Final Workshop

Risk assessment of biomass to DME industrial plants

T. JAYABALAN & G. MARLAIR

L'Institut National de l'Environnement Industriel et des Risques (INERIS),
Parc Technologique Alata,
60550 Verneuil-en-Halatte (France).

INERIS
maîtriser le risque
pour un développement durable

Outline

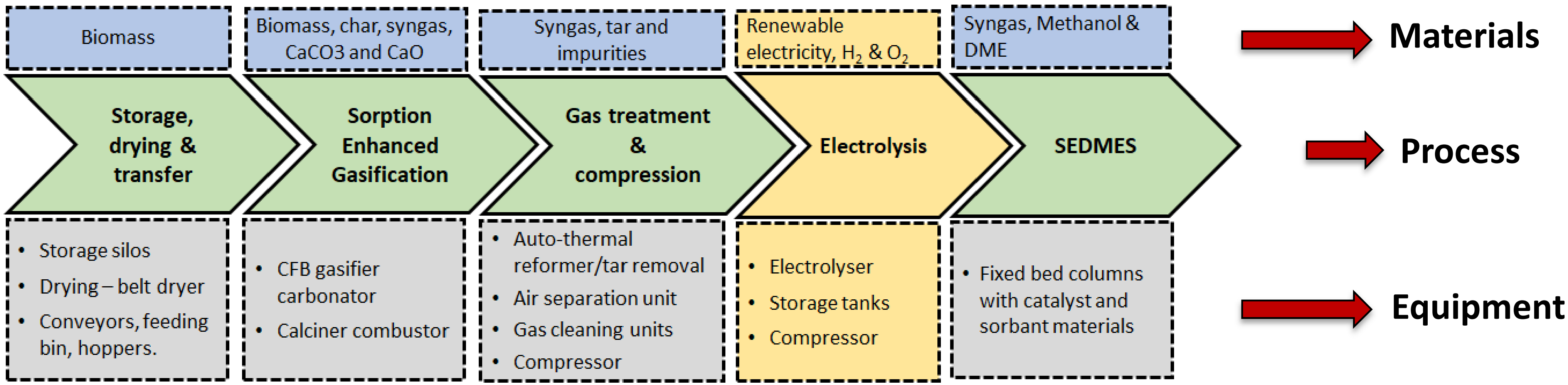
- Risks associated with biomass to DME plants.
- Comparison of safety impacts between an intensified DME process as optimized in FLEDGED vs a conventional DME plant focusing on:
  - Benefits from Inherently Safer Design guiding principles,
  - Safety assessment from modelling of risk scenarios.
- A few insights on regulatory requirements in support of commercial deployment of FLEDGED plants in EU.

Risk assessment – From Biomass storage to DME plant operation

Evaluation of technological risks is important at the early stages of development.

Efficient and proactive cost-effective decision making with respect to safety through :

- Reducing or eliminating root causes of hazards through alternative design and technical safety measures (timely selection of most appropriate safety barriers).
- Preventing additional cost for design modifications at the later stages.
- Anticipating regulatory legal requirements for FLEDGED process deployment and commercialization.



Biomass Feedstock flexibility analysis in terms of safety aspects

Diversity in feedstocks

- Wood based
- Municipal solid wastes
- Refuse derived fuels
- Straw
- Grape seeds.....

Characterization of biomass of interest shall integrate safety-driven data to prevent dust explosion and self-heating hazards for optimal design and operation of storage and handling equipment

Equipment/process unit	Substances associated	Risk scenarios
Storage of biomass in silos	Biomass, CO	Fire due to self-heating Gas explosion with CO produced by self-heating in silos. Dust explosion
Fuel preparation facilities (sieving, grinding, sorting etc.)	Biomass	Fire Dust explosion
Transfer of biomass (conveyors, grapple…)	Biomass	Fire (friction in moving part, and accumulation of biomass dust…) Dust explosion
Feed hoppers	Biomass	Fire Dust explosion
Filter section	Biomass, char and $CaCO_3$, CaO dust	Fire Dust explosion
Ash management	Ash	Residual oxidation of ash leading to fire

Experimental characterisation of self-heating & dust explosion risks

Self-heating characteristics

Solid waste (ECOH) < Wood

Sample	Height of non-compacted stacks (m)
ECOH pellets @10 % humidity	**16**
MSW granules	**15**
Wood pellets	**20**
Wood chips	**14**
Decomposed logging residues**	7
Sawdust**	6
Bituminous coal**	3

Characterized experimentally at INERIS

Pellets are better suited for safe storage & transfer.

