Principles for Design and Grid Application of Green Energy Storage Systems

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Outline

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- Case Study
- Categories of Principles for Design and Grid Application of Green Energy Storage Systems
  - Deployment for Grid Applications
  - Operation & Maintenance
  - Design and manufacturing
- Conclusion

Introduction:
Energy Storage Grid Applications

- Solution for several grid applications such as **renewables integration** and **T&D upgrade deferral**

- Environmental Impact
- Price Volatility

- Green Alternative
- Challenges (e.g. **intermittency**)

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Why Principles for Green Energy Storage ?

The integration of energy storage systems into the grid can lead to different environmental outcomes.

The outcomes depend on the grid application, the existing generation mix, and demand profile.

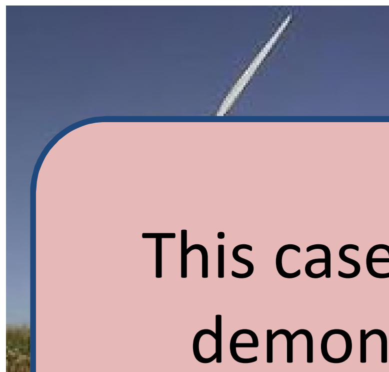
Principles specific to design and grid application of energy storage systems are developed.

Principles can guide design, deployment and operation of storage systems, given the complexity and trade-offs that emerge when integrating these systems into the grid.

Case Study: A Micro-grid System

Natural Gas Reciprocating Engine (3 MW)

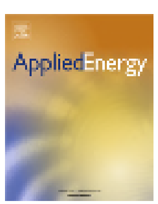
Wind Turbine Vestas (3 MW)



This case study is used to demonstrate selected principles (principles# 4, 6, 7).

