中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES

在中国二氧化碳化学利用的早期机会
Early opportunities of CO_2 Chemical tilization In China

魏伟

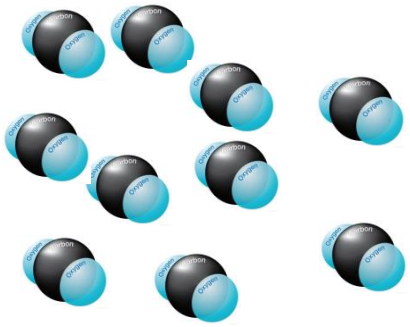
Wei Wei

中国科学院上海高等研究院

Shanghai Advanced Research Institute, CAS

Chemical Utilization of CO_2: What and Why?

Chemical utilization of CO_2 is feature by the **chemical conversion process**, which produces **value-add** products **from CO_2 and other co-reactants**.



Co-reactants

Catalysts

Bulk Chemicals (Established)

High-quality fuels

Functional materials

Fine chemcials

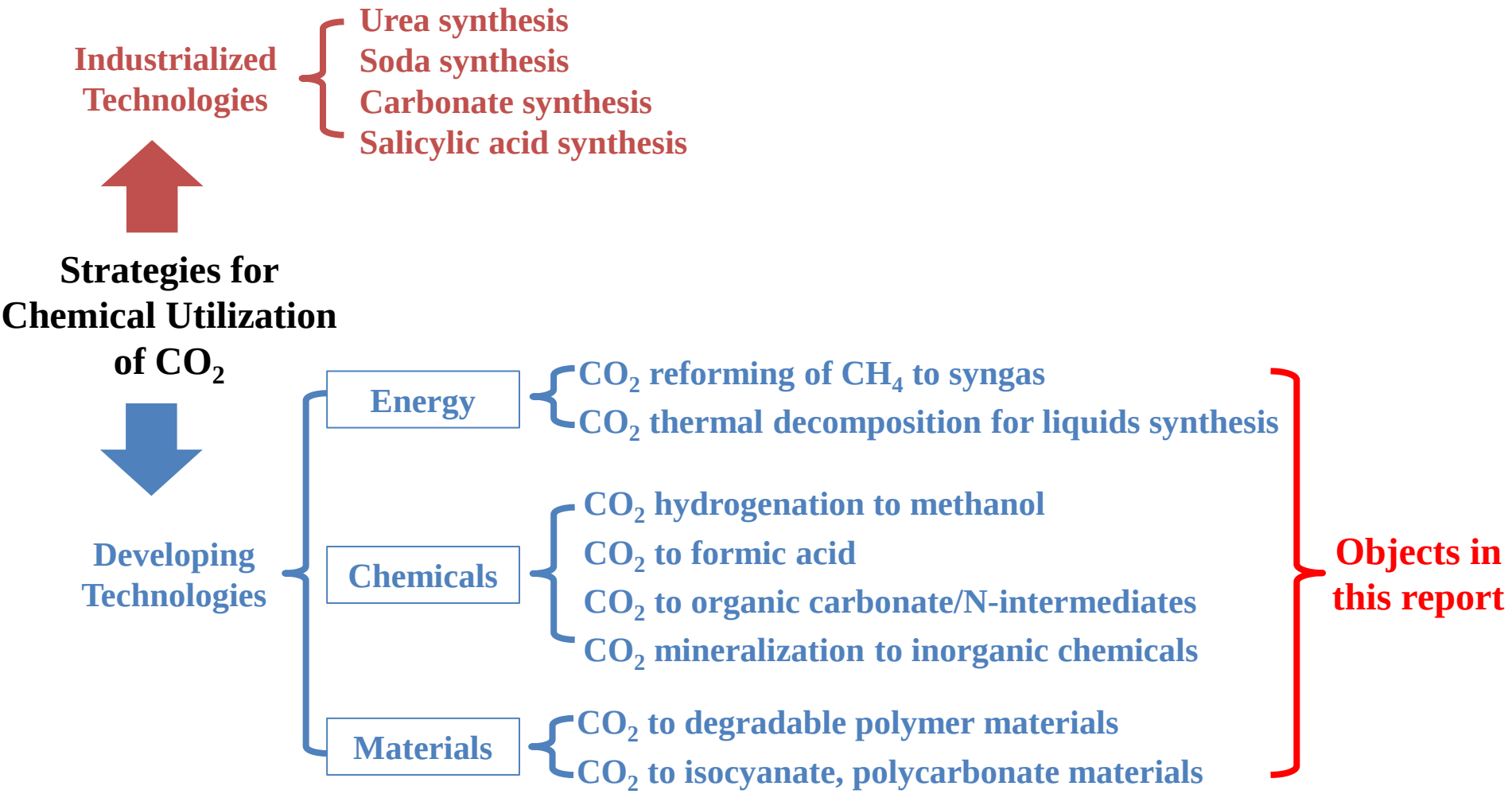
Interests from:

