data, filling in details not covered by existing databases.
  - **Real-Time Analysis**: Processes global information in real-time, allowing rapid adaptation to new technologies and market shifts.
  - **Cost-Effective Data Collection**: Offers high-precision estimates even when field data collection is challenging, reducing costs and effort.
- **Beyond Traditional Data Processing**
  - Generative AI surpasses traditional data processing limitations, providing integrated insights into complex systems and detailed processes including process-solvents and waste management.
  - In TMR assessments for products with advanced technologies, AI-driven estimates offer detailed understanding of environmental impacts across production stages until resource edges.

Considerations and Challenges of Using Generative AI in LCA Data Mining

1. Accuracy of AI Predictions

- Generative AI relies on past data to make predictions, but accuracy heavily depends on data quality.
- Process data required for LCA varies greatly by industry, and tracking latest technologies and operations can be difficult.
- Human expertise is essential to validate AI predictions to ensure reliability.

2. Transparency and Interpretability

- AI models often act as "black boxes," making it hard to understand their decision-making process.
- LCA requires transparency and reproducibility, and lack of clarity in AI's outputs can undermine result credibility.

3. Potential for Bias

- AI predictions depend on the datasets it learns from; if biased, AI results may be skewed.
- This can lead to unfair outcomes for certain countries or companies, or underestimations of true environmental impacts.

Addressing Challenges in Using Generative AI for LCA Data Mining

- **Balancing Opportunities and Challenges**
- Using generative AI for LCA data mining presents new opportunities but also introduces challenges related to accuracy, transparency, and bias.
- It is crucial to understand AI's limitations and strengthen collaboration with human expertise to effectively address these challenges.

- **Strategies for Effective AI Utilization**

1.Setting Data Ranges for Uncertainty

  - AI provides not only a single estimate but also upper and lower bounds.
  - This allows LCA calculations to consider uncertainties, providing scenarios for both best and worst-case outcomes.

2.Expert Validation of AI Estimates

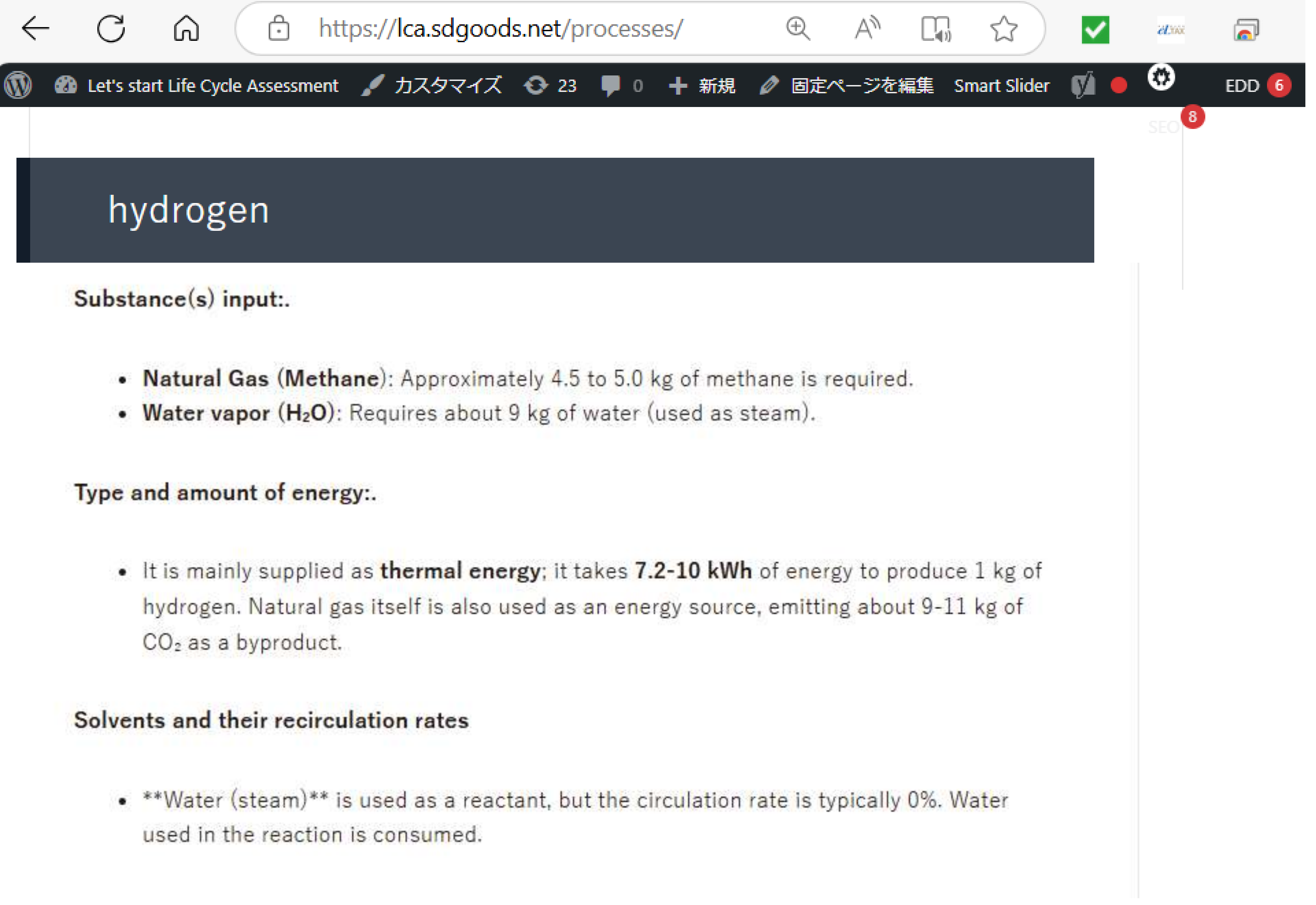
  - Experts in LCA and production processes validate AI-derived data, discarding or adjusting any inappropriate results.
  - Example: Specialists review AI's estimates for rare metal usage against historical data and current technology trends.

