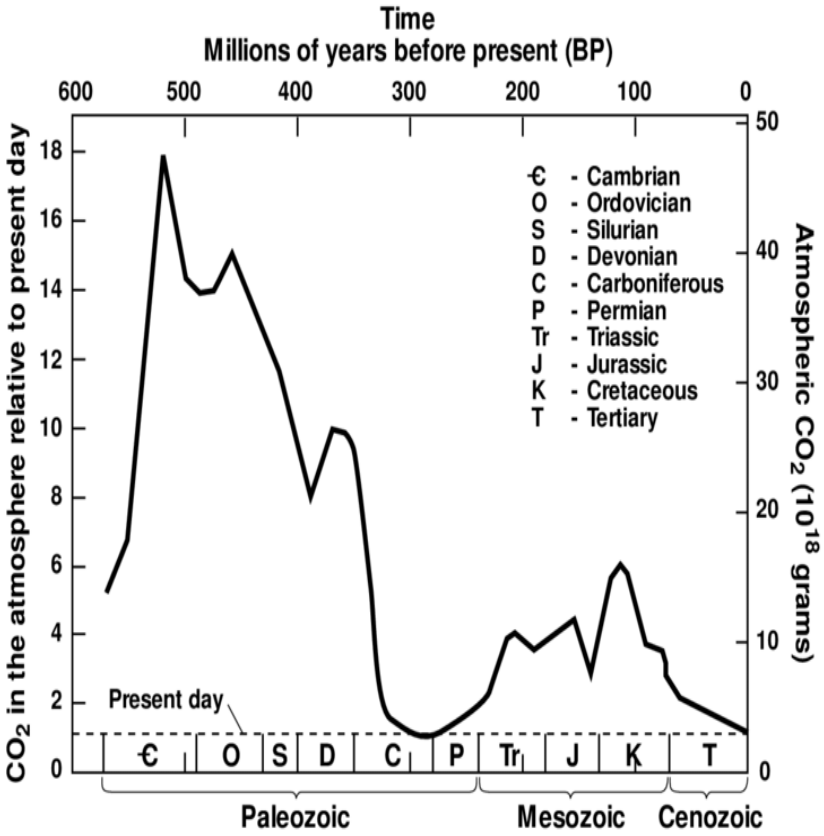
The future of photosynthesis?

