



MOVING TOWARDS A MORE EFFICIENT USE OF ENERGY

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Alex M. Stanković
Northeastern University, Boston

astankov@ece.neu.edu

90% of U.S. Electricity Today



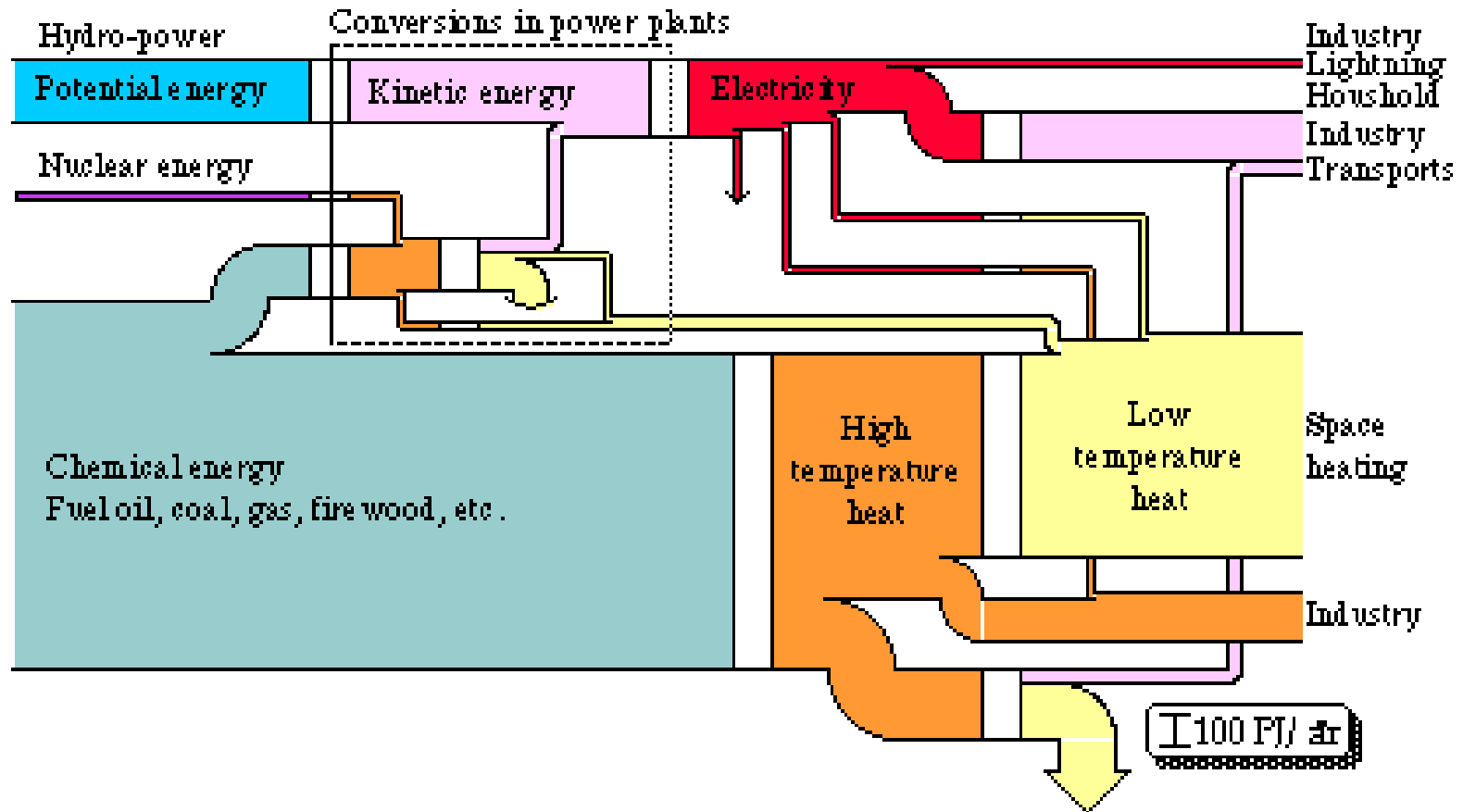
Environmental Effects



Presentation Map

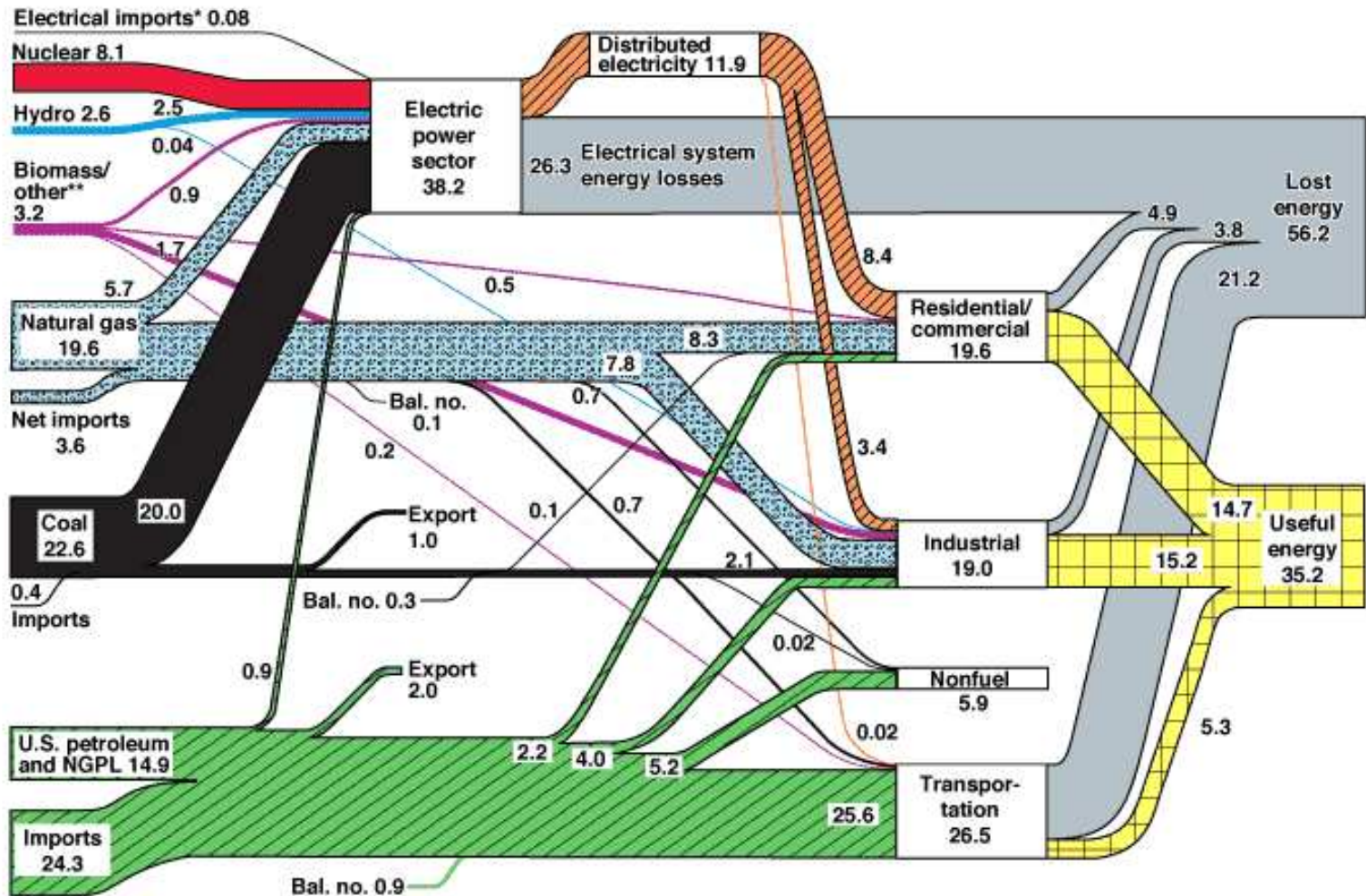
- Energy as a **Systems** Issue,
- Electricity as the Integration Medium,
- Energy Systems - Past & Present,
- Energy Systems - a Possible Future,
- A Role for the NU Family

Overall Energy Flows



Energy Flows in the U.S.

U.S. Energy Flow Trends – 2002 Net Primary Resource Consumption ~97 Quads



