MIDD Conference Topic Suggestion:

Charting the Complex Relationships among Energy, Water, and Carbon; Energy, Water, and Carbon Informatics.

This topic area will provide an overview of the U.S. energy system and related carbon emissions, and the stress placed on the U.S. hydrological system (especially surface water).

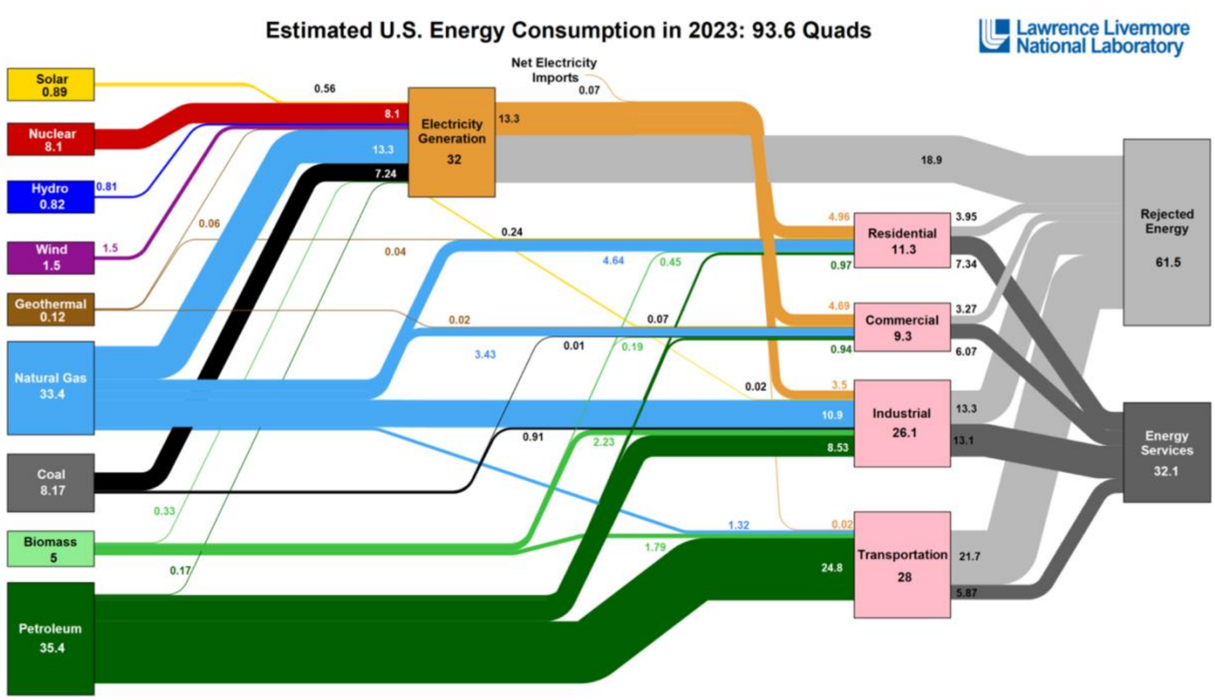
Overall, the U.S. energy consumption is approximately 100 Quads (quadrillion BTUs) annually at a cost of 5% - 6% of GDP. The U.S. energy system—from resource extraction to end use—is only 34.3% efficient, with 65.7% of energy rejected (wasted). The Transportation and Electricity Generation sectors are the most wasteful, accounting for 66.0% of total rejected waste (35.3% for Electricity Generation, 30.7% for the Transport Sector). In 2022, total U.S. end-use energy expenditures were approximately $1.76 trillion (6.9% of GDP), with petroleum accounting for the largest share ($1 trillion), followed by electricity ($482 billion) and natural gas ($179 billion).

1.1. Where do we go next?

System-wide energy efficiency: Research, develop, and promote public policies based upon "energy return on energy invested (EROEI)" with fiscal policies based upon energy savings finance.