3.Reducing Bias Through Prompt Engineering

  - The AI is fed diverse data sources to prevent reliance on a single viewpoint.

Enhancing Data Quality in LCA with Advanced Prompt Engineering for Generative AI

- **Prompt Engineering Strategies for Generative AI**
  - **Specialist Perspective**
    - Specified AI as a “resource and materials engineering expert familiar with LCA, industry practices, and patents.”
    - Limited search scope to high-quality, specialized information, reducing the influence of general blogs or non-expert articles.
  - **Focusing on Established Industrial Methods**
    - Added prompts specifying “common industrial methods for obtaining target material.”
    - Ensured focus on commercially viable, practical data, reducing the risk of including lab-scale or speculative research data.
  - **Validation of Numerical Outputs**
    - When AI’s estimates diverged significantly from expert knowledge, prompted AI to generate reaction names or equations.
    - This helped confirm data relevance, reducing the chance of unrelated information mixing into AI outputs.
- **Outcome and Benefits**
  - Combining generative AI’s capabilities with expert input and diversified data sources ensures high-quality, reliable data for CFP analysis.
  - This approach enhances the accuracy of LCA results by managing uncertainties and mitigating bias, making it a robust tool for assessing complex materials.



hydrogen

Substance(s) input:.

- **Natural Gas (Methane)**: Approximately 4.5 to 5.0 kg of methane is required.
- **Water vapor (H_2O)**: Requires about 9 kg of water (used as steam).

Type and amount of energy:.

- It is mainly supplied as **thermal energy**; it takes **7.2-10 kWh** of energy to produce 1 kg of hydrogen. Natural gas itself is also used as an energy source, emitting about 9-11 kg of CO_2 as a byproduct.

Solvents and their recirculation rates

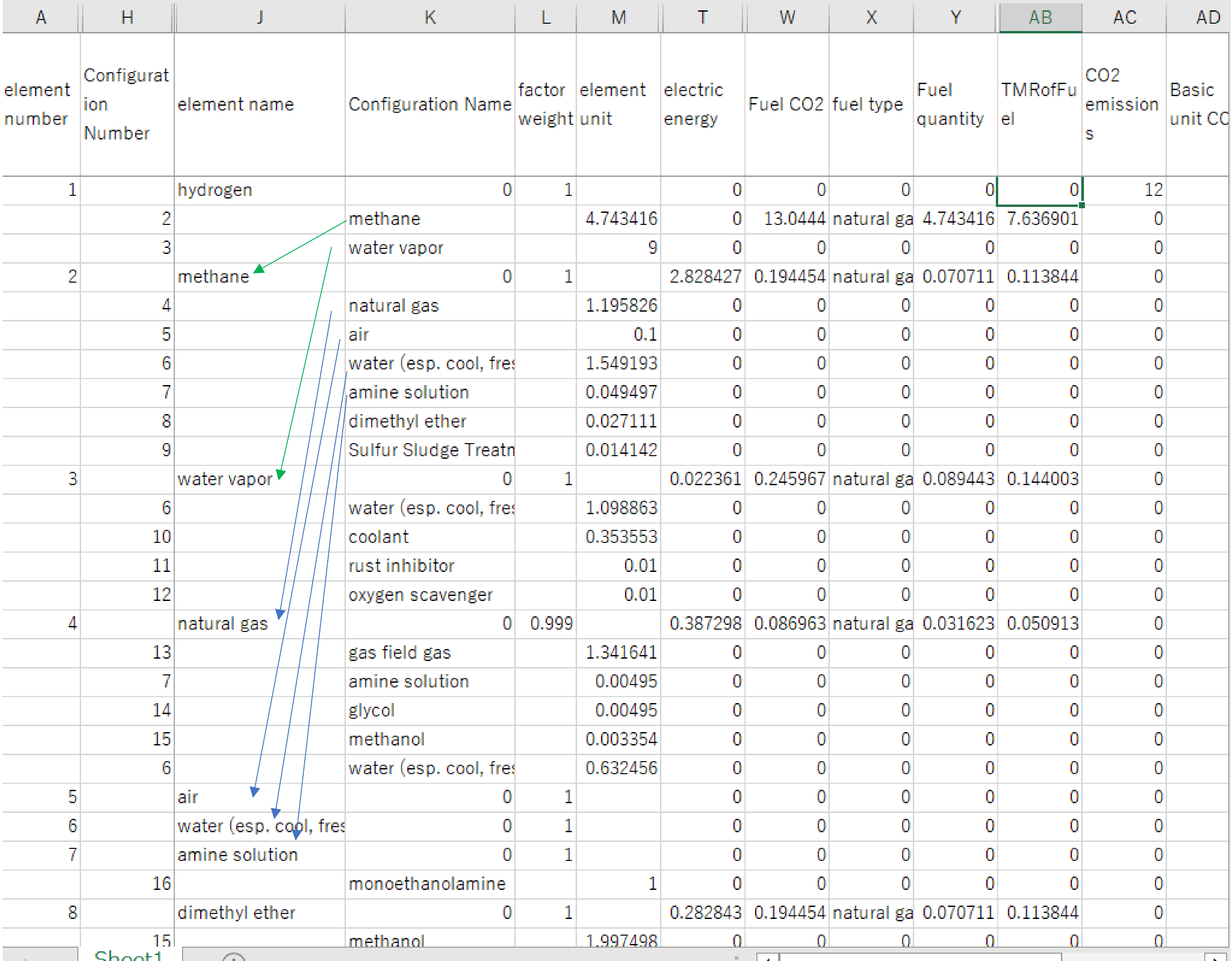
- **Water (steam)** is used as a reactant, but the circulation rate is typically 0%. Water used in the reaction is consumed.

