RESULTS OF THE CO_2 CAPTURE DEMONSTRATION FACILITY AT EDF'S LE HAVRE POWER PLANT

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OUTLINE OF THE PRESENTATION

1. Strategic approach
2. Le Havre CCS Pilot
3. Main Results and Lessons Learned
4. Conclusions

1. Strategic Approach

- Reducing Carbon Use Step by Step
- Specific Needs by Country
- CCS Energy Penalty Reduction

REDUCING CARBON USE STEP BY STEP

- Promote Demand Side Management on the customers' side and
- Reduce carbon use intensity in generation:
  - 1st step: reduce share of carbon based generation in energy mix
  - 2nd step: maximize energy output per quantity of carbon used
  - 3rd step: enhance energy efficiency.
- Then next steps; towards CCS:
  - Prove, develop and apply post-combustion technologies
  - Develop oxycombustion
  - Watch on other technologies in order to prepare the future
- In parallel contribute to develop CO_2 transport and storage

SPECIFIC NEEDS BY COUNTRY

STRUCTURE OF GENERATION MIX FOR EACH COUNTRY

	Share of generation (2011, %)				Carbon intensity
	Hydro	O. Renew	Nuclear	Fossil	g CO_2 / kWh
▪ Poland	2,0	6,1	0,0	91,9	912
▪ UK	1,7	7,7	18,1	72,4	450
▪ Germany	3,9	18,5	17,7	59,8	464
▪ Italy	16,2	12,7	0,0	71,1	405
▪ France	9,4	3,6	77,5	9,5	50
▪ *EDF*	*7,0*	*0,8*	*89,5*	*2,7*	*25*

Sources : EURELECTRIC, EDF.

CCS ENERGY PENALTY REDUCTION

- 10 to 15 efficiency points loss for CO_2 capture not sustainable:
  - would lead to a 20 to 30 % increase in coal consumption
- Doubling the investment cost per MW not economically sustainable:
  - would jeopardize competitivity
- Therefore:

  Energy Penalty Reduction and

  Investment Overcosts Reduction

  are our main priorities for post-combustion CO_2 capture

… after proving the faisability of the technical routes …

… in order to keep some competitivity …

2. Le Havre CCS Pilot

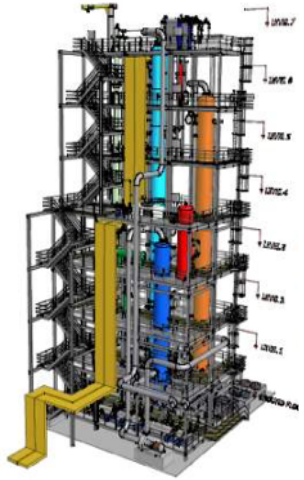
- The Capture Pilot Plant Project at EDF'S Le Havre
- Le Havre Power Plant
- Features of Le Havre Capture Pilot Plant (1/2)
- Features of Le Havre Capture Pilot Plant (2/2)
- AAP @ Le Havre: Main Objectives

LE HAVRE CCS PILOT

THE CAPTURE PILOT PLANT PROJECT AT EDF'S LE HAVRE

photos © EDF 2013

EDF Le Havre coal power plant
(field pilot represented in orange)



