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# Ocean Alkalinity Enhancement Research Overview

The development and advancement of a new field

JUNE 30, 2025

Today you will see how a new field, ocean alkalinity enhancement (OAE), was initiated and has developed.

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*Three phases of research:*

- 01 **Basic research** lays the foundation to hypothesize about OAE as a climate solution
- 02 **Early testing** of the OAE hypothesis by a few brave researchers
- 03 **Rapid expansion** of the field as the need for CDR becomes clear and the high potential of OAE holds up to initial scrutiny

Summarize topics that have been investigated.

# Basic Science Paved the Way for OAE

01

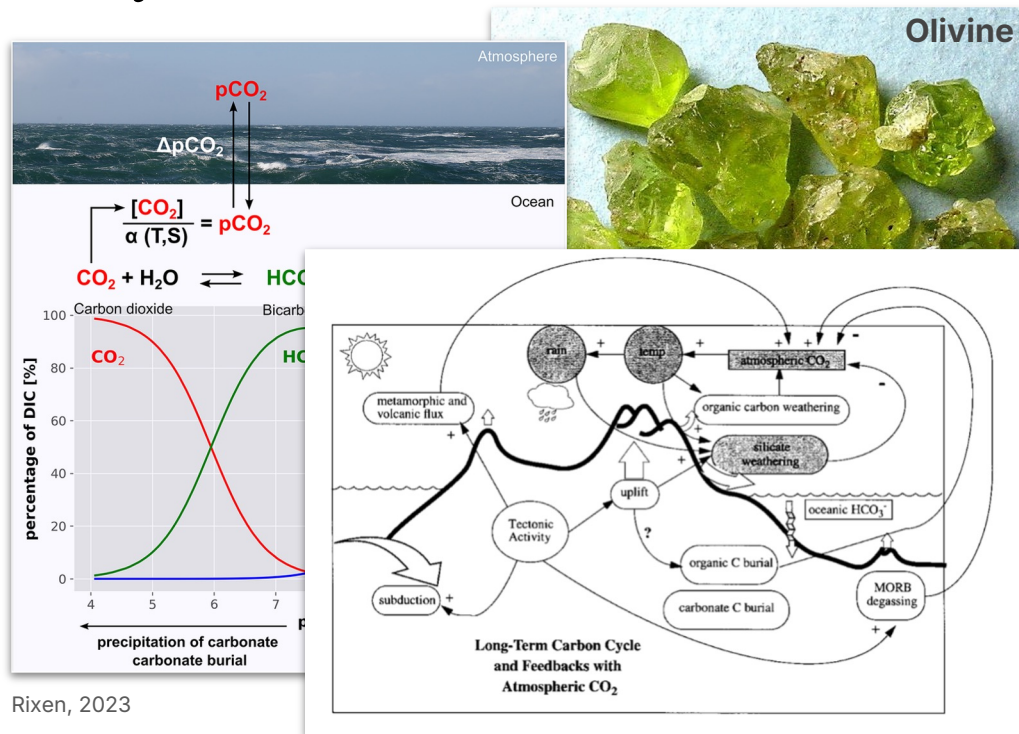
*Mineralogy*

02

*Chemical oceanography  
& carbonate chemistry*

03

*Climate system science*



# Ocean Alkalinity Enhancement is Proposed as a Climate Solution. 1st Publication on OAE in 1995

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Pergamon

0360-5442(95)00035-6

*Energy* Vol. 20, No. 9, pp. 915-922, 1995  
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0360-5442/95 \$9.50 + 0.00

## SEQUESTERING ATMOSPHERIC CARBON DIOXIDE BY INCREASING OCEAN ALKALINITY

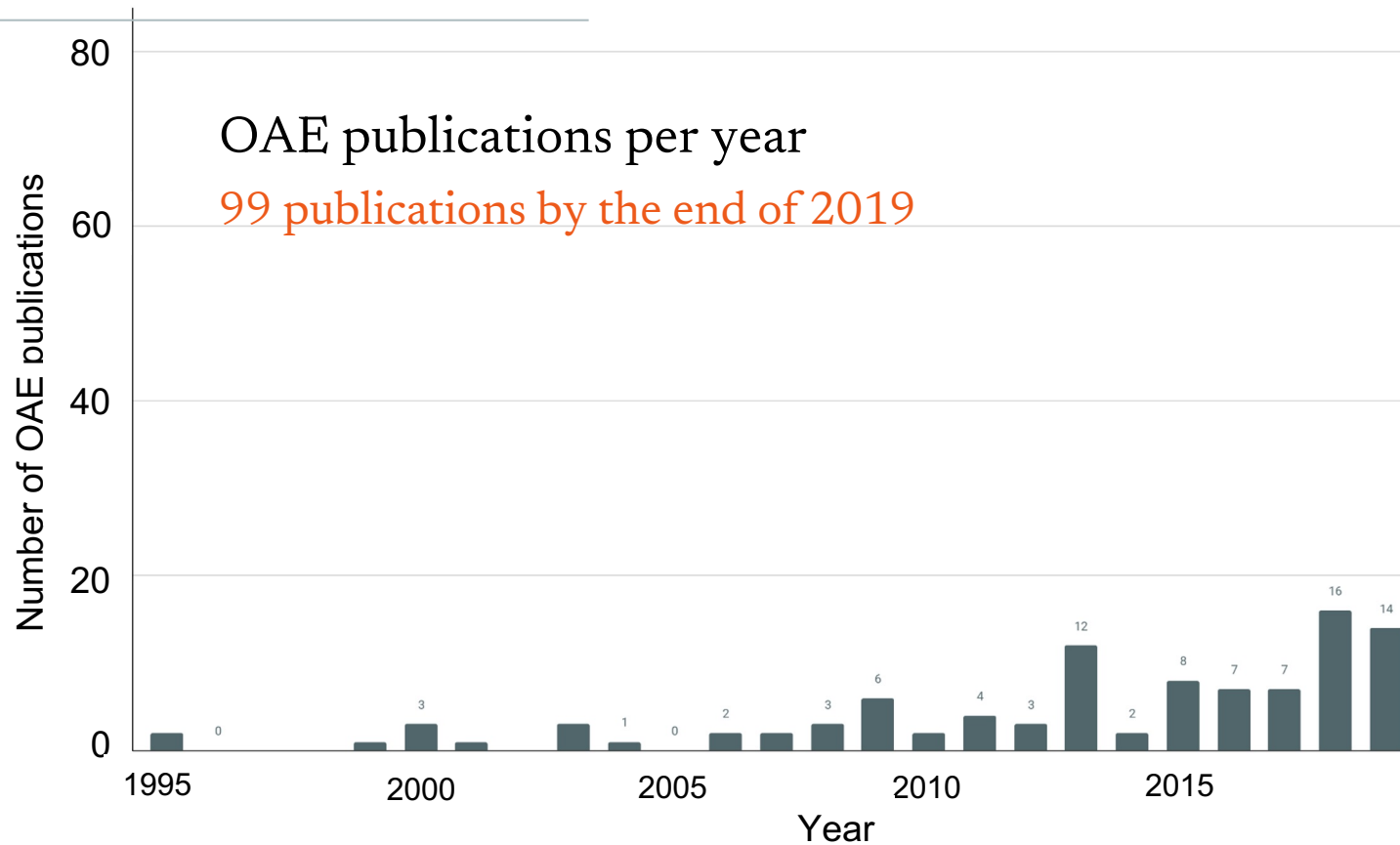
HAROON S. KHESHGI

Corporate Research Laboratories, Exxon Research and Engineering Company, Annandale, NJ 08801, U.S.A.