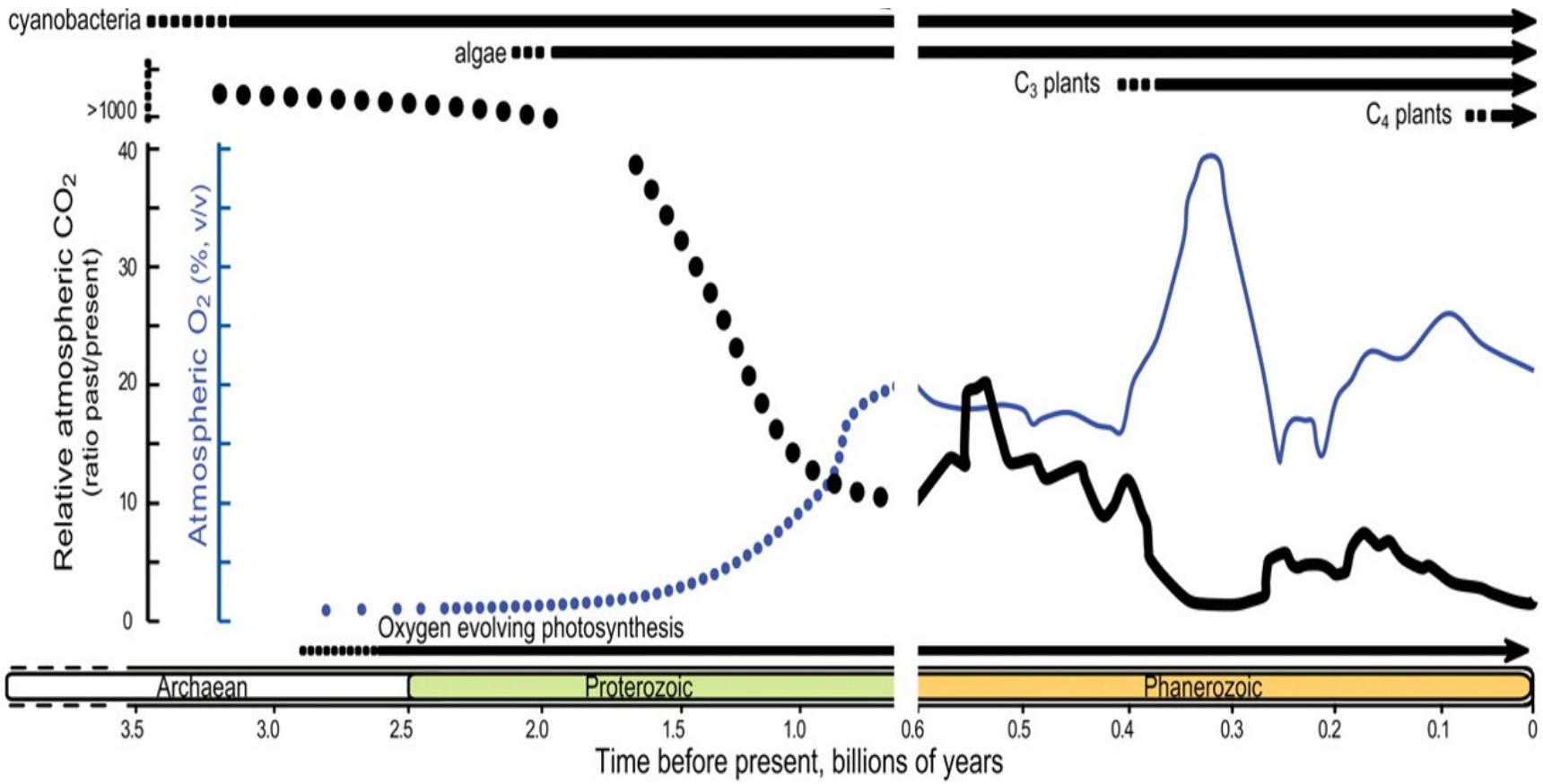
25 September, 2020

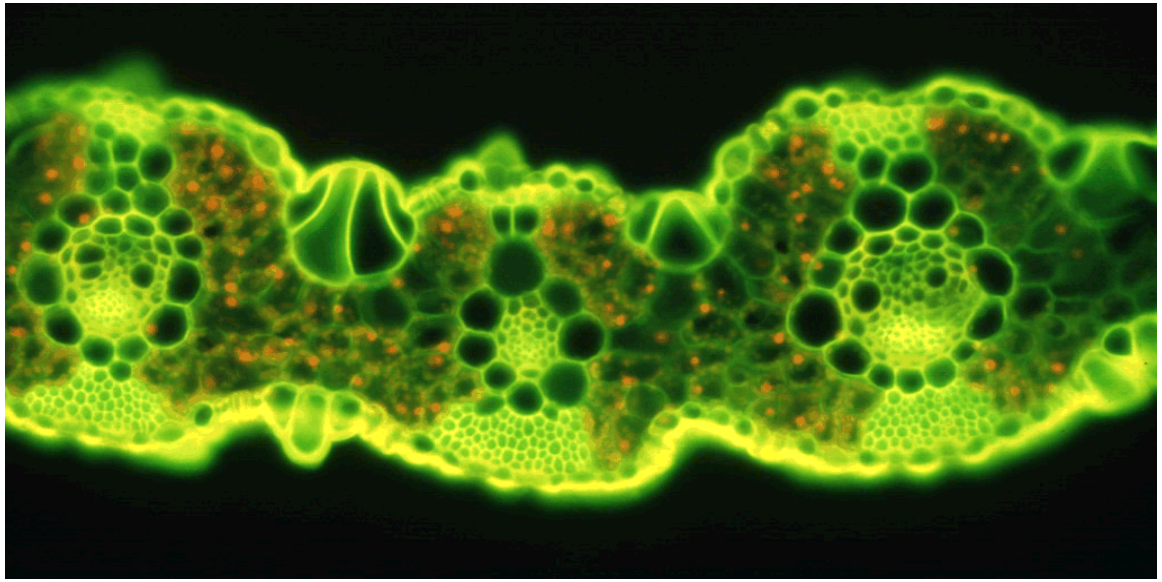
Atmospheric CO_2 varies across geologic time

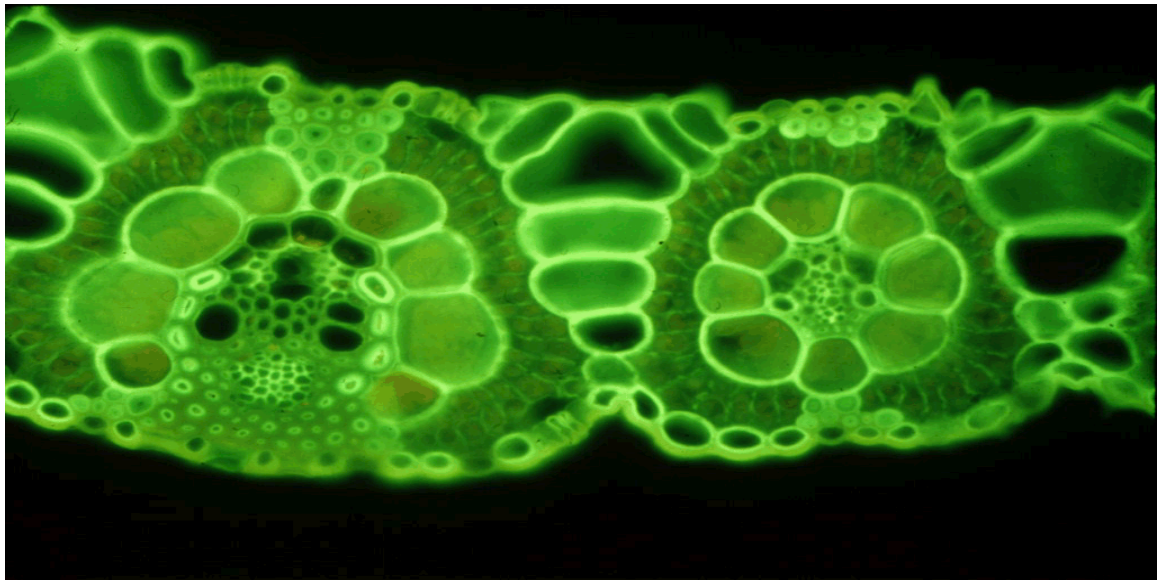


- CO_2 ranged 180 - 4000 ppm in last 500 million years
- CO_2 changes impact living things via photosynthesis
  - primary source of energy in food chain
  - large evolutionary selection pressure
- Large decline in CO_2 last 30 million years
- What does this mean for the current efficiency of C3 photosynthesis?