***Reference :*

- *Combustion and explosion characteristics of dusts, BIA report 13-97.*
- *Health and Safety Aspects of Solid Biomass Storage, Transportation and Feeding, IEA Bioenergy, ask 32: Biomass Combustion and Co-firing, May 2013.*

Dust explosion characteristics

ECOH pellets < RDF < Wood dust

Sample	Dust explosion index Kst (bar.m/s)	Dust Explosion Classification
Refuse derived fuel (dp_{50} 63µm)	**34**	**St-1**
ECOH pellets (dp_{50} 225µm & humidity 10 %)	**15**	**St-1**
Wood chips (dp_{50} 550 µm) **	40	St-1
Straw biomass (dp_{50} 500 µm) **	47	St-1
Saw dust (dp_{50} 70 µm) **	238	St-2

Dust Explosion Classification	Dust explosion index Kst (bar.m/sec)	Qualification
St-0	0	No explosion
St-1	0-200	Weak to moderate explosion
St-2	201-300	Strong explosion
St-3	>300	Very strong explosion

Severe incidents of explosion have occured even with St-1 materials (e.g Imperial sugars, USA - https://www.csb.gov/imperial-sugar-company-dust-explosion-and-fire/)

Flammable gases & liquids

Fire and risks scenarios related to flammable gases :

- Fire and explosion risks related to electrolyser integration.
- Explosion risks in gas cleaning equipment when the temperature of syngas is reduced.
- Gas leaks from adsoprtion columns.
- Controlling flows of hot gases and ensuring effective transfer of solids at high temperature is important.

$CaO/CaCO_3$ in the calcium looping cycle can act as heat sink - a positive point with respect to safety.

Equipment/process unit	Substances associated	Risk scenarios
Gasifier/combustor	Syngas	Fire & Explosion during transient phases, start up and shut down
Gas treatment	Syngas	Explosion due to syngas as the temperature of the syngas is reduced to around 300 °C below its auto-ignition temperatures.
SEDMES	DME	Gas leaks and jet fire
SEDMES	Methanol	Pool fire in case of leaks
Electrolyser	H_2	Fire and Explosion of H_2
Storage vessels	H_2	Tank rupture Explosion and fire

Comparison of safety impacts

Intensified FLEDGED process

Storage, drying & transfer
- Input: Biomass
- Storage silos
- Drying – belt dryer.
- Conveyers & feeding equipment

Sorption Enhanced Gasification
- Input: Biomass, char, syngas, CaCO3 and CaO
- CFB gasifier carbonator
- Calciner combustor

Gas treatment & compression
- Input: Syngas
- Auto-thermal reformer
- Air separation unit
- Gas cleaning units
- Compressor

Electrolysis
- Input: Renewable electricity, H_2 & O_2
- Electrolyser
- Storage tanks
- Compressor

SEDMES
- Input: Syngas, Methanol & DME
- Fixed bed columns with catalyst and sorbant materials

Conventional process

Storage, drying & transfer
- Input: Biomass
- Storage silos
- Drying – belt dryer
- Conveyors, feeding bin, hoppers.

Direct Gasification
- Input: Biomass, char, syngas
- Gasifier
- Air separation unit

Tar removal
- Input: Syngas, CO_2, tar and impurities
- Auto-thermal reformer/tar removal
- Air separation unit

WGS
- Input: Syngas, CO_2
- WGS reactor

Gas treatment & compression
- Input: Syngas, CO_2 and impurities
- Gas cleaning units
- Compressor

CO_2 removal and compression
- Input: Syngas, CO_2
- Amine unit
- Compressors

DME synthesis
- Input: Syngas, Methanol & DME
- Methanol synthesis reactor
- Dehydration reactor