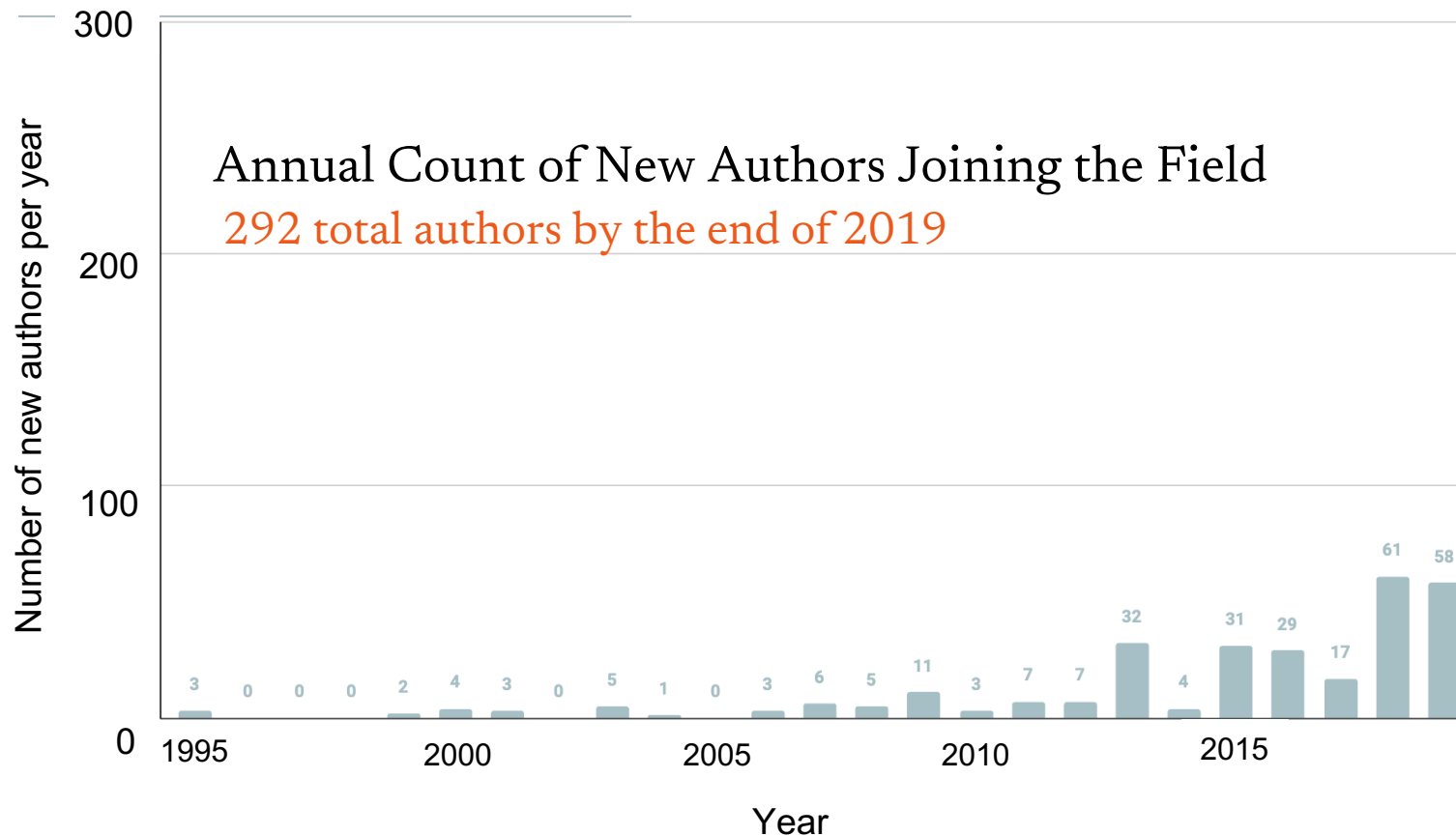
(Received 14 October 1994)



# OAE Research Proceeds Slowly for 25 Years



# OAE Research Proceeds Slowly for 25 Years



# OAE Research Proceeds Slowly for 25 Years

1995





OAE Research  
Proceeds Slowly  
for 25 Years

2005





OAE Research  
Proceeds Slowly  
for 25 Years

2015

# Little Public Funding for OAE for Over 25 Years (1995-2019)

German Priority Program  
on Climate Engineering

2013 - 2020, €9M  
Limited OAE research



Risks, Challenges,  
Opportunities?

2013

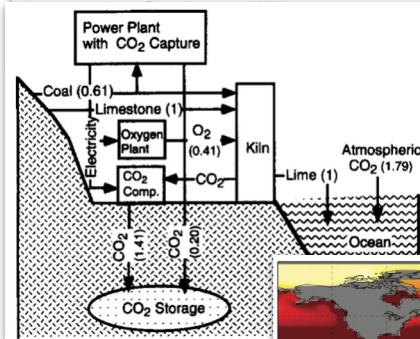
Funders have doubts about OAE and give out few grants.

# Early Testing of the OAE Hypothesis (1995-2019)

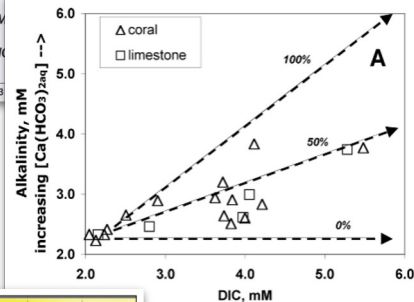
- 01 *Chemical equations derived & compiled*
- 02 *OAE tech ideas*
- 03 *Small scale experiments to prove the chemistry*
- 04 *Earth system modeling to explore CO<sub>2</sub> removal potential*

**Table 1.** Carbon Sequestration Reactions for a Range of Naturally Occurring and Anthropogenically Produced Minerals

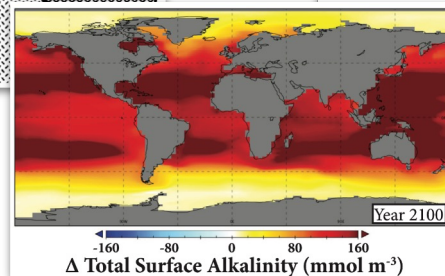
Equation Number	Mineral	$\Delta G_f$ (kJ/mole) <sup>a</sup>	Reaction	$\Delta G_r$ (kJ/mole) <sup>a</sup>	$\Delta G_r$ (kJ/mole C) <sup>a</sup>	gCO <sub>2</sub> /g(mineral)
<i>Naturally Occurring Minerals</i>						
1	Magnesite	-1029.5	$MgCO_3 + CO_2 + H_2O \rightarrow Mg^{2+} + 2HCO_3^-$	22.5	22.5	0.52
2	Calcite	-1128.5	$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$	22.8	22.8	0.44
3	Dolomite	-2161.7	$CaMg(CO_3)_2 + 2CO_2 + 2H_2O \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$			



