Safety in the chemical industry: Progress field of domino effects, risk assessment & risk management

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Presentation outline

1. Who am I?
2. Background – Major accidents and Seveso legislation
3. Book 'Domino effects in the process industries' (Reniers & Cozzani, 2013)
4. Present research – overview papers
5. New book 'Dynamic risk assessment and management of domino effects and cascading events in the process industry' (Reniers & Cozzani, 2021)
6. What's happening in the Netherlands?
7. Conclusions & Recommendations

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Who am I?

- Full Professor Delft University of Technology
- Chemical engineer, Safety and Security Scientist
- Focus on industries using chemical substances
- Engineering & Technology
- Management & Economics
- Published 40 books (author + editor)
- Published 200+ articles

- MSc. in Chemical engineering
- Ph.D. in Applied Economic Sciences
- Full Professor TUDelft

(Chair on Safety of hazardous materials)

Prof. dr. ir. Genserik Reniers

- MSc. in Chemical engineering
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Prof. dr. ir. Genserik Reniers

- **Expert in**
  - Domino effects in the Process Industries
  - Cluster safety and security (culture)
  - Safety and security collaboration
  - Uncertainty analyses and game-theory
  - Systemic risks in the process industries
  - Safety and security prevention and economics
  - Security risk assessments in the chemical industry
  - Dynamic risk assessments (BN, Petri-nets)
  - Leadership and performance mgt science
  - Safety and security fundamentals
  - Bibliometrics on safety and security

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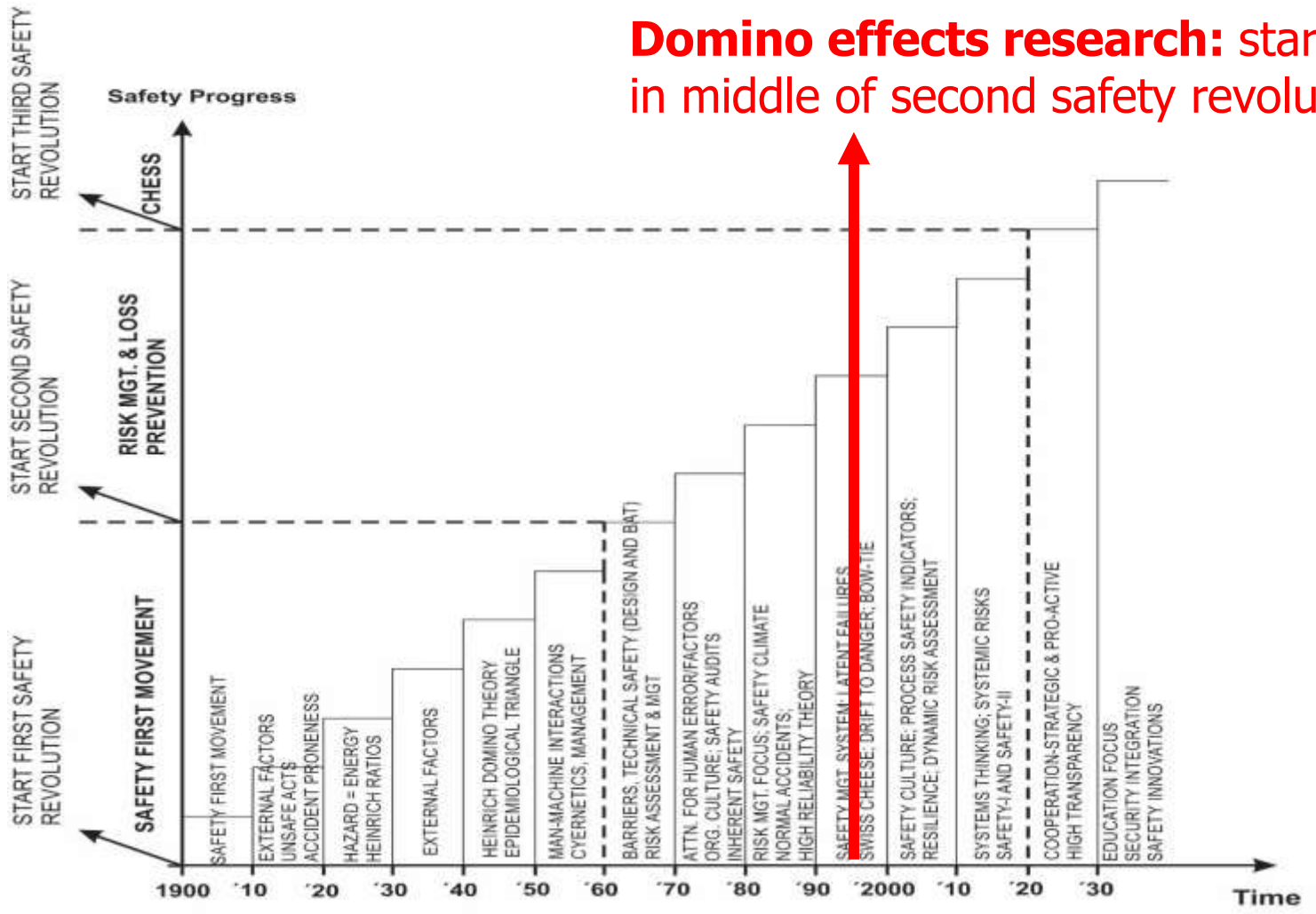
What are domino effects?

