



U.S. DEPARTMENT OF
ENERGY



Carbon Strategies for CO₂ Utilization by Algae

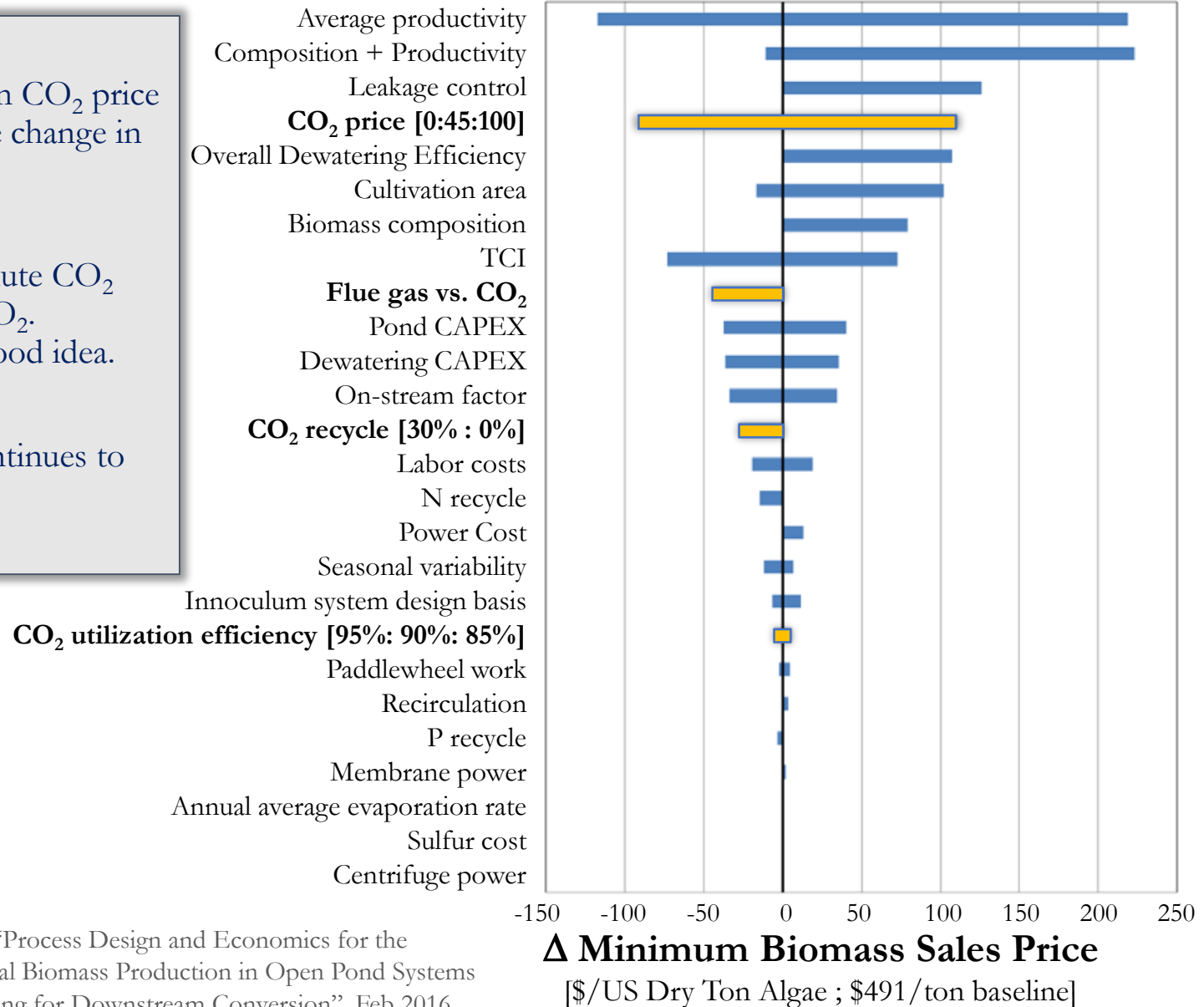
Bioeconomy 2017
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CO₂ has a sizeable contribution to the cost of algal biomass production, a component of the fuel sales price.

NREL analysis shows

- A \$1/tonne change in CO₂ price leads to a \$2.2/tonne change in biomass cost.
- It's cheaper to use dilute CO₂ than concentrated CO₂. Recycling CO₂ is a good idea.
- The biggest lever continues to be algae productivity [g/m²/day].