rust inhibitor

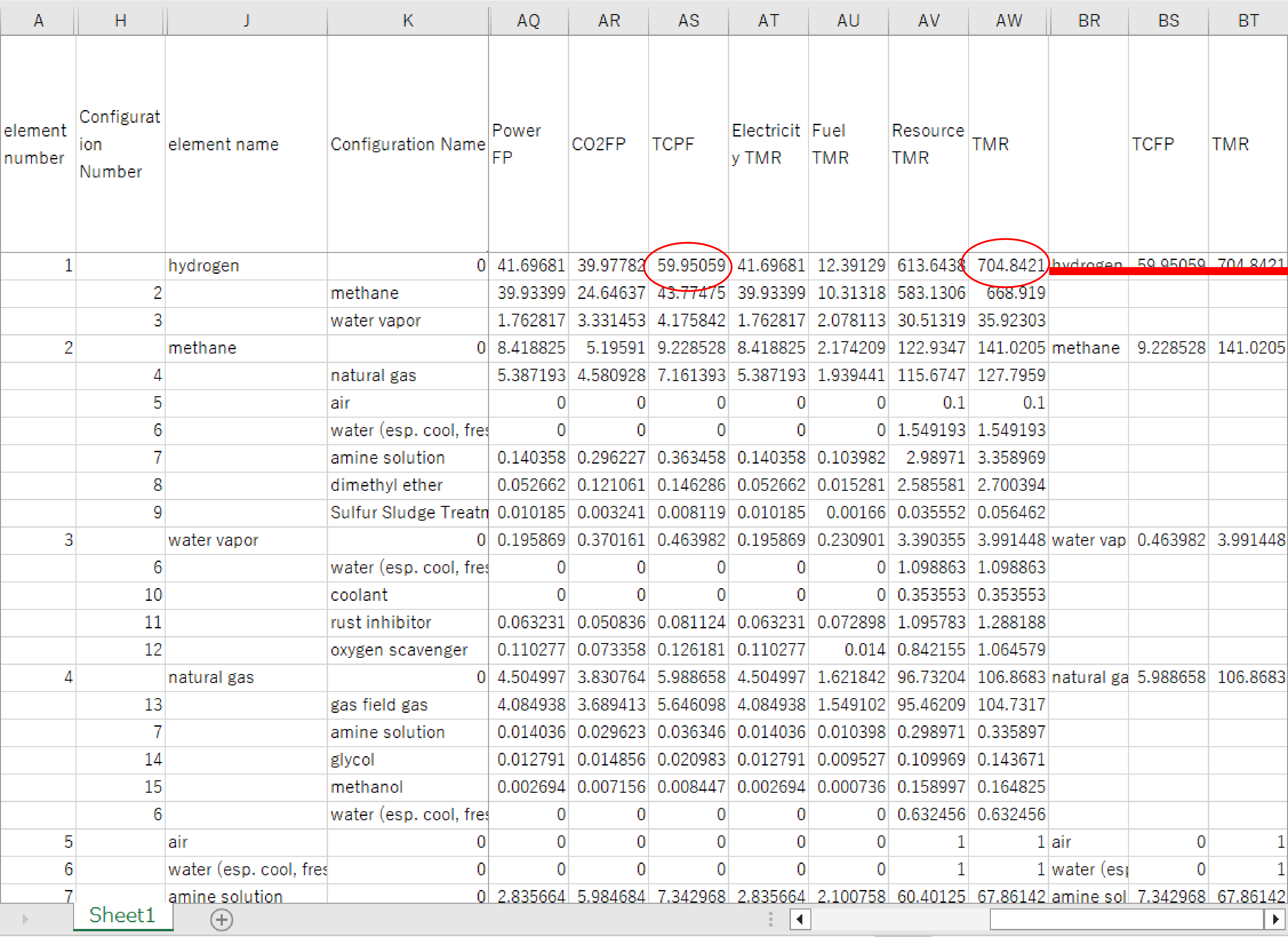
Input Item Name	Suggested input amount
Phosphoric acid (H_3PO_4, 85% concentration)	0.4 to 0.5 kg
Zinc sulfate ($ZnSO_4$, 98% concentration)	0.6 to 0.7 kg
Water (for reaction adjustment and dilution)	0.1 to 0.2 kg

Solvents and other process substances Name	Approximate amount used (kg)	Cycloparametric rate
Catalyst (acidic or basic catalyst)	0.005 to 0.01 kg	Almost 100%.
coolant	5-10 kg	80-90% (reused)
Solvent for cleaning (e.g., methanol)	0.05 to 0.1 kg	70-85% of the total

Type and amount of energy	Approximate consumption (kWh/kg)
electric power	0.2 to 0.4 kWh