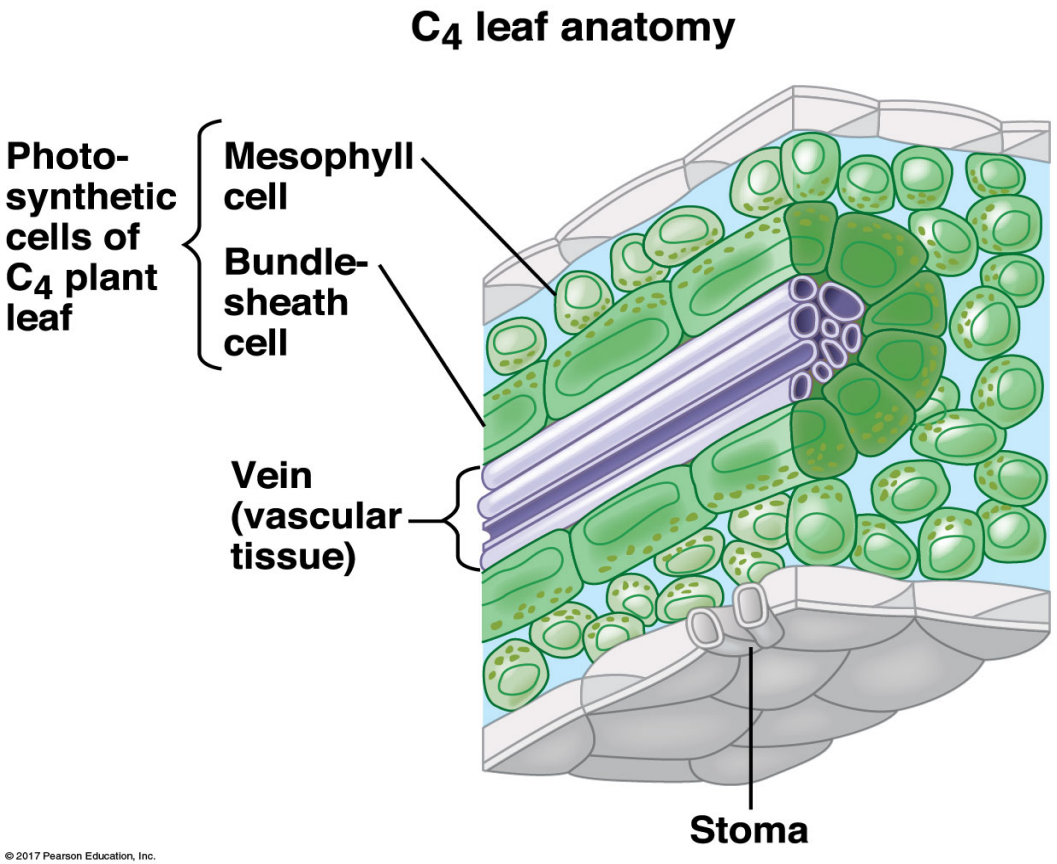
New pathways evolved ~30 MYA





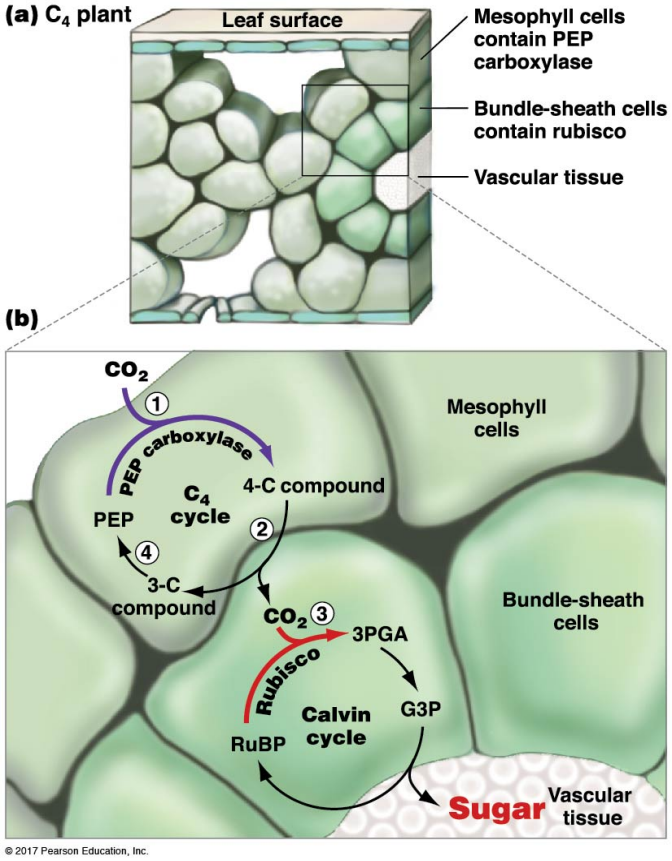


Evolution of C4 photosynthesis



- Calvin cycle moved to *Bundle Sheath Cells* surrounding leaf veins
  - chloroplasts now present
- BSC cells are less permeable to gases
  - what does this mean for photorespiration?

C4 plants concentrate CO_2 around Rubisco *spatially*



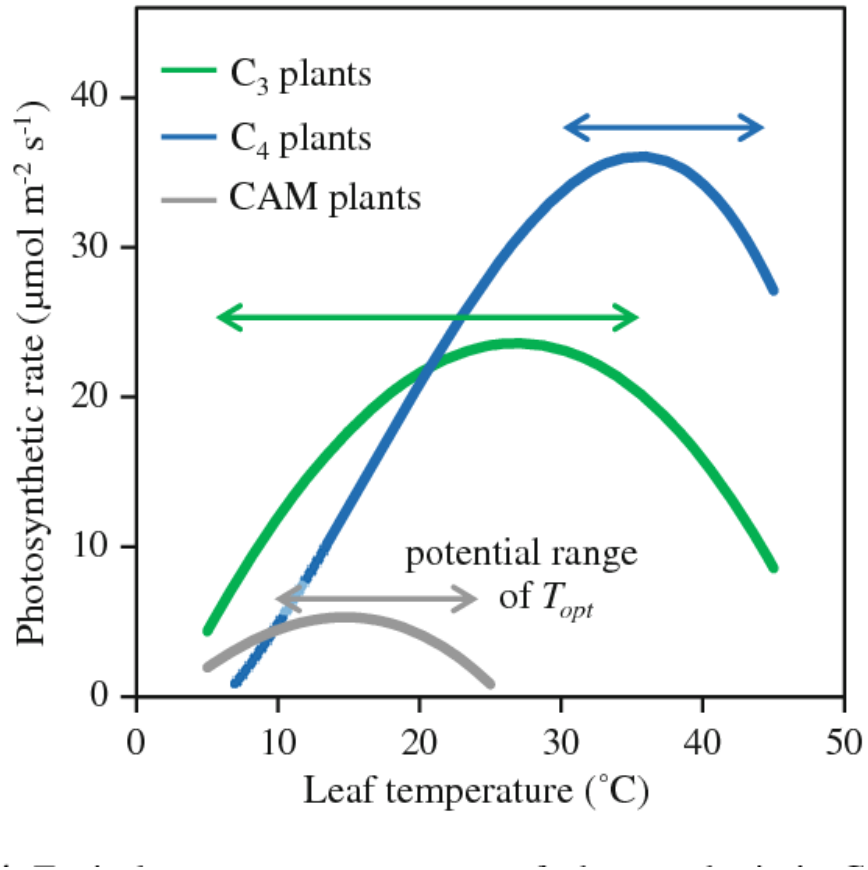
- **C4 mechanism separates Calvin cycle from high O_2**
  - 2 compartments

