Sustainable Fuels and Chemicals by Carbon Recycling

Guest Lecture, University of Iceland
November 13th 2015

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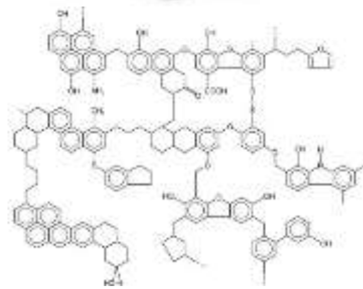
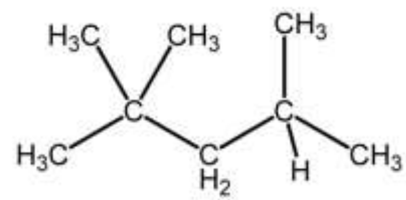
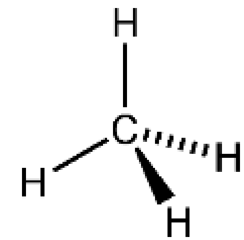
Source of our Carbon – Fossil Hydrocarbons





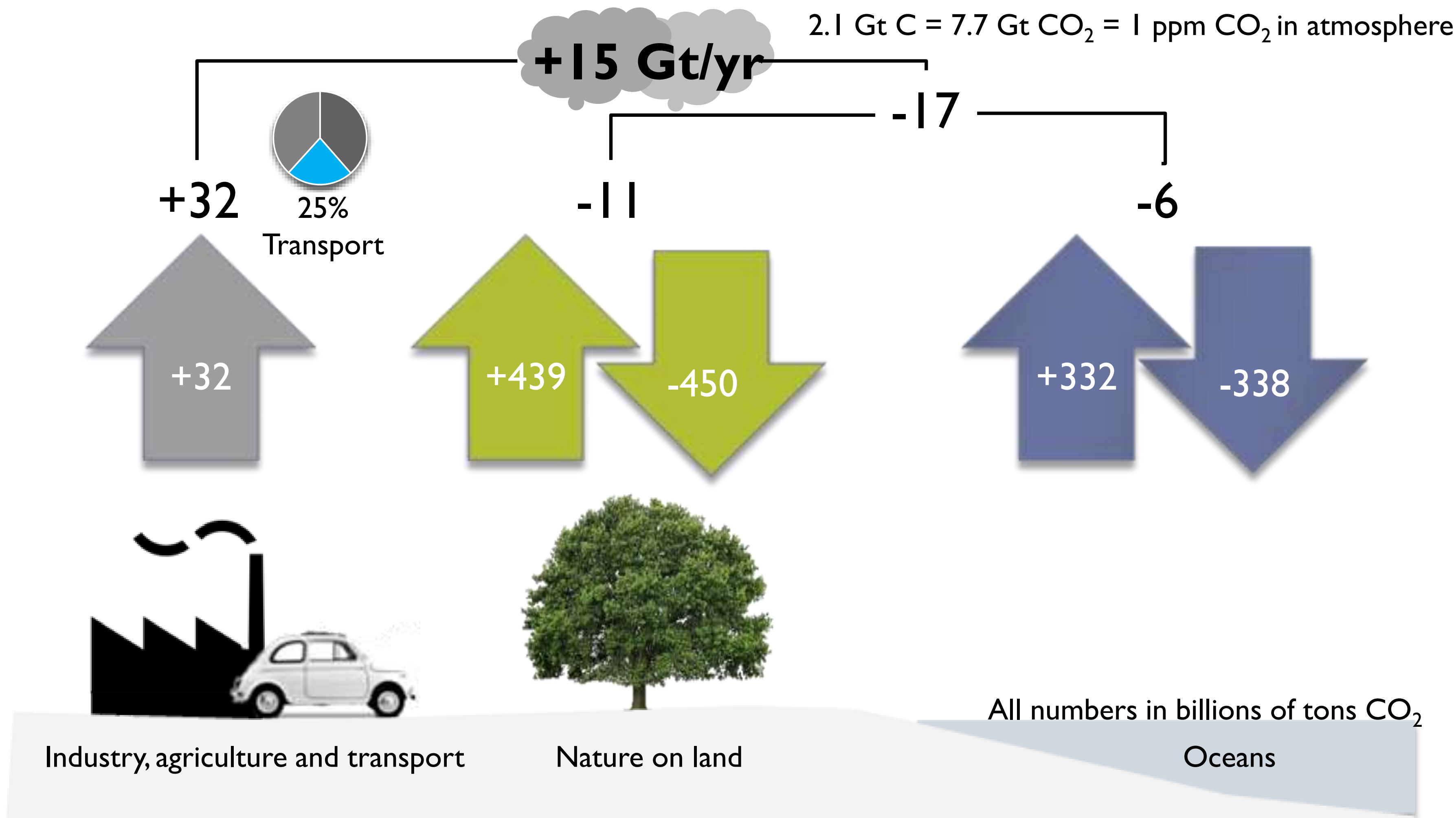


	Coal	Oil	Natural Gas
World Consumption Gtoe/year	**3.9**	**4.2**	**3.1**
Reserves/Production years	110	52	54