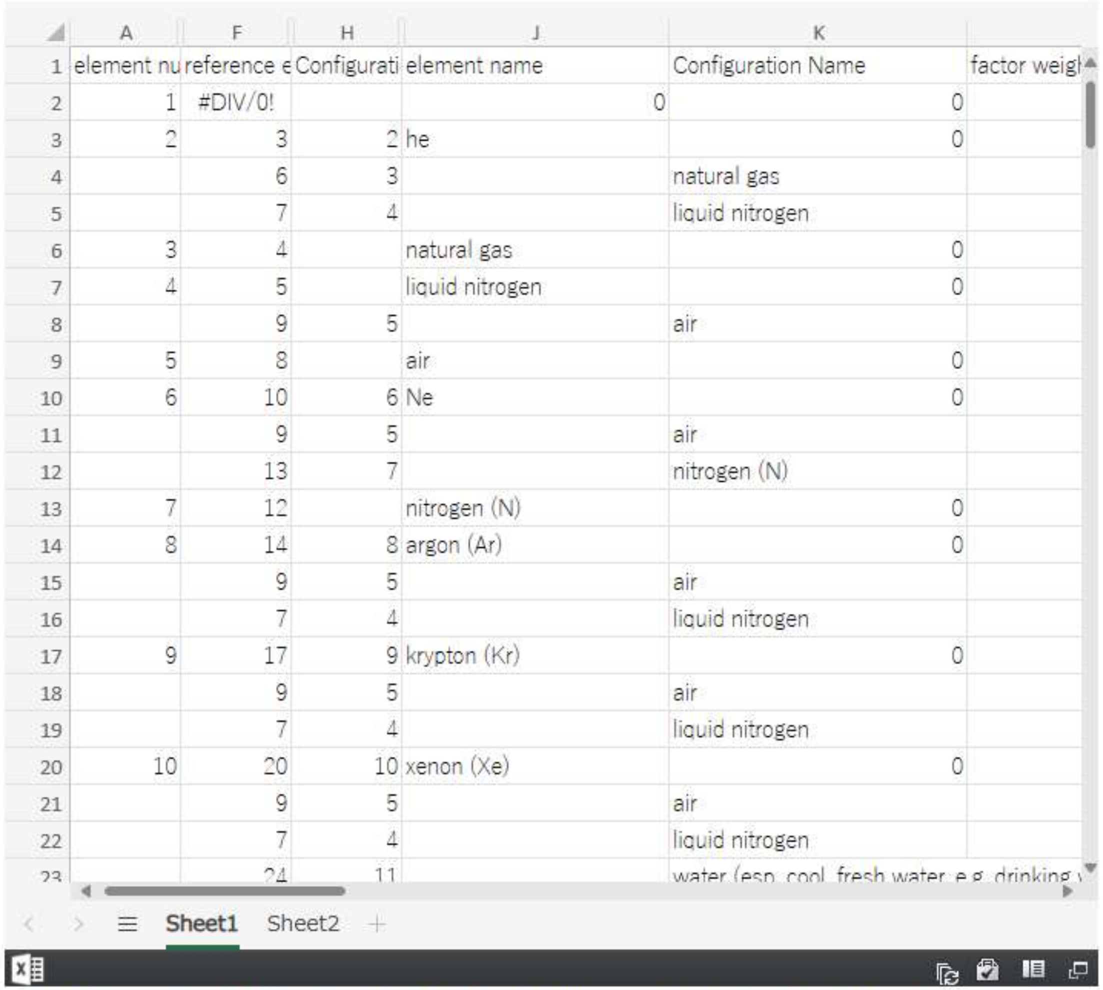
A	H	J	K	L	M	T	W	X	Y	AB	AC	AD
element number	Configuration Number	element name	Configuration Name	factor weight	element unit	electric energy	Fuel CO2	fuel type	Fuel quantity	TMRofFuel	CO2 emissions	Basic unit CC
1		hydrogen	0	1		0	0	0	0	0	12	
	2		methane		4.743416	0	13.0444	natural ga	4.743416	7.636901	0	
	3		water vapor		9	0	0	0	0	0	0	
2		methane	0	1		2.828427	0.194454	natural ga	0.070711	0.113844	0	
	4		natural gas		1.195826	0	0	0	0	0	0	
	5		air		0.1	0	0	0	0	0	0	
	6		water (esp. cool, fres		1.549193	0	0	0	0	0	0	
	7		amine solution		0.049497	0	0	0	0	0	0	
	8		dimethyl ether		0.027111	0	0	0	0	0	0	
	9		Sulfur Sludge Treatn		0.014142	0	0	0	0	0	0	
3		water vapor	0	1		0.022361	0.245967	natural ga	0.089443	0.144003	0	
	6		water (esp. cool, fres		1.098863	0	0	0	0	0	0	
	10		coolant		0.353553	0	0	0	0	0	0	
	11		rust inhibitor		0.01	0	0	0	0	0	0	
	12		oxygen scavenger		0.01	0	0	0	0	0	0	
4		natural gas	0	0.999		0.387298	0.086963	natural ga	0.031623	0.050913	0	
	13		gas field gas		1.341641	0	0	0	0	0	0	
	7		amine solution		0.00495	0	0	0	0	0	0	
	14		glycol		0.00495	0	0	0	0	0	0	
	15		methanol		0.003354	0	0	0	0	0	0	
	6		water (esp. cool, fres		0.632456	0	0	0	0	0	0	
5		air	0	1		0	0	0	0	0	0	
6		water (esp. cool, fres	0	1		0	0	0	0	0	0	
7		amine solution	0	1		0	0	0	0	0	0	
	16		monoethanolamine		1	0	0	0	0	0	0	
8		dimethyl ether	0	1		0.282843	0.194454	natural ga	0.070711	0.113844	0	
	15		methanol		1.997498	0	0	0	0	0	0	



