Quantifying Risk in Energy Systems

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Davion M. Hill, Ph.D.
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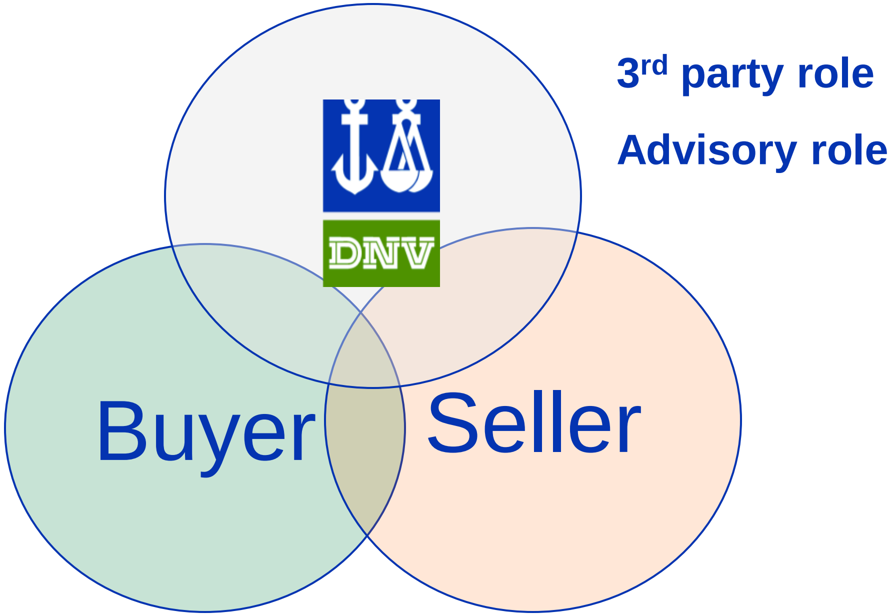
MANAGING RISK DNV

What does DNV do?

- DNV was founded in 1864 to fill a need for an objective third party to assess sailing ships for their seaworthiness
  - In the19th century, sailing and shipping was risky business, but with great rewards possible
  - Ship builders needed an objective reviewer to prove their worth to buyers and insurers

- Milestones
  - 1951: Internal Research
  - 1969: Oil in the North Sea
  - 2004: Offshore Wind



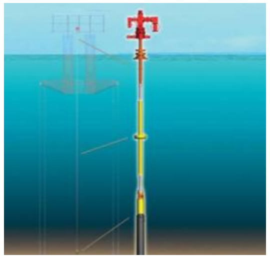
Predictions

Don't cross a river if it is four feet deep *on average*.

Risk in Energy Systems

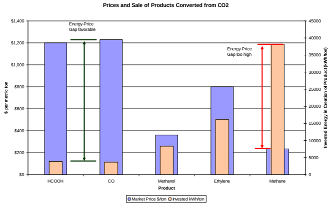
Wind

Solar



Oil & Gas

Nuclear



CO_2 Recycling

WIND AND SOLAR

Two Case Studies: US Wind Turbine Fleet and 1 MW Solar Farm

Case 1: Wind Fleet

Inputs

Capacity Factor

Sale price of electricity

Electrical Subsystem Failure Rates

Blade Failure Rates

Gearbox Failure Rates

First Level Outputs

Output of fleet per year (MWh/year)

Earnings of fleet per year ($/year)

Risk Metrics

Energy: Total Output (MWh/year)

CO_2: Total Offset Emissions (ton/year) based on MWh output (includes avoided and life cycle emissions)

Dollars: Product of Total Output and cost of electricity ($/year)

What effect would reliability have on meeting the 20% Wind by 2030 goal?

Case 2: Solar Farm

Inputs

Efficiency of Panel

Cost of electricity

First Level Outputs

Output per panel per day (kWh/day)

Earnings per panel per day ($/day)

ROI Outputs

Energy: Total Output (kWh/day)

CO_2: Total Offset Emissions (ton/day) based on kWh output (includes avoided and life cycle emissions)

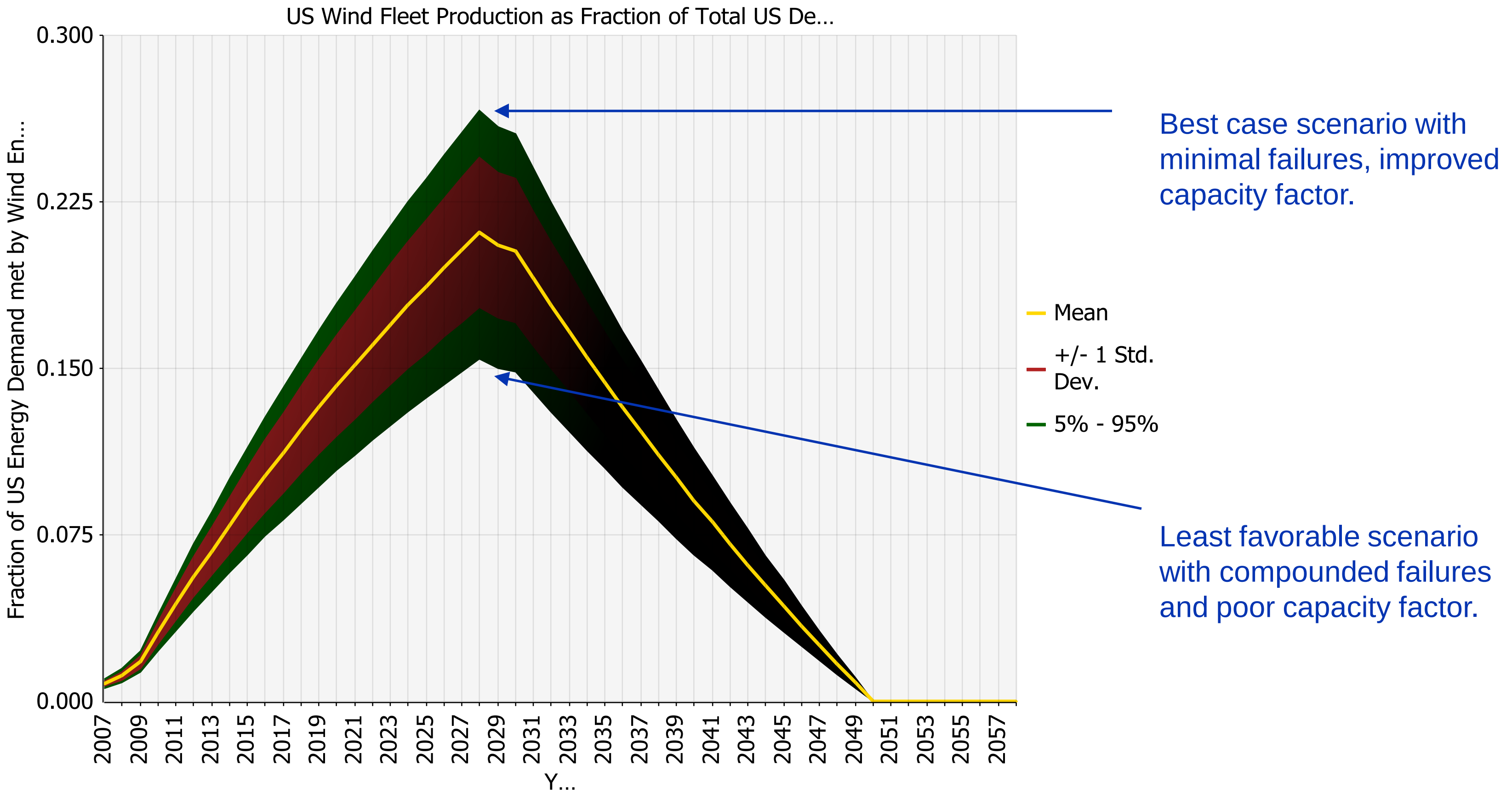
Dollars: Product of Total Output and cost of electricity ($/day)

How much does panel efficiency degradation matter for large scale solar farms?