This type of accidents features a generic schematization with the following elements:

1) there is a "primary event", initiating the domino effect;
2) there is an escalation vector (e.g., fire impingement, heat radiation, explosion overpressure, etc.), facilitating the propagation of the domino effect;
3) one or more secondary accident events happen, involving one or more target equipment
4) with consequences worse than the primary consequences.

Brief history of safety progress

Domino effects research: started in middle of second safety revolution



Several periods in domino effects research and policy

First period: 1966-1995

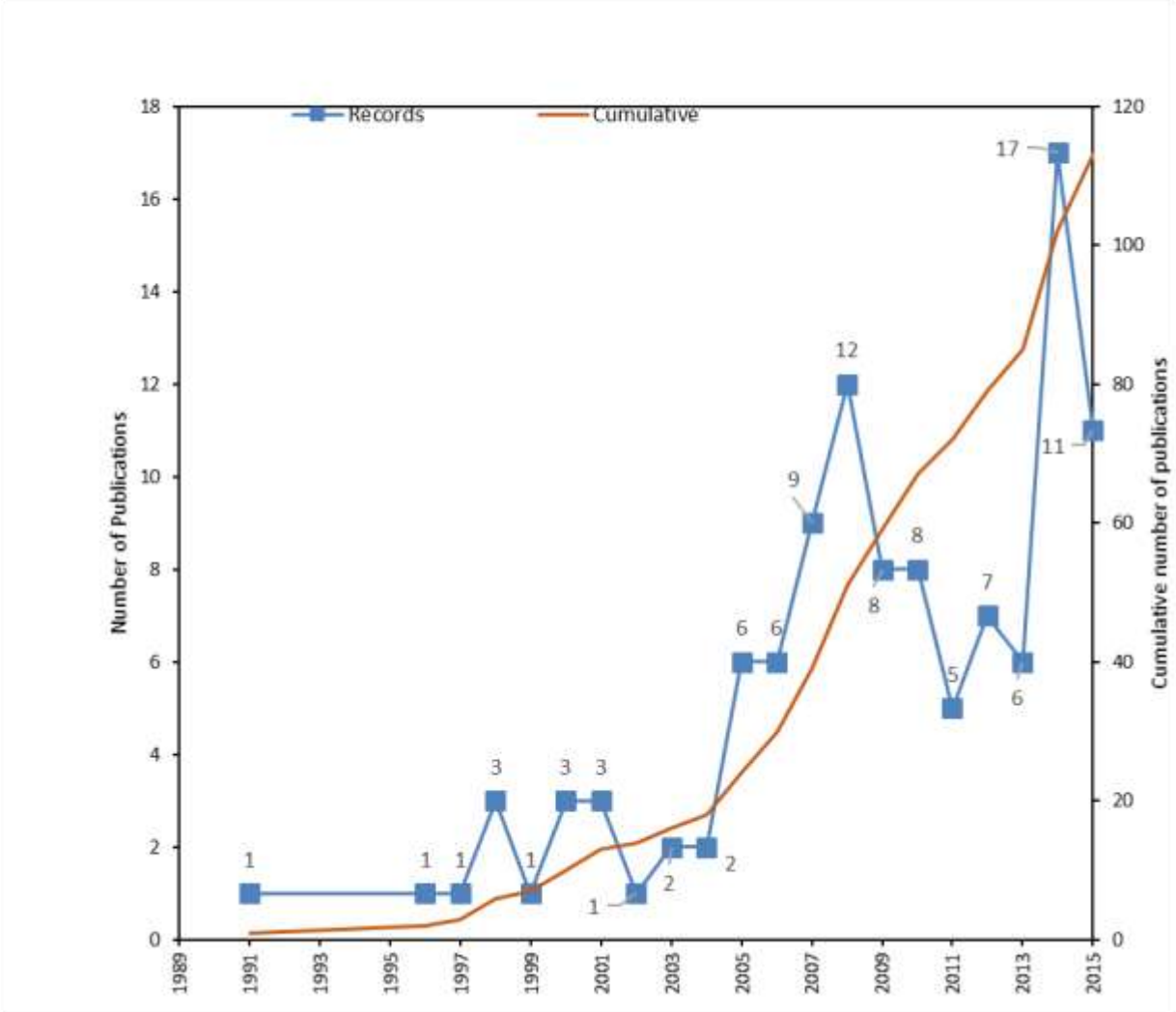
- Feyzin-1966 (France), Flixborough-1974 (UK) and Mexico City-1984 (Mexico)
- COVO study, the Netherlands (1982) – domino effects not included
- Risk calculations, e.g. ARIPAR (Italy)