Government
Industry
R&D Institutions
……

Promising in:

CO_2 reduction
Economy competence
……

Chemical Utilization of CO_2: Strategies



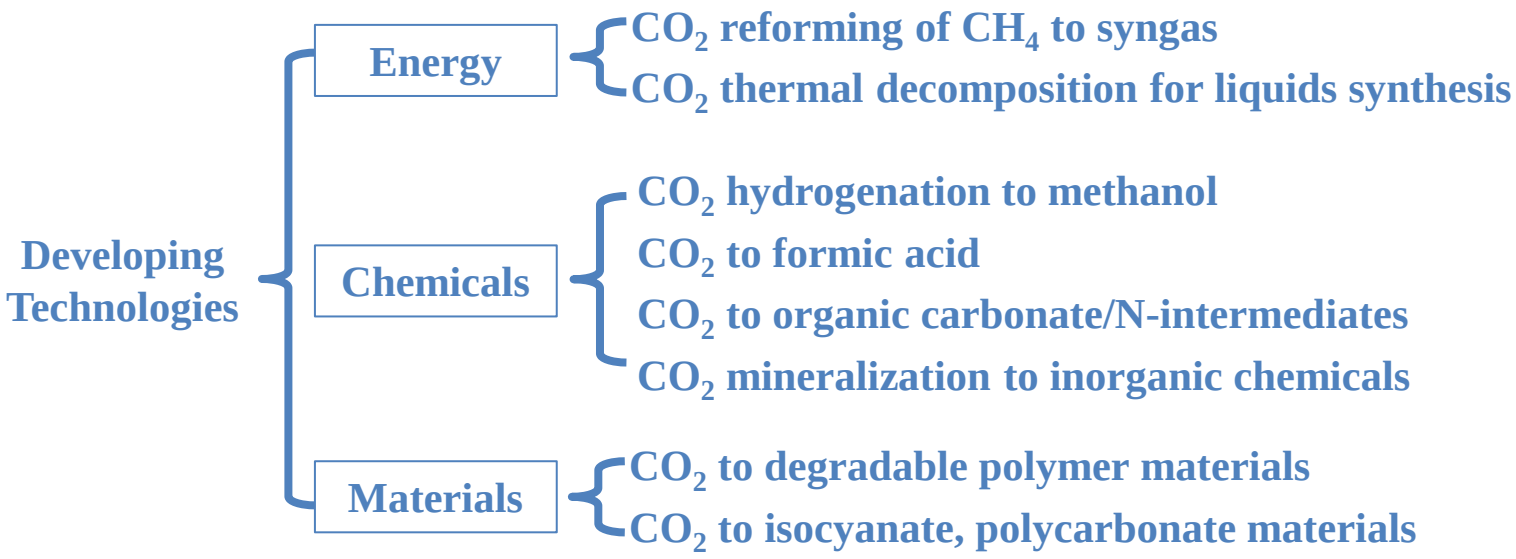
Chemical Utilization of CO_2: Established Processes