- **New enzyme, phosphoenolpyruvate carboxylase (PEPC)**
  - fixes CO_2 to PEP (no affinity for O_2)
  - new 4C malate pumped to bundle sheath cells
  - malate broken down to release CO_2

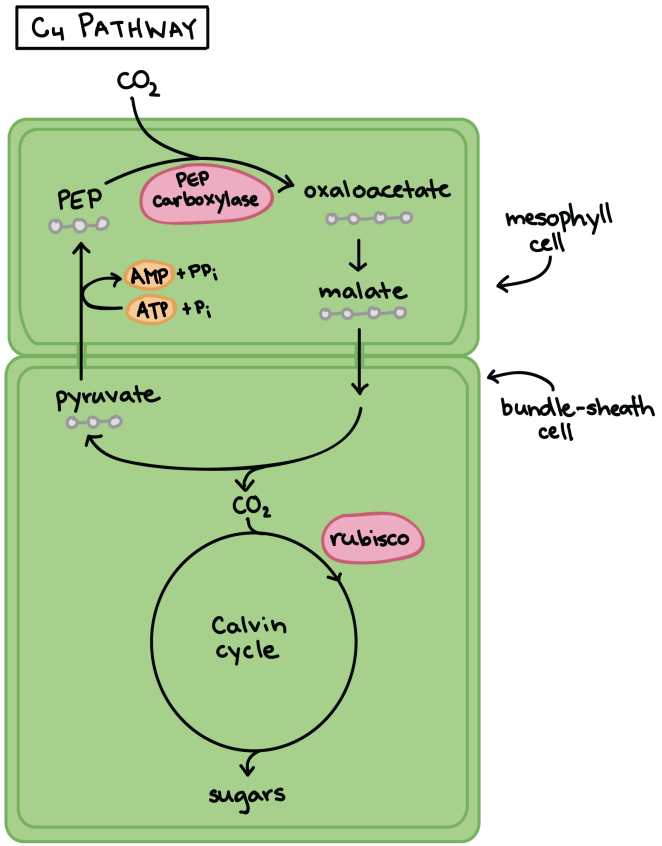
- **Hyper efficient with use of CO_2**
  - How does this impact stomata behavior?

C4 is turbo-charged from of photosynthesis

- **Most productive C4 plants have rates ~50% higher than C3 plants**
  - evolved independently ~70 times
- **~435,000 plant species, only *2%* are C4**
  - 3 of top 10 crop plants are C4
  - extremely rare in trees (1 family)
- **C4 plants still account for 25% of productivity**