Second period: 1996-2011

- Seveso II legislation: article 8 (external domino effects)
- Real research activities begin – understanding the phenomenon, accident scenario studies, escalation vectors, threshold determination, probit models, first simple software, QRA and game-theory based modeling

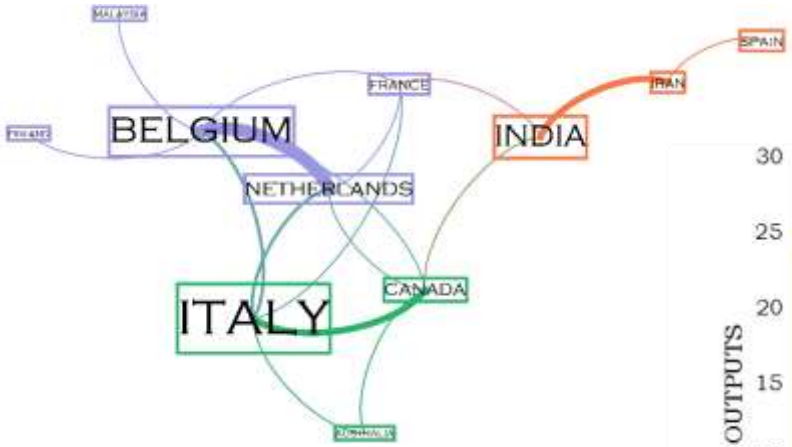
Third period: 2012-2018

- Sharp increase of research: deeper elaboration of techniques, more BNs, economics, security, probit modeling, Petri-nets, etc.

