**CHUGACH ELECTRIC ASSOCIATION, INC.**
**ANCHORAGE, ALASKA**

**OPERATIONS COMMITTEE MEETING**

**AGENDA**

| | |
|---|---|
| Mark Wiggin, Chair | Erin Whitney, Director |
| Harold Hollis, Vice Chair | Sisi Cooper, Director |
| | Bettina Chastain, Director |

**November 15, 2022** **4:00 p.m.** **Chugach Board Room**

I. CALL TO ORDER *(4:00 p.m.)*

*A. Roll Call*

II. APPROVAL OF THE AGENDA* *(4:05 p.m.)*

III. APPROVAL OF THE MINUTES* *(4:10 p.m.)*

*A. October 19, 2022 (Doyle)*

IV. PERSONS TO BE HEARD *(4:15 p.m.)*

*A. Member Comments*

V. NEW BUSINESS *(scheduled) (4:20 p.m.)*

*A. Decarbonization Goals and Board Policy (Ayers/Skaling*

VI. EXECUTIVE SESSION* *(scheduled) (5:20 p.m.)*

*A. RPS vs. Clean Energy Standard (Ayers/Skaling) (5:20 p.m.)*

*B. 2023-2027 Strategic Plan (Richards) (6:20 p.m.)*

*C. RCA Order on Regulatory Asset / Eklutna PPA Expense Deferral; Implications on 2023 Budget and Rate Case (Clarkson/Highers/Miller) (6:50 p.m.)*

VII. NEW BUSINESS *(none)*

VIII. DIRECTOR COMMENTS *(7:30 p.m.)*

IX. ADJOURNMENT* *(7:45 p.m.)*

* ***Denotes Action Items***
** ***Denotes Possible Action Items***

**CHUGACH ELECTRIC ASSOCIATION, INC.**
**Anchorage, Alaska**

**October 19, 2022**
**Wednesday**
**4:00 p.m.**

**OPERATIONS COMMITTEE MEETING**

Recording Secretary: Ashton Doyle

## I. CALL TO ORDER

Chair Wiggin called the Operations Committee meeting to order at 4:01 p.m. in the boardroom of Chugach Electric Association, Inc., 5601 Electron Drive, Anchorage, Alaska.

*A. Roll Call*

*Committee Members Present:*
Mark Wiggin, Chair
Harold Hollis, Vice Chair
Bettina Chastain, Director *(via teleconference)*
Erin Whitney, Director
Sisi Cooper, Director

*Board Members Present:*
Sam Cason, Director
Rachel Morse, Director *(via teleconference)*

*Guests and Staff Attendance Present:*

| | | |
|---|---|---|
| Arthur Miller | Josh Resnick | Karen Griffin |
| Sherri Highers | Kate Ayers | Bart Armfield, Consultant |
| Andrew Laughlin | Julie Hasquet | Mike Miller |
| Matthew Clarkson | Todd McCarty | Justin Scanio, ECI |
| Sean Skaling | Mike Miller | Brian Meissner, ECI |
| Ron Vecera | Jean Kornmuller | Mark Foster, Member |

*Via Teleconference:*

| | | |
|---|---|---|
| Arden Quezon | Peyton Reid | Mark Henspeter |
| Sandra Cacy | Philip Zempel | |

## II. APPROVAL OF THE AGENDA

Director Hollis moved and Director Whitney seconded the motion to approve the agenda. The motion passed unanimously.

*Director Cooper joined the meeting and time was not noted.*

## III. APPROVAL OF THE MINUTES

Director Hollis moved and Director Whitney seconded the motion to approve the August 10, 2022, Operations Committee Meeting minutes. The motion passed unanimously.

Director Hollis moved and Director Whitney seconded the motion to approve the August 23, 2022, Operations Committee Meeting minutes. The motion passed unanimously.

## IV. PERSONS TO BE HEARD

*A. Member Comments*

Mark Foster, Member, gave comments on the Dixon Diversion and associated transmission upgrade.

*Director Morse joined the meeting via teleconference and time was not noted.*

## V. NEW BUSINESS

*A. Heat Pump Feasibility Study (Henspeter/Skaling)*

Arthur Miller, Chief Executive Officer (CEO) introduced the Heat Pump Feasibility Study and Sean Skaling, Sr. Manager, Business & Sustainable Program Development, gave a presentation on the study. Sean Skaling and Mark Henspeter responded to questions from the Committee.

*B. Third Quarter 2022 BRU Production Update (Armfield)*

Bart Armfield, Fuel and Corporate Planning Consultant provided an update on Third Quarter 2022 BRU Production and responded to questions from the Committee.

*C. Quartz Creek Transmission Line Rebuild - Girdwood to Indian Project Authorization (Laughlin/M. Miller)*

Arthur Miller, CEO, Andrew Laughlin, Chief Operating Officer, and Mike Miller, Vice President of Engineering and Distribution discussed the project and responded to questions from the Committee.

Director Hollis moved and Director Cooper seconded the motion that the Operations Committee recommend the Chugach Electric Association, Inc. Board of Directors approve the attached resolution authorizing the Chief Executive Officer to approve project expenditures for the transmission line rebuild between the Girdwood Substation and the Indian Substation at an estimated total cost of $21,200,000 and with an estimated completion date of December 2024. The motion passed unanimously.

## VI. EXECUTIVE SESSION

*A. One Campus Plan Update (Resnick)*
*B. Gas Supply Update (Armfield/White)*
*C. Decarbonization: Goals and Proposed Board Policy (Ayers)*
*D. Renewable Portfolio Standard (Skaling/Ayers)*
*E. Battery Energy Storage System Update (Laughlin)*

At 5:28 p.m., Director Whitney moved and Director Hollis seconded the motion that pursuant to Alaska Statute 10.25.175(c)(1) and (4) the Board of Directors go into executive session to: 1) discuss and receive reports regarding financial matters, the immediate knowledge of which would clearly have an adverse effect on the finances of the cooperative; and 2) discuss with its attorneys legal matters, the immediate knowledge of which could have an adverse effect on the legal position of the cooperative. The motion passed unanimously.

*The meeting reconvened in open session at 7:47 p.m.*

## VII. NEW BUSINESS

None.

## VIII. DIRECTOR COMMENTS

Comments were made at this time.

## IX. ADJOURNMENT

At 7:53 p.m., Director Cooper moved and Director Whitney seconded the motion to adjourn. The motion passed unanimously.

# Decarbonization

Chugach Electric Association, Inc.
Operations Committee Meeting
November 15, 2022

POWERING ALASKA'S FUTURE

# Objective – to answer the following:

- What do carbon reduction goals include?
- What are Chugach's carbon emissions?
- Does Chugach want a carbon reduction goal?
- How do renewables relate to carbon reduction?
- Next Steps?

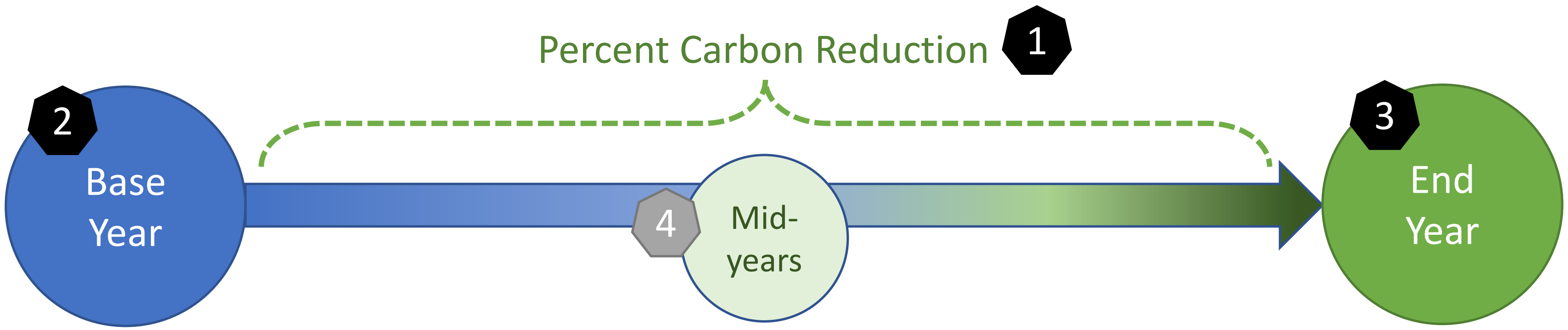
# What do carbon reduction goals include?

# What does a carbon reduction goal measure?

| | Carbon Emissions | Carbon Emissions Rate |
|---|---|---|
| **Emissions Unit** | **Metric Tons of $CO_2$ (or $CO_2e$)** | **Metric Tons of $CO_2$ (or $CO_2e$)/MWh** |
| Definition | Carbon dioxide ($CO_2$) is the most common greenhouse gas (GHG).<br><br>Carbon dioxide equivalent ($CO_2e$) is a term for describing different greenhouse gases (GHG), including $CO_2$, in a common unit. | Emissions Rate or Carbon Intensity is the emission rate of $CO_2$ or $CO_2e$ relative to the intensity of a specific activity, or an industrial production process; for example, amount of $CO_2e$ released per unit of energy generated (MWh). |
| *Also referred to as:* | *Carbon Emissions*<br>*Carbon Equivalent Emissions*<br>*Greenhouse Gas Emissions* | *Carbon Emissions*<br>*Carbon Emission Rate*<br>*Carbon Intensity*<br>*Carbon Equivalent Emission Rate*<br>*Greenhouse Gas Emissions Rate* |


CHUGACH
POWERING ALASKA'S FUTURE

# Carbon Reduction Goals




Federal

- 52% reduction from 2005 levels in 2030 and net zero emissions by no later than 2050

State

- 25 states have adopted carbon reduction goals

Anchorage

- 40% reduction from 2008 levels in 2030 and 80% reduction by 2050

# What are Chugach’s carbon emissions?

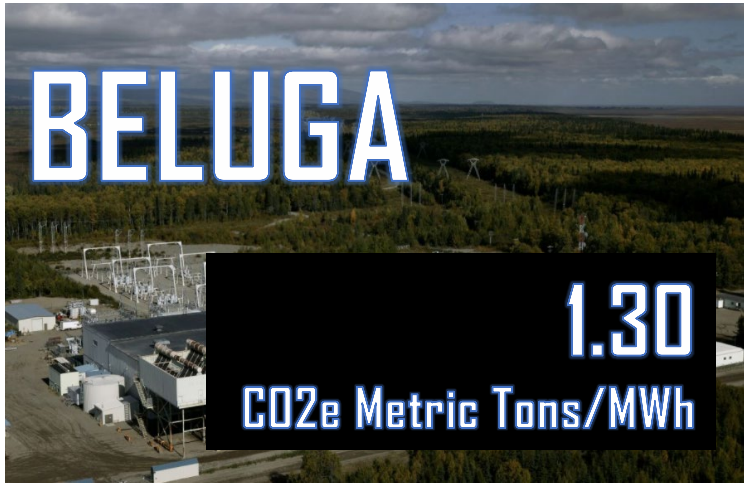
# Chugach's Carbon Footprint

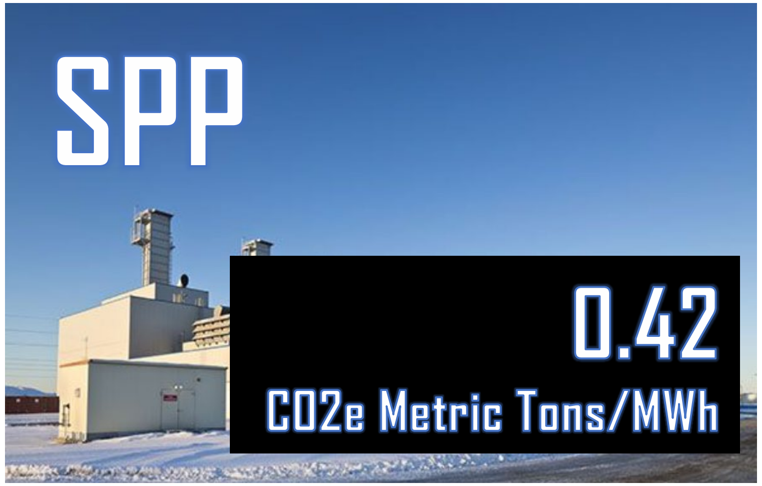
Generation

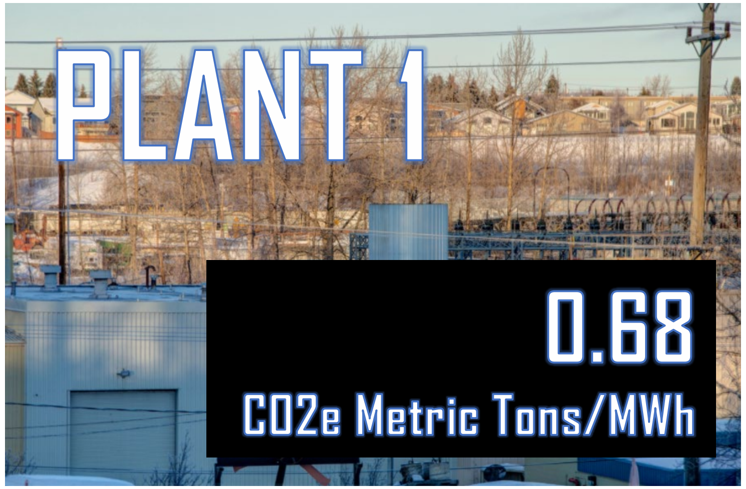
BRU


Fleet

# Chugach's Owned Generation







*Average emission rates from 2012 - 2021 emissions rates

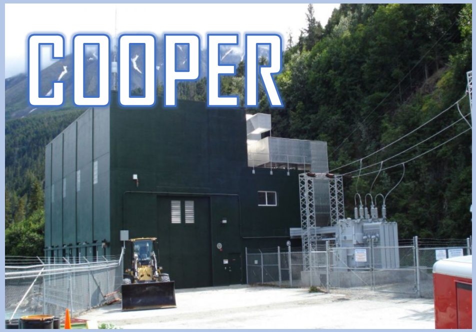
CHUGACH
POWERING ALASKA'S FUTURE

# Chugach's Generation for Retail

OWNED






SOLD

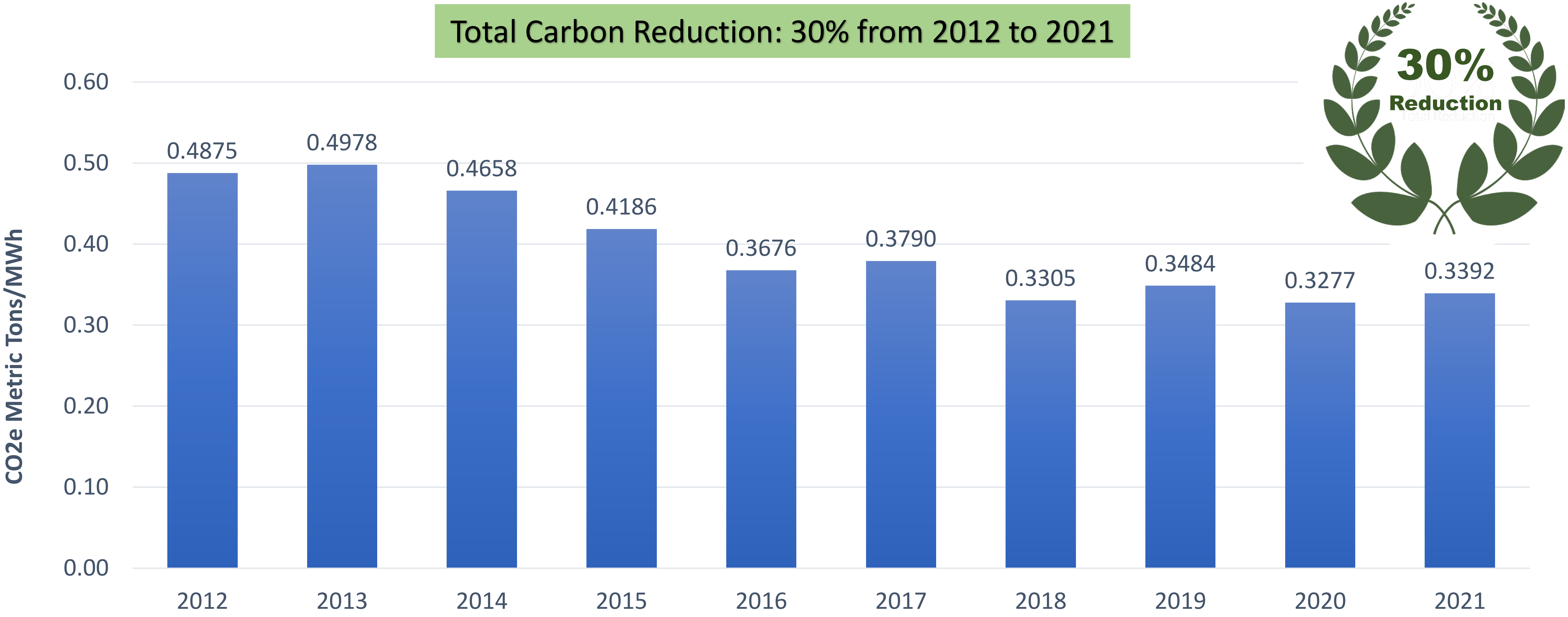



PURCHASED

CHUGACH
POWERING ALASKA'S FUTURE

# Chugach's Carbon Intensity

Total Carbon Reduction: 30% from 2012 to 2021



# Does Chugach want a carbon reduction goal?

# Carbon Reduction Goal

## PROs to establishing a carbon reduction goal?

- Identified in Strategic Priority # 6 : Decarbonization
- Impacts each pillar of Sustainability
  - Planet - Decreases emissions
  - People - Meets member's requests and world trends
  - Performance – Leverage federal funding opportunities & diversify generation portfolio
- Leader in the community
  - Enable others to meet their own carbon goals (MOA, Organization Goals, etc.)
- Set direction and pace for Chugach's future
- Doing our part to fight climate change

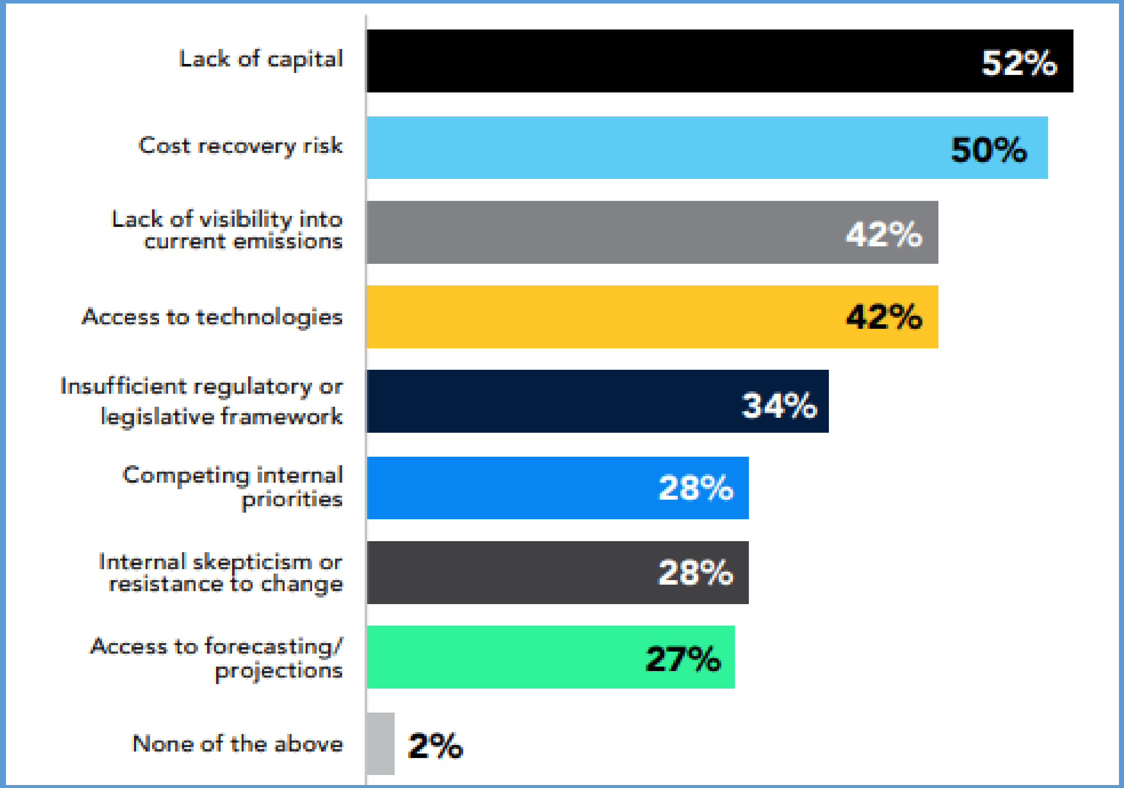
CHUGACH
POWERING ALASKA'S FUTURE

# Carbon Reduction Goal

## CONs to establishing a carbon reduction goal?

- Unable to accurately forecast long term conditions
  - Natural Gas
  - Clean Energy Technologies in R&D only
  - Unknown costs
  - Regulatory environment
  - Changing political objectives
  - Unrealistic, and unattainable goals
- Carbon Reduction Goal is more complicated than a Renewable Portfolio Standard

**Which of the following, if any, are potential barriers that could prevent your organization from achieving its emissions reduction or decarbonization strategy/goals?**




CHUGACH
POWERING ALASKA'S FUTURE

# Goal Parameter - Considerations

## Baseline Year - 2012

- EPA used 2012 emission data to project its 2030 goals in the Clean Energy Plan
- Emission data prior to this year is inadequate
- Consistent with Railbelt Utilities