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.

*Net fossil-fuel electrical imports.

**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
<http://eed.llnl.gov/flow>

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Why Electric Energy Systems?

Systems aim to achieve level **reliability** that far exceeds the reliability of individual components, through corrections of control actions based on **evaluating or sensing** its current state.

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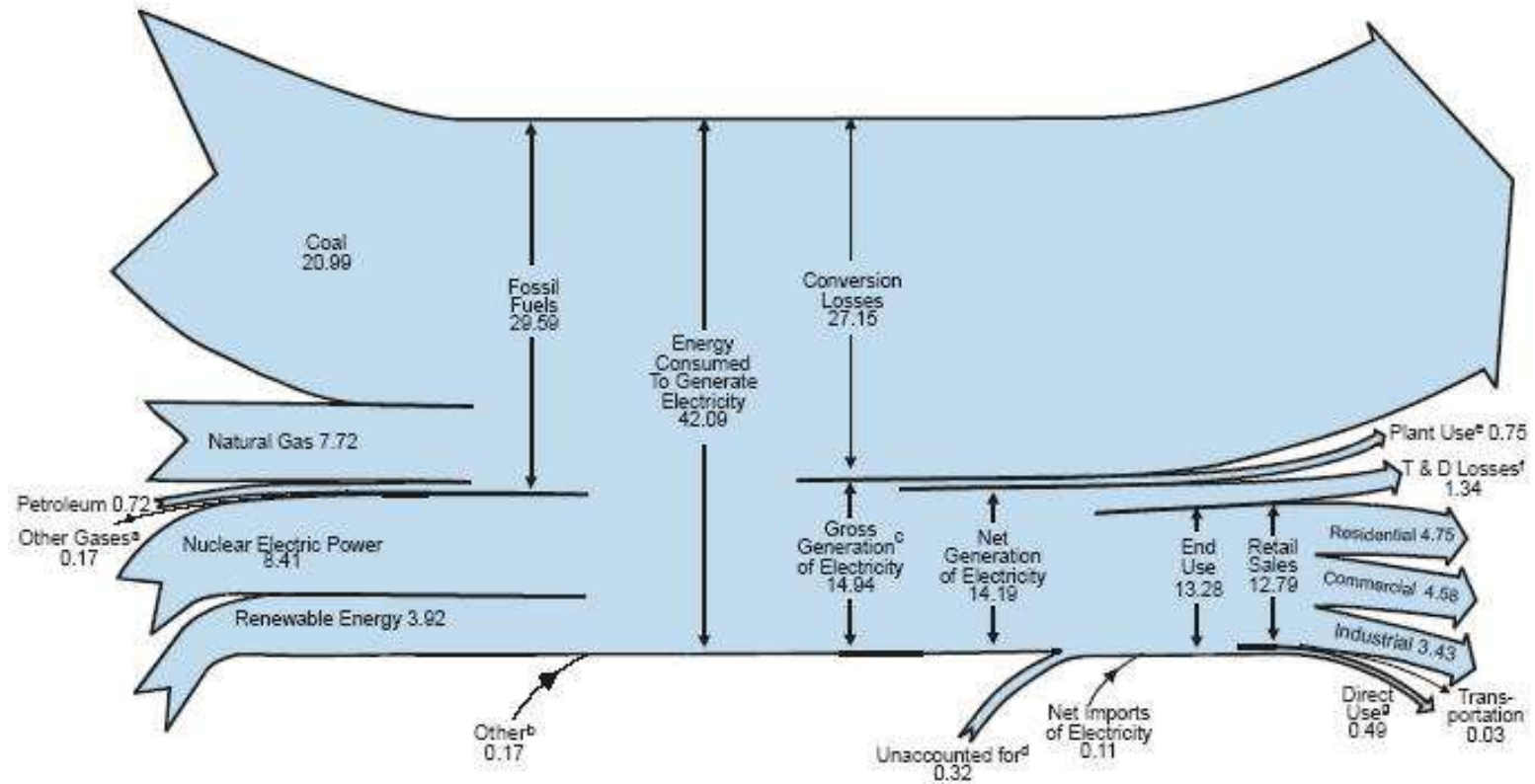
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Events from real life (G.T. Heydt):