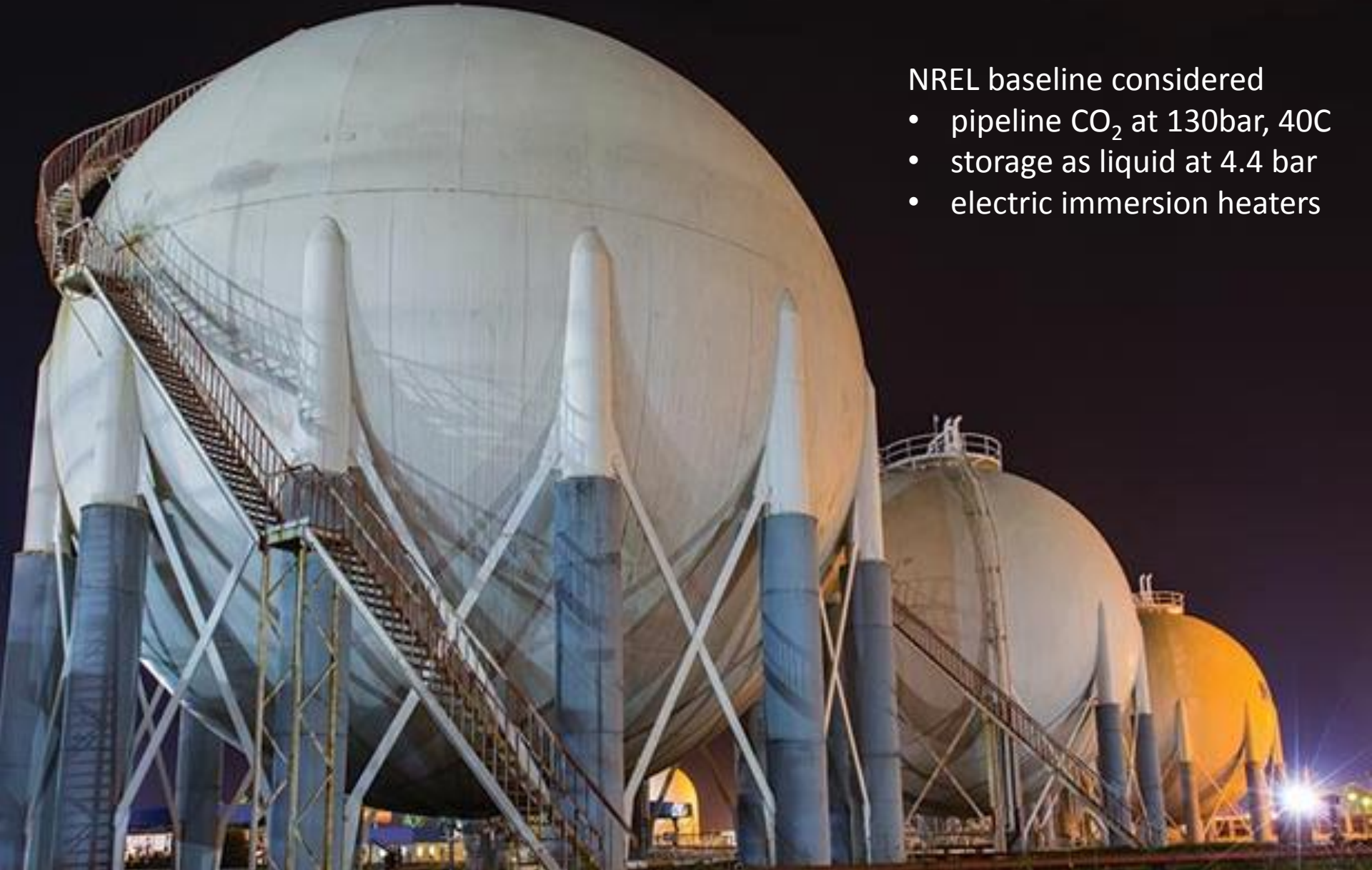


SOURCE: adapted from NREL, "Process Design and Economics for the Production of Algal Biomass: Algal Biomass Production in Open Pond Systems and Processing Through Dewatering for Downstream Conversion", Feb 2016.

If pipeline CO₂ with onsite storage is part of your design, there may be process opportunities that help you extract more value for the CO₂.