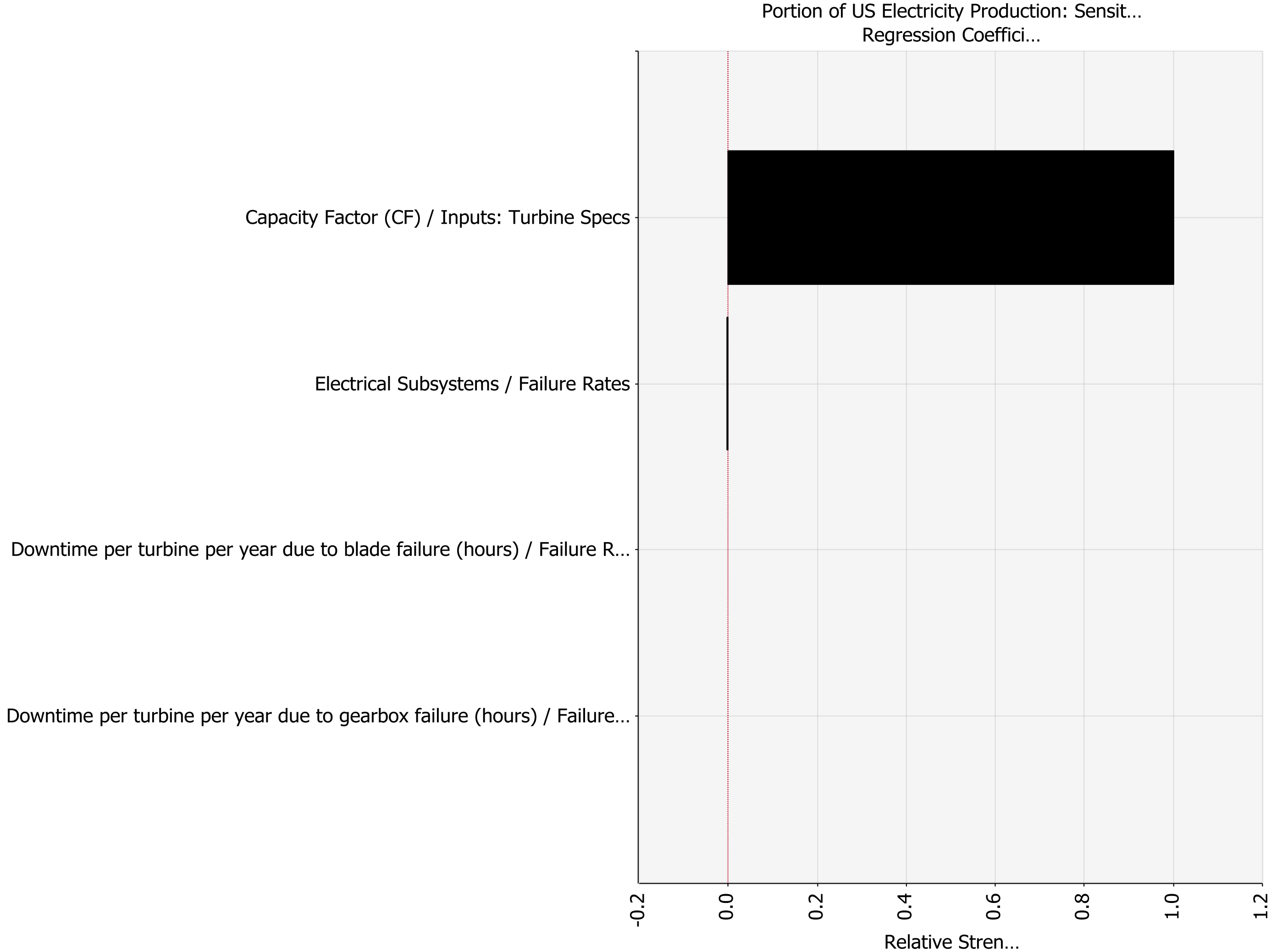
“Probabilistic Energy ROI Models: Carbon, Energy, and Dollars”. ASME Energy Sustainability, 2010. #90408 Phoenix, AZ.

Life Cycle Estimates Including Materials Failure: Wind Turbines

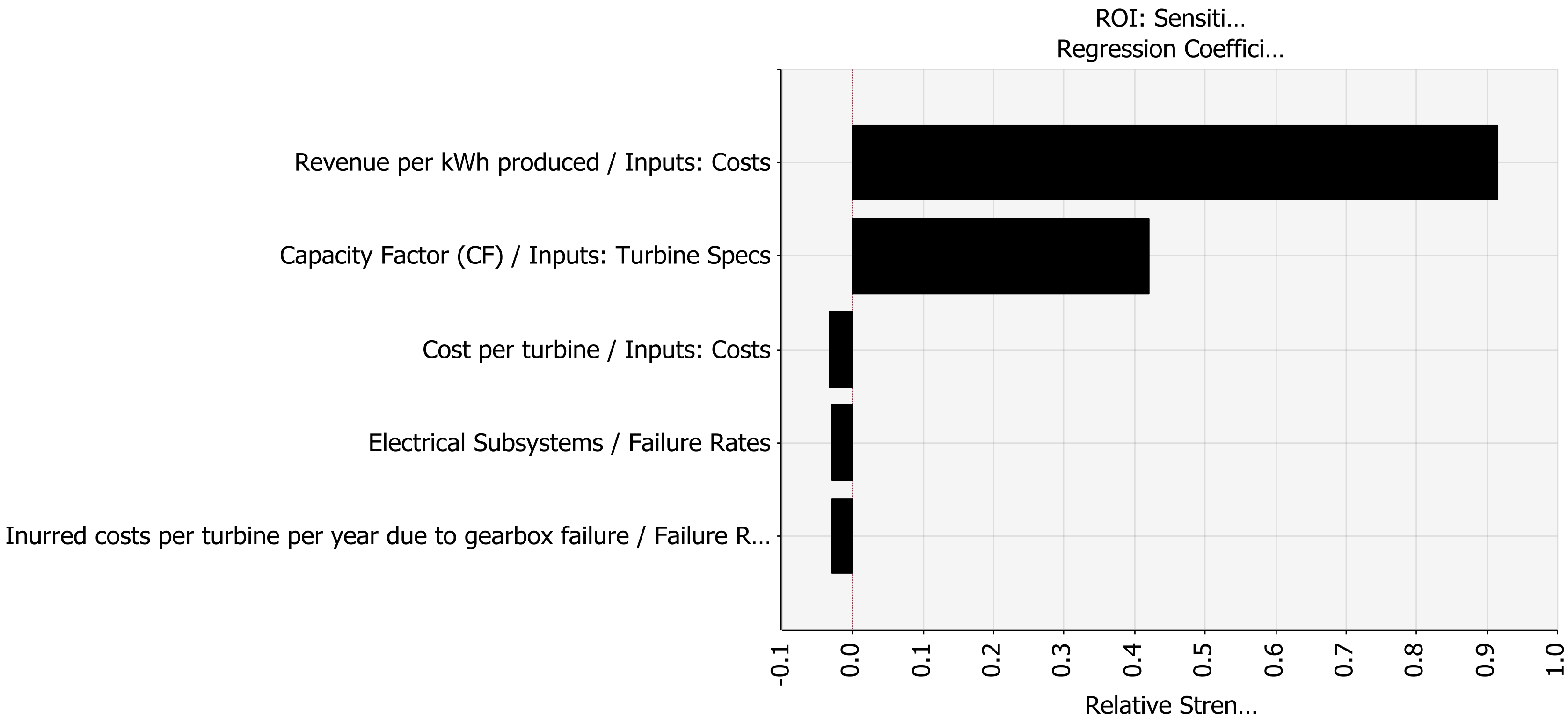
Production of hypothetical US wind fleet between present and 2030, including blade, gearbox, and electronics failures (first generation turbines).



Capacity Factor dominates



Sensitivity to Return on Investment

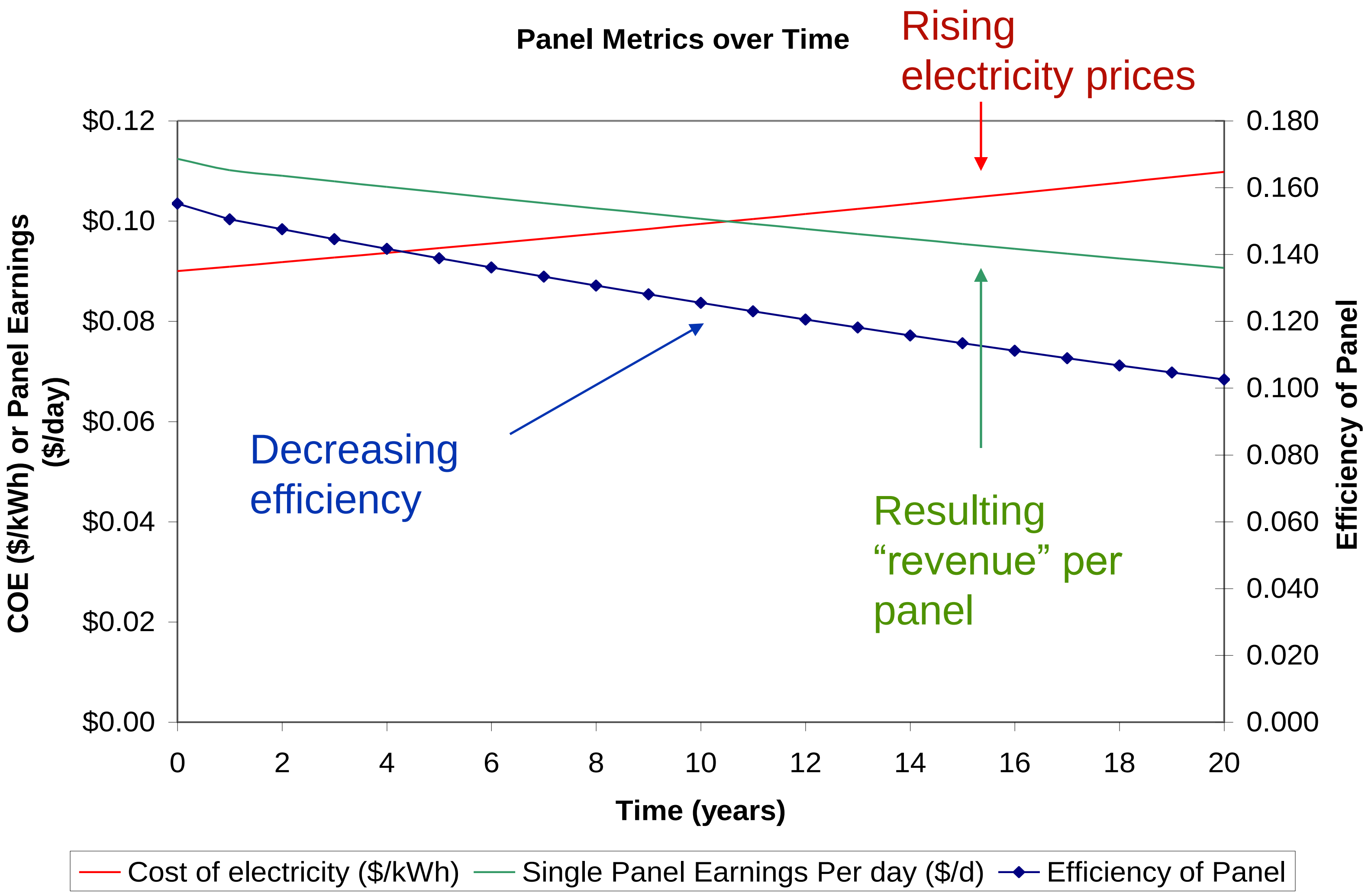


Impact on ROI is more visible from failures, but revenue per kWh produced and capacity factor are again dominant.

