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OAE Research Overview

The development and advancement of a new field

MAY 20, 2025

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

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

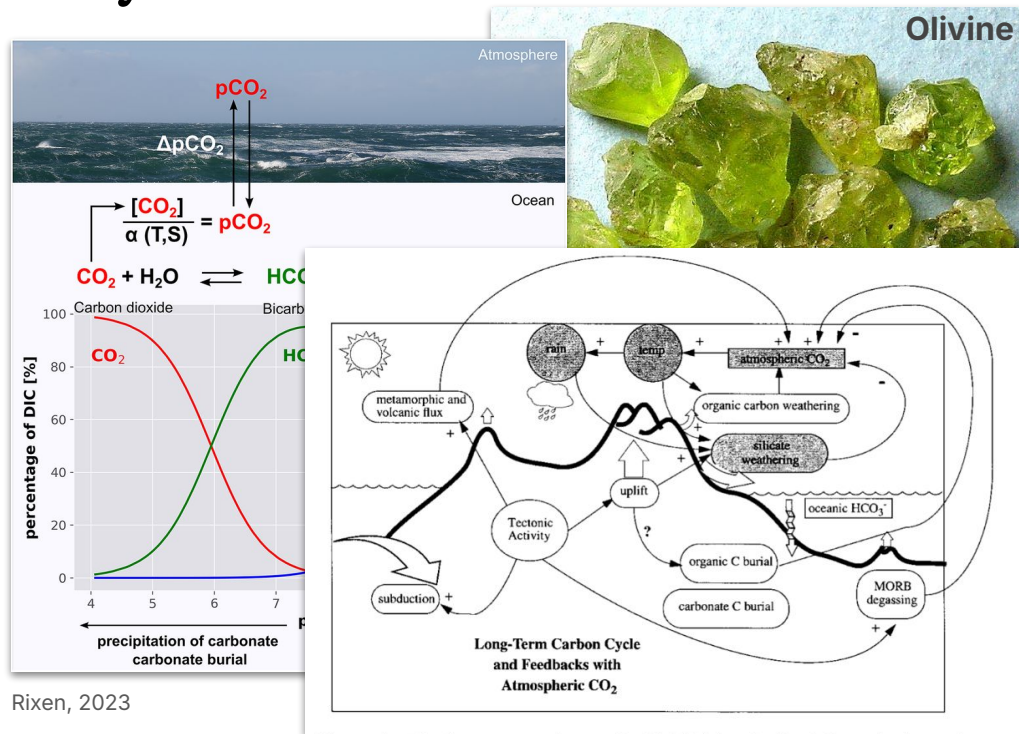
Mineralogy

02

*Chemical oceanography
& carbonate chemistry*

03

Climate system science



Rixen, 2023

Kump et al., 2000

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



Pergamon

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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

