New Madrid and Wabash Valley Seismic Study: Assessing the Impacts on Natural Gas Transmission Pipelines and Downstream Markets by Using “NGFast”

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Order of Presentation

- Brief Description of NGFast Simulation Model
- Objectives of the New Madrid Natural Gas Pipeline Study
- Scenarios Covered by the Study
- Major Assumptions and Methodology
- Overview of the U.S. Natural Gas Pipeline System
- Key Findings – New Madrid and Wabash Events
- Summary of Damages and Estimated Restoration Time
- Seismic Performance of Underground Storage Facilities
- Conclusions – Natural Gas Pipeline Study
- Conclusions – New Madrid Electric Transmission Line Study
NGFast: Model for Natural Gas Pipeline Breaks and Downstream Impacts – Salient Features

- Linear, steady-state model provides a quick estimate of impacts on the downstream market of:
  - single or multiple pipeline breaks
  - flow reduction problems

- This national model includes:
  ~ 80 interstate and other pipelines
  ~ 1,800 local distribution companies (LDCs)
  ~ 800 state border points

- Compensated/uncompensated modes account for effects of mitigating measures such as:
  - underground storage (UGS)
  - liquefied natural gas (LNG)
  - production facilities
  - spare pipeline capacity

- Graphical user interface (GUI) navigation uses “point-and-click” features, is super fast, and is easy to use

- Graphical and tabular HTML – formatted outputs

- Applications
  - DOE exercise analysis
  - hurricane analysis
  - seismic analysis
  - others as appropriate
NGFast Analysis Output

For a postulated flow disruption in a specific border point(s) and month of the year, NGFast assesses impacts, including:

- Downstream states affected
- LDCs affected per state
- Load shed per customer class per LDC
- Number of customers per class type
- MW of electric power plants affected
- Detailed per state pre- and post-disruption load and flow levels
- Options on remedial actions to minimize overall impact
Primary Objectives of the Current Seismic Study

- Assessment of impact on natural gas interstate transmission pipelines
- Identification of specific pipelines affected
- Identification of probable location of pipeline breaks
- Assessment of downstream impacts in terms of population and business customers affected
- Estimate of restoration time from the perspective of industry experts
Three Scenarios Covered

1: New Madrid Event with M 7.7 quake involving the northern segment and the Boot Heel of Missouri.

2: Wabash Valley Event with M 6.8 quake

3: Simultaneous New Madrid and Wabash Events with M 7.7 and 6.8, respectively
Key Assumptions Used for Impact Assessment

- Events occurred on Feb. 24 at 2:00 a.m.
- A pipeline segment break triggered by the earthquakes implies 100% flow reduction along the pipeline.
- Transmission pipelines through the seismic zones are generally ductile, made of steel, are arc welded, and are buried at an average of 4 to 6 ft below ground surface.
- Order of load shedding:
  - gas-fired power plants
  - industrial
  - commercial
  - residential
Methodology, Models, and Sources of Data

Methodology and Models
- Used HAZUS MH-MR3 for damage functions and fragility curves
- Used Argonne’s NGFast model for pipeline break simulation and assessment of downstream impacts
- Used industry-based experience for estimating restoration time

Data Sources and Graphics
- For ground motion, used FEMA-provided shake maps (PGA, PGV, liquefaction)
- For NGFast and pipe characterization, used:
  - EIA 176
  - EIA state border files
  - FERC 567
  - Platts PowerMap
  - DOT’s National Pipeline Mapping System
  - ESRI Arc Map
  - Industry experts
- Natural Gas Storage Assessment and Restoration: used inputs from industry subject-matter experts
Overview of U.S. Natural Gas Pipeline System

The U.S. natural gas system is a complex network of interconnected high-volume, high-pressure pipelines.
Scenario 3: Combined New Madrid and Wabash Valley Seismic Events

- Occurring simultaneously
- Emergency remedial actions implemented

Summary of Key Findings
New Madrid and Wabash Valley: Key Finding 1

Ten interstate pipelines are at high risk for multiple damage from New Madrid and Wabash Valley earthquakes.
New Madrid and Wabash Valley: Key Finding 2