Khesghi, 1995



Rau, 2011



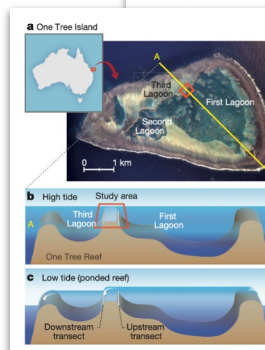
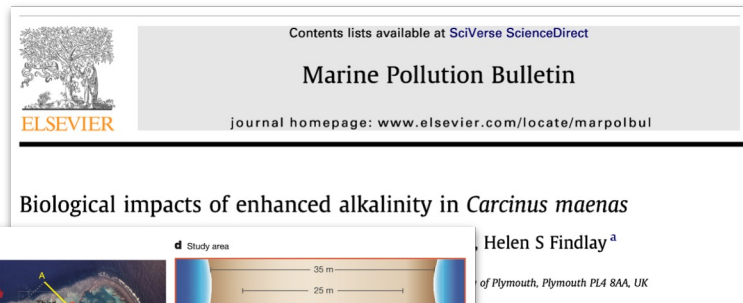
Keller et al., 2014

608 Gt  
atmospheric CO<sub>2</sub>  
removal over 80  
years

# Early Testing of the OAE Hypothesis (1995-2019)

Indirect (?) contributions via  
ocean acidification research &  
mitigation approaches

- 01 *A few biological impact studies*
- 02 *One field experiment*
- 03 *Shellfish hatcheries do OAE,  
but not for CDR*