## Mid Year - 2030

- Near term goal of 2030,
- Consistent with Railbelt Utilities end goals

## End Year - 2050

- Aspirational long-term goal of 2050

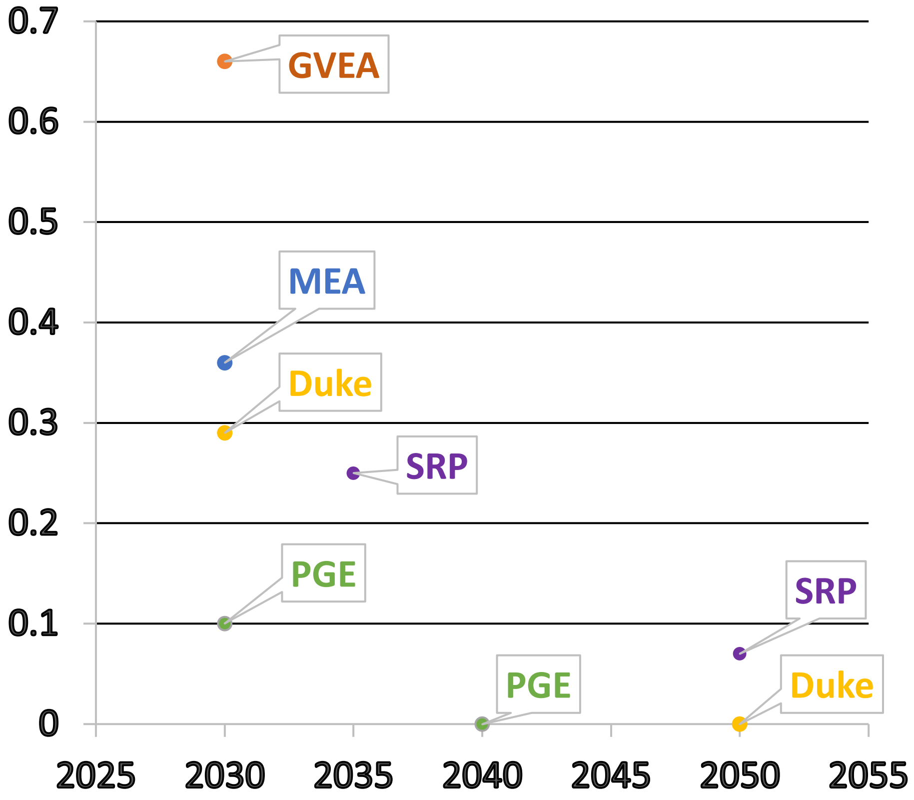
## Goal Metric

- Based on an emission rate: Metric Tons of $CO_2e$/MWh

CHUGACH
POWERING ALASKA'S FUTURE

# Electric Utility Carbon Reduction Goals

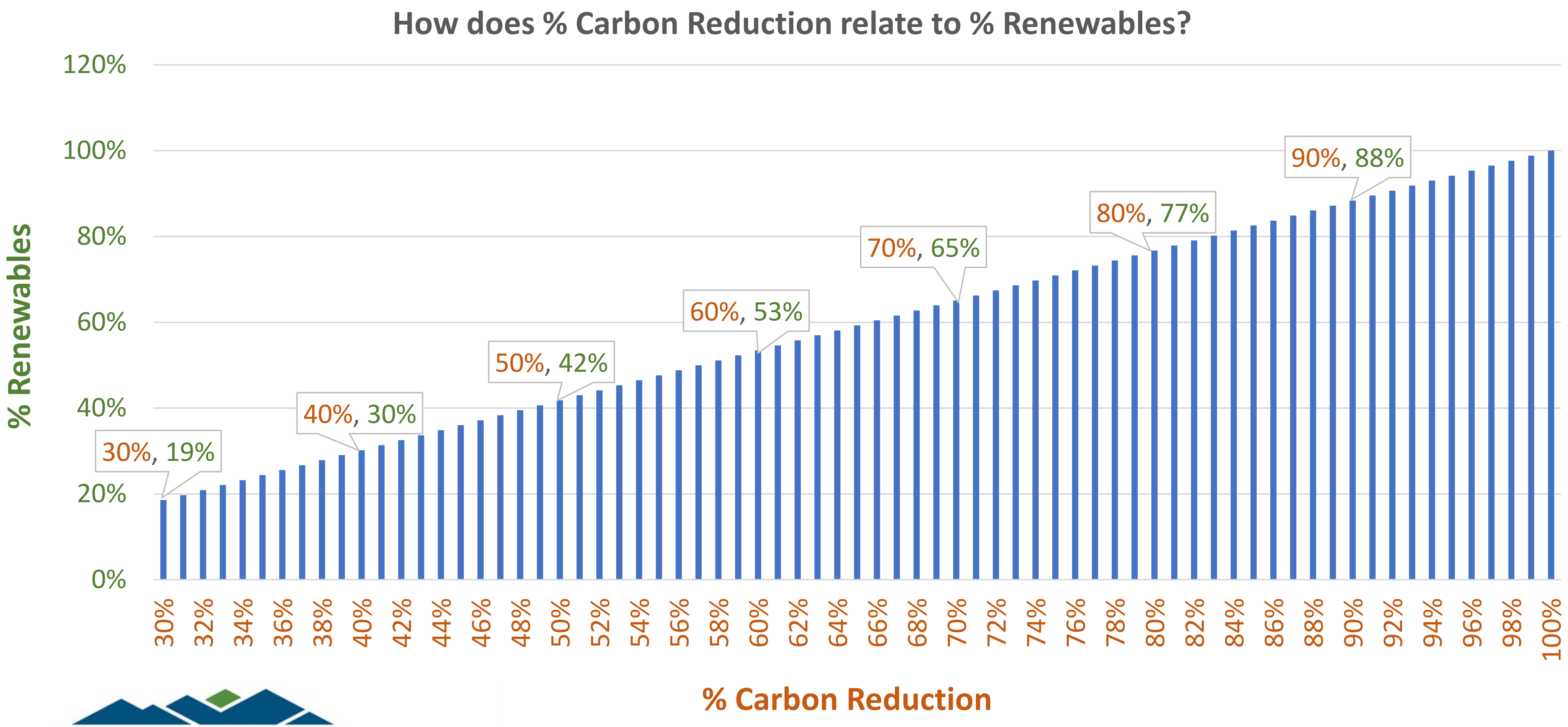
| Utility (Examples) | Base Year | Mid-Year | End Year | % Carbon Reduction | Emissions (MT CO2e/MWh) |
|---|---|---|---|---|---|
| MEA | 2012 | - | 2030 | 28% | 0.36 |
| GVEA | 2012 | - | 2030 | 26% | 0.66 |
| Portland General Electric | 2010 | 2030 | 2040 | 80%<br>Net-Zero | 0.10<br>0.00 |
| Duke Energy | 2005 | 2030 | 2050 | 50%<br>Net-Zero | 0.29<br>0.00 |
| Salt River Project | 2005 | 2030 | 2050 | 65%<br>90% | 0.25<br>0.07 |




CHUGACH
POWERING ALASKA'S FUTURE

# How do renewables relate to carbon reduction?

# Carbon Reduction vs. Renewables




CHUGACH
POWERING ALASKA'S FUTURE

Assumptions: Flat load growth, Average thermal emissions rate of 0.41, no carbon capture

# Member Opinions on Renewables

**23.1%**

Do not support renewables

**35.5%**

Support, unless they need to pay

**41.4%**

Support, even if they need to pay more

**88.4%**

Of these members would pay 2% or more.

CHUGACH
POWERING ALASKA'S FUTURE

# Renewables vs. Clean Energy


## Renewables

- Hydro
- Wind
- Solar
- Geothermal

## Clean Energy

- Renewables
- Nuclear
- Carbon Capture
- Energy Efficiency


CHUGACH
POWERING ALASKA'S FUTURE

# Next Steps?

# Discuss and Answer:

**Does Chugach want a carbon reduction goal?**

- What is the end year?
- Will there be a mid-year?
- What is the percent reduction?

**How will Chugach formalize its goal?**

- Resolution?
- Board Policy?
- Both, or other?

CHUGACH
POWERING ALASKA'S FUTURE

**CHUGACH ELECTRIC ASSOCIATION, INC.**

**BOARD POLICY: ** DRAFT ****

**DECARBONIZATION PLAN**

## I. OBJECTIVE

To support the Association's sustainability business philosophy through decarbonization activities that include the adoption of clean energy resources and other measures that reduce carbon emissions.

Decarbonization is critical to managing reductions in global greenhouse gas emissions, and Chugach's decarbonization plan shall take into consideration both supply and demand side impacts. The decarbonization plan supports the transition towards a clean, affordable, and reliable energy future by adopting clean energy resources, advancing beneficial electrification, and other measures that reduce carbon emissions.

## II. CONTENT

1. The Association will establish a decarbonization plan that supports diversification of the Association's resource portfolio through: (a) improved utilization of existing assets; (b) responsible incorporation of clean energy resources and supporting technologies; and (c) active examination of opportunities to increase beneficial electrification.

2. The decarbonization plan will outline a long-term plan describing how the Association will manage its reduction in carbon emissions. Emission reductions may be achieved through a variety of activities including but not limited to producing low or carbon-free electricity, capturing carbon emissions, implement alternative rate designs, and advancing beneficial electrification.

3. The decarbonization plan will move the Association toward its carbon emissions reduction goal; to reduce carbon emissions by __% by 20XX and by __% by 20XX, using a baseline year of 2012.

   a. Decarbonization Goal Metric: The carbon dioxide equivalent of net emissions per megawatt-hour of net generation; Metric Tons CO2e/MWh.

   b. Other metrics as directed by the Chief Executive Officer.

4. The Association will implement programs to encourage the adoption and transition

toward beneficial electrification, provide member education on beneficial electrification, and will support related community activities.

5. The Association will adopt business practices and advance alternative rate designs that promote a culture of energy conservation.

6. The Association will, consistent with established targets, develop a plan to reduce reliance on natural gas generation in a manner that meets the Association's needs and complements efforts undertaken by the Railbelt Reliability Council.

7. The Association will pursue carbon capture, sequestration, and utilization activities to reduce carbon emissions.

8. The Association will participate in local, state, and federal planning activities regarding decarbonization to ensure partnerships are created to achieve reductions of community carbon emissions and benefits for its members.

9. The Association will report annually to the Board of Directors on its effectiveness in achieving its carbon reduction goal.

## III. <u>RESPONSIBILITY</u>

A. The Chief Executive Officer is responsible for the implementation, management, and administration of all activities and plans prescribed in this Policy. The Chief Executive Officer may delegate specific responsibilities as deemed appropriate.

B. The Chief Executive Officer shall periodically report to the Board on the Association's progress in satisfying the requirements of this policy.

Date Approved: Attested: ______________________________

Samuel Cason
Secretary of the Board

# RESOLUTION

## Decarbonization Plan
## (Plan for a Clean, Affordable, and Reliable Energy Future)

WHEREAS, Chugach Electric Association, Inc. (Chugach or Association) has adopted sustainability as a business management philosophy that considers financial, social, and environmental impacts to guide decision making in order to create greater long-term business value for its members;

WHEREAS, the Association is committed to “Powering Alaska’s future” through ongoing evaluation and adoption of business practices, policies, and goals consistent with that core sustainability business philosophy;

WHEREAS, the Association believes that a sustainable future is one that provides clean, affordable, and reliable energy to its members;

WHEREAS, investments in clean energy resources, energy efficiency, and adoption of business practices that reduce carbon emissions provide long-term environmental benefit;

WHEREAS, the Association believes that a decarbonization plan will help enable it to achieve such a sustainable future;

WHEREAS, the Association’s decarbonization plan will support the diversification of Chugach’s resource portfolio through (i) improved utilization of existing assets, (ii) responsible incorporation of clean energy resources and supporting technologies, and (iii) active examination of opportunities to increase beneficial electrification (collectively “Decarbonization Principles”); and

WHEREAS, the Association’s decarbonization plan shall incorporate the following action items: (i) reduce Chugach’s carbon intensity by __% by 20XX and __% by 20XX, using 2012 as the baseline year; (ii) consistent with established targets, develop a plan to reduce reliance on natural gas generation in a manner that meets Chugach’s needs and complements efforts undertaken by the Railbelt Reliability Council; (iii) advance beneficial electrification initiatives, including but not limited to electric vehicle charging infrastructure, battery operated tools and equipment, and air/ground source heat pumps; (iv) adopt business practices that reduce carbon; (v) support development of rate structures that reduce carbon emissions and incentivizes beneficial electrification; and, (vi) support clean energy resources without compromising system reliability (collectively “Decarbonization Plan”).

NOW THEREFORE BE IT RESOLVED, the Board of Directors adopts the Decarbonization Principles and directs the Chief Executive Officer to create a Decarbonization Plan;

BE IT FURTHER RESOLVED, the Board of Directors directs the Chief Executive Officer to incorporate consideration of the Decarbonization Plan and Decarbonization Principles into future business management and strategic planning policies, proposals, and recommendations advanced to the Board by the Association's management team; and

BE IT FINALLY RESOLVED, the Board of Directors encourages other state and local entities to join the Association by taking steps to invest in a clean, affordable, and reliable energy future for all residents of the State of Alaska.

**CERTIFICATION**

I, Samuel Cason, do hereby certify that I am the Secretary of Chugach Electric Association, Inc., an electric non-profit cooperative membership corporation organized and existing under the laws of the State of Alaska: that the foregoing is a complete and correct copy of a resolution adopted at a meeting of the Board of Directors of this corporation, duly and properly called and held on the _____ day of ______, 2022; that a quorum was present at the meeting; that the resolution is set forth in the minutes of the meeting and has not been rescinded or modified.

IN WITNESS WHEREOF, I have hereunto subscribed my name and affixed the seal of this corporation on the _____day of ______, 2022.

______________________________
Secretary

CHUGACH ELECTRIC ASSOCIATION

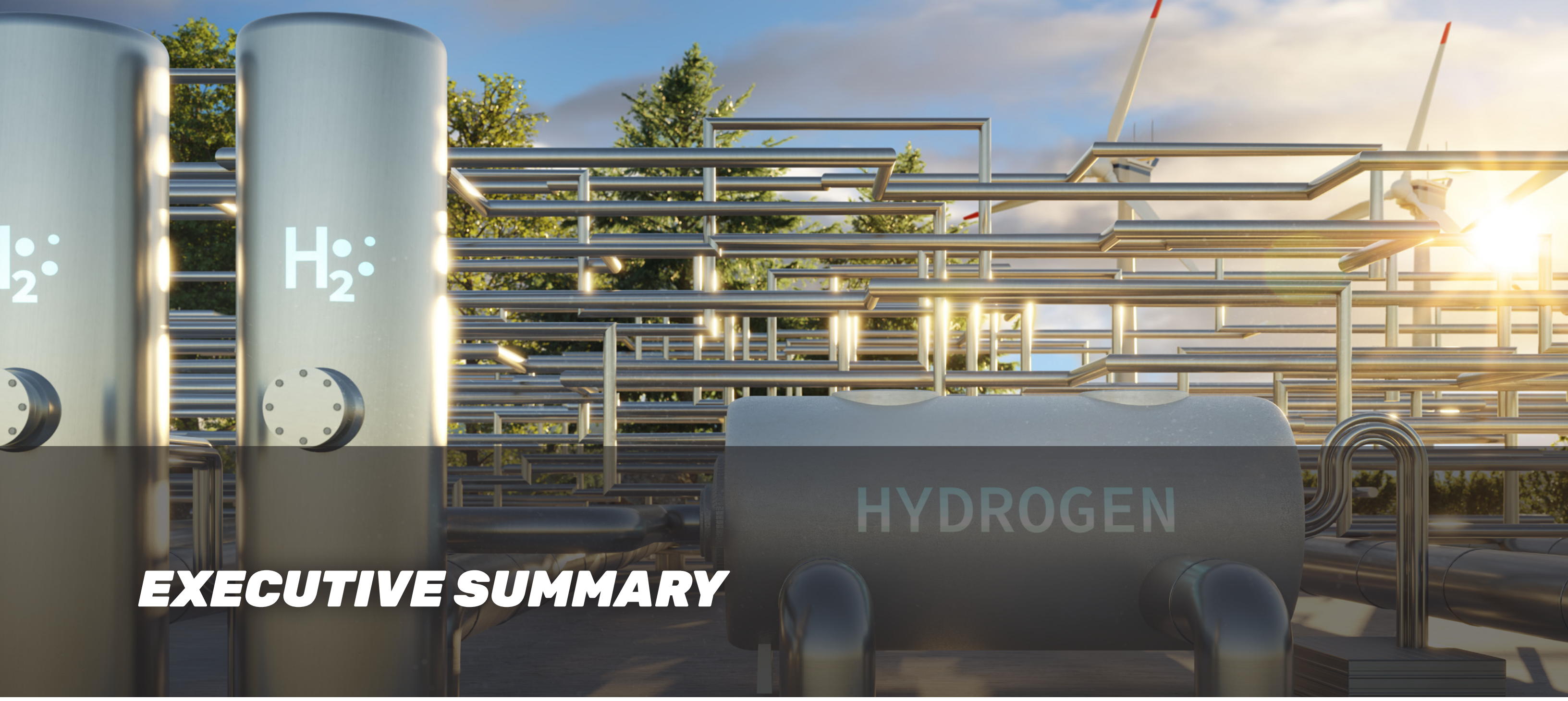
# DECARBONIZATION TECHNOLOGIES

AUGUST 2022

Rev 1

**PREPARED BY: Coffman Engineers**
800 F Street | Anchorage, AK 99501
907.276.6664

**PREPARED FOR: Chugach Electric Association**
5601 Electron Dr | Anchorage, AK 99518
907.563.7366




## EXECUTIVE SUMMARY

The Alaska Railbelt electric grid has an opportunity to reduce carbon emissions by increasing the deployment of renewable and alternative energy technologies, hydrogen, and carbon capture utilization and storage. This paper identifies potential technologies that can be used to decarbonize the grid and provides a high-level scoring of the technologies based on Technology Readiness Level, Alaska Scalability, Project Impact Timeline, Commercial Viability, and Carbon Intensity.

Decarbonization has become a large priority across the world due to current and foreseeable policy interventions and regulatory requirements at local, state, and federal levels that impact the viability of maintaining the status quo. Drivers for decarbonization vary by location and industry and may include renewable portfolio standards, incentives and tax credits, and carbon pricing. Electric utilities are among the top industries that are expected to be significantly impacted by market and regulatory structures.

Ultimately, the Railbelt can use a mixture of renewable and alternative energy technologies to reduce carbon emissions from its operations, while also keeping costs reasonable and adhering to grid reliability requirements that are now part of the electrical landscape.

The following paper is intended to illustrate the range of available technologies that will decrease the carbon footprint of the Railbelt electric grid. The paper does not recommend or identify specific technologies to be deployed. A review is provided for each technology, which also includes a current market status for deployment / integration.

The paper outlines the following sections:

- Renewable Energy
- Energy Storage
- Hydrogen
- Carbon Capture Utilization and Storage
- Nuclear
- Grid Modernization

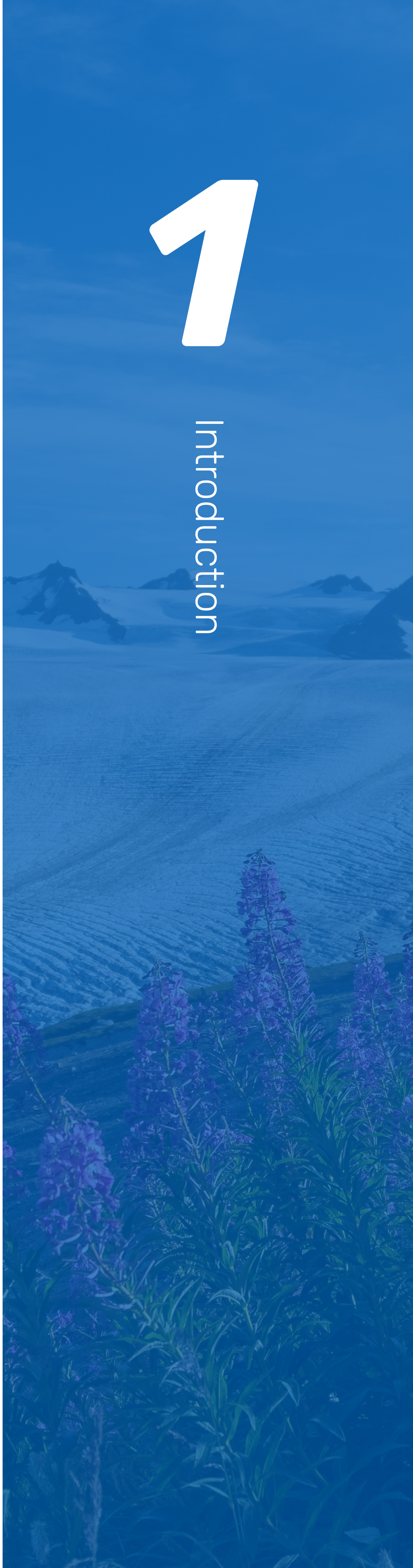
**A final scorecard of all technologies can be found in the conclusion section.**

# ACRONYMS

| | |
|---|---|
| AEA | Alaska Energy Authority |
| AS | Ancillary Services |
| ATR | Autothermal Reforming |
| BECCS | Bioenergy with Carbon Capture & Storage |
| BESS | Battery Energy Storage System |
| CAES | Compressed Air Energy Storage |
| CEA | Chugach Electric Association |
| CCUS | Carbon Capture Utilization & Storage |
| CSP | Concentrated Solar Thermal |
| CTR | Central Tower Receiver |
| DNI | Direct Normal Irradiance |
| DACCS | Direct Air Carbon Capture & Storage |
| DOE | Department of Energy |
| ESS | Energy Storage System |
| FES | Flywheel Energy Storage |
| GHI | Global Horizontal Irradiance |
| GMI | Grid Modernization Initiative |
| GVEA | Golden Valley Electric Association |
| GW | Gigawatts |
| GWh | Gigawatt hours |
| HARS | Heat Absorbing and Releasing Structure |
| HEA | Homer Electric Association |
| IPP | Independent Power Producer |
| kWh | Kilowatt-hour |
| LDES | Long Duration Energy Storage |
| LFP | Lithium-Iron-Phosphate |
| MEA | Matanuska Energy Association |
| MDS | Multi-Day Storage |
| Metric Ton | 1,000 kilograms (~2,205 pounds) |
| ML&P | Municipal Light & Power |
| MW | Megawatts |
| MWh | Megawatt hours |
| NaS | Sodium Sulphur |
| NaNiCl | Sodium-Nickel Chloride |
| NERC | North American Electric Reliability Corporation |
| NiCd | Nickel-Cadmium |
| NiMH | Nickel-Metal Hydride |
| NMC | Nickel-Manganese-Cobalt |
| NREL | National Renewable Energy Lab |
| ORC | Organic Rankine Cycle |
| PCM | Phase Change Material |
| PHES | Pumped Hydroelectric Energy Storage |
| PSB | Polysulfide Bromide |
| PSH | Pumped Storage Hydropower |
| psi | Pounds Per Square Inch |
| PV | Photovoltaics |
| RFP | Redox Flow Battery |
| RNG | Renewable Natural Gas |
| RPM | Revolutions Per Minute |
| SC | Supercapacitors |
| SMES | Superconducting Magnetic Energy Storage |
| SMR | Steam Methane Reforming |
| TES | Thermal Energy Storage |
| TOU | Time of Use |
| TRL | Technology Readiness Level |
| VRB | Vanadium Redox Flow Battery |
| ZBR | Zinc-Bromine |

# TABLE OF CONTENTS

# 1 Introduction



COFFMAN
ENGINEERS

# INTRODUCTION

The purpose of this paper is to identify existing renewable and alternative energy technologies, hydrogen, and carbon capture utilization and storage technologies and discuss their applicability to the Alaska Railbelt. This effort has become a large priority across the world with carbon reduction, increased electric vehicle use, regulatory requirements, increased renewable portfolio standards, energy incentives, and their impact on high grid reliability requirements that are now part of the electrical landscape.