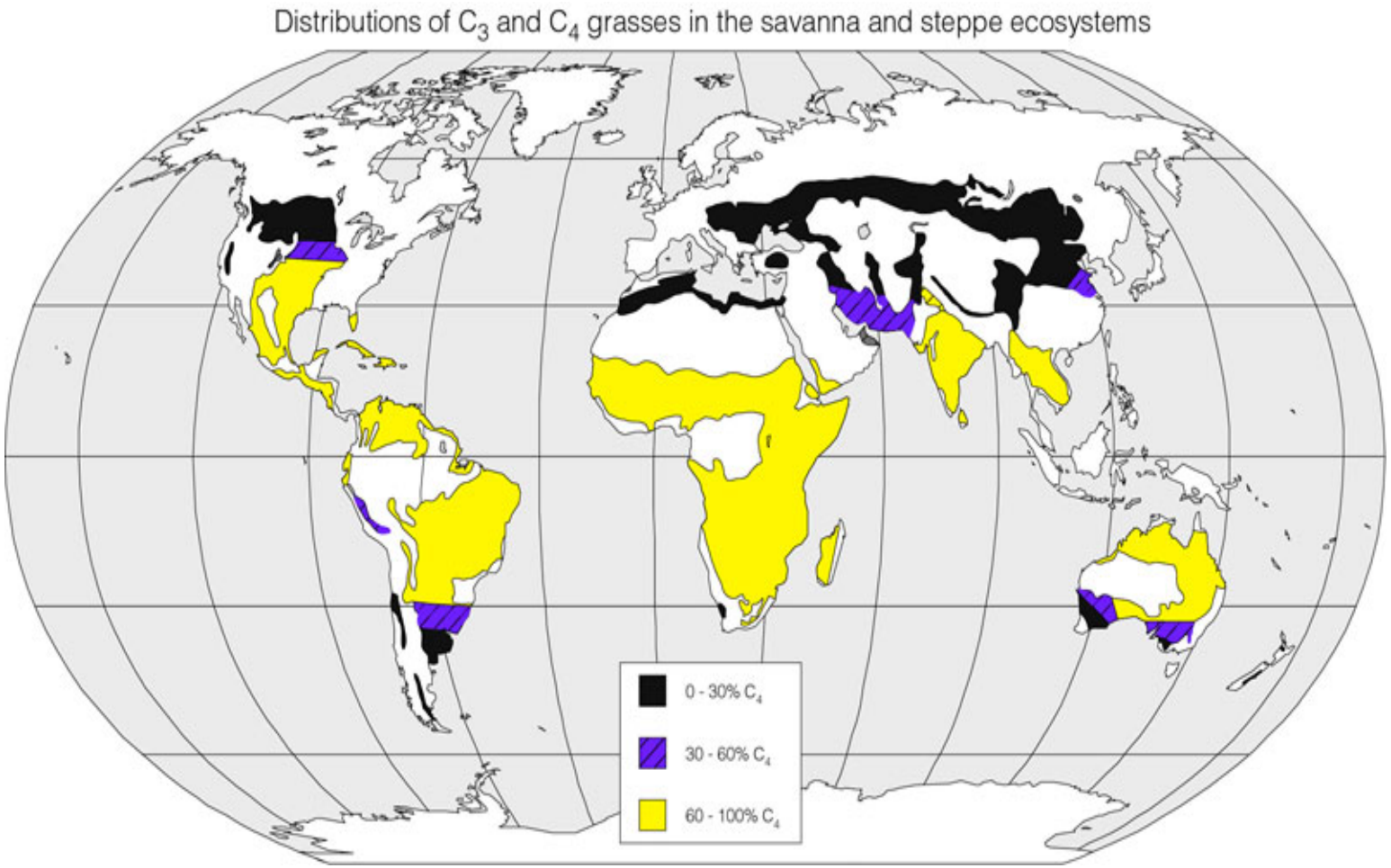


Why is C4 photosynthesis not dominant?

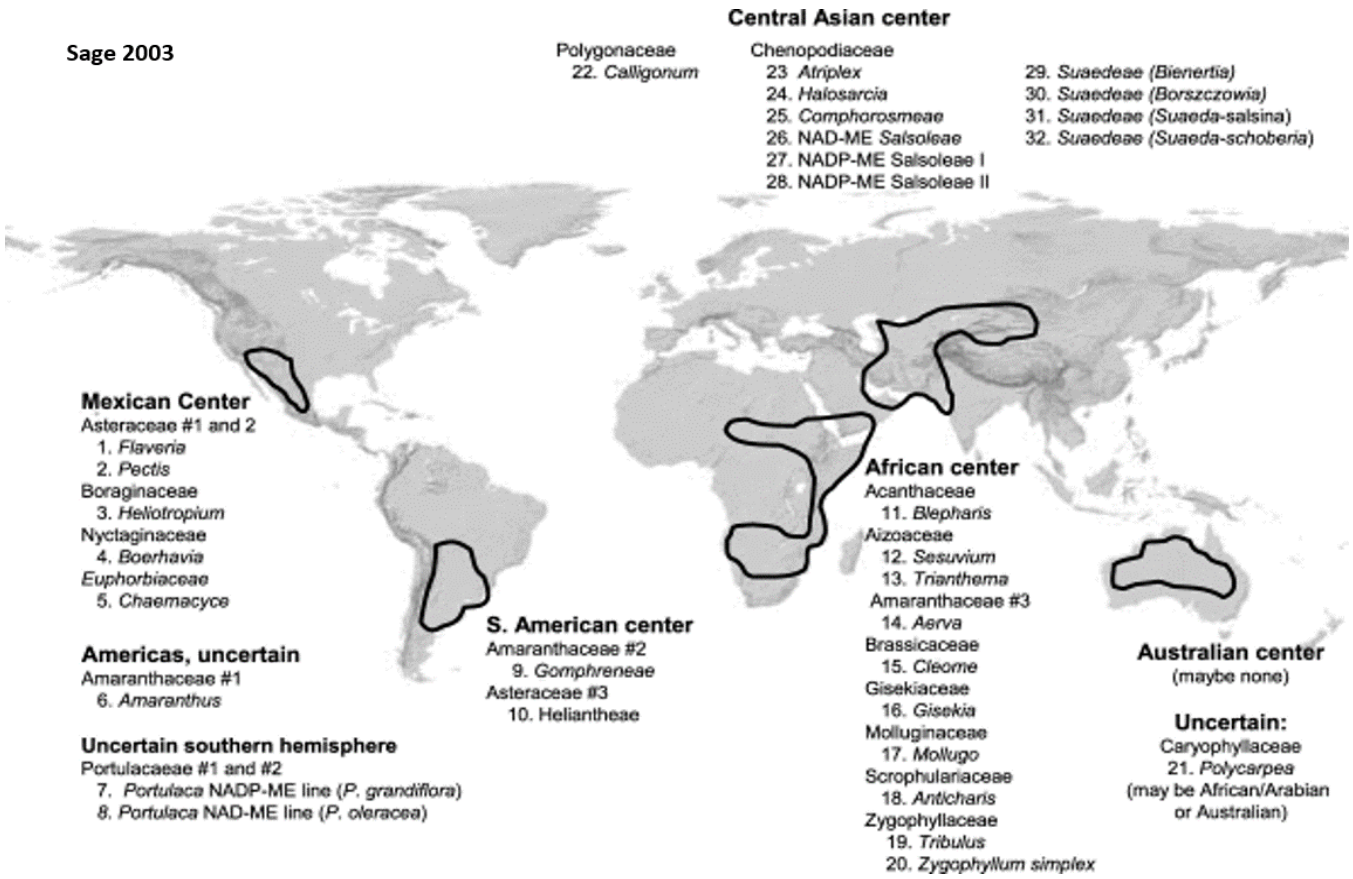


- **Regeneration of PEP expensive (ATP)**
  - in addition to ATP needed for Calvin cycle
- **Where is needed ATP generated?**
- **Where should C4 plants live**
  - efficiency vs dehydration