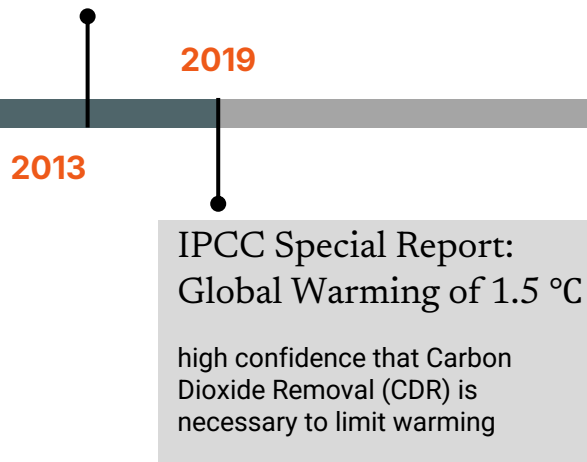
Albright et al., 2016



# Carbon Dioxide Removal Gets More Attention

German Priority  
Program on Climate  
Engineering

2013 - 2020, €9M  
Limited OAE research



# More Research on OAE is Funded

German Priority  
Program on Climate  
Engineering

2013 - 2020, €9M  
Limited OAE research

EU OceanNETs  
project

2020 - 2025, €7.2M  
~60% focused on OAE



2013

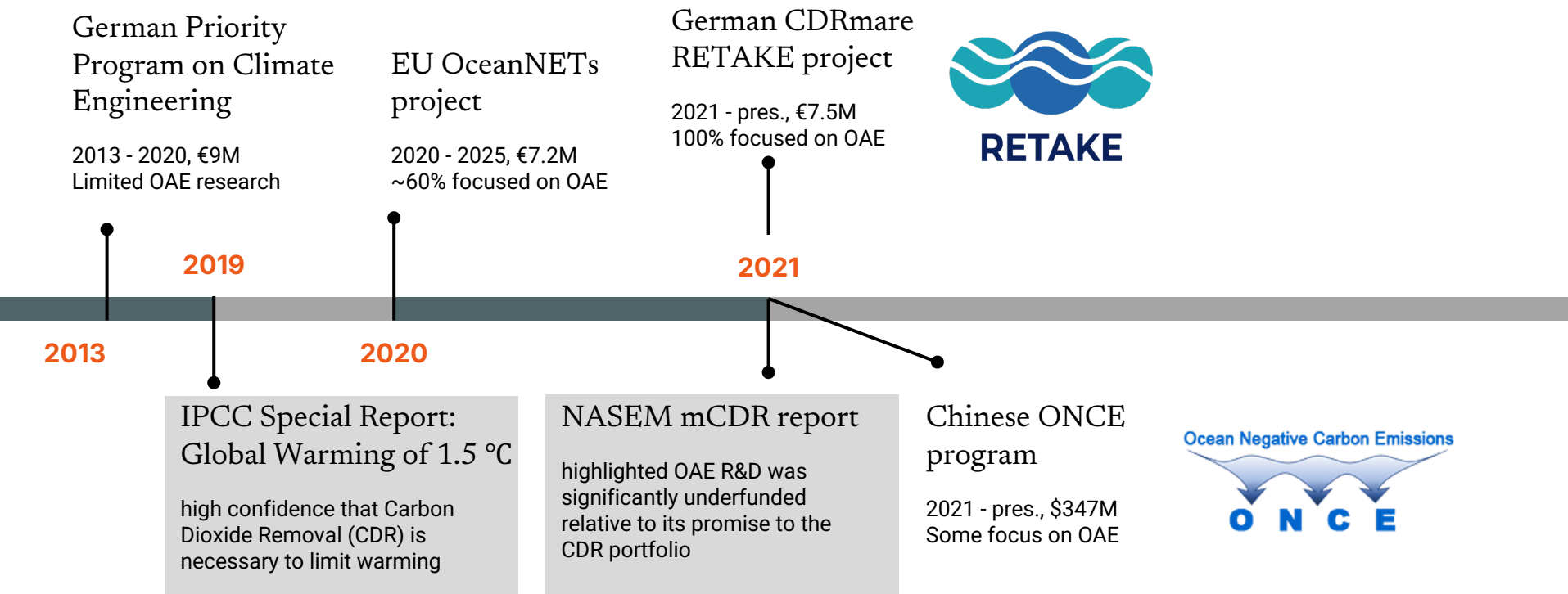
2019

2020

IPCC Special Report:  
Global Warming of 1.5 °C

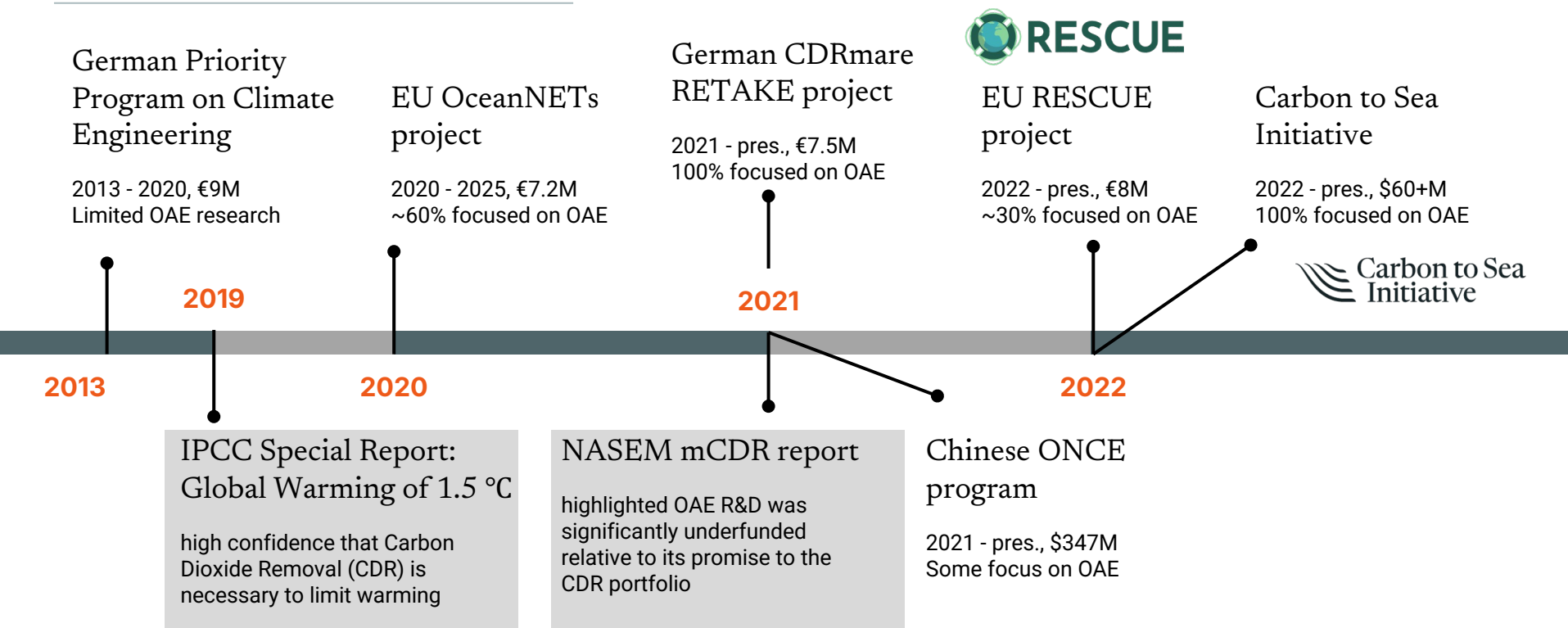
high confidence that Carbon  
Dioxide Removal (CDR) is  
necessary to limit warming