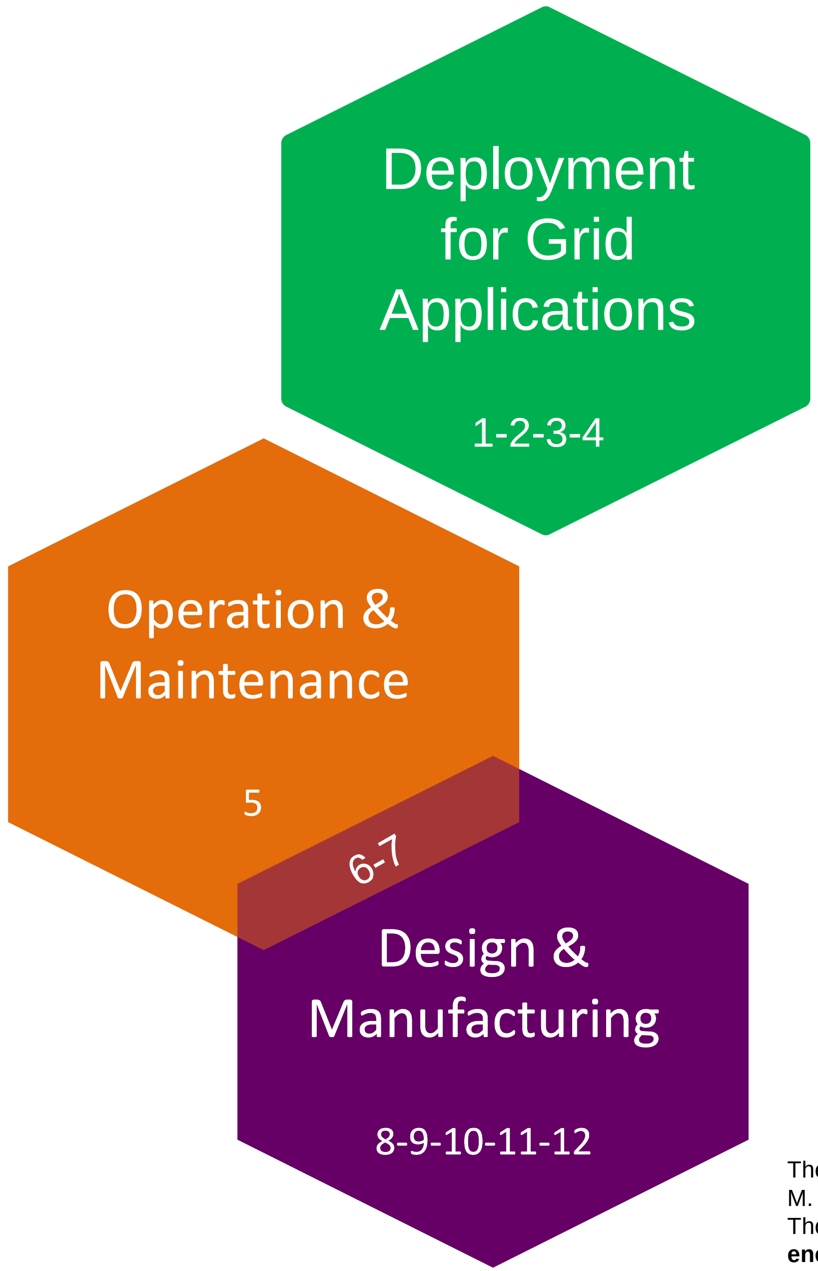
Vanadium Redox Flow Battery

Energy Demand, Represents "Grosse Ile, MI" (Annual Demand: 10.6 MWh/capita, Annual Peak Demand: 22 MW)



M. Arbabzadeh, J.X. Johnson, R. De Kleine, G.A. Keoleian, "**Vanadium redox flow batteries to reach GHG emissions targets in an off-grid configuration**," Applied Energy, vol. 146, pp. 397-408, 2015.

Categories of Principles for Design and Grid Applications of Green Energy Storage Systems



The study is submitted as:
M. Arbabzadeh, J.X. Johnson, G.A. Keoleian, Levi T. Thompson, Paul G. Rasmussen,"**Twelve principles for green energy storage**," *Envi Sci & Tech*, Under review, Aug 2015.

Deployment for Grid Applications

✓1. Charge clean & displace dirty.

2. Energy storage should have lower environmental impacts than displaced infrastructure.

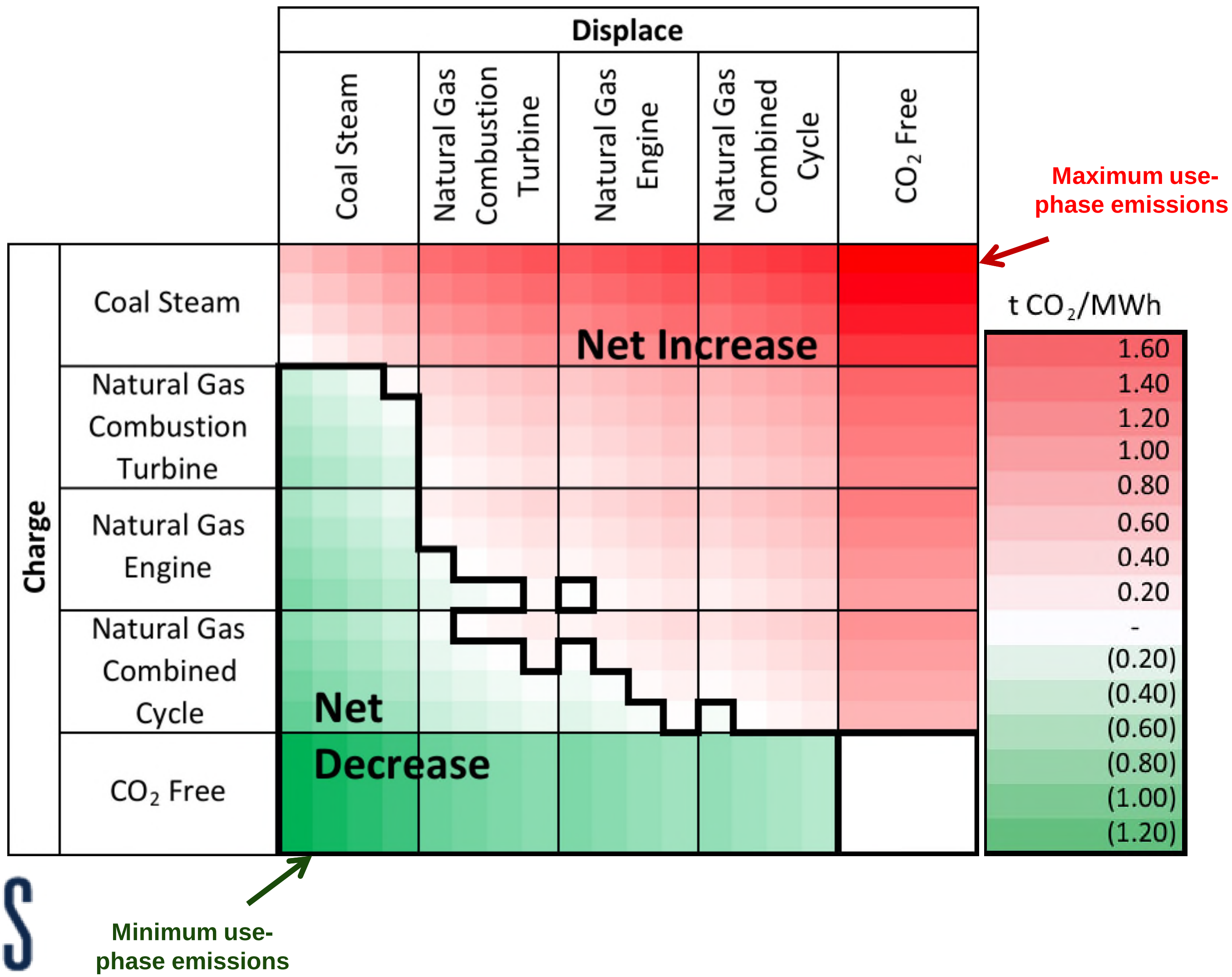
3. Match application to storage capabilities to prevent storage system degradation.