toe= tons of oil equivalent

Source: BP Statistical Review of World Energy 2015

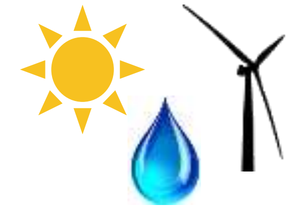
Global GHG impact from human and natural activity



Source: UN IPCC / IEA

How can we reduce carbon emissions?

- Low carbon renewable energy sources!
  - Wind, Solar, Hydro, Geothermal



- Increased efficiency & lower consumption

η

- Biomass utilization

- Carbon Capture and Sequestration (CCS)

- Carbon Capture and Utilization (CCU)?

Where will we continue to need carbon?

- Smelting: Iron, Steel, Aluminum, etc.
  - Carbon needed for reduction of ore

- Organic Chemicals and Plastics
  - methanol, ethylene, propylene, butadiene,
  - benzene, toluene, and xylenes

- Fuel for Trucks, Ships and Airplanes
  - Liquid energy carriers needed for their high energy density

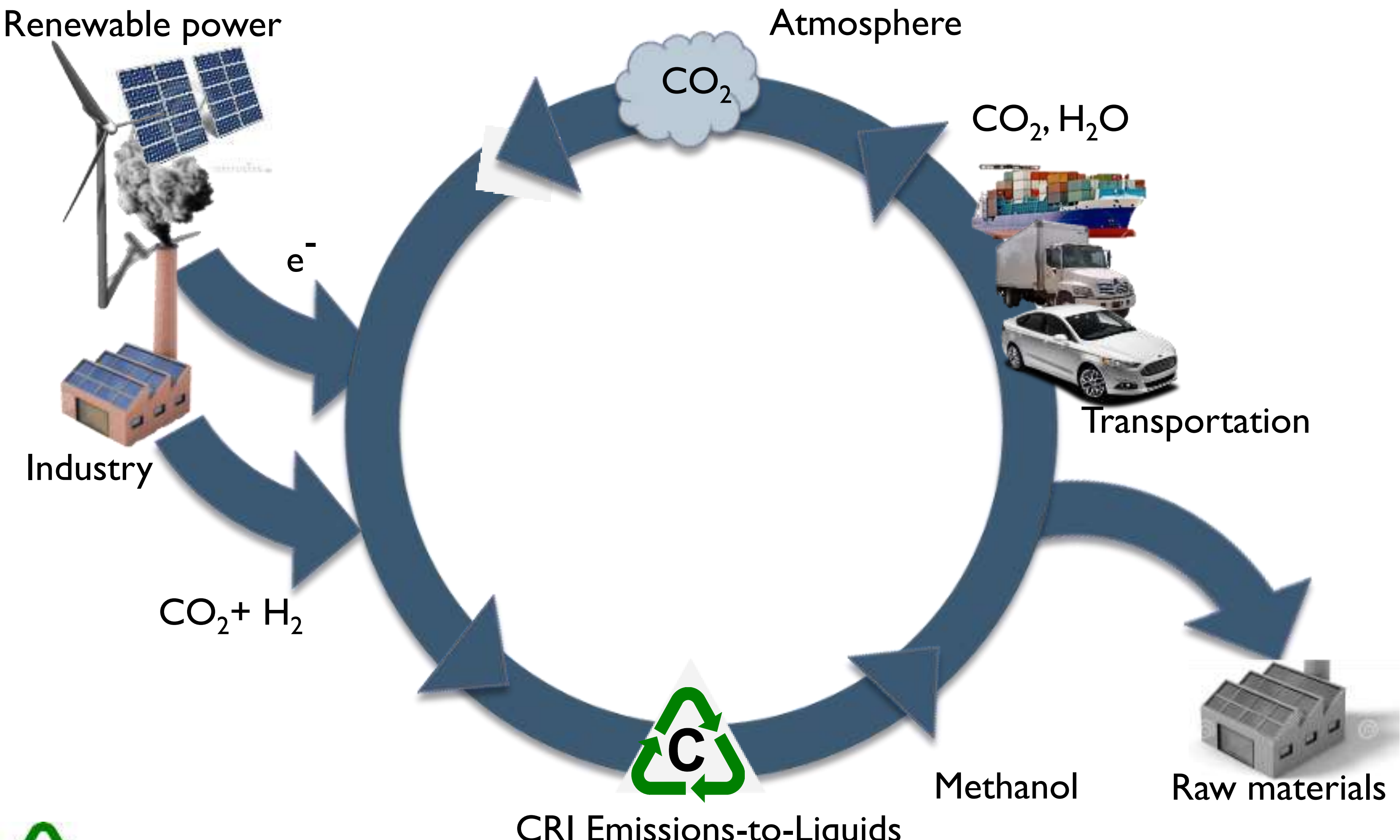
Can we replace fossil carbon with biomass?