Although the emphasis of this paper is on the Railbelt, these technologies can be deployed throughout the greater state of Alaska. For example, stranded natural gas on the North Slope could have a huge influence on the strategy for blue hydrogen or ammonia production for the Railbelt or export. Also, rural Alaskan communities continue to pursue renewable energy and energy storage technologies to lower energy costs.

In the future, renewable energy can be a major source of energy in the state, with energy storage being used to respond to the intermittent power production of renewables. Excess renewable energy can be converted to hydrogen (instead of being curtailed by utility, the excess power can be directed to off grid electrolyzers to make hydrogen) for longer term storage for use in Alaska or for export. Carbon capture, utilization, and storage can be used to drive down carbon emissions. Grid modernization upgrades will further decrease carbon emissions through increasing the efficiency of the electric grid. With the suite of technologies available now and in the near future, Alaska can move towards decarbonization.

## RAILBELT

The Railbelt refers to the interconnected electric grid from Fairbanks through the Kenai Peninsula, which serves roughly 75 percent of Alaska's population. Utilities within the Railbelt include Chugach Electric Association (CEA), Golden Valley Electric Association (GVEA), Homer Electric Association (HEA), Matanuska Electric Association (MEA), and Seward Electric System. As of 2022, Alaska's energy mix was dominated by natural gas and hydroelectric power generation.

## PREVIOUS STUDIES

The National Renewable Energy Laboratory (NREL) and others have evaluated pathways to increase renewable energy into the Railbelt grid, which will reduce carbon emissions.

In NREL's 2022 Renewable Portfolio Standard Assessment for Alaska's Railbelt[1], five scenarios were modeled that can reach 80% renewables by the year 2040, while maintaining grid reliability and still meeting demand even under extended outages of major transmission lines and generation resources. In 2010, AEA also created an Integrated Resource Plan for the Railbelt.[2]

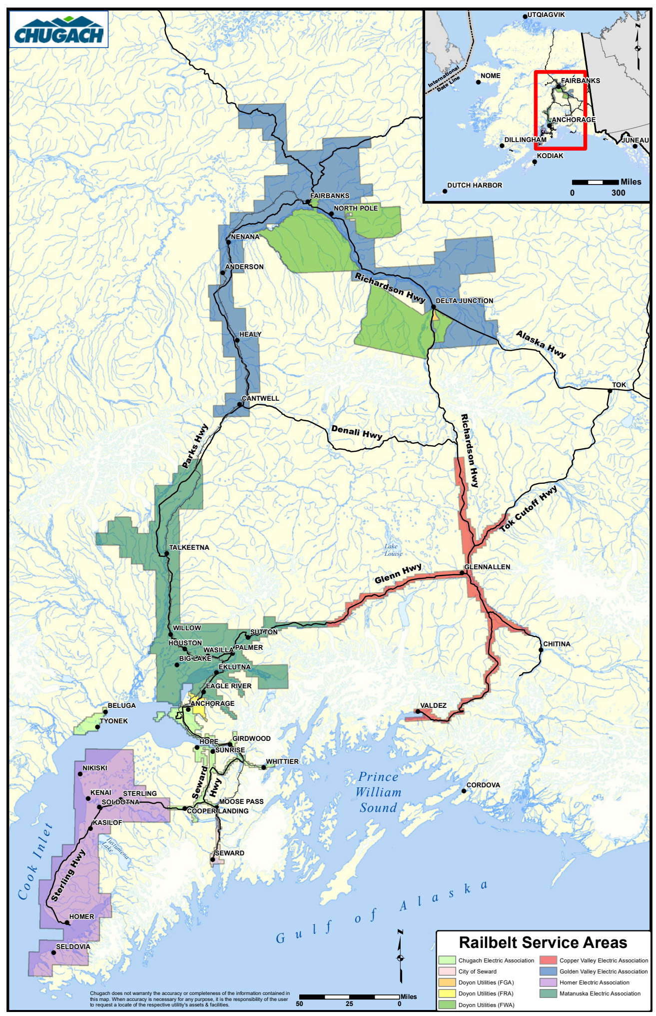



***FIGURE 01***
Alaska's Railbelt Service Areas (2022).[3]

1 www.nrel.gov
2 www.akenergyauthority.org
3 AK Railbelt Service area, provided by Chugach Electric

As of 2020, utilities within Alaska's Railbelt in sum generated approximately 20% of power from renewable sources (see Figure 02 below). The 2022 NREL Renewable Portfolio Standard (RPS) Report for the Alaska Railbelt points out that due to reliability requirements to operate during intertie failures as well as the relatively small size of each utility, the Railbelt utilities carry a significant reserve margin in generation capacity (143%), relative to the North American Electric Reliability Corporation (NERC) recommended reserve margins of 13-17%.

***FIGURE 02***
Alaska Railbelt power generation by resource type (NREL).

| Generator Type | Capacity [a] (MW) | Generation (GWh) | Generation Fraction |
|---|---|---|---|
| Gas/oil combustion turbine (CT) | 754 | 632 | 14% |
| Gas/oil internal combustion (IC) | 193 | 732 | 16% |
| Gas/oil combined cycle (CC) | 561 | 1,676 | 36% |
| Coal | 75 | 348 | 8% |
| Unspecified fossil purchases[b] | n/a | 310 | 7% |
| **Fossil Subtotal** | **1,585** | **3,698** | **80%** |
| Hydropower | 190 | 815 | 18% |
| Wind | 44 | 97 | 2% |
| Landfill gas | 7 | 39 | 1% |
| Solar | 1 | 1 | <1% |
| **Renewable Subtotal** | **241** | **951** | **20%** |
| **Total[c]** | **1,826** | **4,649** | **100%** |

**a** This does not include the 147 MW of combined heat and power plants in the Railbelt system reported on EIA 861. These units generated about 444 GWh in 2020. Much of this electricity was use on site. However, some of this was sold to utilities and accounts for some of the unspecified energy.

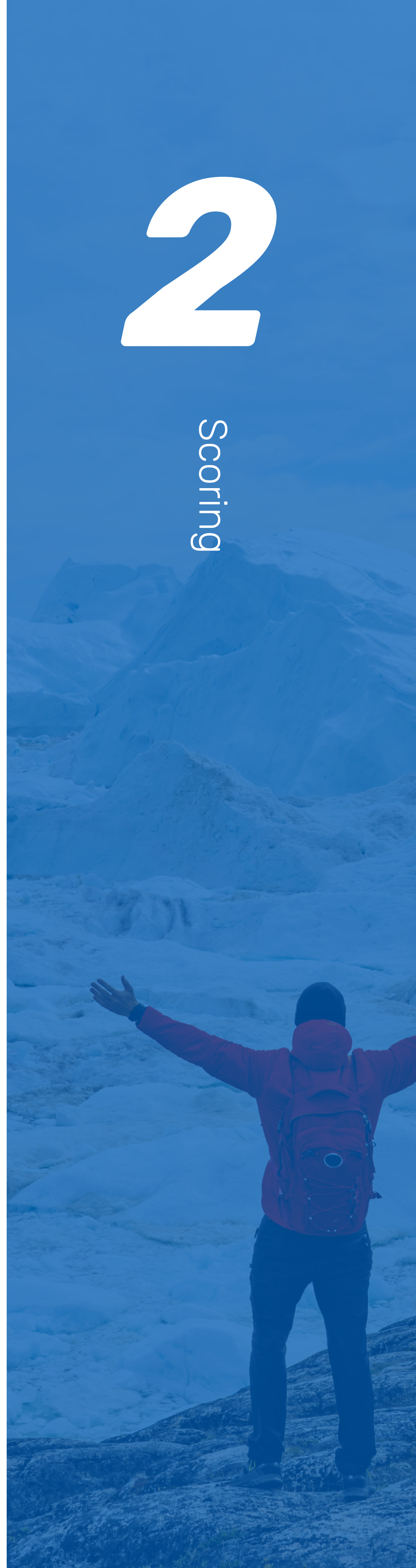
**b** This value was estimated based on estimated total generation (see note c) minus the total generation accounted for in Form EIA-923.

**c** This value was estimated based on the total generation required for retail sales plus losses reported in Form EIA-861.

Overall, the system obtained about 80% of its electricity from fossil resources in 2020, and about 20% from renewables with the majority derived from hydropower.

# 2

## Scoring



COFFMAN ENGINEERS

# SCORING

With so many technologies available, different opportunities have been ranked with a scoring system to easily assess each technology's viability in Alaska. The scoring is based on five general categories:

- Technology Readiness Level
- Alaska Scalability
- Project Impact Timeline
- Commercial Viability
- Carbon Intensity

## TECHNOLOGY READINESS LEVEL

The Department of Energy (DOE) has established Technology Readiness Levels (TRL), which are used to score each technology.[4] TRL is determined and assigned based on Figure 03.

## ALASKA SCALABILITY

Each technology has a potential market size in Alaska, determined by the total power provided across the state.

- **Green**: Greater than 1 Gigawatt
- **Yellow**: 1 Megawatt to 1 Gigawatt
- **Red**: Less than 1 Megawatt

## PROJECT IMPACT TIMELINE

The time required to bring a particular technology online depends on multiple factors including environmental permitting, project complexity, and size of capital expenditures.

- **Green**: 1 to 5 years, with known permitting path and low project complexity
- **Yellow**: 5-10 years
- **Red**: Beyond 10 years, with large capital requirements, complex project definition, large environmental review, and/or technology advancement required

## COMMERCIAL VIABILITY

In the current market conditions, each technology has its own economic pathway. *The Inflation Reduction Act was not passed at the time this paper was written.*

- **Green**: Clear economics that attract capital
- **Yellow**: Potential economic pathway, but will require some level of funding (state, federal, etc.) external to the utilities
- **Red**: Uneconomic in current market conditions, will require significant government support

## CARBON INTENSITY

The Carbon Intensity refers to the carbon emissions released or captured through the operation of the technology. *Note*: metric does not account for the embodied energy or carbon associated with the manufacturing of the technology itself or the implementation of the project.

- **Green**: Carbon negative
- **Yellow**: Carbon neutral or low carbon
- **Red**: Significant carbon emissions

### TECHNOLOGY READINESS LEVEL (TRL)


*FIGURE 03*

4 www.energy.gov

## SCORING METHODOLOGY TABLE

| | Green | Yellow | Red |
|---|---|---|---|
| Technical Readiness | TRL of 8, 9<br>(Established Technology) | TRL of 5, 6, 7<br>(Pilot Project) | TRL of 1, 2, 3, 4<br>(Research Level) |
| AK Scalability | > 1 GW | 1 MW to 1 GW | < 1 MW |
| Impact Timeline | 1 to 5 years<br>(Known permitting path/low complexity engineering) | 5 to 10 years | Beyond 10 years<br>(Large capital requirements/ complex project definition/ large environmental review/ technology advancement required) |
| Commercial Viability | Clear economics that attract capital | Potential economic pathway but will require DOE funding or state funding | Uneconomic in current market conditions, will require significant government support |
| Carbon Intensity | Carbon negative | Carbon neutral or low carbon | Significant Carbon emissions |

***FIGURE 04***

Beech Energy Storage Project

# 3

## Renewables

COFFMAN ENGINEERS

# RENEWABLES

Renewable energy is defined as “energy derived from natural sources that are replenished at a rate as fast as they are consumed”.[5] Renewable energy typically has a low carbon footprint during operation and its energy sources are sustainable because they can be used through multiple generations without depleting the underlying resource.

The table below depicts the five main categories of renewable energy sources discussed in this paper. Those in grey boxes are not discussed either because their technology readiness level is currently too low to yield a major impact in Alaska in the next 10 years, or the implementation of these technologies would not have a major impact on the decarbonization of the Alaska grid.

**RENEWABLE ENERGY SOURCE CATEGORIES**

| Wind | Solar | Geothermal | Hydro | Biomass |
|---|---|---|---|---|
| Onshore Wind | Photovoltaic (PV) | Hydrothermal | Hydroelectric | Wood Biomass |
| Offshore Wind | Concentrated Solar Power (CSP) | Organic Rankine Cycle | Tidal | Biogas/Renewable Natural Gas |
| | Solar Thermal Heating | Ocean Thermal | Wave | |
| | | | River Hydrokinetic | |
| | | | Salinity Gradient | |

***FIGURE 05***
Main categories of renewable energy sources discussed in this paper.

## WIND

Wind turbines use the kinetic energy of air in motion to generate electricity. The movement of air across the turbine blades causes them to rotate a shaft that drives a generator.

The capacity of a wind turbine is proportional to the dimensions of the rotor and to the cube of the wind speed.[6] Wind turbines are typically idle during periods of calm or light wind. With wind speed, power production increases exponentially, up to the maximum rated capacity of the machine itself. Modern wind turbines actively control the pitch of their blades to regulate rotational speed and power output as the local wind conditions change.

According to the World Wind Energy Association, an international trade organization, as of 2021 global wind capacity is in excess of 840 Gigawatts (GW) or about 7% of the global power demand.[7] The dominant wind turbine technology today is for horizontal axis, three-bladed machines. Utility-scale wind turbines range from approximately 2 to 14 megawatt (MW) capacity, with rotor lengths over 220 meters. Site specific characteristics such as daily and seasonal weather variations, peak gusts, turbulence, shear, and topography impact suitability of wind power in any given location.

5 www.un.org
6 www.irena.org/wind
7 https://emp.lbl.gov/wind-technologies-market-report

***FIGURE 06***
Fire Island Wind Farm in Anchorage, AK [8]

## Onshore Wind

Onshore wind refers to wind turbines that are installed on land rather than over a body of water. Where adequate space and wind resources are available on land, onshore wind energy development is often the most economically viable with a national average price between $20/MWh[9] to $30/MWh.

Nearly all wind power currently generated in the United States is from onshore wind farms. All wind power installations in Alaska are onshore.

| TABLE 1. Onshore Wind | | |
|---|---|---|
| Technology Readiness | TRL 9 | Utility scale wind projects of all shapes and sizes exist in Alaska and across the world. |
| AK Scalability | >1GW | Alaska has a very large wind resource and land area suitable for development. |
| Impact Timeline | 1 to 5 years | Projects can be completed within 1-5 years depending on size. |
| Commercial Viability | Clear Economics | The national average price for wind power makes it one of the lowest cost forms of energy. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

8 www.chugachelectric.com
9 https://emp.lbl.gov/wind-technologies-market-report

***FIGURE 07***
Offshore wind mooring system examples are spar-buoy, barge, and tension-line floating offshore wind turbines (left to right).[10]

## Offshore Wind

Offshore wind power is a large and growing market that takes advantage of stronger and steadier winds while not requiring land acquisition or placing turbines directly in people's backyards. While still a relatively limited footprint in the U.S, offshore wind has been developed in many European countries as well as off the coasts of Virginia and Rhode Island.

Currently, Alaska does not have an offshore wind presence. With a 50-year history of offshore oil and gas platforms in the Cook Inlet, offshore wind is viable. Multiple wind resource locations near shore have been identified that are shallow and could be provided with foundations sitting directly on the seafloor (like the existing offshore platforms in Cook inlet).

**Challenges in Alaska include:**

- Deep water
- Ice flows
- High tidal currents
- Protected marine ecosystems and wildlife

| TABLE 2. Offshore Wind | | |
|---|---|---|
| Technology Readiness | TRL 7 to 9 | Offshore wind farms have been in use for decades throughout the world. |
| AK Scalability | >1GW | Alaska has a very large coastal wind resource near existing Railbelt infrastructure. |
| Impact Timeline | 3 to 10 years | Environmental permitting may lengthen project timelines. Utilizing existing offshore oil platforms may improve timeline. |
| Commercial Viability | Potential Economic Pathway | A potential economic pathway for implementing offshore wind at large-scale development. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

10 www.energy.gov

## SOLAR

Solar as a renewable energy involves the capture of energy from the sun, either via radiation heat or photons. The amount and consistency of energy captured is dependent upon geographic region. Systems include photovoltaics (PV) and concentrated solar power (CSP).

***FIGURE 08***
Coffman provided design services for three individual PV systems on US Army Garrison, Kwajalein Island.

### Photovoltaic

Photovoltaics (PV), also called solar cells, are electronic devices that convert sunlight directly into electricity.[11] Solar PV installations are scalable; they can provide energy to power a light in a remote cabin or they can be sized to provide electricity on a commercial scale. According to the U.S. Energy Information Administration (EIA), starting in 2021, solar was set to account for the largest share of new power plants built in the U.S., surpassing those of both wind and gas plants.[12] Alaska's solar PV resource is similar to that of Germany, which is a major developer of solar PV.[13] Alaska currently has active utitility scale solar PV projects as well as residential and commercial solar PV installations.

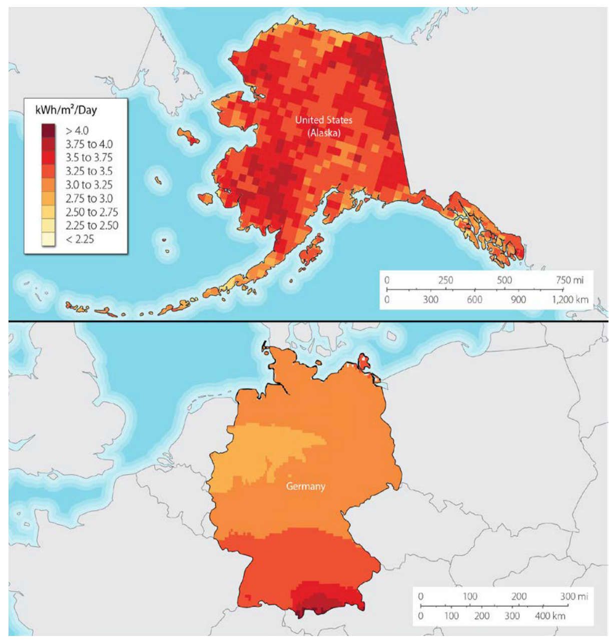



***FIGURE 09***
Solar resource comparison of Alaska and Germany[13]

| TABLE 3. PV Solar | | |
|---|---|---|
| Technology Readiness | TRL 9 | There are active utility solar PV projects in Alaska. |
| AK Scalability | >1GW | Solar PV can be deployed throughout Alaska. |
| Impact Timeline | 0.5 to 2 years | Installations have project timelines around 2 years or less. |
| Commercial Viability | Clear Economics | There are clear economics associated with solar PV with Alaskan projects currently providing power to the Railbelt. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

11 www.irena.org
12 www.eia.gov
13 www.energy.gov

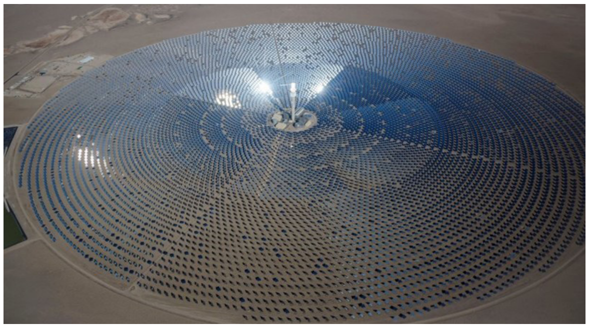


***FIGURE 10***
Example of a Concentrated Solar Project (CSP).[14]

## Concentrated Solar Power

Concentrated Solar Power (CSP), sometimes called concentrated solar thermal, uses reflectors to concentrate the sun's rays on a receiver. Parabolic trough and central power receivers are the two most common CSP technologies in deployment today, although the overall impact of CSP is limited to specific regions. These systems heat fluid (water, molten salt, oils, or other), which is used to generate steam to drive a turbine and generate electricity. CSP has been applied to generate electricity in large scale power plants, remote mining facilities, and other locations with high power or steam load. Typically, areas with annual Direct Normal Irradiance (DNI) solar resources of 2,500 or higher are considered acceptable for CSP development. CSP is not considered to be an applicable technology for Alaska, given its low solar DNI and high seasonal variation of solar resource (see Figure 11). For this reason, a scoring table for CSP is not provided.

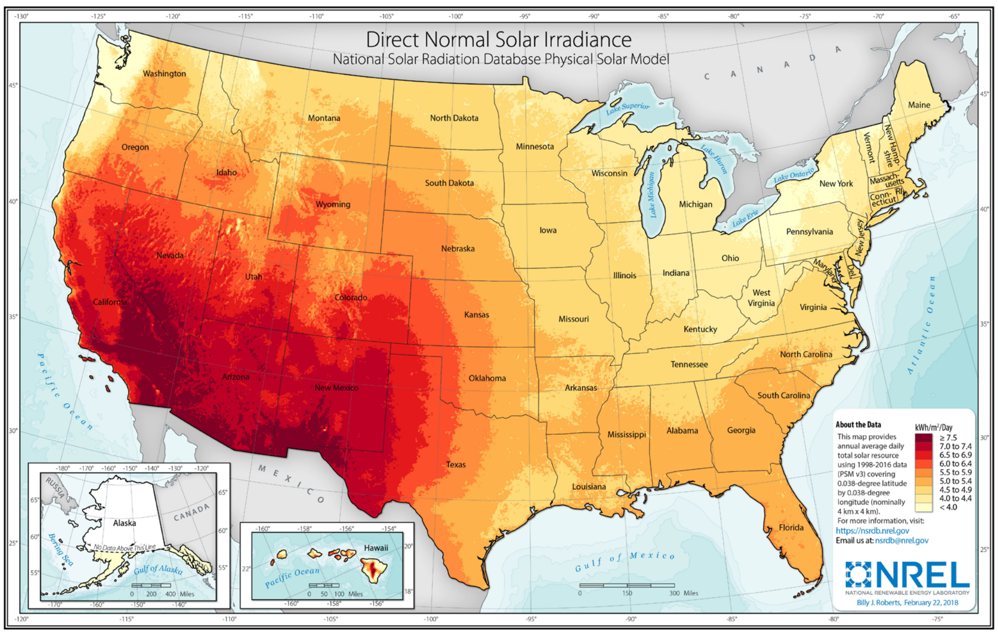



***FIGURE 11***
NREL maps of annual solar Direct Solar Irradiance (DNI) used for CSP applicability.[15]

## Solar Thermal Heating

Solar energy can be captured to generate hot water for residential, commercial, or industrial applications. Solar thermal collectors are used to capture the solar radiation and heat either water or another working fluid for use. Solar thermal collectors for preheating domestic hot water have been used in Alaska to offset energy consumption.