Losing in roulette	N=1.6
Losing the PowerBall lottery	N=6
FAA design for aircraft	N=9-12

Electricity in the U.S.



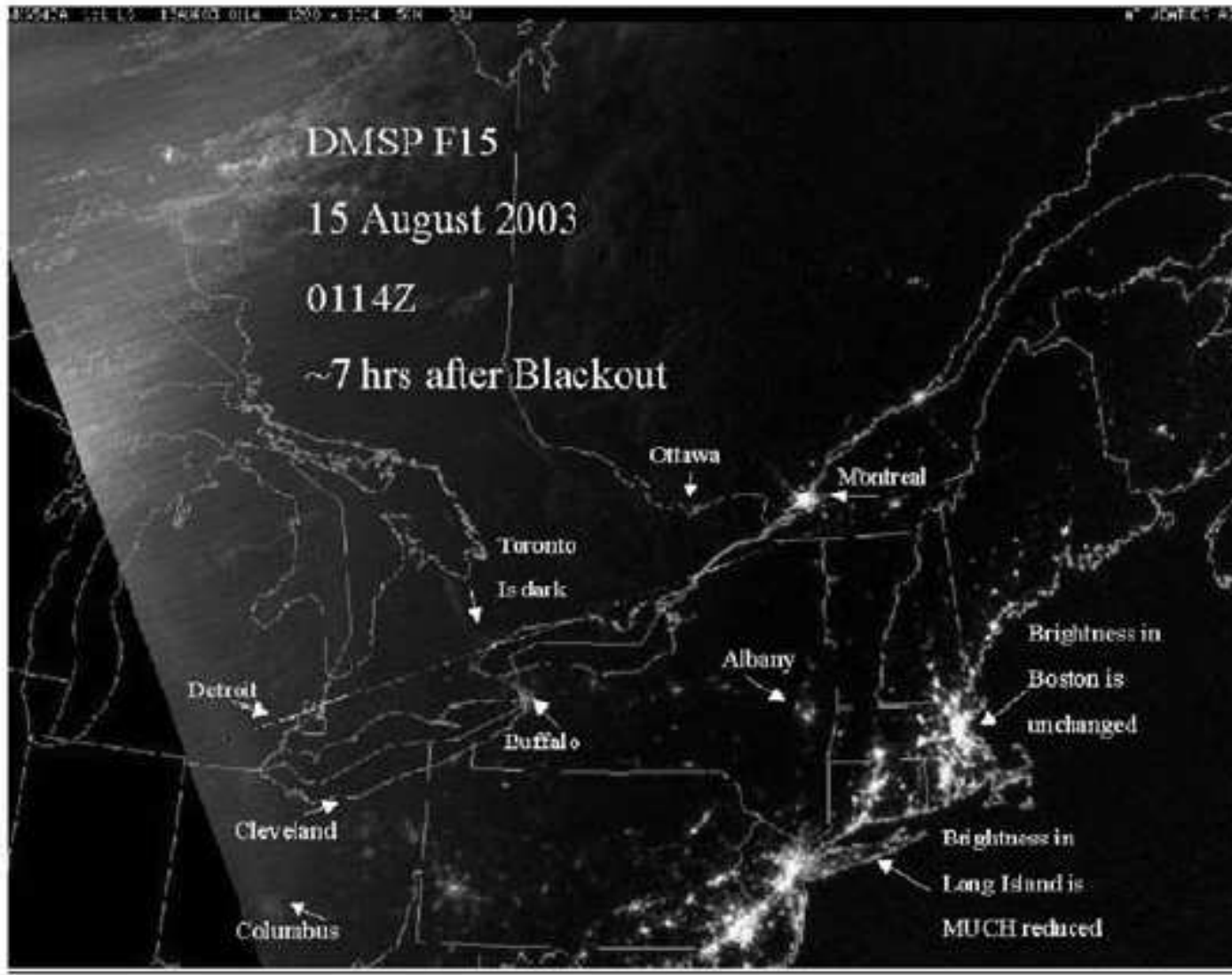
Characteristics of Electric Energy Network

- Built for **efficiency**.
- **Multi-scale** in time (>10 orders of magnitude), space (>7 orders of magnitude) and by power flow (>10 orders of magnitude).
- **Hybrid** - continuous and discrete acting components.
- **Normal** and **faulted** operation (nature and human adversaries).