✓4. Avoid oversizing energy storage systems.

Example

Principle 1: Charge clean & displace dirty.

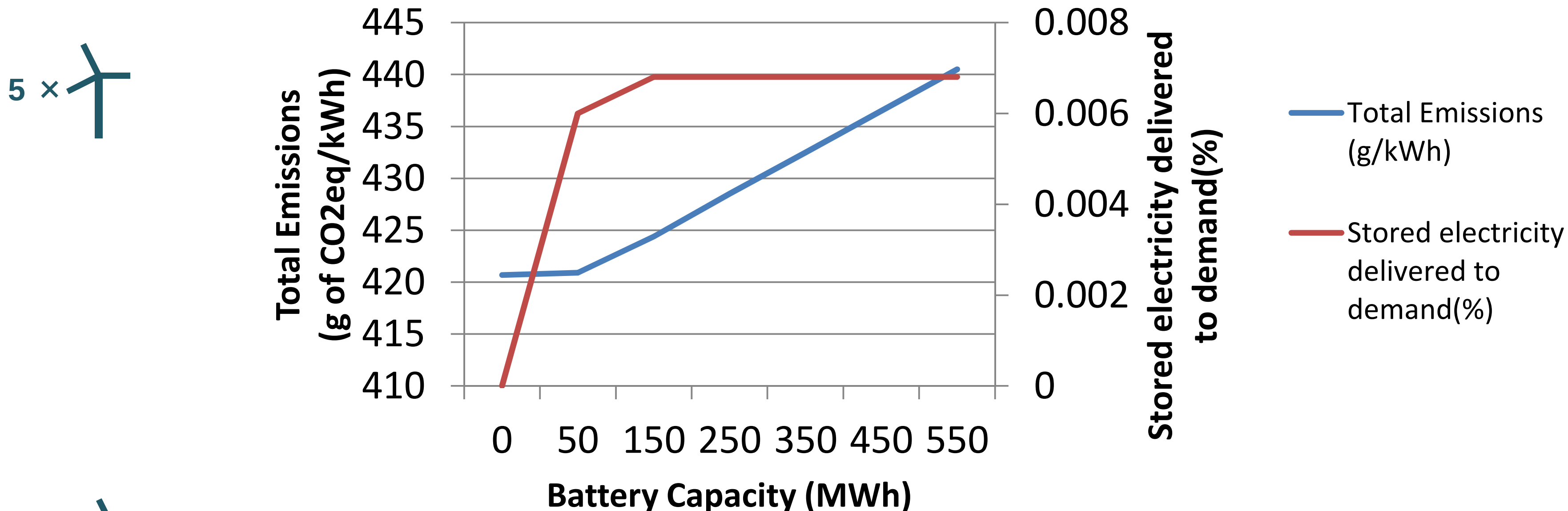
- Net use-phase emissions in different charge/displace scenarios.