# More Research on OAE is Funded

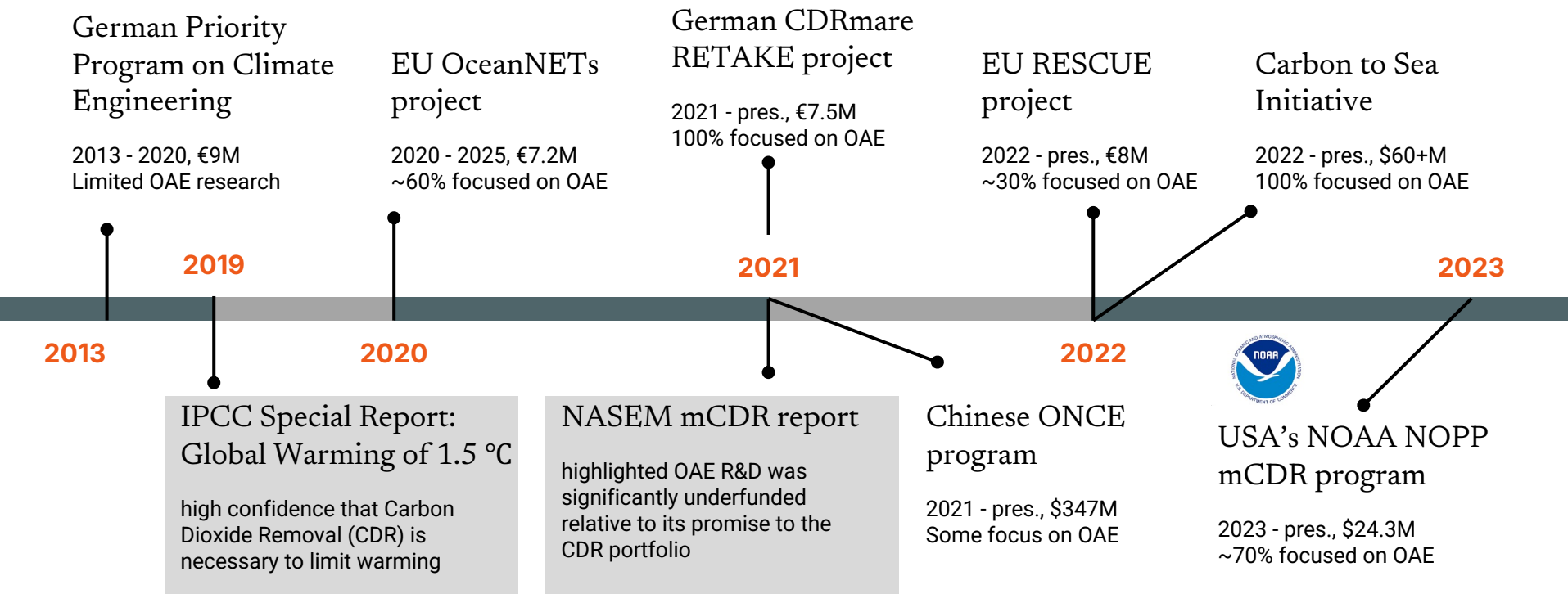




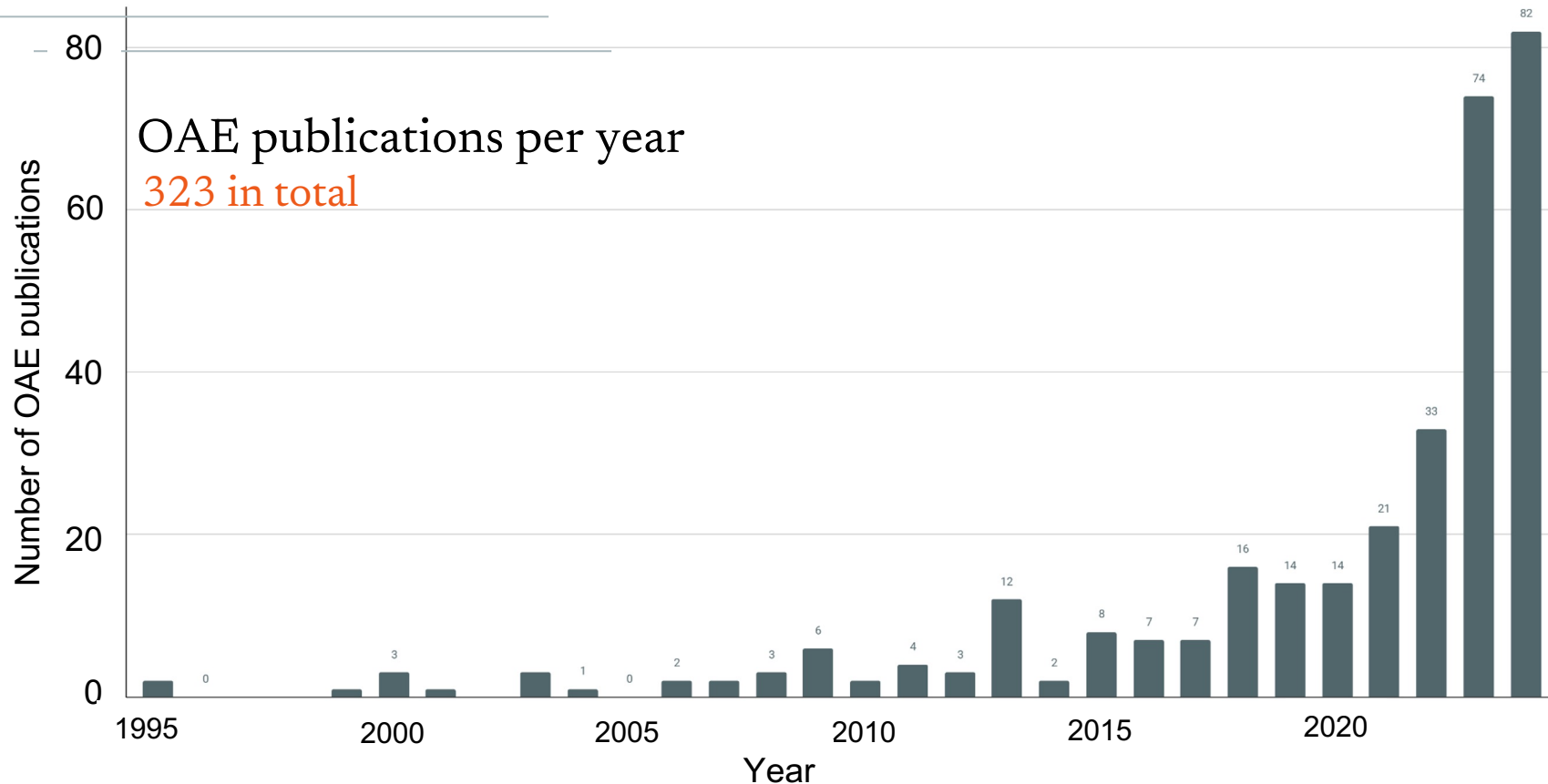
# More Research on OAE is Funded



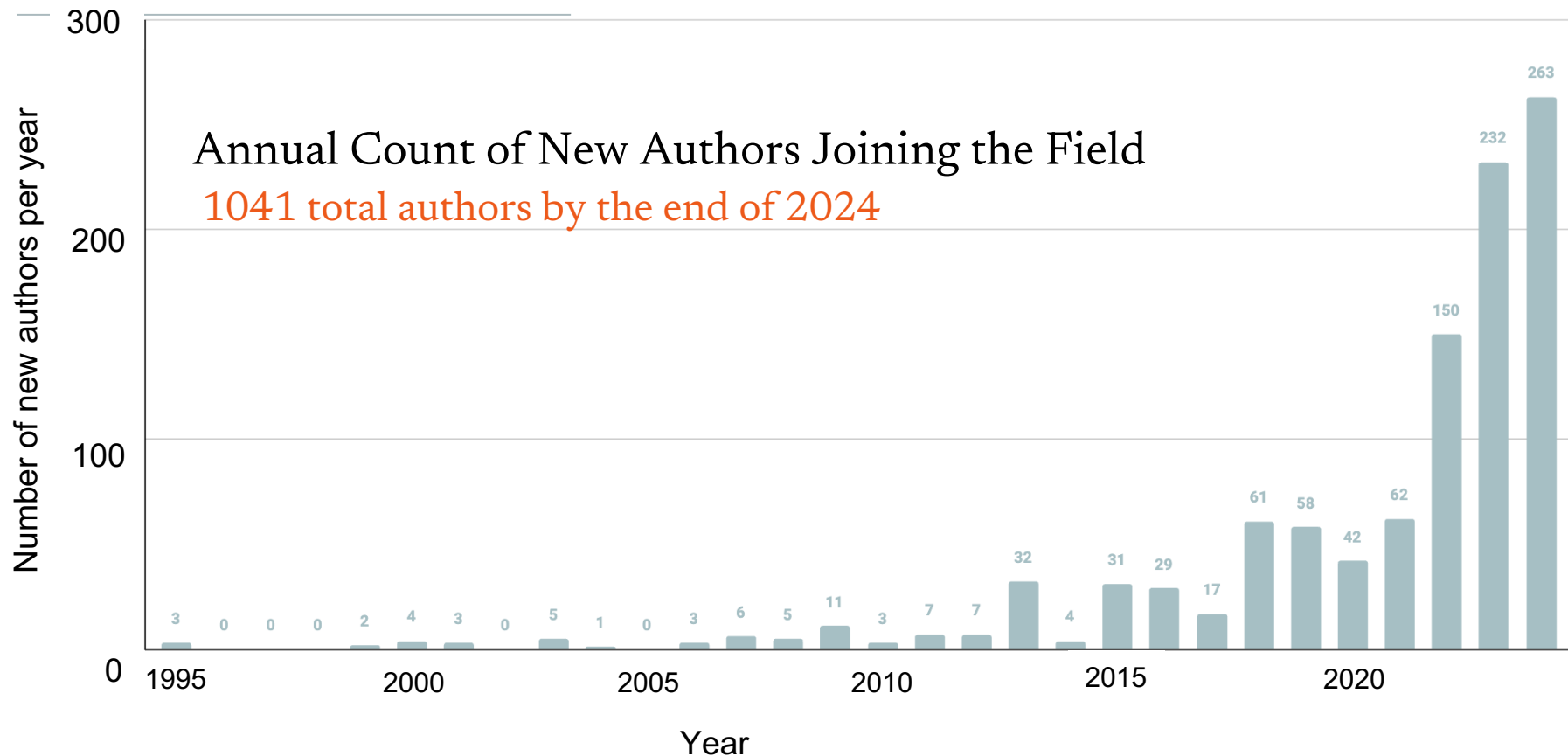
# More Research on OAE is Funded



# Recent Rapid Growth of OAE Research