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- **Hybrid** - continuous and discrete acting components.
- **Normal** and **faulted** operation (nature and human adversaries).
- Two main layers - **energy** and **information** flow.
- Limited actuation.
- **Uncertainty** (epistemic and aleatory).
- Input/Output characteristics are **regularized** by physics (conservation laws, coherences and invariants).

Cascading Faults



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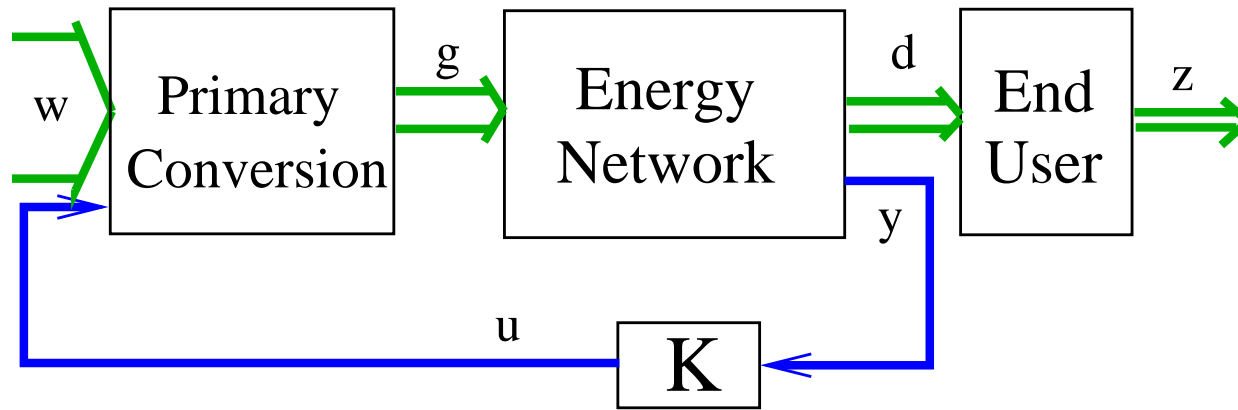
A Contemporary Technology...



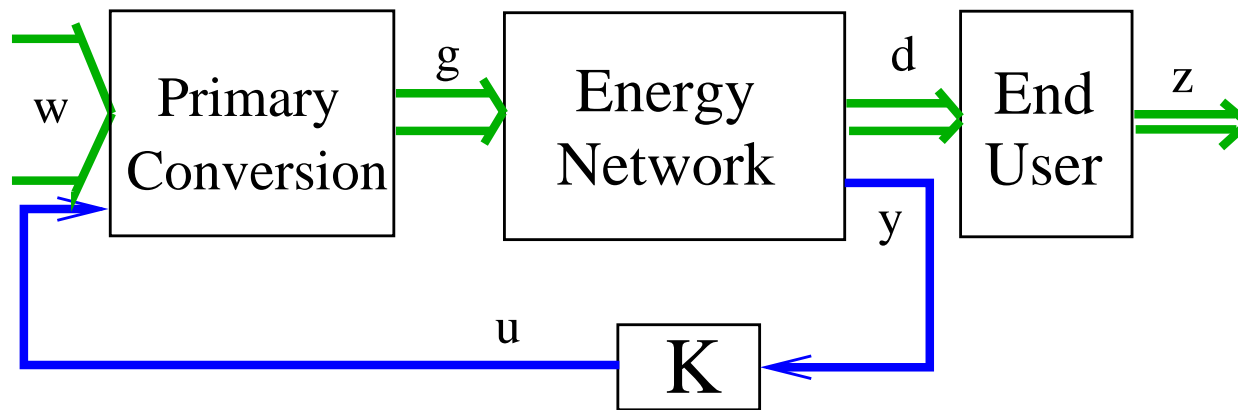
Existing Grid...