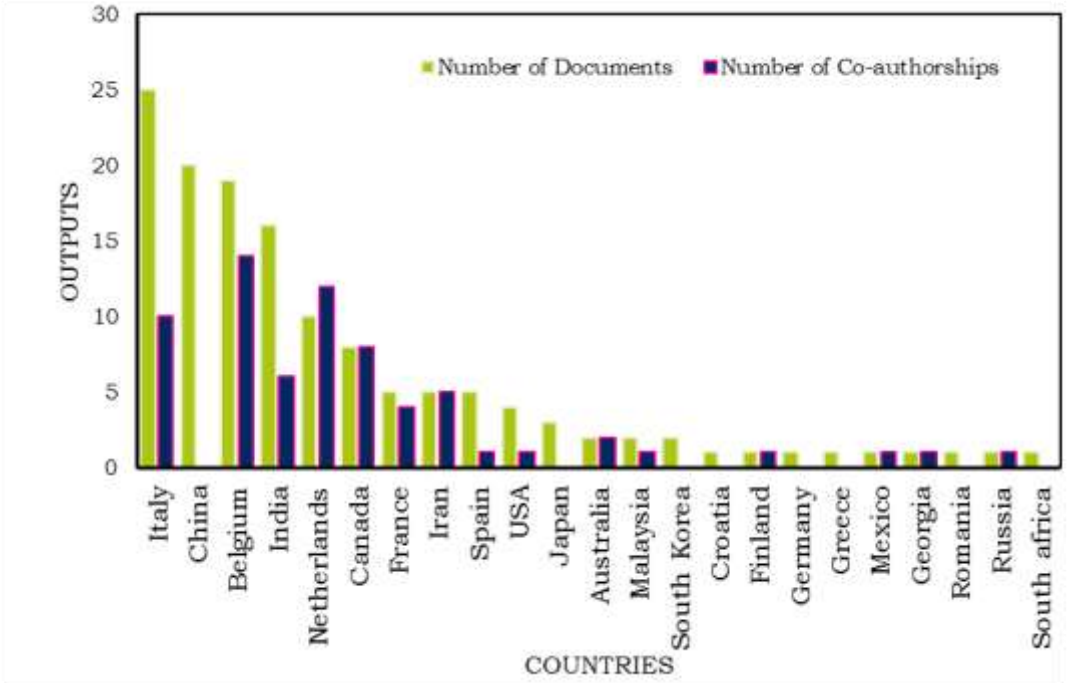


Annual distribution of publications on domino effects in the chemical industry.

Worldwide cooperation wrt domino effects



The countries with the highest contribution/cooperation in the domain of domino effects in the chemical industry.



Number of publications and co-authorships per country in the domain of domino effects in the chemical industry.

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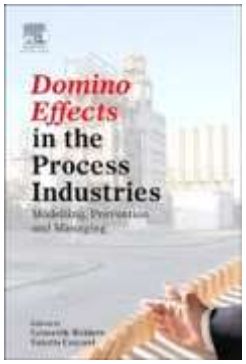
Table of Contents of the 2013 book



- Part 1: **Causes of domino effects**
  - Analysis of past accidents and relevant case-studies
  - Features of escalation scenarios
  - Overpressure effects
  - Heat radiation effects
  - Missile projection effects
  - Other causes of escalation
- Part 2: **Prevention of domino effects from a technological perspective**
  - Approaches to domino effect prevention and mitigation
  - Threshold-based approach
  - Quantitative assessment of risk caused by domino effects
  - Detailed studies of domino scenarios
- Part 3: **Prevention of domino effects from a managerial perspective**
  - Managing domino effects from a design-based viewpoint
  - Managing domino effects in a chemical industrial area
  - Decision-support systems for preventing domino effects

Table of Contents of the 2013 book - observations

- Overview of case histories of domino effects
- Focus on state-of-the-art standard research
- Definition of domino effects was established
- Effects leading to escalation identified and discussed
- Approaches to deal with domino effects (technological and managerial)
- Existing DSSs/software for dealing with domino effects

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Post-2011 research – excerpt from Science direct

A matrix-based modeling and analysis approach for fire-induced domino effects
Process Safety and Environmental Protection, Volume 116, May 2018, Pages 347-353
Jianfeng Zhou, Genserik Reniers

Texas LPG fire: Domino effects triggered by natural hazards
Process Safety and Environmental Protection, Volume 116, May 2018, Pages 354-364
Mohsen Naderpour, Nima Khakzad

How to address model uncertainty in the escalation of domino effects?
Journal of Loss Prevention in the Process Industries, In press, accepted manuscript, Available online 2 March 2018
Nima Khakzad, Paul Amyotte, Valerio Cozzani, Genserik Reniers, Hans Pasman

Low-capacity utilization of process plants: A cost-robust approach to tackle man-made domino effects
Reliability Engineering & System Safety, In press, corrected proof, Available online 27 March 2018
Nima Khakzad, Genserik Reniers

Cost-effective fire protection of chemical plants against domino effects
Reliability Engineering & System Safety, Volume 169, January 2018, Pages 412-421
Nima Khakzad, Gabriele Landucci, Valerio Cozzani, Genserik Reniers, Hans Pasman

Petri-net based evaluation of emergency response actions for preventing domino effects triggered by fire
Journal of Loss Prevention in the Process Industries, Volume 51, January 2018, Pages 94-101
Jianfeng Zhou, Genserik Reniers