A	H	J	K	AQ	AR	AS	AT	AU	AV	AW	BR	BS	BT
element number	Configuration Number	element name	Configuration Name	Power FP	CO2FP	TCPF	Electricity TMR	Fuel TMR	Resource TMR	TMR		TCFP	TMR
1		hydrogen	0	41.69681	39.97782	59.95059	41.69681	12.39129	613.6438	704.8421	hydrogen	59.95059	704.8421
	2		methane	39.93399	24.64637	43.77475	39.93399	10.31318	583.1306	668.919			
	3		water vapor	1.762817	3.331453	4.175842	1.762817	2.078113	30.51319	35.92303			
2		methane	0	8.418825	5.19591	9.228528	8.418825	2.174209	122.9347	141.0205	methane	9.228528	141.0205
	4		natural gas	5.387193	4.580928	7.161393	5.387193	1.939441	115.6747	127.7959			
	5		air	0	0	0	0	0	0.1	0.1			
	6		water (esp. cool, fres	0	0	0	0	0	1.549193	1.549193			
	7		amine solution	0.140358	0.296227	0.363458	0.140358	0.103982	2.98971	3.358969			
	8		dimethyl ether	0.052662	0.121061	0.146286	0.052662	0.015281	2.585581	2.700394			
	9		Sulfur Sludge Treatn	0.010185	0.003241	0.008119	0.010185	0.00166	0.035552	0.056462			
3		water vapor	0	0.195869	0.370161	0.463982	0.195869	0.230901	3.390355	3.991448	water vap	0.463982	3.991448
	6		water (esp. cool, fres	0	0	0	0	0	1.098863	1.098863			
	10		coolant	0	0	0	0	0	0.353553	0.353553			
	11		rust inhibitor	0.063231	0.050836	0.081124	0.063231	0.072898	1.095783	1.288188			
	12		oxygen scavenger	0.110277	0.073358	0.126181	0.110277	0.014	0.842155	1.064579			
4		natural gas	0	4.504997	3.830764	5.988658	4.504997	1.621842	96.73204	106.8683	natural ga	5.988658	106.8683
	13		gas field gas	4.084938	3.689413	5.646098	4.084938	1.549102	95.46209	104.7317			
	7		amine solution	0.014036	0.029623	0.036346	0.014036	0.010398	0.298971	0.335897			
	14		glycol	0.012791	0.014856	0.020983	0.012791	0.009527	0.109969	0.143671			
	15		methanol	0.002694	0.007156	0.008447	0.002694	0.000736	0.158997	0.164825			
	6		water (esp. cool, fres	0	0	0	0	0	0.632456	0.632456			
5		air	0	0	0	0	0	0	1	1	air	0	1
6		water (esp. cool, fres	0	0	0	0	0	0	1	1	water (esp	0	1
7		amine solution	0	2.835664	5.984684	7.342968	2.835664	2.100758	60.40125	67.86142	amine sol	7.342968	67.86142

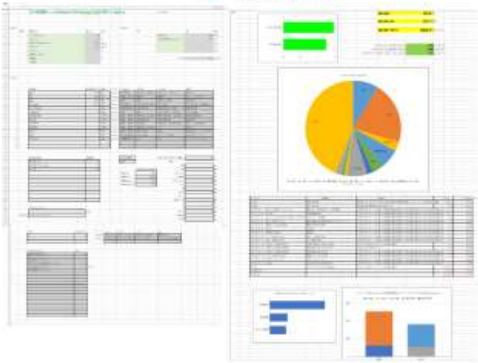
Excel Sheet for TMR and TCFP

The Excel sheet for calculation of TMR and TCFP

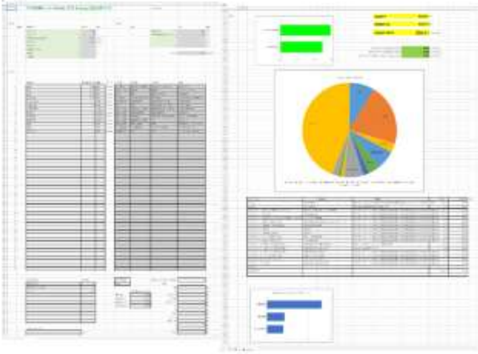


	A	F	H	J	K	
1	element nu	reference e	Configurati	element name	Configuration Name	factor weigh
2	1	#DIV/0!		0	0	
3	2	3	2	he	0	
4		6	3		natural gas	
5		7	4		liquid nitrogen	
6	3	4		natural gas	0	
7	4	5		liquid nitrogen	0	
8		9	5		air	
9	5	8		air	0	
10	6	10	6	Ne	0	
11		9	5		air	
12		13	7		nitrogen (N)	
13	7	12		nitrogen (N)	0	
14	8	14	8	argon (Ar)	0	
15		9	5		air	
16		7	4		liquid nitrogen	
17	9	17	9	krypton (Kr)	0	
18		9	5		air	
19		7	4		liquid nitrogen	
20	10	20	10	xenon (Xe)	0	
21		9	5		air	
22		7	4		liquid nitrogen	
23		24	11		water (esp. cool, fresh water e.g. drinking	