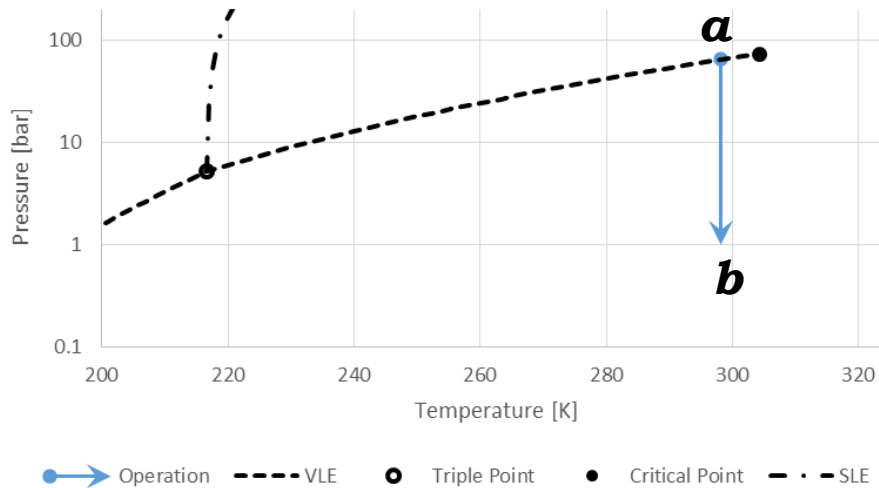
NREL baseline considered

- pipeline CO₂ at 130bar, 40C
- storage as liquid at 4.4 bar
- electric immersion heaters



Cooling and work derived from pressurized gas may be helpful tools for your process.

Consider a reversible, quasi-static process: liquid CO₂ at VLE, V-L transition, then expansion.



	Theoretical Potential
$W_{\text{reversible}}$	65.2 kWh/tonneCO ₂
$Q_{\text{reversible}}$	78.1 kWh/tonneCO ₂

2nd virial gas assumption.

c.f. $\Delta H_{\text{fus}, \text{H}_2\text{O}} = 92.7 \text{ kWh/tonneH}_2\text{O}$

There is significant potential to provide cooling for separation and power generation.

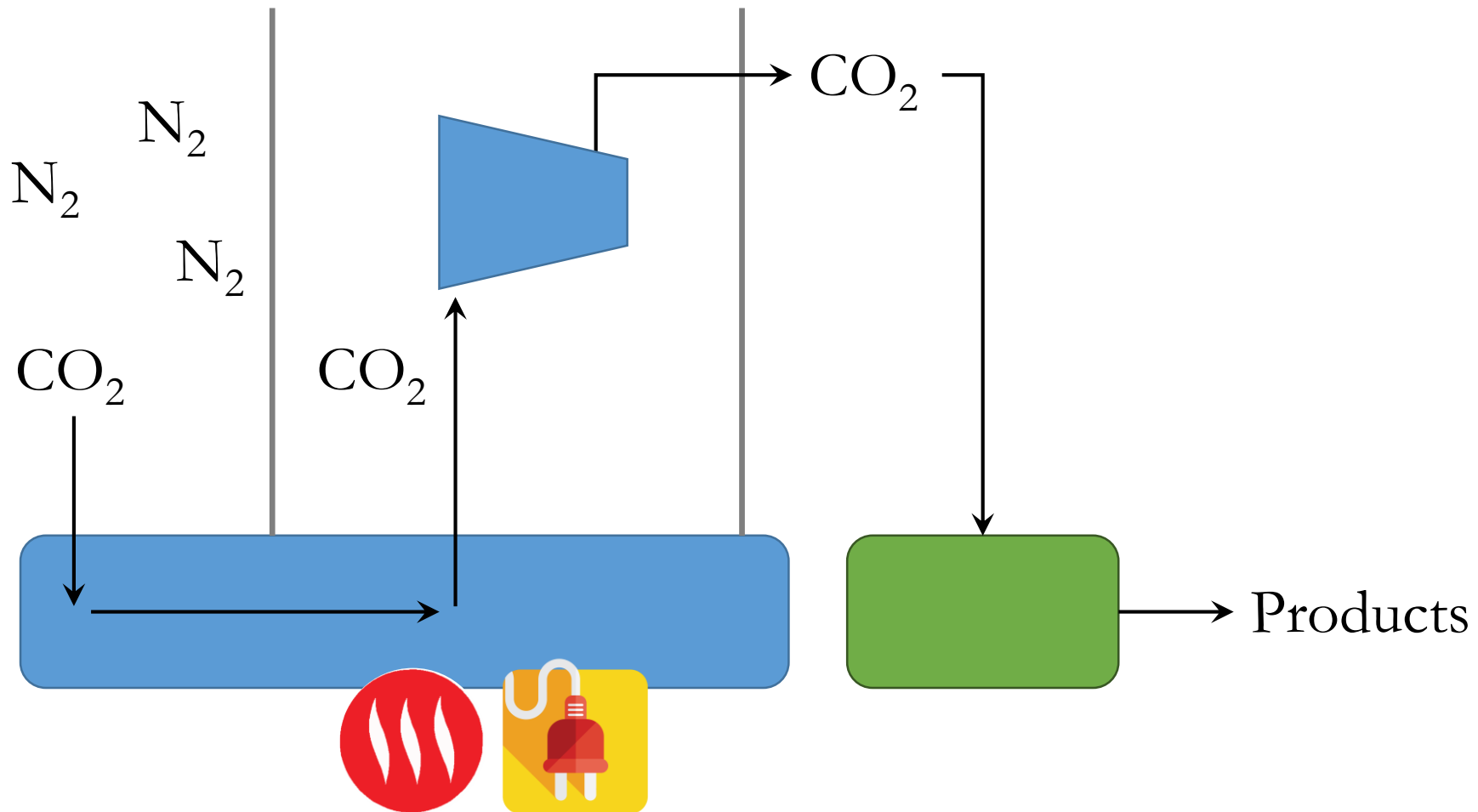
Freeze fractionation, an alternative to distillation, is intended for separating constituents with differing melting points;