Existing Energy Systems



Existing Energy Systems

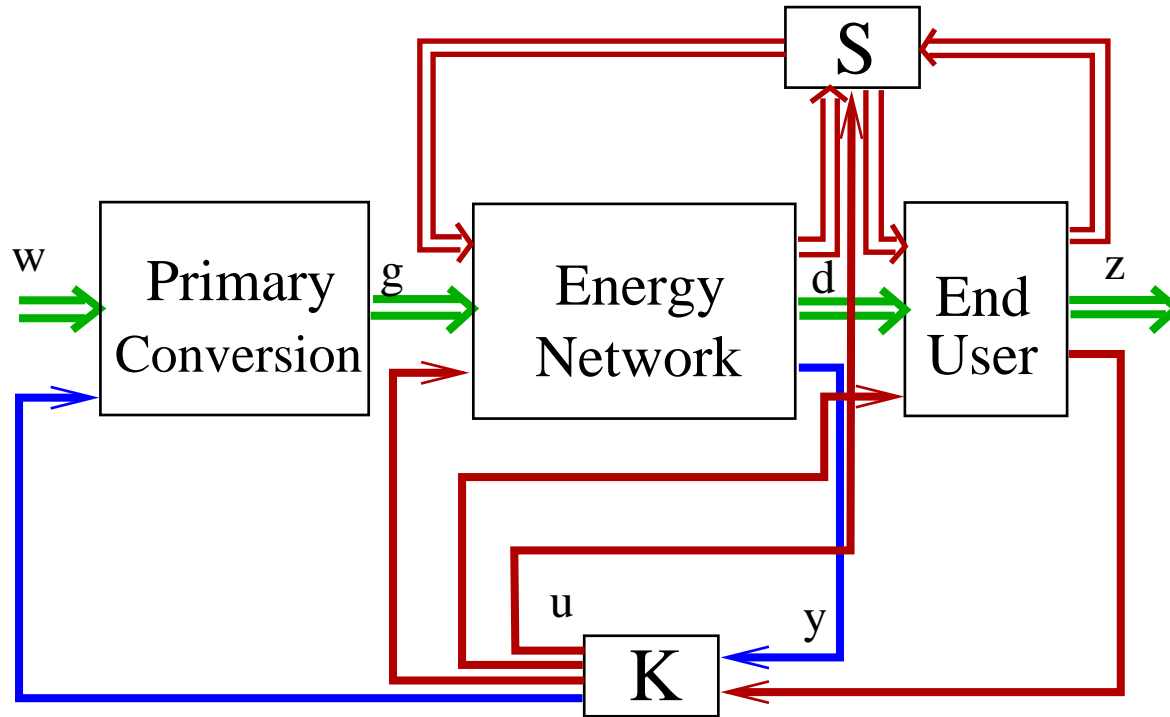


- w too large, little from renewables,
- Unable to integrate novel components,
- Non-functional markets,
- Over-designed components - variations in z ,
- Over-designed components - fault accommodation,
- Cascading faults.

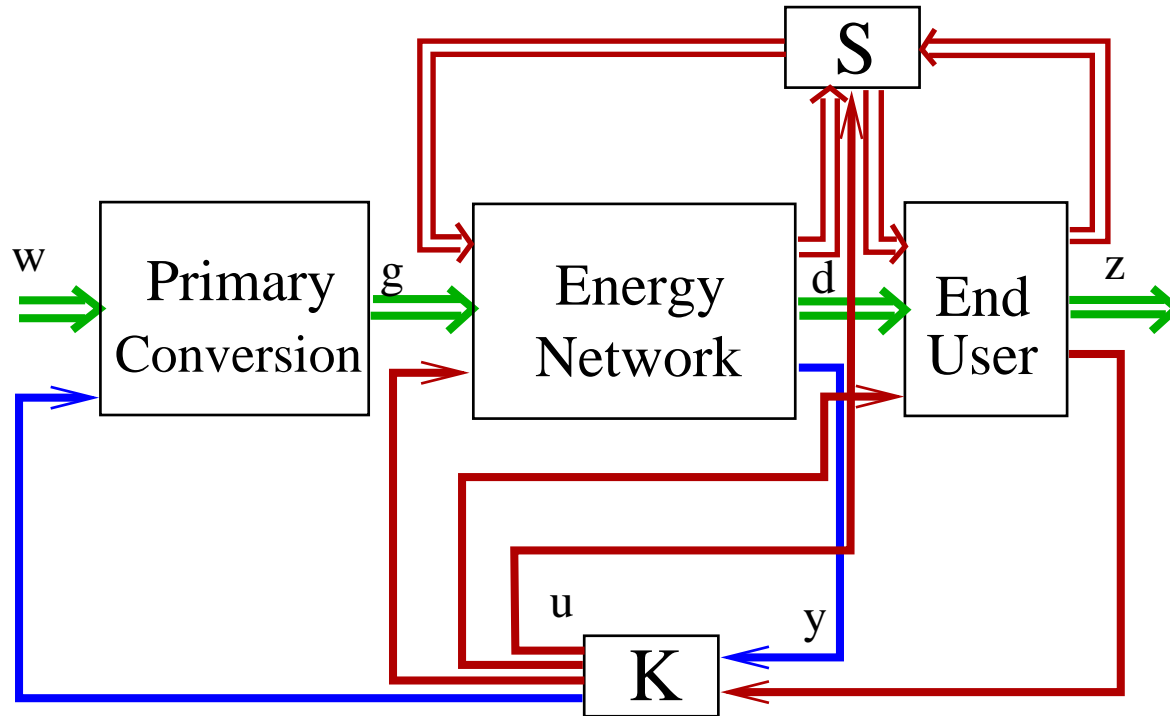
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Future Energy Systems VLSIE