---

14 www.energy.gov
15 www.nrel.gov

*FIGURE 12*
Geothermal power plant in Iceland.[16]

## GEOTHERMAL

Geothermal facilities capture heat derived from the sub-surface of the earth to generate electricity. Typically, water or a brine mixture is used to carry the heat from a deep reservoir to the surface where it either flashes to steam or provides indirect heat to a steam cycle, which generates electricity. Geothermal energy capture technologies include, among others, hydrothermal power and the organic rankine cycle. Within Alaska, potential exists to reuse depleted oil and gas (O&G) wells to create below ground loops using directional drilling to connect nearby wells. Many companies are exploring these opportunities now across the U.S.

### Hydrothermal

Hydrothermal resources are 'conventional' geothermal resources and have naturally occurring heat, fluid, and permeability within the geologic formation. These three factors make it relatively straightforward to extract heat from the formation. High temperature geothermal energy is typically converted to electricity through a standard steam turbine cycle. The hot geothermal fluid is pumped to the surface, used to drive a steam turbine, then pumped back down into the rock formation, making a closed loop.

For electricity generation, a high or medium temperature resource is needed. The resources are usually located close to tectonically active regions. Alaska contains large geothermal resources; however, the locations of these resources are typically not near the required point of use, resulting in high construction and transmission costs.

| **TABLE 4. Geothermal - Hydrothermal** | | |
|---|---|---|
| Technology Readiness | TRL 9 | Geothermal energy is a mature industry. |
| AK Scalability | >1GW | Large geothermal resources exist on the west side of Cook Inlet and in other coastal regions. |
| Impact Timeline | 5 to 10 years | Geothermal projects require time for resource identification and transmission construction. |
| Commercial Viability | Potential Economic Pathway | Large geothermal resources are not road accessible or near load centers, contributing to larger project costs that affect project economics and may require government funding. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

16 https://commons.wikimedia.org/wiki/File:NesjavellirPowerPlant_edit2.jpg#/media/File:NesjavellirPowerPlant_edit2.jpg

## Organic Rankine Cycle

The Organic Rankine Cycle (ORC) is a thermodynamic process used to generate power on a similar principle to the steam cycle that is used in coal, combined cycle, and nuclear power plants. The ORC utilizes a working fluid that has a lower boiling point than water and can therefore make use of a lower temperature heat source to drive the turbine generator.

The ORC has been shown to be an effective power generation technology for heat sources in the 160ºF to 200ºF range, which is suitable for low-grade geothermal heat, reciprocating engine jacket water heat, or other industrial waste heat streams. Heat sources in this temperature range are more likely to be found at shallow depths and closer to population centers than higher temperature geothermal resources that utilize the hydrothermal steam cycle. Alaska's Chena Hot Springs Resort, near Fairbanks, has been operating an ORC geothermal powerplant since 2006. Cordova Electrical currently operates an ORC unit that generates power utilizing waste heat from the main power cycle at the plant.

| **TABLE 5. Geothermal – Organic Rankine Cycle** | | |
|---|---|---|
| Technology Readiness | TRL 8 | ORC technology is available for commercial use from limited number of manufacturers. |
| AK Scalability | 1MW to 100MW | Lower temperature geothermal resources are used. |
| Impact Timeline | 5 to 10 years | Geothermal projects require time for resource identification and transmission construction. |
| Commercial Viability | Potential Economic Pathway | There is a potential economic pathway. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

## HYDRO

Hydropower is energy derived from flowing water. It has been utilized for thousands of years and today is among the most cost-effective means of generating electricity. Whether the water is stored and released in a hydroelectric facility, flowing in a river (hydrokinetic energy), or moving in the ocean's waves and tides, all forms can be used to produce electricity.

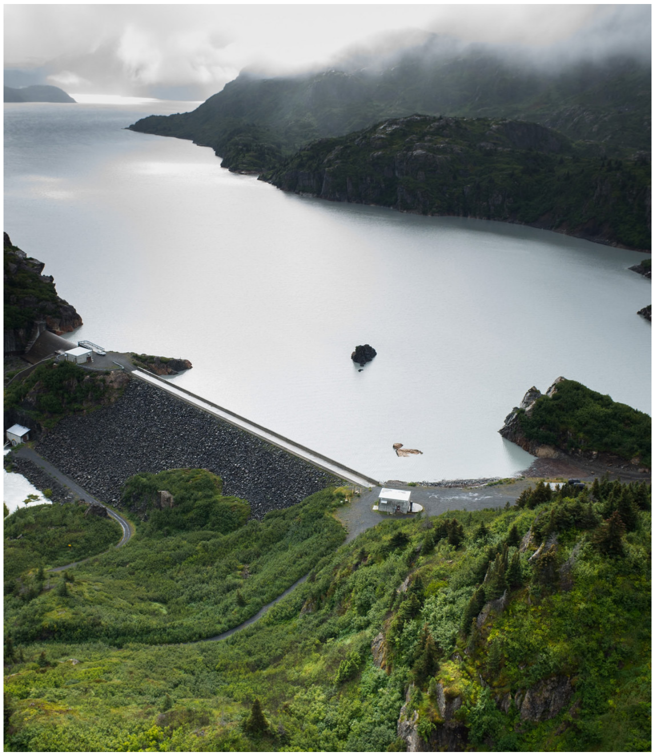


***FIGURE 13***
Bradley Lake Project [19]

### Hydroelectric

In basic form, hydroelectric energy generation utilizes the flow of water to drive turbines to create electricity. Hydroelectric facilities designed with dams and reservoirs store water over periods of time to be released to meet peak energy demands. Hydroelectric without these structures provides smaller scale production, typically from a facility designed to operate in a river without interfering its flow such as river hydrokinetic.[17]

Alaska's climate and topography make it well suited for hydroelectric power. Owned by the Alaska Energy Authority (AEA), the Bradley Lake Hydroelectric Project is the largest hydroelectric facility in the state. This facility generates about 10 percent of the total annual power used by Railbelt electric utilities.[18] Challenges to hydroelectric include environmental impacts such as salmon runs, which must be accounted for and in some areas may increase costs for mitigation.

| TABLE 6. Hydroelectric | | |
|---|---|---|
| Technology Readiness | TRL 9 | Hydroelectric projects of all shapes and sizes exist in Alaska. |
| AK Scalability | >1GW | There are large hydroelectric resources in Alaska and are typically close to point of use. |
| Impact Timeline | 5 to 15 years | Permitting for large scale hydroelectric projects may require longer project timelines. Smaller scale hydroelectric projects may have shorter timelines. |
| Commercial Viability | Potential economic pathway | Large hydroelectric projects may require state or federal funding due to large capital costs. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

17 www.irena.org/hydropower
18 www.akenergyauthority.org
19 www.akenergyauthority.org

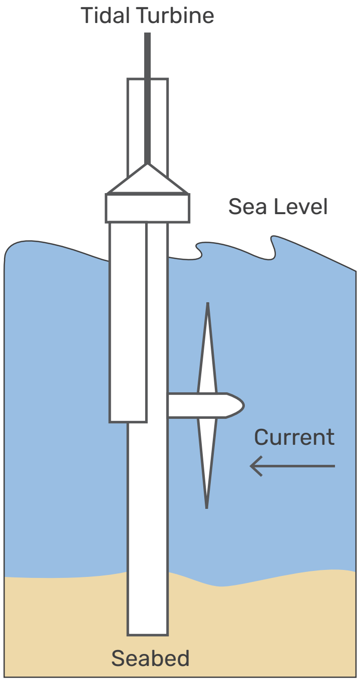



***FIGURE 14***
Tidal Turbine Example.[21] Similar to NYC installed system by Verdant.

## Tidal

Tidal power is produced by capturing the energy associated with the rise and fall of the ocean's tides and converting it to electricity. Technologies either use a dam-like barrage which restricts the flow in and out of an ocean's bay or inlet, or a tidal turbine which can be placed on the sea floor. There are few operating tidal systems in the world; however, in March 2021, Ocean Renewable Power Company (ORPC, Inc.) published plans for a 5 MW pilot project in Cook Inlet with a long-term goal of supplying electricity to HEA. ORPC plans to use a squirrel cage design similar to an existing pilot installation located off the coast of Maine (similar to Hydrokinetics system below).[20] Tidal power technology is currently in a state where multiple manufacturers are working to further develop designs to harness this vast potential energy source.

***FIGURE 15***
Sihwa Lake Tidal Power Station, located in Gyeonggi Province, South Korea, is the world's largest tidal power installation, with a total power output capacity of 254 MW.

| TABLE 7. Tidal | | |
|---|---|---|
| Technology Readiness | TRL 5 to 7 | Few operating tidal systems in the world. |
| AK Scalability | 1 MW to 1 GW | Large resource close to populations centers. |
| Impact Timeline | 5 to 10 years | Technology not fully matured and large permitting timeline. |
| Commercial Viability | Potential economic pathway | Large projects may require state or federal funding due to large capital costs. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |

Some very large systems are in place across the world by creating tidal lagoons (similar to pumped hydro but the tide is used to "pump" the water into the artificial lagoon. The cold winter weather and marine life protections would make these systems more complex in Alaska (ice impacts, salmon, etc.).

20 www.renewableenergymagazine.com
21 www.eia.gov

## Wave

Wave energy is harnessed when converters capture the energy contained in ocean waves and use it to generate electricity. Converters include oscillating water columns that trap air pockets to drive a turbine; oscillating body converters that use wave motion; and overtopping converters that make use of height differences.

Alaska is well suited to this technology, with a longer coastline than the lower 48 states and a large population near the ocean. Although winter ice conditions may be a challenge, many subsea systems which can alleviate surface ice concerns are in review. The large quantity of aquatic animals in Alaska significantly increases permitting and environmental reviews for these systems.

| TABLE 8. Wave | | |
|---|---|---|
| Technology Readiness | TRL 5 to 6 | Few operating systems in the world. |
| AK Scalability | 1 MW to 100 MW | Large resource close to populations centers. |
| Impact Timeline | Beyond 10 years | Technology not fully matured and large permitting timeline. |
| Commercial Viability | Potential economic pathway | Large projects may require state or federal funding due to large capital costs. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Power is generated without directly producing carbon emissions. |


***FIGURE 16***
The ORPC RivGen Power System prior to installation on the Kvichak River in Igiugig, Alaska.[22]

## River Hydrokinetic

Similar in concept to the ocean's tidal power, in-stream energy can be collected from rivers using hydrokinetic devices placed directly in the river current. The devices extract energy from flowing water by using turbines to rotate a shaft and power a generator. Advantages of in-stream hydrokinetic systems (as with tidal energy systems) include predictability and the avoidance of intermittency issues observed with wind and solar. Disadvantages include impacts to the environment and local river ecology.

River hydrokinetic systems could provide options for renewable generation to Alaskan villages, and may be of particular interest to those located off the grid. Costs of electricity in off-grid locations where diesel generators are typically used may be as high as 70 cents per kWh, which may be an order of magnitude higher than other locations.

| TABLE 9. River Hydrokinetic | | |
|---|---|---|
| Technology Readiness | TRL 5, 6 | Smaller pilot project operating in Igiugig, Alaska. |
| AK Scalability | < 1 MW | Impacts from winter weather still being addressed. |
| Impact Timeline | Beyond 10 years | There are large river resources in Alaska and are typically close to point of use (towns) |
| Commercial Viability | Potential economic pathway | Permitting for hydrokinetic projects requires longer project timelines. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Projects may require state or federal funding due to large capital costs. |

22 www.energy.gov

## BIOMASS

Biomass energy is found in organic materials that are burned directly for heat, electricity generation, or converted to renewable liquid and gaseous fuels through various processes. Biomass sources for energy include wood, wood processing wastes, agricultural crops and waste materials, biogenic materials in municipal solid waste and animal manure, and sewage.[23] Biomass energy systems can also be coupled with carbon capture technologies to sequester carbon in the soil (biochar) or geologically.

***FIGURE 17***
Wood Biomass District Heat System in Galena Alaska (Coffman) water vapor exhaust, not smoke.

### Wood Biomass

Alaska is well suited for wood biomass energy utilization as wood biomass such as cord wood, wood chips and wood pellets are currently widely used. A large number of the population lives near wooded areas and land is available to manage forests as a renewable resource. To reduce emissions and particulates in the air, high efficiency boilers are used. These systems can also be used to make steam to generate heat and power.[24]

| TABLE 10. Wood Biomass Energy | | |
|---|---|---|
| Technology Readiness | TRL 9 | There are many small to medium scale operating high efficiency wood boiler systems across Alaska and many utility scale systems throughout the Lower 48. |
| AK Scalability | 1 MW to 1GW | Utility scale is possible. Biomass needs to be supplied to the renewable supply in the geographic area. |
| Impact Timeline | 1-5 years | Project timeline is less than 5 years. |
| Commercial Viability | Potential Economic Pathway | The main driver of wood biomass economics is the comparative cost to heating fuels and locally available sources of feedstocks. |
| Carbon Intensity | Carbon neutral or low carbon | Burning wood produces carbon emissions, however these emissions are non-fossil fuel based and will be recaptured by photosynthesis with sustainable harvesting practices. If combined with Carbon capture utilization and storage (CCUS), it can be carbon negative. |

23 www.nrel.gov
24 www.irena.org

***FIGURE 18***
Anchorage Landfill Gas Power Plant (Coffman).

## Biogas and Renewable Natural Gas

Biogas is produced from various biological sources through a biochemical process, such as anaerobic digestion, or through thermochemical means, such as gasification. The biogas is conditioned and used to generate electricity and heat, which can be used as a replacement for traditional natural gas to generate combined electricity and heating for power plants. Biogas can also be created in landfills and wastewater treatment facilities for energy use.[25]

Renewable natural gas (RNG) is a biogas that has been fully conditioned to pipeline-quality gas that is fully interchangeable with conventional natural gas and can be used to create heat and power.

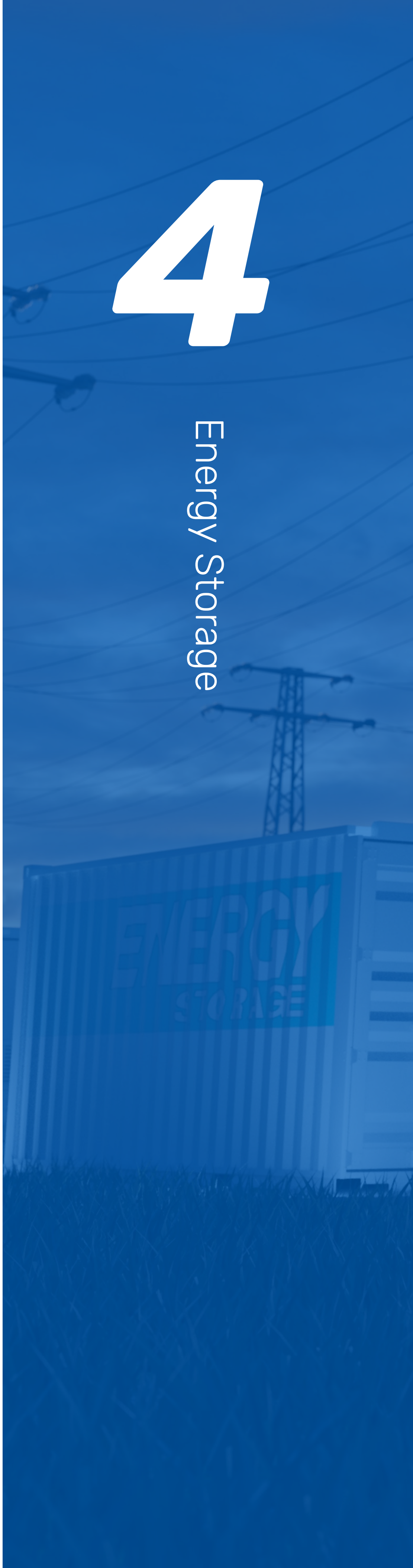
Biogas is already in use in Alaska at the Anchorage Landfill to create power. Utilizing this technology reduces greenhouse gas emissions because the biogas (methane) is burned to create carbon dioxide (a less potent greenhouse gas). Biogas can also be produced using local organic wastes or at wastewater treatment facilities.

| TABLE 11. Biogas and Renewable Natural Gas | | |
|---|---|---|
| Technology Readiness | TRL 9 | Anchorage landfill has a biogas system that creates power. Many other biogas/RNG projects throughout the US. |
| AK Scalability | 1 MW to 1GW | Medium to large scales are possible. |
| Impact Timeline | 1-5 | Project timeline can be less than 5 years |
| Commercial Viability | Clear economics | The main economic driver is the local source of feedstocks. |
| Carbon Intensity | Carbon neutral or low carbon | Reduces greenhouse gas emissions and carbon credits can be created by biogas projects. |

25 https://afdc.energy.gov/

# 4

## Energy Storage



COFFMAN
ENGINEERS

# ENERGY STORAGE

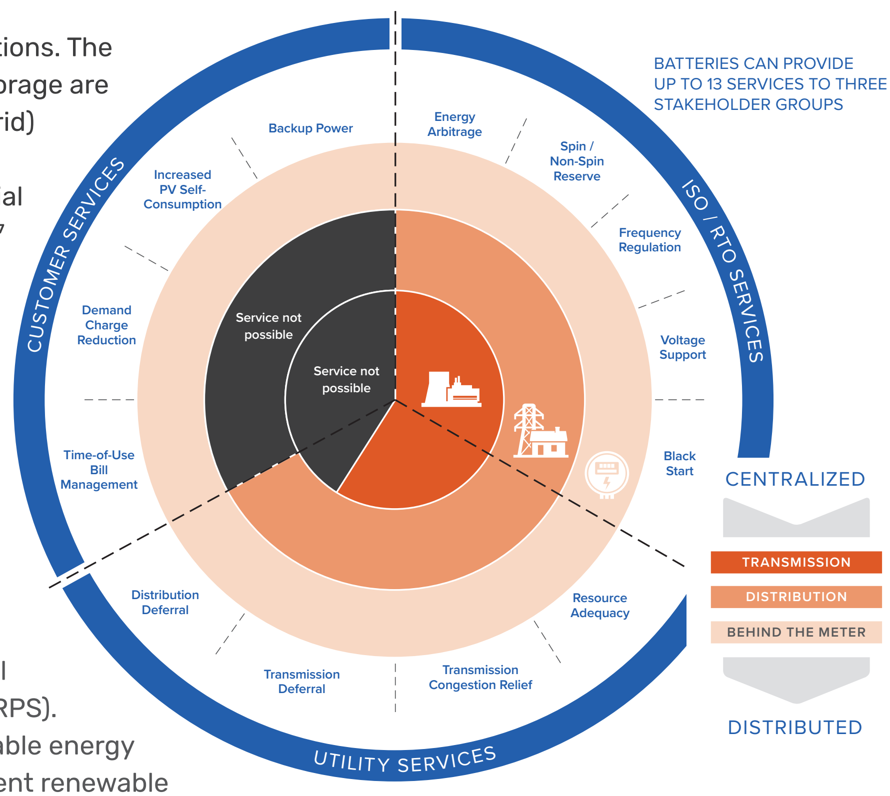
Energy storage devices are used to capture energy produced at one time for planned later use to address imbalance in energy supply and demand. The stored energy can be generated from renewable or non-renewable sources. Energy storage decouples generation and load service, allowing for asynchronous production and dispatch.

For the purpose of this paper, a technology must remove carbon from the cycle to be considered carbon negative. Since energy storage devices are essentially reservoirs of energy, they are considered 'carbon neutral.' Energy storage systems are considered key enablers to greater use of renewable energies, which can have a net overall effect of lowering carbon intensity for a given system.

## TYPICAL MARKET APPLICATIONS

Energy storage has wide ranging applications. The two main market segments for energy storage are mobile (transportation) and stationary (grid) applications. Stationary energy storage applications for residential and commercial customers, as well as utilities, include:[26 27]

- Demand charge reduction.
- Time of Use (TOU) bill reduction.
- Energy arbitrage.
- Resiliency/Back up power.
- Avoided renewable curtailment.
- Resource adequacy.
- Transmission and distribution upgrade deferral.
- Transmission congestion relief.




Credit: Rocky Mountain Institute

Regulated utilities may be obliged to fulfill specific Renewable Portfolio Standards (RPS). Energy storage can enable higher renewable energy penetration when coupled with intermittent renewable generation resources. Additionally, depending on the energy market and regulatory framework, utilities and Independent Power Producers may utilize energy storage assets for revenue generation by offering services including: demand response, frequency regulation, reserve markets, voltage support, and black start capabilities.[28]

26 https://www.nrel.gov
27 https://rmi.org/wp-content
28 www.energy.gov

## ENERGY STORAGE CATEGORIES

Energy storage devices are typically grouped in categories associated with the primary mechanism of energy storage and conversion (see Figure 19 below). Those highlighted light gray will not be addressed in this discussion, as either the TRL is not advanced enough to have significant impact in the next 10 years, or the technology is not applicable to state-of-the-art stationary grid storage due to advancements in superior technologies.

| Electrical | Electro-Chemical | Mechanical | Thermal | Chemical |
|---|---|---|---|---|
| Supercapacitors | Lithium-Ion Batteries | Flywheel | Molten Salt TES | Hydrogen |
| SC magnets | Flow Batteries | Pumped Storage | Cryogenic | Natural Gas |
| | Nickel-Metal Hydride | Compressed Air | Phase Change Materials | Methane |
| | Nickel-Cadmium Batteries | Gravity Systems | | |
| | Sodium-Sulpher Batteries | Buoyancy Systems | | |
| | Lead-Acid Bateries | | | |

***FIGURE 19***
Main categories of energy storage technologies discussed in this paper.

As shown in Figure 20 below, the energy densities and discharge capabilities inherent in each energy storage technology lead to suitability for different applications and use cases. Systems such as supercapacitors with high power capacities, high current, and short discharges, are more suitable to uninterruptible power supply (UPS) and frequency support; whereas pumped hydro with significant energy capacities and scalability allow for bulk storage, peak-shaving, and renewable penetration optimization.