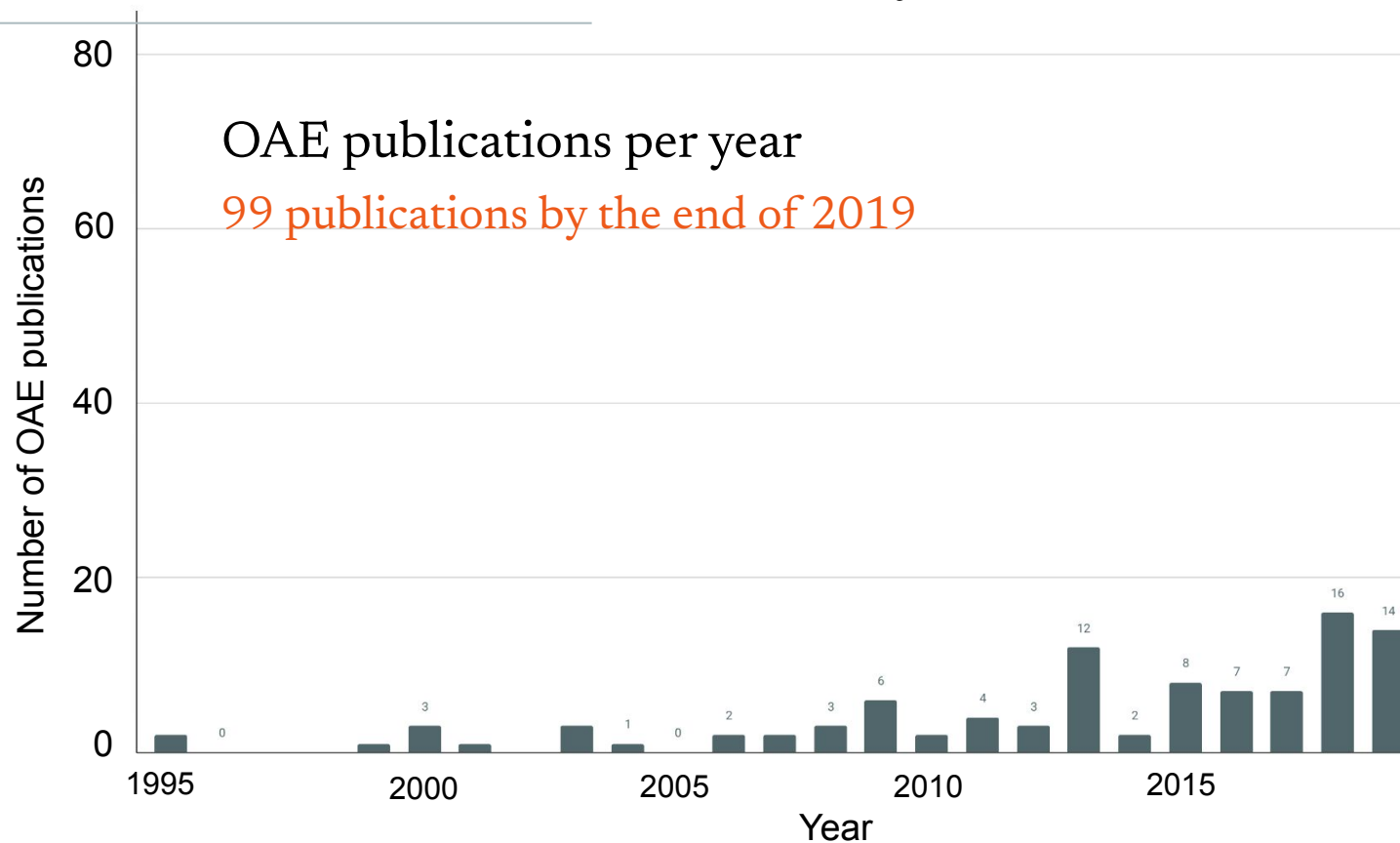
HAROON S. KHESHGI

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

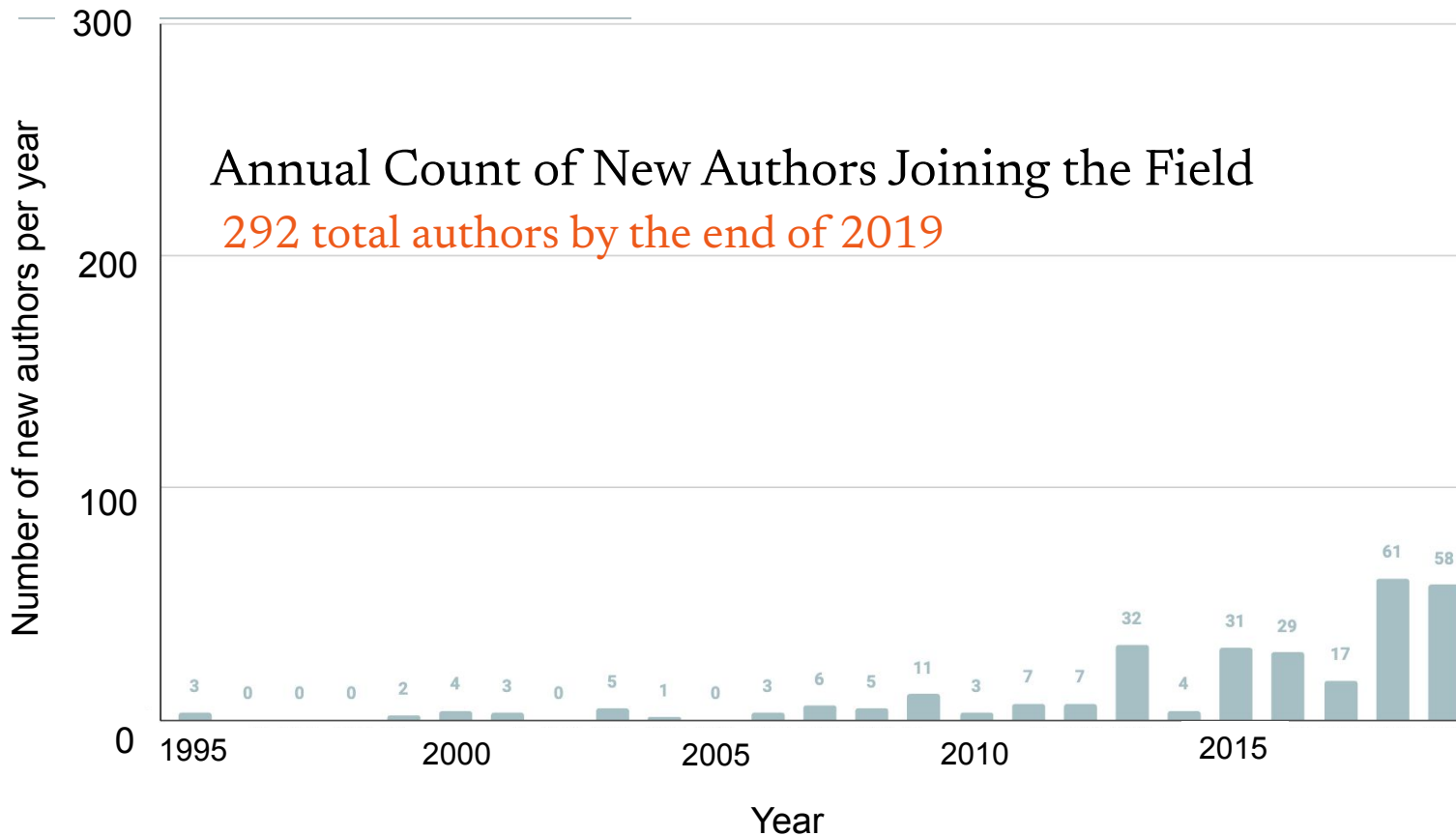
(Received 14 October 1994)



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

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*

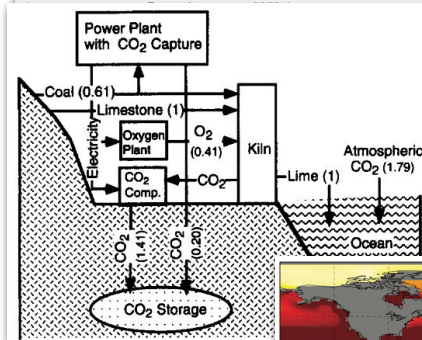
02 *OAE tech ideas*

03 *Small scale experiments to prove the chemistry*

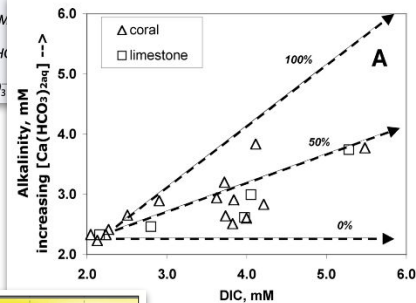
04 *Earth system modeling to explore CO₂ removal potential*

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

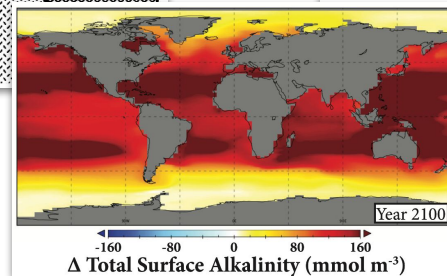
Equation Number	Mineral	ΔG_f (kJ/mole) ^a	Reaction	ΔG_r (kJ/mole) ^a	ΔG_r (kJ/mole C) ^a	gCO ₂ /g(mineral)
<i>Naturally Occurring Minerals</i>						
1	Magnesite	-1029.5	$MgCO_3 + CO_2 + H_2O \rightarrow Mg^{2+} + 2HCO_3^-$	22.5	22.5	0.52
2	Calcite	-1128.5	$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$	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