An innovative methodology for quickly modeling the spatial-temporal evolution of domino accidents triggered by fire
Journal of Loss Prevention in the Process Industries, Volume 54, July 2018, Pages 312-324
Chao Chen, Genserik Reniers, Laobing Zhang

The probability prediction method of domino effect triggered by lightning in chemical tank farm
Process Safety and Environmental Protection, Volume 116, May 2018, Pages 106-114
Yunfeng Yang, Guohua Chen, Peizhu Chen

Risk Analysis on Domino Effect Caused by Pool Fire in Petroliferous Tank Farm
Procedia Engineering, Volume 211, 2018, Pages 46-54
Fu-zhen Chen, Ming-guang Zhang, Jian Song, Feng Zheng

Etc etc etc

"domino effects chemical industry": 1886 results of which

- 40 in 2011
- 75 in 2012
- 83 in 2013
- 106 in 2014
- 109 in 2015
- 103 in 2016
- 149 in 2017
- 114 in 2018
- 143 in 2019
- 204 in 2020
- 55 in 2021 (on 10 Jan 2021)

Post-2011 research - observations

- More use of techniques such as BNs, Petri-nets, Markov chains, graph theory → dynamic risk assessment of domino effects
- Nature-related events and impact on domino effects
- Security-related events wrt domino effects
- Economic parameters into domino effects research
- Domino effects in other (eg, bio-related) industries

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Table of Contents of the new book (i)

- Part 0: - The importance of innovation and new findings in domino effects research
  - Domino effects history and state-of-the-art problems
- Part 1: **Dynamic risk assessment** for domino effects
  - Dynamic risk assessment for dealing with domino effects
  - A Bayesian Network based methodology for domino effect assessment
  - A Petri-net based methodology for domino effect assessment
  - Application of Agent-based modeling to domino effects (DAMS)
- Part 2: **Security innovations** for dealing with domino effects
  - Using graph theory for managing domino effects from a security viewpoint
  - Stand-off distances for domino effect caused by intentional acts
  - Vulnerability assessment of chemical plants to intentional acts
  - Economic model for takling intentional domino effects in a chemical facility

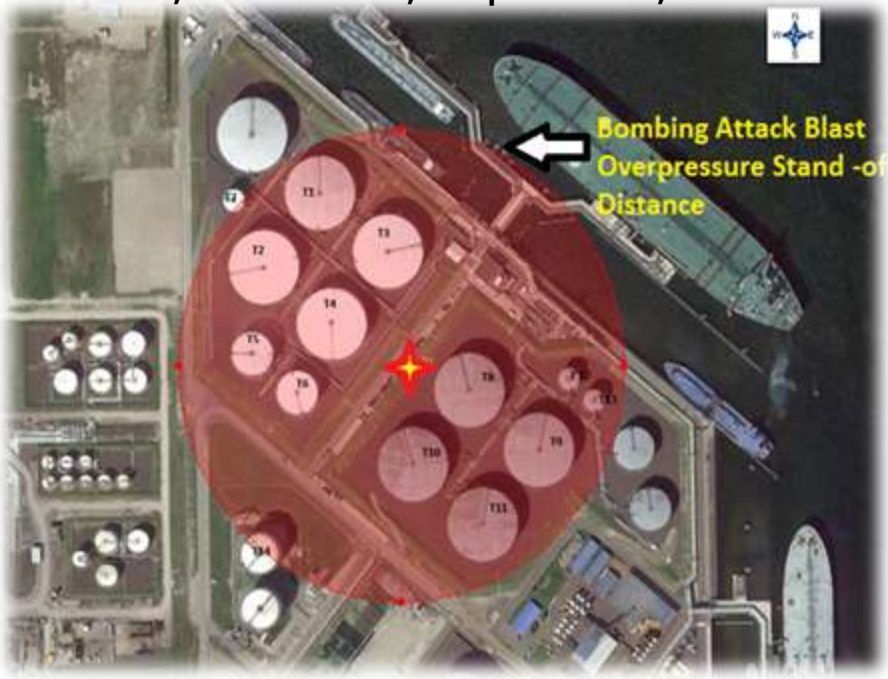
Table of Contents of the new book (ii)

- Part 3: **Mitigation and emergency management** of domino scenarios
  - Mitigation barriers for domino effects
  - Assessment of safety barriers and mitigation of domino scenarios
  - mitigation of fire-induced domino scenarios
  - The influence of harsh environment in the management of safety barriers
  - Optimal firefighting to prevent domino effects
  - The emergency planning in the event of safety and security related domino effects

The importance of **Security** - Industrial Case Study with several plants involved

Safety Event:
Loss of Containment in Ammonia Tank,
Pool fire scenario

Terrorist Attack at a parking lot with truck (+/- 12,000kg TNT eq):
Blast overpressure stand-off distance to cause damages at storage tanks (200 m)
Secondary scenarios : Pool fires , Toxic release, Tank fires, Explosions,..