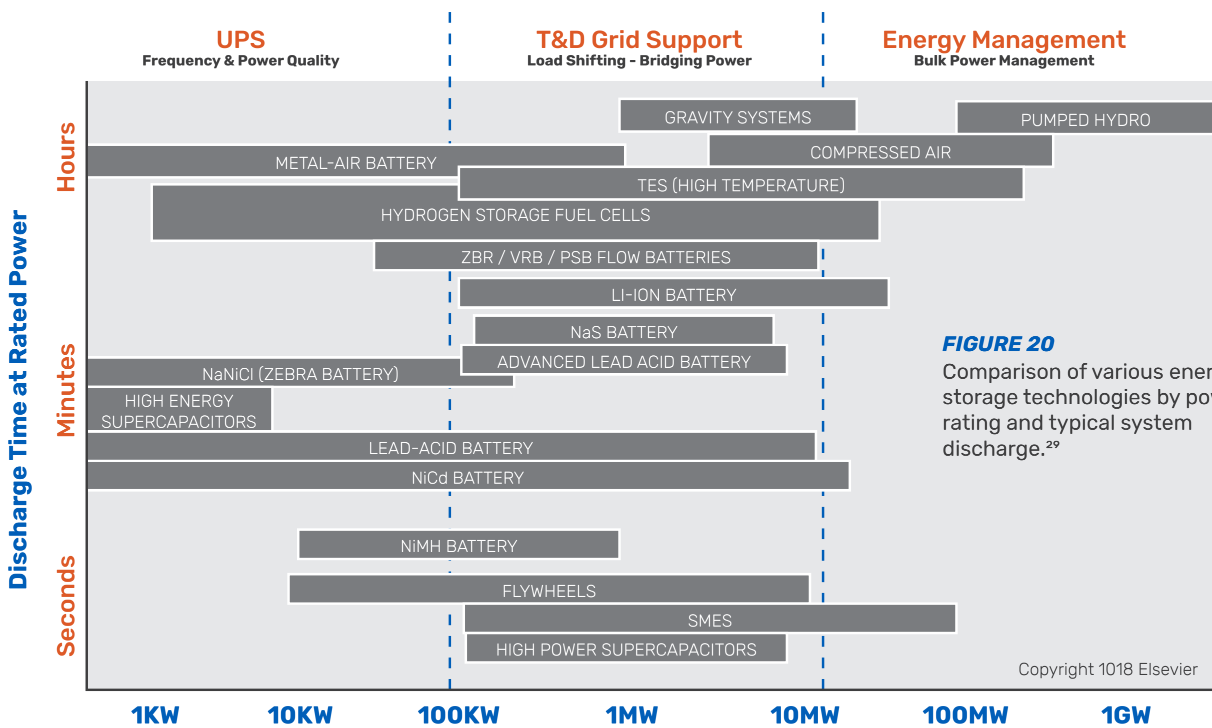



***FIGURE 20***
Comparison of various energy storage technologies by power rating and typical system discharge.[29]

29 www.gwern.net

## ELECTRICAL ENERGY STORAGE

Electrical energy storage systems are characterized by devices using electric principles to capture electrical energy. These include magnets, capacitors, inductors, and other systems utilizing electrons and/or electro-magnetic fields.

### Supercapacitors

Supercapacitors are electrical energy storage devices that store and release energy by reversible adsorption and desorption of ions at the interfaces between electrode materials. They are generally considered simple devices and have high cycling capabilities, are able to operate in a wide temperature range, and can generate high currents. Downsides to supercapacitors include relatively low voltage per cell and overall low energy density, leading to applications that require short bursts of energy such as momentary power backup, regeneration devices, and compensation devices for short term fluctuations in grid voltage. Supercapacitors have limited applicability for Alaskan decarbonization efforts, but may be helpful for specific utilities and others to offset use of carbon fuels in specialized applications.

| TABLE 12. Supercapacitors | | |
|---|---|---|
| Technology Readiness | TRL 9 | Commercial, large-scale capacitors have been in operation throughout the U.S. for decades. |
| AK Scalability | < 1 MW | Limited AK scalability, since capacitors in general are for short duration energy storage. |
| Impact Timeline | 1-5 years | Permitting and construction timelines are typically 6-12 months for most commercial projects. |
| Commercial Viability | Clear Economics | Monetizable through merchant sale, power purchase agreements or other off-take agreements, as well as servicing the ancillary services market. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

## ELECTRO-CHEMICAL

Electro-chemical energy storage devices include rechargeable batteries that convert chemical energy into electrical energy through a reversible oxidation-reduction reaction.

### Lithium-Ion Batteries

In lithium-ion batteries the oxidation-reduction reaction takes place as lithium ions migrate between an anode, and a cathode through a permeable membrane, in the presence of an electrolyte. Lithium ion batteries presently dominate the energy storage sector for stationary applications because they are relatively light weight, have high energy density, are relatively easy to deploy using standard engineering and construction techniques, and can be incorporated into existing grid infrastructure. Lithium-ion battery cells are manufactured in a wide range of shapes and sizes; however, all have a similar setup of being encased in a hermetically sealed pouch or enclosure and contain anode and cathode sheets surrounded by electrolyte.

Most lithium-ion energy storage batteries deployed today for grid storage utilize either Lithium-Iron-Phosphate (LFP) or Lithium-Nickel-Manganese-Cobalt (NMC). NMC typically has a higher energy density than LFP and lower self-heating rate; however, LFP is considered by some to have a slightly better performance on safety factors and cycle duration/lifespan.[30]

30 https://batteryuniversity.com

The smallest unit of a lithium-ion battery is the cell. Cells are usually aggregated together into modules, which are then strung together in racks (see Figure 21 below). In common vernacular, the term “battery” may be used to refer to any of these components.

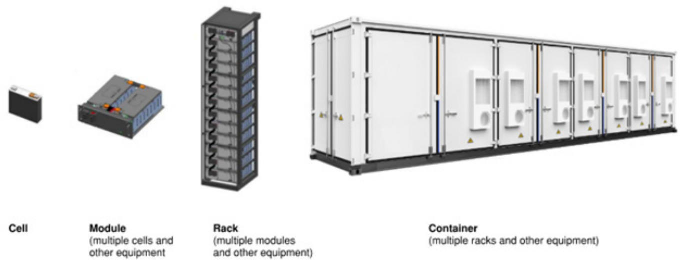



***FIGURE 21***
Comparison of various energy storage technologies by power rating and typical system discharge.

Individual Battery Energy Storage System (BESS) facilities range in size from 500kW to over 1GW and typically have a discharge duration between 1 and 4 hours at their rated power. Systems are housed and deployed in buildings, containers (e.g. steel-frame) or outdoor enclosures. Each structure type has its own set of advantages and disadvantages related to operations and maintenance, energy density per unit area, serviceability, permitting, construction cost, thermal management, and augmentation plans.

Lithium-ion batteries may be deployed for grid storage in Alaska at multiple locations, including:

- Substations.
- Power plants.
- Commercial and industrial locations.
- Military installations.
- Residential buildings.
- Renewable generation facilities.
- Campuses (educational/healthcare).

| TABLE 13. Lithium-Ion Batteries | | |
|---|---|---|
| Technology Readiness | TRL 9 | Commercial, utility scale lithium-ion installations are in Alaska and throughout the US. |
| AK Scalability | >1GW | Can be deployed at multiple substations, power plants, and other sites totaling in the GW range. |
| Impact Timeline | 1-5 years | Permitting and construction timelines are typically 12-26 months for most commercial projects. |
| Commercial Viability | Clear Economics | Monetizable through merchant sale, power purchase agreements or other off-take agreements, as well as servicing the ancillary services market. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

## Flow Batteries

Flow batteries, also called reduction-oxidation flow batteries (redox, RFB), are a type of electro-chemical storage technology in which an electrolyte fluid is pumped from tanks in close proximity to another fluid or component. The electrolyte is pumped through an electrochemical cell from one or more tanks, and typically separated by an ion-selective membrane. The electrolyte gains or loses electrons to the other liquid through the membrane as power is either applied (charging) or generated (discharged), changing the oxidation state in compounds contained in the electrolyte.

The most common flow batteries are vanadium, iron-chromium, and zinc-bromine. Vanadium redox flow batteries (VRFB) are the most widely deployed flow batteries and have specific advantages such as a relatively high cycle capability. Currently, flow batteries are considered suitable for deployment of long duration energy storage (LDES) or multi-day storage. Flow batteries can have strong applicability and scalability in Alaska, given LDES will likely be a key component in successful deployment of renewable and low-carbon fuels.

| TABLE 14. Flow Batteries: At a Glance | | |
|---|---|---|
| Technology Readiness | TRL 6-7 | One large-scale demonstration plant, multiple modular systems, but no large-scale commercial applications. |
| AK Scalability | 1 MW to 100 MW | Likely can be deployed to levels up to 100MW, and recent advancements in chemistries allow for operation to lower temperatures than previous. |
| Impact Timeline | 3 to 10 years | Longer permitting and development timeline due to large scale and size of projects. |
| Commercial Viability | Potential Economic Pathway | Flow batteries are best suited for LDES, which may not be economical for all markets without subsidy. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

## MECHANICAL

Mechanical energy storage systems leverage gravity, rotational inertia, and other mechanical characteristics to shift between potential and kinetic energy.

### Flywheel

Flywheel Energy Storage (FES) is a mechanical method of storing rotational energy in a cylindrical rotor (flywheel) that is spinning at a very high speed. Rotors typically spin in a vacuum enclosure to reduce friction and thus minimize losses. Advanced FES systems utilize high strength rotors with magnetic bearings and can spin up to 50,000 RPM. Electric motors are typically used to accelerate the flywheel to speed during charging, and the spinning flywheel is used to rotate a generator when discharging, producing electricity.

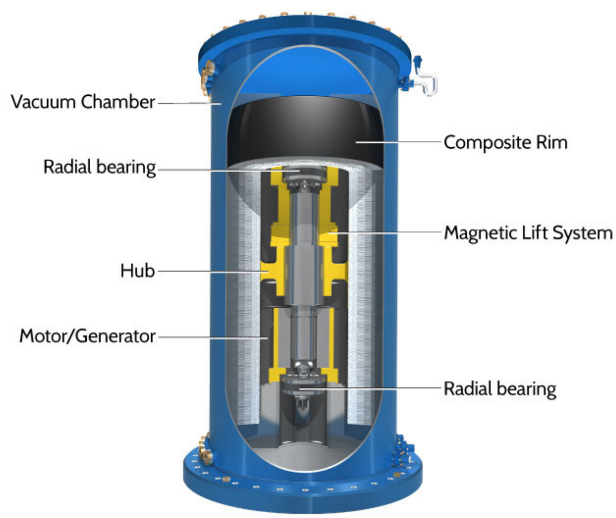



***FIGURE 22***
Beacon Power BP400 flywheel cutaway. [31]

When applied to grid storage, FES are typically used for spinning reserve and momentary grid frequency regulation. Such energy storage configurations are typically for short duration discharge, for instance 5MWh (20MW over 15 minutes); however, FES have also been deployed in 4-hour configurations, FES is a mature technology that can be readily deployed in Alaska for frequency regulation, voltage support, spinning reserve, and other short-duration ancillary services. Overall scalability is likely mid-range, since the inherent characteristics of flywheels (lower energy density) lend themselves toward short duration energy storage.

Flywheels are currently in use in Alaska at both the Chugach power plant in Anchorage and near the Port in Kodiak. They have been providing grid support services for large electric cranes and wind farms, as well as supporting other grid outage events to limit overall impacts to the grid.

31 https://energystorage.org

| TABLE 15. Flywheels (FES) | | |
|---|---|---|
| Technology Readiness | TRL 6 to 9 | Widescale commercial deployment of flywheels by utilities for black start, frequency regulation, and voltage control. |
| AK Scalability | 1MW to 100 MW | Flywheels are power-oriented and are for short durations of high power reserves. Large scale deployment depends on specific markets. |
| Impact Timeline | 1-5 years | Permitting and construction timelines are typically 6-24 months for most commercial projects. |
| Commercial Viability | Potential Economic Pathway | Economics depend on specific application and regulatory environment. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

## Pumped Storage Hydropower

A type of mechanical energy storage, pumped storage hydropower (PSH) represents approximately 95% of utility-scale energy storage capacity in operation in the United States, leveraging the principles of hydroelectric power generation discussed above.[32] PSH facilities store potential energy in water which has been raised to a height and contained in one of two reservoirs, and convert this energy to electricity by releasing the water to a second reservoir at a lower elevation (and through hydroelectric generating turbines). During off-peak hours, low-cost or surplus energy is used to pump water back up to the higher elevation reservoir for storage.

***FIGURE 23***
La Muela 1,772 MW pumped storage hydro plant in Valencia, Spain.[33]

This storage technology has been used for decades in power plants across the world to allow generation at peak times. PSH facilities coupled with renewable energy facilities such as wind or solar can facilitate increased renewable penetration by utilizing curtailed renewable power for pumping water to the upper reservoir, similar to producing green hydrogen. Two main types of PSH exist: open loop and closed loop systems. Open loop PSH systems have an ongoing hydrologic connection to a natural body of water with natural inflows and outflows. Closed loop systems are not connected to a naturally flowing water source or system.

Some sources estimate Alaska has hundreds of possible hydroelectric sites with more than 4.7 GW of potential power, which is about ten times greater than the current installed Alaska hydroelectric capacity.[34] When coupled with renewable generation sources such as wind, PSH could provide a significant impact on carbon negative energy generation in Alaska.

| TABLE 16. Pumped Hydro | | |
|---|---|---|
| Technology Readiness | TRL 9 | Advanced and operating across the world all shapes and sizes. |
| AK Scalability | >1GW | Large resources exist in Alaska for pumped hydro. |
| Impact Timeline | 5-10 years | Longer impact timeline due to project permitting. |
| Commercial Viability | Potential economic pathway | Potential economic pathway but will require government loan support, due to long payback period. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

32 www.energy.gov
33 www.enr.com
34 www.hydroreview.com

## Compressed Air

Compressed Air Energy Storage (CAES) is a type of mechanical storage where compressed air or other gas is stored and then released later for power by running it through a turbine. According to the ideal gas law, the temperature of the gas increases when compressed, and decreases when allowed to expand. How this head of compression is handled comprises the main differentiating factor in the types of CAES configurations. Air storage vessels are either constant volume or constant pressure. Constant volume systems include mined caverns, above ground vessels, aquifers, and tanks. Constant pressure storage includes underwater pressure vessels, hybrid pumped hydro-CAES tanks, and other systems.

CAES may be deployed in Alaska with a small but realized carbon reduction impact if coupled with renewable energy sources. CAES has less limiting geographical factors than other potential energy storage technologies.


***FIGURE 24***
Hydrostor 2.2MW / 200MWh A-CAES facility in Goderich, Canada.[35]

| TABLE 17. Compressed Air: At a Glance | | |
|---|---|---|
| Technology Readiness | TRL 6-8 | Less than 10 large-scale (1MW or larger) systems in operation for less than 5 years. |
| AK Scalability | 1MW-100 MW | Mid-range scalability. Applicability dependent on ability to develop underground cavern. |
| Impact Timeline | 1-5 years | Relatively standard permitting and construction timelines. |
| Commercial Viability | Potential Economic Pathway | Economic pathway depends on application, coupled generation source, and regulatory environment. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

35 www.hydrostor.ca

## Gravity Systems

Gravitational energy is considered an emerging technology which includes systems with stacked blocks or weights suspended from cables. In essence this is very similar to pumped hydro, using solid components instead of flowing water. When energy is either readily available or inexpensive, the potential energy of these blocks is increased by raising them to a height, and when energy is in demand the blocks are lowered while turning a generator to produce power.

Large scale commercial deployment is likely limited in regions characterized by significant seismic activity. Full carbon intensity evaluations may indicate less than ideal overall life cycle carbon neutrality, if the weights are made of newly cured concrete. Three utility-scale gravity projects were recently announced, each approximately 500MW in capacity, in Louisiana, Ohio, and British Columbia.[36] In Alaska, gravitational energy storage systems may require special design considerations due to the region's seismic zone.

***FIGURE 25***
The Energy Vault system from fully charged (left) to fully discharged (right) by lowering blocks.[37]

| TABLE 18. Gravity Systems: At a Glance | | |
|---|---|---|
| Technology Readiness | TRL 5 to 7 | Only two prototype systems built in the last year. |
| AK Scalability | < 1MW | Scalability may be limited due to seismic considerations in AK. |
| Impact Timeline | 1-5 years | Permitting and construction techniques appear standard. |
| Commercial Viability | Potential Economic Pathway | Economic pathway depends on application, coupled generation source, and regulatory environment. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Energy storage is carbon neutral. |

36 www.pv-magazine.com
37 https://newatlas.com/

## THERMAL

Thermal energy storage (TES) technologies include systems where heat (sensible or latent) can be either absorbed or released from a material, sometimes changing the phase of the material.

***FIGURE 26***
A direct Molten Salt Tower Receiver (MSTR) used for CSP with molten salt storage tanks and power block at the Crescent Dunes plant in Nevada.[38]

### Molten Salt TES

Molten salt TES involves an ionic salt which is solid at room temperature, has the appearance and viscosity of water when melted, and remains stable at temperatures beyond 550ºC (over 1000ºF). Molten salt TES systems have been commercially deployed at nuclear power plants and also have applications for Concentrated Solar Power (CSP) generating plants and LDES facilities. This energy storage technology is matched to these generating facilities due to the high temperatures involved.

When applied to CSP renewable energy generation, molten salts are heated either via a Molten Salt Receiver (MSR), parabolic collector, or secondary heat exchanger, and pumped to a nearby tank for storage. When power is to be generated, the heated salt is pumped through a steam generator, and the steam is routed to a steam turbine for power generation.

Given thermal losses and overall plant efficiencies can be optimized at larger scale, the inherent characteristics of molten salt TES systems (e.g. higher temperatures, thermal mass, steam turbine generator) favor longer-duration storage configurations (8+ hours) and baseload operation. It is unlikely molten salt storage would successfully be applied to a CSP facility in Alaska, but may have other applications in the state where high temperatures are present. A scoring table is not included for TES due to it’s low applicability to Alaska at this time.

## CHEMICAL

Energy can be stored in chemical form such as liquid or gaseous fuels that can be converted at a later time to mechanical, electrical, or thermal energy.

### Hydrogen

See hydrogen section for hydrogen storage.

### Natural Gas

Natural gas can be stored in depleted subsurface reservoirs for use during peak times. Cook Inlet Natural Gas Storage Alaska (CINGSA) located in Kenai, is an example of gas storage used to provide higher gas flows during peak winter loads due to the declining natural gas pressures in Cook Inlet. Additional gas storage could be added in Cook Inlet if needed, to provide additional gas flows during peak times.

***FIGURE 27***
Natural gas storage facility in Kenai, AK.[39]

| TABLE 19. Natural Gas Storage: At a Glance | | |
|---|---|---|
| Technology Readiness | TRL 9 | CINGSA project completed in Alaska. |
| AK Scalability | 1MW–1GW | Storage volume depends on available reservoirs. |
| Impact Timeline | 1-5 years | CINGSA was formed and built in ~2 years |
| Commercial Viability | Potential Economic Pathway | CINGSA required government legislation and a tariff for gas storage. |
| Carbon Intensity | Significant Carbon emissions | Natural Gas is combusted by customers, which results in carbon emissions. |

38 http://energystoragereport.info/
39 https://cingsa.com/about-cingsa/

# 5

## Hydrogen


COFFMAN ENGINEERS

# HYDROGEN

Colorless, odorless, tasteless, non-toxic, and highly combustible, hydrogen is the most abundant chemical substance in the universe, constituting roughly 75% of all normal matter. Hydrogen is low energy density by volume but by weight it is very energy dense.

Unfortunately, hydrogen does not occur in large quantities in its purified gas state; it must be separated (aka produced) from either fossil fuels, water, or biomass. Technologies to produce hydrogen from fossil fuels and water are described below. Equally technically important and challenging are the means of transporting and storing hydrogen.

The "Hydrogen Economy" has been a concept for over 50 years but has recently experienced a rapid growth period with 300-500+ projects in development depending on information source with new projects being announced almost daily. Europe is a global leader, but America has seen a tremendous expansion following the passage of the Infrastructure Investment and Jobs Act with a focus on hydrogen hub development.