All ten at-risk pipelines would be damaged by at least one break and several leaks due to PGA, PGV, and liquefaction with implications on Region V states.
Typical Emergency Actions by Pipeline Companies to Mitigate Impacts

- Declare emergency gas days and enforce “force majeure” measures
- Coordinate, prioritize, decide, and implement gas re-routing options
- Prioritize, decide, and implement load shedding options
- As much as possible, spare residential customers from being shed
- Assess, prioritize, and implement temporary, quick work-around remedial actions on damaged pipes
- Organize crews, materials, supervisory personnel, and support staff to immediately commence temporary and permanent repair work
New Madrid and Wabash Events Emergency Remediation Measures before Permanent Restoration

- **Available Emergency Mitigation Measures**
  - selectively shed interruptible loads (e.g., power plants, industrial loads)
  - increase withdrawal from UGS
  - increase flow from spare capacity from interconnected but unaffected pipelines
  - withdraw LNG from storage
  - increase production from nearby fields

- **Other Possible Sources of Gas**
  - Rocky Mountains
  - Canada
  - Gulf of Mexico via other unaffected pipelines
All FEMA Region V states, except Minnesota, would experience substantial delivery reduction, ranging from 2% to 27%.
Downstream Impacts with Emergency Remedial Measures: Key Finding 4

Implementation of emergency remedial measures could limit the number of people affected to about 60,000–100,000 (or 20,000–33,000 households) across several states; a large number of electric, industrial, and commercial customers (50,000–140,000) would also be shed.

<table>
<thead>
<tr>
<th>State</th>
<th>People Affected:</th>
<th>Residential Sector Not Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missouri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kentucky</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td></td>
<td></td>
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<tr>
<td>Michigan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennessee</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Number of Customers Affected**

- **Illinois**
  - Resid: 31,145
  - Comm: 11,593
  - Indust: 845
  - Elect: 1
  - Total: 43,583

- **Kentucky**
  - Resid: 7,028
  - Comm: 1,113
  - Indust: 272
  - Elect: 4
  - Total: 8,197

- **Indiana**
  - Resid: 896
  - Comm: 1,113
  - Indust: 221
  - Elect: 4
  - Total: 2,324

- **Missouri**
  - Resid: 985
  - Comm: 1,113
  - Indust: 221
  - Elect: 4
  - Total: 2,324

- **Ohio**
  - Resid: 2,560
  - Comm: 458
  - Indust: 9
  - Elect: 2
  - Total: 3,028

- **Wisconsin**
  - Resid: 4,860
  - Comm: 16
  - Indust: 4
  - Elect: 1
  - Total: 5,021

- **Michigan**
  - Resid: 4,860
  - Comm: 16
  - Indust: 4
  - Elect: 1
  - Total: 5,021

- **Tennessee**
  - Resid: 4,860
  - Comm: 16
  - Indust: 4
  - Elect: 1
  - Total: 5,021

**Type Low High**

- **Resid**: 31,145 31,145
- **Comm**: 11,593 67,964
- **Indust**: 845 2,535
- **Elect**: 1 2
- **Total**: 43,583 91,646

**Residential Sector Not Affected**

- **People Affected**: -
  - Type: Low High
  - Resid: - -
  - Comm: 2,560 12,801
  - Indust: 458 1,375
  - Elect: 9 27
  - Total: 3,028 14,203

*Shaded by Owner/Operator"
New Madrid and Wabash Valley Downstream Impacts with Emergency Remedial Measures: Key Finding 5

In terms of amount of natural gas-fired power plants’ capacity affected due to gas curtailment, the amount of megawatts of power at risk per state is low

<table>
<thead>
<tr>
<th>State</th>
<th>Total Shed (MW)</th>
<th>2007 Capability (MW)</th>
<th>% of In-state Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>330</td>
<td>42,300</td>
<td>0.78%</td>
</tr>
<tr>
<td>WI</td>
<td>280</td>
<td>16,400</td>
<td>1.71%</td>
</tr>
<tr>
<td>MI</td>
<td>270</td>
<td>30,200</td>
<td>0.89%</td>
</tr>
<tr>
<td>IN</td>
<td>110</td>
<td>26,900</td>
<td>0.41%</td>
</tr>
<tr>
<td>OH</td>
<td>30</td>
<td>33,900</td>
<td>0.09%</td>
</tr>
<tr>
<td>MO</td>
<td>15</td>
<td>20,600</td>
<td>0.07%</td>
</tr>
<tr>
<td>TN</td>
<td>10</td>
<td>20,900</td>
<td>0.05%</td>
</tr>
<tr>
<td>KY</td>
<td>0</td>
<td>20,100</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total</td>
<td>1,045</td>
<td>211,300</td>
<td>0.49%</td>
</tr>
</tbody>
</table>
Summary of Damages in New Madrid Area

