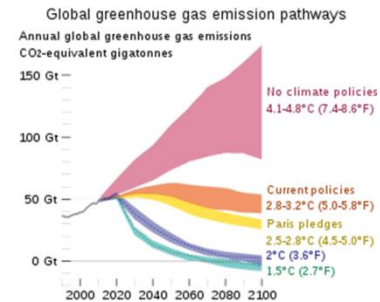


True Sustainability with Low Embodied Energy

Background

Embodied energy is the energy required to produce or make the things humans use or rely on. **Sustainability** is the ability to sustain life and future generations of life without diminishing the natural capital on which all life depends. **True sustainability** assures that the approach to obtaining sustainability does not itself lead to non-sustainability.

Reducing Greenhouse Gases (GHG) in order to prevent or mitigate Climate Change is a primary goal of humanity in the 21st Century. We will face a CO2 Budget. We will face a Cost Budget. We face a post Industrial Age. **How do we get to Zero Net Carbon?**



Making Things is what the Industrial Age does. Producing the materials takes energy, and contributes most to embodied energy.

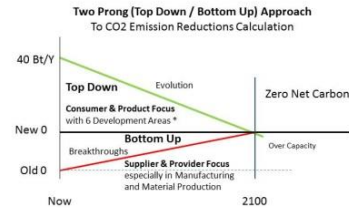
Wood from standing timber	0.830-1.950 KWh/kg
Iron from Iron Ore	5.55-6.95 KWh/kg
Steel from Iron	5.55-13.9 KWh/kg
Silicon from Silica	63.9-65.3 KWh/kg
Aluminum from Bauxite	63-95 KWh/kg
Plastics from Crude Oil	17.2-31.95 KWh/kg
Electronic grade Silicon Si	2,108-2,154 KWh/kg

The planned renewable (clean) energy infrastructure will require energy to make, consuming about 20% of the CO2 Budget of about 1000 Bt CO2. We globally emit 40 Bt CO2 per year, 31% from Making Things.

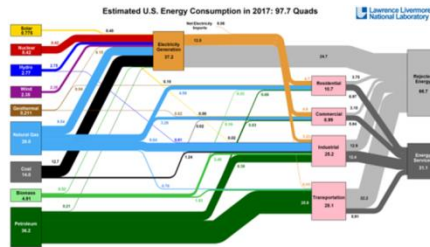
Approach

A **Practical Scenario** is defined, with significant build up in **6 Development Areas**: Solar PV, Wind, Electric Vehicles, Efficiency, Energy Storage, and Buildings, achieving significant build up by 2050, including a 30% solar electricity grid.

A second build up in 2050-2100 achieves a 100% renewable energy electric grid and all EVs.



* Development Areas: Solar PV, Wind, EVs, Efficiency, Energy Storage, and Buildings
NOTE: Agriculture, Forestry, and Aviation, being socio-political in nature, and with potential for adopting renewable fuels, existing low carbon options, and localization of activities: to reduce emissions, follow a different path to Zero Net Carbon, with progress somewhat dependent on accomplishments in the other (Top Down / Bottom Up) categories.



2/3 of energy consumed is rejected = wasted. CO2 emissions are 3 times larger than necessary. REDUCE/REUSE/RECYCLE (Old Adage New Urgency)

Embodied energy is estimated for each development area and a build up is laid out consistent with established Climate Change goals. The transition to a renewable energy future is essentially a very large construction project, costing tens of trillions of dollars, spent over a period of 80 years.

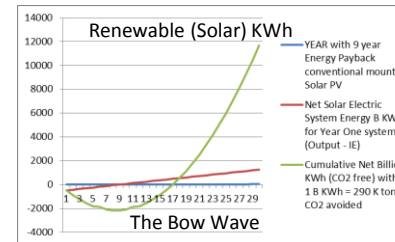
When embodied energy data is not available, analysis focuses on material content.