Primary Reference Resource: Lawrence Livermore National Laboratory (LLNL) Sankey Analysis Charts. https://flowcharts.llnl.gov/ PDF: https://flowcharts.llnl.gov/sites/flowcharts/files/2024-10/energy-2023-united-states.pdf

Energy Flows in the U.S. Economy



Carbon Flows in the U.S. Economy

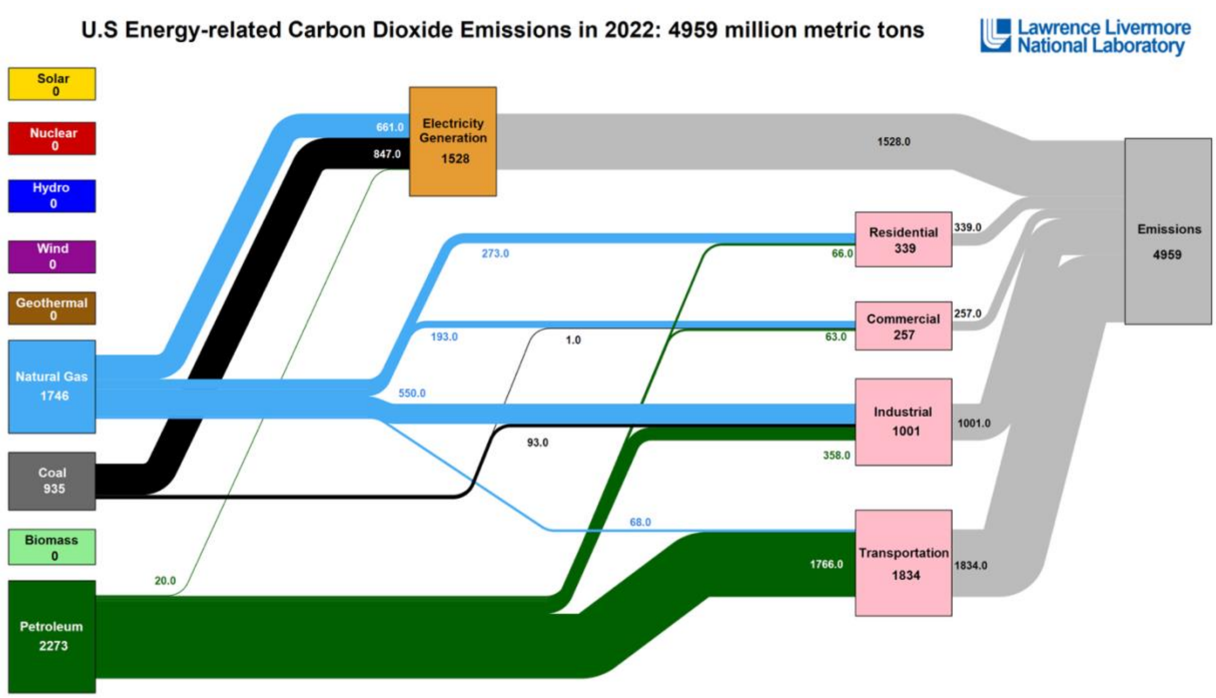
U.S. energy-related carbon emissions are approximately 4,959 million metric tons (MMT) CO_2 on an annual basis, approximately 19% of the annual energy-related global CO_2 fossil fuel emissions. The Transport and Electricity Generation sector combined emit 3,362 MMT, with Transport accounting for 1,834 MMT (37.0%), and Electricity Generation 1,528 MMT 30.8%.

1.2. Where do we go next?

Carbon Intensity: Research, develop, and promote public policies based upon "carbon intensity per unit of GDP."

In the energy sector, a finance sector has emerged since the 1990's referred to as the "ESCO" (energy savings contract) model in which energy efficiency measures are paid from avoided energy cost savings. A similar contract model can be applied to a carbon intensity in-lieu of the carbon tax model, which has been resisted in U.S. public policy. The carbon trading and cardon offset models have emerged with questionable reviews. For the Transport sector, imagine consumers who purchase electric vehicles getting an avoided carbon emissions payment per mile driven (the tax rebate scheme has ended under the Trump administration); and imagine a similar payment system for Electricity Generation in-lieu of support tax relief for the wealthy (which still remains for infrastructure finance under the Master LLC business structure). The public policy conversation now, rather, is how to establish a highway infrastructure tax for electric vehicle owners and cutting IRA-based tax incentives on renewable energy infrastructure.