- Replacing 5 Gigatons C with biomass (assuming 50% carbon in biomass) gives:

Carbon conversion efficiency	Biomass needed annually	Land requirement
100%	10 Gigatons	3 Million km^2
50%	20 Gigatons	6 Million km^2
25%	40 Gigatons	12 Million km^2

  - Iceland is 103.000 km^2
  - Europe covers around 10 million km^2
- IEA 2011: 27% transport fuel from Biomass in 2050
  - Requires: 3 Gigatons of Biomass and 1 million km^2
- Carbon conversion efficiency and recycling is critical!

Emission-to-Liquids – Power-to-Fuel

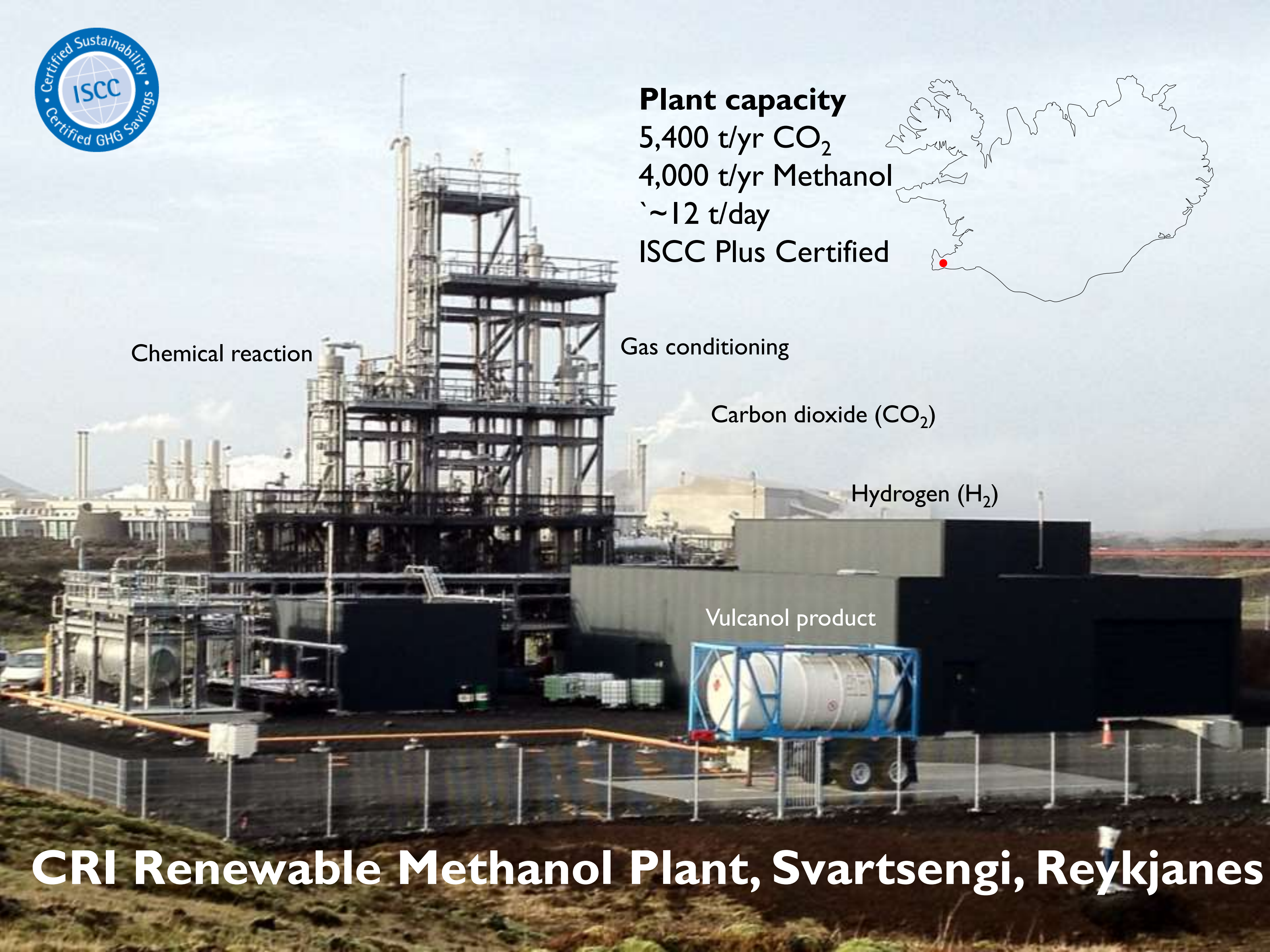


Brief history of CRI

2007	2008	2009	2010	2011	2012	2013	2014	2015
Company launched in Reykjavik	Technology development	Pilot plant production	Plant engineering	Plant construction	**Plant opening** with 1,300 t/yr capacity	**First sales** (exports and domestic) **Methanex largest methanol provider invests**	**Plant expanded** to 4,000 t/yr capacity	Marketing of technology & partnerships **Investment by Geely owner of Volvo Cars**

CRI Renewable Methanol Plant, Svartsengi, Reykjanes

Plant capacity
5,400 t/yr CO_2
4,000 t/yr Methanol
`~12 t/day
ISCC Plus Certified



