Agrobiotechnological Direct Air Capture Towards Carbon Circulation Society

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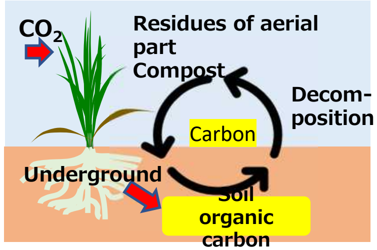
Negative emission technology in agriculture, forestry and fisheries

Utilization of photosynthesis（CO_2 absorption）

・**Super Crop**
Development of crops with high photosynthesis capacity

・**Biochar**
Agricultural land application of rice husk and wood



・**Soil carbon storage**
Agricultural land application of organic matter

・**Material conversion**
Bioethanol and bioplastics

・**Reforestation and forest regeneration**
Elite tree and
new materials derived from wood

・**Blue Carbon**
Carbon storage by algae bed

Source : "Negative emission technology (NETs)" (NEDO Technology Strategy Center)

Potential of CO_2 absorption/fixation of crops

Assumption: 10t/ha biomass increase

＜Present＞

Average crop yield
10t/ha/year
CO_2 absorption/Fixation

1.5 kg- CO_2/m^2/year

world arable land:1500 M ha
→22.5 Gt CO_2 Fixation

= 67% of global GHG emissions (33.5Gt)

＜2050＞

20t/ha/year
3.0 kg- CO_2/m^2/year

→ **45 Gt** CO_2 Fixation

= 134% of global GHG emissions (33.5Gt)

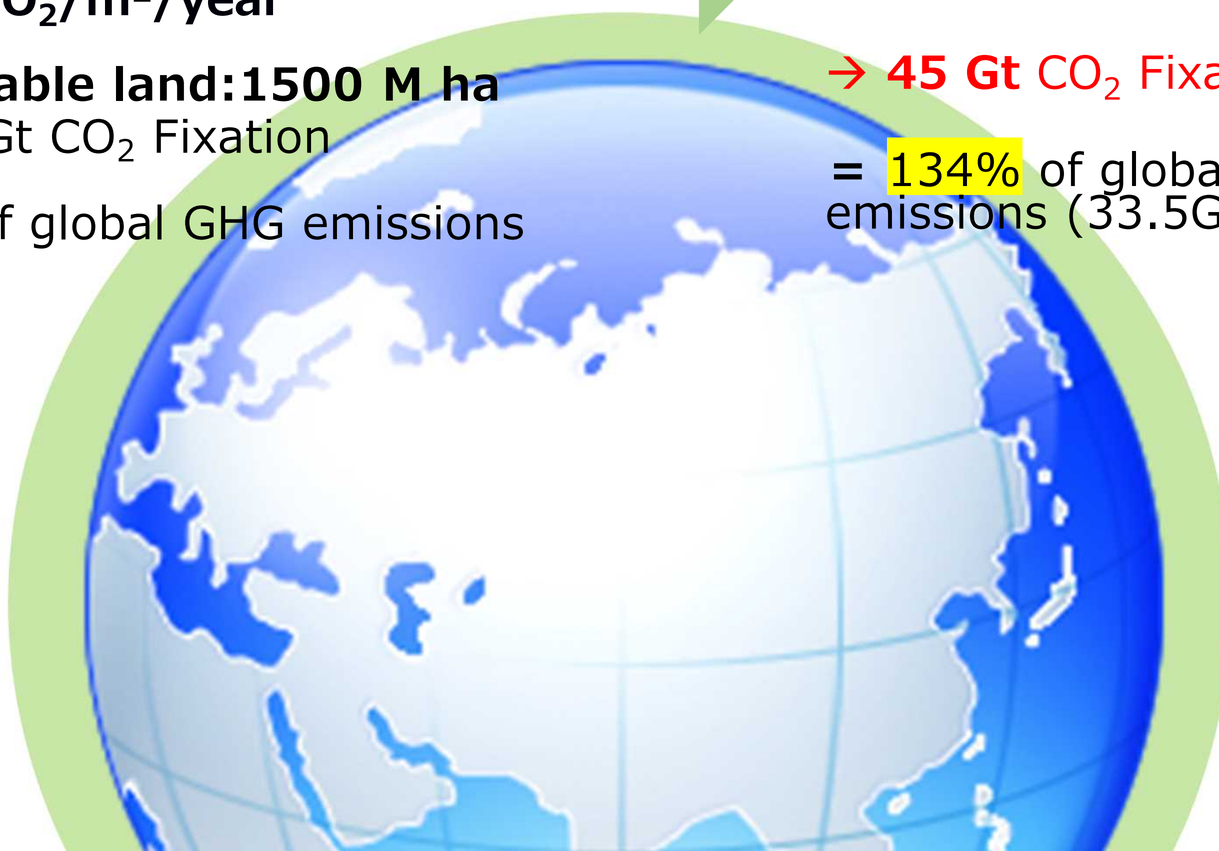
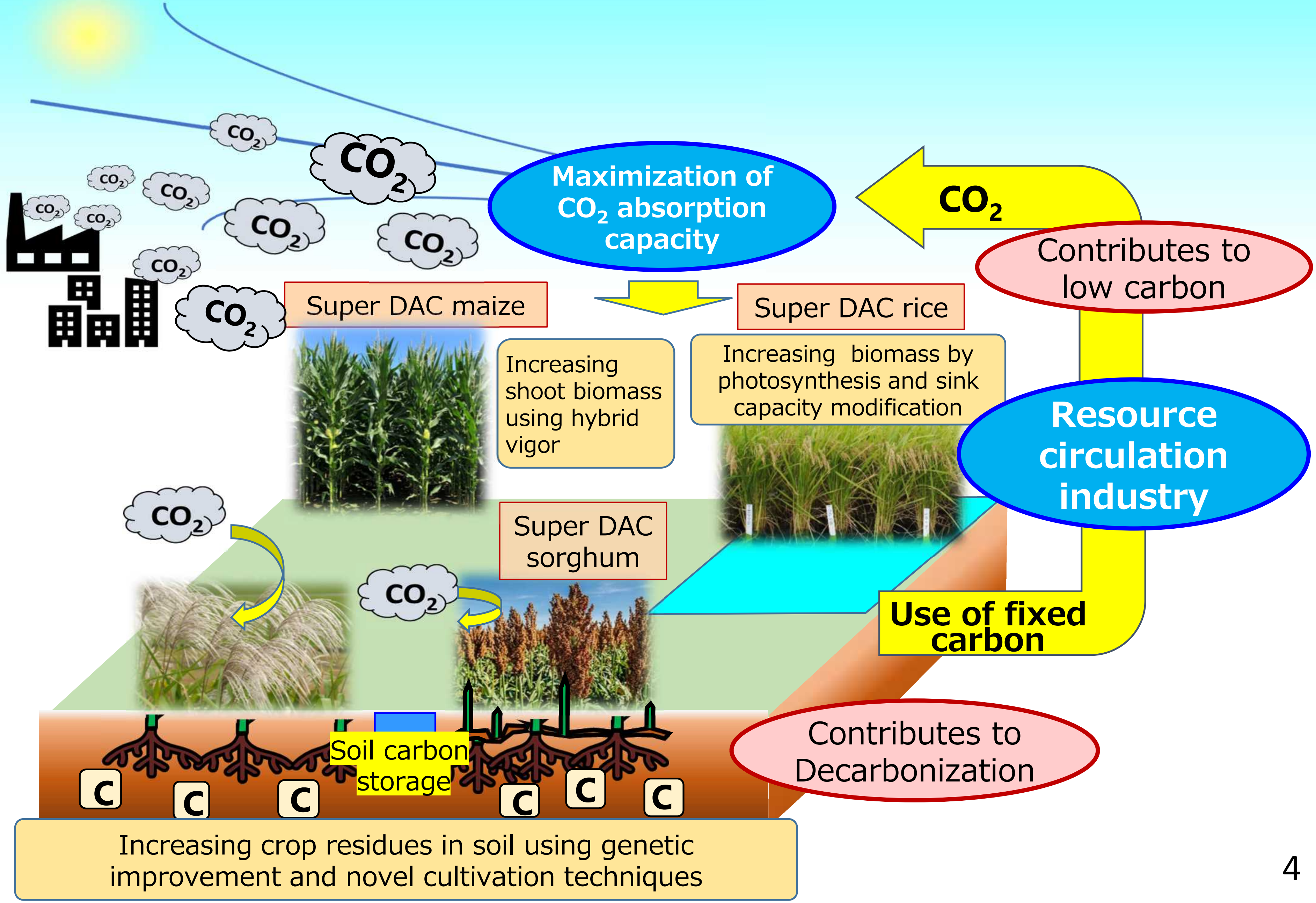
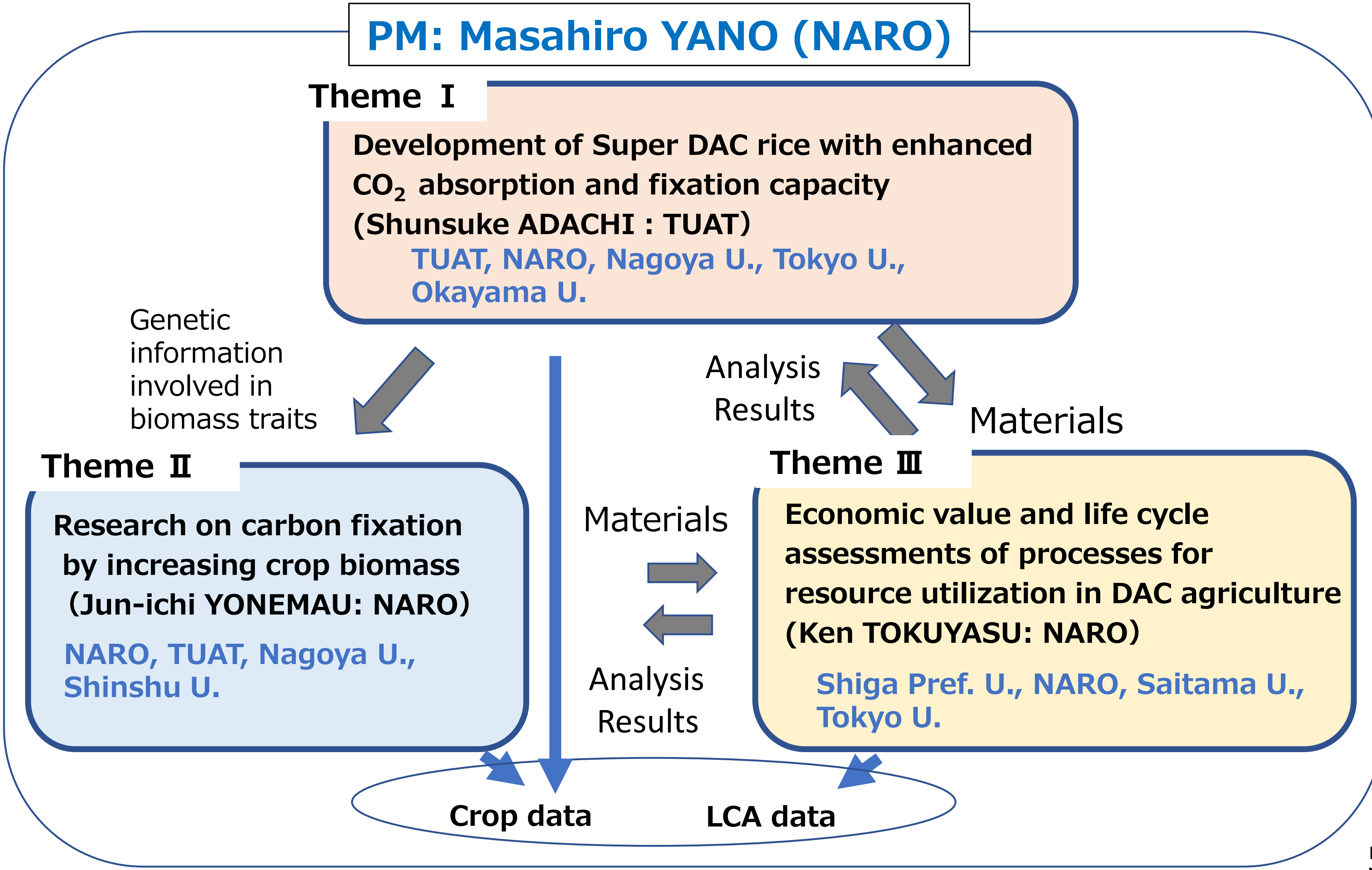