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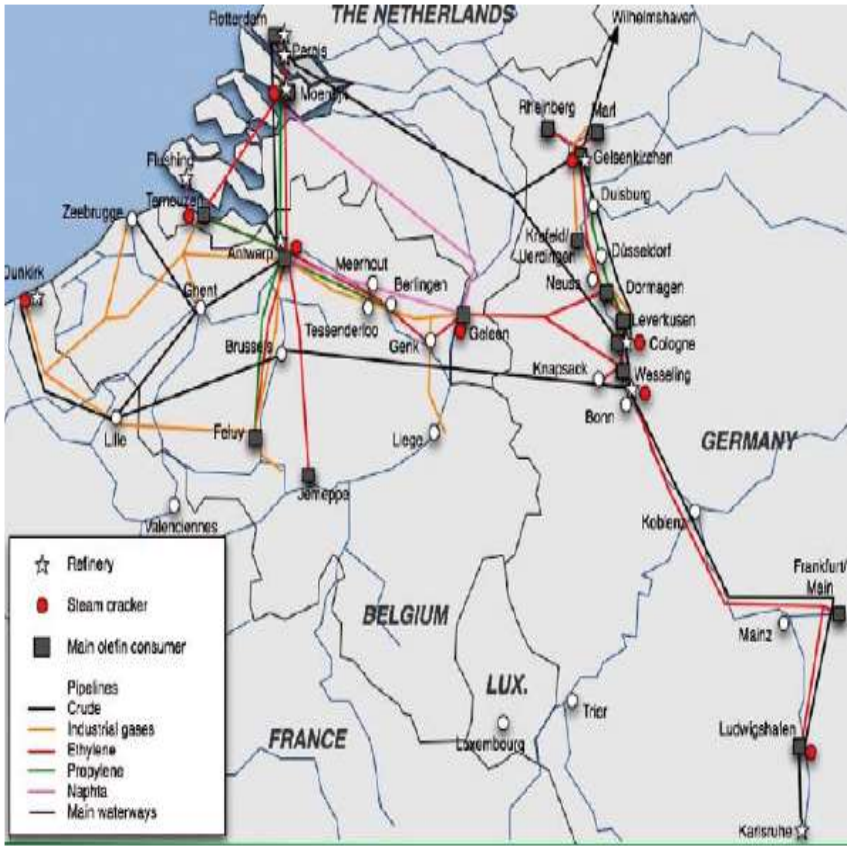