## TYPICAL MARKET APPLICATIONS

The current market for hydrogen is primarily heavy industrial applications such as petrochemical with hydrocracking and fertilizer production. There has been decades of research and development in hydrogen fuel cell for transportation. Hydrogen is an energy carrier seen as a key fuel to decarbonize medium to heavy transport, rail, aviation, steel making, ammonia / fertilizer, synthetic fuels, long term energy storage from renewables, and the power sector. Hydrogen as a fuel source can be mixed into natural gas pipeline systems up to ~15% without requiring equipment upgrades.[40]

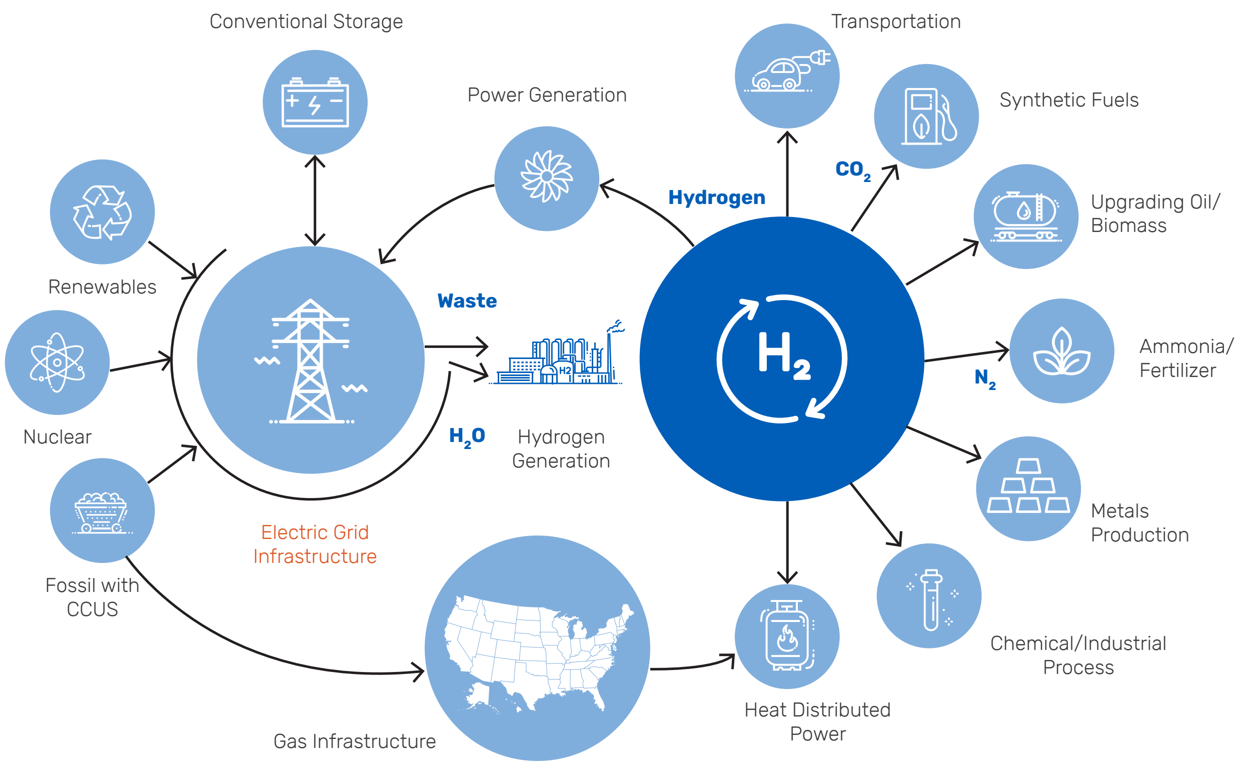



***FIGURE 28***

CCUS: Carbon Capture, Utilization, and Storage[41]

40 https://www.nrel.gov

41 www.energy.gov

## COLORS OF HYDROGEN

The “colors of hydrogen” is a useful tool to connect the technology used to isolate hydrogen and the technology’s relative carbon intensity. For example, electrolysis isolates (or produces) hydrogen through the use of electricity, but the electricity source may be from nuclear, low intensity renewables, or a high intensity coal plant.

| | TERMINOLOGY | TECHNOLOGY | FEEDSTOCK / ELECTRICITY SOURCE | GHG FOOTPRINT |
|---|---|---|---|---|
| PRODUCTION VIA ELECTRICITY | Green Hydrogen | Electrolysis | Wind, Solar, Hydro, Geothermal, Tidal | Minimal |
| | Purple/Pink Hydrogen | | Nuclear | |
| | Yellow Hydrogen | | Mixed-origin grid energy | Medium |
| PRODUCTION VIA FOSSIL FUELS | Blue Hydrogen | Natural gas reforming + CCUS<br>Gasification + CCUS | Natural gas, coal | Low |
| | Turquoise Hydrogen | Pyrolysis | Natural gas | Solid carbon (by-product) |
| | Grey Hydrogen | Natural gas reforming | | Medium |
| | Brown Hydrogen | Gasification | Brown cool (lignite) | High |
| | Black Hydrogen | | Black coal | |

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

***FIGURE 29***

An Illustrative Hydrogen Color Spectrum[42]

## HYDROGEN TECHNOLOGY CATEGORIES

The table below outlines the different technologies covered in this paper for hydrogen production and storage.

| Production from Fossil Fuels | Production from Water | Storage |
|---|---|---|
| Steam Methane Reforming (SMR) | PEM Electrolysis | Compressed Gas |
| Auto Thermal Reforming (ATR) | Alkaline Electrolyzers | Cyro/Compressed Gas |
| Pyrolysis | Solid Oxide Electrolyzers | Liquid Hydrogen |
| Partial Oxidation | | Ammonia |
| Gasification | | Methanol |

42 https://globalenergyinfrastructure.com

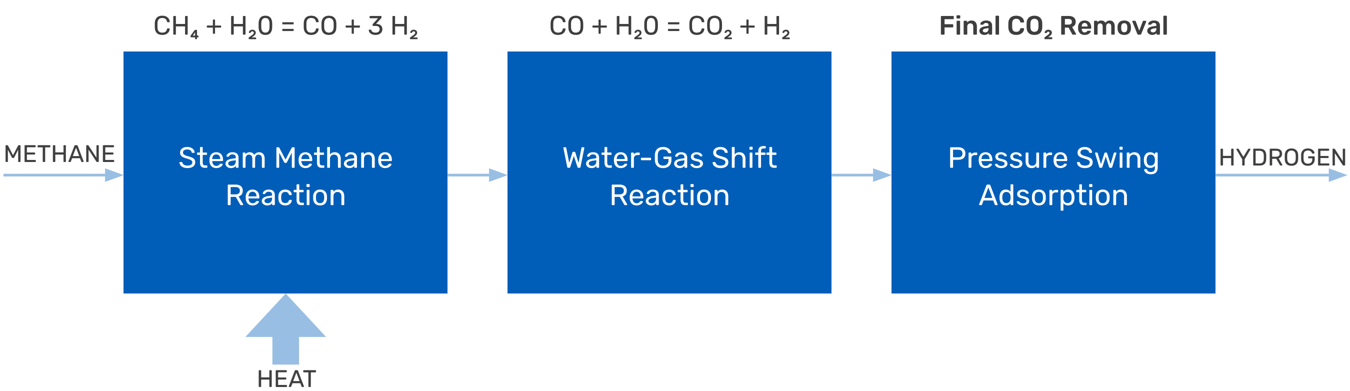
## HYDROGEN FROM FOSSIL FUELS

Natural gas is currently the primary source of hydrogen production, accounting for around three quarters of the annual global dedicated hydrogen production.

A methane reformer is a device based on steam reforming, autothermal reforming or partial oxidation and is a type of chemical synthesis which can produce pure hydrogen gas from methane using a catalyst. There are multiple types of reformers in development but the most common are steam methane reforming (SMR) and autothermal reforming (ATR). Most methods work by exposing methane to a catalyst (usually nickel) at high temperature and pressure.[43] Hydrogen can also be made from pyrolysis from natural gas.

### Steam Methane Reforming

Steam Methane Reforming (SMR) is the dominant production method of hydrogen today. The process uses high-temperature steam to produce hydrogen from methane. The methane reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Heat must be applied to the process for the reaction to occur. A Water-Gas shift reaction follows to create additional Hydrogen followed by a Pressure Swing Adsorption step to create high purity Hydrogen. A very simplified process flow is seen below.



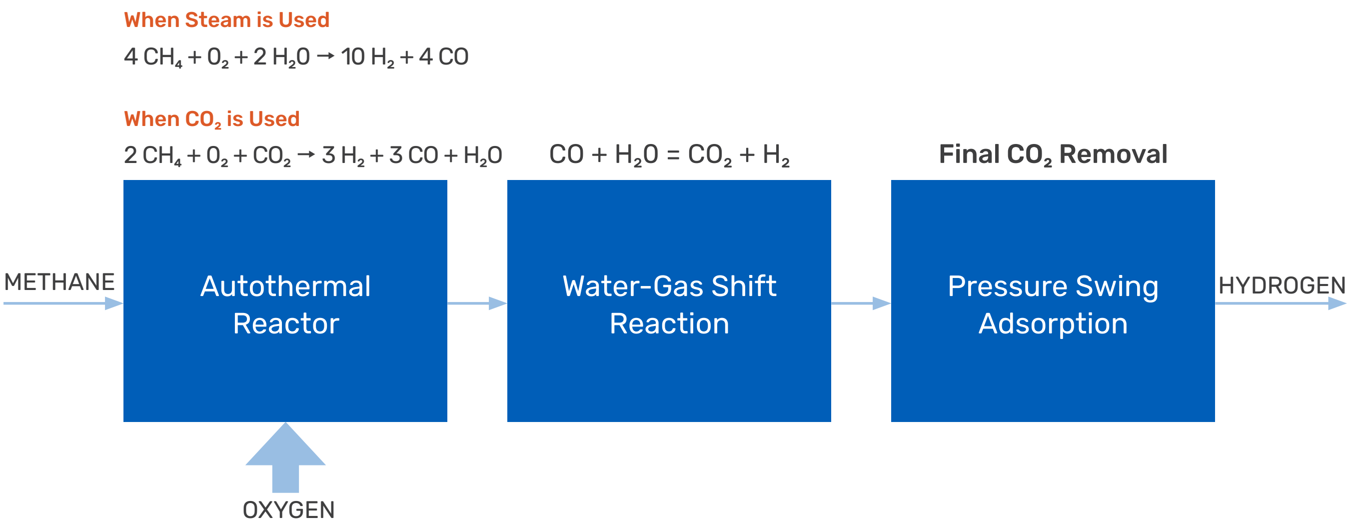

In order for this process to be considered low carbon hydrogen, the carbon dioxide must be captured with Carbon Capture Utilization & Storage (CCUS). Alaska has a large natural gas resource with excellent geology for storing carbon dioxide in depleted oil and gas fields, saline aquifers, and coal bed methane.

| TABLE 20. Steam Methane Reforming | | |
|---|---|---|
| Technology Readiness | TRL 9 | Commercial hydrogen production is existing at the Kenai refinery. |
| AK Scalability | >1GW | AK has large north slope stranded gas and excellent geology to store captured $CO_2$. |
| Impact Timeline | 10+ years | Large gas supplies would likely be either new discoveries or north slope gas needing a pipeline infrastructure. |
| Commercial Viability | Marginal | SMR is one of the cheaper forms of hydrogen production but Alaska would be a limited market and natural gas would be cheaper for heating or power generation unless there is a carbon tax. In order to be low carbon, the CCUS cost needs to be considered. Cost of methane is a major factor in this process. |
| Carbon Intensity | Low Carbon | In order for SMR Hydrogen to be low carbon, it would have to be designed with CCUS, source incremental power requirements with renewables, and the natural gas would need to have no leaks in the supply chain. |

43 https://en.wikipedia.org/wiki/Methane_reformer

## Autothermal Reforming

Autothermal reforming (ATR) uses oxygen and carbon dioxide or steam in a reaction with methane to form hydrogen. An ATR requires oxygen normally produced with an air separation unit which can be capital and energy intensive.




| TABLE 21. Autothermal Reforming | | |
| --- | --- | --- |
| Technology Readiness | TRL 9 | Many commercial ATR units are in operation. |
| AK Scalability | >1GW | AK has large north slope stranded gas and excellent geology to store captured $CO_2$. |
| Impact Timeline | 10+ years | Large gas supplies would likely be either new discoveries or north slope gas needing a pipeline infrastructure. |
| Commercial Viability | Marginal | ATR is one of the cheaper forms of hydrogen production but Alaska would be a limited market and natural gas would be cheaper for heating or power generation unless there is a carbon tax. In order to be low carbon, the CCUS cost needs to be considered. Cost of methane is a major factor in this process. |
| Carbon Intensity | Carbon Neutral / Low Carbon | In order for ATR Hydrogen to be low carbon, it would have to be designed with CCUS, source incremental power requirements with renewables, and the natural gas would need to have no leaks in the supply chain. |

## Pyrolysis

Pyrolysis is the thermal decomposition of materials at elevated temperatures in the absence of oxygen. In the case of methane, that thermal decomposition results in hydrogen and solid black carbon. The solid carbon could potentially be used in soil enhancement, carbon based composite buildings, carbon fiber, plastic, or stored as a solid.

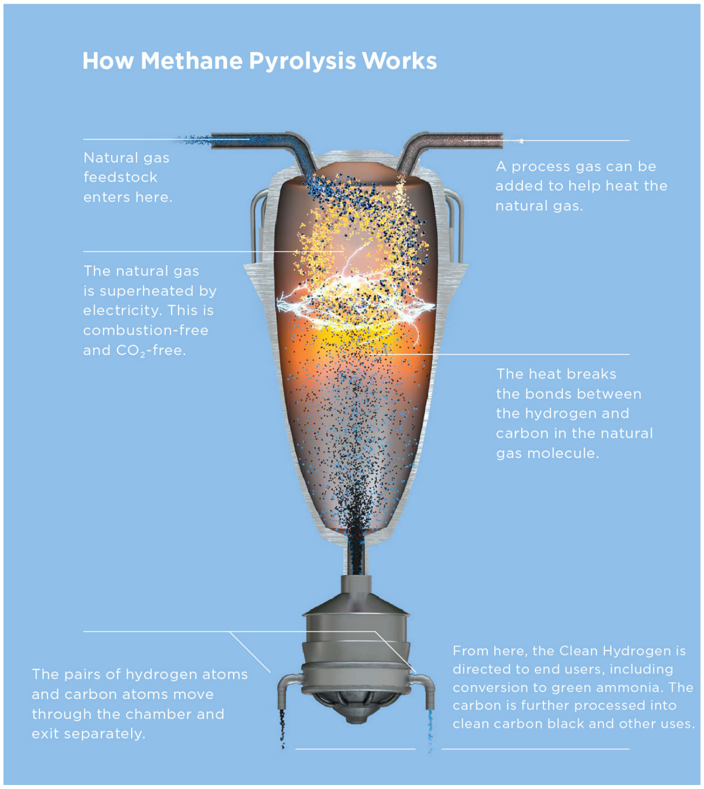



***FIGURE 30***
How methane pyrolysis works[44]

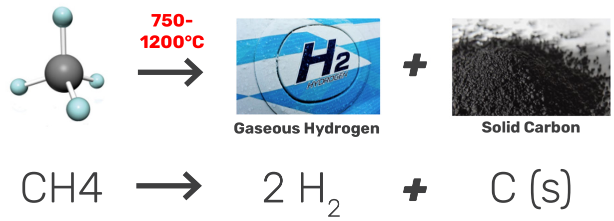



***FIGURE 31***
Methane Pyrolysis[45]

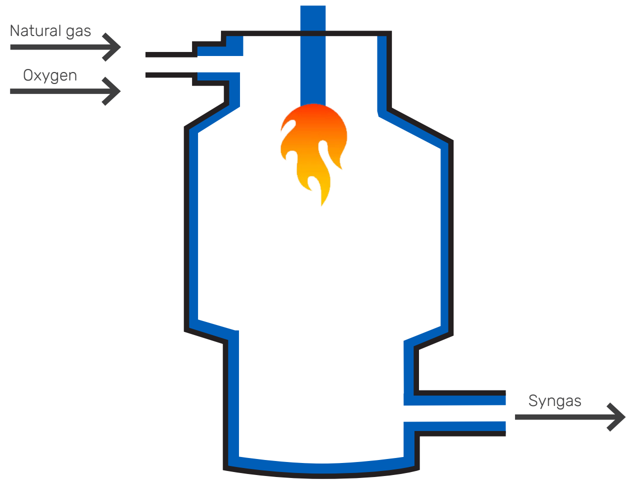
| TABLE 22. Pyrolysis | | |
|---|---|---|
| Technology Readiness | TRL 5-9 | Pyrolysis is a well established technology but only one hydrogen commercial plant exists in Nebraska. |
| AK Scalability | >1GW | AK has large north slope stranded gas. |
| Impact Timeline | 10+ years | Large gas supplies would likely be either new discoveries or north slope gas needing pipeline infrastructure. |
| Commercial Viability | Marginal | Due to the large amount of electricity consumption, the cost of electricity is a driving factor for commercial viability. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Pyrolysis produces carbon in solid form as part of the process. Methane would need to have no leaks in the supply chain. |

44 https://monolith-corp.com
45 www.energy.gov

## Partial Oxidation

Partial oxidation is a mature process in which fuel is burned with limited oxygen. Fuels for this process could be heating oil, natural gas, bio-mass, coal, or any hydrocarbon fuel.

$$C_nH_m + \frac{n}{2}O_2 \rightarrow nCO + \frac{m}{2}H_2$$




| TABLE 23. Partial Oxidation | | |
|---|---|---|
| Technology Readiness | TRL 9 | Partial oxidation is a well established process dating to the 1940s. |
| AK Scalability | >1GW | AK has large north slope stranded gas and coal. |
| Impact Timeline | 5-10 years | Existing coal mining from Healy or biomass is readily available. |
| Commercial Viability | Marginal | The feedstock cost is a major driver for the product cost of the syngas. The market for syngas depends on local use cases. |
| Carbon Intensity | Carbon Neutral / Low Carbon | In order for partial oxidation to be low carbon, it would have to be designed with CCUS, source incremental power requirements with renewables, and the natural gas would need to have no leaks in the supply chain. |

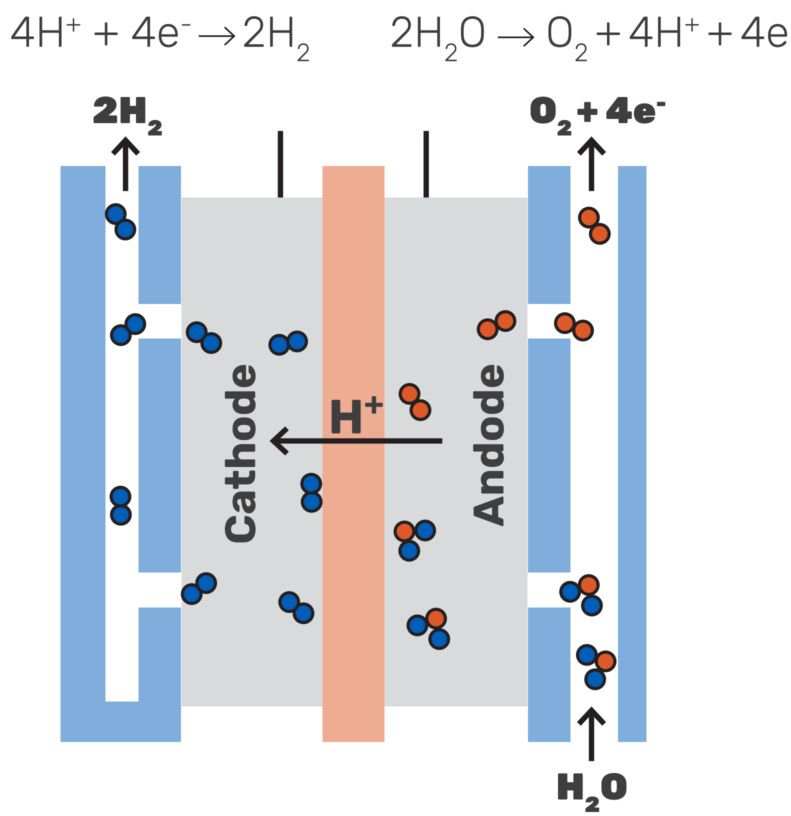
## HYDROGEN FROM WATER

Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment that is well-suited for small-scale distributed hydrogen production to large-scale central production facilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

Like fuel cells, electrolyzers consist of an anode and a cathode separated by an electrolyte. As discussed below, electrolyzer technologies function in different ways, mainly due to the different type of electrolyte material involved and the ionic species it conducts.[46]

### PEM Electrolyzers

In a polymer electrolyte membrane (PEM) electrolyzer, the electrolyte is a solid specialty plastic material. Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons). The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode. At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas.




| TABLE 24. PEM Electrolyzers | | |
|---|---|---|
| Technology Readiness | TRL 7-9 | Commercial hydrogen production from PEM electrolyzers has been recently constructed in Canada, USA, and Europe |
| AK Scalability | >1GW | AK has renewable potential. |
| Impact Timeline | <5 years | PEM packaged units are generally 18-24 months from order. |
| Commercial Viability | Market exists but production cost is a barrier | Asia market if very robust for hydrogen and could be a replacement for natural gas in Alaska for power and heating. |
| Carbon Intensity | Carbon Neutral / Low Carbon | The production of hydrogen from PEM electrolyzers is zero carbon if electricity is sourced from renewables. |

46 www.energy.gov

### Alkaline Electrolyzers

Alkaline electrolyzers operate via transport of hydroxide ions (OH-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode side. Electrolyzers using a liquid alkaline solution of sodium or potassium hydroxide as the electrolyte have been commercially available for many years. Newer approaches using solid alkaline exchange membranes (AEM) as the electrolyte are showing promise on the lab scale.[47]

| TABLE 25. Alkaline Electrolyzers | | |
|---|---|---|
| Technology Readiness | TRL 8-9 | Commercial hydrogen production from Alkaline electrolyzers has been recently constructed in Europe. |
| AK Scalability | >1GW | AK has large renewable potential. |
| Impact Timeline | <5 years | Alkaline packaged units are generally 18-24 months from order. |
| Commercial Viability | Market exists but production cost is a barrier | Asia market if very robust for hydrogen and could be a replacement for natural gas in Alaska for power and heating. |
| Carbon Intensity | Carbon Neutral / Low Carbon | The production of hydrogen from Alkaline electrolyzers is zero carbon if electricity is sourced from renewables. |

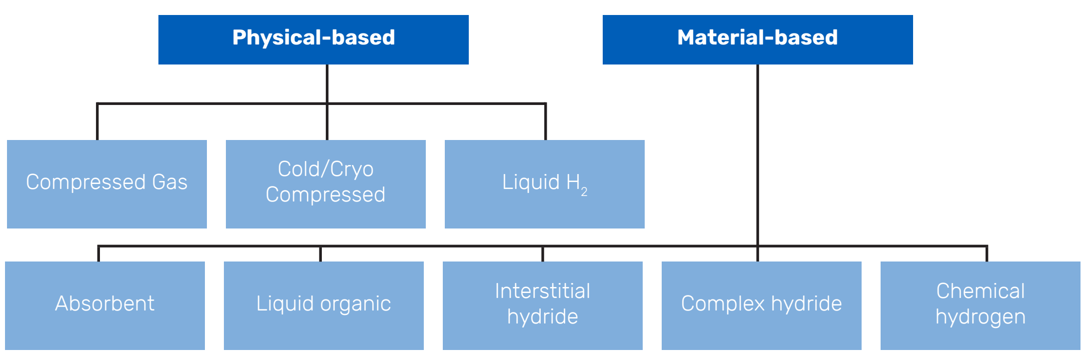
## HYDROGEN METHODS FOR STORAGE, TRANSPORT, AND USE AS A FUEL SOURCE

Hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density.

Hydrogen can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks ( 5,000–10,000 psi tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C (colder than -400°F). Storing between liquid and gas is generally an economic and engineering trade off analysis with lower pressures to store larger volumes at colder temperatures with associated engineering and material challenges. Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption) but this is an area of low technology readiness.

The physical storage of hydrogen can be done in various forms; salt caverns, pipelines, high pressure storage tanks either vertical or horizontal. It may also be stored and transported in ammonia and methanol discussed in sections below, which may also be used as fuel sources as a substitute for natural gas.