In hot conditions, the benefits of reduced photorespiration likely exceed the ATP cost of moving CO_2 from the mesophyll cell to the bundle-sheath cell



C4 photosynthesis: Evolved independently 60-70 times



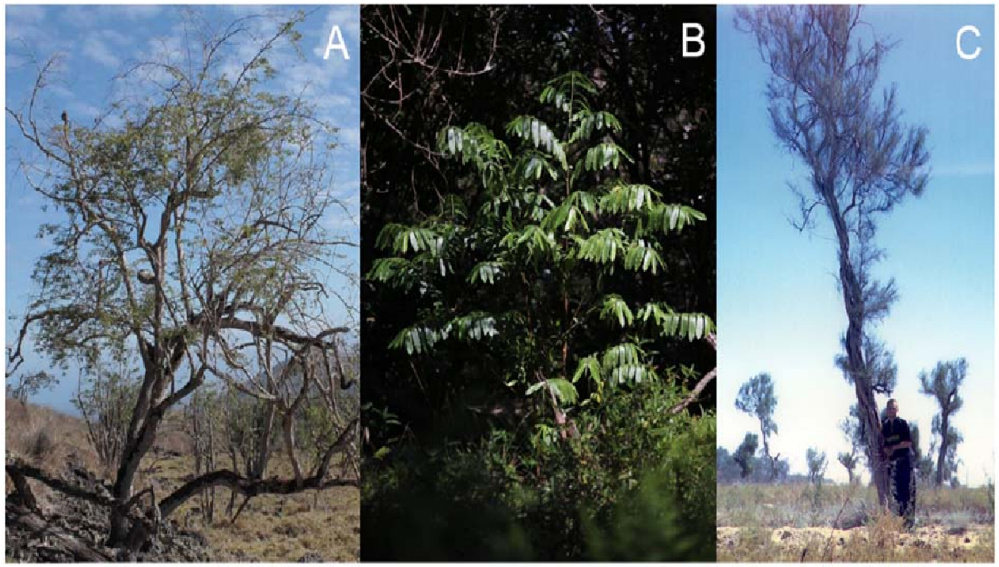
C4 vs C3 vs principles of evolution

- **Recruitment of enzymes into new functions**
- **Massive shifts in distribution of parts**
  - proteins and organelles
- **Anatomical modifications to cell structure**
  - vein structure
- **Predict: In what type of plants would this most likely occur?**

Figure 1

Why are there virtually no C4 trees?

- **Is it difficult for trees to transition from C4→C4?**
  - long generation times



- **Why do C4 shrubs not evolve into C4 trees?**
  - they should have improved growth…

- **Was shade a problem?**
  - some Hawaiian C4 trees live in understory

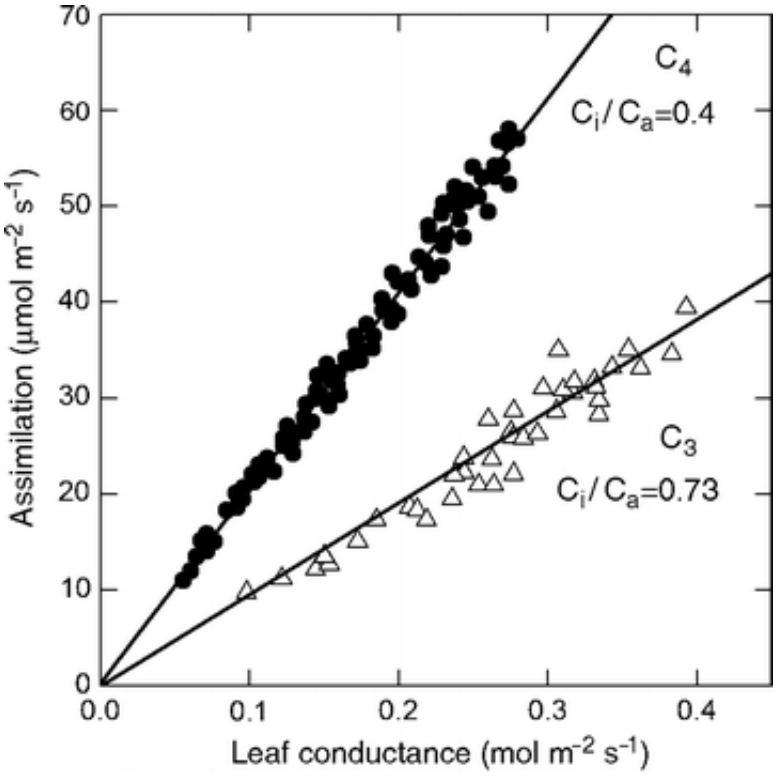
- **C4 plants seem to have an issue growing tall…**

Why C4 matters to you: Water-use-efficiency

- **Climate change impacts photosynthesis:**
  - ↑ CO_2
  - ↑ temperatures
  - variable precipitation
  - variations in humidity

- **C4 plants can make the same amount of sugars as C3, with less water usage**
  - *more CO_2 assimilated per molecule of water loss*
  - ability to keep stomata closed more often

- **C3 & C4 plants should both benefit from extra CO_2**
  - only works in C3 if enough H_20



Why C4 matters to you: Crops

- **C4 plants are economically important**
  - corn, sugarcane, sorghum & switchgrass
- **So are C3 crops**
  - beans, rice, wheat, potatoes (temperate crops)
- **Global water use is set to triple by 2050**
  - 70% to the agriculture sector
  - 50% transpired through stomata

IMPACTS OF CLIMATE CHANGE

By **2030**, nine out of 10 of the major crops will experience reduced or stagnant growth rates, while average prices will increase dramatically as a result, at least in part, due to climate change.