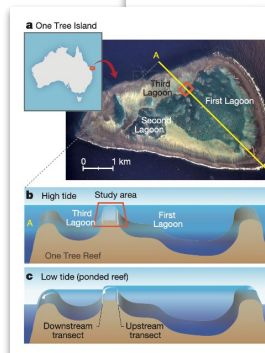
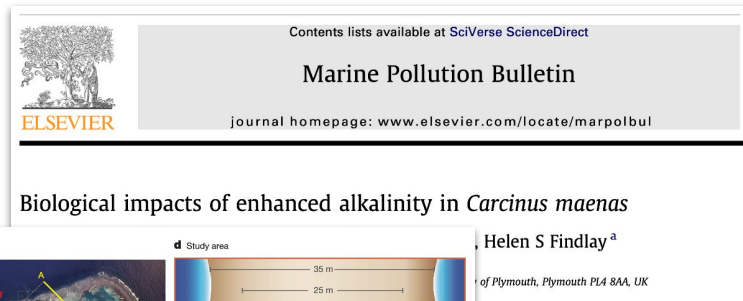
Keller et al., 2014

608 Gt
atmospheric CO₂
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

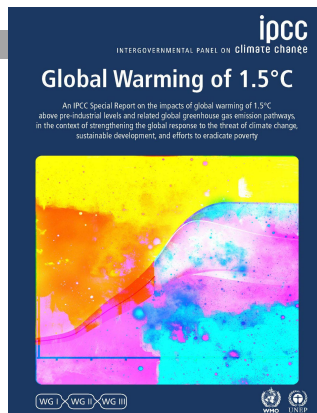
2013 - 2020, €9M
Limited OAE research

2013

2019

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

German Priority
Program on Climate