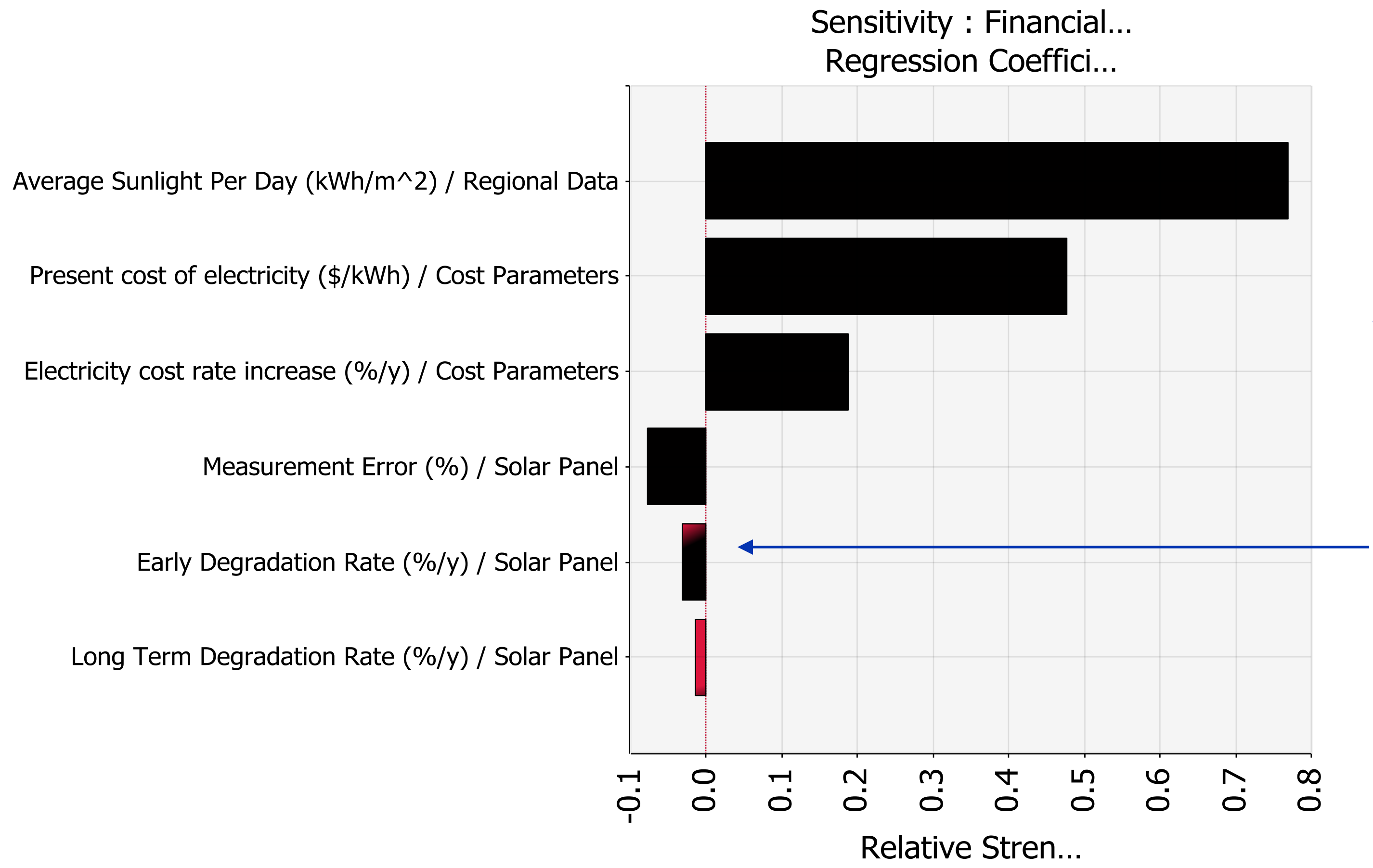
Payback projections to 2050 (multiples of original investment).

ROI Parameter	Minimum	Mean	Maximum
Energy ROI	22	30	37
CO_2 ROI	210	270	370
Financial ROI	1.2	3	4.5

Reliability of Solar Photovoltaic Panels



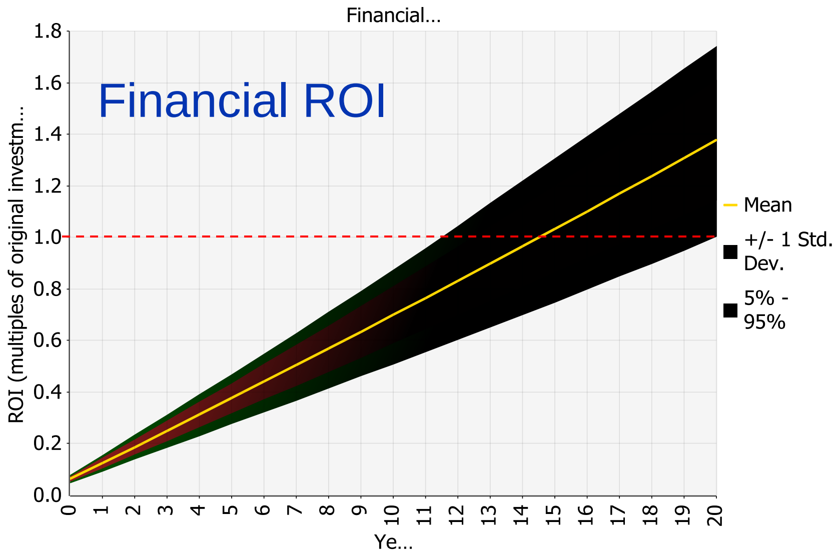
Financial ROI Sensitivity of 1 MW Farm

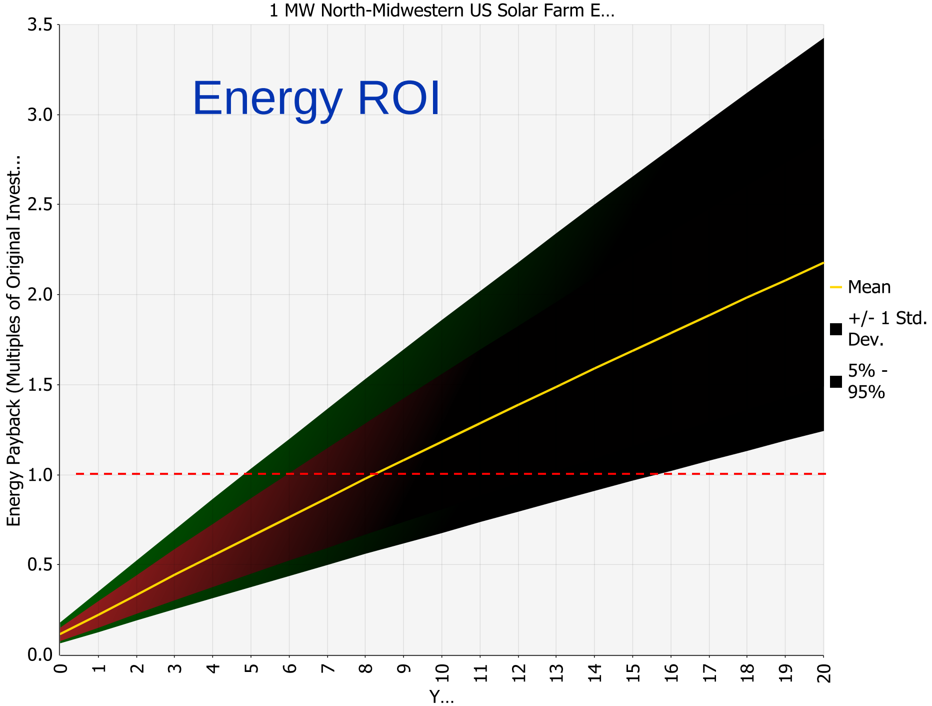


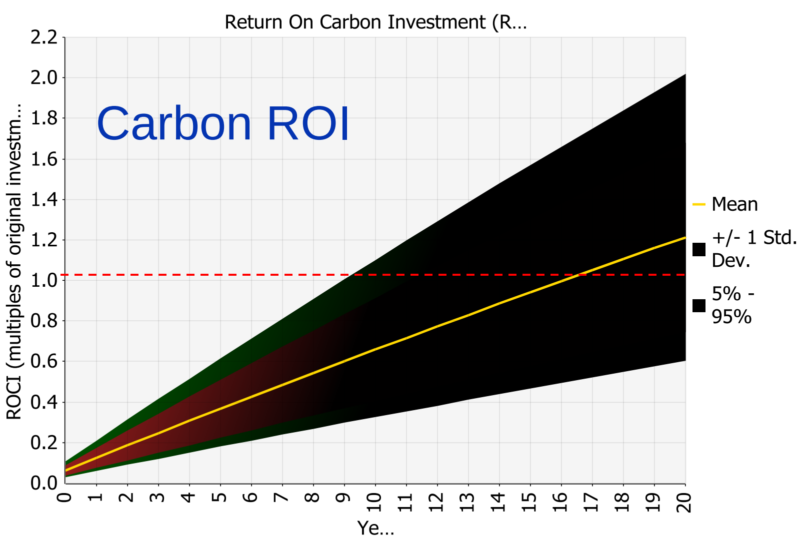
Sun exposure and electricity revenue are dominant variables.