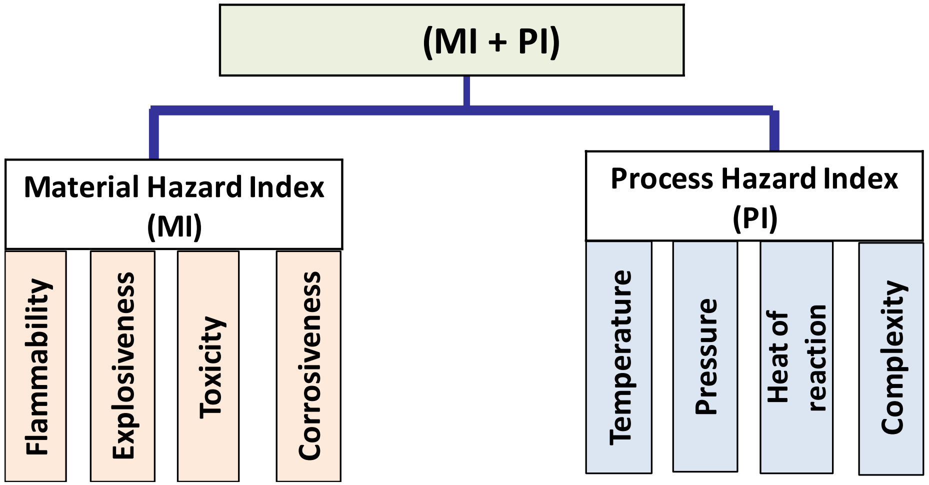
Comparison studies - Inherent Safety Index

Inherent safety design (ISD) is mainly driven by the elimination of the hazard, instead of focusing only on the mitigation of the effects through implementation of safety barriers wherever possible.

ISI = (MI + PI) + 10 % SU

ISI – Inherent safety index; MI – Material hazard index
PI – Process hazard index; SU – Secondary units

- Gasification units,
- SEDMES units,
- Amine unit,
- WGS unit,
- Methanol synthesis.



Scoring of ISD parameters

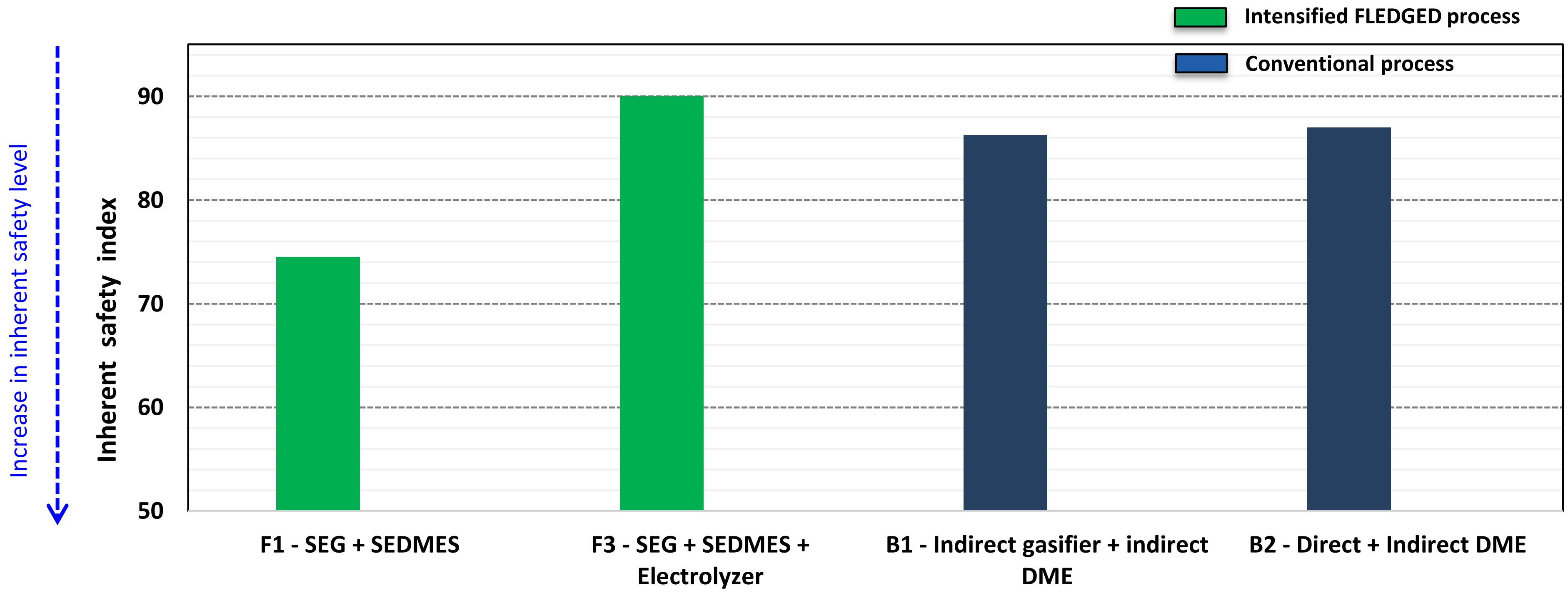
Process temperature °C	Score
> 0	1
1- 70	0
70 - 150	1
150-300	2
300-600	3
> 600	4