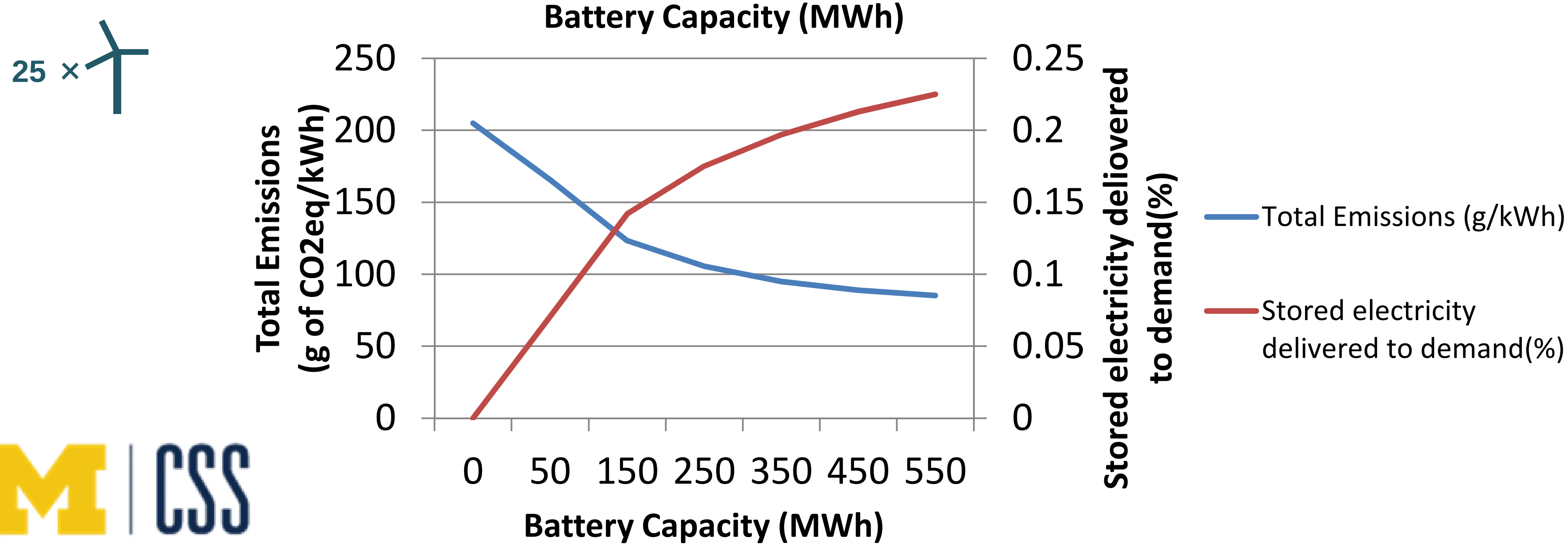


Example

Principle 4: Avoid oversizing energy storage systems.

- The impact of battery sizing on total emissions and stored electricity utilization.