# Recent Rapid Growth of OAE Research





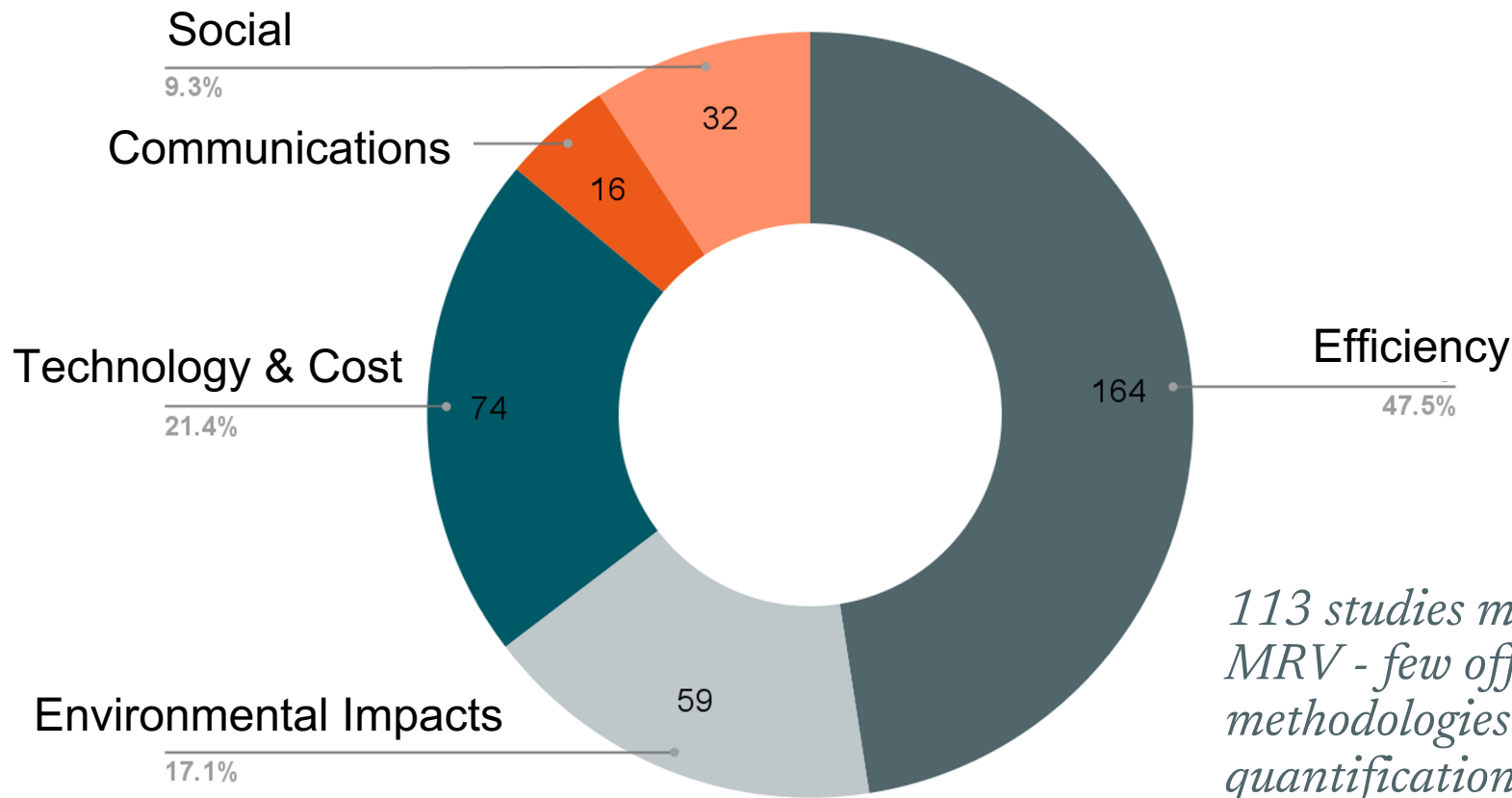
OAE Research  
is Done in More  
Locations

2015



OAE Research  
is Done in More  
Locations

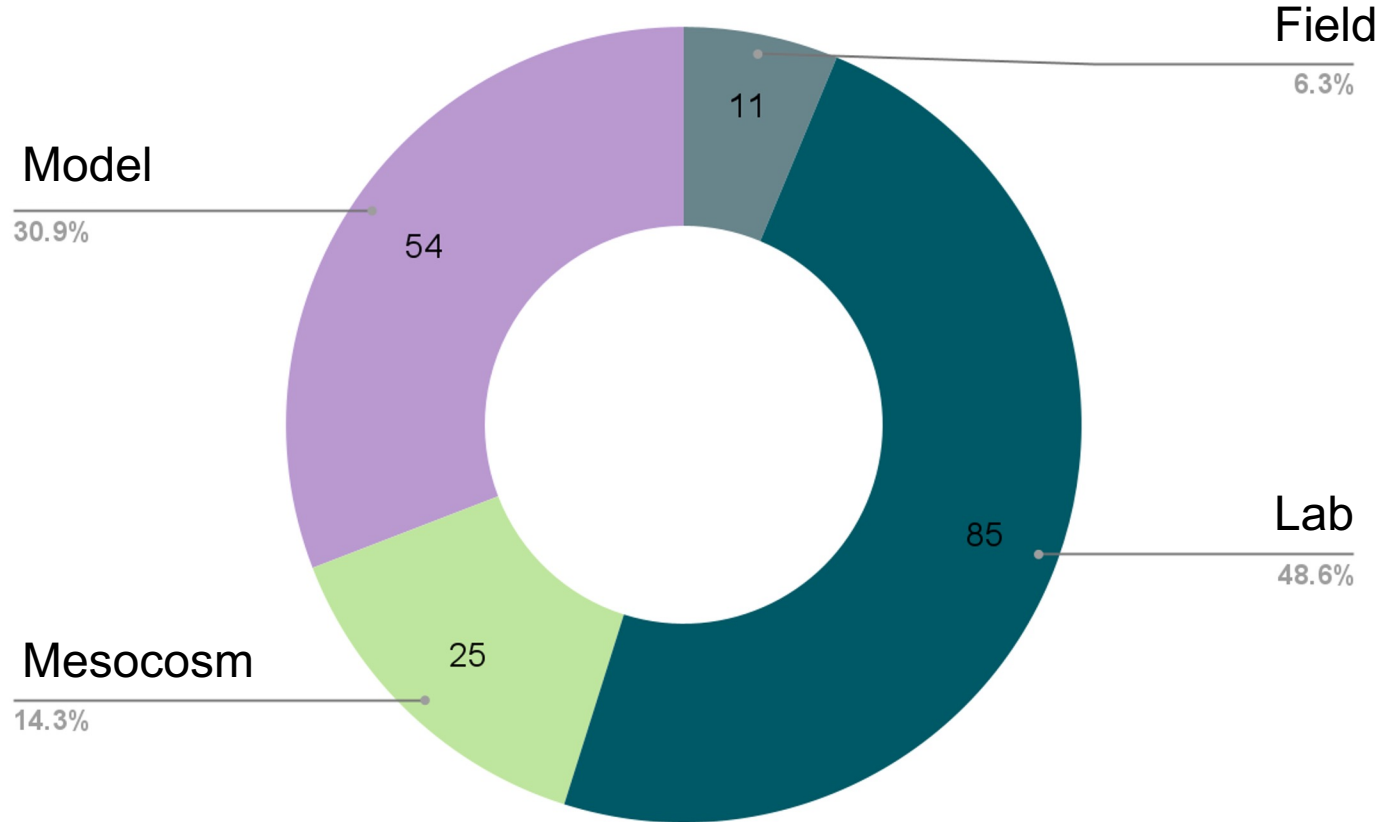
# Focus on OAE Research (1995- Present)