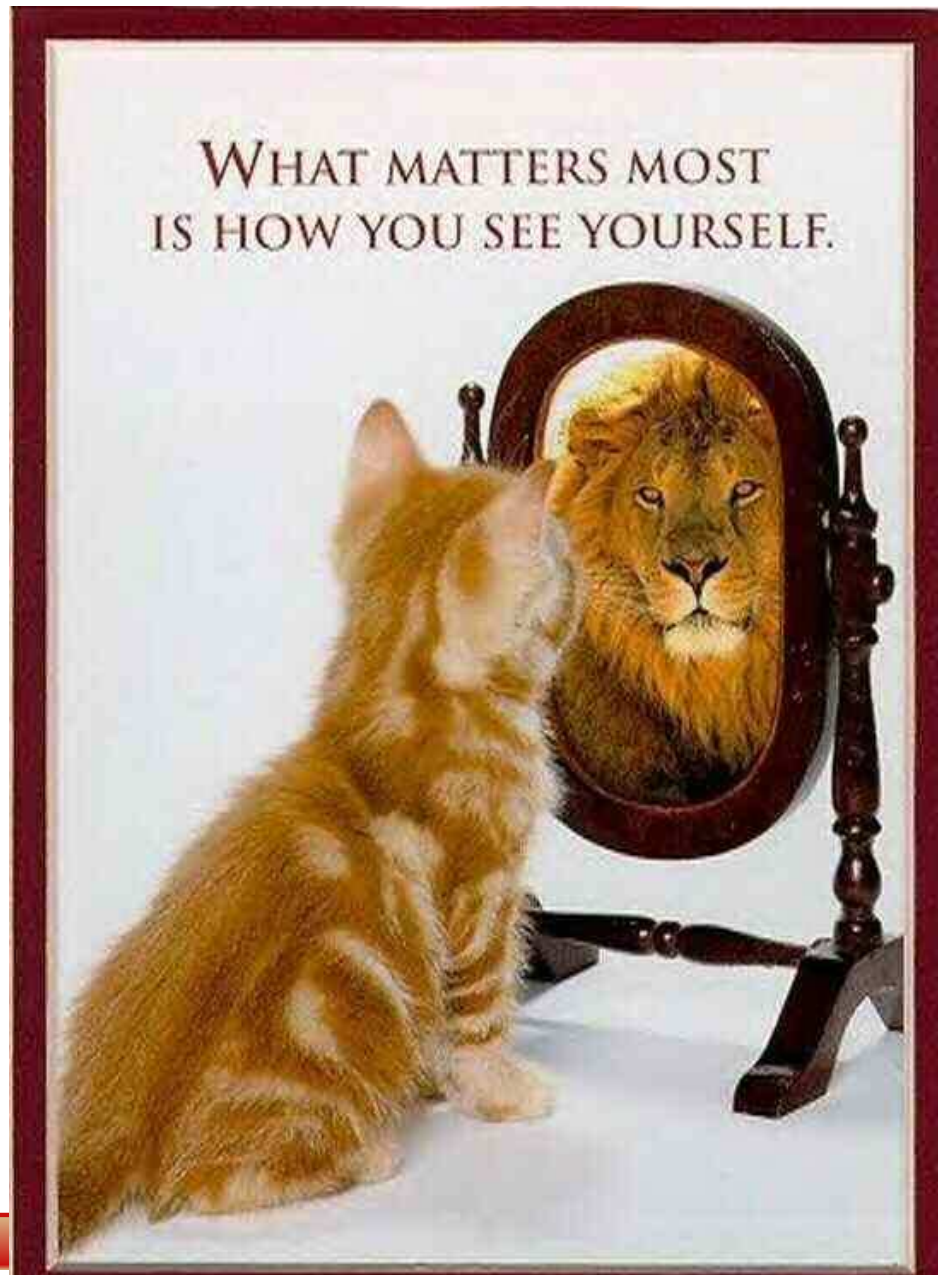
Future Energy Systems VLSIE



- **Information layer**
 (sensors, coordinated K = local + global context, loads inside)
- **Better blocks,**
- **More w from renewables,**

- **Flatter control** - decoupling from above and below, faster, more authority via storage and routing,
- **Better design** while steering component development.

Renewables Today



A Scenario for the Future

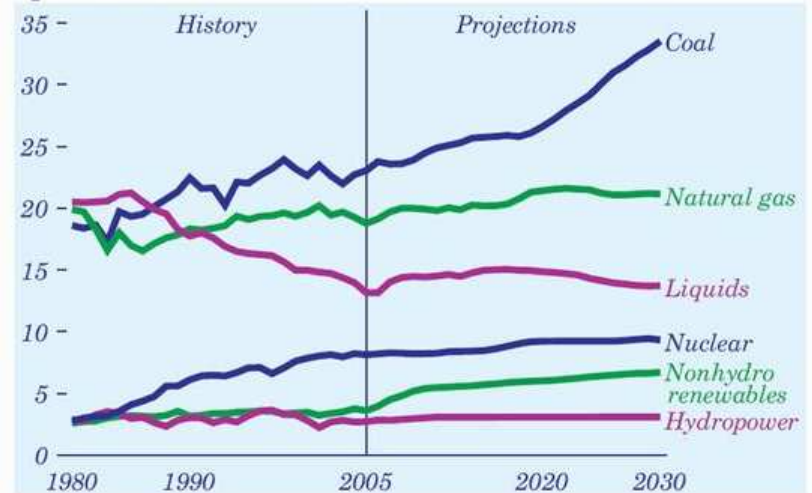
U.S. net energy imports

Figure 6. Total energy production and consumption, 1980-2030 (quadrillion Btu)