Additional economic modeling is required to advance public policy mechanisms that incentivize carbon intensity as finance mechanism for the Transport and Energy Generation sectors that, potentially, will reduce carbon emissions, reduce energy intensity, increase economic productivity, and increase economic development (jobs).



Water Flows in the Energy Sector

Climate change is making weather patterns more extreme and more unpredictable—longer dry spells, followed by heavier rains. Scientists call this the “climate whiplash” effect. The number of drought-to-flood events has doubled in the past 40 years. In the U.S., flood disasters that follow drought years have increased by 45% since 1980. Key mitigation efforts include nature-based solutions to restore land health, including improved carbon sequestration in the agriculture sector:

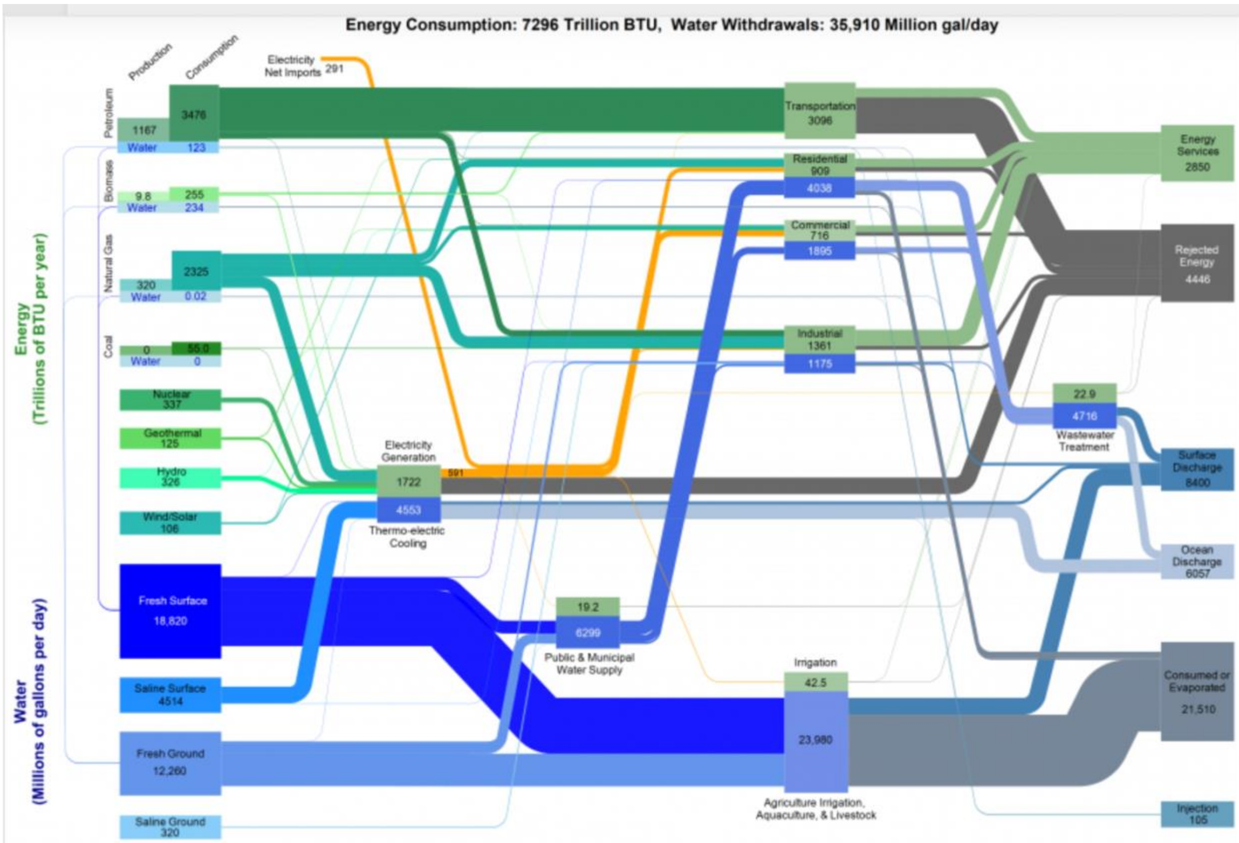
Water flows required to generate electricity are increasing stress on the surface water component of the U.S. hydrological system, as surface water is the primary source of water for generation (boiling water) and for nuclear reactor cooling. The U.S. Department of Energy is working to re-energize the domestic nuclear sector by nurturing collaborations among universities, national laboratories, and industry to advance nuclear science and develop a range of nuclear technology solutions to help maintain and expand the nation’s nuclear fleet. The United States operates the largest fleet of commercial reactors in the world with 94 units in operation in 28 states. These reactors generate nearly half of the nation’s clean energy supply and enhance energy security. As the U.S. government and nuclear energy industry continue to favor investments in nuclear energy development, the U.S. hydrological system will come under increasing pressure to provide surface water supply for energy generation and reactor cooling.