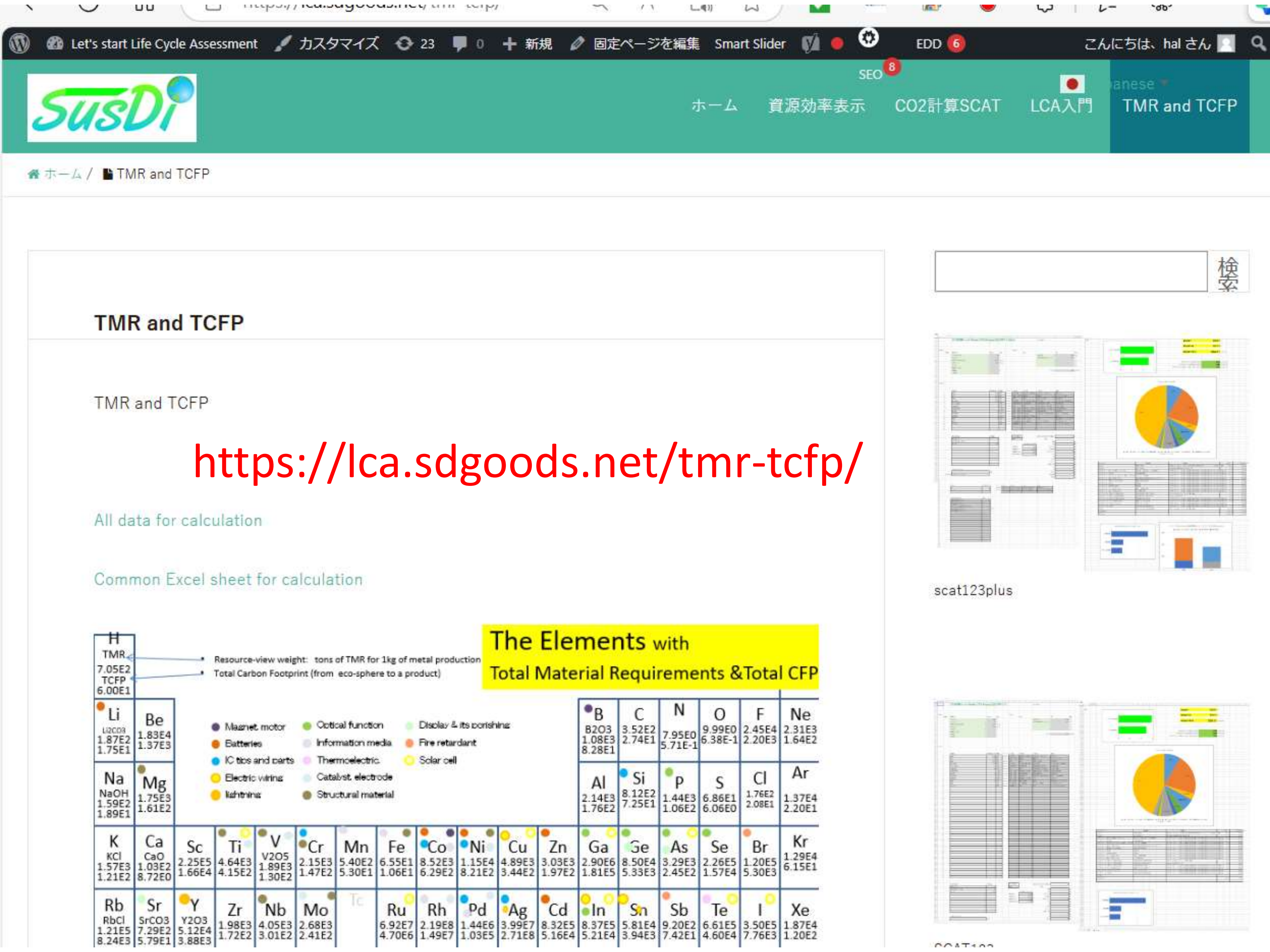
The sheet consists of “element name J” and “configuration name K” and data from L to AH, where all elements forming the system are described.



scat123plus



SCAT123
https://lca.sdgoods.net/scat123/



TMR and TCFP

TMR and TCFP

https://lca.sdgoods.net/tmr-tcfp/

All data for calculation

Common Excel sheet for calculation

The Elements with
Total Material Requirements &Total CFP

- Resource-view weight: tons of TMR for 1kg of metal production
- Total Carbon Footprint (from eco-sphere to a product)

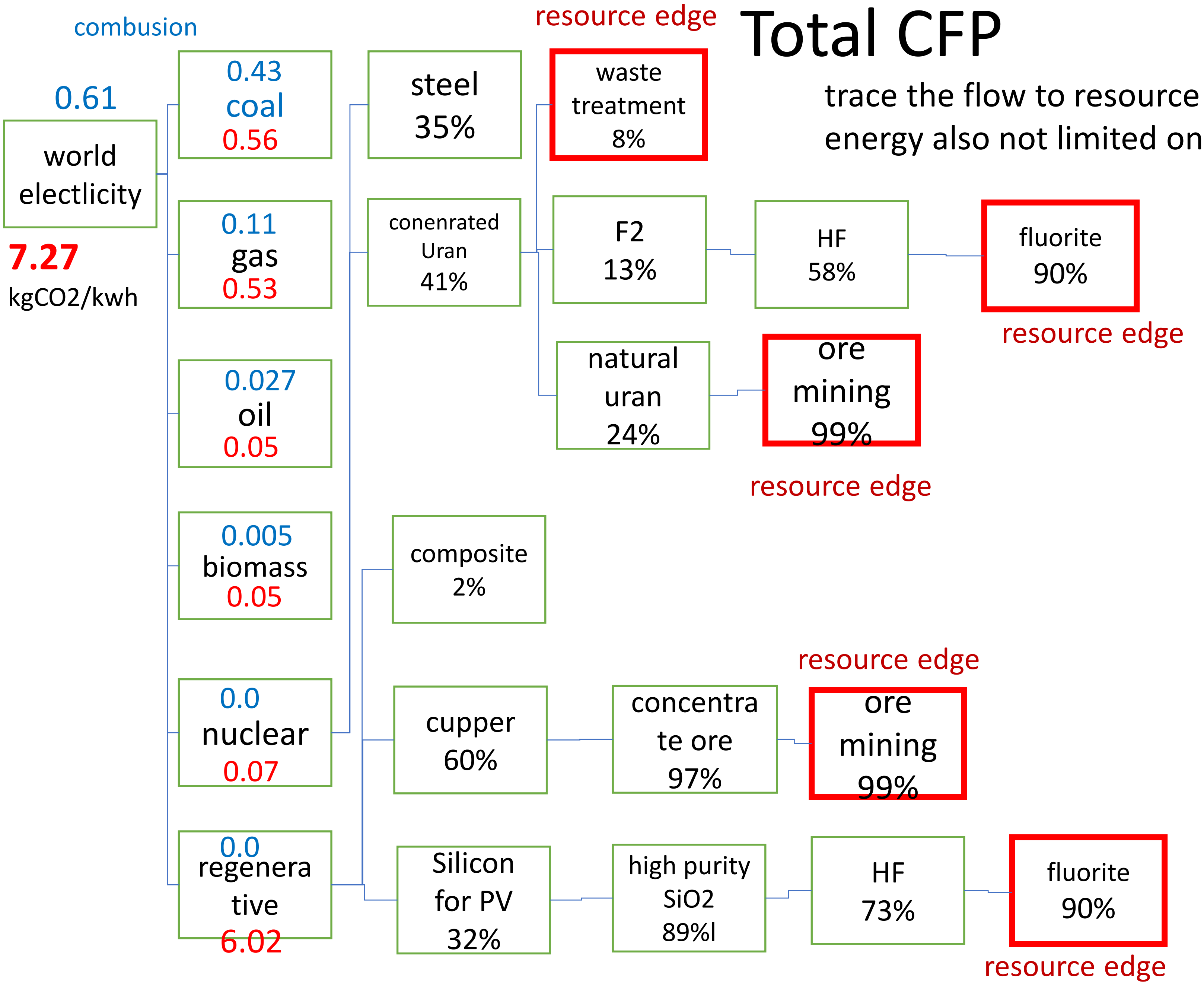
● Magnet motor
● Batteries
● IC tips and parts
● Electric wiring
● lightning
● Optical function
● Information media
● Thermoelectric
● Catalyst, electrode
● Structural material
● Display & its porishing
● Fire retardant
○ Solar cell