Secondary negative effect from efficiency degradation factors.

ROI: Multiples of Original Investment







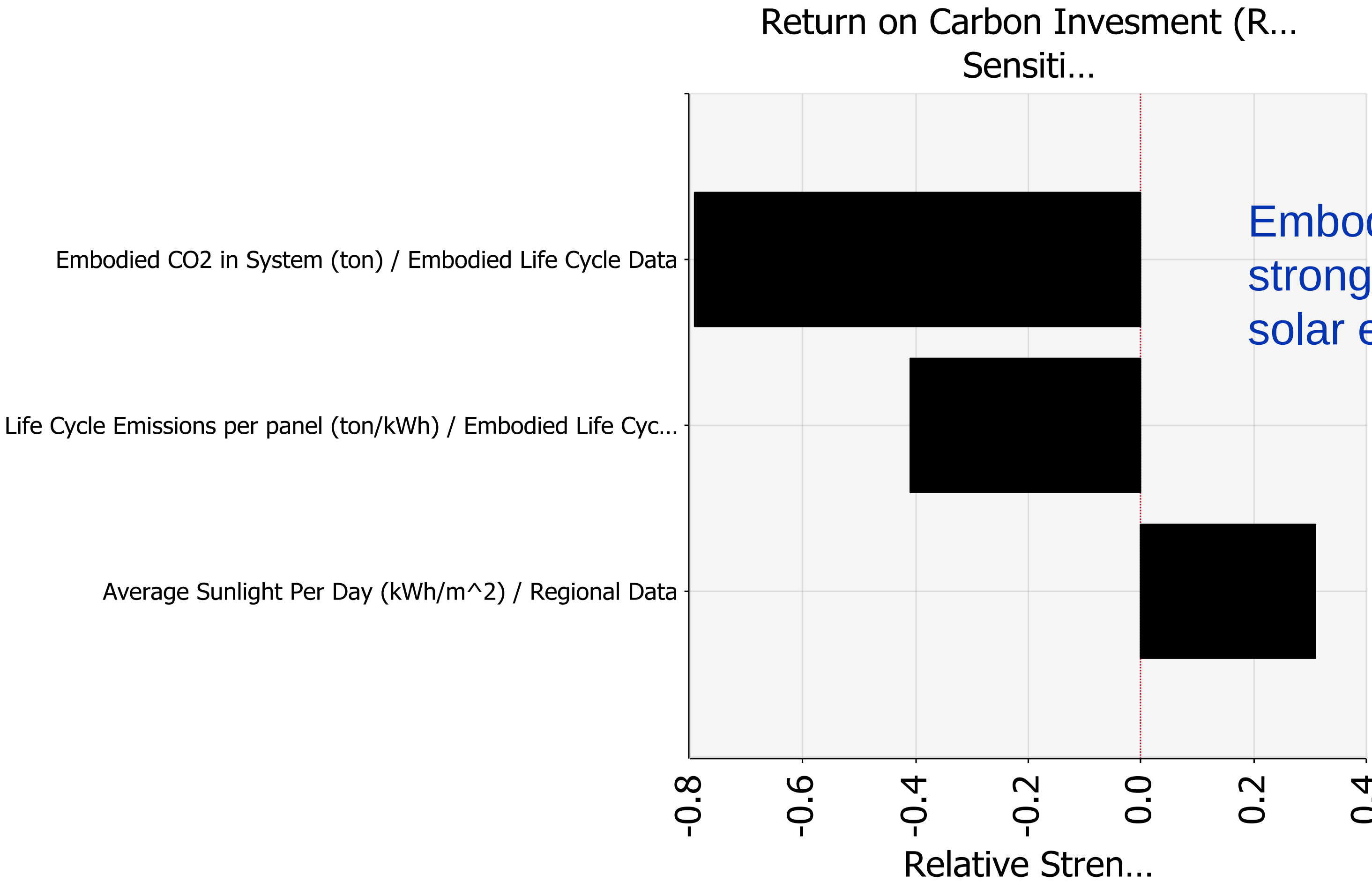
Factors that make ROI <1…

-Manufacturing location

-Operation location

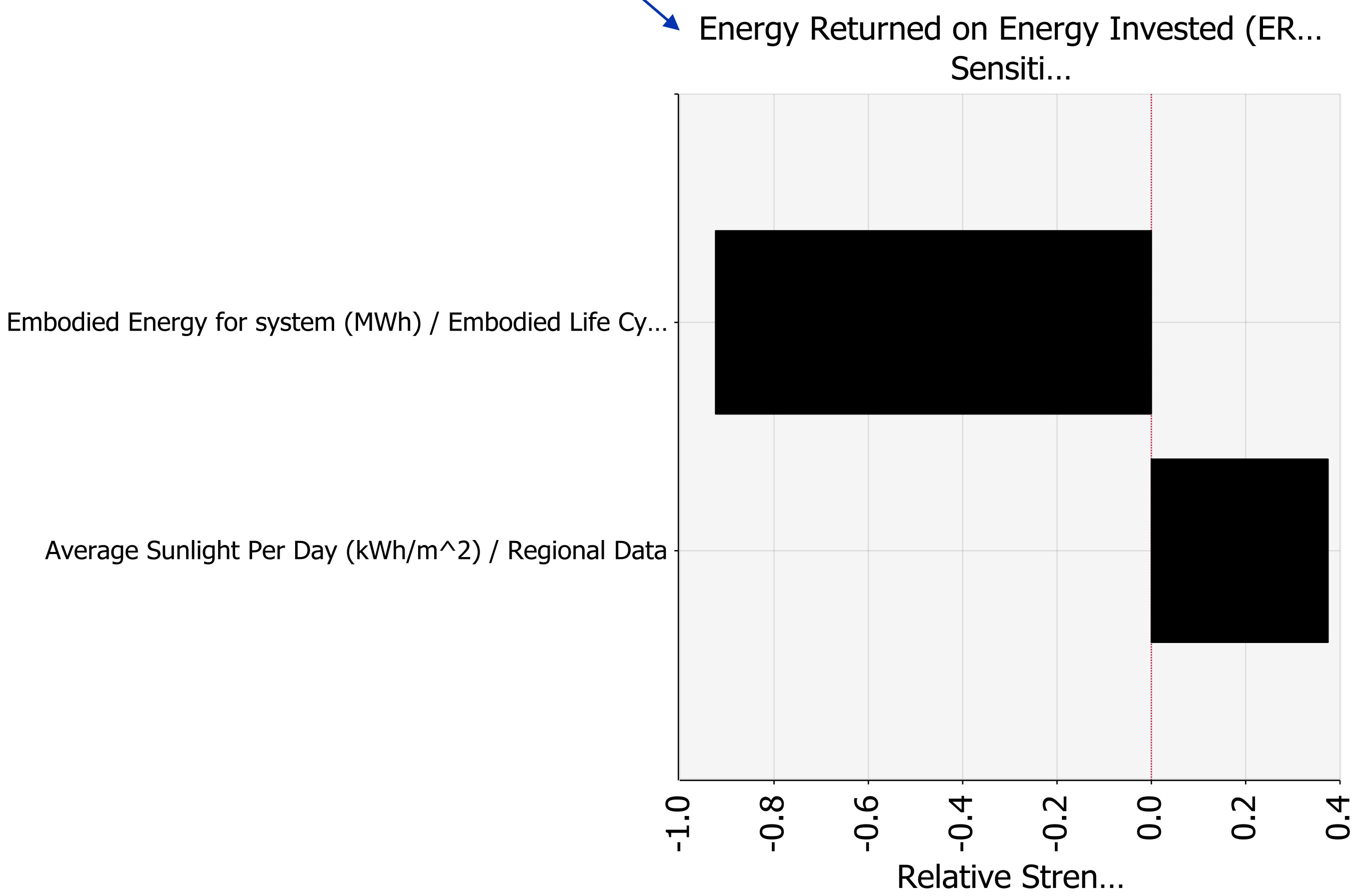
-(sensitivity analyses to follow)

Sensitivity for Return on Carbon Investment (ROCI)



Embodied CO_2 is a strong factor for solar energy.

Sensitivity for EROEI



Embodied energy is a strong factor for solar energy.

Unexpected Findings - Wind and Solar

- Embodied CO_2: 0.01 ton/W for the solar panel, and 0.0002 ton/W for the turbine (2 order of magnitude difference)
- Where it is manufactured can matter as much as where it is employed.
- Resource utilization dominates all forms of payback for the renewable energy systems studied.
- Though materials failures have direct financial consequences, the uptime is dominant.