Engineering

2013 - 2020, €9M
Limited OAE research

EU OceanNETs
project

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



2013

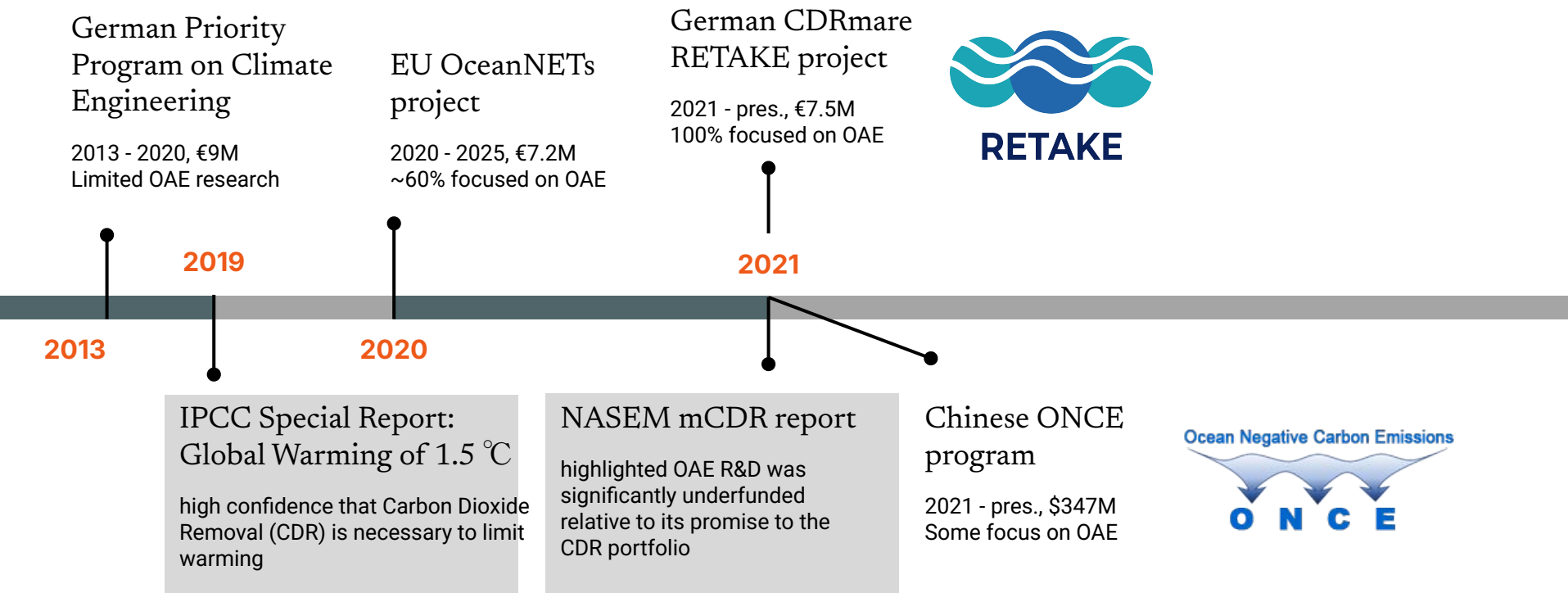
2019

2020

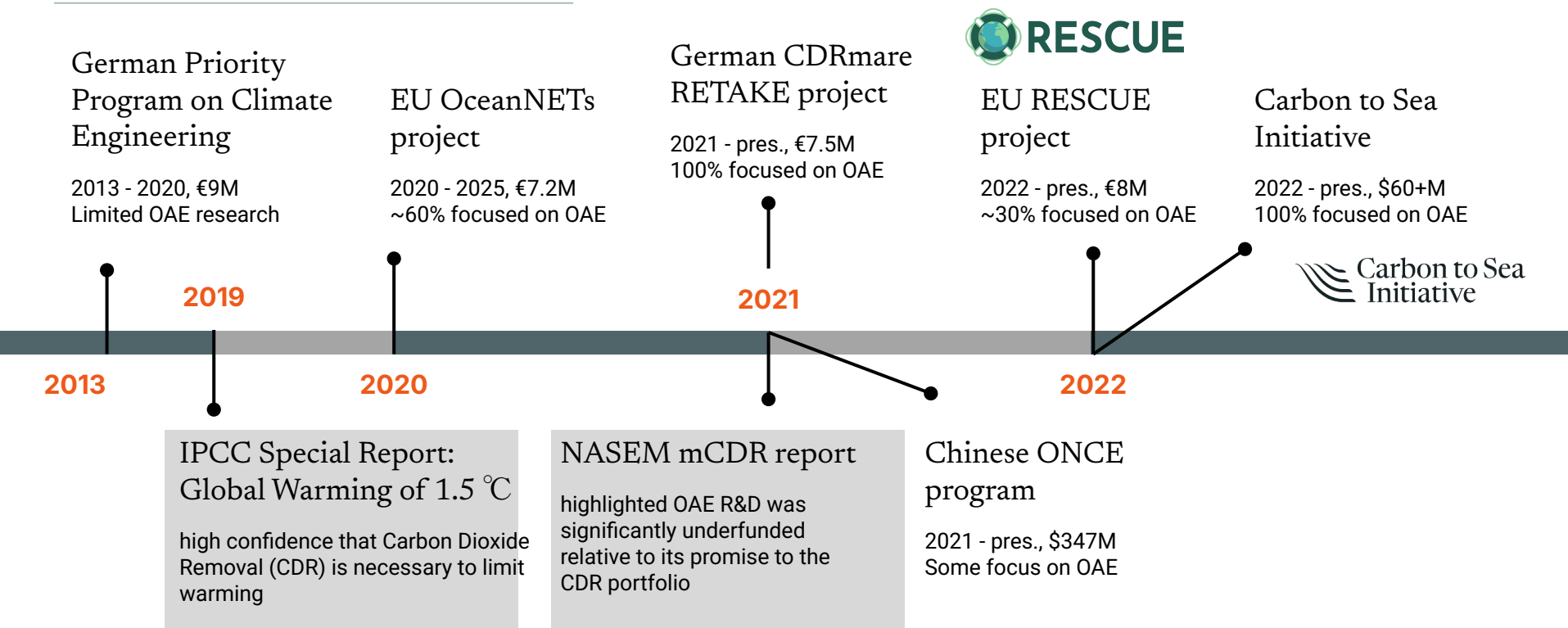
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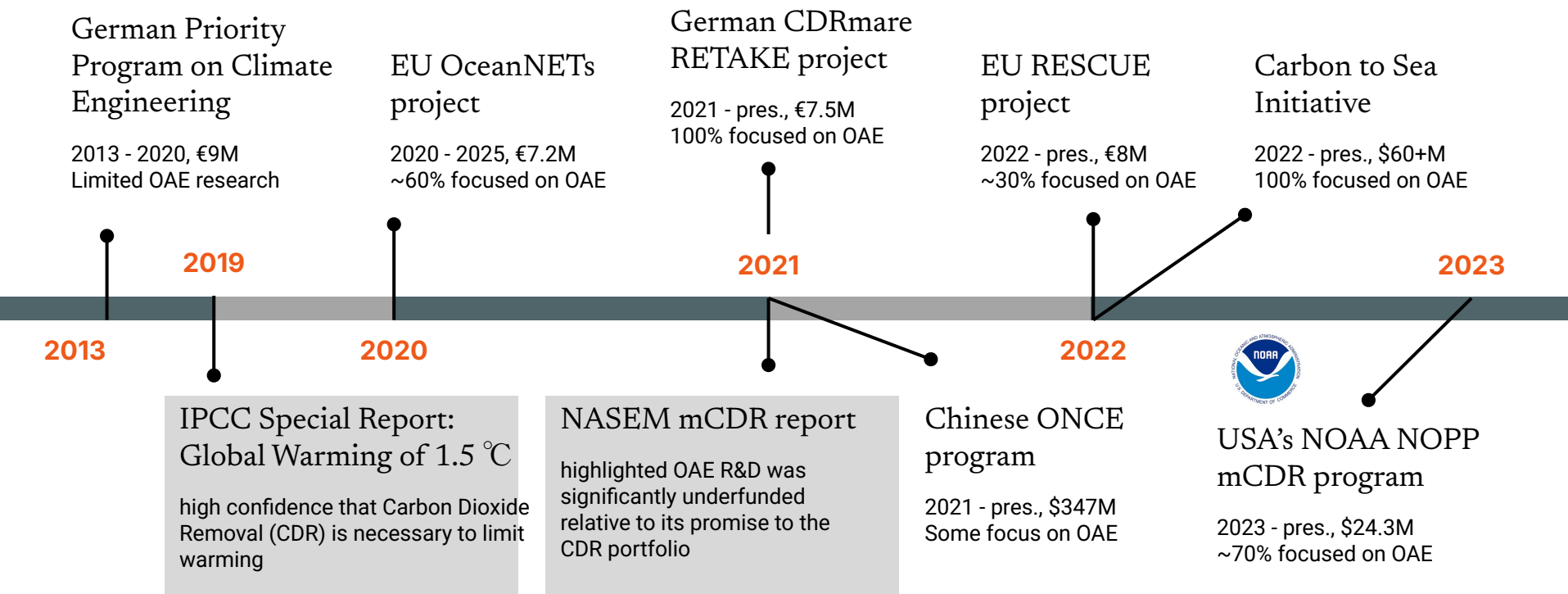
More Research on OAE is Funded