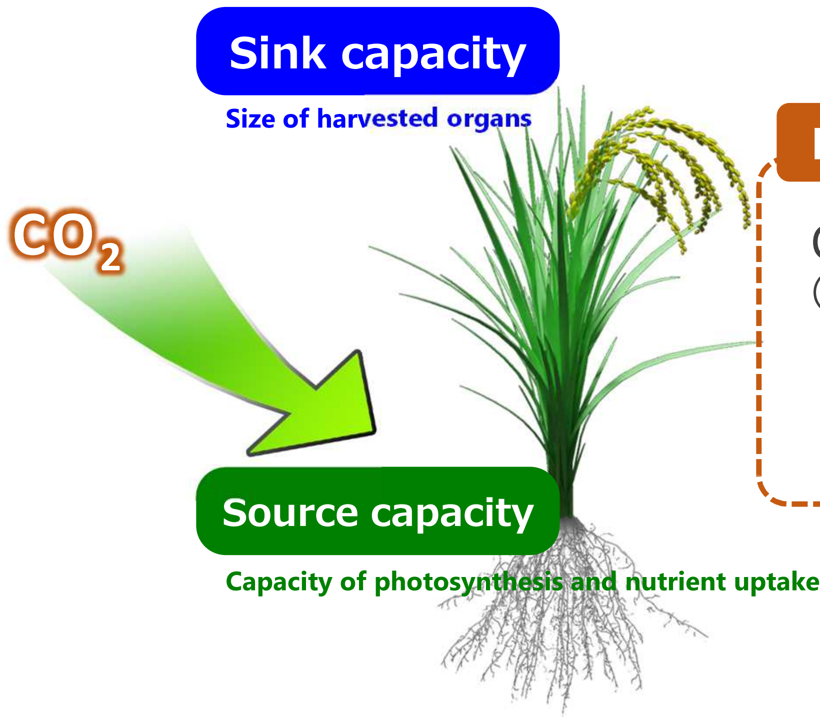
Image of DAC agriculture in 2050



Research and development system and collaboration between projects



Development Goals of Super DAC Rice

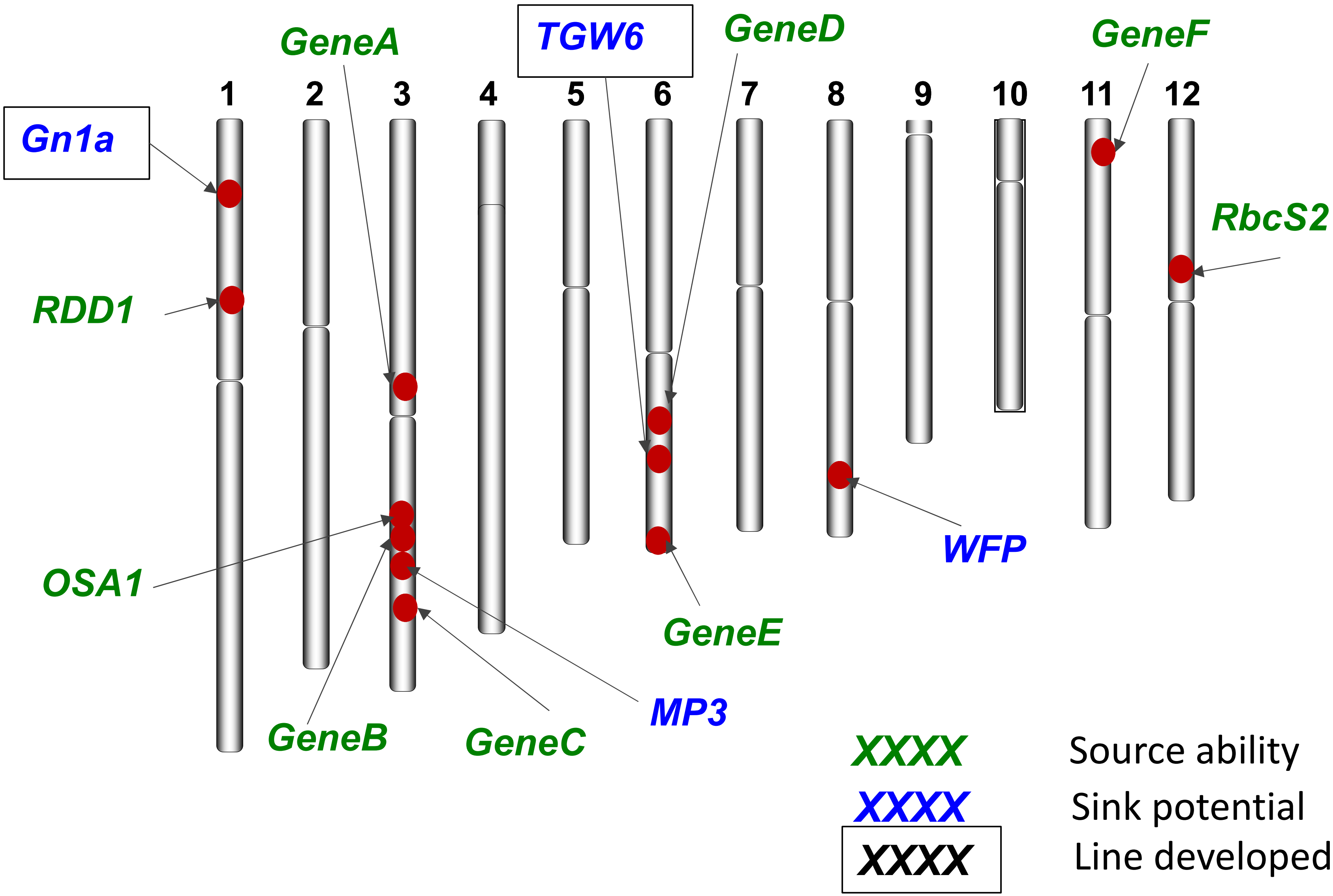


	The highest yielding variety "Hokuriku 193"		Target value for new species in 2029
Biomass	total 20 t/ha		**total 24 t/ha**
Grain yield (including husks)	10 t/ha	›››	**14 t/ha**
Straw yield	10 t/ha		**10 t/ha**

Use as a carbon resource

Development of Super DAC paddy rice with high CO_2 absorbing capacity by breaking the limits of sink and source capacities.

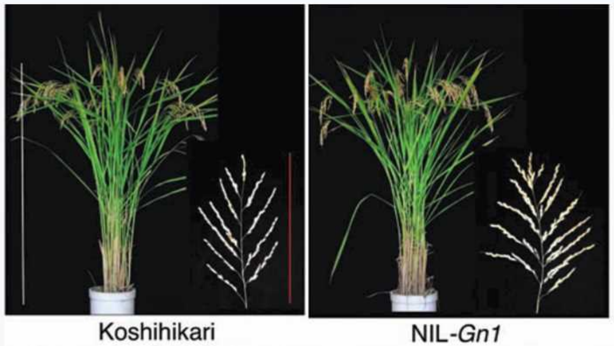
List of genes subject to modification



Theme I： Development of Super DAC Rice

List of genes subject to modification

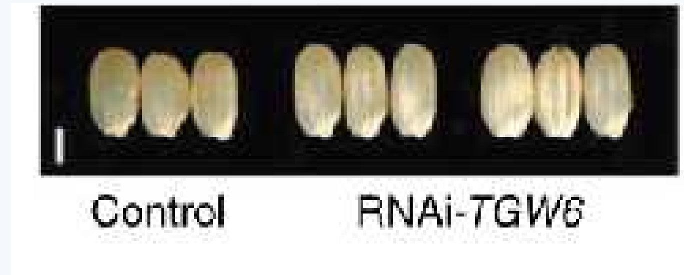
Gn1a (*Grain number 1a*)



Loss of function increases the number of rice grain

Ashikari *et al*. (2005) ***Science***

TGW6 (*Thousand-Grain Weight 6*)



Loss of function increases the size of rice grain

Ishimaru *et al*. (2013) ***Nature Genetics***

OSA1

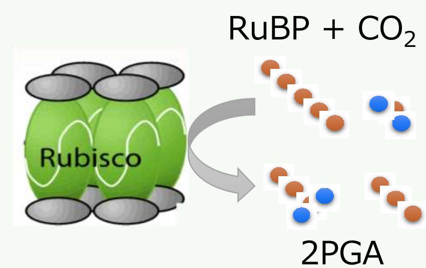
(*Oryza sativa* Plasma Membrane H⁺-ATPase)

Increased expression increases stomatal opening and biomass yield

Zhang *et al*. (2021) ***Nature Communications***

RbcS2

(*Rubisco small subunit 2)*



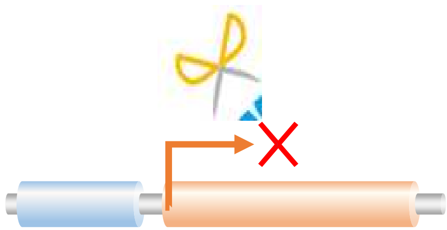
Increased expression increases CO_2 fixation enzyme Rubisco content and biomass yield

Yoon *et al*. (2020) ***Nature Food***

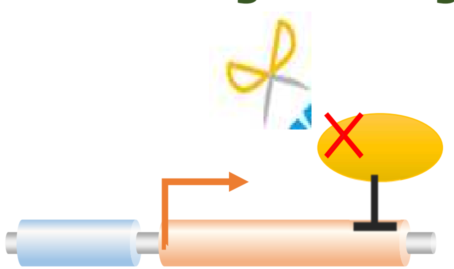
Two approaches for developing breeding materials

① Genome editing

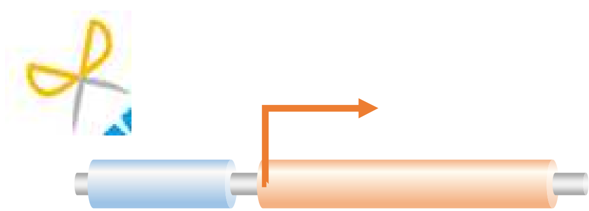
Knockout target gene



Knockout negative regulator

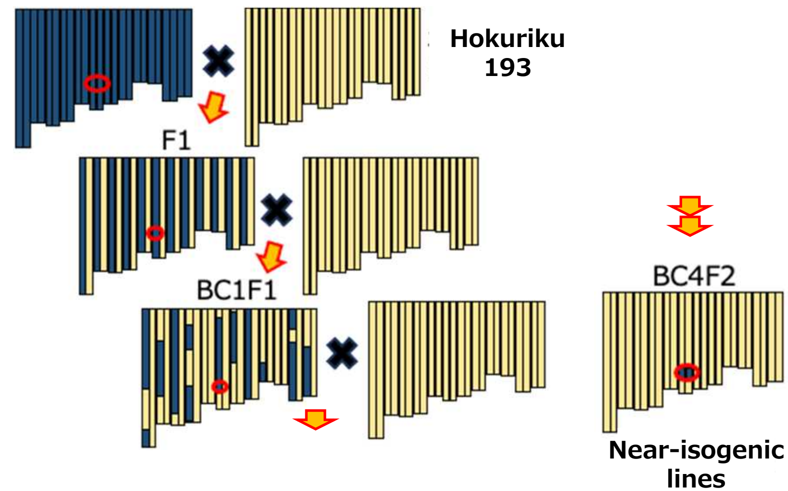


Enhance gene expression by mutation of promoter region



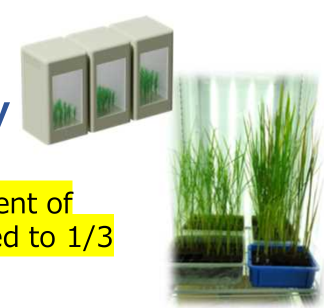
②DNAマーカー選抜

Developing near-isogenic lines with the genetic background of “Hokuriku 193”



Introducing the target genes by artificial crosses to enhance DAC properties

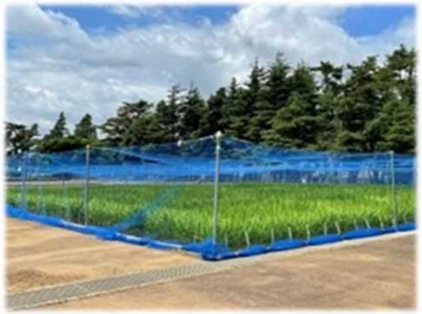
High-Speed Generation Acceleration Technology