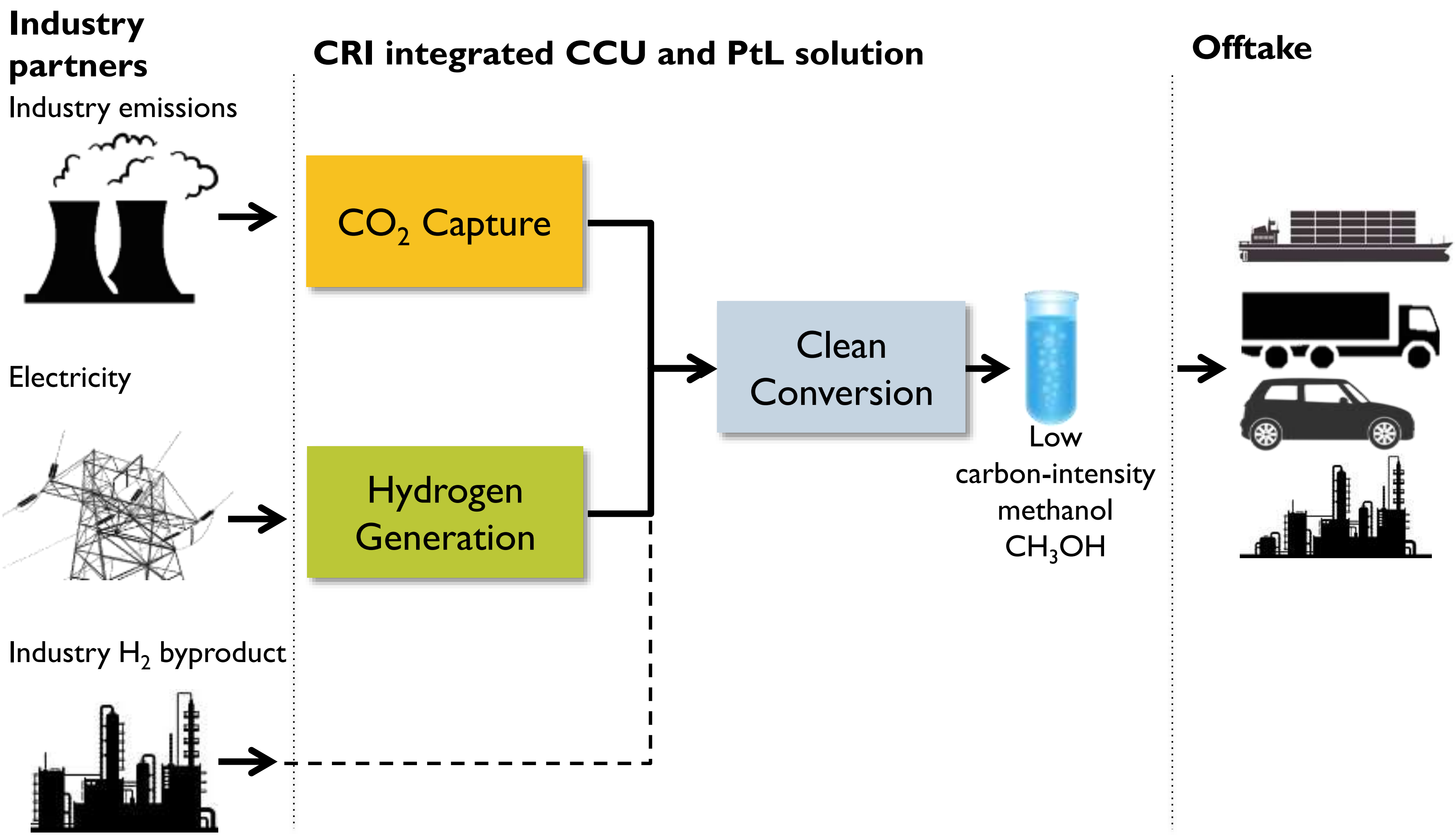
George Olah Renewable Methanol plant

Innovation in technology and business model

- **First** to recycle kiloton CO_2 to produce liquid transport fuel
- **First** to install multi MW water electrolyzers (6 MW) for power to liquids application
- **First** to deliver renewable fuel of non-biological origin to the largest independent oil provider in EU
- **First** to hold sustainability certification with 90% reduction of CO_2 compared to gasoline