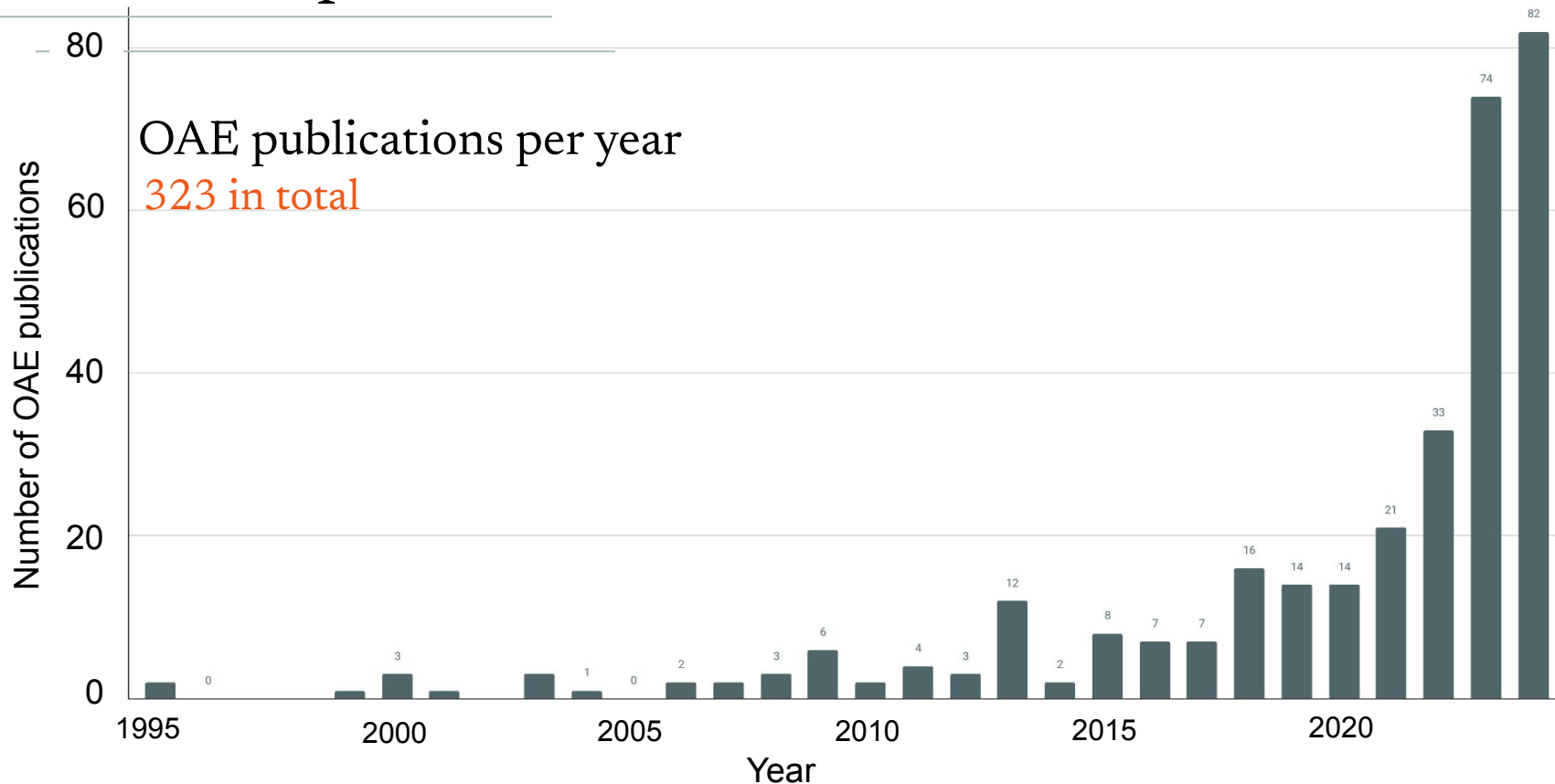
More Research on OAE is Funded



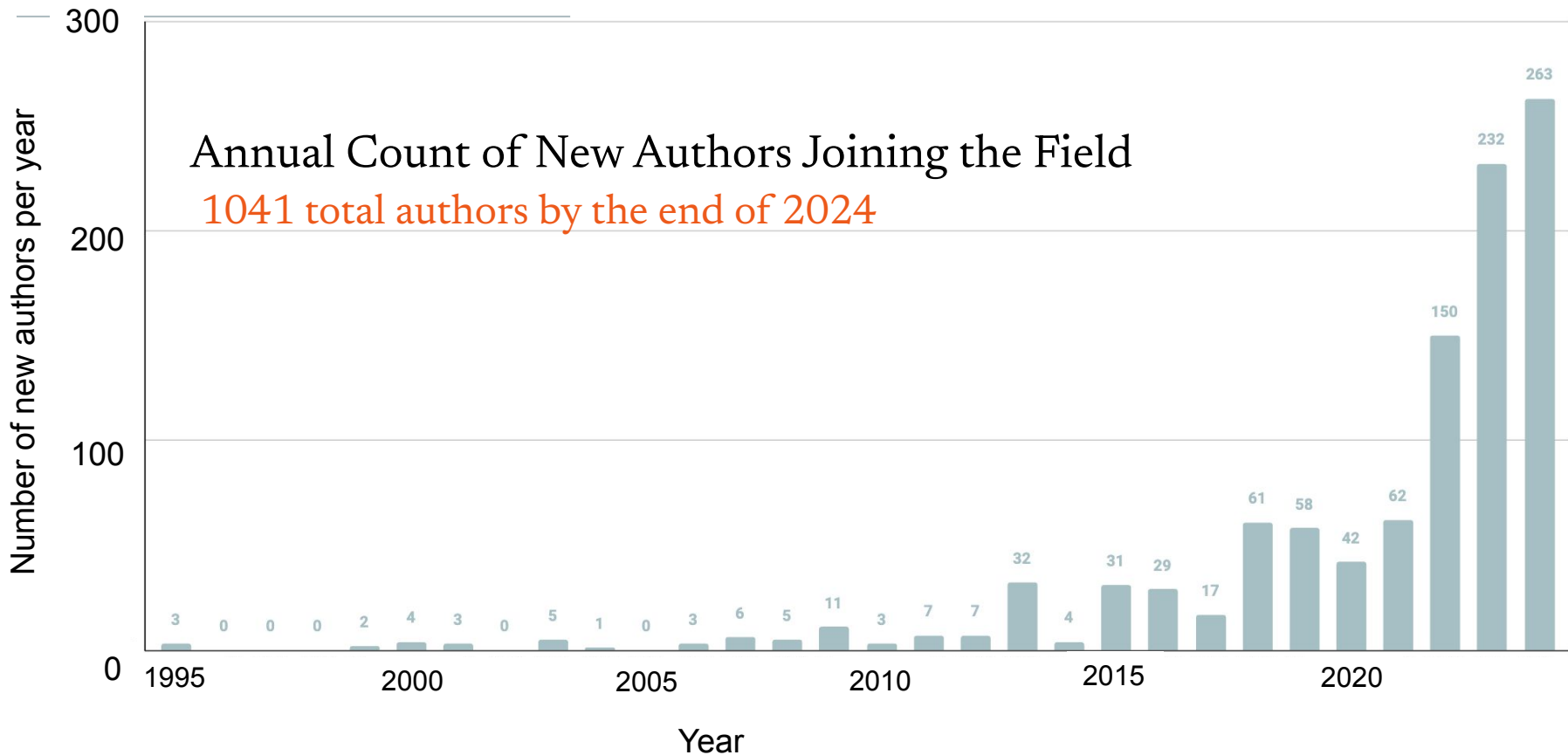
More Research on OAE is Funded



Recent Rapid Growth of OAE Research