TRADITIONAL ENERGY SYSTEMS (OIL, GAS, NUCLEAR)

Nuclear Waste Storage

Carbon steel ASTM A-516, double-walled tanks

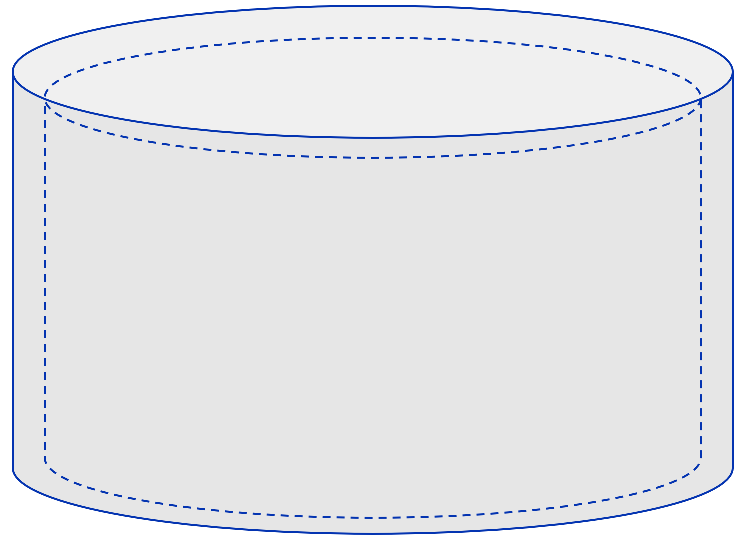
Liquid interior kept at ~pH 13

½” (12.5 mm) or 5/8” (16 mm) walls

750,000-1,300,00 gallons (2.8M to 5M L)

Diameter: 75-85 ft (23-26 m)

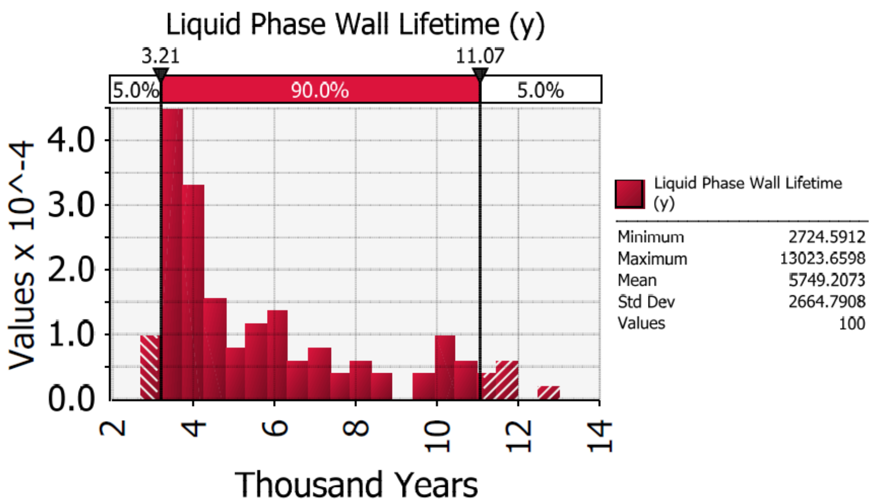
Depth (Height): 24-33 ft (7.5-10.3 m)

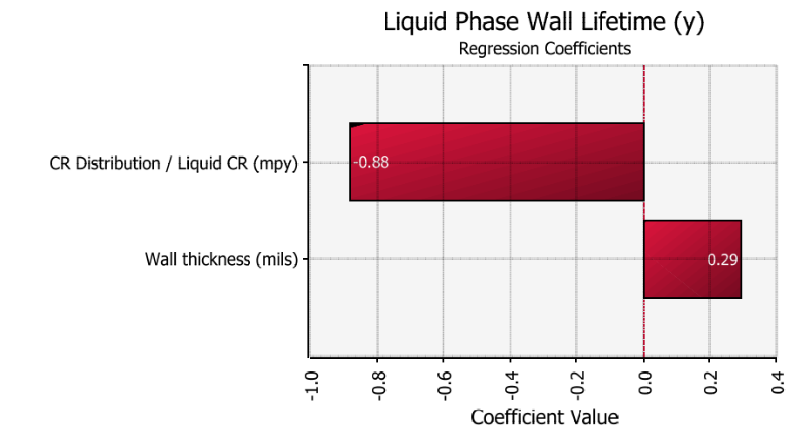


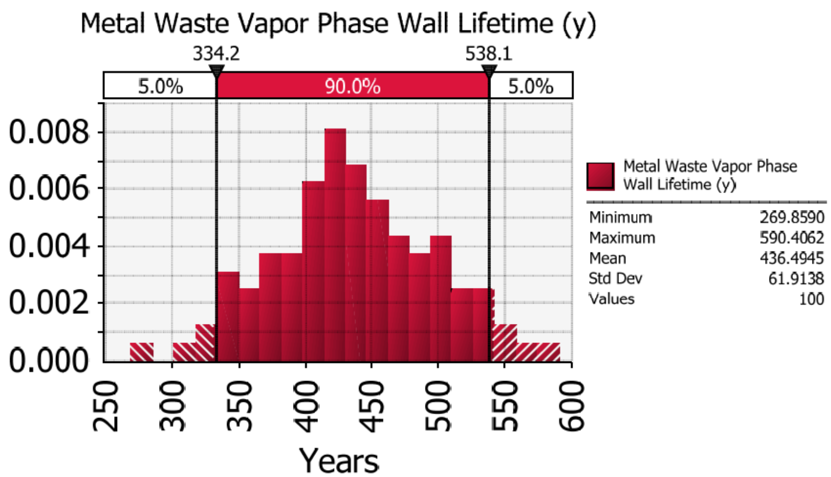
Liquid CR (mm/y)	Vapor CR (mm/y)	MW Vapor CR (mm/y)
0.004572	0.001524	0.054864
0.003658	0.000914	0.054864
0.002438	0.001219	0.06096
0.006706	0.001219	0.064008
0.006401	0.002438	0.054864
0.00701	0.003962	0.06096

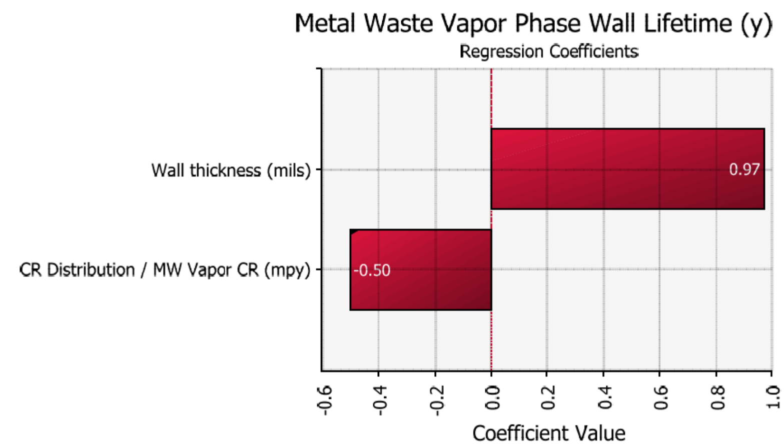
“Risk Models for Materials Selction and Corrosion Inhibition in Offshore Oil/Gas Risers and Nuclear Waste Storage Tanks”. NACE 2010. San Antonio TX.

Nuclear Waste Storage Tanks: Wall Lifetime





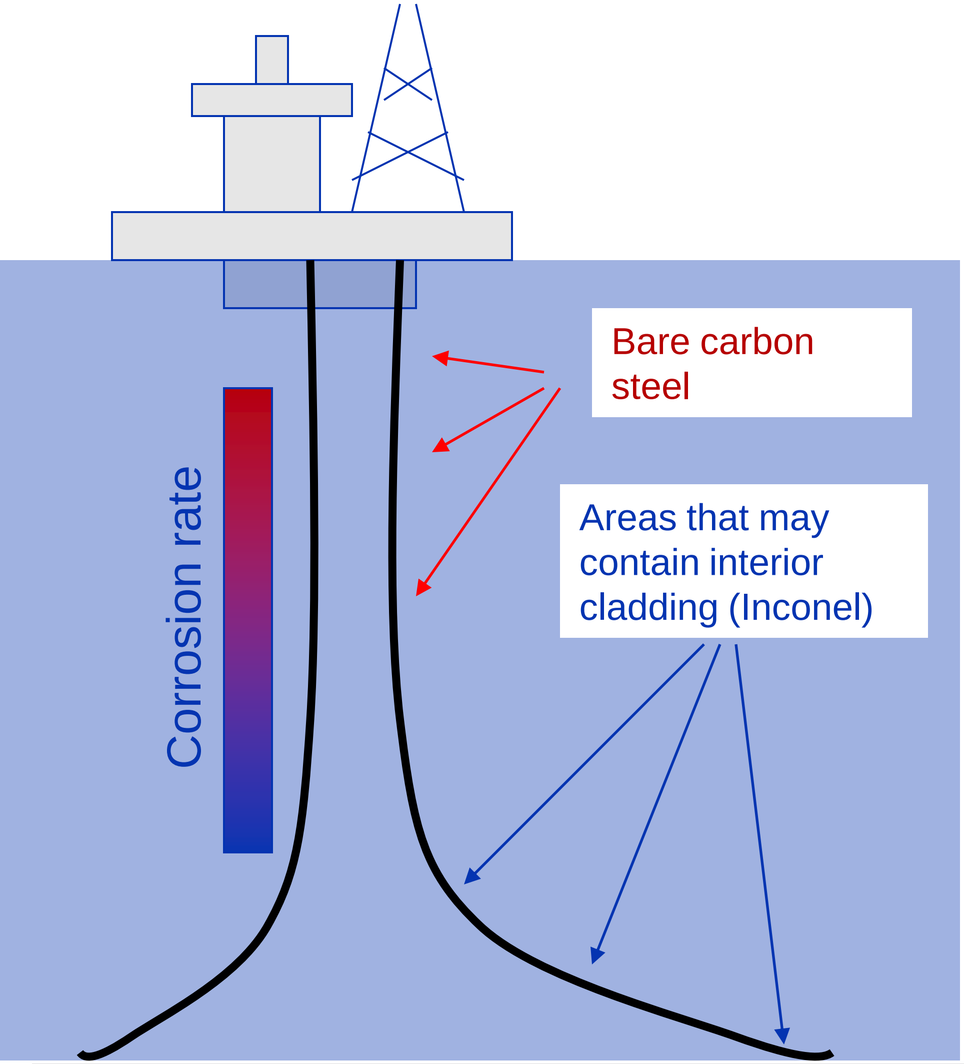




Analysis does not include stress.