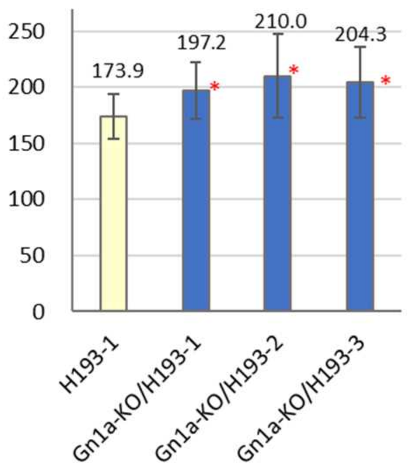
The period required for development of a near-isogenic line can be reduced to 1/3

Improvement of sink capacity（*Gn1a, TGW6*)

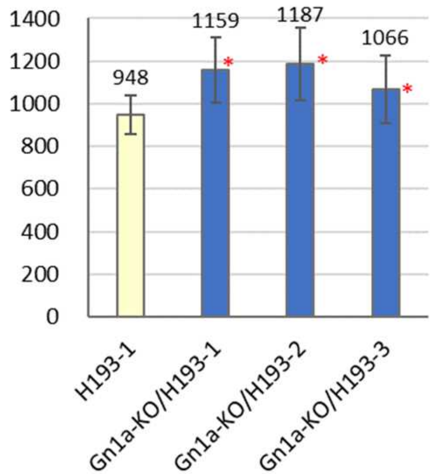
Gn1a (*Grain number 1a*) Knockout



Spikelets per panicle

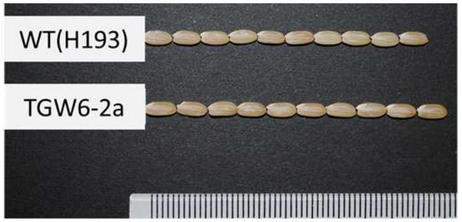


Sink capacity (g/m²)

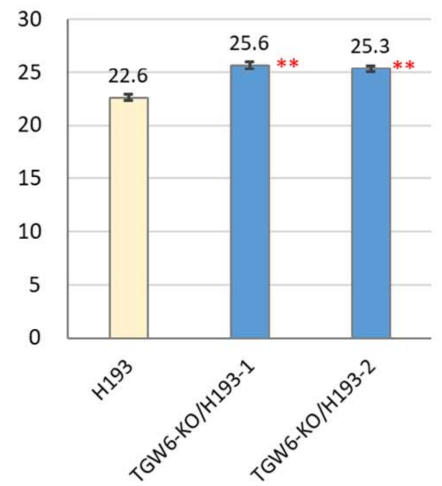


✓ *Gn1a*-KO genome-edited lines grown in field isolation increased **sink capacity by up to 25%** compared to Hokuriku 193

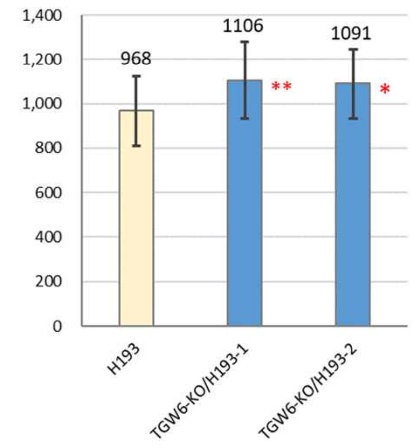
TGW6 (*Thousand-Grain Weight 6*) Knockout



Thousand-grain weight (g)



Sink capacity (g/m²)



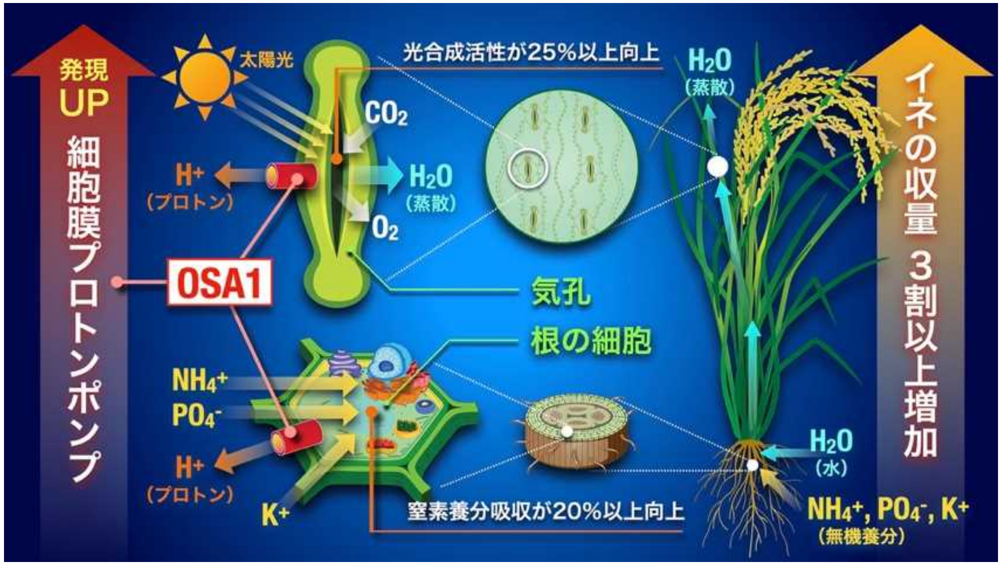
✓ *TGW6*-KO genome-edited lines grown in field isolation increased **sink capacity by up to 14%** compared to Hokuriku 193

✓ The pyramiding lines will be developed for field evaluation

Marker-selection

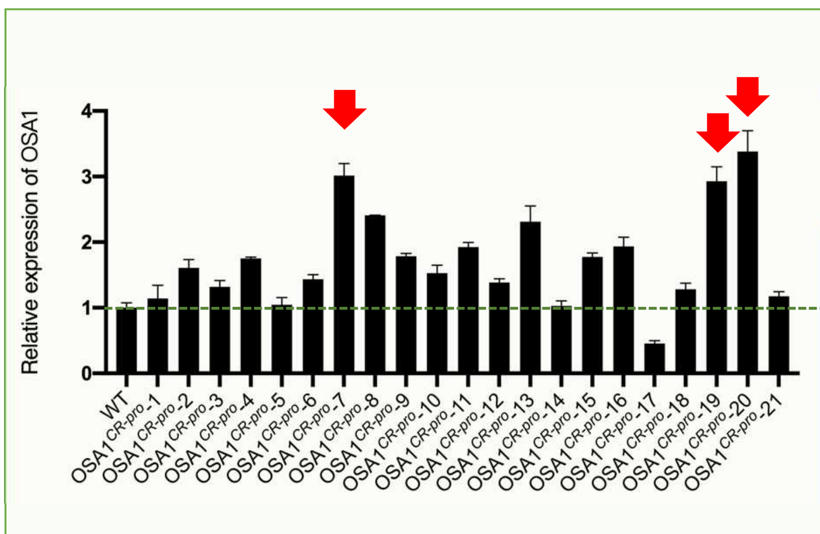
Theme I： Development of Super DAC Rice

Improvement of source capacity (*OSA1* overexpression)

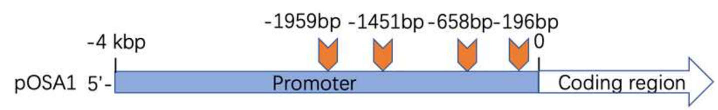


Overexpression of *OSA1* in rice variety "Nipponbare" **significantly improves photosynthesis and yield**

Zhang, Kinoshita et al. 2021 Nature Communications 12: 735



Overexpress *Genome editing*



- ✓ Mutations were introduced into the promoter region by genome editing to achieve a transformation-independent increase in *OSA1* expression.
- ✓ In Nipponbare background T0 plants, several lines with higher expression levels than Nipponbare appeared.