Recent Rapid Growth of OAE Research



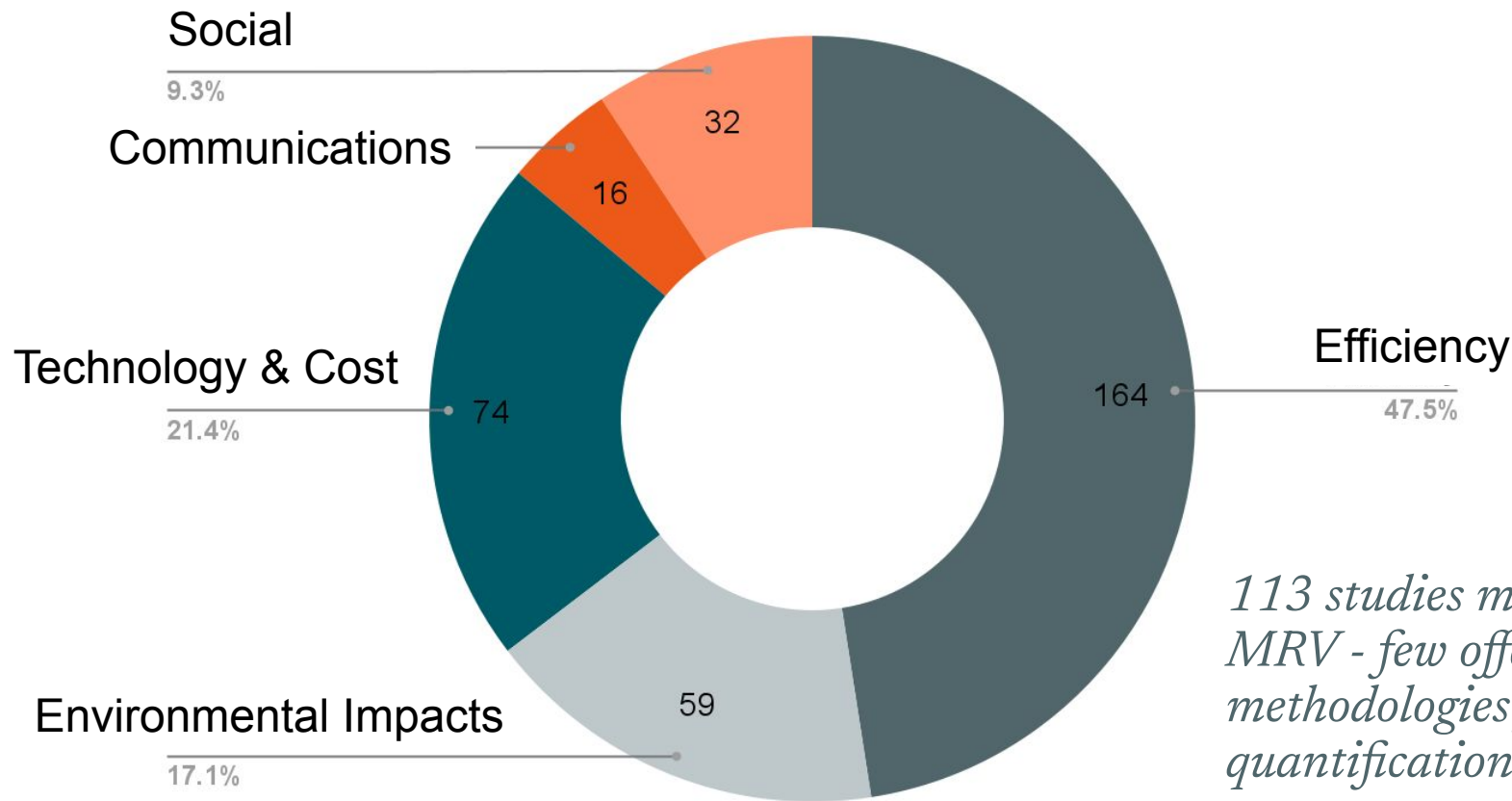


2015



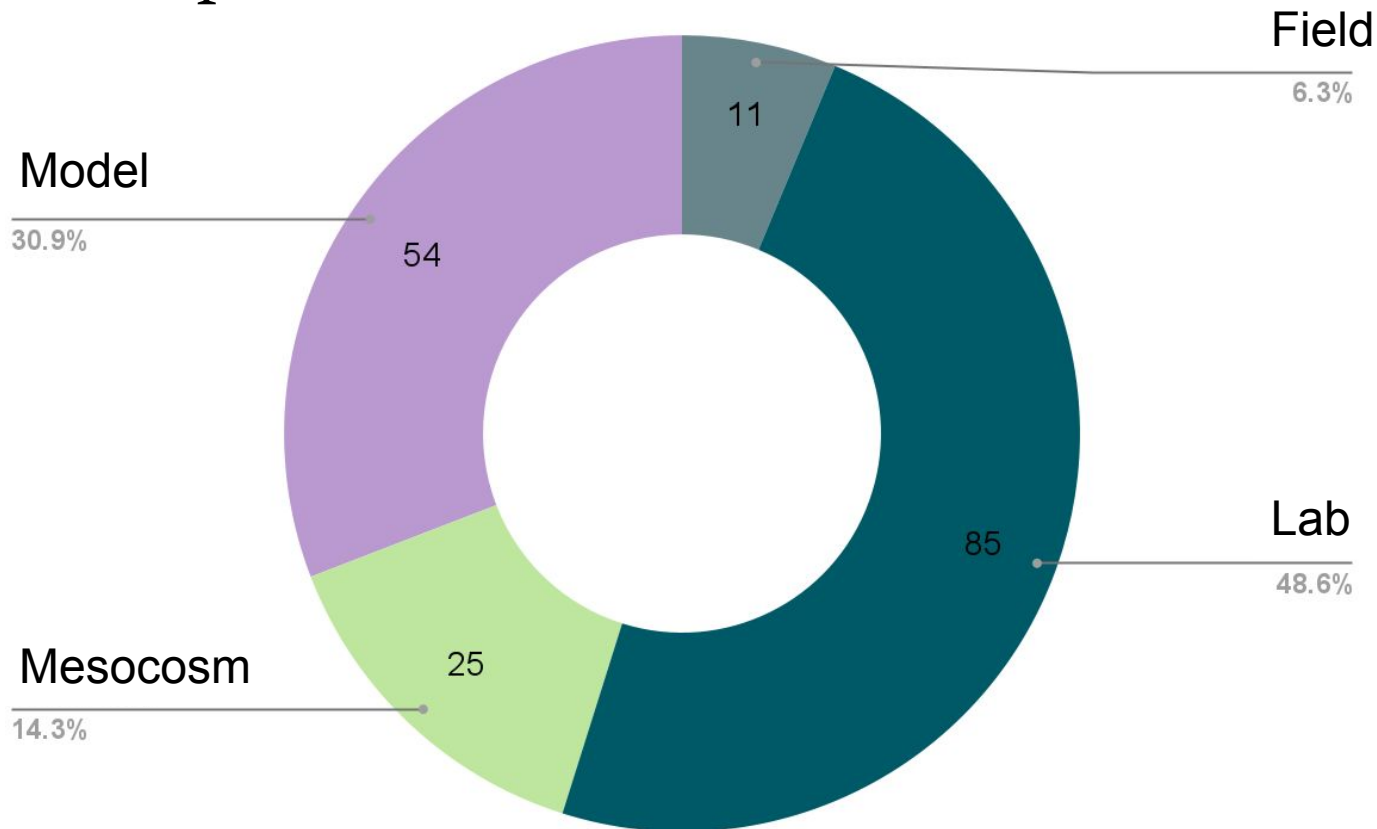
OAE Research
is Done in More
Locations

Focus on OAE Research (1995- Present)