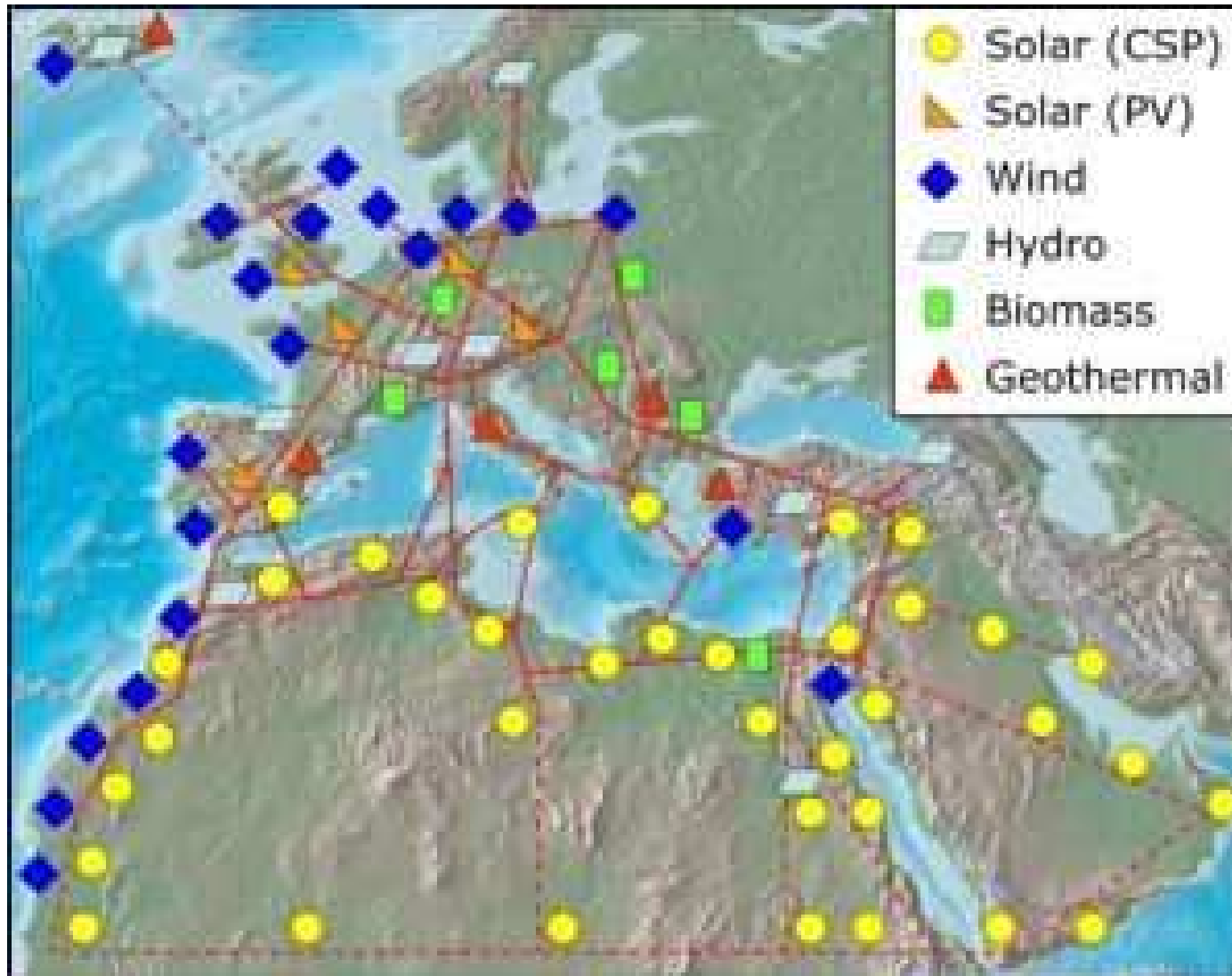


U.S. domestic energy production by type

Figure 7. Energy production by fuel, 1980-2030 (quadrillion Btu)



Thinking Big



A First Glimpse - Smart Grid



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Getting there...

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- Our future - existing and **new** research centers,
- “The energy crisis appears to me to be more a crisis of momentum than of energy – a crisis of enterprise, solidarity, common spirit, determination and cooperation for the common good.” - Ulam

ACKNOWLEDGMENTS

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Contact info:

astankov@ece.neu.edu

www.ece.neu.edu/faculty/stankovic

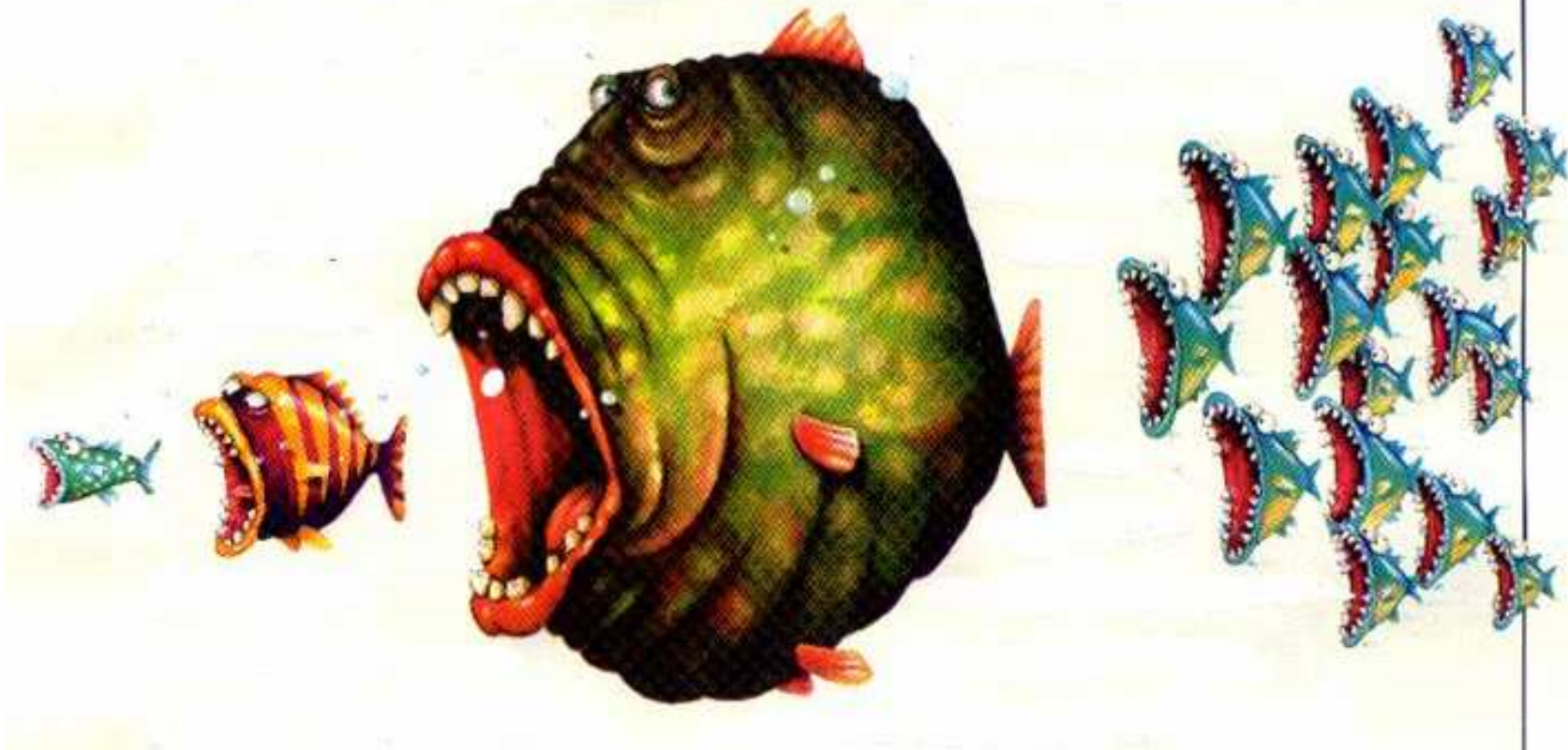
System Evolution...