A. Pipeline Damage Due to PGV and Estimated Restoration Time

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Pipeline Company</th>
<th>No. of Leaks</th>
<th>No. of Breaks</th>
<th>No. of Pipes per corridors</th>
<th>Total Leaks</th>
<th>Total Breaks</th>
<th>Diameter (inches)</th>
<th>Length Span involed Per Pipe corridor (km)</th>
<th>Total Restoration Days Leaks + Breaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TRUNKLINE</td>
<td>40</td>
<td>4</td>
<td>2</td>
<td>80</td>
<td>8</td>
<td>30,36</td>
<td>440</td>
<td>29 / 69</td>
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<tr>
<td>2</td>
<td>TEXAS GAS</td>
<td>17</td>
<td>2</td>
<td>4</td>
<td>68</td>
<td>8</td>
<td>30,36,26</td>
<td>250</td>
<td>32 / 87</td>
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<tr>
<td>3</td>
<td>TEXAS EASTERN</td>
<td>25</td>
<td>3</td>
<td>1</td>
<td>25</td>
<td>3</td>
<td>24</td>
<td>345</td>
<td>20 / 49</td>
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<tr>
<td>4</td>
<td>ANR PIPELINE</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>27</td>
<td>3</td>
<td>36,30,30</td>
<td>432</td>
<td>22 / 53</td>
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<tr>
<td>5</td>
<td>NGPL</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>27</td>
<td>3</td>
<td>36,36,30</td>
<td>520</td>
<td>22 / 53</td>
</tr>
<tr>
<td>6</td>
<td>MISSISSIPPI RIVER TRANS</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>27</td>
<td>3</td>
<td>26,26,22</td>
<td>470</td>
<td>22 / 53</td>
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<tr>
<td>7</td>
<td>Tennessee Gas TRANS</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>14</td>
<td>2</td>
<td>30,24</td>
<td>680</td>
<td>22 / 69</td>
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<tr>
<td>8</td>
<td>CENTERPOINT ENERGY</td>
<td>33</td>
<td>4</td>
<td>1</td>
<td>33</td>
<td>4</td>
<td>18</td>
<td>156</td>
<td>24 / 65</td>
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<tr>
<td>9</td>
<td>MOZARK GAS TRANS</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>16</td>
<td>503</td>
<td>17 / 41</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>309</td>
<td>35</td>
<td></td>
<td>210 / 539</td>
<td></td>
</tr>
</tbody>
</table>
## B. Compressor Station Damage and Restoration