Current Available Processes for Chemical Utilization*

	Urea	Soda	Carbonate/Salicylic Acid
2012 Production (Mt)	**70**	**24**	**~6**
2012 CO_2 Reduction (Mt)	**50**	**10**	**~4**
Value (Bn RMB)	**140**	**36**	**-****
Predicted 2020 CO_2 Reduction (Mt)	**60**	**20**	**-****
Predicted 2030 CO_2 Reduction (Mt)	**70**	**29**	**-****

* *China Based Data*
* *Unpredictable due to technical competance*

Technical Evaluation



1. CO_2 reforming of CH_4 to syngas

$$CO_2 \xrightarrow[\text{Catalysts}]{CH_4} \text{Syngas}$$

CO_2 reduction analysis ($t\ CO_2/t$ Product)

Direct utilization	0.73
Direct reduction	0.20
Substitution of Raw Materials	1.80
Substitution of Products	0.00
Overall	2.00

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
1.50	133.50	15.00	60.00	300.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
5.00	45.00	50.00	150.00	500.00

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Pilot scale testing is on going
- 2~4 years to commercialization
- Better catalysts are needed
- Reactor design and process scale up

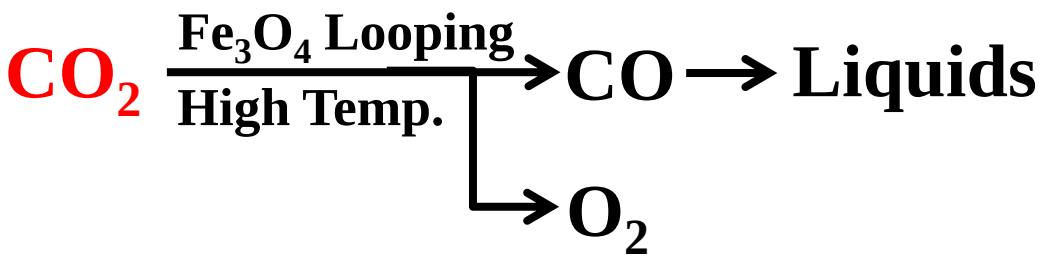
Economical…

- Comparable with current technologies and policy in locations close to coal-bed methane and/or coal-conversion exhaust gas resources
- Further reduction of process cost is possible
- Output values of 4.5 and 15 billion RMB can be achieved by 2020 and 2030

Social and Environmental…

- Large amounts of solid pollutants and waste water can be avoided
- Extra options on raw materials for energy-related industries
- New growth sector in low carbon & green industries

2. CO_2 thermal decomposition for liquids synthesis



CO_2 reduction analysis

($t\ CO_2/t$ Product)

Direct utilization	1.57
Direct reduction	1.57
Substitution of Raw Materials	1.80
Substitution of Products	0.00
Overall	3.37

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
0	0	0	0	29.6

2030				
Direct	Indirect	Total	Compulsory*	Capacity
1.16	1.34	2.50	10.11	40.44

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Initial laboratory testing
- Difficulties in high temperature reactor and integration with solar collector
- More efficient looping agents are needed

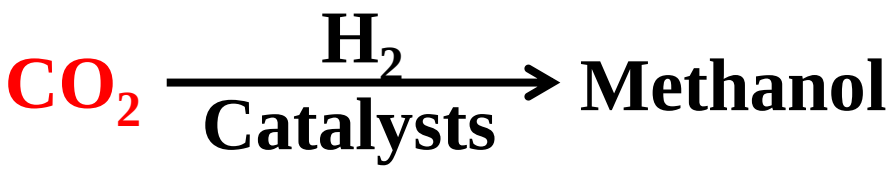
Economical…

- Currently cost ineffective
- Potentially comparative once technical difficulties are solved