Operation & Maintenance

5. Maintain to limit degradation.

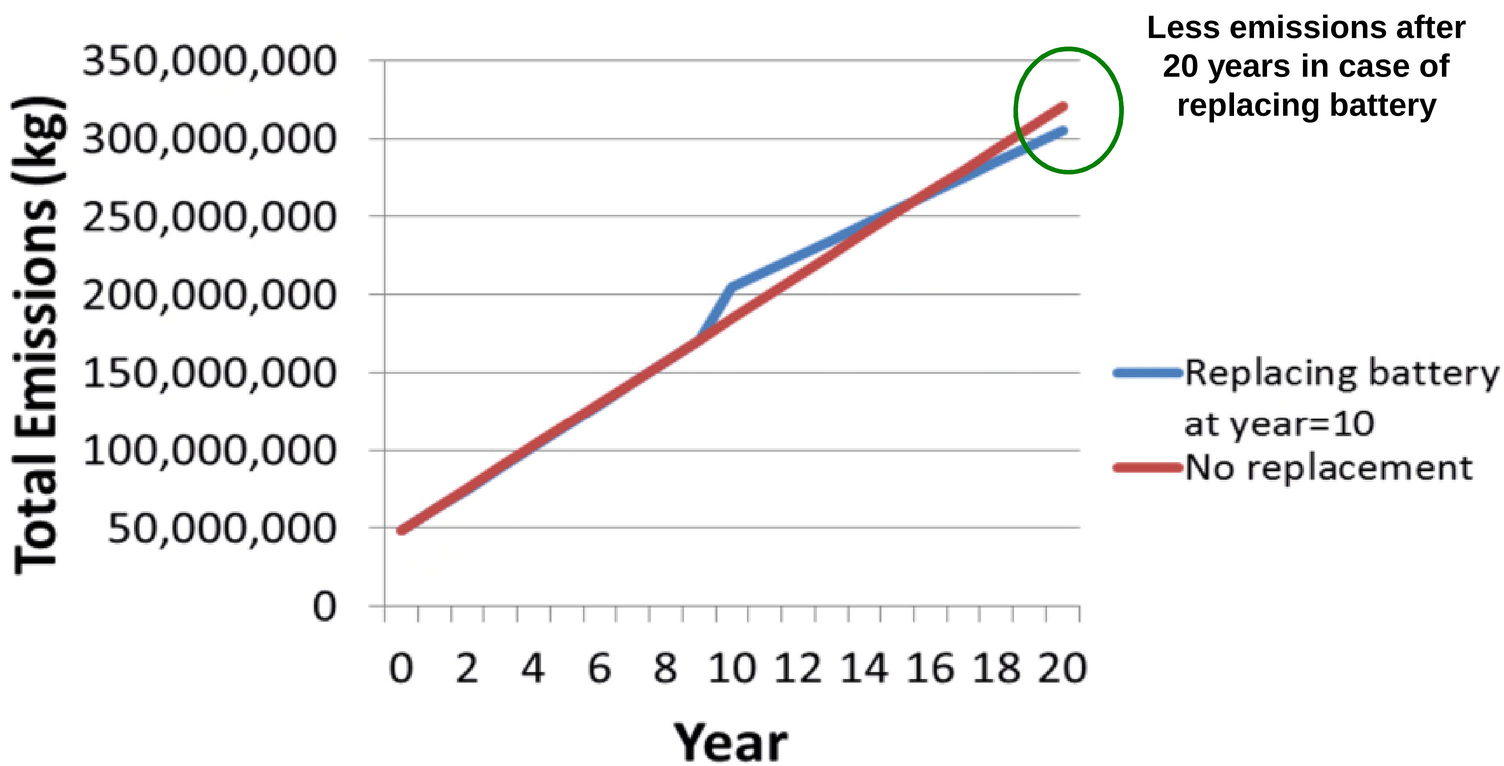
✓ 6. Design and operate energy storage for optimal service life.

7. Design and operate energy storage with maximum round-trip efficiency.

Example

Principle 6: Design and operate energy storage for optimal service life.

- Total emissions of the off-grid configuration after 20 years in 2 scenarios: Replacing the battery (η=60%) with a more efficient one (η =95%) at year 10 and no replacement scenario.



Design & Manufacturing

6. Design and operate energy storage for optimal service life.

✓ 7. Design and operate energy storage with maximum round-trip efficiency.

8. Minimize consumptive use of non-renewable materials.

9. Minimize use of critical materials.

10. Substitute non-toxic and non-hazardous materials.

✓ 11. Minimize the environmental impact per unit of energy service for materials and manufacturing.