Process Pressure (bar)	Score
0 – 1	1
1 - 5	1
5 - 20	2
20 – 100	3
100 – 200	4

Secondary unit	Score
Heat exchanger, distillation column, flash	1
Pump, blower, cyclone, cryogenic heat exchanger	2
Compressor, ASU, ATR	3

- *Heikkila A.M, 'Inherent safety in process plant design. An index-based approach, VTT publications, VTT Technical Research Centre of Finland, Espoo.*
- *S. Park et al., Incorporating inherent safety during the conceptual process design stage: A literature review, 2020. Journal of Loss Prevention in Process Industries.*
- *Trevor Kletz, Inherently Safer Design, The growth of an idea. Process Safety Progress, 1996*

Comparison studies - results of Inherent Safety indices



Lower index score for a configuration implies a higher inherent safety level.

- Intensification of the FLEDGED process improves the inherent safety profile.
  - *Less number of units : CO_2 removal unit, WGS eliminated in FLEDGED process (concerned with higher flammable gas concentrations, volatile solvents).*
- F3 case with higher scores : electrolyzer dealing with pure hydrogen and complexity.

Modeling and simulation of risk scenarios

- Useful in scale-up and design of new facilities
  - Optimisation of separation distances between process units to avoid dominos effects in case of local accident,
  - Identification of pertinent technical safety barriers,
  - Provision of useful data for emergency planning purposes, workable firefighting options and training and devising evacuation scenarios,
  - Provision of useful information to competent authorities for nearby land use and planning policies *(consideration of the potential impact at the vicinity which may include public facilities, schools, hospitals, infrastructures (road, railways, airports…)*

Risk scenarios

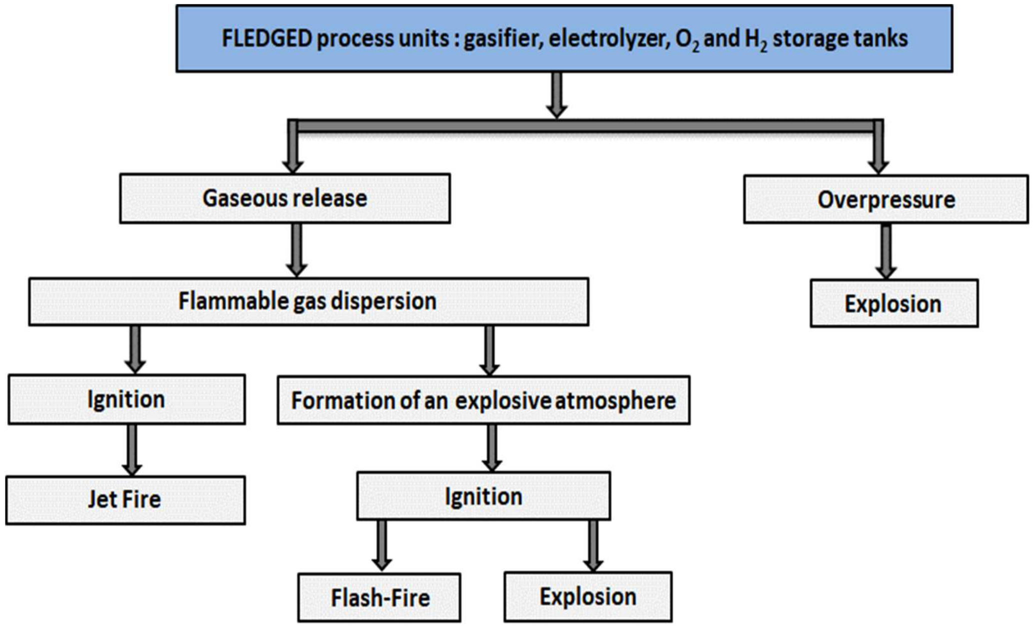


Illustration of results from modeling and simulation of risk scenarios

- Overpressure in the cooling section due to explosion of syngas/air mixture through thermodynamic calculations.
- Tsyngas < Auto Ignition Temperature in the cooler section.
- Fledged cases case have lower explosion effects than then conventional B1 case.