### HOW IS HYDROGEN STORED?




47 www.energy.gov

## Ammonia

Ammonia is produced in the Haber-Bosch process where hydrogen is mixed with nitrogen and processed at high temperature and pressure with a catalyst to produce ammonia. The most common uses of ammonia are in the production of fertilizers, as a refrigerant and to make plastics and other products.[48]

Ammonia can capture, store, and ship hydrogen for use in emission-free fuel cells and turbines. Efforts are also underway to combust ammonia directly in power plants and ship engines. Ammonia has a higher energy density, at 12.7 MJ/L, than even liquid hydrogen, at 8.5 MJ/L. Liquid hydrogen has to be stored at cryogenic conditions of −253 °C, whereas ammonia can be stored at a much less energy-intensive −33 °C. And ammonia, though hazardous to handle, is much less flammable than hydrogen.[49]

| TABLE 26. Ammonia | | |
|---|---|---|
| Technology Readiness | TRL 8-9 | Commercial Ammonia from hydrogen production has been recently constructed in Europe (Spain) and is planned for Australia and Brazil. |
| AK Scalability | >1GW | AK has renewable potential. |
| Impact Timeline | 5 to 10 years | Ammonia plants are generally capital intensive endeavors with detailed permitting and environment reviews. Ammonia is toxic and corrosive resulting requiring detailed planning. |
| Commercial Viability | Market exists but production cost is a barrier | Asia market if very robust for hydrogen and could be a replacement for natural gas in Alaska for power and heating. |
| Carbon Intensity | Carbon Neutral / Low Carbon | The production of ammonia from hydrogen is zero carbon if electricity is sourced from renewables. GHG impact from nitrous oxide would need to be considered. |

## Methanol (CH3OH)

Methanol is produced in a two step process, 1st a steam reforming natural gas followed by distilling the syngas to produce methanol. Methanol is easily reformed to hydrogen for use in fuel cells (reformed methanol fuel cells). Methanol is a good liquid hydrogen carrier, effectively a liquid battery. One drawback is the energy density of methanol is lower than traditional fuels so roughly twice the storage volume would be needed compared to say diesel. Engines are available which run on methanol and many marine diesel engines can burn methanol at lower $CO_2$ and NOx emissions. There are no Sulfur Oxide emissions when burning methanol. Natural gas machines could be converted to this low carbon fuel for in-state power production. Methanol could also be exported as a low carbon fuel source. Global methanol production was 160 million metric tons and expected to increase by 80% by 2030.[50]

| TABLE 27. Methanol | | |
|---|---|---|
| Technology Readiness | TRL 7-9 | Methanol production is a well-established process at commercial scale globally. |
| AK Scalability | >1GW | AK has large renewable potential. |
| Impact Timeline | 5 to 10 years | Methanol plants are generally capital-intensive endeavors with detailed permitting and environment reviews. |
| Commercial Viability | Market exists but production cost is a barrier | Estimated additional 15% cost for methanol container ship over a conventional vessel. Assumed similar for power production. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Methanol could be produced from renewable energy. The production of methanol from natural gas hydrogen is low carbon if carbon is sequestered or solidified. |

48 www.ammoniaenergy.org

49 https://cen.acs.org

50 www.methanol.org

# 6

# Carbon Capture Utilization & Storage

COFFMAN ENGINEERS

# CARBON CAPTURE UTILIZATION & STORAGE

Carbon Capture Utilization and Storage (CCUS) refers to technologies that capture and transport the greenhouse gas carbon dioxide ($CO_2$) and then either utilize the gas or store it safely underground so that it does not contribute to climate change. CCUS includes capturing $CO_2$ from large emission sources (referred to as point-source capture) and directly from the atmosphere via either direct air capture and storage (DACCS) or bioenergy with capture and storage (BECCS).

Point-source capture occurs when a large emission source, such as an industrial facility, is equipped with technology enabling the capture of $CO_2$ and its diversion to storage. It is also possible to remove historical $CO_2$ emissions which are already in the atmosphere, through Direct Air Carbon Capture (DACCS) or Bioenergy with Carbon Capture (BECCS). CCUS can be applied across multiple sectors in Alaska's economy, including the production of cement, steel, fertilizers, clean hydrogen, power generation and natural gas processing.[51]

## CARBON CAPTURE

The first stage of CCUS is capturing the carbon before it is emitted. Carbon capture generally refers to the process of taking low to high concentration $CO_2$ from industrial emissions and processing the flue gas to high purity $CO_2$. This can be performed in the three methods outlined below. Many of the industrial benchmark studies also include compression and dehydration in this category from a cost perspective.

### Pre-combustion

Pre-combustion processes convert fuel into a gaseous mixture of hydrogen and $CO_2$. The hydrogen is separated and can be burnt without producing any $CO_2$; the $CO_2$ can then be compressed for transport and storage.

PRE-COMBUSTION $CO_2$ CAPTURE

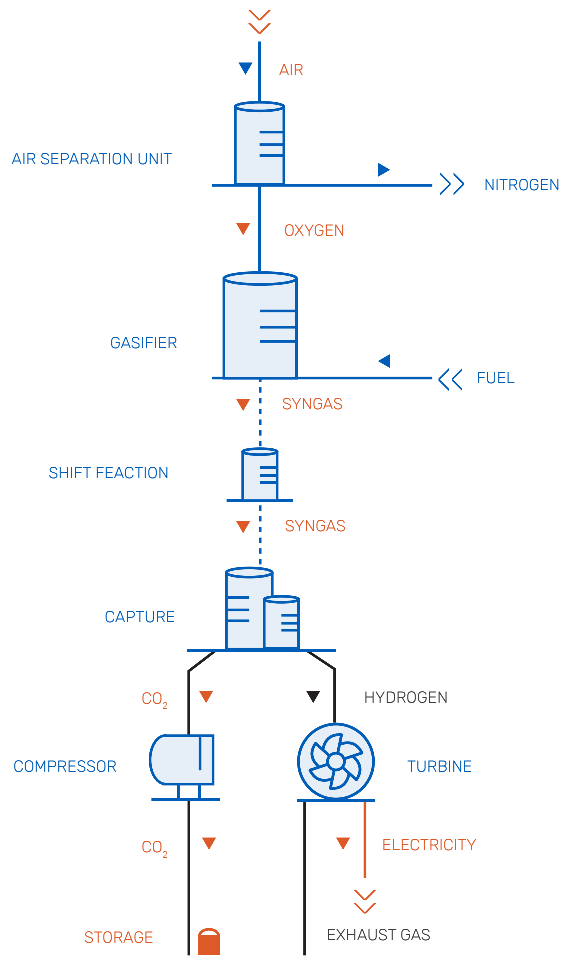



***FIGURE 32***
Provided by Global CCS Institute

| TABLE 29. Pre-Combustion | | |
|---|---|---|
| Technology Readiness | TRL 4 to 7 | DOE has funded multiple projects across industry with additional scaling projects planned. |
| AK Scalability | >1GW | Broad application for point source of emissions to use this technology or for new build. |
| Impact Timeline | 1-5 years | Projects are complicated but generally should improve emissions of a facility so should facilitate shorter environmental review. |
| Commercial Viability | Increase to 45Q and/or carbon tax | The main economics are driven by 45Q tax credits. The cost of pre-combustion currently exceeds the tax credits offered but many technology pilots are underway to meet the DOE $30 / ton goal. Needs additional policy support. |
| Carbon Intensity | Carbon Neutral / Low Carbon | Prevents carbon emissions when combined with geological storage. Could be synergies to combine with application with Green Hydrogen to use oxygen to eliminate air separator. |

51 www.globalccsinstitute.com

## Post Combustion

Post-combustion processes separate $CO_2$ from combustion exhaust gases. $CO_2$ can be captured using a liquid solvent or other separation methods. In an absorption-based approach, once absorbed by the solvent, the $CO_2$ is released by heating to form a high purity $CO_2$ stream. This technology is widely used to capture $CO_2$ for use in the food and beverage industry.

*See Table 30 on the following page.

## Oxy Combustion

Oxyfuel combustion processes use oxygen rather than air for combustion of fuel. This produces exhaust gas that is mainly water vapor and $CO_2$ that can be easily separated to produce a high purity $CO_2$ stream.

*See Table 31 on the following page.

**POST-COMBUSTION $CO_2$ CAPTURE**

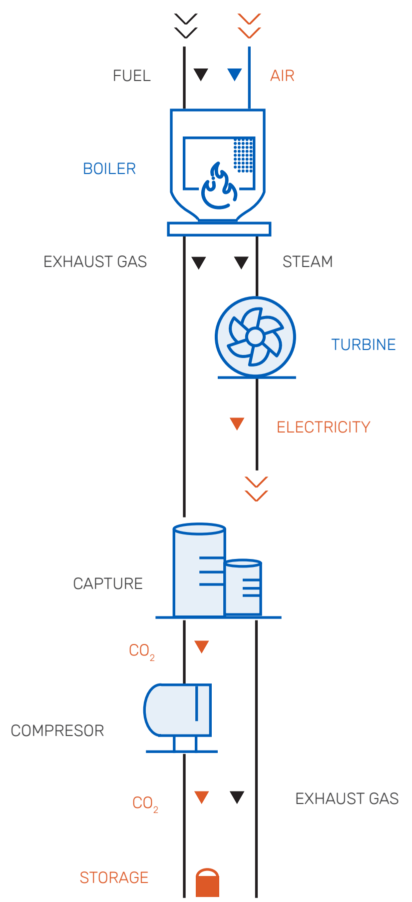



***FIGURE 33***
Provided by Global CCS Institute

**OXYFUEL $CO_2$ CAPTURE**

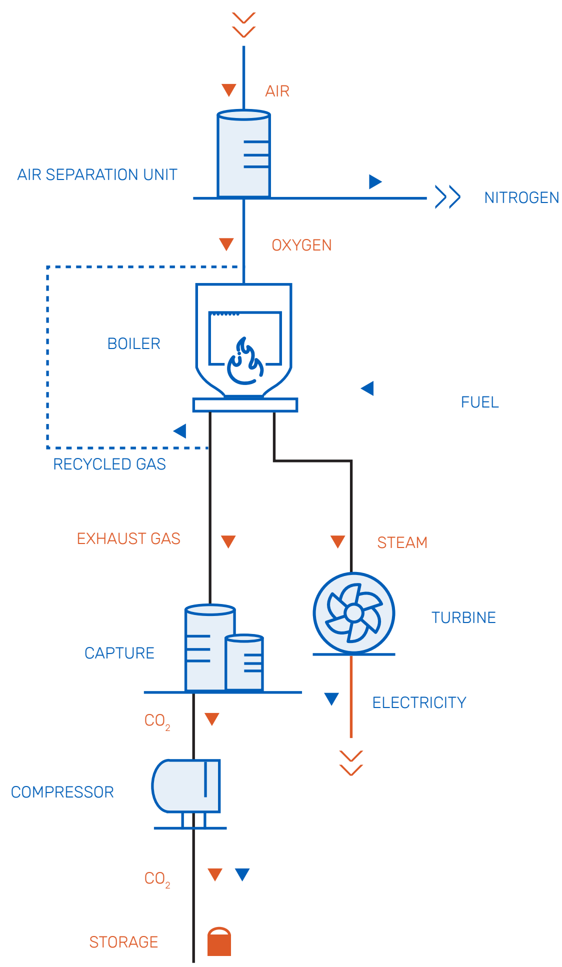



***FIGURE 34***
Provided by Global CCS Institute

| TABLE 30. Post Combustion | | |
|---|---|---|
| Technology Readiness | TRL 2 to 9 | For power generation, Petra Nova has a commercial scale application on a coal plant in TX. DOE has funded multiple projects across industry with additional scaling projects planned. |
| AK Scalability | >1GW | Broad application for point source of emissions to use this technology or for new build. |
| Impact Timeline | 5-10 years | Projects are complicated but generally should improve emissions of a facility so should facilitate shorter enviromental review. |
| Commercial Viability | Potential Economic Pathway | The main economics would be driven by 45Q tax credits. The cost of post-combustion is economic with current tax credits for certain emission types such as ethanol plants. |
| Carbon Intensity | Low Carbon | Prevents carbon from going into the atmosphere. |

| TABLE 31. Oxy Combustion | | |
|---|---|---|
| Technology Readiness | TRL 5 to 7 | Being tested at various stages with support of DOE. |
| AK Scalability | >1GW | Process can use natural gas or coal which Alaska has large reserves to generate power. |
| Impact Timeline | Beyond 10 Years | Technology maturity and complexity of projects places this technology beyond ten years. |
| Commercial Viability | Uneconomic in current market conditions. | The main economics would be driven by 45Q tax credits and technology levelized costs exceed credits. Combining this technology with electrolyzer hydrogen production can use the oxygen created in that process will eliminate the air separation unit which is a large cost component of this technology. |
| Carbon Intensity | Low Carbon | Combined with geological storage, this technology could be low carbon. |

## TRANSPORT

The second stage of CCUS is transporting. Once separated, the $CO_2$ is compressed for transportation, meaning an increase of pressure so that the $CO_2$ behaves like a liquid. The compressed $CO_2$ is then dehydrated before entry to the transport system. Pipelines are the most common mode of transport for large quantities of $CO_2$. For some regions of the world, $CO_2$ transport by ship rail or truck is an alternative that would likely be some form of cryogenic shipment.

## STORAGE

Storage or geologic sequestration is the process of injecting carbon dioxide into subsurface rock formations for long-term storage to be permanently and securely stored. Depending on the type of rock formation, the mechanism for storage is different.

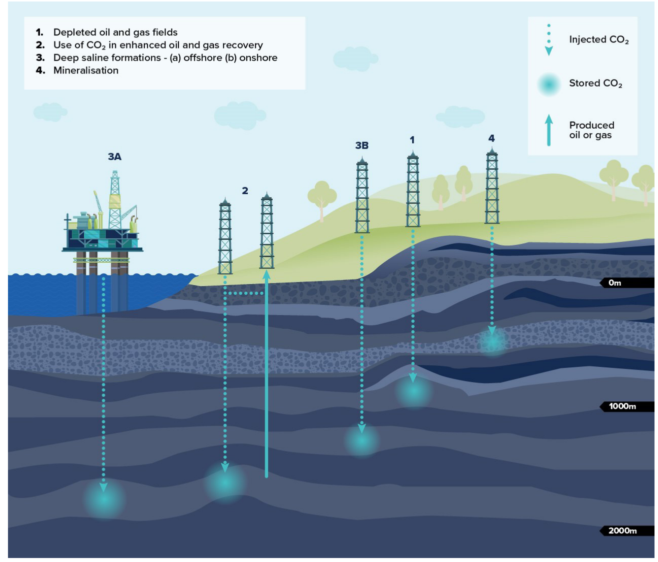



***FIGURE 35***
Types of geological formations, provided by Global CCS Institute.[52]

**EOR well injection is covered in the Utilization section of this paper.*

In 2011, a report was issued to assess the geological potential of Alaska saline aquifers and coal seams. Recently, the injection of $CO_2$ into saline aquifers in the USA has been established under the EPA Class 6 permitting process, unless a state has achieved primacy. A high level overview of the storage potential in Alaska can be seen in in figure 36 below.

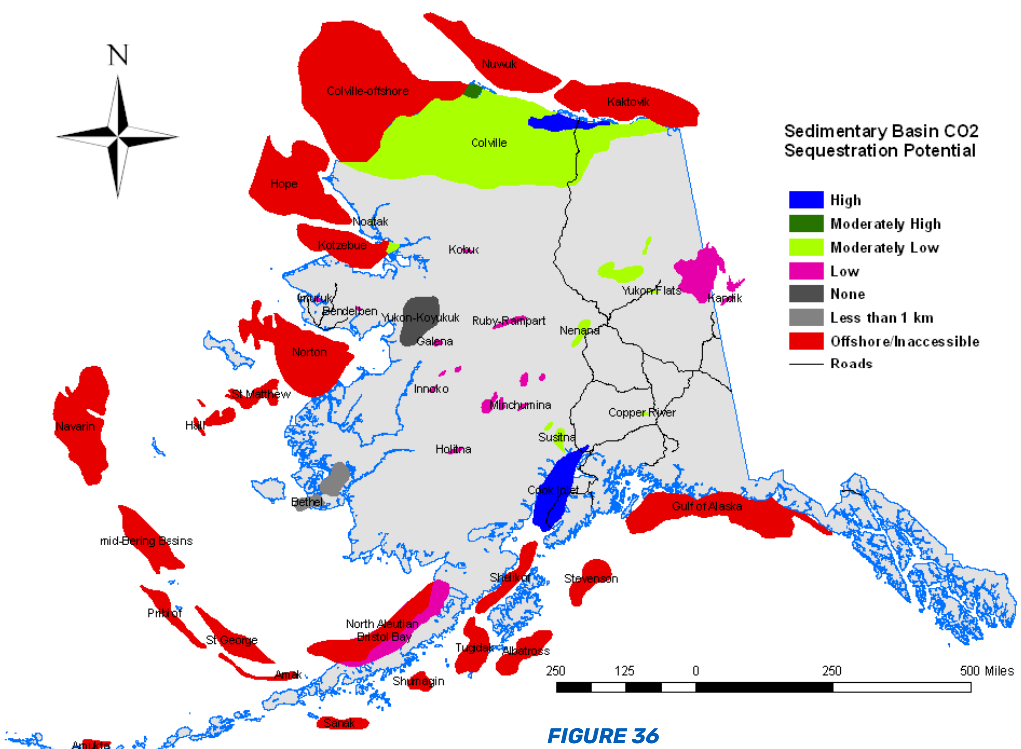



***FIGURE 36***
Sedimentary Basin $Co_2$ sequestration potential[53]

52 www.globalccsinstitute.com
53 https://dog.dnr.alaska.gov

## Coal Seams

$CO_2$ is injected into coal seams which displaces methane in the pore space or coal seams. The process is known as $CO_2$ Enhanced coal bed methane production. The process builds on a well-established industry of producing methane from coal seams.

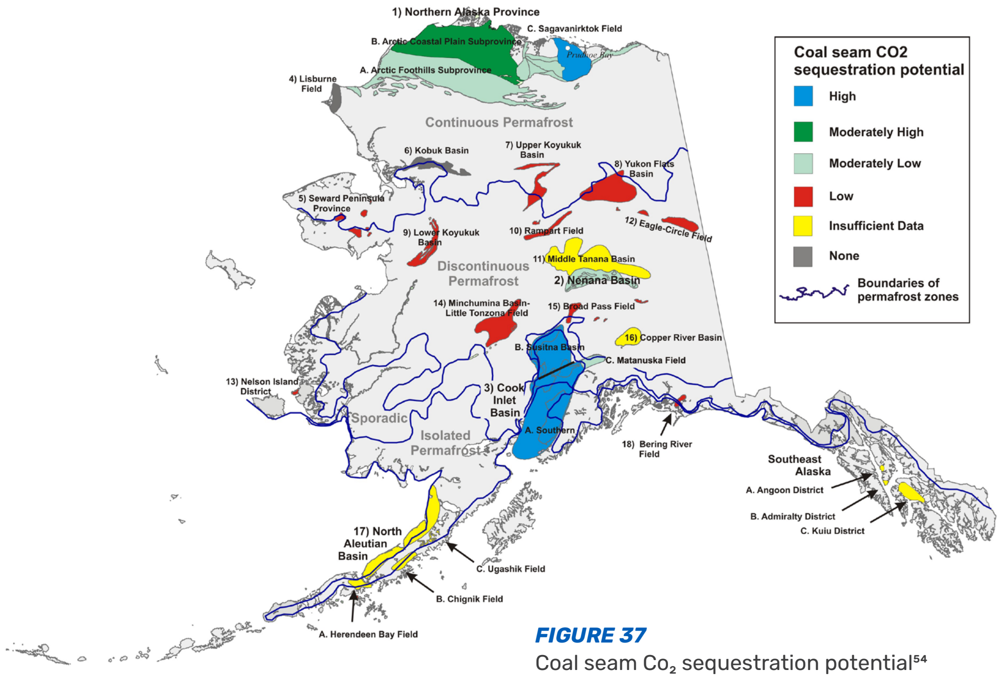



***FIGURE 37***
Coal seam $Co_2$ sequestration potential[54]

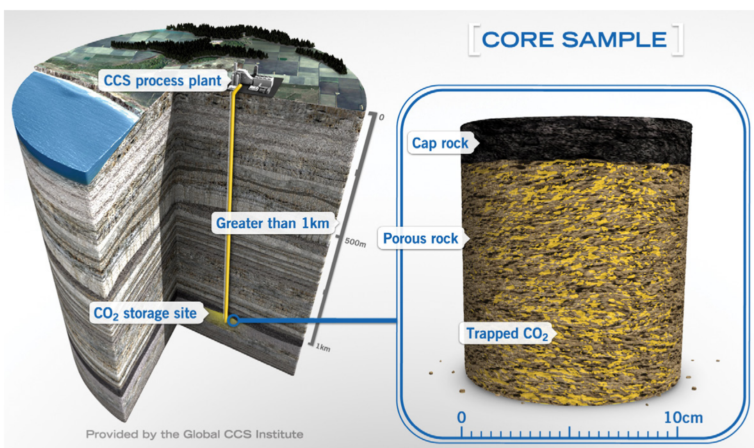



***FIGURE 38***
Storage - Core Sample | provided by Global CCS Institute

## Saline Aquifers

Saline aquifers are deep rock formations that have water contained in the pore space that is too high of salinity to have any beneficial use such as agricultural, livestock or drinking water. The geological formation would need to have the proper depth, reservoir rock properties, and multiple layers of seal rock to be appropriate for $CO_2$ injection. The injection rate would need to be designed to ensure near well bore pressure does not exceed the fracture pressure of the rock.

## Depleted Oil & Gas Fields

$CO_2$ storage in depleted oil and gas fields takes advantage of a known geological trap as the trapping mechanism that allowed oil and gas to collect over millions of years has already been proven. Many times, existing infrastructure can be re-purposed to inject $CO_2$ or as monitoring wells. Not all oil and gas fields are good candidates for $CO_2$ injection. Generally a reservoir would need multiple layers of seal rock, proper depth, and a risk review on the existing well penetrations would need to be performed as they can offer potential leak pathways.

54 https://dog.dnr.alaska.gov

## UTILIZATION

Carbon utilization is an umbrella term to describe different ways mostly $CO_2$ and sometimes CO can be used in producing economic products and increasingly how carbon credits can be generated. DOE categorizes utilization in four themes:

- Uptake
- Conversion
- Mineralization
- Services

***Only "services" or EOR is covered from a technology scoring assessment in this paper.***

### Uptake

*"Algae are extremely efficient photosynthetic organisms. The biomass produced in algal systems can be processed and converted into a variety of products, including fuels, chemicals, soil supplements, food for fish, animals and humans, and other specialty and fine products."*[55]

Organic algae to capture $CO_2$ from industrial process holds a number of advantages and can be done in either closed or open systems but has many challenges to overcome to scale or compete with industrial carbon capture systems. The use of microalgae for carbon capture is extremely complicated and multiple factors need to be considered for a commercial project: land use, proximity to point source, microalgae species selection, and numerous other factors. Other forms of uptake include forestry, enhanced weathering, and soil carbon sequestration. These have the potential to generate carbon credits to help offset hard to decarbonize emissions.