12. Design for end-of-life.

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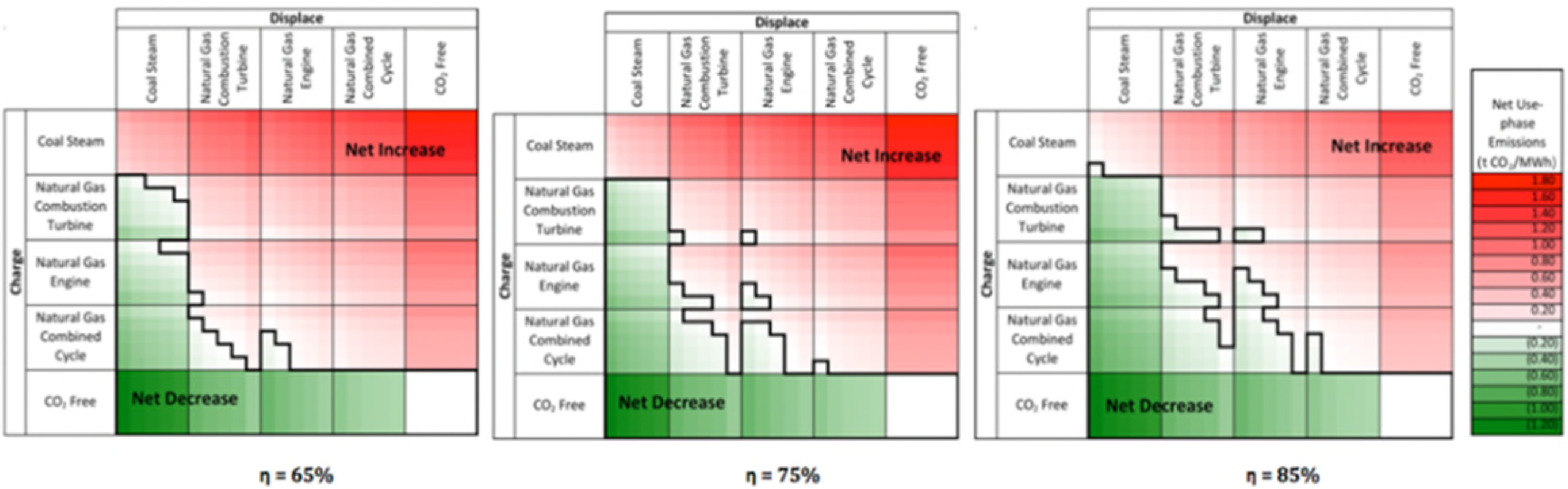
* Several principles in this category has overlaps with : P. Anastas, J. Zimmerman, **"Design through the 12 principles of green engineering**," Env. Sci.&Tech., vol. 37, pp. 94A-101A, 2003.

Example

Principle 7: Design and operate energy storage with maximum round-trip efficiency.

- Net use-phase emissions in different charge-displace scenarios, assuming 3 values for the battery round-trip efficiency



Environmental benefits are increasing by increasing the round-trip efficiency.

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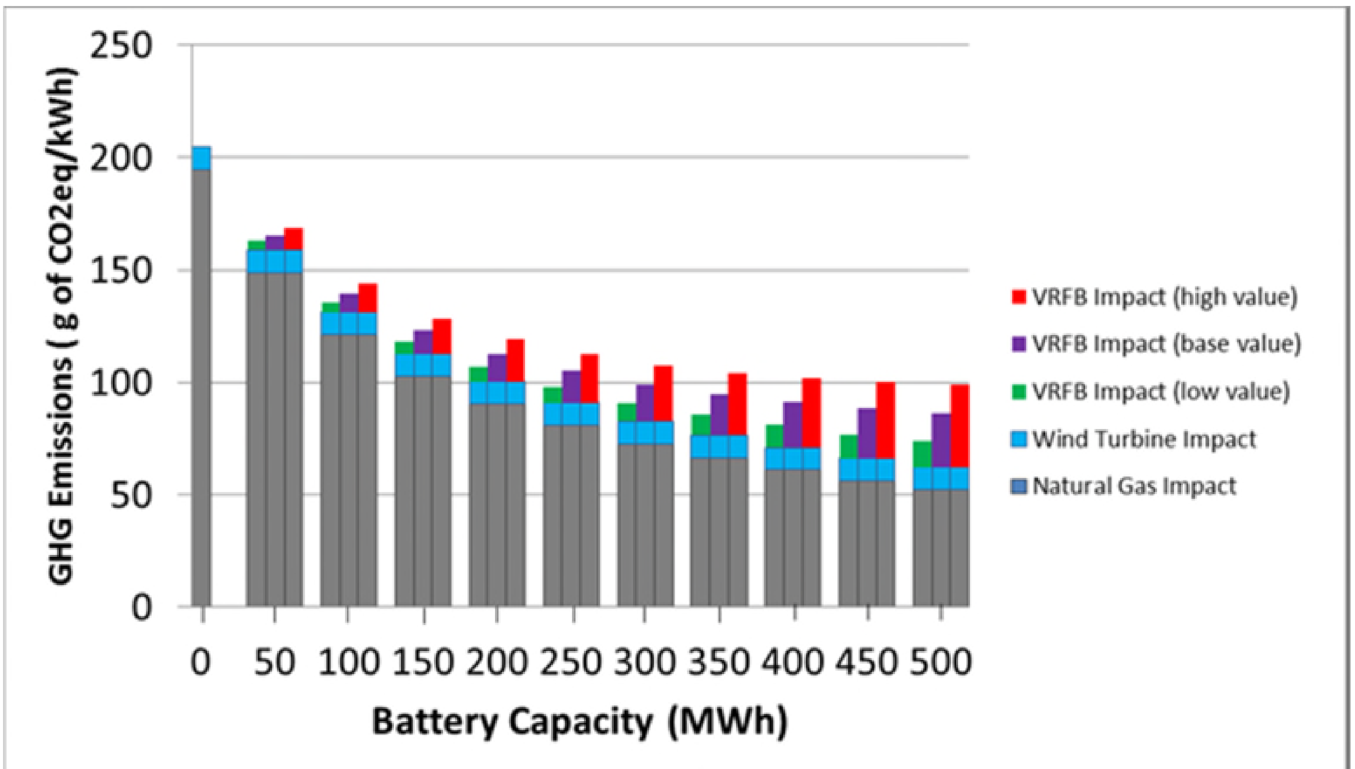
Example