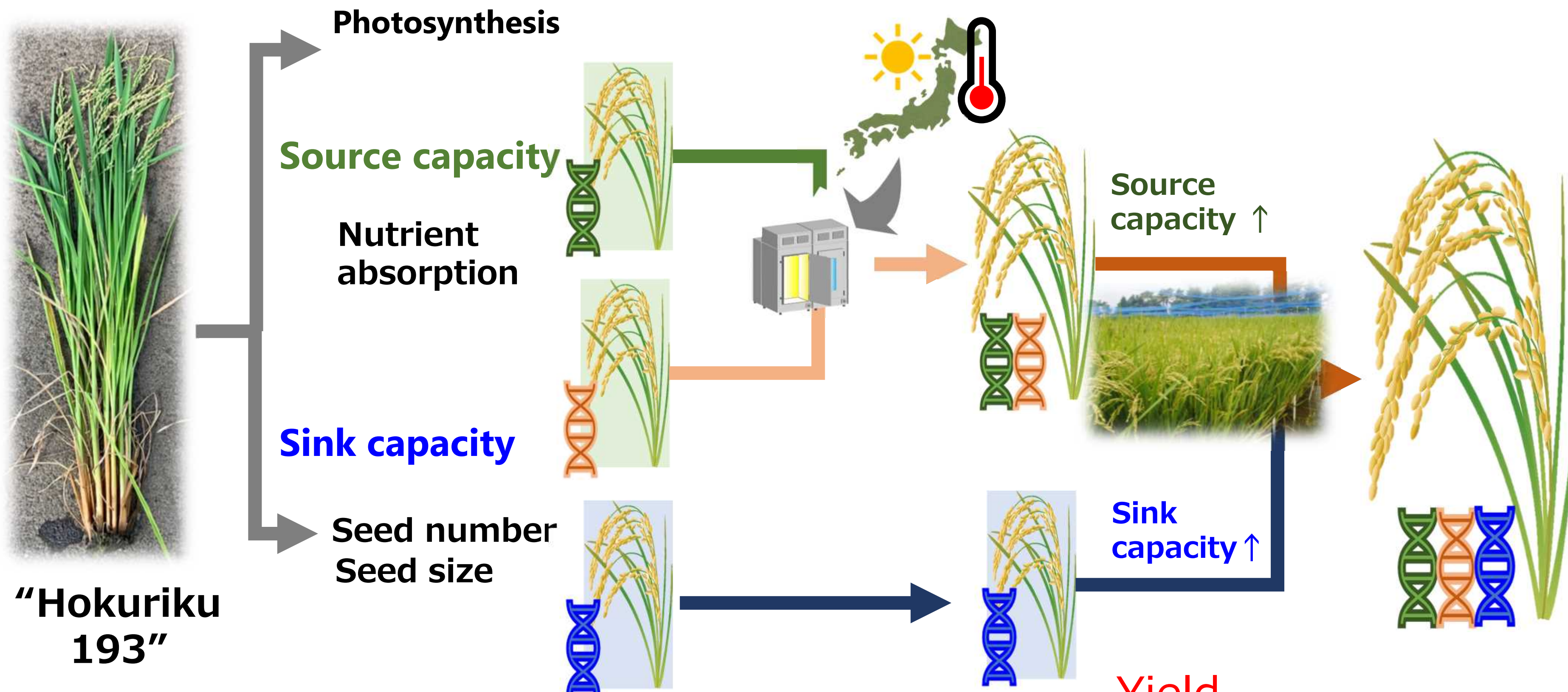
Theme I : Development of Super DAC Rice

Strategies aimed at improving DAC capacity

(Present) (2022-2024 : FS stage) (2025-2030)

- ✓ Development of breeding material by genome editing
- ✓ Evaluation under growth chamber

- ✓ Staking of genes by generation acceleration
- ✓ Evaluation under field condition



Yield

1.3 times that of "Hokuriku 193"
More than twice as much as "Koshihikari"

Development of Super DAC maize

(Present)	(2022-2024 : FS stage)	(2025-2030)

Mi29 *Zea nicaraguensis*

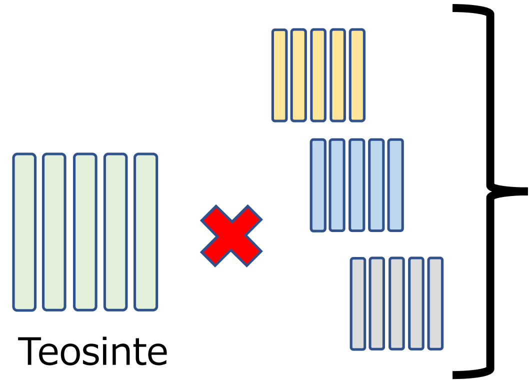
Maize is susceptible to wet soils.

A maize relative with moisture tolerance, Teosinte

Dozens of maize inbred lines

F1 hybrid between maize x teosinte

2 times that of maize (shoot biomass)

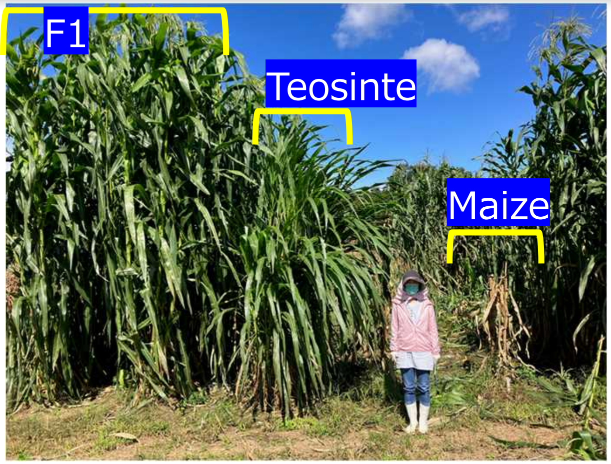


Dozens of Maize inbred lines

Identification of genomic regions controlling “hybrid vigor”

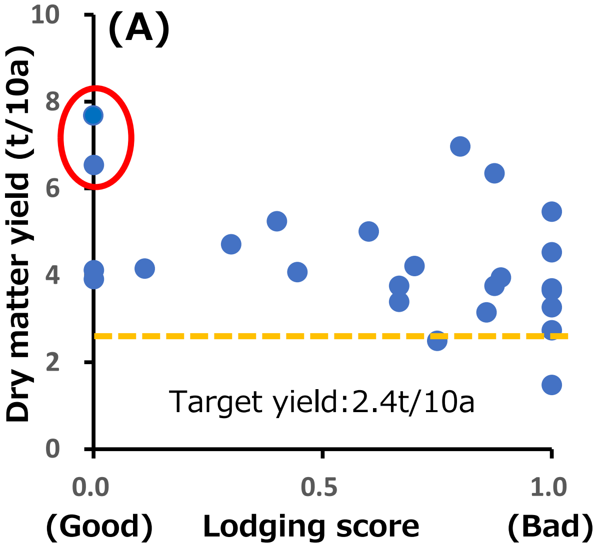
Evaluation of lodging resistance

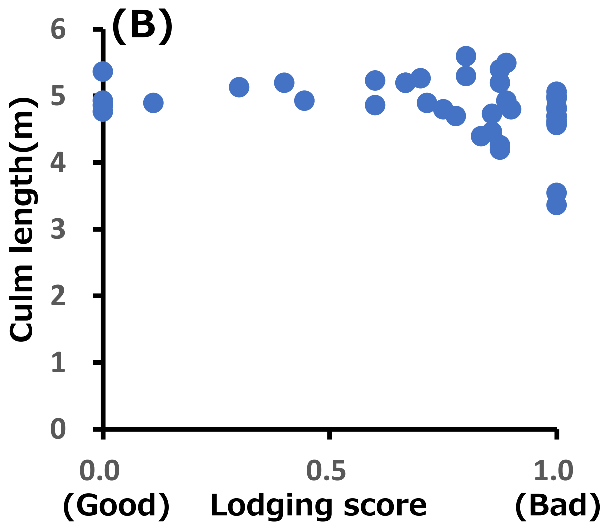
Development of Super DAC maize



Field test for Super DAC maize

Evaluation test for lodging





Scatter diagrams of lodging score between dry matter yield (A) and culm length (B).

・High-yielding with lodging-resistant lines (red circles)
・Target yield of 2.4 t/10a was achieved in many lines.