Configuration	F1 case cooling section (220 °C)		B1 case cooling section (220°C)	
	Initial pressure (bar)	Pressure rise (bar)	Initial pressure (bar)	Pressure rise (bar)
Explosion overpressure rise (bar)	1.2	4.5	3.3	13.5

Results of overpressure developed in the cooling section due to internal explosion

- Storage tank burst (physical explosion)

Simulation carried out in PROJEX® tool for 2 storage capacities 15 m^3 and 90 m^3

Effects	Effect distance [m]	
	15 m^3 storage tank	90 m^3 storage tank
Irreversible effects	75	136
First lethal effects	33	59
Significant lethal effects	26	46

Results of propagation distances to given effects to people for the tank burst scenario

Regulatory review for commercial deployment in EU

In Europe, regulations applicable to Fledged plant are primarily derived from :

- **SEVESO 3** (Directive 2012/18/EU) : The Directive covers situations where dangerous substances may be present (e.g. during processing or storage) in quantities exceeding certain thresholds.

  The quantity of hydrogen for the application of lower-tier requirements (≥ 5t) and upper-tier requirements (≥ 50t). For quantities of less than 5 tonnes of hydrogen, none of the obligations above would apply.

- **"IED"** Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control)

  Large combustion plants, waste incineration and co-incineration plants.

- **CLP Regulation** (EC) No 1272/2008 on classification, labelling and packaging of substances [CLP regulation]
- **ATEX** Directives:
  - Directive 2014/34/EU - covering equipment and protective systems intended for use in potentially explosive atmospheres
  - Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.
- Directive (EU) 2018/2001 of The European Parliament and of The Council of 11 December 2018 on the promotion of the use of energy from renewable sources (**RED II**) and replacing Directive 2009/28/EC.
- Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (**AFID**).

Conclusions

- Process intensification to convert biomass to DME by implementation of the FLEDGED process showed positive trends in terms of inherent safety.
- The integration of electrolyzer is adding sustainability gain, provided H_2 & O_2 storage options be optimized to reduce pressure effect distances.
- The regulations applicable for the deployment will depend on the size of the plant.

Acknowledgements

Benno WEINBERGER

Lauris JOUBERT

Barbara LUCIANO

Ghislain BINOTTO

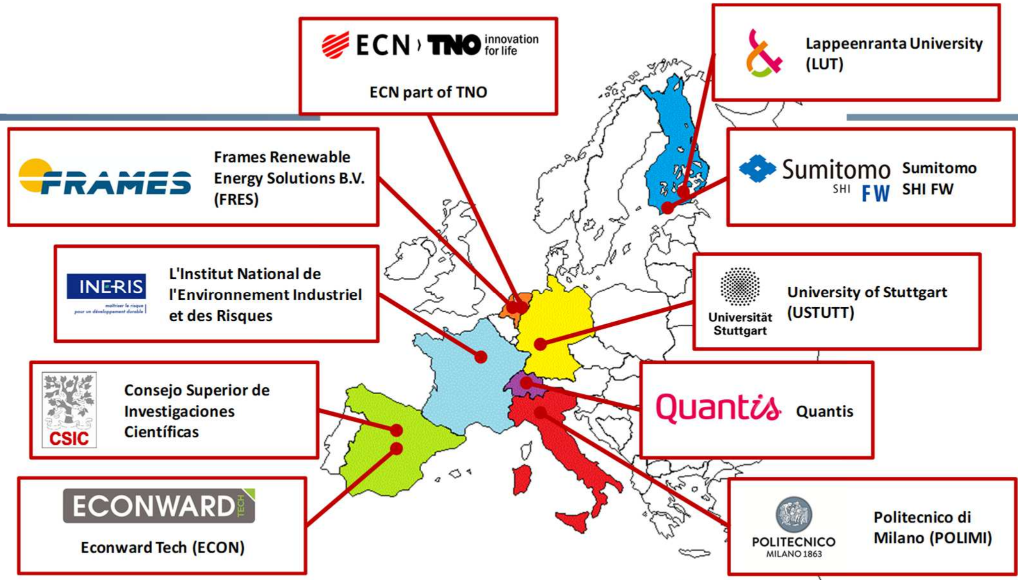
Alexis VIGNES

Sébastien EVANNO

Peggy GRUEZ

Aurélie AUBE

Valérie MALVAUX



Thank you for your attention !

Find out more: www.fledged.eu
Contact us: info@fledged.eu
Follow us: @FledgedProject
Fledged H2020 Project

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727600