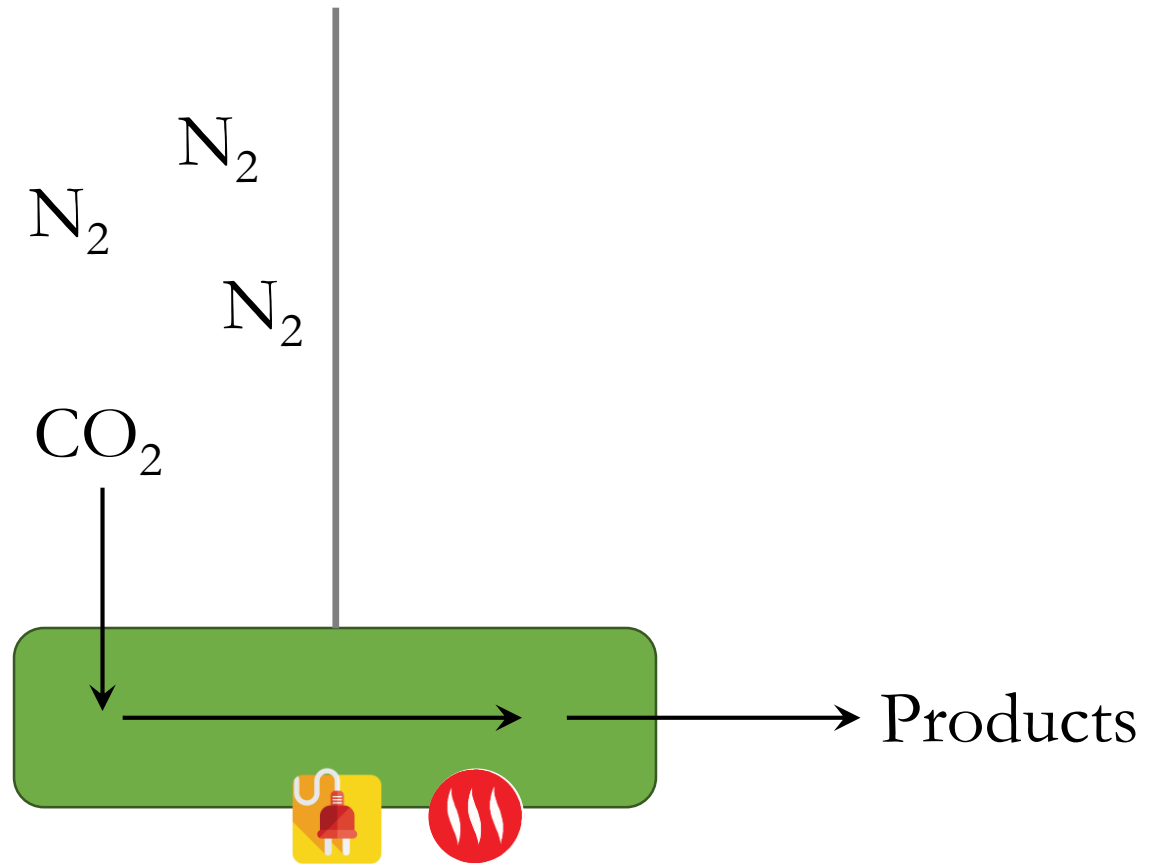
... and is well appreciated in the field of biotechnology.

Pipeline CO₂ contains useful energy.

The cost of captured CO_2 is attributable to the absorption, heating, compression, and associated equipment.