<table>
<thead>
<tr>
<th>Owner</th>
<th>Name</th>
<th>Type of Damage</th>
<th>HP rating</th>
<th>Rated Suction Pressure</th>
<th>Rated Discharge Pressure</th>
<th>No. of Units</th>
<th>No. of Pipelines</th>
<th>Vol MMCF/D</th>
<th>Estimated Restoration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>TRUNKLINE</td>
<td>JOPPA</td>
<td>Extensive</td>
<td>30,800</td>
<td>553</td>
<td>834</td>
<td>9</td>
<td>2</td>
<td>30&quot;, 36&quot;</td>
<td>1300</td>
</tr>
<tr>
<td>TRUNKLINE</td>
<td>DYERBERG</td>
<td>Moderate</td>
<td>30,000</td>
<td>564</td>
<td>840</td>
<td>8</td>
<td>2</td>
<td>30&quot;, 36&quot;</td>
<td>1380</td>
</tr>
<tr>
<td>TEXAS EASTERN</td>
<td>ORAN</td>
<td>Moderate</td>
<td>10,000</td>
<td>490</td>
<td>800</td>
<td>10</td>
<td>1</td>
<td>24&quot;</td>
<td>380</td>
</tr>
<tr>
<td>TEXAS EASTERN</td>
<td>POLLARD</td>
<td>Moderate</td>
<td>4,500</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>24&quot;</td>
<td>300</td>
</tr>
<tr>
<td>TEXAS EASTERN</td>
<td>WALNUT RIDGE</td>
<td>Moderate</td>
<td>8,000</td>
<td>628</td>
<td>600</td>
<td>4</td>
<td>2</td>
<td>24&quot;</td>
<td>300</td>
</tr>
<tr>
<td>TEXAS EASTERN</td>
<td>DICK CREEK</td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>TENN GAS PIPELINE</td>
<td>MIDDLETON</td>
<td>Minor</td>
<td>34,350</td>
<td>480</td>
<td>730</td>
<td>23</td>
<td>3</td>
<td>24&quot;, 26&quot;, 30&quot;</td>
<td>1520</td>
</tr>
<tr>
<td>NGPL</td>
<td>308 BIGGERS</td>
<td>Minor</td>
<td>30,850</td>
<td>586</td>
<td>850</td>
<td>9</td>
<td>2</td>
<td>30&quot;, 36&quot;</td>
<td>1600</td>
</tr>
<tr>
<td>MRT</td>
<td>BIGGERS</td>
<td>Minor</td>
<td>12,150</td>
<td>573</td>
<td>720</td>
<td>7</td>
<td>2</td>
<td>24&quot;, 26&quot;</td>
<td>660</td>
</tr>
<tr>
<td>ANR</td>
<td>COTTAGE GROVE</td>
<td>Minor</td>
<td>30,030</td>
<td>600</td>
<td>655</td>
<td>8</td>
<td>1</td>
<td>30&quot;</td>
<td>1400</td>
</tr>
<tr>
<td>ANR</td>
<td>SARDIS</td>
<td>Minor</td>
<td>33,200</td>
<td>580</td>
<td>650</td>
<td>6</td>
<td>2</td>
<td>30&quot;, 36&quot;</td>
<td>1420</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>35</td>
</tr>
</tbody>
</table>
# Wabash Valley Area Summary of Underground Storage and Pipeline Damages

## A. Underground Storage at Risk Due to PGA and Estimated Restoration Time

<table>
<thead>
<tr>
<th>Owner</th>
<th>Name</th>
<th>Location</th>
<th>Types of Damage</th>
<th>Estimated Restoration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>TEXAS GAS TRANS</td>
<td>OAKTON</td>
<td>INDIANA</td>
<td>Moderate above ground facilities</td>
<td>2</td>
</tr>
<tr>
<td>SOUTHERN INDIANA GAS And ELECTRIC</td>
<td>MONROE</td>
<td>INDIANA</td>
<td>Moderate above ground facilities</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

## B. Pipeline Damage Due to PGV, PGA, and Liquefaction and Estimated Restoration Time

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Pipeline Company</th>
<th>No. of Leaks</th>
<th>No. of Breaks</th>
<th>No. of pipes per corridor</th>
<th>Total Leaks</th>
<th>Total Breaks</th>
<th>Diameter (inches)</th>
<th>Length Span involed Per Pipe corridor (km)</th>
<th>Total Restoration Days Leaks + Breaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TRUNKLINE</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>26, 30</td>
<td>650</td>
<td>15 (44)</td>
</tr>
<tr>
<td>2</td>
<td>MIDWESTERN GAS TRANS</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>36, 36</td>
<td>502</td>
<td>10 (34)</td>
</tr>
<tr>
<td>3</td>
<td>NGPL</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>36, 36, 30</td>
<td>3</td>
<td>5 (14)</td>
</tr>
<tr>
<td>4</td>
<td>TEXAS EASTERN</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>24</td>
<td>2</td>
<td>5 (14)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>6</td>
<td>14</td>
<td>3</td>
<td>6</td>
<td>14</td>
<td>2</td>
<td>35</td>
<td>106</td>
</tr>
</tbody>
</table>
## Wabash Valley Area Summary of Compressor Damages