MAIZE

12% GROWTH RATE DECREASE

90% PRICE INCREASE

RICE

23% GROWTH RATE DECREASE

89% PRICE INCREASE

WHEAT

13% GROWTH RATE DECREASE

75% PRICE INCREASE

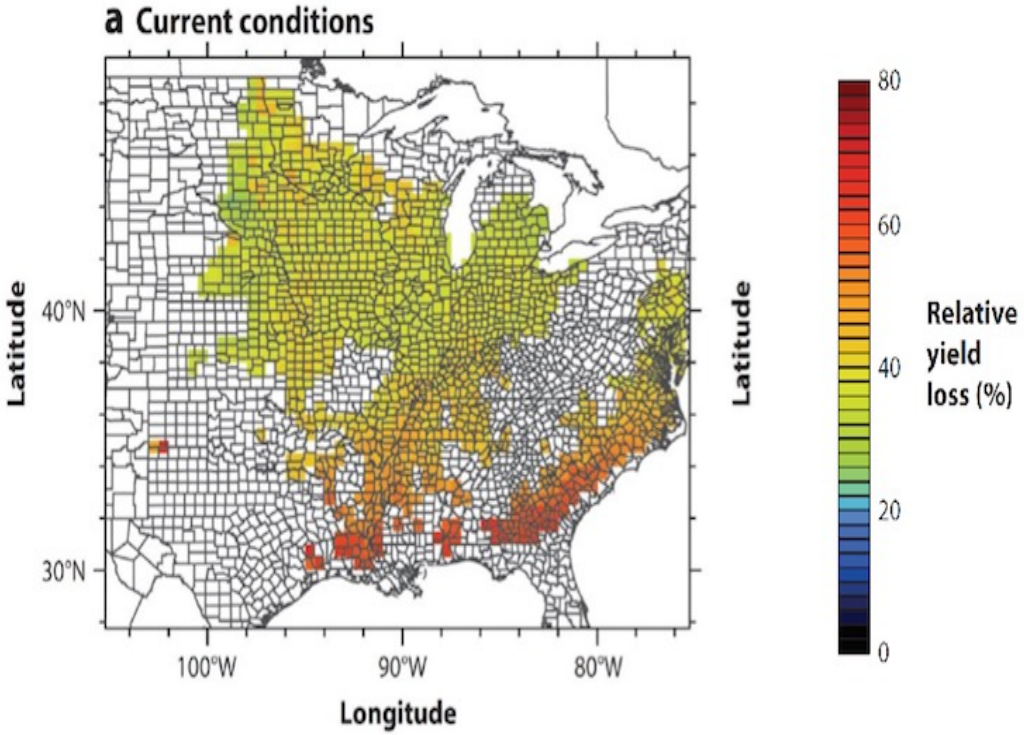
OTHER CROPS

8% GROWTH RATE DECREASE

83% PRICE INCREASE

Can science TUNE photosynthesis?

- **Eliminating photorespirtion is unrealistic**
  - can we *tweak* Rubisco?
- **Small improvement = huge gains in crop yield**
- **5% reduction = extra 68 million bushels of soybean**
  - 23 million bushels of wheat
  - $540 million value (Walker et al. 2016)