Pictures from the GO plant in Svartsengi

CRI's Power-to-Liquids platform



Customers

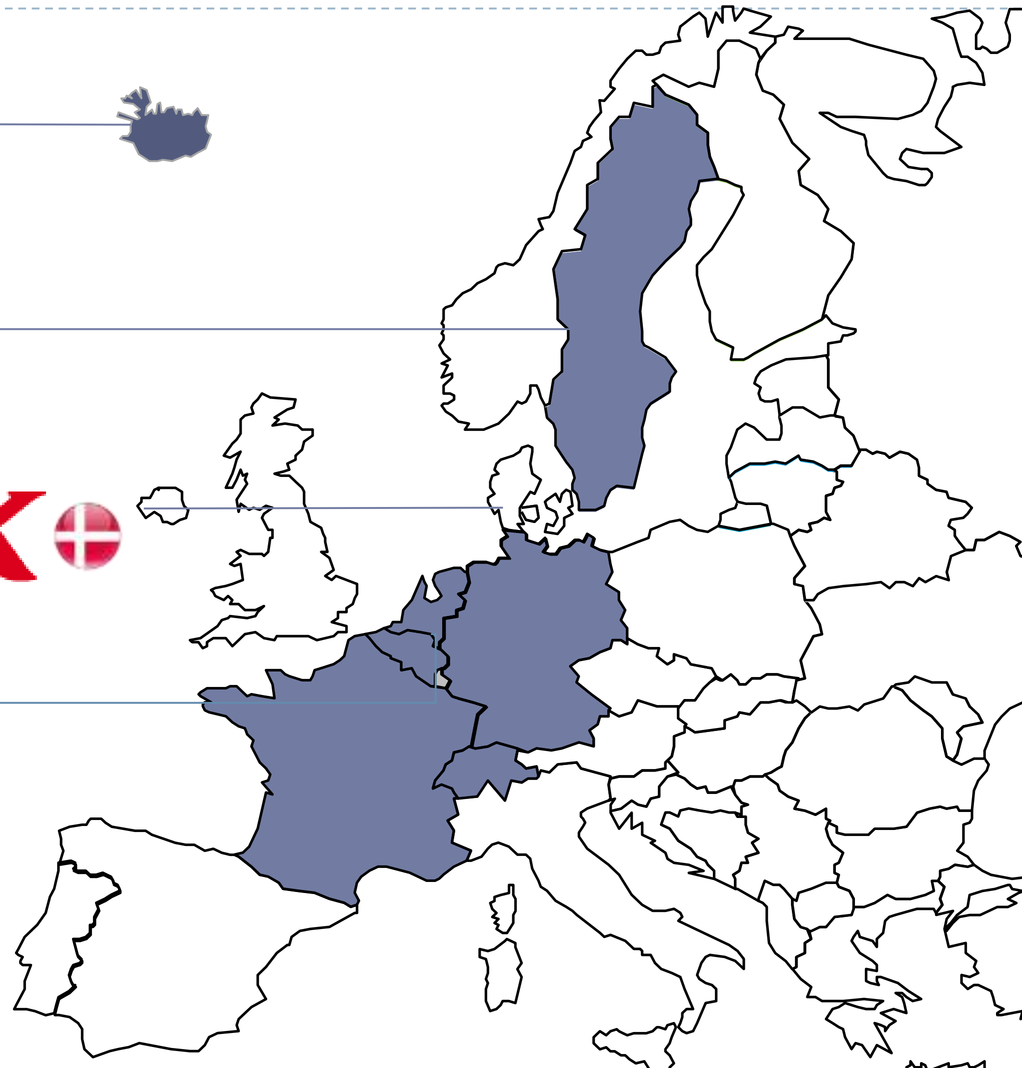
Perstorp

Serenergy® The Power of Simplicity

OK

Argos

GUTTS®



Methanol fuel initiatives around the world

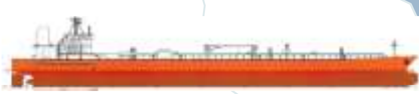
Iceland: Fleet testing of M50 in Ford FFV vehicles

UK: M95 fuel no tax

Sweden: M100 zero sulfur marine fuel

EU/EEA: M3 in SP95 standard

China: M15-M100 tests in 11 major cities



Canada: 9 x 50,000 t fuel tankers powered by M100

Denmark: test of EVs with methanol fuel cells

Fuel Choices Initiative

Israel: Public private fleet testing of M15

Australia: Government supporting launch of M7

Other countries demo programs: Trinidad, Azerbaijan, Uzbekistan, Iran, Libya

Research and Development at CRI

Projects:

CyclicCO2R
Fine chemicals from CO_2

Electra

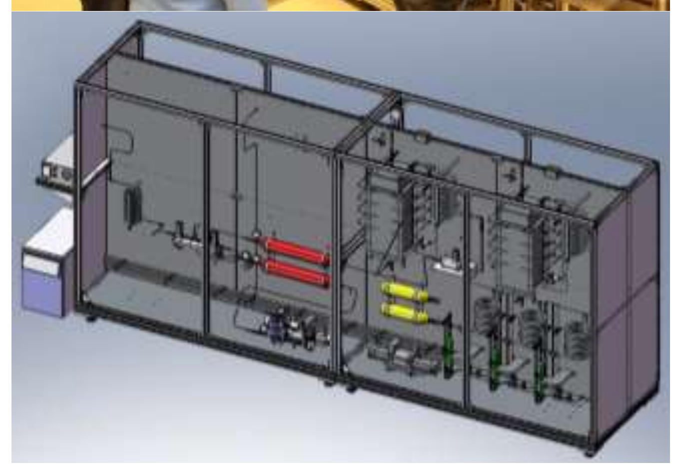
Funding:

HORIZON 2020

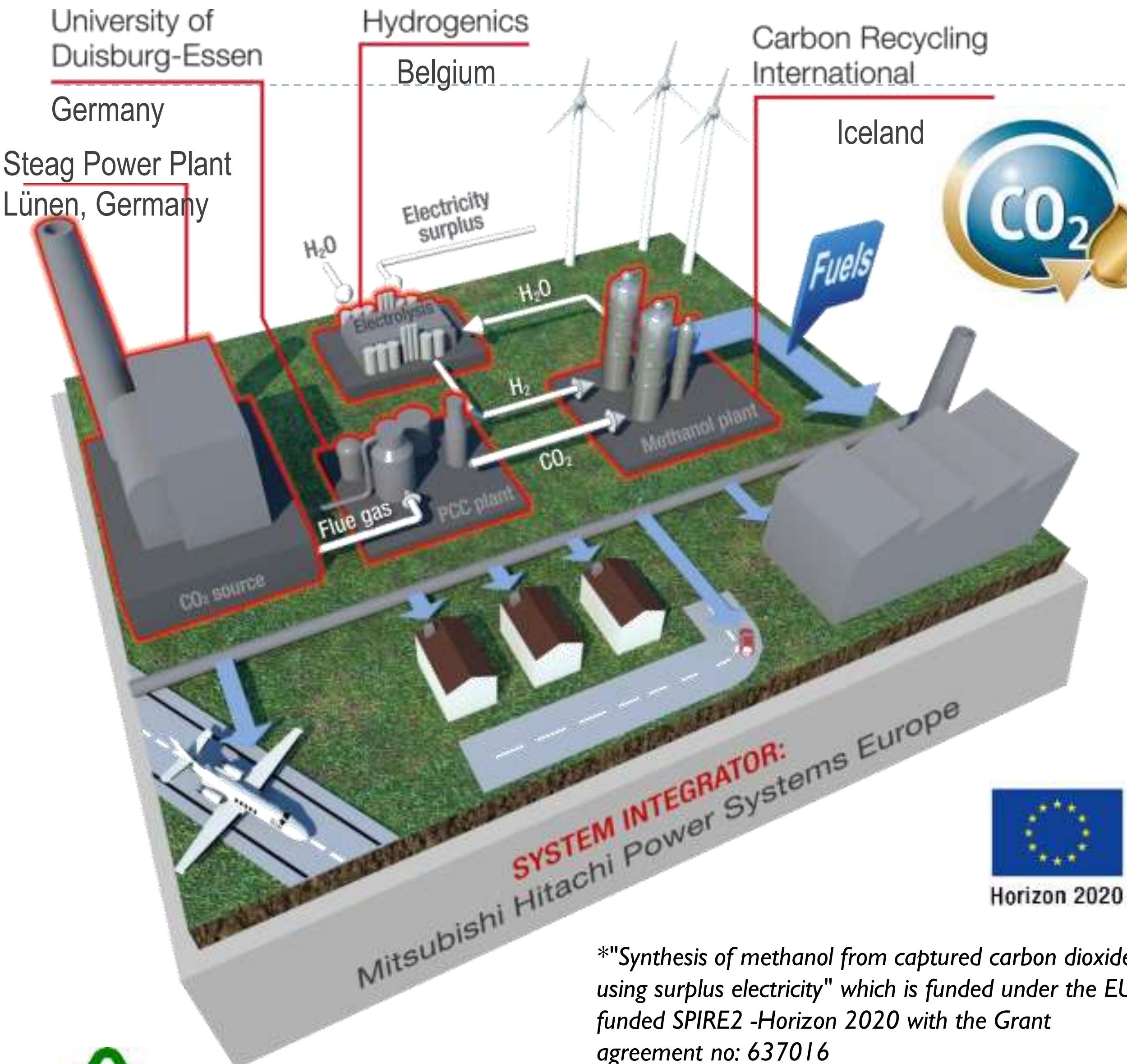
Technology Development Fund

SEVENTH FRAMEWORK PROGRAMME

Facilities:



MefCO2 project



1 MW_{el} (peak)
1 t/day Methanol

EUR 11million
80% EU funding *
Project start: 12.2014
Duration: 4 years

Other partners:
- Genoa University (Italy)
- Cardiff University (UK)
- Catalysis Institute (Slovenia)
- I-deals (Spain).

*"*Synthesis of methanol from captured carbon dioxide using surplus electricity" which is funded under the EU funded SPIRE2 -Horizon 2020 with the Grant agreement no: 637016*

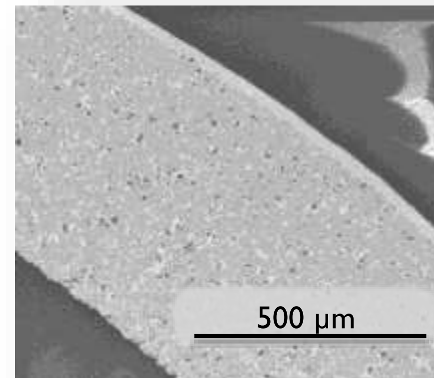
High temperature steam electrolyser with novel proton ceramic tubular modules

