Synthetic fuels potential by Power-To-Gas integration at National level for enhancing energy independency

Benedetto Nastasi
Michel Noussan
Outline

• Background
• Research Questions
• Data
• Methodology
• Power-to-Gas (P2G)
• Results
• Conclusions
Background

- 25% is maximum integrable RES share today
- RES intermittency, e.g. PV peak, overcomes 25%
  ✓ Storage & sector coupling to firm RES capacity
- Long term contracts signed for fossil fuel supply
- Energy security linked to geopolitical issues
  ✓ RES-based energy independency strategies
  → Electro-fuel as strategic reserve for security
What **Fuels** could be involved in RES-excess based synthesis considering the **different sectors and their demand** (fuel, heat, power)?

*Electrolysers as electricity-based process*

What improvements in **security and CO₂ emission** could be achieved by RES-based reserve fuel?

**Potential for blending and pure fuel substitution**
Data – Italy 2012-2017

- Hourly data of Power Grid
- Hourly data of Natural Gas Grid
- Solar energy for electricity production

<table>
<thead>
<tr>
<th>Year</th>
<th>Renewable Share</th>
<th>Primary Energy Factor</th>
<th>CO₂ Emissions Factor (g/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Median</td>
<td>Max</td>
</tr>
<tr>
<td>2012</td>
<td>13.6%</td>
<td>33.6%</td>
<td>61.1%</td>
</tr>
<tr>
<td>2013</td>
<td>20.7%</td>
<td>40.6%</td>
<td>73.8%</td>
</tr>
<tr>
<td>2014</td>
<td>22.9%</td>
<td>46.0%</td>
<td>78.0%</td>
</tr>
<tr>
<td>2015</td>
<td>19.1%</td>
<td>40.3%</td>
<td>73.8%</td>
</tr>
<tr>
<td>2016</td>
<td>18.9%</td>
<td>38.4%</td>
<td>72.5%</td>
</tr>
<tr>
<td>2017</td>
<td>16.4%</td>
<td>36.2%</td>
<td>73.8%</td>
</tr>
</tbody>
</table>

Table. Calculated values for Renewable share, Primary Energy Factor and CO₂ Emissions Factor.
Data – Power Supply Performance
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Data

Performance Indicators of Electricity Generation at Country Level—The Case of Italy

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Received: 14 February 2018; Accepted: 13 March 2018; Published: 14 March 2018

Energies 2018, 11, 650; doi:10.3390/en11030650

https://doi.org/10.3390/en11030650
Research Question 1

What **Fuels** could be involved in RES-excess based synthesis considering the **different sectors and their demand (fuel, heat, power)**?
Conventional fuel supply – CH$_4$

- Natural Gas Power Plant
  - **Combined Cycles** $\rightarrow$ Fuel to Electricity
- Natural Gas Heating Systems
  - **Boilers** $\rightarrow$ Fuel to Heat
- Natural Gas Engines
  - **Vehicles & Machines** $\rightarrow$ Fuel to Transport
Future fuel supply – $H_2$

- Hydrogen Power Plant
  - Solid Oxide Fuel Cell → Fuel to Electricity
- Hydrogen Heating Systems
  - Catalytic Converters → Fuel to Heat
- Hydrogen Fuel Cell - Engines
  - Vehicles & Machines → Fuel to Transport
Transition fuel supply – H$_2$NG

- Hydrogen Enriched Natural Gas Power Plant
  ✓ Combined Cycles $\rightarrow$ Fuel to Electricity
- Hydrogen Enriched Natural Gas Heating Systems
  ✓ Boilers $\rightarrow$ Fuel to Heat
- Hydrogen Enriched Natural Gas Engines
  ✓ Vehicles & Machines $\rightarrow$ Fuel to Transport
Transition fuel supply – $\text{H}_2\text{NG}$

- **Natural Gas Engines**
  - ✓ **Number of Methane** $\rightarrow$ up to 20% $\text{H}_2$ vol. fraction
- **Natural Gas Grid**
  - ✓ **Leakage & Corrosion** $\rightarrow$ up to 5% $\text{H}_2$ vol. fraction
- **Storage facilities**
  - ✓ **Location and Mixing** $\rightarrow$ up to direct injection
Power-to-Gas (P2G)

Electrolyser efficiency
\[ \eta_{ELY} = \frac{E_{H2}}{E_{el,ELY}} \]