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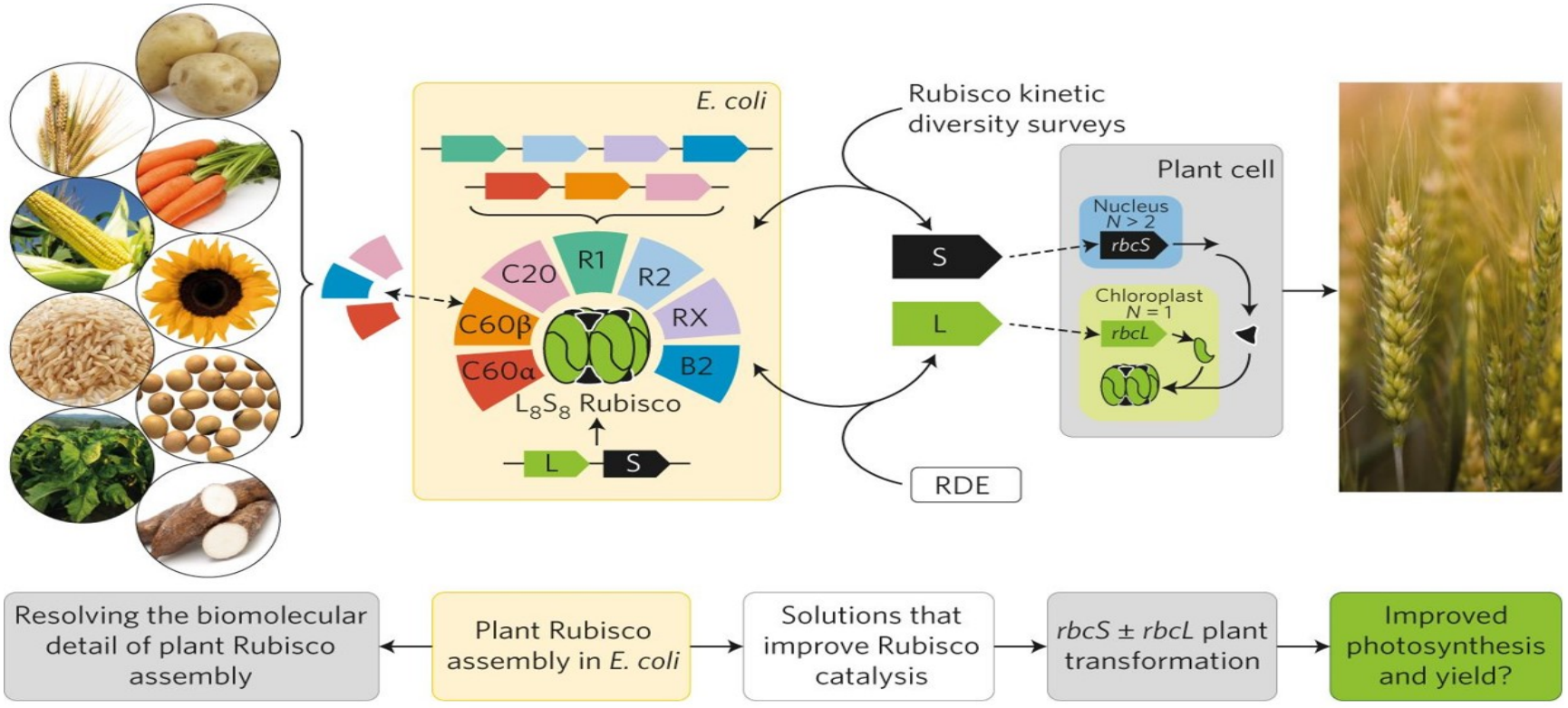
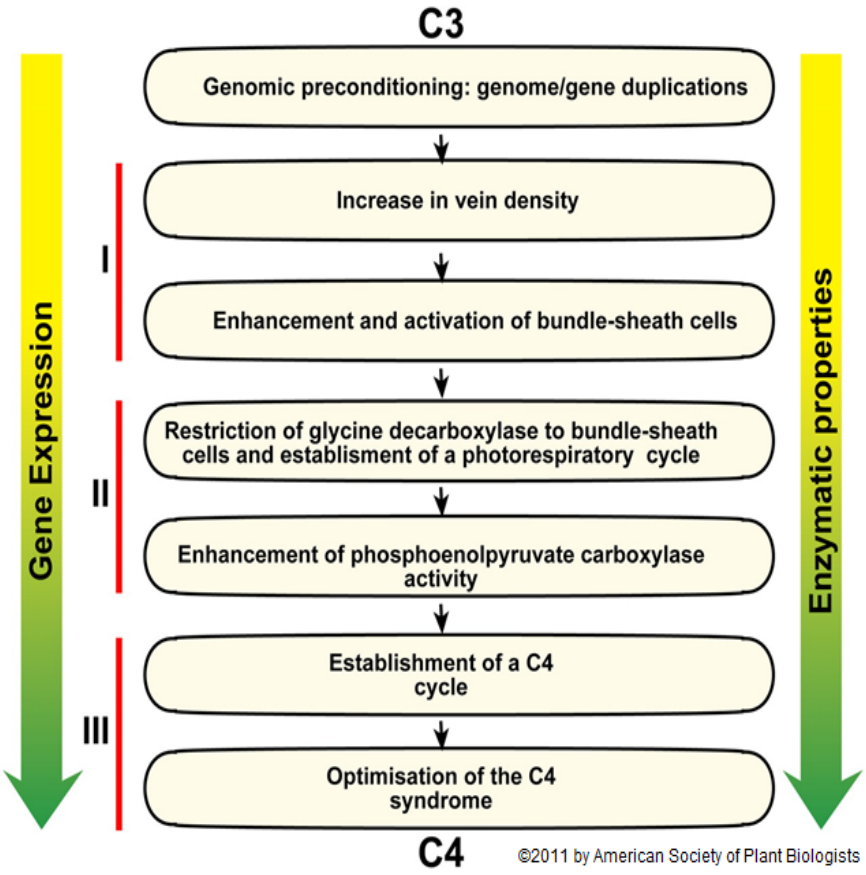
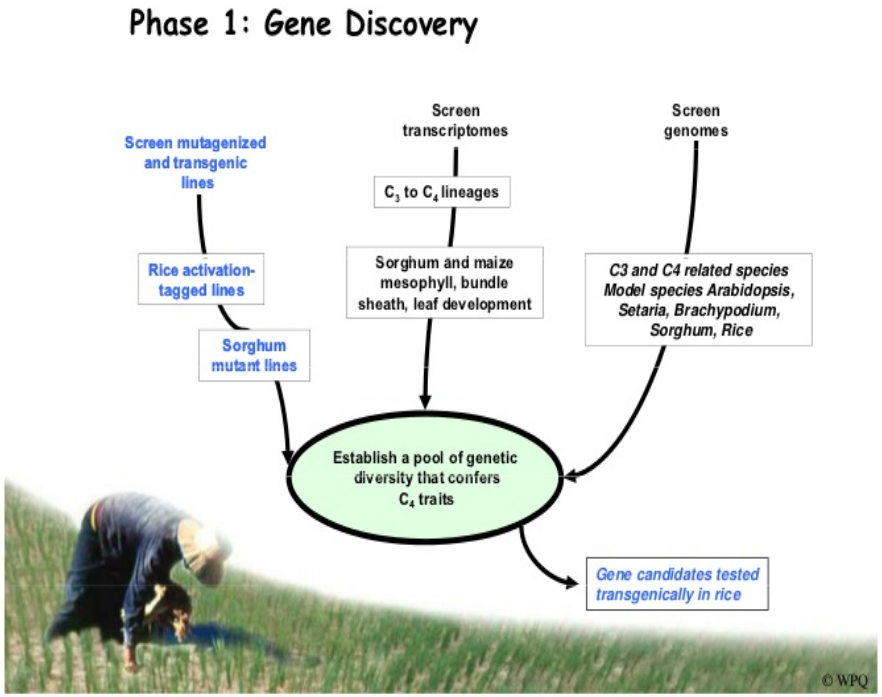


Resolving the biomolecular detail of plant Rubisco assembly → Plant Rubisco assembly in *E. coli* → Solutions that improve Rubisco catalysis → *rbcS* ± *rbcL* plant transformation → Improved photosynthesis and yield?

Conlan & Whitney 2018, Nature Plants 4: 12-13

Genome work on C4 plants already underway





Special Topics lecture: C4 rice project