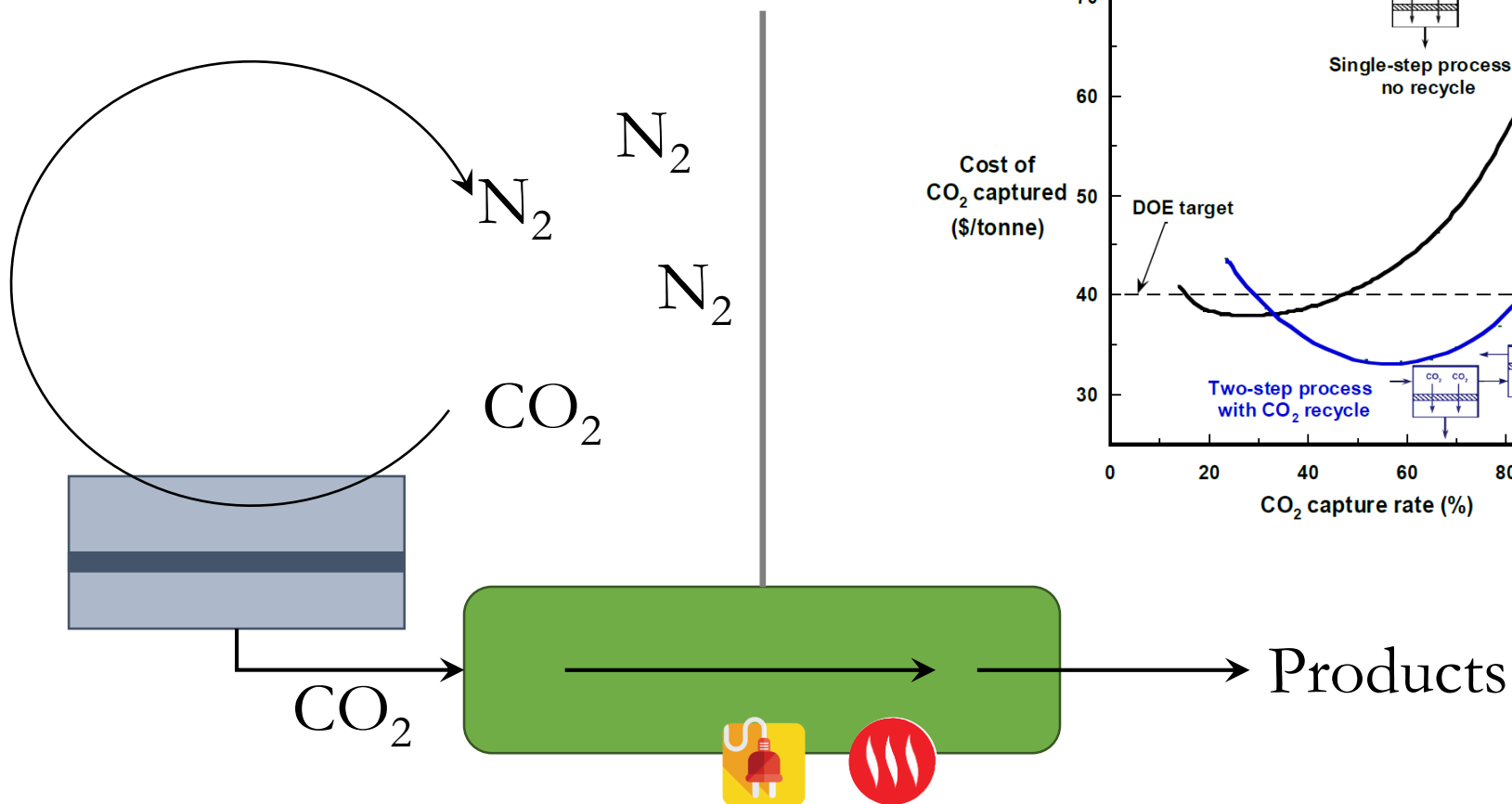


Next generation approaches will find new ways of concentrating CO_2 in the media. Current algae processes already use flue gas directly.