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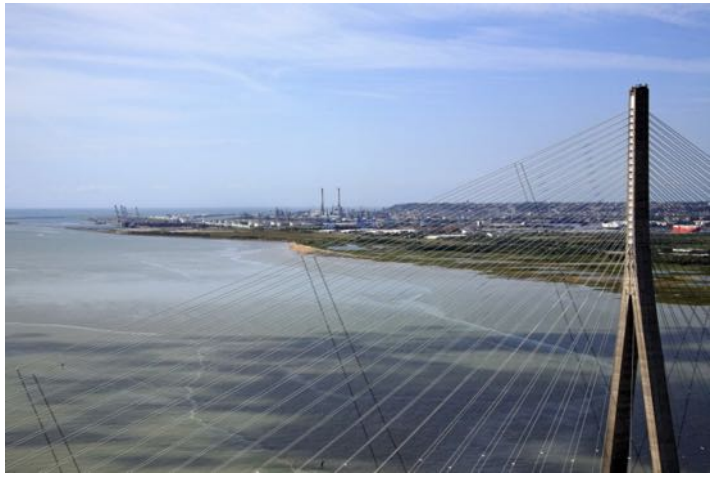
- **Designed to capture 25 t CO_2/day at 90% CO_2 capture, (CO_2 ~ 12 vol%)**
- **Flue gas: slipstream from 580 MWe coal unit (EDF host facility)**
- **22 M€ budget (construction & operation, all included)**
- **25% public funding by ADEME**
  (French Environment and Energy Management Agency)
- **Project schedule :**
  - **Overall 2010 - 2014 project**
  - **1st tonne captured on 8 July 2013**
  - **Testing from October 2013 until March 2014 (down from 1 year originally programmed)**

LE HAVRE CCS PILOT

LE HAVRE POWER PLANT

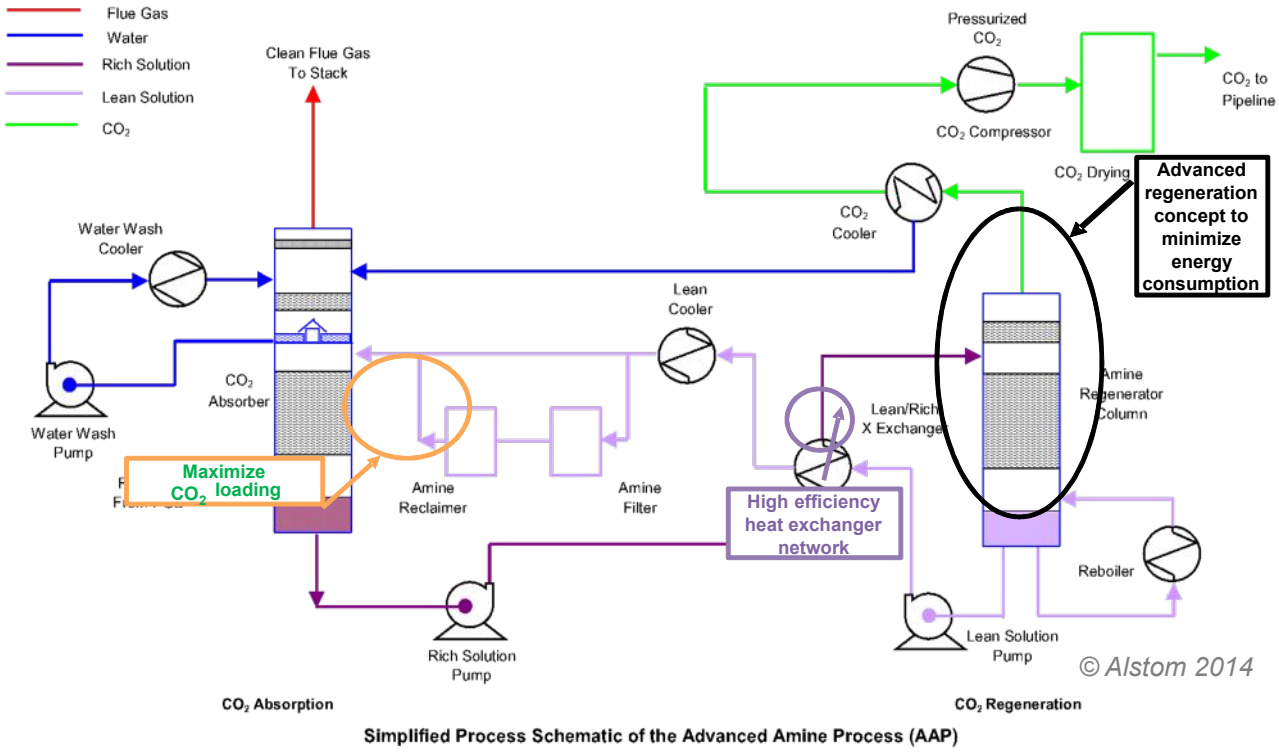
- **Located in the biggest French harbour, at the mouth of the Seine River**
- **1 coal unit still in operation**
  - **Unit 1, coal, 250 MWe-net [1968 – 2013]**
  - **Unit 2, coal, 585 MWe-net [1969 – 2014]**
  - **Unit 3, heavy fuel oil, 585 MWe-net [1973 – 1995]**
  - **Unit 4, coal, 580 MWe-net [1983 –>2035]**
    - **Major renovation works currently on-going to extent operation until 2035**
- **Le Havre unit 4**
  - **Lowest marginal costs of the French fossil plants**
  - **Burns international coals**
  - **Equipped w/ full AQCS (SCR, ESP, wet-FGD)**
- **Typical operation is**
  - **5,000 – 5,500 h a year**
  - **High level of grid services**
    - **i.e. operates daily between 50% and full load**