DOE is supporting all stages of development through several programs aimed at bringing advanced reactor systems to market:

- **Advanced Reactor Demonstration Program (ARDP)** aims to speed the demonstration of advanced reactors through cost-shared partnerships with U.S. industry. ARDP leverages the **National Reactor Innovation Center (NRIC)** to efficiently test and assess technologies by using the national laboratory system to move these reactors from blueprints to reality.
- **Gateway for Advanced Innovation in Nuclear (GAIN)** provides the nuclear energy community with access to the technical, regulatory, and financial support necessary to move new or advanced nuclear reactor designs toward commercialization while ensuring the continued safe, reliable and economic operation of the existing nuclear fleet.
- **The Office of Advanced Reactor Technologies (ART)** sponsors research and development activities for advanced reactors, including molten salt reactors, high temperature gas-cooled reactors, liquid metal fast reactors, and microreactor concepts, to promote safety, technical, economic and environmental advancements of innovative nuclear energy technologies.
- **Generation III+ Small Modular Reactor (SMR) Program** intends to de-risk first-of-a-kind light-water SMR deployments and establish an orderbook for follow-on deployments. In October 2024, DOE released a funding solicitation to provide up to $900 million through the program.

However, there is no clear evidence that these programs are examining the socioeconomic and environmental risks to increase stress on the U.S. hydrological system.