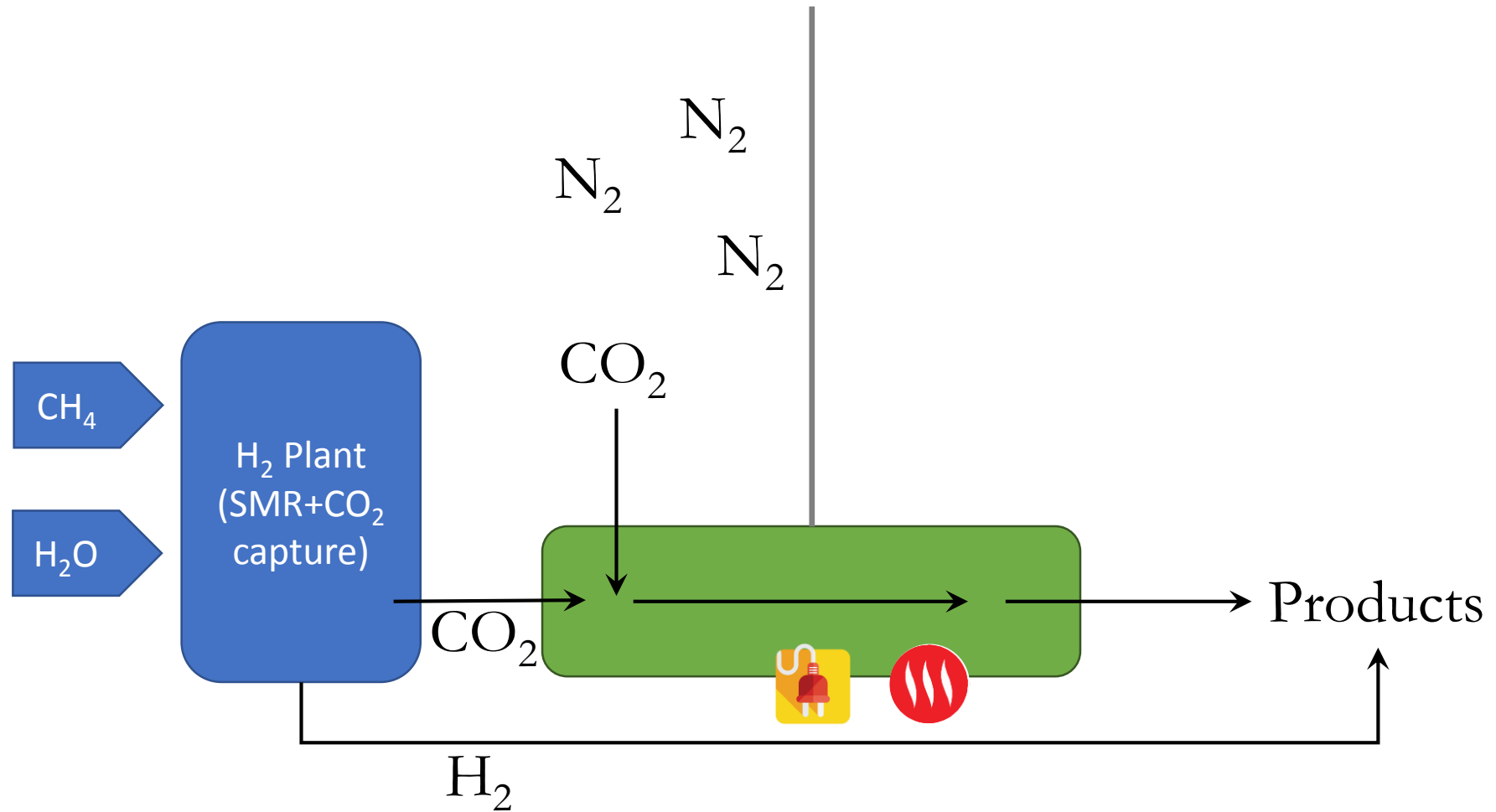
How can a micro-algae suspension change the thermodynamics of CO_2 dissolution?

In the interim, membrane-based partial-capture approaches may provide a large marginal value at low cost.



SOURCE: T. Merkel and B. Freeman, "Membranes: An Emerging CO₂ Capture Technology", presentation at USEA, June 2017.

Yet another approach to concentrate your CO₂ stream is to co-locate a reforming operation that makes H₂ for upgrading your product.