© EDF 2013 – Didier Marc – bird's eye view: Normandy bridge and Le Havre and its Power Plant

Location of Le Havre on a map of north-west France

FEATURES OF LE HAVRE CAPTURE PILOT PLANT (1/2)



Simplified Process Schematic of the Advanced Amine Process (AAP)

- **Advanced Flow Scheme (= latest generation of AAP scheme) is implemented at Le Havre**
  - **Improved absorber design**
  - **Advanced regeneration concept**
  - **High efficiency heat exchanger network**
  - **Additionally: O_2 stripper**

FEATURES OF LE HAVRE CAPTURE PILOT PLANT (2/2)

Parameter	Value
Inlet flue Gas Flow Rate	2500 – 5000 Nm^3/hr
Inlet flue Gas Flow Temperature	36 – 45°C
Inlet flue Gas SOx Content	< 220 mg/Nm3 @6% O_2
Amine Solvent Flow Rate	12 – 25 metric tonnes/hr
CO_2 Removal Efficiency Target	90%
CO_2 production Rate	25 metrics tonnes/day

Parameter	Value
Flue Gas Conditioning Column	11.8 m x 110 cm ID
Flue Gas Conditioner, $DeSO_x$ Rating	> 91% SO_2 removal
Absorber, Lower Section Column	20.7 m x 120 cm ID
Absorber, Upper Section + Water Wash Column	24.3 m x 110 cm ID
Amine Regeneration Column	26.0 m x 60 cm ID

AAP @ LE HAVRE: MAIN OBJECTIVES

Test Programme Aim

- **Evaluate key process issues:**
  - **CO_2 capture efficiency & thermal performance**
  - **Solvent management**
- **Environmental study**
  - **Emissions to atmosphere**
  - **Liquid waste**
- **Oxygen stripping impact on solvent degradation & performance**
- **Corrosion resistance of steel and non-metallic materials**
- **Reliable operation during transient modes,**
  i.e. load variations, start-ups & shut-downs