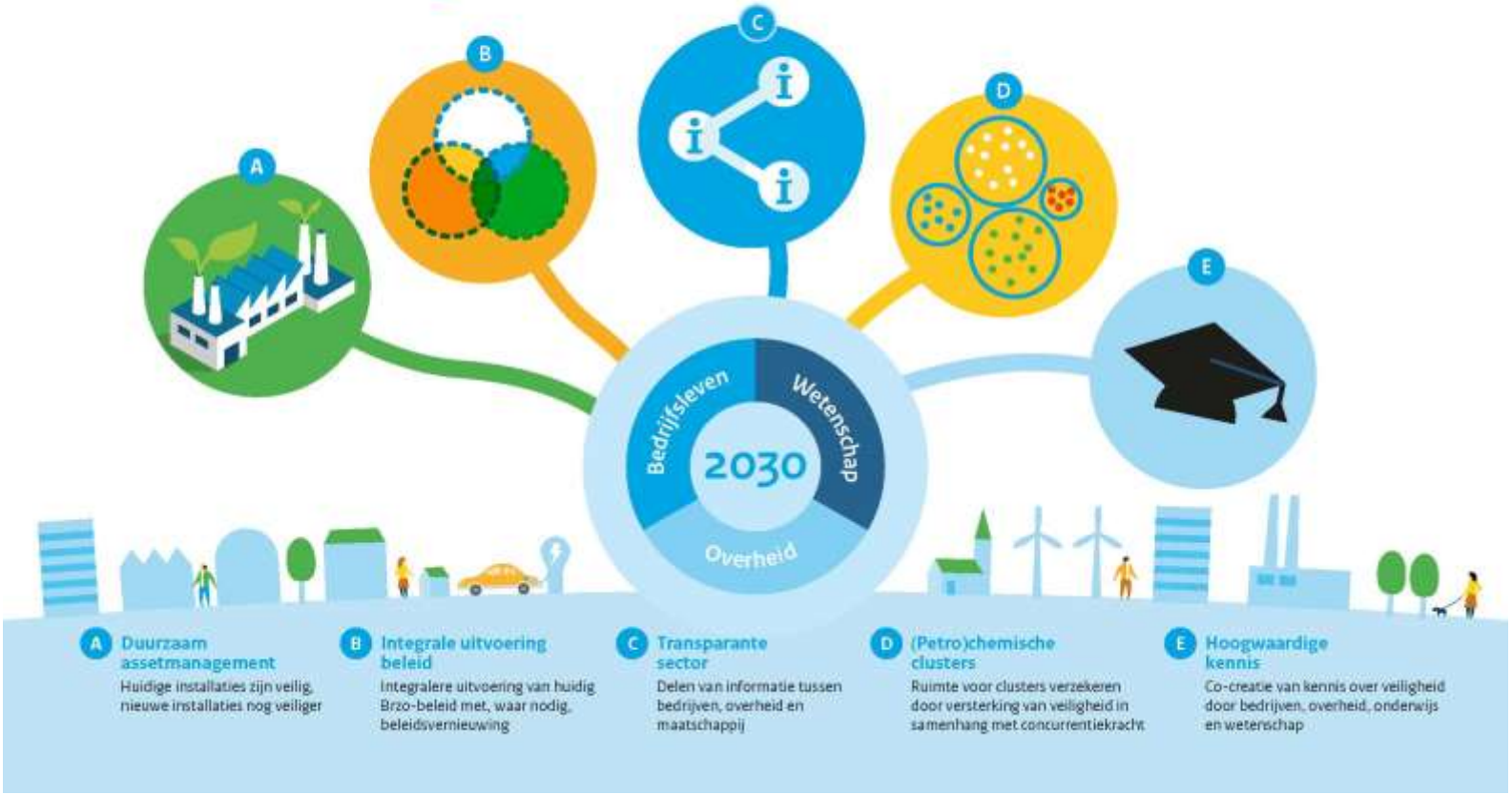
Chemical industrial areas