Social and Environmental…

- Pollutant & emission free process
- Substitution of fossil fuels by CO_2

3. CO_2 hydrogenation to methanol



CO_2 reduction analysis

($t\ CO_2/t$ Product)

Direct utilization	1.37
Direct reduction	0.70
Substitution of Raw Materials	4.00
Substitution of Products	0.00
Overall	4.70

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
2.98	17.02	20.00	47.00	235.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
74.56	42.55	50.00	94.00	376.00

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Pilot scale testing is on going
- ~5 years to industrial demonstration
- Substantially rely on the development of renewables to provide low-price hydrogen

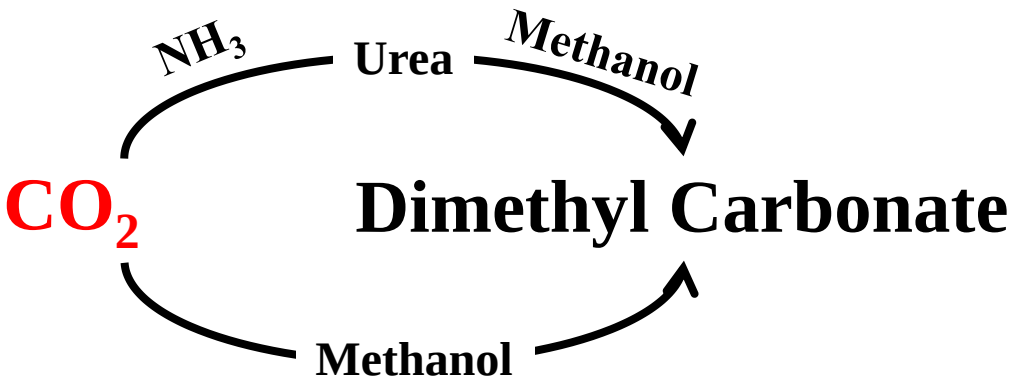
Economical…

- Lower cost compared with the current coal-based methanol in H2-rich locations such as salt industries
- Even more competitive when hydrogen can be supplied from renewable energies
- Output values of 12.5 and 35 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Large amounts of CO_2 reduction
- Saving of fossil fuels
- Make the most of by-produced H_2 in certain sites

4. CO_2 to organic carbonate



CO_2 reduction analysis

($t\ CO_2$/t Product)

Direct utilization	0.50
Direct reduction	0.20
Substitution of Raw Materials	0.50
Substitution of Products	0.00
Overall	0.70

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
1.00	2.50	3.50	5.60	7.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
1.43	3.57	5.00	8.40	10.50

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Industrial demonstration is on going
- More efficient catalysts are needed
- Necessary improvement on process/separation design

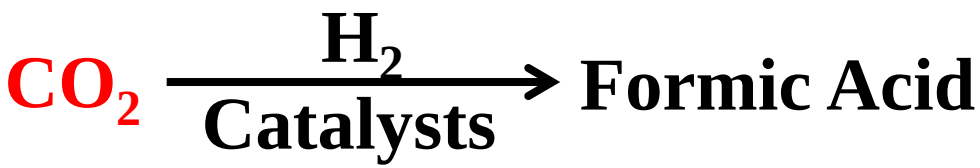
Economical…

- Lower cost compared with the current transesterification process
- Output values of 32.5 and 48.7 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Much greener than current technology
- Value-add product with a wide range of applications

5. CO_2 hydrogenation to formic acid



- Environmental friendly
- Important potential in CO2 reduction (Multi-million t/year in 2020)

- Research in starting stage, far from scale up
- Unpredictable

6. CO_2 to degradable polymer materials

$$CO_2 \xrightarrow[\text{Catalysts}]{} \text{PPC+PC}$$

PPC: poly(propylene carbonate)
PC: polycarbonate

CO_2 reduction analysis

($t\ CO_2$/t Product)

Direct utilization	0.43
Direct reduction	0.25
Substitution of Raw Materials	0.36
Substitution of Products	0.00
Overall	0.61