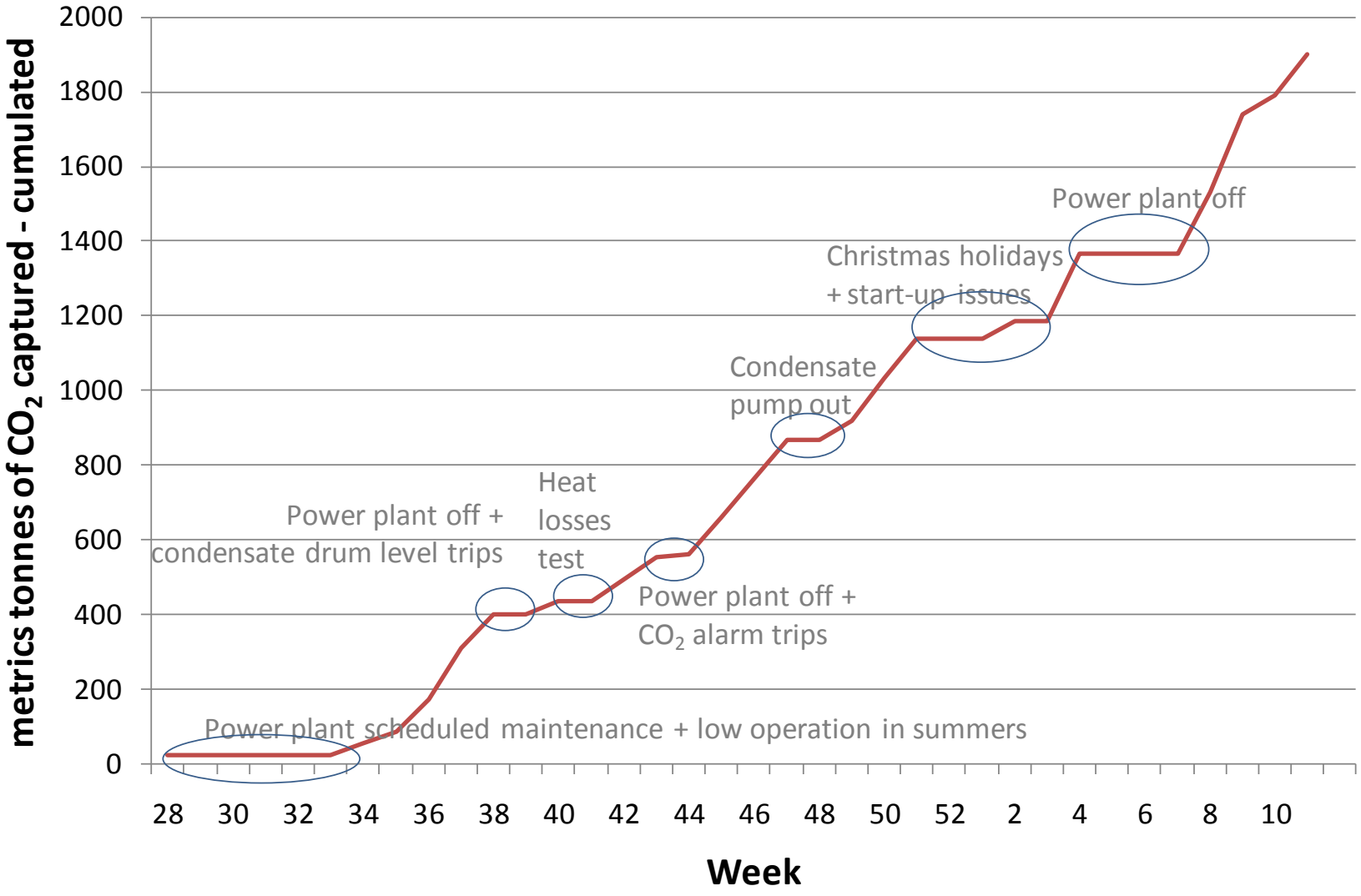
More Interests of the Power Producer

- **Aware buyer of the technology**
- **Develop O&M skills and knowledge**
- **Arise awareness on capture part of CCS**