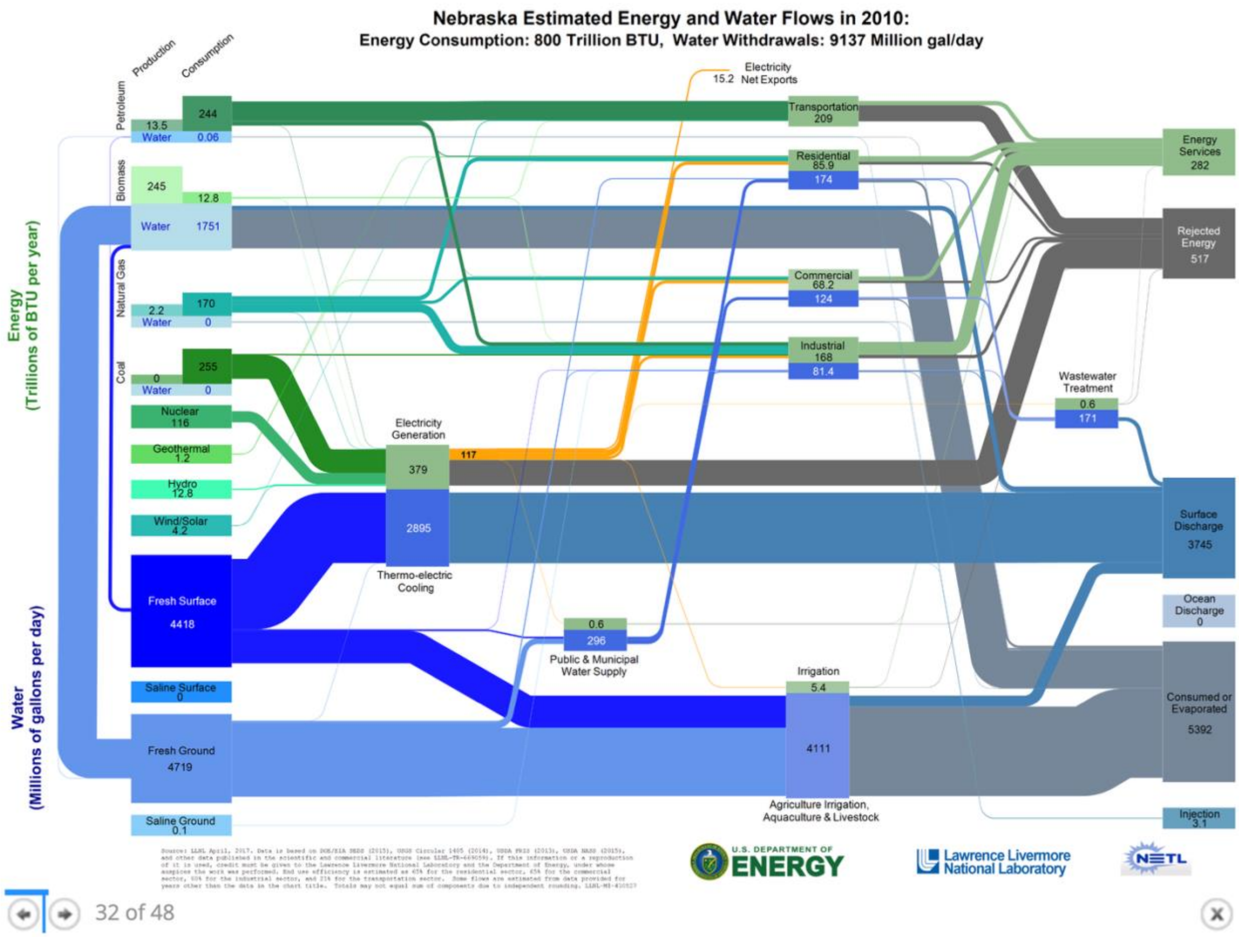
Water Flows in the U.S. Economy



National-scale (state-by-state) surface water modeling has not been updated since 2010, and no federal funding has been allocated to support modeling research at national or state levels. Such modeling activities are extremely critical for public policy decision support, especially in landlocked states, as drought and flood cycles continue to increase due to climate change.

In the State of Nebraska, for example, is utilizing 65.5% of available surface water for thermal electric cooling, while only 30% is allocated for farmland irrigation. Nebraska, instead, utilizes 87.1% of available ground water supply for farmland irrigation, placing enormous pressure on subsurface aquafers, specifically the Ogallala Aquifer, which is facing challenges due to over-extraction and pollution.

See example of landlocked state water flow for Nebraska, below:

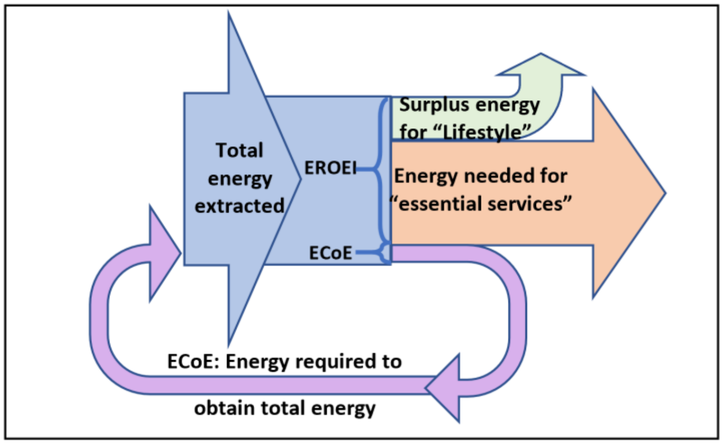


Energy Returned on Energy Invested (ERoEI)