Principle 11: Minimize the environmental impact per unit of energy service for material production and processing.

- The reduction in total emissions is steeper when the battery production burden is decreased.



Conclusions & Current Research

Universal principles for design and grid application of green energy storage are proposed.

The application of selected principles are demonstrated using a case study.

A systematic sustainability assessment algorithm will be proposed to apply principles into both *development* and *deployment* of energy storage systems.

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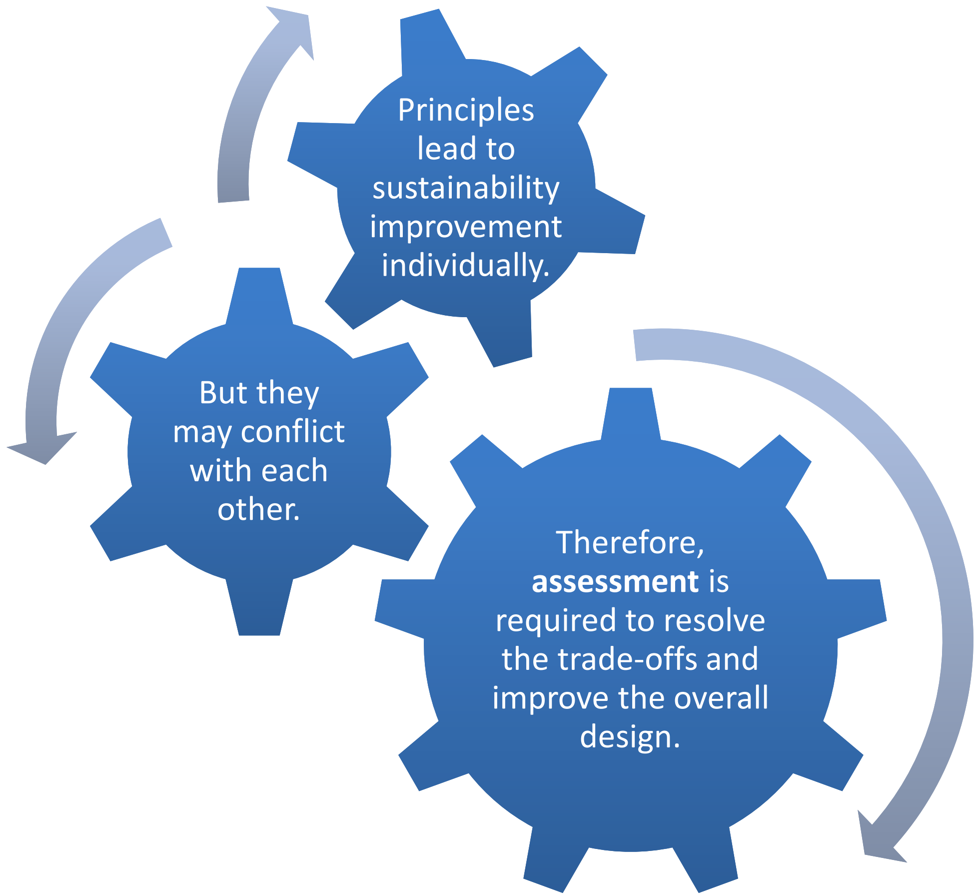
Sustainability Assessment



Green Energy Storage Design Algorithm

- The principles are applied in the design algorithm, where they influence *development* of energy storage technology and its *deployment* in power system.