3. Main Results and Lessons Learned

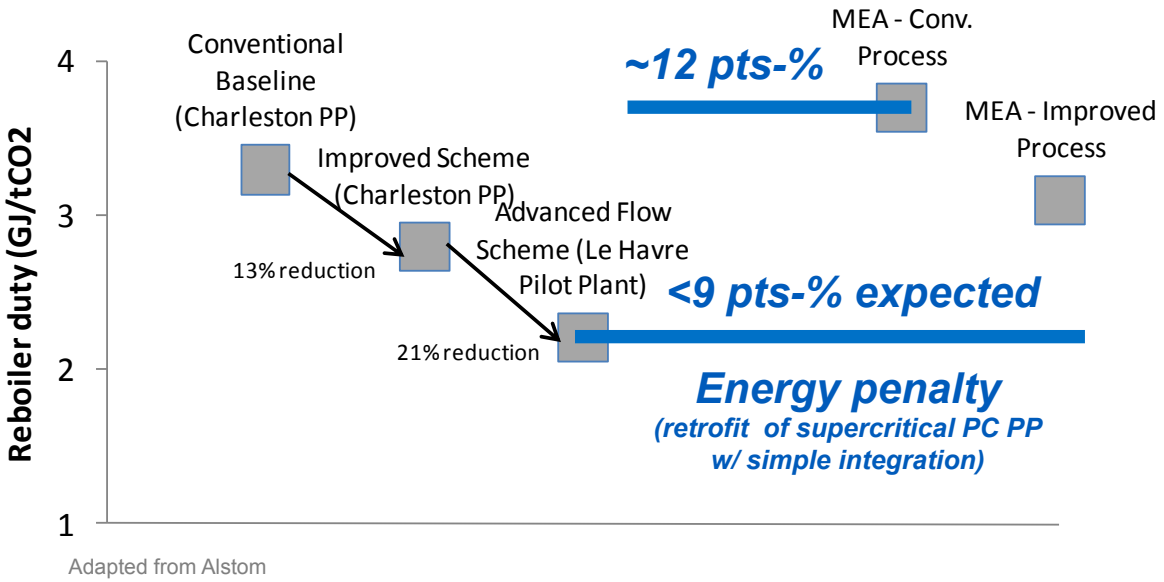
- 1,900 Tonnes of CO_2 Captured
- Energy Performance
- Solvent Management
- Emissions

1,900 TONNES OF CO_2 CAPTURED



ENERGY PERFORMANCE

- *A thermal performance of 2.3 – 2.4 GJ/t CO_2 at 90% capture rate was demonstrated consistently*
  - **These values were obtained in slightly different process conditions than the design case (namely Liquid/Gas ratio)**
  - **Results indicate that there is a potential for further slight energy improvement with minor modifications to the existing equipment**



Adapted from Alstom

ALSTOM Advanced Flow Scheme has significantly lower energy demand than Conventional Flow Scheme

SOLVENT MANAGEMENT

- No additives were added (save a small quantity of anti-foam UCARSOL™ GT10)

- Max. reboiler outlet solvent T° kept slightly below 130°C for most of the campaign

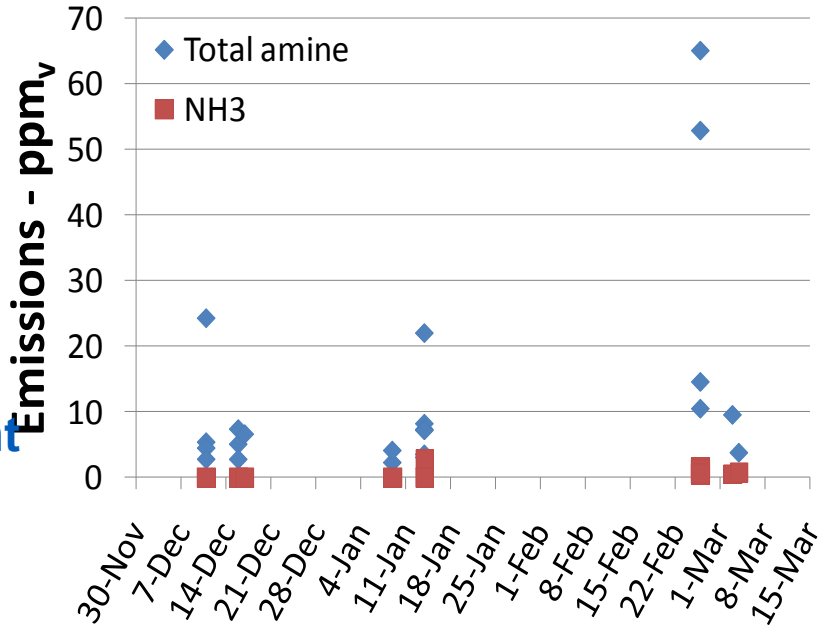
- Within these conditions, UCARSOLTM FCG 3000 shows good stability behaviour

  - An amine loss around **0.23 – 0.3 kg/tonne of CO_2** was reported (emission + degradation): the degradation rate and rate of by-product build-up is comparable to published pilot plant degradation studies on MEA.