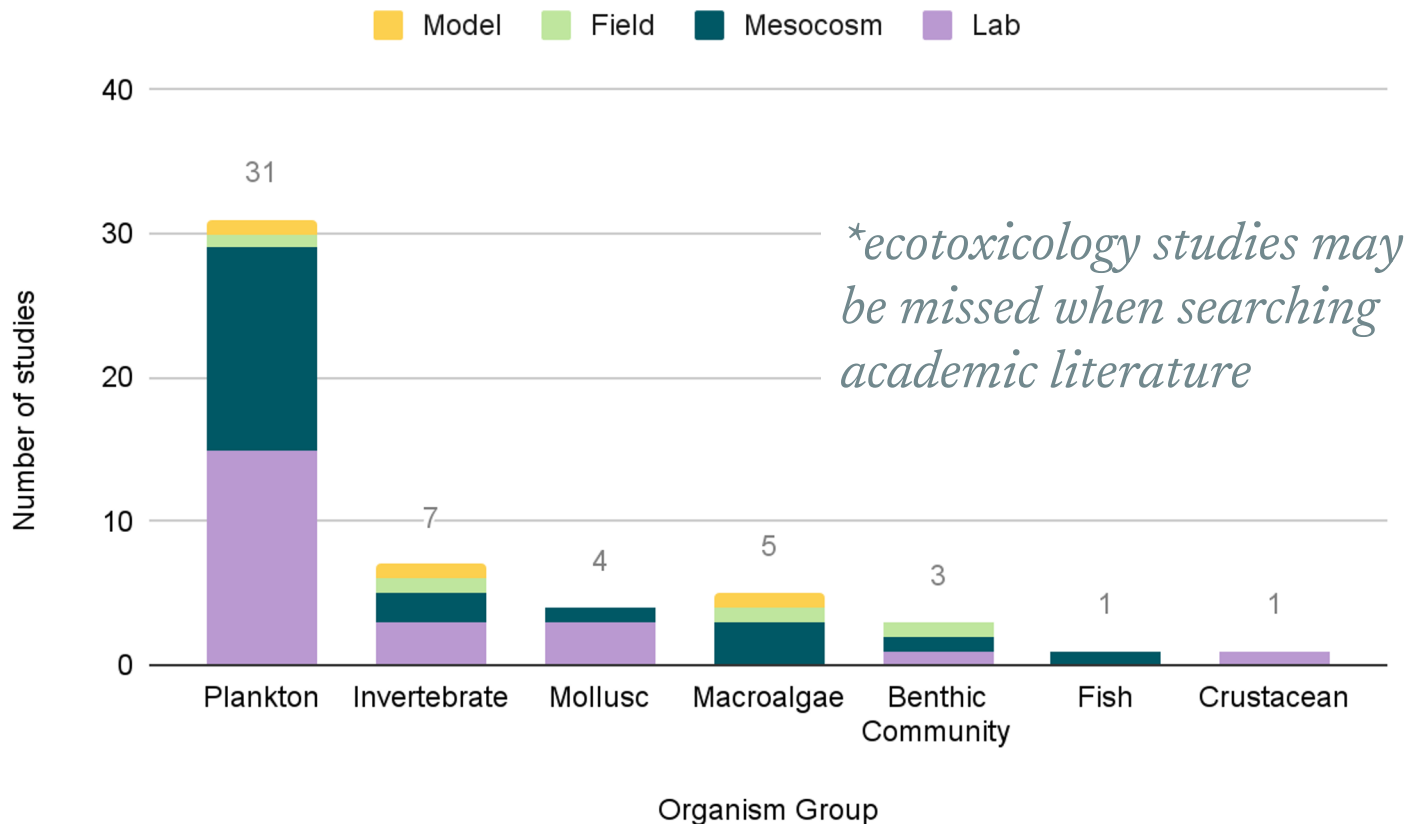
*113 studies mention  
MRV - few offer  
methodologies for  
quantification*



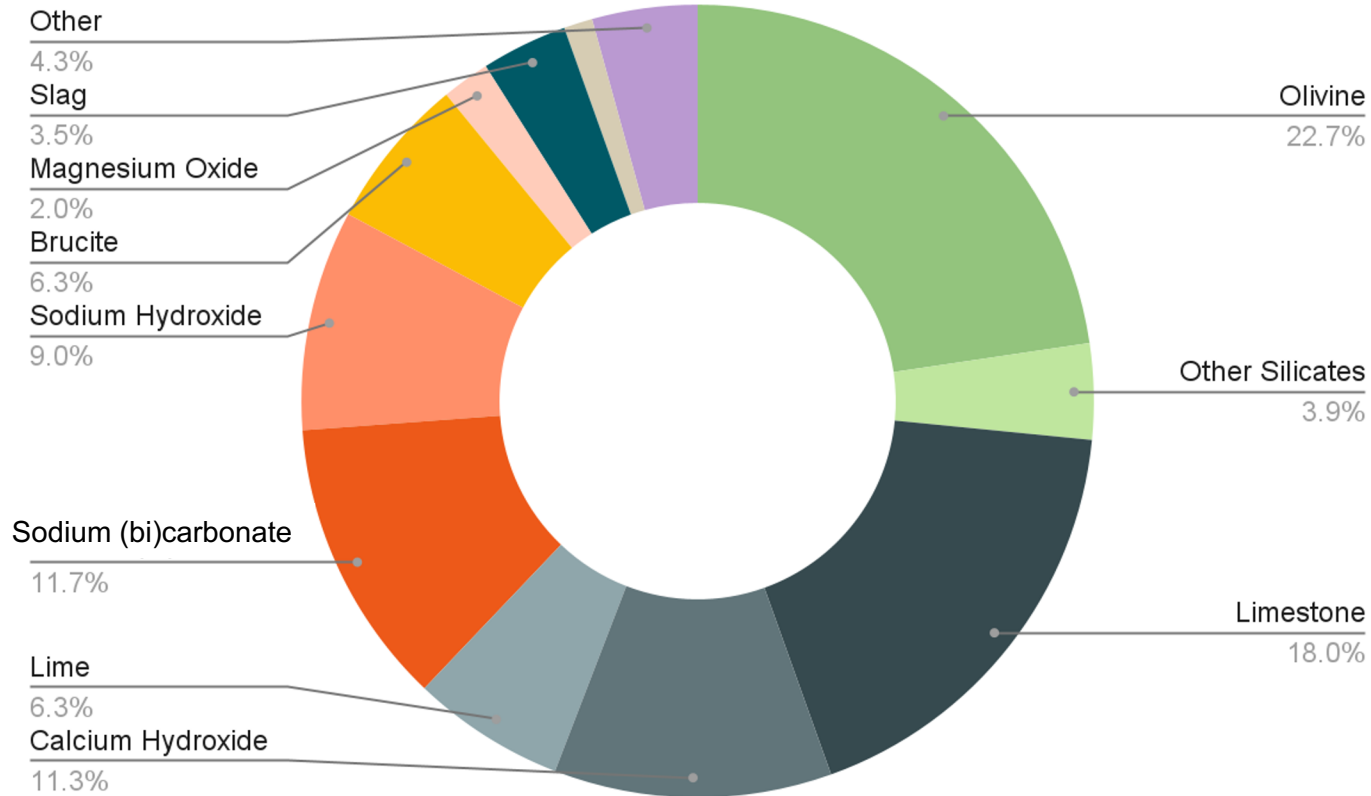
# Approaches used to Study Efficiency and Biological Impacts (1995-Present)