MANAGING RISK

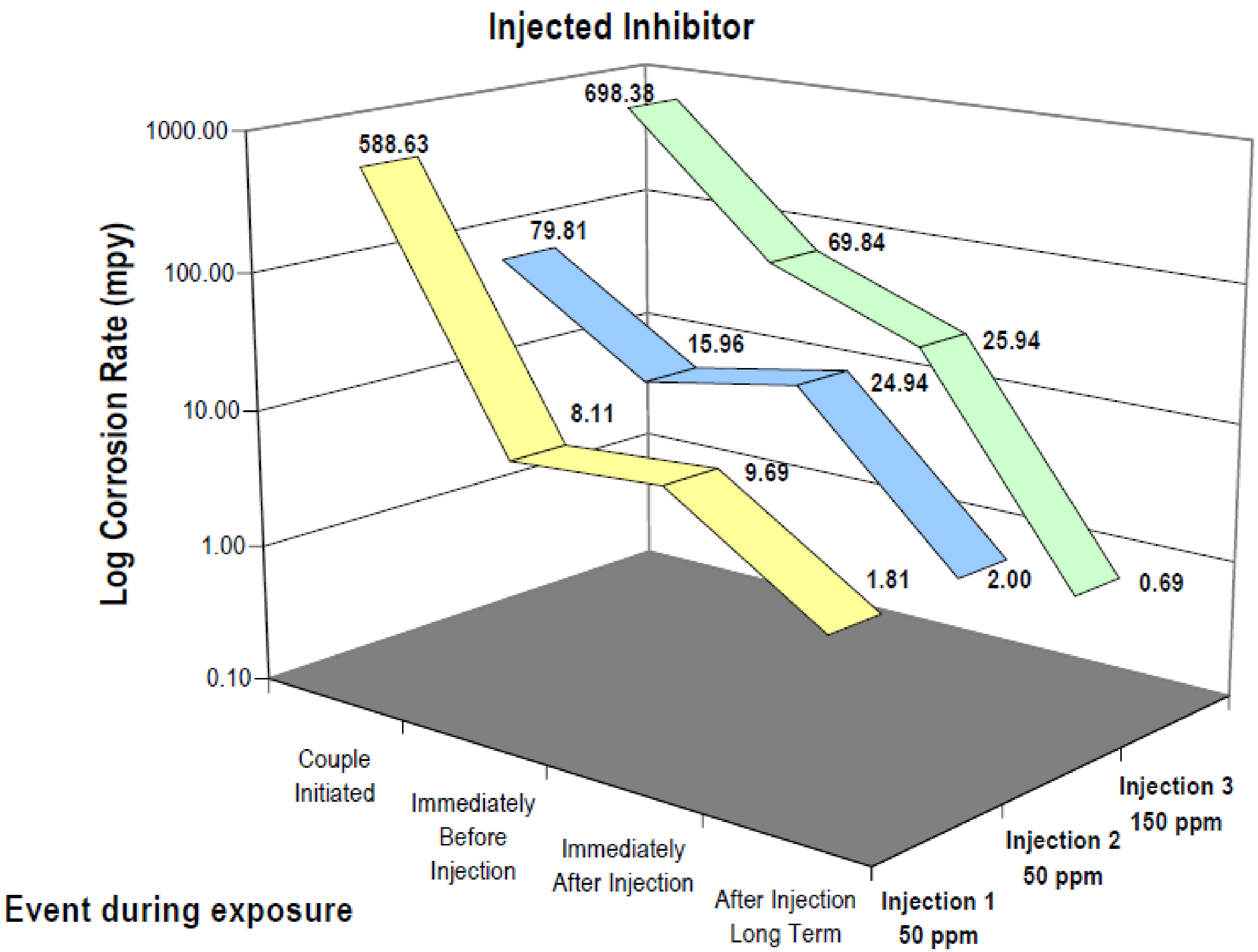
Offshore Oil and Gas Risers



- Majority of riser material is conventional carbon steel such as C1018 or pipe steel.
- Near bend and subsea stations, interior is clad with nickel alloy such as Inconel 625.
- Cladding important for stressed sections (like bends)
- Corrosion rate profile is affected by galvanic corrosion.
- Desire to add inhibitor to reduce corrosion rate of carbon steel and improve lifetime.

Experimental and Field Data Conditions

- 150,000 ppm chloride, 55 ppm bicarbonate simulated brine
- CO_2 purged through system
- 10:1 area ratio of I625:C1018



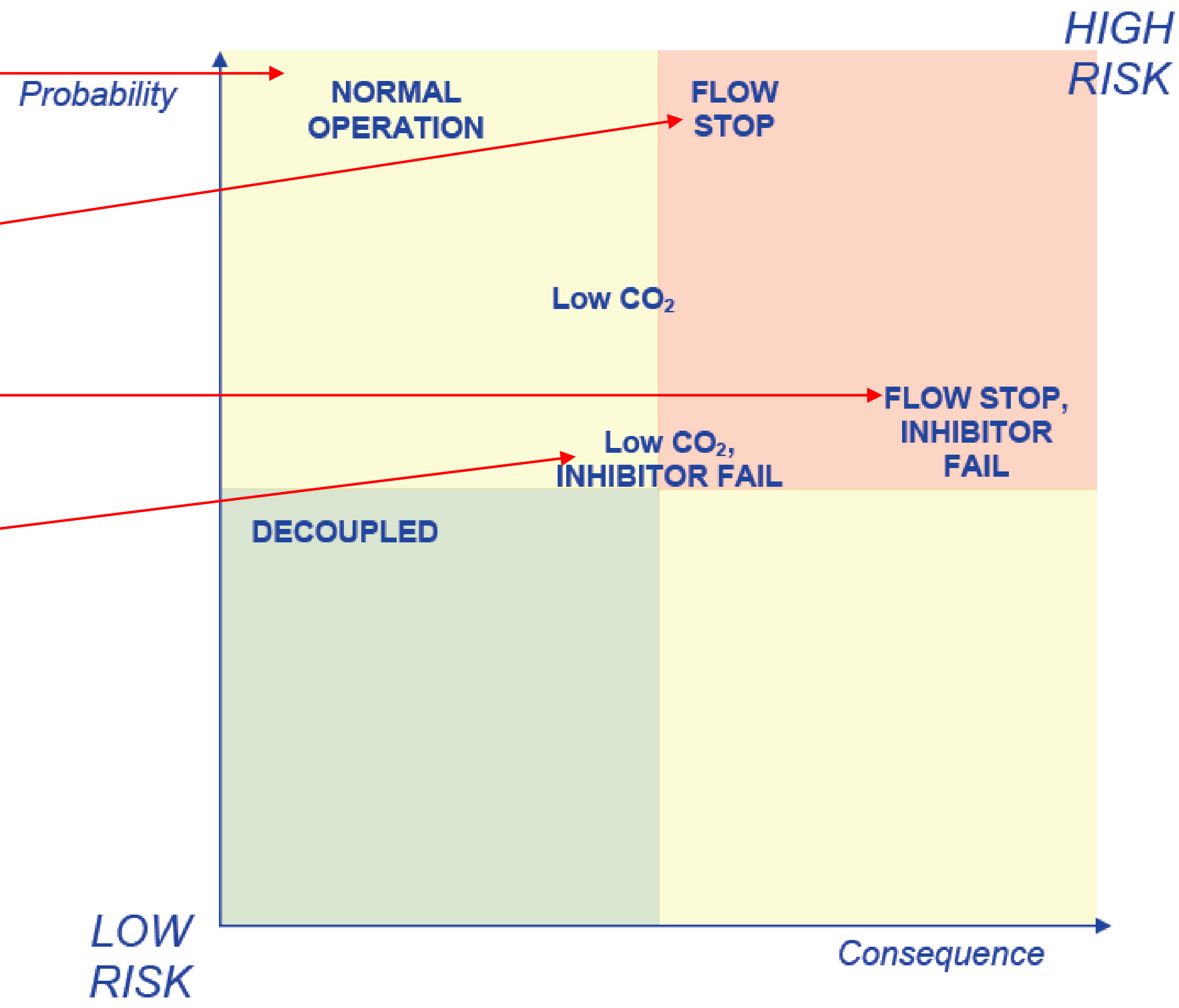
Probability vs. Consequence: Operations Risk for Offshore Operations

Highest probability, lowest consequence.