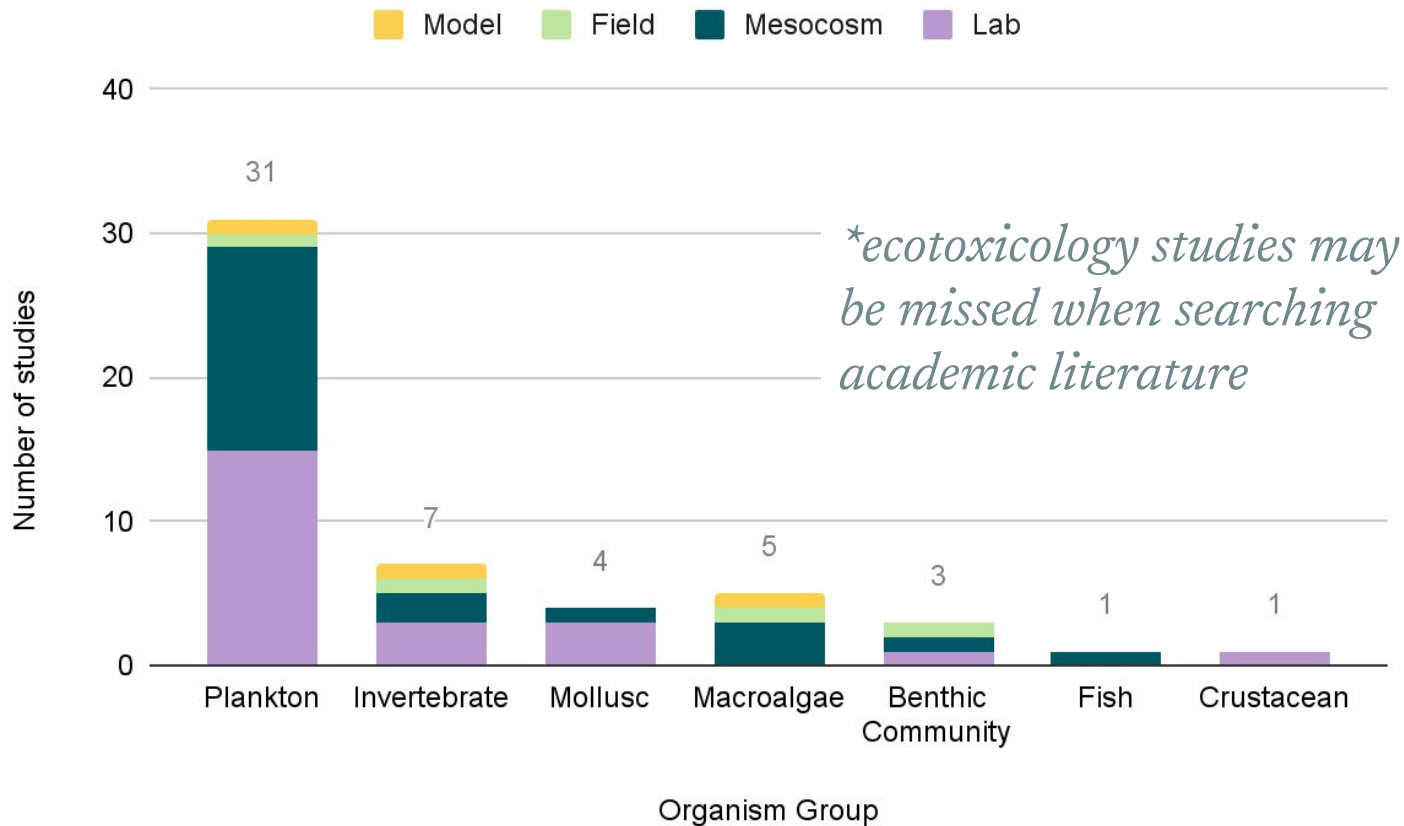


*113 studies mention
MRV - few offer
methodologies for
quantification*

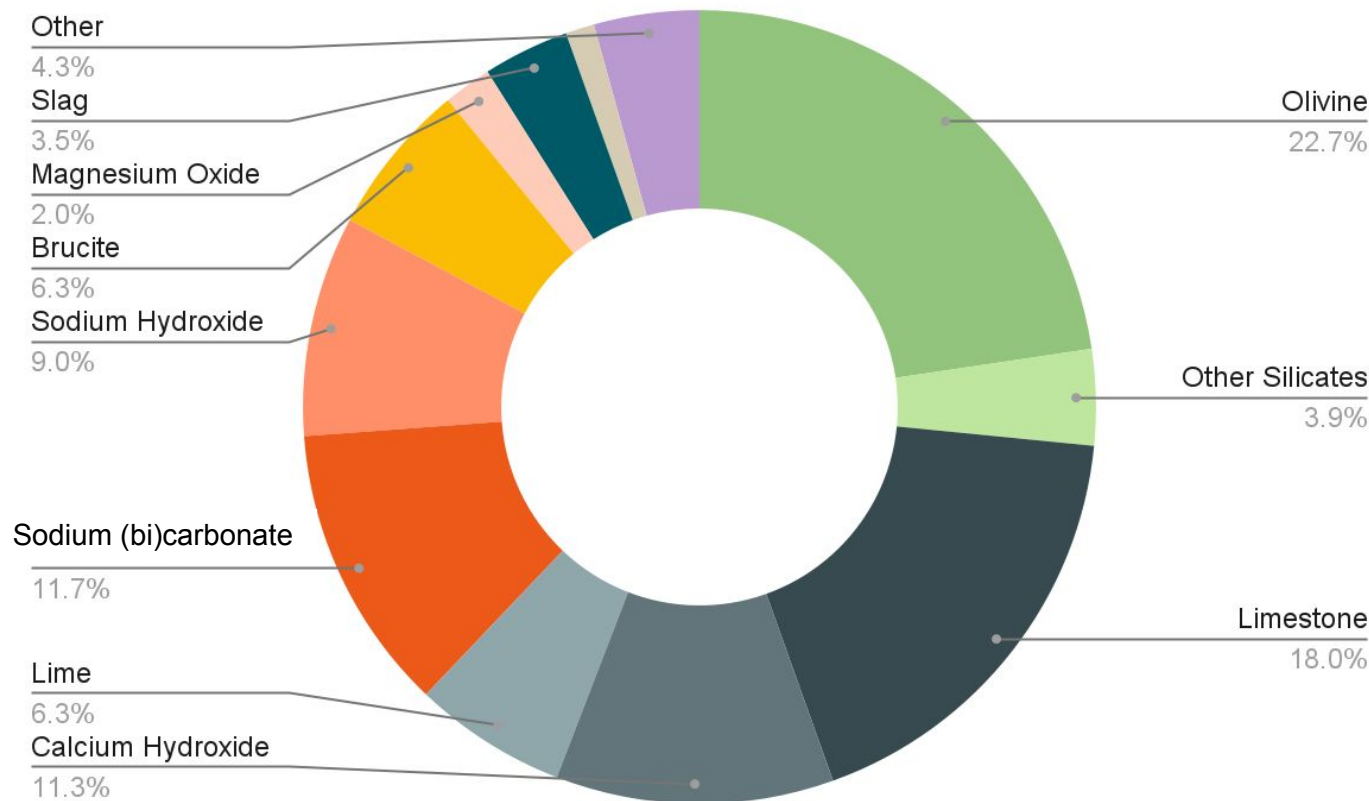
Approaches used to Study Efficiency and Biological Impacts (1995-Present)