Analysis

Categories (Energy-related)	Invested Energy (U.S.) CO ₂ Levelized	Invested Energy (U.S.) thru 2050 CO ₂ released, tons	U.S. CO ₂ Reductions through 2050	Global CO ₂ Reductions through 2050
Solar PV	195 M/y	5.85 B	(522M/y) 15.7 B	62.8 B
Wind	30 M/y	900 M	(400M/y) 14.7 B	58.8 B
Electric Vehicles	169 M/y	5.07 B	(501M/y) 15.5 B	60.8 B
Efficiency	236 M/y	7.08 B	(507M/y) 15.2 B	60.8 B
Energy Storage	16 M/y	480 M	0	0
Buildings (11M/y)	8 M/y	240 M	(35M/y) 1.0 B	4.8 B
TOTALS	654 M/y	19.6 Bt total (78 Bt Global)	61.6 Bt (U.S.)	246 Bt (Global)

Categories (Energy-related)	Invested Energy (U.S.) CO ₂ Levelized (2050+)	Invested Energy (U.S.) thru 2100 tons	U.S. CO ₂ Reductions through 2100	Global CO ₂ Reductions through 2100
Solar PV	195 M/y (390)	25.5 B	(1562 M/y) 93.8 B	375 B
Wind	30 M/y (60)	3.9 B	(1273 M/y) 78.1 B	312 B
Electric Vehicles	169 M/y (169)	13.6 B	(1.03 B/y) 51.5 B	206 B
Efficiency	236 M/y (0)	7.1 B	(1.13 B/y) 56.5 B	226 B
Energy Storage	16 M/y (51)	3.1 B	0	0
Buildings (11M/y)	8 M/y (8)	0.6 B	(70M/y) 3.5 B	14 B
TOTALS	654 M/y (678)	54 Bt total U.S. (216 Bt Global)	283 Bt (U.S.)	1133 Bt (Global)

216 Bt CO₂ emissions to build the infrastructure
1133 Bt CO₂ emissions reduced/avoided by 2100
4 Bt CO₂/y to maintain the infrastructure
6 Bt CO₂/y to Make Things (steel, concrete, etc.)
500 Bt CO₂ Budget Gap by 2100, growing since 2050



Utility-scale mounting is material intensive. Residential mounts use lots of concrete.

We must do more with less, as less embodied energy means far less CO2 emissions. The TCS* G1 is low embodied energy, less material. *Tensioned Cable System Reducing the CO2 Budget Gap is the Big Challenge

Going Forward

The Practical Scenario means building upon the current state of the art, while also pursuing R&D in reliability, energy storage, carbon capture, and hydrogen. The build up of solar and wind power will eventually need a lot of energy storage. **Carbon capture** presumes use of non-renewable resources, thus, is not sustainable.

The long term challenge is definitely in figuring ways to Make Things without reliance on fossil fuels. Avoiding Tipping Points in this age of Climate Change will put an urgency on reckoning with this challenge of embodied energy, as CO₂ emissions in the future happen when there is no CO₂ Budget left.

Doing more with less to Make Things is a powerful approach to reducing emissions of CO₂, as rejected energy (waste) is avoided. CO₂ emissions in 2100 will almost entirely come from Making Things.

A design science *in the use of tensioned cables for structural applications like mounting solar PV panels* continuously moves toward doing more with less, which will allow a less costly transition to **Zero Net Carbon**.

Low embodied energy solutions are suited for transfer to Developing Countries, as well as Developed Countries like the U.S. and China. Low embodied energy infrastructure leads to a juxtaposition of **Jevon's Paradox**, in a good way...incentivizing a push toward lower cost and lower embodied energy solutions, rather than an ironic tendency to consume more natural (and unrennewable) resources.

Content herein is based on a white paper, titled "*True Sustainability With Low Embodied Energy*", by Jonathan A. Clemens, prepared for the ASES 2021 National Solar Conference. Rev 06/17/2021