### C. Compressor Damage Due to PGA and Estimated Restoration Time

<table>
<thead>
<tr>
<th>Owner</th>
<th>Name</th>
<th>Type of Damage</th>
<th>HP rating</th>
<th>Rated Suction Pressure</th>
<th>Rated Discharge Pressure</th>
<th>No.of Units</th>
<th>No. of Pipelines</th>
<th>Vol MMCF/D</th>
<th>Estimated Restoration Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUNKLINE</td>
<td>JOHNSON VILLE</td>
<td>Moderate</td>
<td>30,000</td>
<td>597</td>
<td>900</td>
<td>8</td>
<td>2 (30&quot;, 36&quot;)</td>
<td>1,250</td>
<td>4</td>
</tr>
<tr>
<td>MIDWESTERN GAS TRAN</td>
<td>2113 CARLISLE</td>
<td>Moderate</td>
<td>9,100</td>
<td>680</td>
<td>877</td>
<td>1</td>
<td>1 (30&quot;)</td>
<td>644</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>8</strong></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>
Seismic Performance of Underground Storage Facilities

- In general, experts agree that UGS within 100 miles of the quake’s epicenter may be at risk of some damage, depending on the intensity of the quake and the direction of the seismic wave.

- In general, UGS fields are quite resilient against seismic disturbance unless the structure is located at the fault line.

- According to seismologists, only the top 50 ft of soil is subject to liquefaction, meaning that little damage is expected to occur to subsurface UGS fields because the typical depth of sandstone and rock is 1,000–2,000 ft.

- Most underground damage involves the vertical surface-to-underground cavern pipeline at a point where the pipeline meets the cap rock of the underground structure.

- Other damage may involve the fracture of the cap rock that lines the storage core of the underground structure; the fracture may result in gas leaking or migrating to the surface.

- Most UGS is located near the Wabash Valley, except for two small facilities whose surface structures may be at risk due to PGA; the other UGSs are assumed to be functional.
Key Finding 1: Ten interstate pipelines would be at risk of damage due to the events.

Key Finding 2: All ten pipelines would experience at least one break and several leaks due to PGA, PGV, and liquefaction.

Key Finding 3: Even with implementation of emergency remedial measures, all FEMA Region V states (except Minnesota) and other nearby states would experience a substantial reduction in delivery, ranging from 2% to 27%.

- Indiana ~18%
- Michigan ~18%
- Illinois ~13%
- Ohio ~12%
- Wisconsin ~2%

Key Finding 4: Even with emergency remedial actions, the seismic events would impact:
- 20,000–30,000 households (or 60,000–100,000 people)
- 50,000–140,000 Industrial and commercial customers or units

Key Finding 5: A well-orchestrated implementation of remediation measures would limit impact on natural gas-fired power to insignificant levels (less than 2% of installed capacity).

Key Finding 6: In general, all underground storage facilities (except for 2) would not experience any serious damage so as to make them dysfunctional.

Key Finding 7: Restoring damaged pipelines to full functionality would take about 1–3 months depending on how the pipeline companies subdivide and “phase” the work, the availability of crews, conditions of access roads, and resolved target completion times; restoration for residential and industrial customers would take 2–4 and 4–8 weeks, respectively.
Conclusions and Key Findings on Electric Transmission Study

- The New Madrid seismic event has a far more devastating potential impact than the Wabash Valley on the basis of all impact metrics used in the study.
- The combined New Madrid and Wabash events could affect as many as 2–3 million people mostly in areas surrounding the epicenter of the earthquakes; blackouts mainly would be due to equipment failures and ensuing line de-energization.
- The combined events could put about 190 high-voltage towers at risk for possible physical damage; most towers are located along or near the New Madrid fault lines.
- The events could potentially de-energize 52 high-voltage transmission lines in both the New Madrid and the Wabash areas.
- The possible line failures would not cause downstream electric supply shortfalls in any of the Region V states because of high reserves during February and a reduction in the possibility of transient stability problems.
- Towers can be procured fairly quickly because there are many approved local suppliers; a new tower could be ordered and erected in about 1–4 months.
- The equipment with the longest lead time is the transformer (8–12 months), but details of substation damages are beyond the scope of this presentation.
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