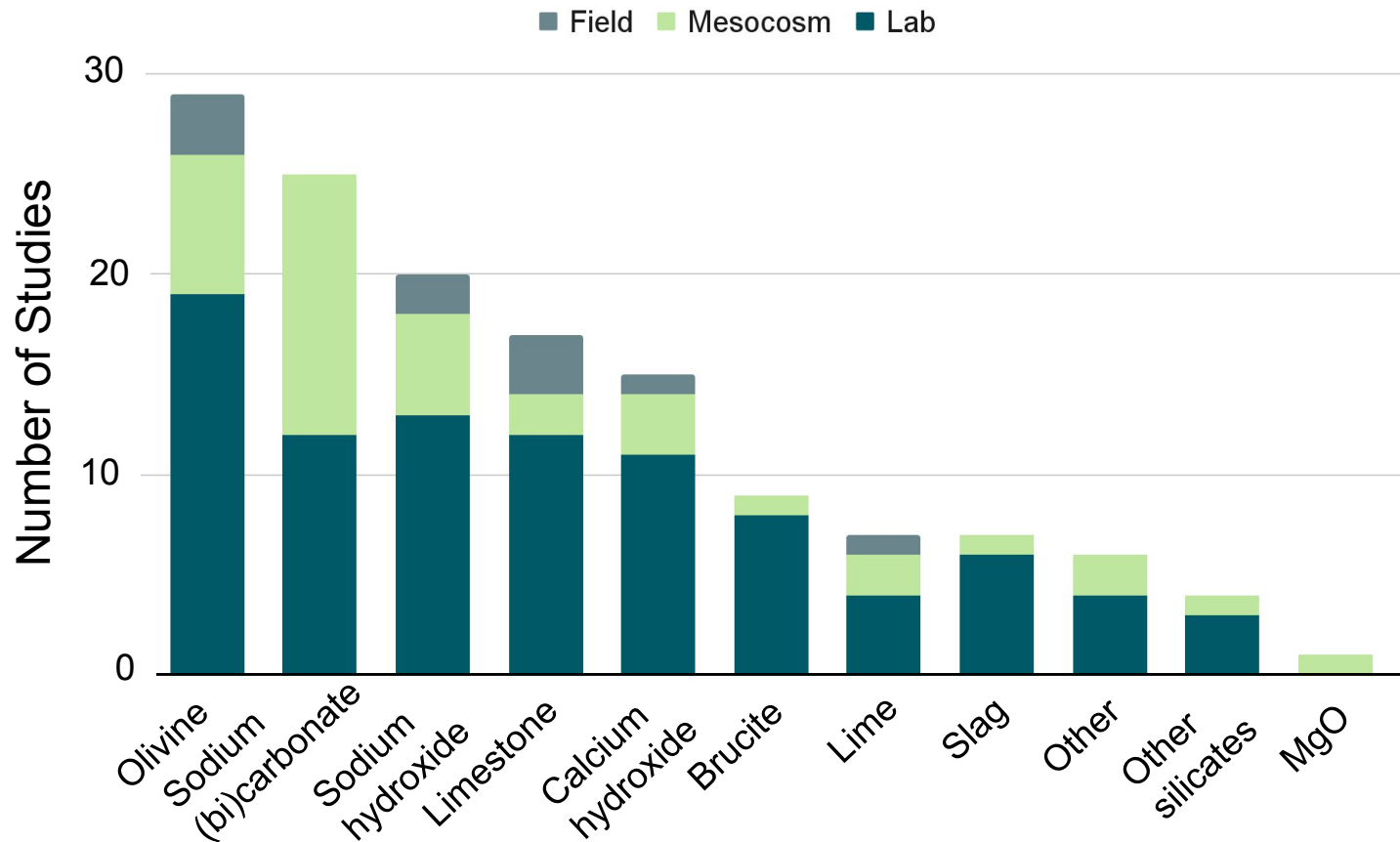
Type of Biological Impact Study by Organism Group (1995-Present)



Key Feedstocks, OAE Research (1995- Present)



Approaches Used to Study Key Feedstocks (1995- Present)

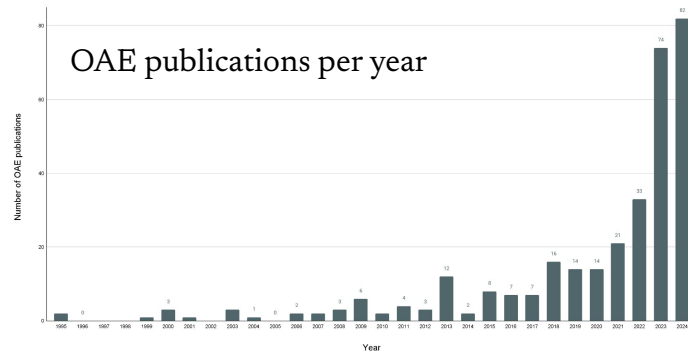


Three phases of OAE research:

- 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