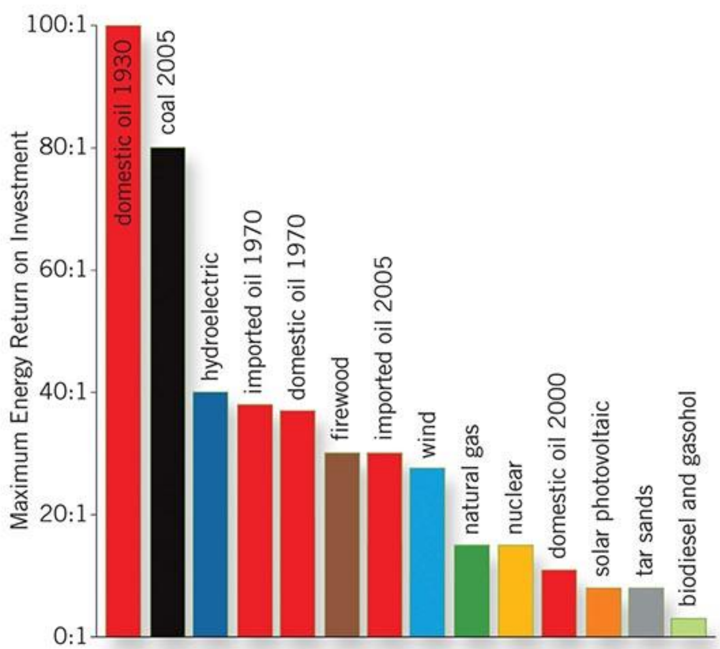
In energy economics and ecological energetics, energy return on investment (EROI), generally referred to as “energy returned on energy invested” or “ERoEI,” is the ratio of the amount of usable energy (the exergy) delivered from a particular energy resource to the amount of exergy used to obtain that energy resource. Exergy is defined as the maximum useful work that can be extracted from a system as it comes into equilibrium with its environment. It measures the quality of energy and indicates the potential of energy to perform work in a thermodynamic process.

When the ERoEI of a source of energy is less than or equal to one, that energy source becomes a net "energy sink" and can no longer be used as a source of energy. However, in the development of new sources of energy (for example, solar energy, geothermal, corn-based ethanol, etc.), large investments in energy (and financial subsidies) have been made during research and development phases on the assumption that economically viable ERoEI can be achieved in the near term with reduced capital costs for infrastructure development. Investment of energy and capital are sometimes maintained for negative ERoEI for socioeconomic and/or political reasons (social costs), such as in the case of farmer subsidies to grow corn for ethanol production, or in the research and development phases for new renewables.

This simple diagram explains the principle of ERoEI:



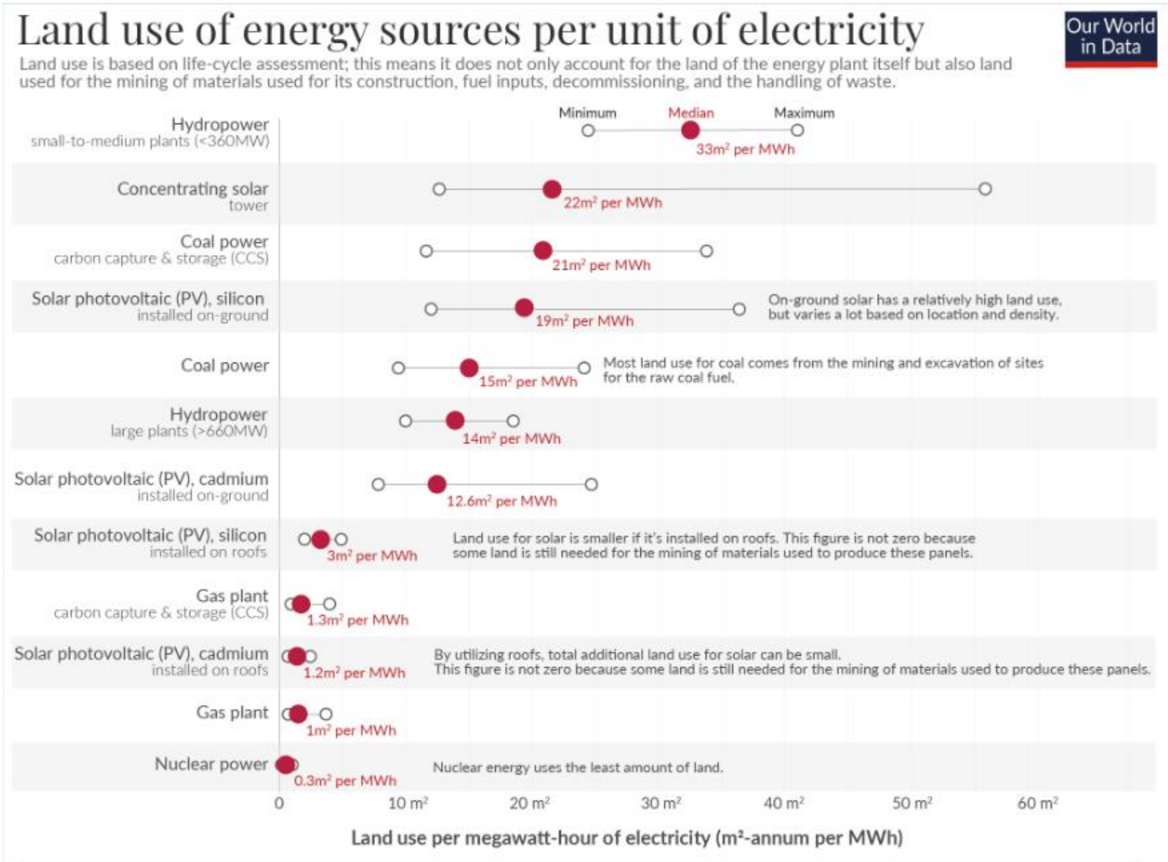
ERoEI Graph:



Today, ERoEI of domestic oil and solar photovoltaics (PV), including PV storage, are competitive, with solar PV achieving lower capital and operating costs.

Land Use for Energy Production:

Land use for each source for primary energy resources should be considered for each energy generation technology. The *Land use or energy sources per unit of Electricity* chart, below, could be graphically illustrated in a Sanky Diagram format, and be integrated into a suite of Sankey diagrams, including ecological impacts.



PROBLEM: Where do we go next?

Sankey diagrams can be used to frame important discussions around energy and material resources, use and disposition.

Lawrence Livermore National Laboratory (LLNL) worked with the Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA) and the National Energy Technology Laboratory (NETL), to produce this atlas of hybrid energy/water Sankey diagrams for each of the U.S. states. These diagrams depict energy use and water flow in each state during the year 2010, the latest year for which comprehensive data is available.

As a nation, we are blind to the issues and unable to set policy without maintaining data and updating data analysis as a key decision support tool.

Middlebury College could establish a national (and international), education-based Technical Support Unit (TSU) to advance essential Sankey services across complex relationships among energy, water, and carbon and other essential areas of energy decision support, such as ERoEI and land use.

Suggestions:

1. Identify an expert in Sankey Analysis and secure a budget from university for an advanced Sankey modeler from LLNL to attend conference as guest speaker and panelist.
2. Recruit a student (SNEG) panelist to moderate panel.
3. For additional panelists, identify faculty that teach relevant MIDD courses, as listed below:

   Earth and Climate Science:

   - ECSC 0105 – Energy and Mineral Resources
   - ECSC 0353 – Hydroclimate and Wildfire
   - ECSC 0335 – Water Resources & Hydrology
   - ECSC 1230 – Data Science Across Disciplines

   Economics

   - ECON 0265 – Environmental Economics
   - ECON 0365 – Climate Change Economics
   - ECON 0466 – Environment and Development
   - ECON 0467 – Econ Growth and Sustainability

   Environmental Studies

   - ENVS 0211 – Conservation and Environmental Policy
   - ENVS 0280 – Climate Change Industrial Policy
   - ENVS 1025 – Renewable Energy - Public
   - ENVS 1230 – Data Science Across Curriculum

(Note: Sources are not cited due to limited time to provide SNEG conference topic decision support. If this topic is advanced, sources will be cited in further documentation.)