Increase in underground biomass and soil carbon assessment

(Present) (2022-2024 : FS stage) (2025-2030)

A sorghum relative with rhizome, Johnsongrass

Collect and Select

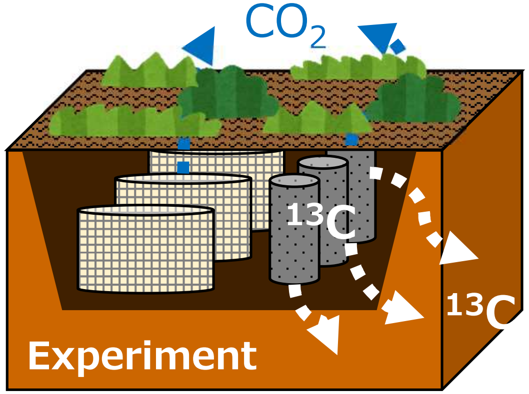
rhizomes

Good Shoot × Good Rhizomes

Shoot & Rhizomes 25% increase

From FY2025 onward

Selection of elite lines with good shoot and rhizomes from the later generations



Assessment of soil carbon storage

Model estimation

Basic data for negative emission of CO_2 with Soil carbon storage

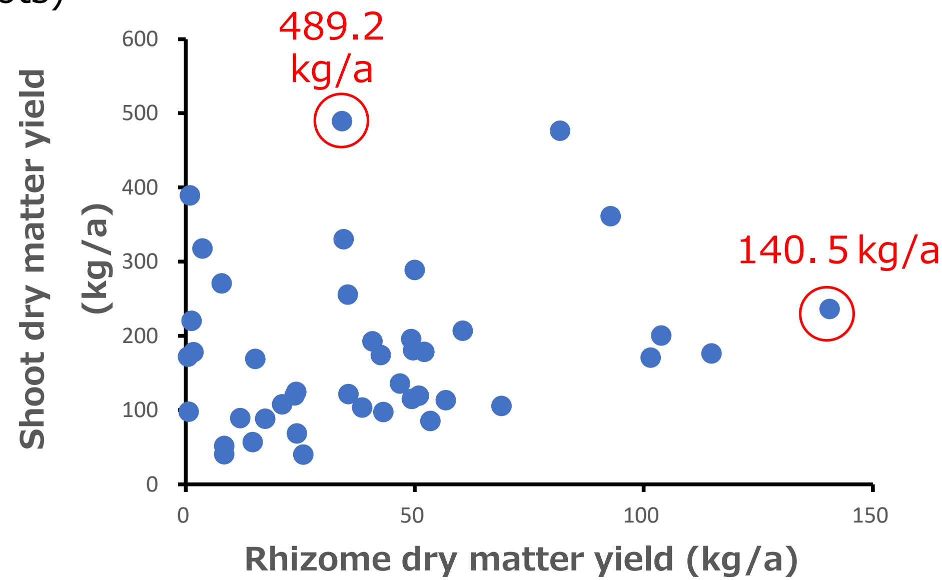
Characterization of crop traits related to increased soil carbon storage

Genetic diversity of above- and below-ground biomass of Johnsongrass

MOONSHOT NEDO

Evaluation for the genetic diversity of Johnsongrass

Above- and below-ground dry matter yield in collected ecotypes (cultivated with pots)

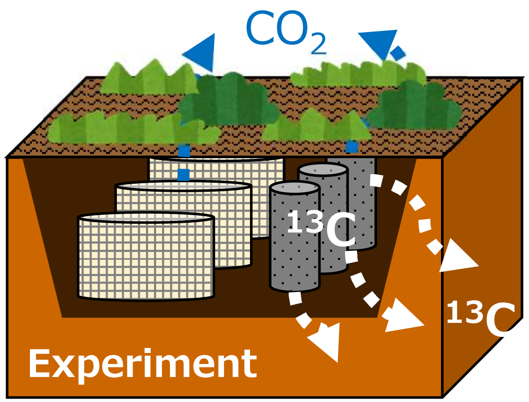


<u>Above-ground</u>
40.3～489.2 kg/a
Mean; 181.8 kg/a

<u>Below-ground</u>
0.5～140. 5 kg/a
Mean; 40.4 kg/a

Diverse variation is found in both above- and below-ground biomass.

Soil carbon storage: Burial experiment with unlabeled crop residue



Assessment of soil carbon storage

Model estimation

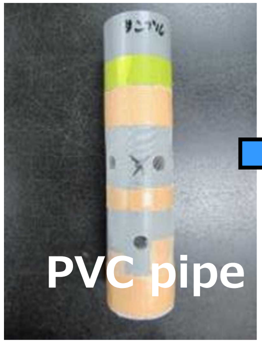
Basic data for negative emission of CO_2 with Soil carbon storage

Characterization of crop traits related to increased soil carbon storage

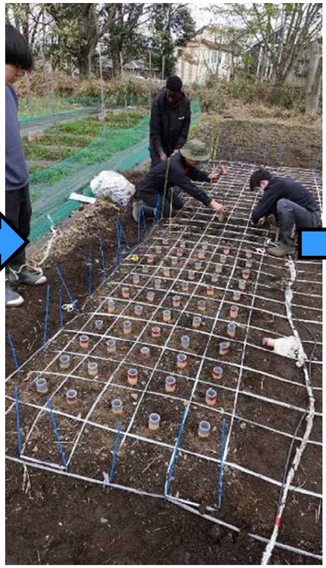
Burial and incubation of C3 soil with various mixtures of C4 crop residues (from the end of March 2023).

Crops:
Maize
Ogisusuki
Sorghum

Organs:
Leaf
Stem
Root



Buried to a depth of 15cm



Soil carbon storage: Burial experiment with unlabeled crop residue

Fractionation of buried soil

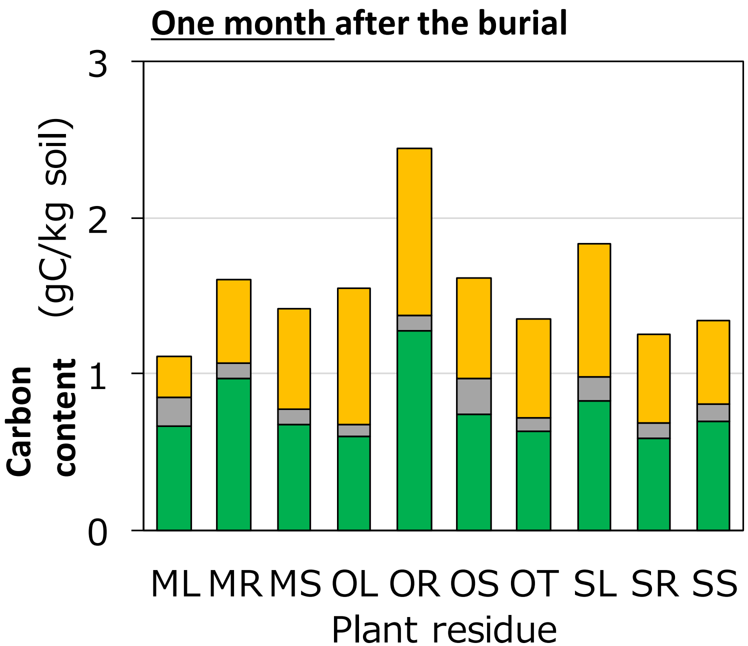
Dry, Weigh

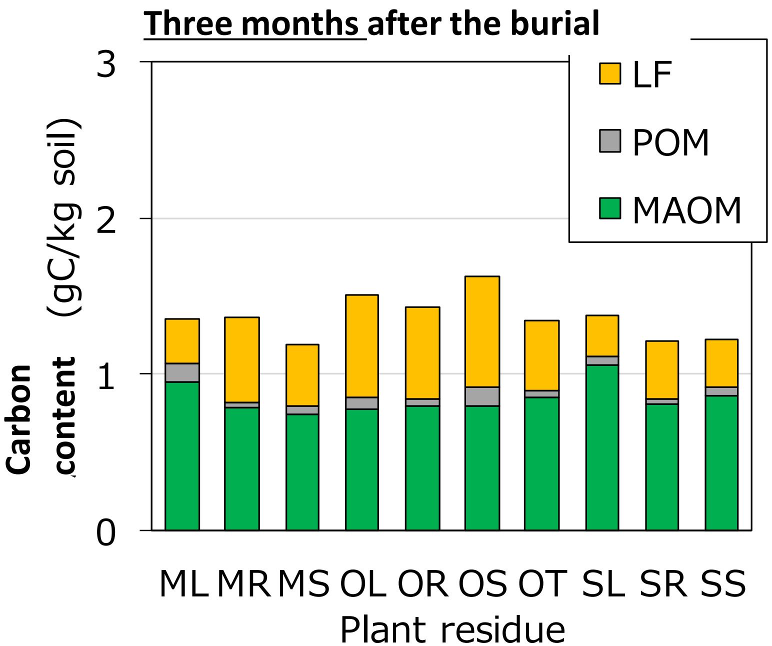
Weight percentages of organic carbon per each fraction

①Light Fraction <1.7 g cm^{-3} ②Particulate Organic Matter 53~2000 μm ③Mineral-Associated OM <53 μm

Crops:
Maize
Ogisusuki
Sorghum

Organs:
Leaf
Stem
Root
T(rhizome)



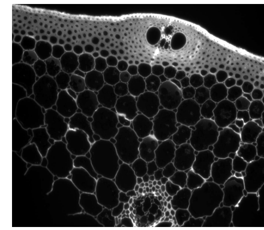


Organic carbons in the degradable fraction (LF) were decreased for all residues and some of them were transferred to the stable soil fraction (MAOM).