Novel functional materials

Scalable production

1 kW multi-tubular module

Integration with renewable energy sources



UiO : Universitetet i Oslo

CoorsTek Membrane Sciences

SINTEF

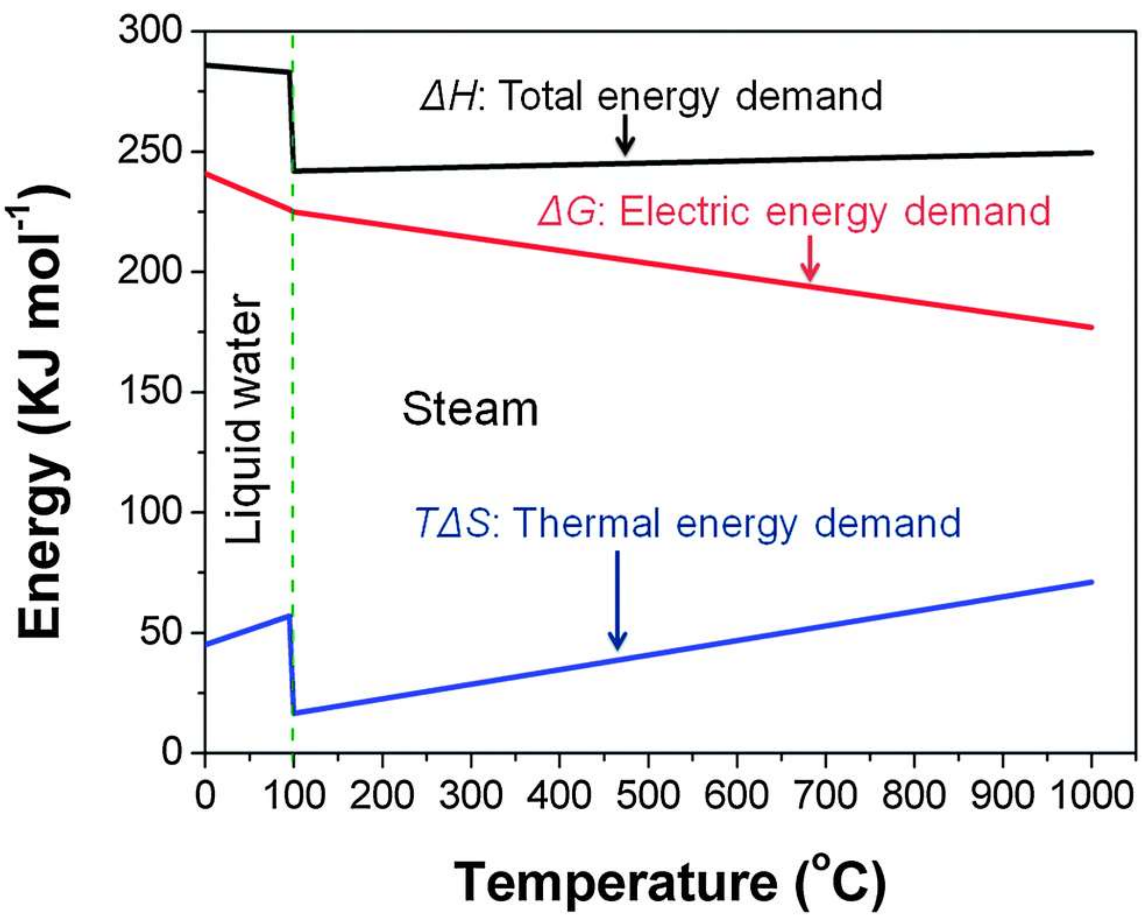
Marion Technologies

CSIC

ABENGOA HIDROGENO

Carbon Recycling International

Increasing the operating temperature can reduce electricity cost and improve total efficiency of hydrogen production



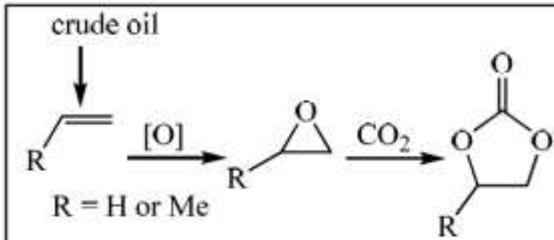
CyclicCO2R

Fine chemicals from CO_2

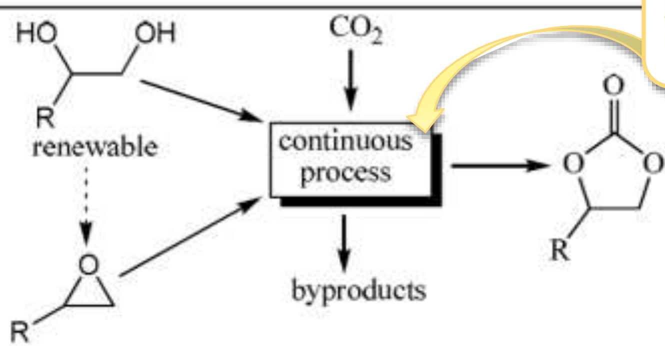
SEVENTH FRAMEWORK PROGRAMME

Glycerol → Allyl alcohol → Glycidol → Glycerol carbonate

Project focus



Scheme 1: Current commercial process for cyclic carbonate synthesis



Scheme 2: Sustainable cyclic carbonate production

Patented catalyst

Challenges:

- Continuous process with immobilized catalyst
- Production of pure glycerol carbonate and other cyclic carbonates

Conclusions

- Recycling of carbon is needed for long term sustainable sourcing of fuels and chemicals
- Strong drivers are in place for increased use of renewable and low carbon fuels in the coming decades
- CRI has built a unique production plant and shown it is possible to produce methanol from recycled CO2 at an industrial scale
- Continued innovation, research and development is key to future success and lasting impact

Acknowledgements

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