PROGRAMMA **DUURZAME VEILIGHEID 2030**

Samen werken aan duurzame veiligheid

De Nederlandse chemische industrie behoort tot de veiligste ter wereld. Maar ieder ongeval blijft er één te veel. Daarom streeft het programma Duurzame Veiligheid 2030 ernaar per 2030 een vitale (petro)chemische industrie zonder noemenswaardige incidenten te bewerkstelligen. Partners uit het bedrijfsleven, overheid en wetenschap werken hiertoe samen in vijf roadmaps.



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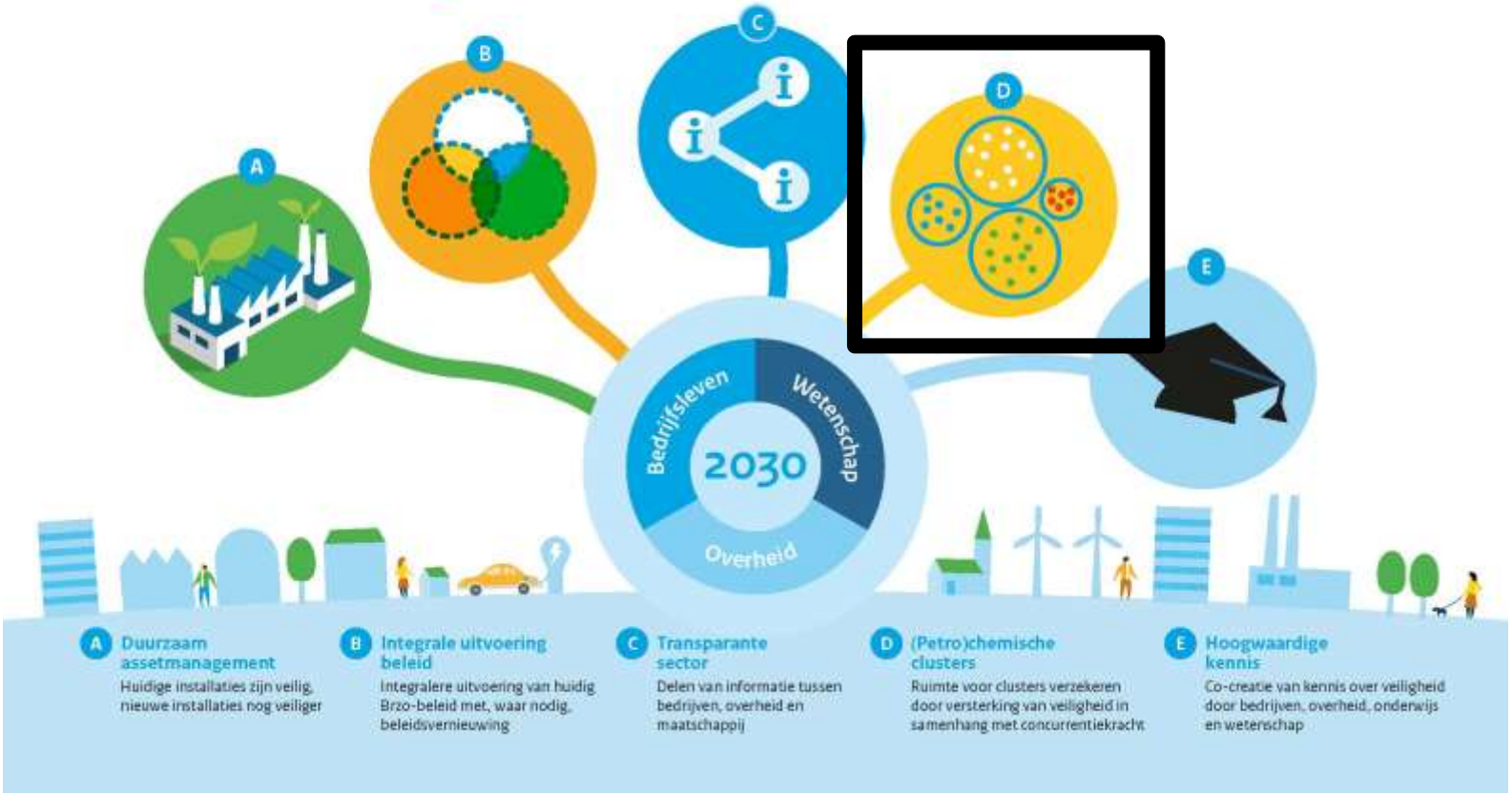

Roadmap 4: Petrochemical clusters - Project: cluster companies versus stand-alone companies

- Very little evidence about the differences between safety of clustered chemical plants and safety of stand-alone chemical plants
- Focus on domino-effects
- Mainly 'safety', very little (if none) 'security'

To make things clear:

<u>According to legislation:</u>

- "Domino effects" = **external** domino effects
- "Escalation effects" = **internal** domino effects

→ Legislation <> real situation

<u>Implications:</u>

- Domino effects are intuitively related to clusters – is this really the case?
- European Legislation: escalation within one establishment ≠ domino

Exchanging information about possible accident scenarios

- Major impact from legislation
  - "domino assignment"
  - Important implications for industrial practice
- BUT: extremely limited knowledge of possible scenarios by neighbouring companies
- Exchanging information with adjacent companies → happens too little, and too limited (even with domino assignment)

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Conclusions & Recommendations

- Domino effects research only started in 1996 with Seveso II legislation article 8
- Since 2011 the research has increased sharply, aiming to understand the domino effects phenomena, defining it and dealing with it from a practitioners viewpoint
- Since 2016 the research has been ever more widened towards dynamic assessment and modeling, security, Natech, economics, clusters
- In the Netherlands: Cluster Safety Parameters need to ensure that clusters can be made safer (and more secure) with respect to domino effects

Thank you very much for your attention!

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