H TMR 7.05E2 TCFP 6.00E1																	
Li Li2CO3 1.87E2 1.75E1	Be 1.83E4 1.37E3											B B2O3 1.08E3 8.28E1	C 3.52E2 2.74E1	N 7.95E0 5.71E-1	O 9.99E0 6.38E-1	F 2.45E4 2.20E3	Ne 2.31E3 1.64E2
Na NaOH 1.59E2 1.89E1	Mg 1.75E3 1.61E2											Al 2.14E3 1.76E2	Si 8.12E2 7.25E1	P 1.44E3 1.06E2	S 6.86E1 6.06E0	Cl 1.76E2 2.08E1	Ar 1.37E4 2.20E1
K KCl 1.57E3 1.21E2	Ca CaO 1.03E2 8.72E0	Sc 2.25E5 1.66E4	Ti 4.64E3 4.15E2	V V2O5 1.89E3 1.30E2	Cr 2.15E3 1.47E2	Mn 5.40E2 5.30E1	Fe 6.55E1 1.06E1	Co 8.52E3 6.29E2	Ni 1.15E4 8.21E2	Cu 4.89E3 3.44E2	Zn 3.03E3 1.97E2	Ga 2.90E6 1.81E5	Ge 8.50E4 5.33E3	As 3.29E3 2.45E2	Se 2.26E5 1.57E4	Br 1.20E5 5.30E3	Kr 1.29E4 6.15E1
Rb RbCl 1.21E5 8.24E3	Sr SrCO3 7.29E2 5.79E1	Y Y2O3 5.12E4 3.88E3	Zr 1.98E3 1.72E2	Nb 4.05E3 3.01E2	Mo 2.68E3 2.41E2	Tc	Ru 6.92E7 4.70E6	Rh 2.19E8 1.49E7	Pd 1.44E6 1.03E5	Ag 3.99E7 2.71E8	Cd 8.32E5 5.16E4	In 8.37E5 5.21E4	Sn 5.81E4 3.94E3	Sb 9.20E2 7.42E1	Te 6.61E5 4.60E4	I 3.50E5 7.76E3	Xe 1.87E4 1.20E2

Total CFP

trace the flow to resource edge

energy also not limited onlt combusion



combusion

0.61

world electlicity

7.27

kgCO2/kwh

0.43 coal 0.56

0.11 gas 0.53

0.027 oil 0.05

0.005 biomass 0.05

0.0 nuclear 0.07

0.0 regenerative 6.02

steel 35%

conenrated Uran 41%

composite 2%

cupper 60%

Silicon for PV 32%

resource edge

waste treatment 8%

F2 13%

natural uran 24%

HF 58%

fluorite 90%

resource edge

ore mining 99%

resource edge

concentrate ore 97%

resource edge

ore mining 99%

high purity SiO2 89%l

HF 73%

fluorite 90%

resource edge

Transition from CFP to TCFP for Comprehensive Resource Impact Analysis

- **Why TCFP (Total Carbon Footprint) Instead of CFP**
  - TCFP extends calculations to the resource extraction phase, avoiding arbitrary boundary settings and cut-offs used in traditional CFP.
  - This broader approach yields higher values, providing a more accurate assessment and reducing confusion with conventional, limited-scope CFP metrics.
  - Traditional CFP mostly covers Scope 1 and 2 emissions of energy; TCFP captures Scope 3 of energy by tracking resources to their resource edge.
  - This comprehensive approach overcomes limitations of arbitrary “system boundaries,” providing a more accurate footprint

Footer: TCFP offers a full-spectrum view of environmental impact by tracing resource use from origin to final application, enhancing transparency and accuracy in carbon assessments..

•Recalculated TMR

•Collaboration between data-mining AI and engineering experts provided TMR values for all elements and accepted chemicals, with open data and calculation basis.

•Application to Total CFP

•Expanded system boundary to resource origins at the Earth-human economy interface, overcoming “system boundary” limitations.

•Integrated process materials and waste treatment, often overlooked in traditional CFP.

•Extended energy calculations beyond Scope 1, accounting for impacts up to resource origin.