High probability, medium-high consequence

Medium probability, high consequence

Medium probability, medium consequence



Calculating the Combined Effect of Corrosion Rate and Pressure

$$Lifetime = \frac{t}{CR}$$

Wall thickness (t)

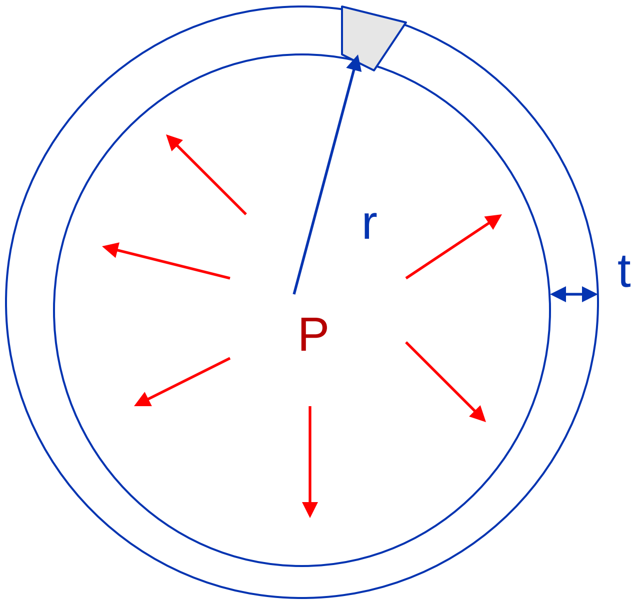
Corrosion Rate (CR)

$$\sigma = \frac{P \cdot r}{t}$$

Pressure (P)

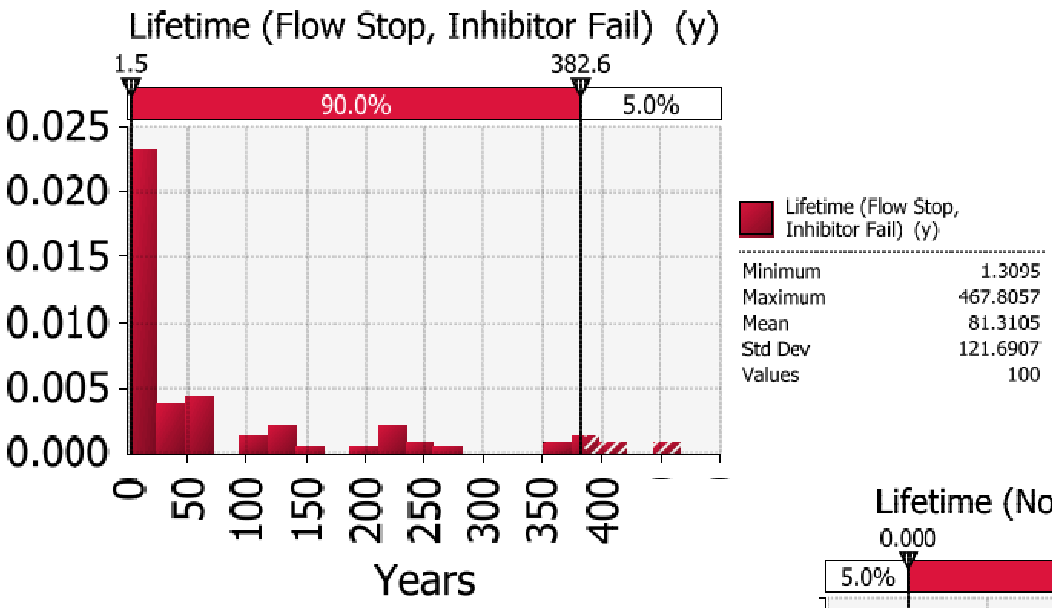
Pipe radius (r)

Effect of Pressure: $$Lifetime = \frac{P \cdot r}{\sigma \cdot CR}$$



Corrosion rate reduces wall thickness over time, but wall thickness is critical to hold pressure. Pressure reduces lifetime further.

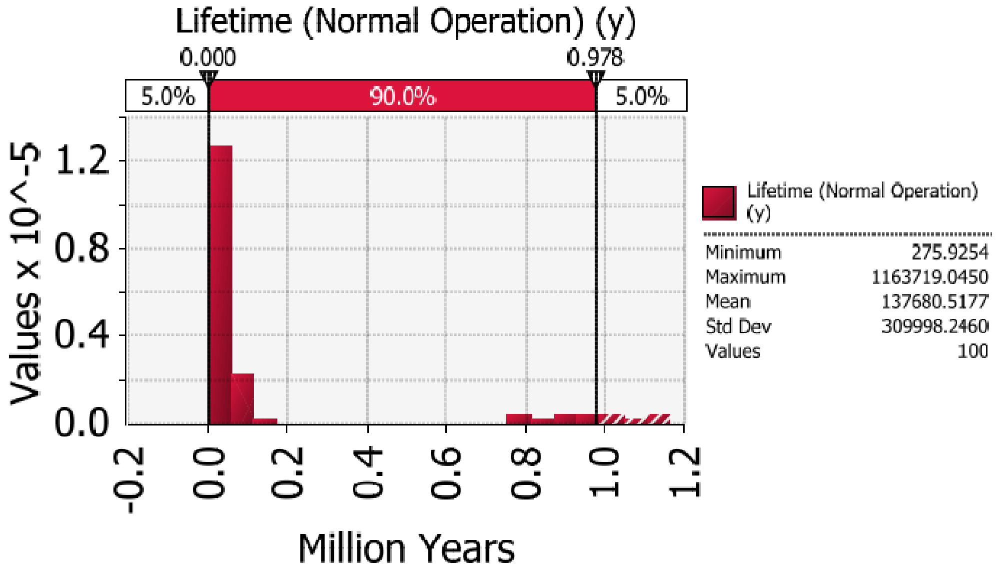
Lifetime Predictions in each case



Stopped flow and failed inhibitor flow are high risk conditions.

Lifetime reduced to <10 years, with high probability of 1.5 year lifetime.