1900

1940

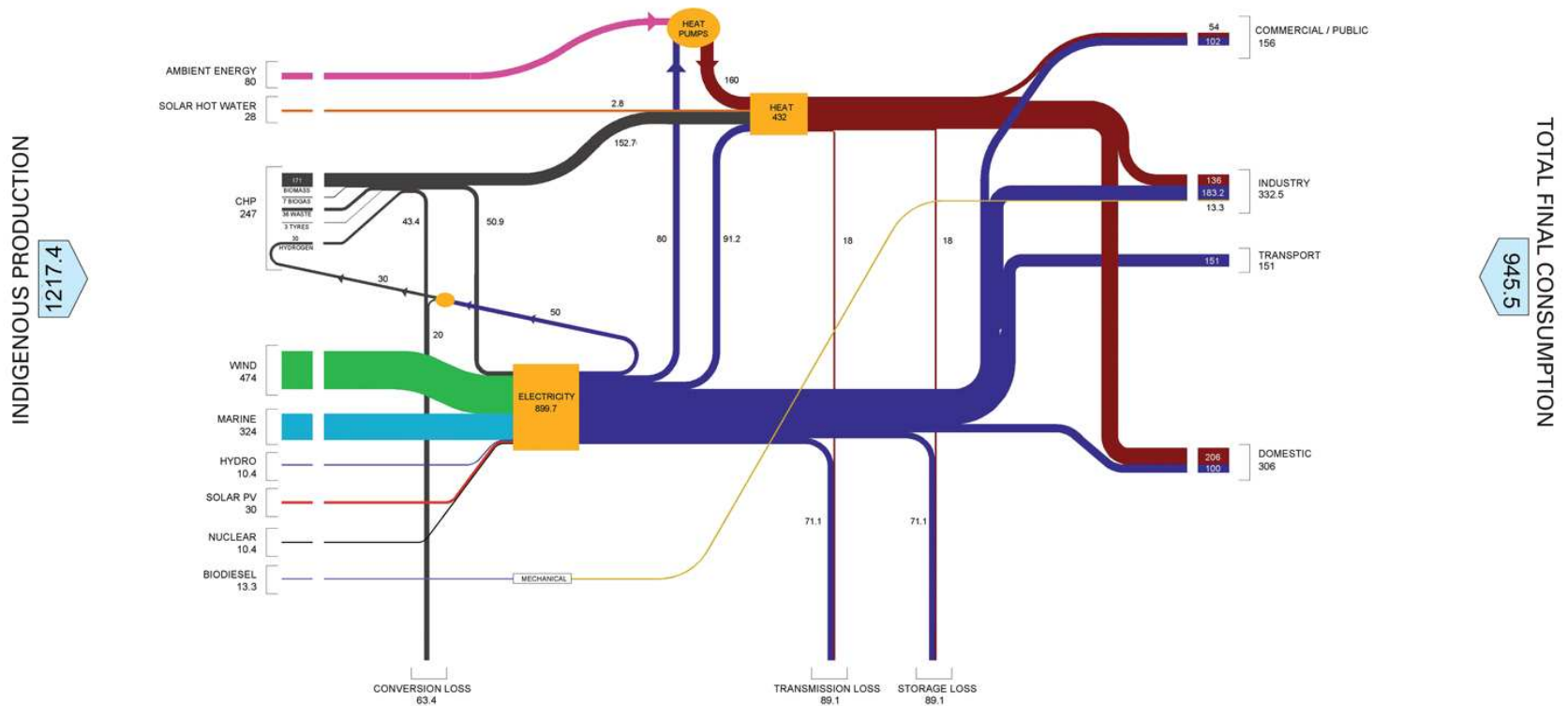
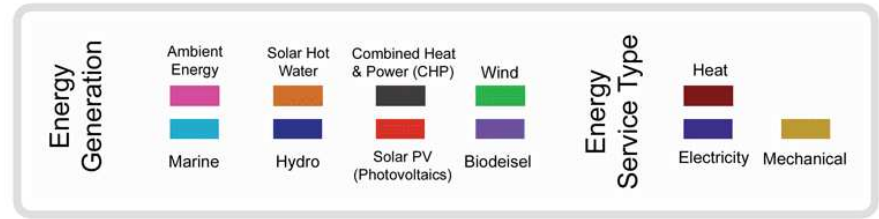
1980

2020



Thinking Green

UK Potential Energy Flows 2027 (TWh)



NAE Grand Challenges

14 grand challenges for engineering in the 21-st century (Feb. 2008):

- 1. Environmentally friendly power.
- 2. Nuclear fusion.
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A **recurring theme**: “The vast networks of electrification are the greatest engineering achievement of the 20-th century.”