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
0.04	0.06	0.10	0.50	3.05

2030				
Direct	Indirect	Total	Compulsory*	Capacity
0.20	0.30	0.50	2.50	6.10

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Industrial demonstration is on going
- 5~10 years to large scale implementation
- Can be further improved by more efficient catalysts

Economical…

- Higher than traditional plastic, promotion policies are needed
- Output values of 6 and 12 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Highly green and pollutants-free process
- Value-add product with a wide range of applications

7. CO_2 to isocyanate

CO_2 —(Aniline, Formaldehyde / Catalysts)→ MDI

MDI: Diphenyl-methane-diisocyanate

CO_2 reduction analysis (t CO_2/t Product)

Direct utilization	0.35
Direct reduction	0.35
Substitution of Raw Materials	0.24
Substitution of Products	0.00
Overall	0.59

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
~0.06	~0.06	~0.12	0.29	1.18

2030				
Direct	Indirect	Total	Compulsory*	Capacity
0.40	0.30	0.70	1.18	2.36

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Industrial demonstration is on going
- Commercially available in 5-10 years
- Can be further improved by more efficient catalysts, reactor design and process integration

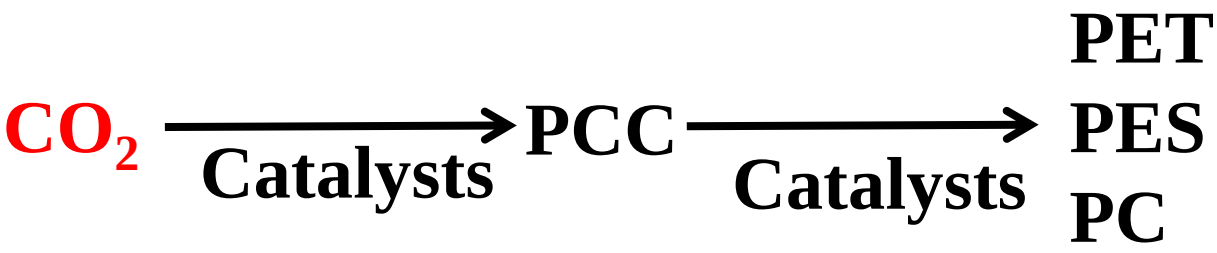
Economical…

- Lower cost than current phosgene route
- Output values of 4 and 24 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Greener by substituting phosgene
- Highly flexible in scale and location
- Value-add product with a wide range of applications
- Improve the carbonate industrial chain

8. CO_2 to polycarbonate



PPC: poly(propylene carbonate)
PET: poly(ethylene terephthalate)
PES: Poly(ethylene succinate)
PC: polycarbonate

CO_2 reduction analysis

($t\ CO_2$/t Product)

Direct utilization	0.68
Direct reduction	0.90
Substitution of Raw Materials	0.30
Substitution of Products	0.00
Overall	1.18

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
1.20	0.50	1.70	5.00	17.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
1.60	0.70	2.20	6.80	22.50

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Under kilo-t scale demonstration
- Commercially available ~5 years
- More efficient catalysts are needed

Economical…

- Comparable whit the current phosgene route for PC synthesis
- Cost-effective than current technologies for PET and PES synthesis
- Output values of 50 and 80 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Substitution of fossil fuels by CO_2
- Greener by substituting phosgene
- Value-added products

9. CO_2 mineralization with steel slag

$$CO_2 \xrightarrow{\text{Steel slag}} \text{Ca/Mg Carbonate}$$

CO_2 reduction analysis

($t\ CO_2$/t Product)

Direct utilization	0.52
Direct reduction	0.62
Substitution of Raw Materials	0.00
Substitution of Products	2.78
Overall	2.36

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
0.51	4.71	5.10	15.00	50.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
2.34	17.04	17.40	40.00	50.00

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Scaling up on multi-kilo t grade
- Efficient reactor for solid-liquid multi phase reactor is needed