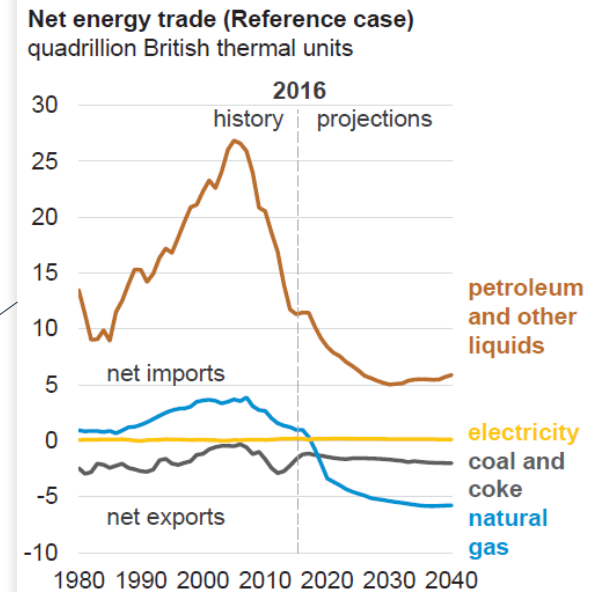
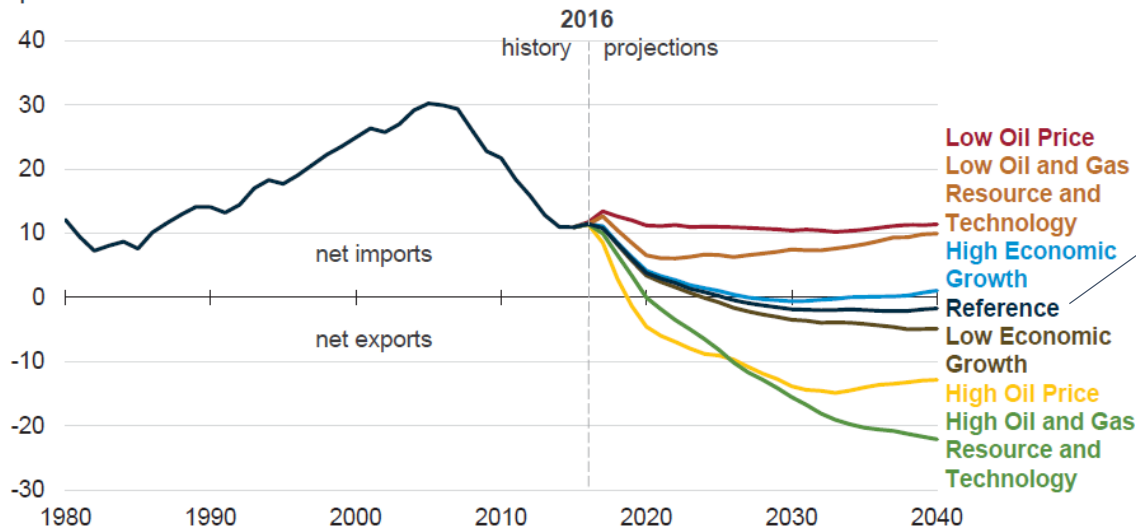


Approaches for partially concentrating flue gas need not be costly and could provide other downstream benefits.

The U.S. is projected to have abundant energy for decades, creating a highly competitive environment for new entrants.

U.S. is projected to become a net energy exporter in most AEO2017 cases. *EIA Annual Energy Outlook 2017*.

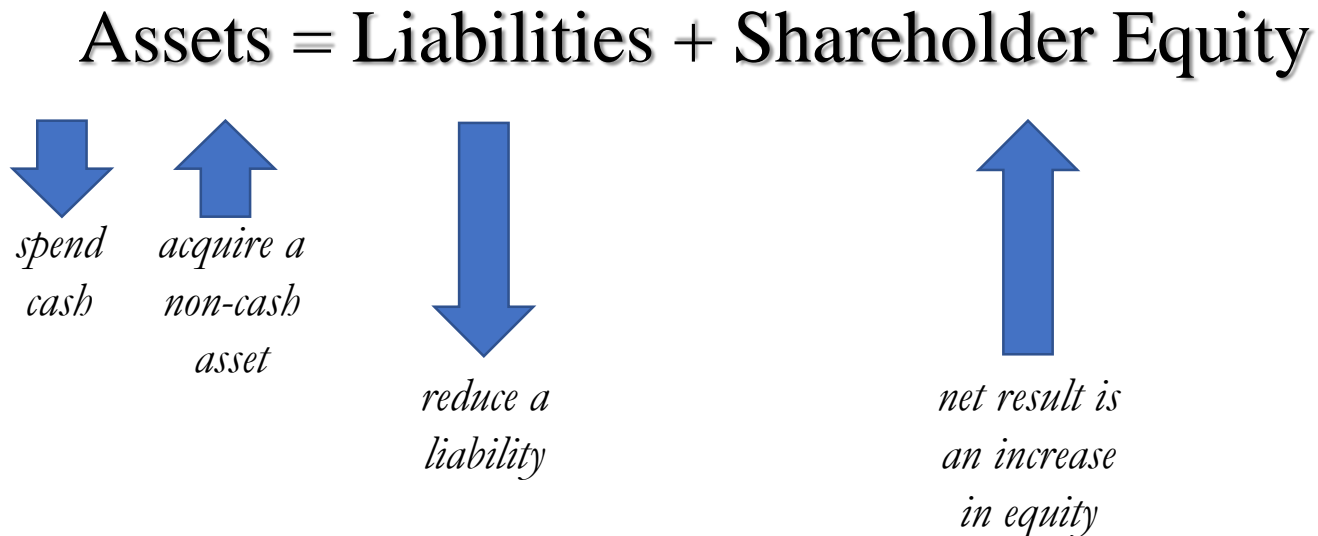
Net energy trade
quadrillion British thermal units



How can one operate an energy business when a large supply threatens to further suppress domestic prices?