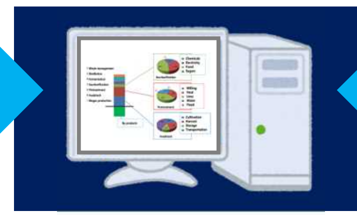
Research and analysis for scenario proposal

Crop cultivation	Harvest, collection, transportation, and storage	Recovery and production of valuables	Selling and consumption





Production/preparation of biomass
(research and analysis)



Components, structures, and conversion efficiencies
(research and analysis)

2022-2024
: FS stage

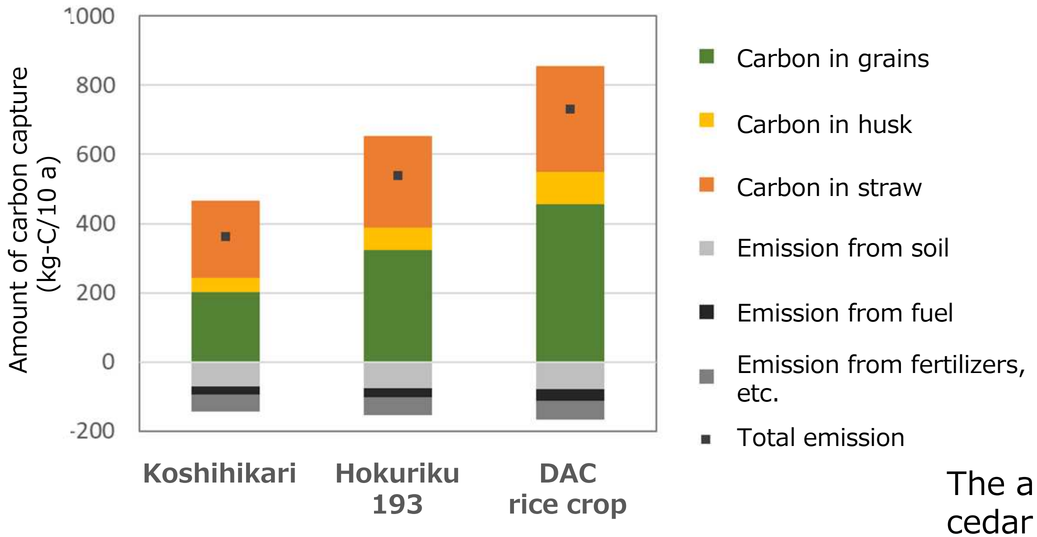
Evaluation of material characteristics and conversion properties of crop biomass
Proposal of scenarios for foundation of novel businesses by resource circulation

2025-2030
: Full project

Demonstration of technologies for utilization of resources from Super DAC crops

DAC during cultivation of rice crop

Amounts of carbon capture (per 10 a)



Values of biomass recoveries used for calculation

	Koshi hikari	Hokuriku 193	DAC rice crop
Seeds (Grains)	636 (530)	1020 (850)	1440 (1200)
Straw	700	830	960

kg/10a、moisture content of 15%

The amount of absorbed CO_2 by 36- to 40-year-old cedar plantation per hectare is estimated to be approximately 8.8 t per year.
(https://www.rinya.maff.go.jp/j/sin_riyou/ondanka/20141113_topics2_2.html)

Amounts of CO_2 capture (per hectare)

CO_2 Capture (t/ha)	11.7	18.3	25.3

7 t-CO_2/ha

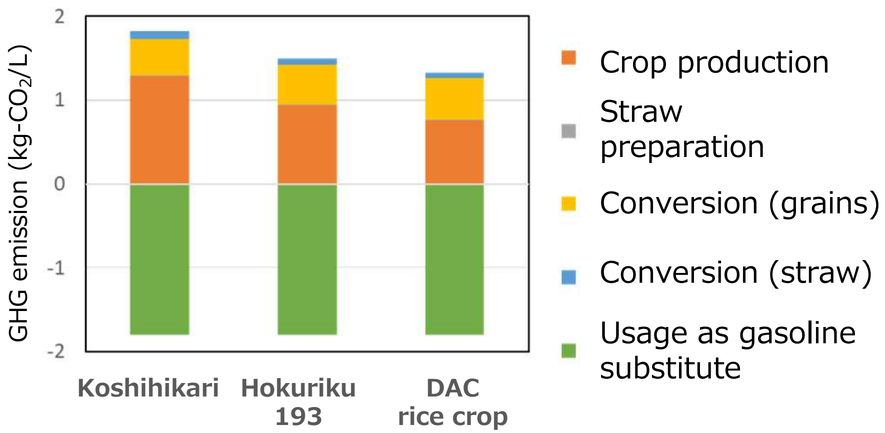
Further strengthening the advantage of grass !

Super DAC rice crop is expected to capture **25.3 t/ha of CO_2.**

GHG emission of ethanol from rice crop

Whole crop→ethanol

GHG balance of ethanol as gasoline substitute (per L)



GHG balance of ethanol as gasoline substitute (per 60,000 ha)

	Koshihikari	Hokuriku 193	DAC rice crop
CO_2 emission (t/60,000ha)	0.026Mt Emission	0.111Mt Reduction	0.227Mt Reduction
EtOH production (kL/60,000ha)	248,000	361,000	482,000

($Mt = 10^6 t$)

Ethanol: attracting again as a bio-fuel!

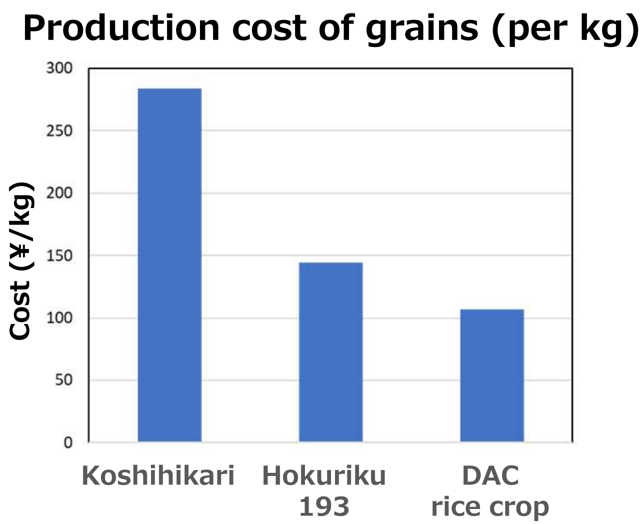
Cultivation of super DAC rice crop (60,000 ha)

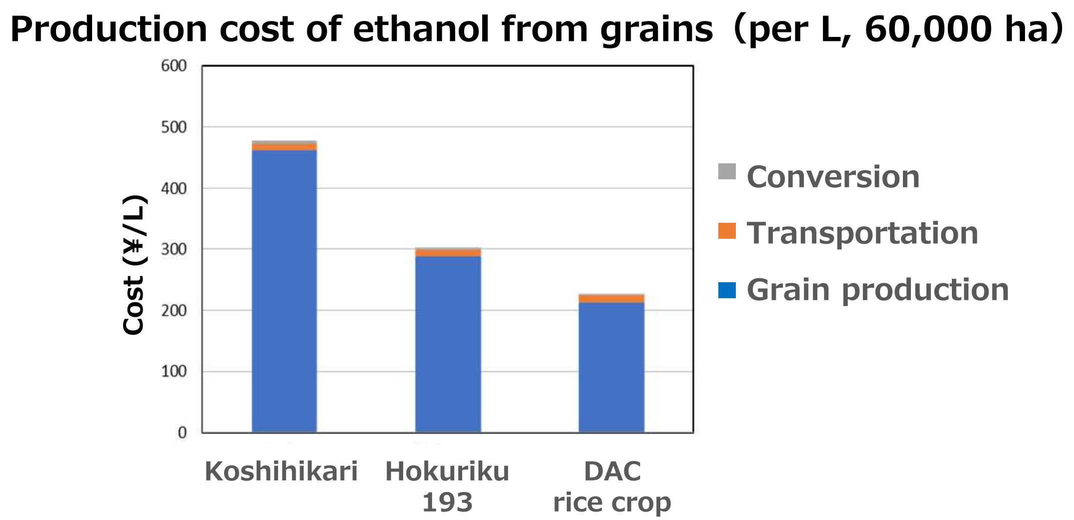
480,000 kL Ethanol → (assuming the conversion efficiency of 50%) **240,000 kL SAF**