Economical…

- Excellent profit due to mineralized products
- Output values of 4 and 15 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Important potential in CO_2 reduction and solid waste disposal
- Considerable contribution to sustainable development

10. CO_2 mineralization with Phosphogypsum

$$CO_2 \xrightarrow{\text{Ammonia, Phosphogypsum}} CaCO_3 + (NH_4)_2SO_4$$

CO_2 reduction analysis

($t\ CO_2$/t Product)

Direct utilization	0.33
Direct reduction	0.23
Substitution of Raw Materials	0.03
Substitution of Products	0.00
Overall	0.26

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
0.09	0.01	0.10	0.30	13.00

2030				
Direct	Indirect	Total	Compulsory*	Capacity
0.88	0.12	1.00	1.66	13.00

** Under strict reduction policy*

Maturation and Challenges

Technical…

- Industrialized for 2-step method
- Under scale up for 1-step method
- 3~5 year to solve technical difficulties

Economical…

- Excellent profit due to mineralized products and by-produced fertilizer
- Further reduction of process cost is possible
- Output values of 0.06 and 0.6 billion RMB can be achieved by 2020 and 2030 under current policies

Social and Environmental…

- Important potential in CO_2 reduction and solid waste disposal
- Minimize environmental footprints of phosphorus chemistry

11. CO_2 mineralization with potash feldspar

CO_2 —Potash Feldspar→ $CaCO_3$+K-based fertilizer

CO_2 reduction analysis

($t\ CO_2/t$ Product)

Direct utilization	0.47
Direct reduction	0.45
Substitution of Raw Materials	0.00
Substitution of Products	0.00
Overall	0.45

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	Indirect	Total	Compulsory*	Capacity
0.10	0.00	0.10	0.50	6.75

2030				
Direct	Indirect	Total	Compulsory*	Capacity
2.00	0.00	2.00	4.50	9.00

** Under strict reduction policy*

Maturation and Challenges

Technical…

- **Technical difficulties such as process integration exists**
- **5~8 year to quasi-industralization**

Economical…

- **Higher than current routs for production of K-based fertilizer**
- **Can be promoted by consider environmental benefits and carbon tax**
- **Output values of 0.4 and 16 billion RMB can be achieved by 2020 and 2030 under current policies**

Social and Environmental…

- **Important potential in CO_2 reduction**
- **Suitable for China due to limited soluble K resources**

Chemical Utilization of CO_2: Summary(1)

Chemical utilization of CO_2 enables the conversion of CO_2 to a wide range of chemicals, which is a potential option for CO_2 reduction.

CO_2 reduction capacity in Mid-long term (Mt/y)

2020				
Direct	**Indirect**	**Total**	**Compulsory***	**Capacity**
7.37	**38.39**	**45.76**	**80.23**	**512.56**

2030				
Direct	**Indirect**	**Total**	**Compulsory***	**Capacity**
20.47	**129.03**	**131.50**	**318.13**	**779.75**

** Under strict reduction policy*

Chemical Utilization of CO_2: Summary (2)

Develop Stages of Strategies for Chemical CO_2 Utilization

Initial Study

- Direct synthesis of dimethyl carbonate from CO_2
- CO_2 hydrogenation to formic acid

Lab Testing

- CO_2 thermal decomposition for liquids synthesis
- CO_2 mineralization with potash feldspar

Pilot Demo

- CO_2 reforming of CH_4 to syngas
- CO_2 hydrogenation to methanol
- CO_2 to isocyanate
- CO_2 to polycarbonate
- CO_2 mineralization with steel slag
- CO_2 mineralization with Phosphogypsum

Approaching Commercialization

- CO_2 to dimethyl carbonate
- CO_2 to degradable polymer materials

Most strategies are in pilot-scale demonstration, funding and supports from government and companies are highly desired to promote the development of related technologies.


协力创新
共赢未来
THANK YOU！
开放与联合