Electricity Node
\[ E_{el,GRID} + E_{el,RES} + E_{el,CHP} - E_{el,HP} - E_{el,ELY} = E_{el,D} \]

RES fraction
\[ f_{RES} = \frac{E_{el,RES}}{(E_{el,D} + E_{el,HP} + E_{el,ELY})} \]
Power-to-Gas (P2G)

Mixing section

Primary Energy

$$R_{H2NG} = \frac{E_{H2}}{E_{fuel,CHP}}$$

$$E_{fuel,sys} = E_{fuel,CHP} \cdot (1 - R_{H2NG}) + \frac{E_{el,GRID}}{\eta_{GRID}}$$
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**Power-to-Gas (P2G)**

\[ \lambda = 1 \]

Fig. 5. Blends consumption vs %H\(_2\) (stoichiometric).
Power-to-Gas (P2G)

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**Power-to-Gas (P2G)**

[Link to full article](https://doi.org/10.1016/j.energy.2016.03.097)
Research Question 2

What improvements in security and CO$_2$ emission could be achieved by RES-based reserve fuel?
Objective function

$\rightarrow$ Energy Security as share of covered reserve

$$ES = \frac{E_{H2}}{E_{Reserve}}$$

$\rightarrow$ Decarbonization Potential

$$DP = \frac{CO2_{BAU} - CO2_{H2NG}}{CO2_{BAU}}$$
Methodology

• Current and Transition Energy Scenarios
  ✓ 2017 data and 2030 projection
• Solar energy-based supply
  ✓ 2017 production and 2030 doubled supply
• Strategic Natural Gas reserve
  ✓ Constant value for 2017 and 2030
  → Monthly trends comparison
Natural Gas supply

- Reserve
- Production
- Import
- Demand

Month: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

Energy [GWh]:
- Jan: 120,000
- Feb: 80,000
- Mar: 60,000
- Apr: 40,000
- May: 20,000
- Jun: 0
- Jul: -20,000
- Aug: -40,000
- Sep: -60,000
- Oct: -80,000
- Nov: -100,000
- Dec: -120,000

Energy [GWh]:
- Jan: 140,000
- Feb: 120,000
- Mar: 100,000
- Apr: 80,000
- May: 60,000
- Jun: 40,000
- Jul: 20,000
- Aug: 0
- Sep: -20,000
- Oct: -40,000
- Nov: -60,000
- Dec: -80,000

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Current Scenario

• Natural Gas Demand
  ✓ 786,112 GWh ~ 82,835 MNm³

• Yearly PV Production
  ✓ 24,811 GWh ~ 17,367 GWh H₂ ~ 4,907 MNm³

• Yearly H₂ volumetric fraction at 5%
  → 1,858 MNm³ avoided Natural Gas
  → 2.2% avoided CO₂ emissions
Transition Scenario

- **Natural Gas Demand**
  - 786,112 GWh ~ 82,835 MNm³

- **Yearly PV Production**
  - 49,622 GWh ~ 34,734 GWh H₂ ~ 9,814 MNm³

- **Yearly H₂ volumetric fraction at 10%**
  - → 4,307 MNm³ avoided Natural Gas
  - → 5.1% avoided CO₂ emissions
Energy Security

• **Current Scenario**
  ✓ 17,632 GWh ~ 1,858 MNm³

• **Transition Scenario**
  ✓ 40,873 GWh ~ 4,307 MNm³

• **Reserve capacity equal to 120,000 GWh**
  → 14.7% solar H₂-based reserve for 2017 data
  → 34.1% solar H₂-based reserve for 2030 data
Conclusions

• Hydrogen plus Natural Gas for the transition
• Decarbonization way for all the sectors
  ✓ Partial substitution as ready solution
• Solar energy is already enough to H2NG @5%
• 15% of the NG reserve is achievable today
  ✓ Reserve as fourth sector in the regulation
  ➞ Dedicated RES-based electro-fuel for RES security
References

Power-to-Gas integration in the Transition towards Future Urban Energy Systems

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https://doi.org/10.1016/j.ijhydene.2017.07.149
Power-to-gas leverage effect on power-to-heat application for urban renewable thermal energy systems

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https://doi.org/10.1016/j.ijhydene.2018.08.119
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5. Energy, water and sustainability database for building, district and regional systems;
6. Best practices and case studies.

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