EMISSIONS

- Amines emissions were low (a few ppm_v).
  - Consistent w/ Charleston Pilot Plant results (below 2 ppm_v)
  - In line w/ what is expected given the volatility of the solvent
- However, somewhat higher amines emissions were randomly, but regularly, observed with peaks infrequently higher than 50 ppm_v
  - Could be linked to aerosol emission
- Amines and ammonia emissions sampled and reported throughout the test period

Note : ALSTOM has now updated the design of the emissions control system to mitigate unexpected peaks in emissions



- Ammonia emissions were even lower (< 2 ppm_v)
- The semi-quantitative FTIR measurement were in good agreement with Dow measurements (gas impingers samples + laboratory analysis) both for amines and ammonia.

LESSONS LEARNED SO FAR

- **Relationship with the authorities:**
  - Transparency and responsiveness are crucial;
    Meetings were organized regularly and monthly reports were issued.
  - We were able to answer satisfactorily to the administration concerns.

- **Capture process operation:**
  - Operators' learning curve needs to be considered in test planing
  - The plant was designed for a multitude of operating conditions, posing challenges to operators and equipment

- **Data quality and instrumentation verification:**
  - Processes this size are build as any 'industrial plant' (but more instrumented). Plant instrumentation measurement chains must undergo a specific qualification to ensure the desired level of accuracy for R&D purposes. It is time- and manpower-consuming
  - Specific effort was dedicated to detailed liquid solvent and emission analysis due to (i) the stakes and (ii) the necessary skills and procedures to reach proper results:
    - Emissions sampling were thoroughly prepared
    - Solvent/emission sampling & analysing requires know-how (ensured by DOW, EPRI, SINTEF and other labs)
    - FTIR continuous measurement is an added value

4. Conclusions

- Wrap-up
- EDF's Vision

WRAP-UP

- ALSTOM's AAP Advanced Flow Scheme, was implemented and successfully demonstrated at EDF's Le Havre, also thanks to ADEME's funding.
- 1,900 metric tonnes of CO_2 were captured between July 2013 and March 2014 at EDF's demonstration facility (designed to capture 25 tonnes/day).
- Many tests data is still to be reviewed, but preliminary results are:
  - Thermal performance of 2.3-2.4 GJ/t CO_2 at 90% capture rate consistently demonstrated.
  - Good thermal and chemical stability of the solvent,
  - Consistently low ammonia emissions (< 2 ppm_v)
  - Low gaseous amine emissions (a few ppm_v), but a few emissions peaks.
- In terms of operation:
  - On-site workforce sized to operate 24/7 (to maximize the amount of tests during time available)
  - Measurements and data quality was a continuous improvement process.
  - We were able to answer satisfactorily to the French administration questions and concerns.

EDF'S VISION

- Climate change identified within EDF as a major issue since 1990, with significant results achieved so far;

- *EDF's Energy mix significantly de-carbonized*
  (25 g CO_2 / kWh in France,120 g CO_2 / kWh worldwide in 2011),

- CCS acknowledged as one of the potential technologies to curb further CO_2 emissions,

- Capture side:
  - valuable experience gained at Le Havre, but developments still needed,
  - need for proving the technologies at industrial scale,
  - reducing costs & energy penalty, while
  - keeping enough manoeuvrability.

- Transport & storage side:
  - present technical bottlenecks in Europe?
  - urgent need for gaining public support and acceptance.

Thank you