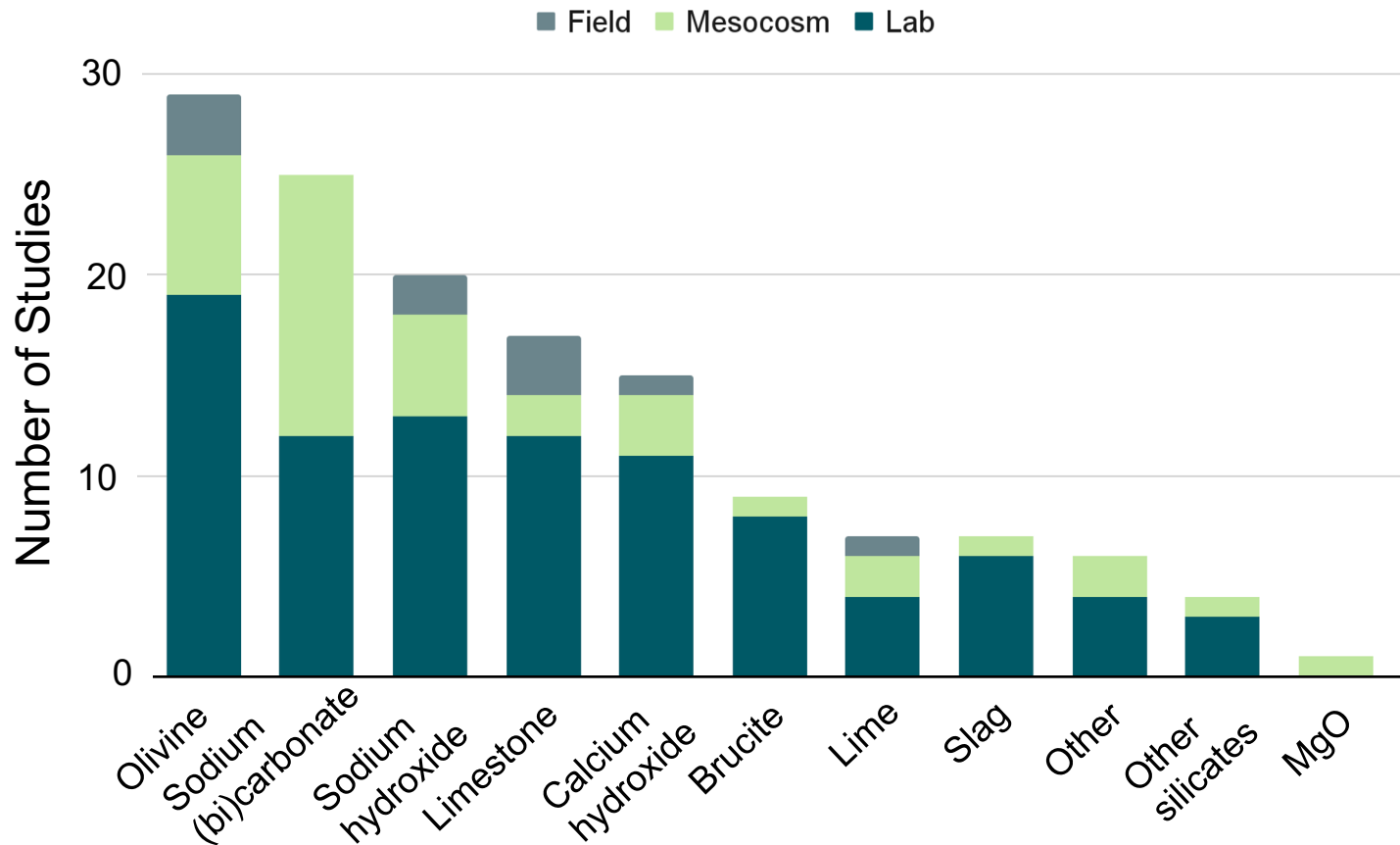
# Type of Biological Impact Study by Organism Group (1995-Present)



# Key Feedstocks, OAE Research (1995-Present)



# Approaches Used to Study Key Feedstocks (1995- Present)

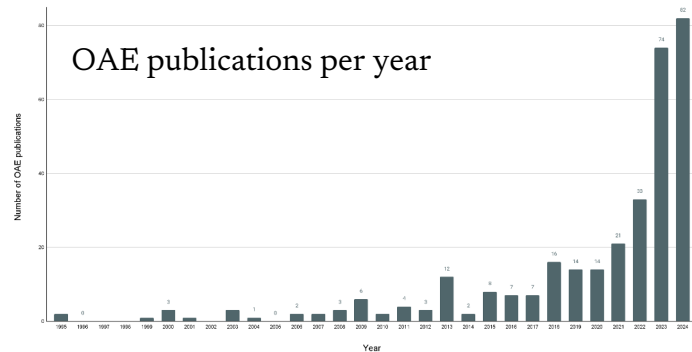


### *Three phases of OAE research:*

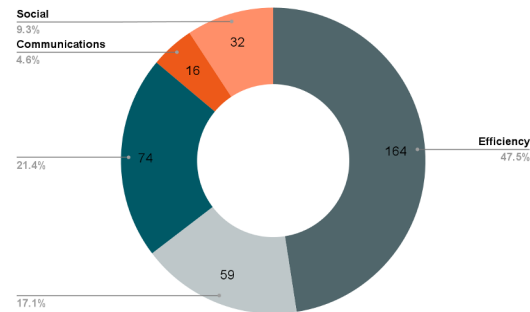
- 01 Foundational basic science
- 02 Early testing of the OAE hypothesis
- 03 Recent rapid expansion of the field

Clear understanding of what, how, and where research has been conducted

Number of recently funded projects indicates that many studies will soon be published



Focus of OAE research, 1995 - 2024





Carbon to Sea  
Initiative