Normal operations, if maintained = lifetime mean of 137,000 years



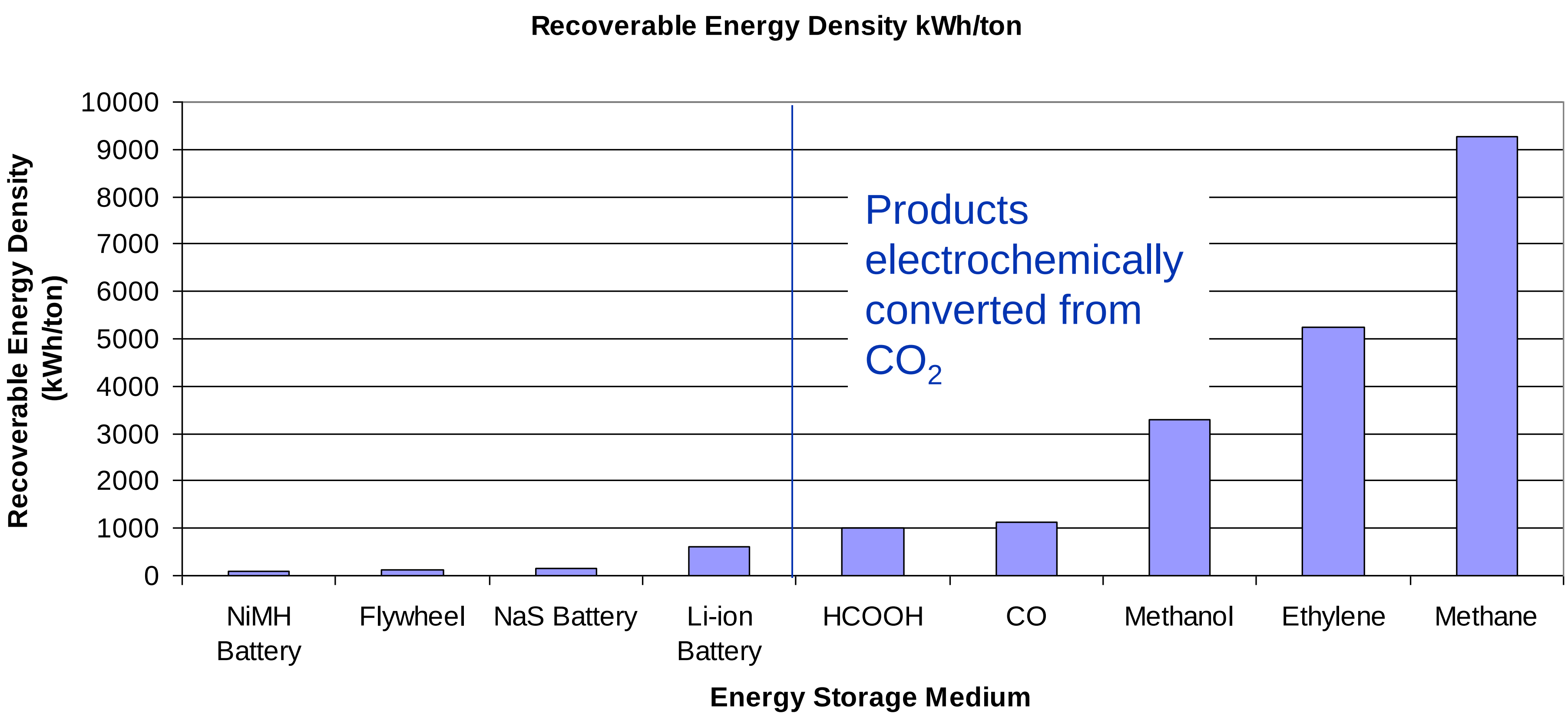
CARBON DIOXIDE VALUE CHAIN

CO_2 → Useful Products

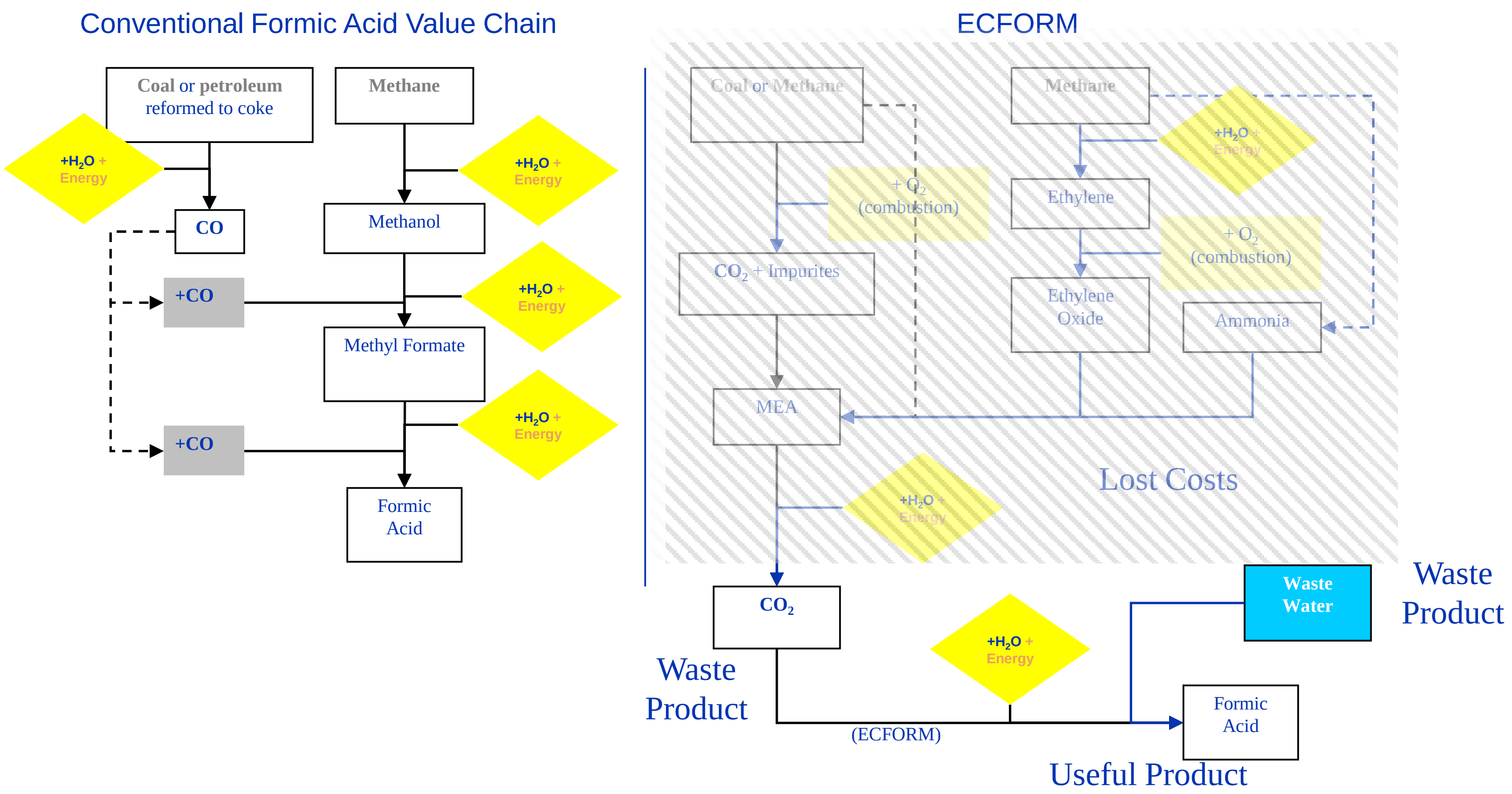
- Thermochemical
- Biochemical
- Photochemical
- **Electrochemical**

DNV Strategic Research program: Investigation of sustainable technologies for carbon dioxide management.

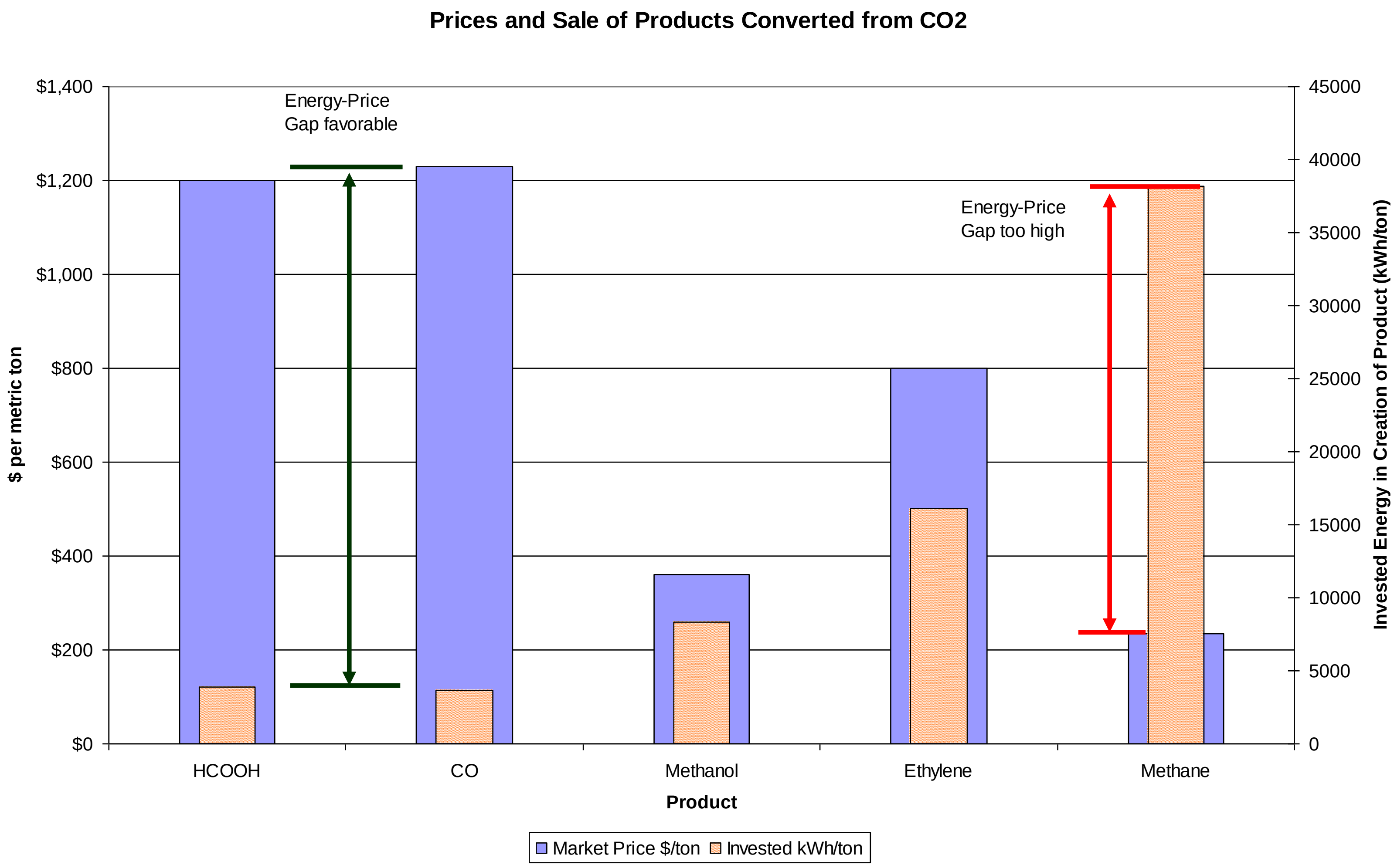
Recoverable Energy Density of Useful Products



Generation of Formic Acid without Dedicated Feedstock

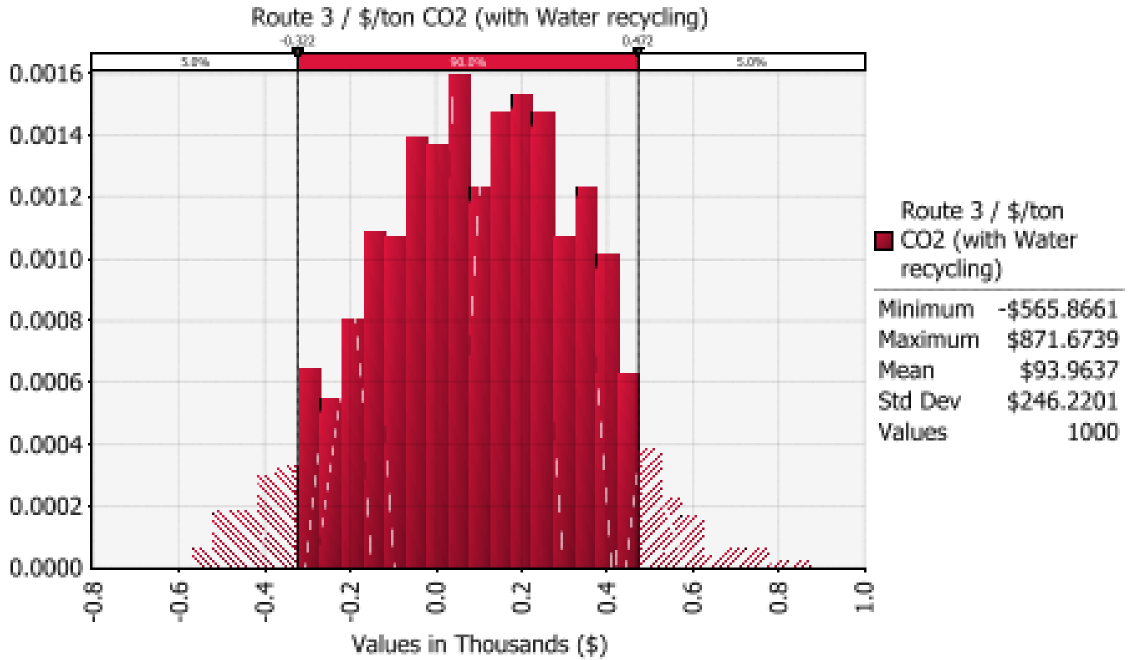


Electrochemical Conversion



CO_2 Recycling

Can it be done profitably, efficiently, and net carbon negative?



Energy dominates the profitability of the reaction, but consumables are minimized with electrolyte selection.

Conclusions

1. Variability Matters: don’t cross a river if it is four feet deep *on average*.
   - We can see the deep spots
2. Forecast degradation: far future is more uncertain than near future (read Orwell’s 1984)
   - Still difficult to capture, but we can at least see *why* uncertainty exists
3. Misunderstanding randomness: don’t underestimate the consequences of rare events
   - Buried within the probability distributions are random and seemingly unlikely events – we can at least acknowledge them and hope for the best

Safeguarding life, property and the environment

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