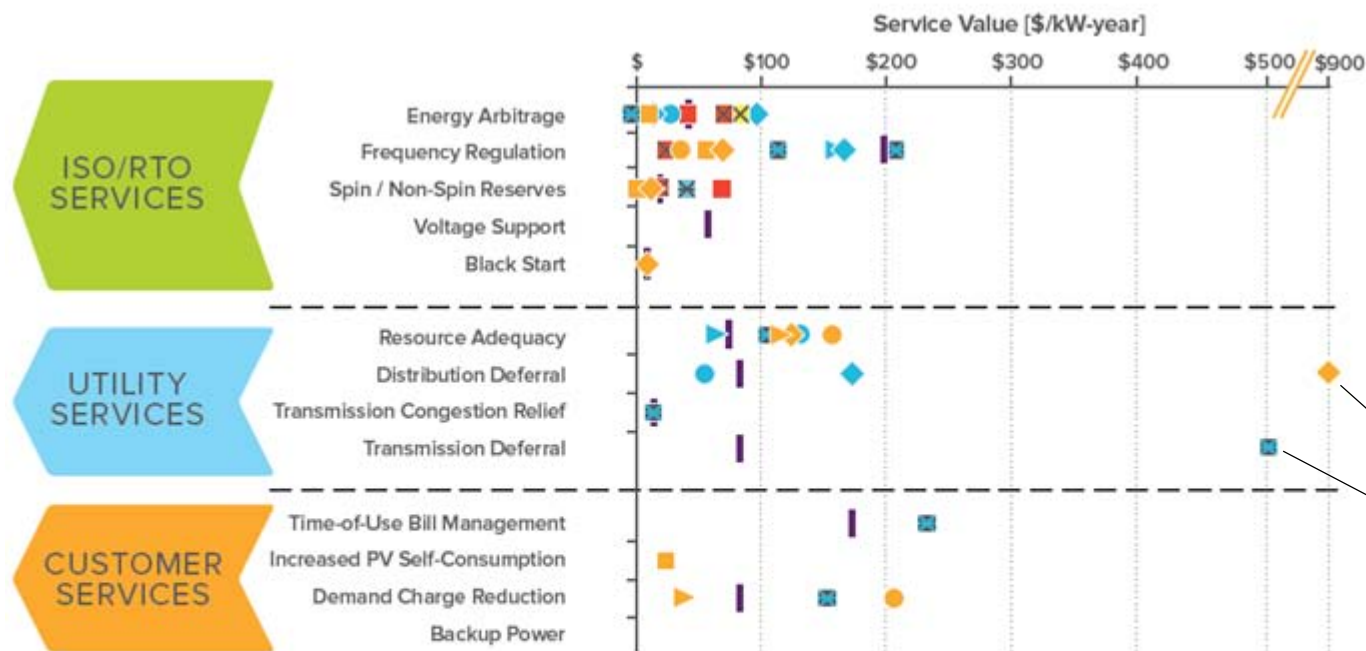
Can algae biofuel technologies provide value differently? How?

In markets with deflationary pricing, and in some cases, it could be helpful to think from the balance sheet instead of focusing on poor prospects for net income.



Growing net income is not the only means for increasing shareholder equity.

Case study: the value of energy storage



The most valuable service that batteries provide is not buying and selling energy for a profit...

Deferred investment in transmission and distribution

Results for both energy arbitrage and load following are shown as energy arbitrage. In the one study that considered both, from Sandia National Laboratory, both results are shown and labeled separately. Backup power was not valued in any of the reports.

● RMI UC I ◆ RMI UC II ▶ RMI UC III ■ RMI UC IV ■ NYSEDA ■ NREL ● Oncore-Brattle ■ Kirby
▶ EPRI Bulk ■ EPRI Short Duration ◆ EPRI Substation | Sandia X Sandia: LF

The need to build infrastructure to assure reliability for a growing load center can be viewed as a liability. Reducing that liability by purchasing an energy storage asset is one example of balance-sheet thinking.

SOURCE: RMI, "The Economics of Battery Energy Storage" (Oct 2015).

How can balance-sheet thinking be useful for technologies producing commodity products in highly competitive environments?

Pipeline CO₂ contains useful energy that has the potential to enhance your process.

Partially concentrating flue gas may provide significant marginal value at relatively low cost. *Using biology itself to concentrate the CO₂ could be a win.*

Balance sheet thinking could lead to other ways of creating value, *and may be the only option in highly competitive markets for commodity products.*

Thank You

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