#### ENHANCED WEATHERING

A process to accelerate natural processes that absorb atmospheric $CO_2$ such as crushing basalt rocks and spreading them on oceans, land, or beaches to form stable carbonates from atmospheric $CO_2$. This could have an additional benefit on agricultural lands by increasing crop yields. Alaska has extensive extrusive basalt due to historical volcanic activity.

***FIGURE 39***
Carbon dioxide capture by green sand beaches.[56]

#### FORESTRY

Forests naturally sequester $CO_2$ as the forest grows through photosynthesis. This increase in biomass can be baselined and measured to demonstrate sequestration. The carbon offset can be generated by reforestation, demonstrating a forest is saved from another land use such as agriculture, or better timber practices to increase carbon storage. Timber from well managed forests can be used in buildings as an alternative to cement or steel. The downside of forestry is the risk of forest fires. Alaska has large forests with ~60% of the land in federal government control.

#### SOIL CARBON SEQUESTRATION

Soil carbon management is similar to forest sequestration but related mostly to agriculture. Examples off farming practices that would increase soil carbon sequestration are reduced or no tillage, erosion control, adding organic material, or other practices. Companies offer farmers to act as the carbon brokerage and also the carbon verification process by baseline the carbon content of the soil and then the increase by the changes in farming practices.

---

55 www.energy.gov
56 www.technologyreview.com

## Conversion

*"Conversion pathways can include thermochemical, electrochemical, photochemical, and microbially-mediated approaches. Many also require catalysts or integrated processes to lower the energy needed to drive these systems. Via this pathway, wasted carbon can transformed into synthetic fuels, chemicals, plastics, and solid carbon products like carbon fibers."*[57]

**THE DOE IS EXPLORING FOUR CATEGORIES:**

- **Thermochemical:** Energy is provided in the form of heat (and pressure) and the reaction is often driven by a catalyst.
- **Electrochemical**: Energy is provided in the form of electricity and catalyzed reactions take place in an electrochemical cell.
- **Plasma-mediated**: $CO_2$ is activated by energetic electrons instead of heat and the reaction is often driven by a catalyst.
- **Biocatalysis**: $CO_2$ conversion processes are mediated by microbes and accelerated by enzymes.

Some of the examples of hydrogen production fall into these categories, such as thermochemical.

## Mineralization

*"Carbon dioxide mineralizes with alkaline reactants to produce inorganic materials, such as cements, aggregates, bicarbonates and associated inorganic chemicals. Carbonate materials may be an effective long-term storage option for $CO_2$, especially for use in the built environment."*[58]

Mineralization is a promising from of utilization as it has advantages over other pathways. One of the most significant is many pathways need energy input to convert $CO_2$ into other useful products such as fuels.

**Mineralization is attractive for a number of reasons:**

- Carbonates are a lower form of energy than $CO_2$
- Cement and aggregate are a growing market that is global and local
- Construction products such as cement, which is 8% of global emissions, can be attractive alternative to areas that don't have geological storage

$CO_2$ can be used to "cure" cement, or in the manufacture of aggregates. Doing so stores some $CO_2$ for the long term and could displace emissions-intensive conventional cement.

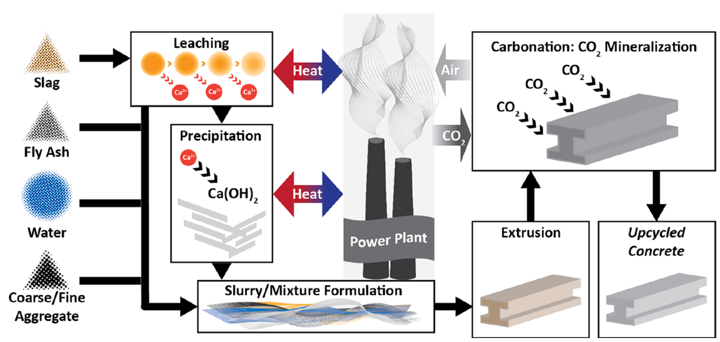



***FIGURE 40***
Upcycled $CO_2$ - negative concrete for construction functions[59]

57 www.energy.gov
58 www.energy.gov
59 netl.doe.gov

## Services

Enhanced oil recovery works by injecting $CO_2$ into the reservoir to displace additional oil that otherwise would not be produced. $CO_2$ is miscible meaning that it mixes with the oil. $CO_2$ swells the oil decreasing the viscosity allowing oil to be sweep from pore space where it would otherwise be trapped. $CO_2$ injection also helps to maintain reservoir pressure. An emerging trend is companies marketing the low carbon intensity of crude oil produced with EOR. There are also plans to increase use of industrial sourced $CO_2$ and inject more $CO_2$ compared to the full scope 1-3 emissions of the oil produced or even more.[60] Meaning you could have crude oil that is carbon neutral or even negative if bio-mass $CO_2$ is utilized or direct air capture.

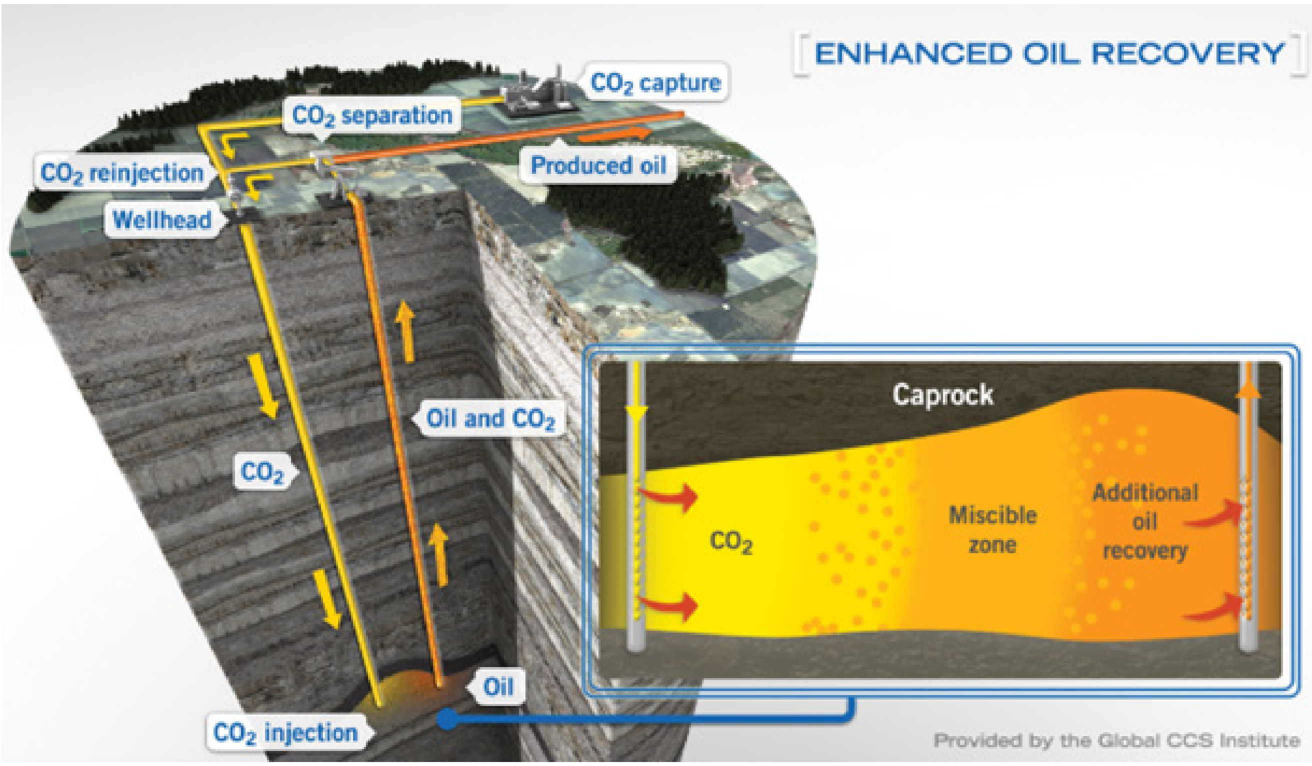



***FIGURE 41***
Enhanced Oil Revovery, provided by Global CCS Institute.

## Bioenergy with Carbon Capture & Storage

Bioenergy with carbon capture and storage (BECCS) is a growing interest for companies to generate heat or electricity with biomass and then sequester the capture $CO_2$ geologically. This has the potential to use nature to scrub the $CO_2$ from the atmosphere and generate negative carbon credits.

60 https://www.denbury.com

# 7

## Nuclear Energy

COFFMAN
ENGINEERS

# NUCLEAR ENERGY

## FISSION

In nuclear fission, atoms are split apart, which releases energy. All nuclear power plants use nuclear fission, and most nuclear power plants use uranium atoms. During nuclear fission, a neutron collides with a uranium atom and splits it, releasing a large amount of energy in the form of heat and radiation. More neutrons are also released when a uranium atom splits. These neutrons continue to collide with other uranium atoms, and the process repeats itself over and over again. This process is called a nuclear chain reaction. This reaction is controlled in nuclear power plant reactors to produce a desired amount of heat. [61]

| TABLE 32. Nuclear Fission | | |
|---|---|---|
| Technology Readiness | 9 | Commercial scale nuclear plants have been in operation since the 1950s and continue to be built today. |
| AK Scalability | 1 GW> | High seismic zone would likely preclude Alaska from building a nuclear power plant. |
| Impact Timeline | 10 years or more | Nuclear plants have a long history of multi decade schedules, long permitting pathways, and major cost overruns. |
| Commercial Viability | Not economic without government support | Due to the major development cost and plant life's normally 50+ years, nuclear is normally backed by federal government loans, grants, or other forms of financial backing. |
| Carbon Intensity | Carbon neutral | Power generation emits zero GHG emissions. |

## FUSION

Nuclear energy can also be released in nuclear fusion, where atoms are combined or fused together to form a larger atom. Fusion is the source of energy in the sun and stars. Developing technology to harness nuclear fusion as a source of energy for heat and electricity generation is the subject of ongoing research, but whether or not it will be a commercially viable technology is not yet clear because of the difficulty in controlling a fusion reaction.[62] ***As the technology is still in development, a scoring table is not included.***

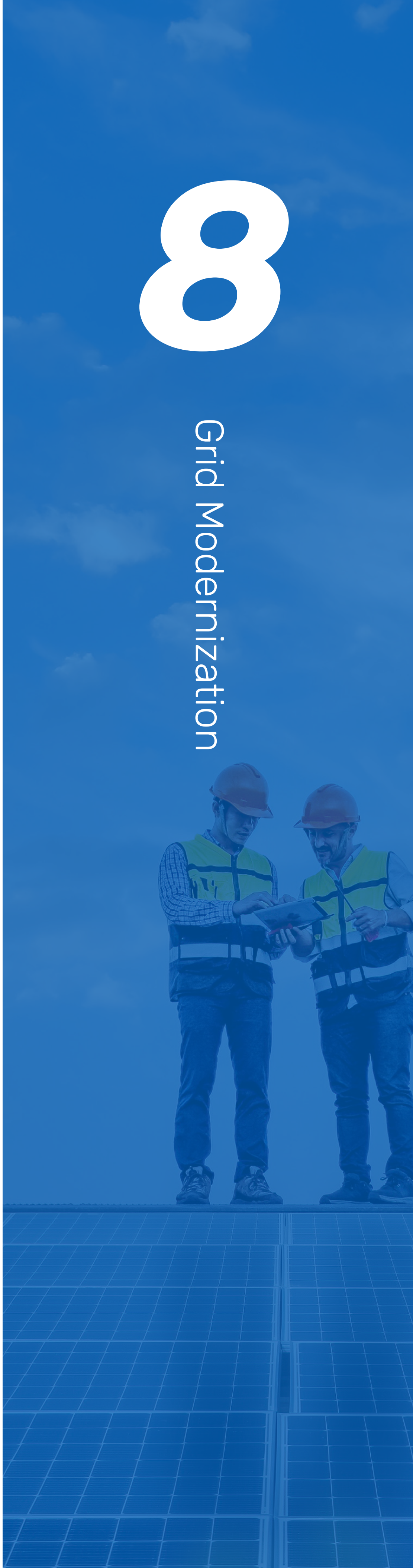
## ADVANCED REACTORS

Advanced nuclear reactors are an area of interest for the federal government. Currently nuclear power is available only on a very large scale and requires extensive development timelines. If development of advanced, modular reactors is successful, reactors may become available for a much wider range of applications, including for Alaska. Product development and testing at controlled facilities (National Laboratories) is in progress.[63] ***As the technology is still in development, a scoring table is not included.***

61 www.eia.gov
62 www.eia.gov
63 www.nuscalepower.com

# 8

## Grid Modernization



COFFMAN ENGINEERS

# GRID MODERNIZATION

Modernization of the grid will help enable grid decarbonization by improving flexibility, reliability and contributions from distributed resources. As decarbonization programs are implemented, the grid will need to adapt in terms of bulk power, resiliency, dispatching, and other functions required to support new and varied loads. Grid modernization should be seen as a wholistic approach to reduce potential barriers to decarbonization while at the same time reducing utility operating costs.

The U.S. Department of Energy's Grid Modernization Initiative (GMI) indicates modernization is a set of improvements to ensure the grid is "flexible, robust, and agile from end to end". The GMI project, along with the key needs summarized in Table 33 , offer excellent suggestions as to how to evaluate needs. Implementation is left to the regional utilities, transmission system operators, and regulators.

**TABLE 33. Grid Modernization Initiative (GMI)**

| Drivers | Requirements |
|---|---|
| Changing mix of types and characteristics of electricity generation | Resilient- Recovers quickly from any situation or power outage. |
| Growing demands for a more resilient and reliable grid, especially due to weather impacts. | Reliable- Improves power quality with fewer power outages |
| Growing threat of cyber and physical attacks. | Secure- Increases protection to our critical infrastructure |
| Opportunities for customers to provide grid services and participate in electricity markets. | Flexible- Responds to variability and uncertainty of conditions across a range of timescales. |
| Increased use of digital communications technologies in control of power systems. | Sustainable- Reduces environmental impact of energy-related activities |

Summary from Updated GMI Strategy 2020, DOE.

## NETWORK/RESILIENCY UPGRADES

The difficulty with network upgrades and/or resiliency upgrades is that they are by definition reactive, meaning that as the electrification and decarbonization activities progress they will uncover inherent limitations in the system to be addressed. However, a general consensus is that upgrades should be made considering higher frequencies of severe weather, temperature extremes, floods, and high winds.

## SMART GRID

The main concept of the 'Smart Grid' is to move past traditional dispatching and scheduling done in fifteen minute blocks with hourly forecasts, to a grid that automatically controls generation assets in a matter of seconds to respond to real-time load and power quality measurements. Although many utilities have implemented some level of Smart Grid, there remains significant room for implementation of new technology and interconnected networking and controls.

## DEMAND SIDE TECHNOLOGIES AND TRENDS

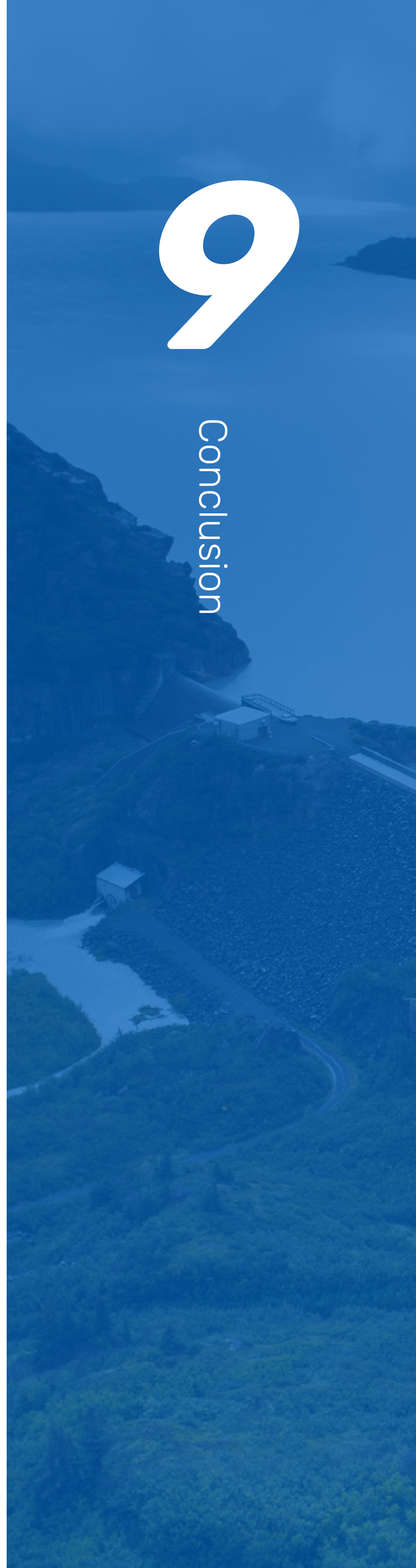
### Energy Efficiency

Energy Efficiency has an important role in reducing current electricity demand to clear a path for additional loads created by the electrification of the building and transportation sectors.

### Electric Vehicles (EVs)

While the electrification of light, medium, and heavy-duty vehicles is not typically considered part of grid modernization, it is a critical piece that should be considered at every level of a utility's future planning. EV adoption has been slower in rural areas and at northern latitudes, but could be a disruptive technology within the Railbelt within the next 10-20 years.

Aside from reacting to the advent of EVs, utilities have the opportunity to benefit from electrification, if managed correctly, to increase revenues and utilization of existing infrastructure.



# 9 Conclusion

COFFMAN ENGINEERS

# CONCLUSION

There are many opportunities to decarbonize Alaska's energy infrastructure. This paper identifies potential technologies that can be used to decarbonize the grid. The combined score card for all the technologies scored is listed below.

Although not addressed in this paper, there are different synergies between the technologies that can be used to implement successful projects. The development of an integrated resource plan is an important next step.

SCORE CARD

| Technology | Technical Feasibility | AK Scalability | Impact Timeline | Commercial Viability | Carbon Intensity |
|---|---|---|---|---|---|
| **Renewables** | | | | | |
| Onshore Wind | TRL 9 | >1GW | 1 to 5 years | Clear Economics | Carbon Neutral / Low Carbon |
| Offshore Wind | TRL 7 | >1GW | 3 to 10 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| PV Solar | TRL 9 | >1GW | 0.5 to 2 years | Clear Economics | Carbon Neutral / Low Carbon |
| Geothermal - Hydrothermal | TRL 9 | >1GW | 5 to 10 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Geothermal – Organic Rankine Cycle | TRL 8 | 1MW to 100MW | 5 to 10 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Hydroelectric | TRL 9 | >1GW | 5 to 15 years | Potential economic pathway | Carbon Neutral / Low Carbon |
| Tidal | TRL 5 to 7 | 1 MW to 1 GW | 5 to 10 years | Potential economic pathway | Carbon Neutral / Low Carbon |
| Wave | TRL 5 to 6 | 1 MW to 100 MW | Beyond 10 years | Potential economic pathway | Carbon Neutral / Low Carbon |
| River Hydrokinetic | TRL 5, 6 | < 1 MW | Beyond 10 years | Potential economic pathway | Carbon Neutral / Low Carbon |
| Wood Biomass Energy | TRL 9 | 1 MW to 1GW | 1-5 years | Potential Economic Pathway | Carbon neutral or low carbon |
| Biogas and Renewable Natural Gas | TRL 9 | 1 MW to 1GW | 1-5 | Clear economics | Carbon neutral or low carbon |

| Technology | Technical Feasibility | AK Scalability | Impact Timeline | Commercial Viability | Carbon Intensity |
|---|---|---|---|---|---|
| **Energy Storage** | | | | | |
| Supercapacitors | TRL 9 | < 1 MW | 1-5 years | Clear Economics | Carbon Neutral / Low Carbon |
| Lithium-Ion Batteries | TRL 9 | >1GW | 1-5 years | Clear Economics | Carbon Neutral / Low Carbon |
| Flow Batteries | TRL 6-7 | 1 MW to 100 MW | 3 to 10 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Flywheels | TRL 6 to 9 | 1MW to 100 MW | 1-5 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Pumped Hydro | TRL 9 | >1GW | 5-10 years | Potential economic pathway | Carbon Neutral / Low Carbon |
| Compressed Air | TRL 6-8 | 1MW-100 MW | 1-5 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Gravity Systems | TRL 5 to 7 | < 1MW | 1-5 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Natural Gas Storage | TRL 9 | 1MW-1GW | 1-5 years | Potential Economic Pathway | Significant Carbon emissions |
| **Hydrogen** | | | | | |
| Steam Methane Reforming | TRL 9 | >1GW | 10+ years | Marginal | Low Carbon |
| Auto Thermal Reforming | TRL 9 | >1GW | 10+ years | Marginal | Low Carbon |
| Pyrolysis | TRL 5-9 | >1GW | 10+ years | Marginal | Low Carbon |
| Partial Oxidation | TRL 9 | >1GW | 5-10 years | Marginal | Low Carbon |
| PEM Electrolyzers | TRL 7-9 | >1GW | <5 years | Market exists but production cost is a barrier | Carbon Neutral / Low Carbon |
| Alkaline Electrolyzers | TRL 8-9 | >1GW | <5 years | Market exists but production cost is a barrier | Carbon Neutral / Low Carbon |
| Ammonia | TRL 8-9 | >1GW | 5 to 10 years | Market exists but production cost is a barrier | Low Carbon |
| Methanol | TRL 7-9 | >1GW | 5 to 10 years | Market exists but production cost is a barrier | Low Carbon |
| **Carbon Capture Utilization & Storage** | | | | | |
| Pre-Combustion | TRL 4 to 7 | >1GW | 1-5 years | Increase to 45Q and/or carbon tax | Carbon Neutral / Low Carbon |
| Post-Combustion | TRL 2 to 9 | >1GW | 5-10 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |
| Oxy Combustion | TRL 6 to 9 | >1GW | 1-5 years | Potential Economic Pathway | Carbon Neutral / Low Carbon |

www.coffman.com