•Outcome

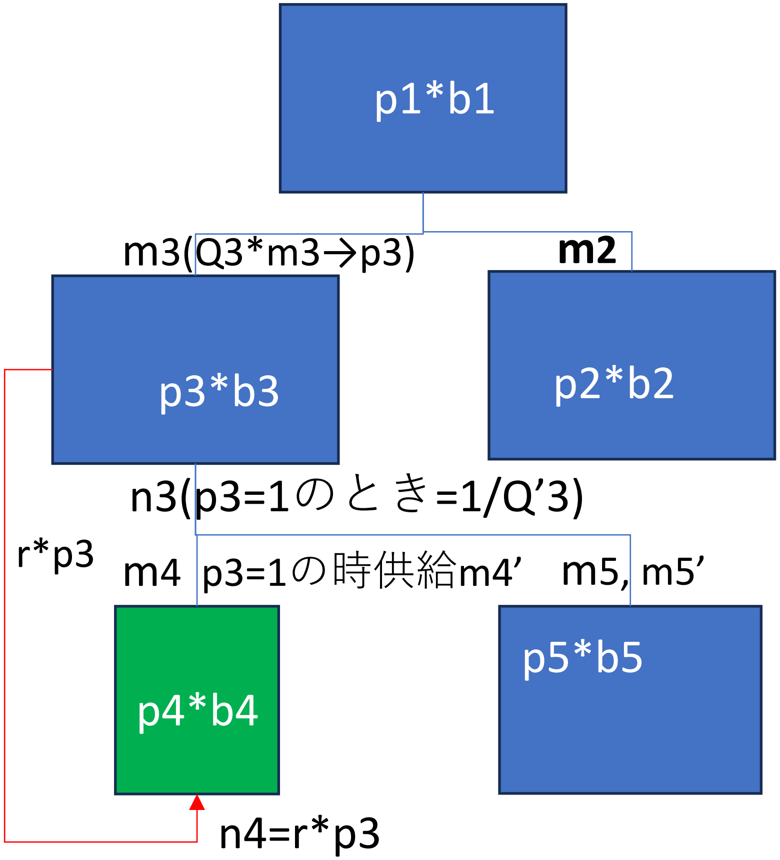
•Transformed footprint calculations into an open data discussion, engaging wider audiences beyond LCA specialists.

- Thank you! and
  Please open https://lca.sdgoods.net/tmr-tcfp/

I introduce you to a Open-data and Open Discussion System for TMR and TCFP !

Recycling issue: → exchange efference flow

プロセス3から出たリサイクル物がプロセス4を経て、プロセス5とともに
プロセス3に循環する場合



pi=Qi*mi

=Q'i*ni

- $B=\sum pi*bi$ ← LCAの基本式
- $=\sum pi*bi+p3*b3+n4*Q'4*b4+(n2-p4/Q4)*Q5*b5$

  i=1,2
- $=S2+ p3*b3+p4*b4+(n2-m4)Q5*b5$
- $=\sum pi*bi +(n2-m4)Q5*b5$

  1=1,4
- $=S4+p3(1/Q'3-m'4)Q5*b5$
- $=S4+p3(1/Q'3-r*1*Q'4/Q4)Q5*b5$

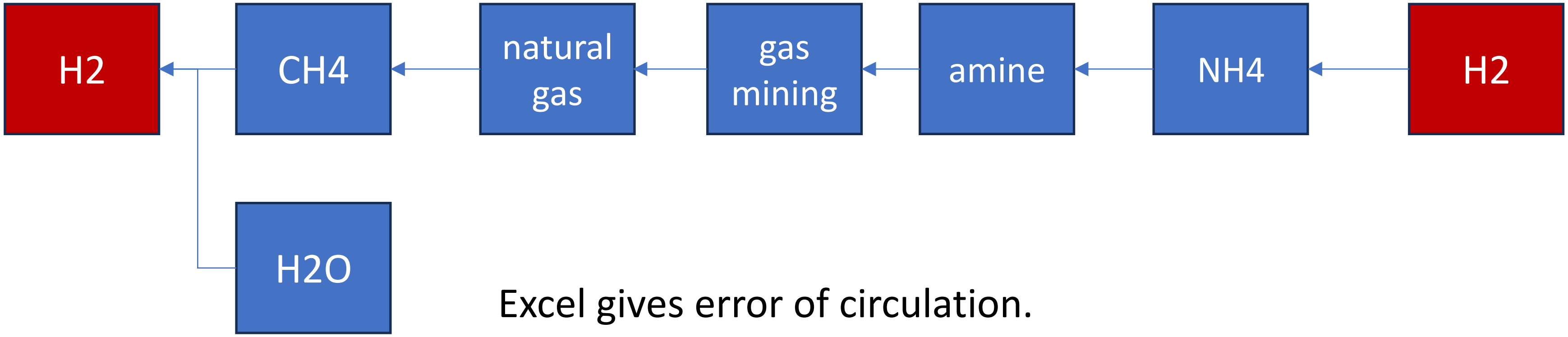
静脈側の4は、供給ではなく処理プロセスとして3からの発生物処理となる。

供給として3は4を要求しない

3の単位操作の要求構成5の量として、単位操作時の5への要求量から4処理プロセスから(2の単位操作で)供給される分を引く。

pi:プロセス量
bi:単位プロセスでの負荷
mi:物質量
ni:入口側物質量
Qi:物質量が1のときのプロセス量
r: 単位プロセスでのリサイクル量

Recursion problem



H_2

CH_4

natural gas

gas mining

amine

NH_4

H_2

H_2O

Excel gives error of circulation.

Then, change recrded H_2 into “rH2“ as another materal

.

And, Manually enter the value of H_2 into the rH2 unit.If this changes the footprint value of H_2, enter the new value.

Repeat this process until the error range is within the acceptable range.