Estimated demand of domestic SAF in 2030: 1.71 MkL
Expected production of biomass plastic by 2030: 2 Mt

Ref. https://www.meti.go.jp/press/2022/02/20230210002/20230210002_3.pdf

Cost for ethanol from rice crop (grains)



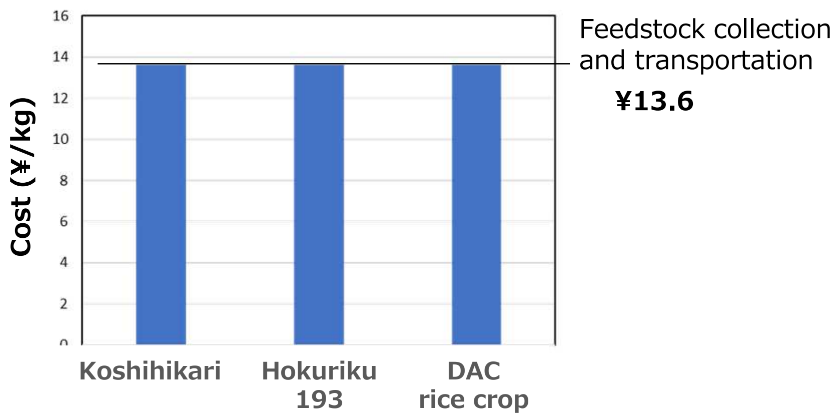


Cost for grain production＝¥**107/kg**

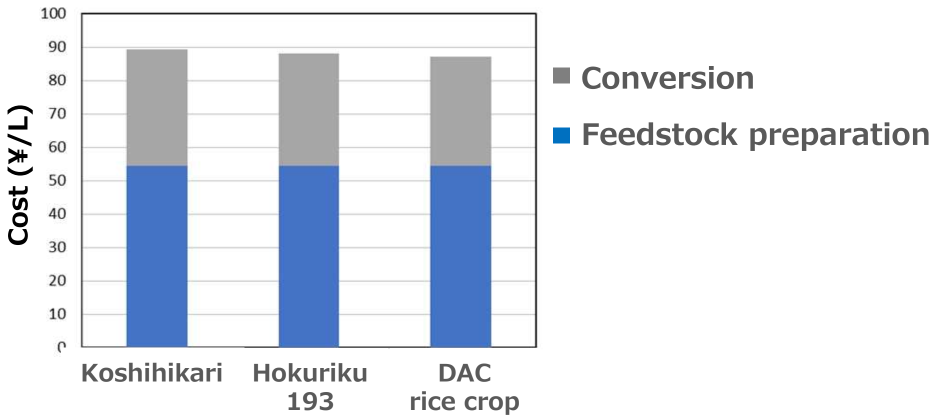
Cost for ethanol production＝¥**227/L**

Cost for ethanol production from rice crop

Preparation cost of straw (per kg)



Production cost of ethanol from straw（per L, 60,000 ha)



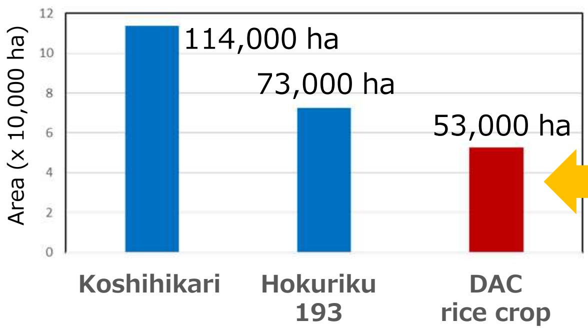
Data for ethanol production from Super DAC rice crop (60,000 ha)

	Parts	Feedstocks (¥/kg)	Amounts of produced ethanol (kL/60,000 ha)	Cost for ethanol production (¥/L)
Super DAC rice crop	Grains	107	360,000	227
	Straw	13.6	122,000	87.0

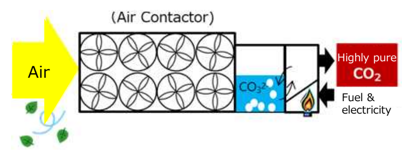
DAC agriculture vs. chemical DAC process

Impact! Characteristics of DAC agriculture (rice crop)

Area needed for capturing 1.33 Mt CO_2 by DAC agriculture



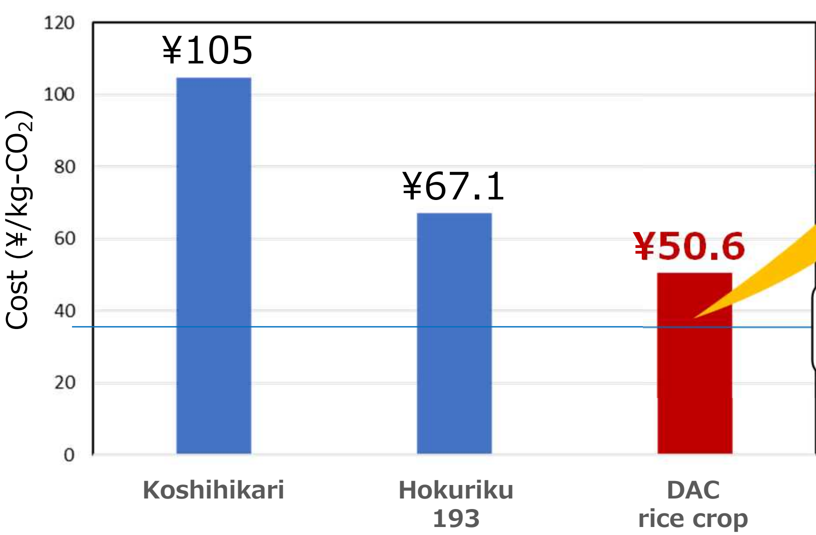
Reference: Chemical DAC process



CO_2 capture ability: 1.33Mt-CO_2/y
Total equipment cost: ¥123B
Cost for CO_2 capture: ¥35/kg-CO_2
Area for the plant: 6.9 ha

Ref: https://www.jst.go.jp/lcs/pdf/fy2019-pp-07.pdf

Cost for CO_2 capture by DAC agriculture (60,000 ha)



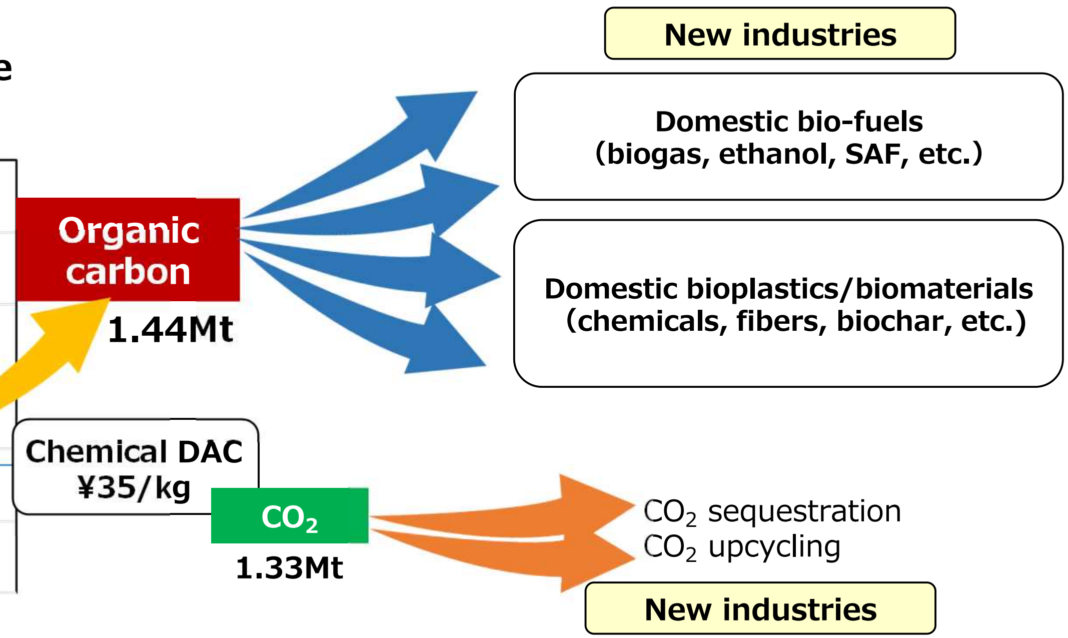


Image of DAC agriculture in 2050